Enhanced Decision Support Tool for the Provision of on-site Loading Docks in New Buildings

White Paper

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iMOVE Australia

Transport for New South Wales (TfNSW)

University of Melbourne

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Project Title: Developing procedures to evaluate loading dock capacity provision

Executive Summary

With a greater focus on placemaking in urban centres, the provision of off-street loading docks can make a significant contribution to traffic management in urban centres This white paper describes the development of a Decision Support System (DSS) to help determine the optimal provision of on-site loading docks in ~~in~~ new major developments or buildings. The DSS tool is based on developing a predictive and forecasting model using regression techniques with cluster membership to estimate parking demand and vehicle movements by freight and service vehicles in loading docks. The model processes various parking surveys collected from 17 buildings of different land uses across a three-weekday period. Prescriptive analytic techniques were applied to generate insights about current vehicle movements so that stakeholders are better informed and to help decision-makers decide a course of action and offer suitable recommendations based on the predicted forecasts, inferred insights and patterns in the datasets. The development and application of the DSS were executed between June 2020 and April 2021 in the iMOVE project (2-010), which was championed by ~~Transportation~~ for New South Wales (TfNSW) along with iMOVE ~~Australia~~ CRC ~~Program~~ as a funding partner and University of Melbourne as a research partner.

The output of the model is presented in two interactive templates. The first one is the 'Optimisation Solver' template that determines the recommended dock configuration for the building under consideration by calculating the optimal number of parking spaces. The goal is to minimise the parking area while keeping the dock's effectiveness (ability to accommodate incoming vehicle demands) to a user configurable service level. The second template is the 'Dashboard' which displays valuable insights about the parking demand, vehicle movements and utilisation of the dock. The Dashboard is an interactive and sharable/transferrable template that various stakeholders could use in different locations to input the parameters and generate the results and outputs. The overall model development approach ensures a mathematically robust process to ensure the outputs' validity based on the observed datasets.

The model has several applications and provides various stakeholders including transport authorities, city planners and property developers, with a user-friendly tool to assess the requirements in advance during the planning and approval process of new developments. Overall, the model templates provide the various stakeholders with a robust and valid decision-making tool that generates reliable estimates of vehicle movements and parking demand for an optimal provision of loading docks, which consequently makes stakeholders better-informed and lead to a greater confidence in the outcomes of the building application process. Model applications include space proofing, supporting planning applications, enhancing the overall logistics delivery and service operations of the development, and streamlining the traffic flows in and around the development, making it more attractive to the future tenants and end-users.

1. Introduction

1.1 Freight Deliveries and Services – Planning and Government Regulations

With insufficient loading facilities, objectives to adapt street scapes away from motor vehicle use and ever-increasing population density, freight deliveries and service operations in inner-city areas face significant challenges. To ensure that freight and service (F&S) vehicles have access, parking space must be provided either on-street or off-street. This is critical as parking spaces in cities face competition from a number of players such as taxi vehicles, private transport, cycling and adaption of street space for pedestrians etc. Since the cost of walking from truck to customer is very high, freight vehicles must park near to their customers. Time limits, pricing techniques, land use and space management, and parking compliance are the four major types of freight vehicle parking policies [1]. The scale, location, and use of curbside space for commercial vehicle operations are covered under the land use and space management policies. Local municipalities have enacted several laws to reduce the dependence on on-street parking for freight and service operations. F&S vehicles can park in specially reserved areas in an off-street loading dock within the buildings rather than overcrowding the heavily used and unpredictable on-street parking facilities.

1.2 On-site Loading Dock Description

Large buildings (e.g., office towers, residential towers, hotels) have an off-street loading dock to allow freight and service vehicles to park and perform their activities within the building. This on-site loading dock is part of the building and maybe located underground in the building or on the ground floor. It is accessible only to freight and service vehicles, such as mail deliveries, food deliveries, electricians, trash collection, or construction services. The practice is to restrict private vehicles, taxis, or other vehicles from using these loading docks as practically as possible. Freight and service vehicles may access and park in the loading dock at most buildings free of charge.

The size of a loading dock depends on some main key building characteristics, such as the size of the building and its primary use and local planning ordinances. It is typically divided into different zones: Parking Area, Office, Equipment, and Storage/Waste. The parking area, which accounts for about 70% of the loading dock area, is divided into individual bays where a single vehicle can park to unload/load products. Some loading bays include different bay sizes, e.g., a small one for a delivery truck, a medium one for a medium-sized truck, and a large one for large trucks.

Factors influencing the size of a Loading Dock facility

- Size of the Building/Development
- Primary Land Use
- Zoning and Local Regulations
- Property Developer's Business Practices
- Vehicle Type Mix
- Operational Practices
- Peak Hour Volumes
- Average Dwell Time
- Characteristics of the Loading dock

To prevent any inconsistency between the vehicle's specifications and the parking space, the on-site loading dock must be constructed according to Australian Design Standard AS2890.2 Parking facilities part 2: Off-street commercial vehicle facilities (Standards Australia 2002). The dimensions of the area used for manoeuvring, the number of loading bays, and each bay's width should all be considered when designing a loading dock. These should be calculated based on the input demand. Local land-use zoning codes, which local planning and transportation agencies enforce, specify the planning and provision for on-site loading docks in new developments via there Development Control Plans (DCPs). Though not always detailed, the DCP specifies requirements for loading docks. The suggested number of loading spaces for a land-use type is calculated by multiplying the applicable parking provision rate by the development's size, the number of dwellings in a residential tower, or the gross floor area (GFA) in a commercial building.

The number of parking spaces available in a typical loading dock facility may be insufficient to accommodate arriving vehicles, particularly during peak hours. Property developers frequently attempt to reduce as much as possible the number of spaces and let service vehicles compete for parking spot. Increasing the number of parking spaces to accommodate all the vehicles will significantly increase the building's infrastructure costs, which property developers will reject. Planning for the optimal size of a loading dock facility is often a matter of contention between planning authorities and developers. Typically, planning for loading docks might be considered a lower priority during the Development Approval process. Specifications that currently support this process are outdated and poorly applied.

The literature on the subject ranges from assessments of commercial parking availability and demand-to supply ratios at various times of day to simulation models of how urban commercial parking behaves. Econometric models primarily consider that the choice of parking or freight generation is influenced by social, economic, and environmental factors. This approach models parking as a function of average turnover rate, parking occupancy, parking price influence coefficient, parking facility level of service, motor vehicle growth, and land use differences. Some publications define the parking demand rate as a freight trip generation rate multiplied by the average parking duration. The goal of this project is to build a predictive model that uses data and statistics to predict outcomes. The second approach of optimisation models relies more on data-driven complex mathematical modelling. Such models require a high computational method through complex software solvers and are challenging to apply in real-life contexts. The final approach is focused on traffic simulation and is, in general, less researched than the other two methods mentioned in the literature. This systematic approach considers various aspects of freight management, such as the preliminary phase, planning criteria, management aspects, and control, as components of a single integrated framework to accurately reflect transportation networks and loading zones, generate commercial vehicle trips and parking time, and estimate commercial vehicle delays.

2. Project Details

2.1 Background

Access to loading docks for freight and service companies is essential to achieve efficient and productive distribution systems. The arrangement and provision of loading dock capacity during the design and planning processes and development approval is often contentious. This is evident in cities around the world. In the city centres of many major cities where land values are high, holding capacity is often a cause of disagreement between planning authorities and developers. Current processes for arrangement and provision of loading dock demonstrate:

- Limited understanding by various stakeholders on the number of goods and services traffic a building generates
- Limited understanding by various stakeholders of the contribution that an adequate loading dock makes to a successful place outcome
- Low confidence in current guidelines used in planning processes that rely on very outdated data
- Inadequate articulation of all the considerations needed to provide suitable facilities which support existing processes

Many building owners consider loading dock facilities to be secondary to maximising valuable retail space in new buildings. The result can be inadequate facilities that detract from the amenity surrounding a building and create other negative externalities. A building with an inadequate design and loading bay capacity relies on roadside space adjacent to the building. Even if this space exists today, it cannot be guaranteed for the life of the building. Most cities are focused on increasing pedestrian space and reducing space for motor vehicles. If off-street loading space capacity is not provided to make a building self-sufficient, and roadside space is not available, buildings could become challenging to serve, inefficient for deliveries, and less attractive to customers/tenants. The resulting impact will be on the urban environment. Currently, the current method of determining loading bay size/capacity relies on transportation and planning authorities either providing quantities and formulae in their Development Control Plans (DCPs) or requiring a property developer to refer to traffic and building guidelines issued by local authorities. Assessments of global best practice trip generation models for developments have also been undertaken; however, these models are considered weak in predicting commercial vehicle generation.

2.2 Issues and Problems

Models and methods that support the process of freight and service vehicles demand estimated are outdated and poorly applied. The loading rates in the DCPs are based on regulations issued by NSW Roads and Traffic Authority (RTA) in 2002, which were produced using old driveway counts carried out in the early 1970s, leading some developers to claim that they are outdated and unreliable. Although these rates provide recommendations for the number of dock spaces to accommodate peak movements; however, they fail to provide operational insights about the utilisation of the docks including the number and profile of vehicle classes and visit types. Further, the recommended rates were developed based on a different of logistics practices. These limitations contribute to unreliable estimates of vehicle movements in a loading dock and utilisation of the recommended number of loading spaces, which are incorrectly based on

- Failing to reflect the current operational activities and requirements of freight and service activities
- Ignoring differences in operational practices and parking patterns between service and freight vehicles,
- A high number of fixed assumptions
- Estimates of vehicle movements based on incomplete vehicle counts and a small number of buildings,

- Ignoring relevant parameters that affect the dwell time and could potentially be strong predictors, contributing to questionable estimated vehicle movements.

Developers complain that the rates proposed in the DCP regulations are too high and irrelevant. However, this claim by many developers is not based on robust models and data analytics in most planning applications as most developers make limited effort to understand the profiles of vehicle movements and the likely utilisation of loading docks. At the same time, local authorities, which commonly carry out comprehensive and systematic data collection and assessment studies of docks utlisation and efficacy, argue that developers are struggling to provide the number of parking spaces without considering the requirements of users. Hence, the planning and approval process for the size and capacity of a loading dock goes through several rounds of feedback and negotiations between local authorities and developers until both parties reach a consensus.

2.3 Project Objectives

The main goal of this project is to offer valuable insight to planners and other stakeholders on adequate loading dock requirements. This can be achieve by improving current forecasting models and develop a robust approach for provision of loading docks in large development so that they are suitable for wider use by transportation planners involved in permitting processes for new buildings. Ultimately, planning and transportation agencies can use the models to provide a new and improved process that provides greater insight, understanding and assistance in evaluating new developments and their loading dock provision. This is achieved by:

- Identifying a process to ensure the model approach is mathematically robust to ensure the validity of the outputs
- Identifying a process to enable the easy addition of new data sets

The approach will lead to greater trust among stakeholders within the Development Approval process and better outcomes for our cities.

3. Data Collection and Descriptive Analytics

This section describes the entire process of data collection, data preparation, related challenges, descriptive analysis and summarises how the dataset was used to develop the model.

3.1 Data Collection Process

The overall goal of this project was to develop a decision-support prediction/forecasting model. To accomplish this, a comprehensive data collection effort was conducted to survey buildings of varying sizes, anticipated vehicle types, and land use types. The project team collected detailed parking surveys "driveway counts" of 17 different buildings for the parking activities of freight and service vehicles that used the on-site loading docks in these buildings to park their vehicles. The parking activities were collected from 12 different commercial buildings and 5 residential towers. Additionally, the sample included a diverse range of building characteristics "commercial area, retail area and/or residential area" in order to ensure including a representative sample of the most common buildings in central business districts of large cities. For instance, the size of commercial buildings ranges from smallest building having 15,000 m2 of commercial area in 26 floors while the largest building has 57,000 m2 of commercial area in 42 floors. Moreover, the residential towers range from a building with 14,000 m2 residential area with 211 apartments in 17 floors to the largest tower having 38,000 m2 residential area with 292 apartments in 50 floors. The parking surveys were conducted over a 3-weekday period - "Tuesday, Wednesday and Thursday" during different weeks in November and December 2020. The loading dock was observed throughout the 24 hours, and each parking event was recorded. The template contained variables for three main categories.

Table 1. Description of the parking survey template

Template #	Survey Template	Content/Description	Data fields captured
A	**Building Information**	This template captured some relevant parameters for each of the 17 specific buildings where the loading dock(s) is located	▪ *address* ▪ *primary land-use type* ▪ *building size* ▪ *operational hours* ▪ *number of floors* ▪ *types of land-use activity units "e.g. commercial area, apartment, etc"* ▪ *number of land-use activity units "e.g. 15,000 m^2 commercial area, 241 apartments"* ▪ *deliveries through foyer/lobby*
B	**Loading Dock Characteristics**	This template captured the parameters for the loading docks.	▪ *operational hours* ▪ *the number and size of loading bays* ▪ *number of loading elevators* ▪ *suitability of loading dock entrance* ▪ *loading bay booking scheme*
C	**Parking events of each unique F&S vehicle**	This template captured the vehicle activities. Each entry represents a different unique parking event for an individual F&S vehicle that is parked in a loading dock during that specific day.	▪ *event date & day* ▪ *parking location* ▪ *camera location* ▪ *entry time* ▪ *vehicle type* ▪ *visit type* ▪ *activity type* ▪ *exit time* ▪ *parking duration*

The design of freight infrastructure and urban logistics initiatives relies on the availability of data and data-driven models that can estimate their potential impacts and guide decision-making. The above data fields are frequently collected and evaluated in many parking and loading studies.

3.2 Data Collection Challenges

Due to the ongoing pandemic (COVID -19), the sample size may be somewhat smaller than expected. This is also due to specific privacy issues. Thus, the model and analysis are based on the robust observations and data collected from 17 buildings.

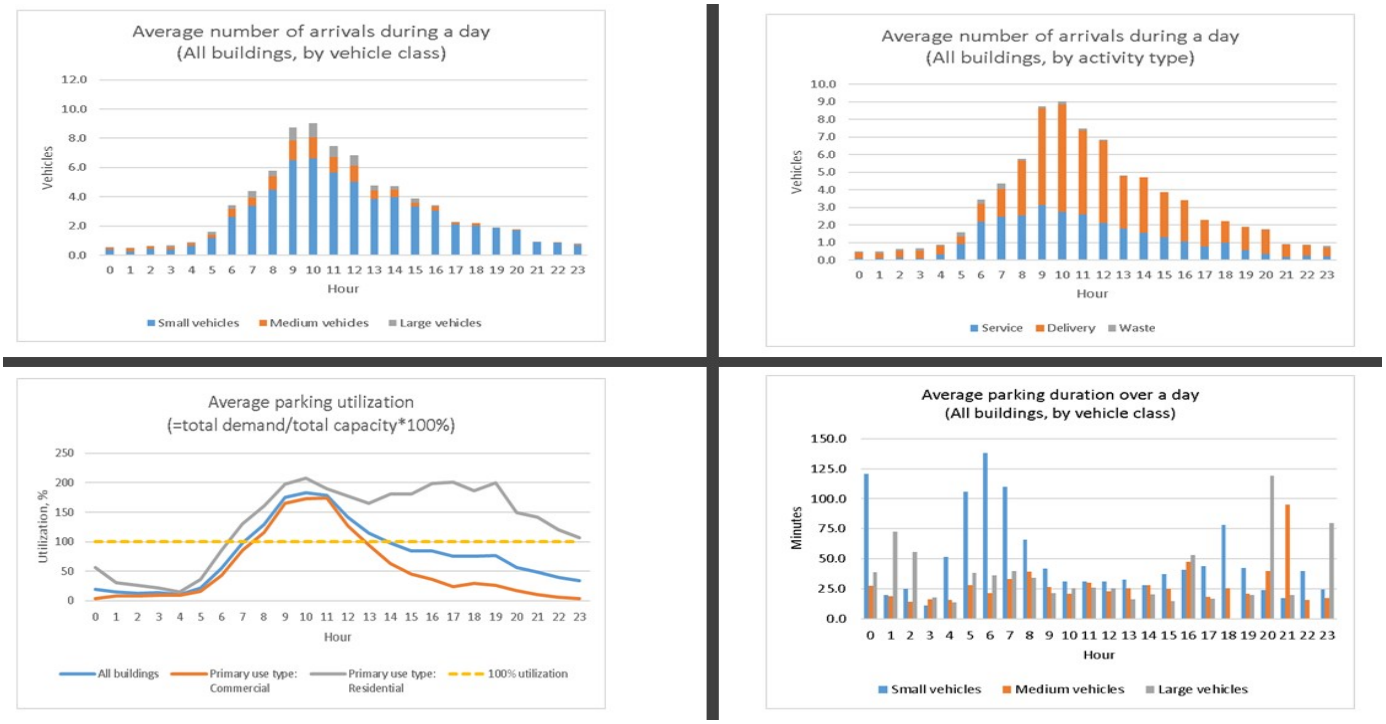
3.3 Descriptive Analytics

A robust assessment of the raw data was conducted to understand the various patterns associated with arriving vehicles, types, relationship to land use type, time of day, and parking duration. The following list summarises the various descriptive analyses performed.

- Characterisation of freight & service (F&S) vehicle movements in a loading dock
- Distribution of vehicle profiles and parking durations per land use type
- Number of all vehicles arriving per hour
- Average number of arrivals during a day by vehicle class and primary land use type
- % of hourly arrivals by vehicle class
- Distribution of arrivals by hour, % of daily arrivals
- Distribution of parking time by the hour of the day
- Vehicle trip rates estimate by hour of the day and land use type

The below figure shows some sample charts of the descriptive analytics

Figure 1. Snapshot of the analysis conducted into assessed buildings



Some key inferences derived from the descriptive analysis of the raw data includes:

- The majority of vehicles observed were of the type' small vehicles', which accounted for around 65-70% of the total freight traffic during the peak hour.
- The peak period observed for the freight traffic was around 9 am to 11 am for the 'commercial building'. For residential buildings, the peak period was around 10 am to 2 pm.
- The average number of vehicle arrivals observed during the peak hours (9 am – 12 pm) was around 7-8 vehicles, of which 5.5 were small, 1.5 medium and 1 large vehicle.
- The average number of vehicle arrivals during the peak hours (9 am - 11 am) for commercial buildings were 8-9 vehicles which is much higher than the average number of vehicle arrivals during the peak hours (10 am -2 pm) for residential buildings which is 4-5 vehicles
- 55% of the large vehicles arrive during 9 am – 12 pm, while 60% of the medium vehicles arrive during 8 am – 12 pm. However, small vehicles are more dispersed throughout the daytime and observed during 7 am – 4 pm.
- Delivery vehicles account for a significant proportion of total vehicle, followed by service vehicles. There were only a few vehicles observed for Waste collection.
- Most visiting hours for the waste vehicle visits were from 5 am – 7 am. Service vehicles mainly were observed from 6 am – 12 pm, and delivery visits are more dispersed throughout the day between 8 am – 15 pm. This pattern somehow reflects the nature of operations with the various types of freight and service vehicle categories.
- On average, the small vehicles were dwelling for about 1.5 hours per trip, whereas medium and large vehicles stayed for 1 hour and 1.25 hours, respectively.
- The distribution of dwell time varied significantly across the observed data, with a small vehicle observed for just 10 minutes, but some vehicles stayed for as long as 6 hours as well.
- Across the commercial land use, small and medium vehicles were observed to be staying for a lesser duration than residential use; however, large vehicles, on average, spent more time at a commercial land use which explains a direct relation between vehicles size and land use type.

- Parking duration was observed to be significantly higher for the service vehicle, with an average of around 1.5 hours. In contrast, the average duration for delivery and waste vehicles were in the range of 14 and 20 minutes, respectively. This provides an insight into the dwell time/staging requirements for different vehicles types.
- For small service vehicles, the average dwell time observed was around 91 minutes as compared to small delivery vehicles, which had an average dwell time of just 12 minutes
- For medium service vehicles, the dwell time observed was just more than 1 hour, while for medium delivery vehicles, the average dwell time was just 20 minutes.
- The parking duration also considerably differs across the different hour intervals in the day. The average parking duration observed during the peak hours (9 am – 2 pm) is shorter than the early morning hours (3 am to 6 am). Interestingly, the parking duration for service vehicles was higher for certain hours in the day, while the delivery parking duration is more consistent throughout the different hour intervals across the day.
- The loading docks of all 17 buildings were heavily over-utilised during peak hours. Several docks were almost 150-200% over utilised, indicating that these existing docks don't offer enough and required loading spaces for incoming F&S vehicles.

4. Model Development

This section describes the development and formulation of the Decision Support tool to deliver the project's aims and objectives as described in section 2.3.

4.1 Model Aim and Objectives

The model's main aim is to develop a decision-support system using a predictive/forecasting model to estimate the parking demand and recommend the optimal dock configuration for the planned building. The model framework is displayed in Figure 2.

The following objectives branched out from the overall aim:

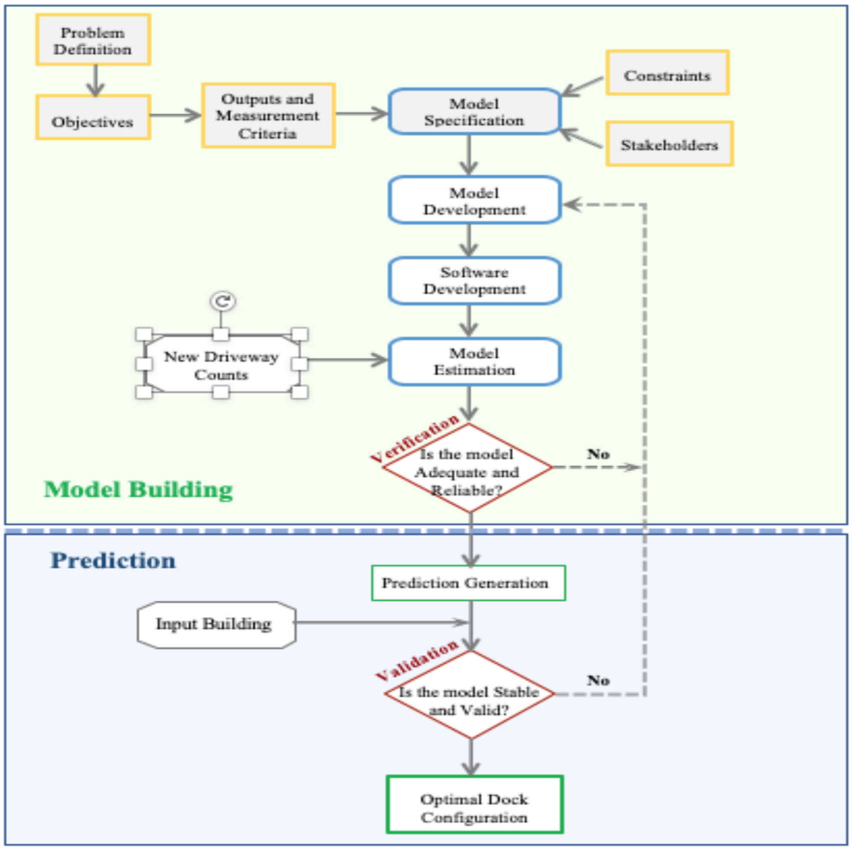
- Estimate the vehicle movements, i.e. total number of daily movements of freight and service vehicles that a future proposed building will typically generate
- Estimate the parking demand based on the estimated vehicle movements, building characteristic and prediction model
- Develop an optimal dock configuration, i.e. determine the recommended number of parking spaces (small, medium, and large spaces) in a loading dock in the proposed building to accommodate these estimated vehicles efficiently.
- Assess the efficacy of the recommended dock configuration.
- The model process and application should facilitate a flexible and scalable approach for model inputs to add future datasets efficiently.

The decision-support tool was developed using a predictive modelling approach that incorporates Regression Analysis with a Clustering approach. The selection of the mathematic approach to building the DSS using predictive modelling was based on several factors covering:

- The modelling methodology systematically promotes a versatile and scalable method for model inputs, allowing different datasets and new variables to be used (e.g. new land-use types or new vehicle types).
- The method is ideal for most typical land-use styles and building sizes due to its importance and applicability. The predictive model was not created with a particular building type or size in mind.

- Externalisation and sharing of the model and its outputs to external stakeholders were made possible by the modelling environment/platform's transferability. Using freely available analytics platforms in the market, the model could be shared in an interactive tool (e.g. MS Excel).
- Prescriptive analytics may be used to assist decision-makers in deciding on a course of action and providing appropriate suggestions based on future predictions and inferred observations and trends in datasets.

Figure 2. Proposed process to formulate a predictive model to achieve the project objectives



4.2 Model Inputs

The model inputs applied the collected parking surveys from 17 different buildings, including:

- Building Information capturing the relevant characteristic for each of the 17 specific buildings where the surveyed loading dock(s) were located.
- Loading Dock Characteristics, capturing the parameters for the loading docks.
- Parking events of each unique F&S vehicle accessing the loading dock, capturing the vehicle activities with each data point representing a different unique parking event for an individual F&S vehicle that is parked in a loading dock during that specific day.

Model Constraints includes the Vehicle types, Activity types (delivery, pickup, service & maintenance, waste, construction), Variable dwell time per vehicle class, Operating capacity of the loading space per hour across the day, estimated vehicle movements and allocation of loading space types.

4.3 Overview of the applied mathematical approach

This section provides an overview of the mathematical approach that was developed and applied to develop the predictive model. The mathematical approach (regularised general linear model with clustering) allows relatively effortless updating of results when new parking surveys become available.

The below steps summarise the approach:

1. **Data entry** - For each of the 17 buildings, vehicle records were captured over three working days. Data was used to generate descriptive statistics
2. **Demand Inference –** Demand was calculated for each time point *t* (minute) of each of 3 days for each building for small, medium and large vehicles
3. **Compute peak demand for each vehicle class for each building - Peak demand** from vehicles of size *j* in building *i* ($Demand\_peak_{ij}$) is the maximum demand observed over the three days corrected for outliers' presence. We used the 99th percentile instead of the maximum so that extremely unusual situations occurring less than 1% of the time are neglected to exclude sporadic demand.
4. **Predictive modelling of peak demand based on a building's characteristics**

   Conceptual Modelling
   - $Demand\_peak_{ij}$ was modelled by creating 3 models: one for each vehicle class, based on 17 observations (1 per building). This model was intended to predict peak demand for each vehicle class for a given building, using residential area, number of apartments, commercial and retail area, and availability of a dedicated elevator as inputs. The potential pool of predictors was based on the conceptual model, which considered moderating effects of the number of floors, presence of a dedicated elevator, and primary use type on the relationship between residential, commercial, and retail space peak demand.

   Modelling method justification
   - The estimation procedure was selected according to several criteria that allow the inclusion of nonlinearities (such as log-linear relationships instead of linear ones) and interactions to account for the possibility of a differential effect of one variable on the outcome depending on the value of another variable. The model should be able to work with many predictors when the sample size is small. Regularised generalised linear regression models appeared to meet the above criteria. Regularisation essentially means eliminating irrelevant predictors. Two variable selection techniques were used, including LASSO and the stepwise variable selection minimisation technique

   Model Results
   - demand for small vehicles is determined by *retail_area*, *commercial_area*, *log(residential_apts+1)* and the interaction between (i.e. product of) *commercial_area* and *elevator_dedicated*. The model implies that having dedicated elevator results in a lower accumulation of small vehicles in the commercial's building dock if there is a dedicated elevator.
   - demand for medium vehicles is determined by *log (retail_area + 1)*, *commercial_area*, *log (residential_apts + 1)*, *log(floors), and commercial_area: elevator_dedicated*
   - demand for large vehicles is determined by *log (retail_area + 1), commercial_area*, and *log(floors)*

   Model Validation
   - Despite the natural presence of some unexplained heterogeneity in peak demand across buildings, the resulting set of 3 models was shown to fit data reasonably well. Predicted demand values and actual demand across the 17 buildings are strongly correlated as Pearson's correlation coefficient of 0.89 represents a high (strong) correlation. The mean absolute error (MAE) is 2 vehicles, which is a good result considering that the total demand varies across 17 buildings from 5 to 21 with a mean of 9.4 and standard deviation of 5. The R^2 of the predictive model is 0.79, which indicates a reliably accurate model prediction for the demand.

5. **Inferring common shapes of intra-day relative demand dynamics**
   - Although peak demand "maximum parking demand throughout the whole day" varies depending on the building's size and other factors, intra-day trends of relative demand (percentage of peak demand)

were found to be consistent across buildings of the same primary use category. Simply, the demand patterns based on relative demand is more accurate than values of demand, i.e. more accurate to predict that 45% of peak demand in a building happens at 9:35AM than predicting 3 small spaces are specifically occupied at 9:35 AM.

6. **Unsupervised clustering of buildings by intra-day dynamics**
   - Buildings were clustered using all 18 variables produced using the 6 time periods and 3 vehicle classes present in the model to reveal common shapes of intra-day dynamics of relative demand (for example, average relative parking demand for small vehicles from 6 am to 9 am and so on.)
   - Two distinct clusters were discovered using a model-based clustering technique. Cluster one is distinguished by a distinct peak between 9 am and 12 pm. Cluster 2 lacks a consistent peak and has a more evenly distributed parking demand during the day. It was discovered that revealed clusters are linked to the primary use sort. Cluster membership prediction is rational and straightforward since all primarily commercial buildings belong to cluster 1 and all primarily residential buildings belong to cluster 2.

4.4 Model Outputs and Measurement Criteria

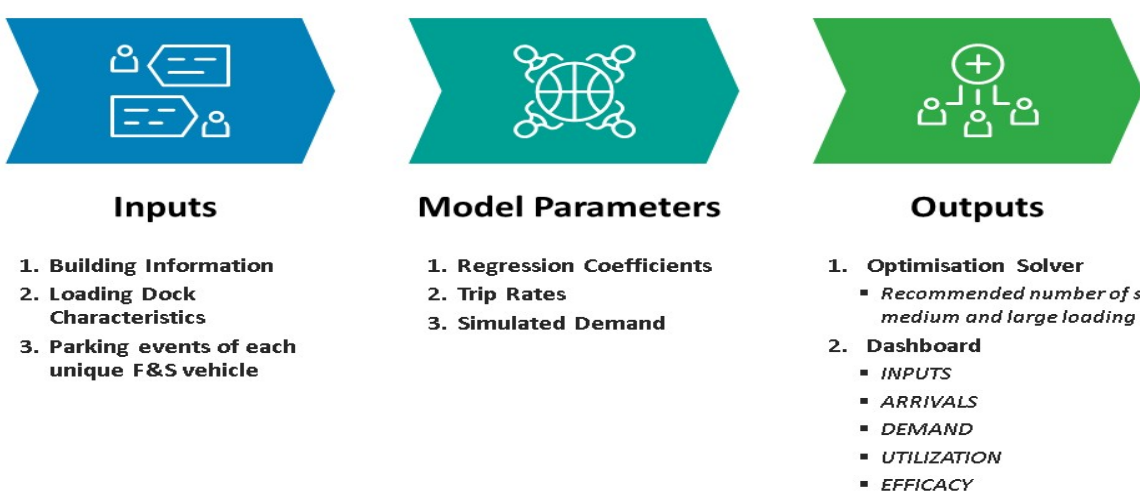
The model outputs have been summarised in the below list:

- Characterisation of the freight and service (F&S) vehicle movements, including arrivals volume, profiles, distribution, and parking duration at any given time for each vehicle class and activity type category.
- Estimation of the parking demand for the three most popular vehicle groups (delivery truck, SRV, and HRV) at various time intervals during the day.
- Recommendation for the number and distribution of the three types of loading spaces that should be used (small, medium and large) in a loading dock.
- Capacity evaluation and use of suggested loading spaces (performance and efficacy evaluation) for the estimated F&S vehicle movements of the three major vehicle groups at various time intervals.

5. Model Application and Solution

This section describes the application of the model. The two main outputs of applying the predictive modelling approach to create the DSS resulted in two model templates (the Optimisation Solver and the Dashboard). The following figure shows a simplified version of the model application.

Figure 3. Model Process Summary



5.1 Description of Solver

Determining an optimal number of parking spaces while keeping the desired efficacy levels is an optimisation problem. Microsoft Excel's Solver Add-in has been used to generate a solution to this problem. The optimisation algorithm searches over various combinations of small, medium and large spaces to find the optimal solution that meets the required efficacy level of meeting a certain threshold of parking demand. Simulated demand for a building with user-specified characteristics is carried out and then assessed to the extent to which a given dock configuration can meet the simulated demand. The peak demand was determined based on the regression coefficient and the input building characteristics. Peak demand (maximum daily demand) was highly dependent on building characteristics. The best-fitting regression models were calculated to allow for peak demand prediction for small, medium, and large vehicles based on building characteristics. The forecasts are strongly associated with real data and make sense from a domain knowledge perspective as well.

The below steps outline the process to run the Optimisation model to obtain the recommended number of spaces of each size:

1. Enter building characteristics (number of floors, land-use unit, land-use unit size)
2. Enter required efficacy (average % of vehicles to be accommodated during the day)
3. Enter the following additional parameters (optional):
    - Loading bay size
    - Minimum and maximum number of small, medium and large spaces
4. Peak demand is estimated based on the above inputs and the regression coefficients (available within the template)
5. Simulated demand is generated in parallel. This simulated demand only considers the demand side of the process, which is solely based on building characteristics.
6. When the optimisation routine (Solver) runs, the optimisation model tries various loading dock configurations, compares their capability to simulated demand, computes efficacy, and selects the configuration that provides adequate efficacy and meets all other constraints while minimising the loading dock's area after trying several possible solutions.
   The total area of parking spaces was minimised using an Excel solver. The optimisation is carried out with the Generalised Reduced Gradient (GRG) algorithm, which tries various values for a small, medium, and large vehicle required number of parking spaces and selected the best combination of three numbers while retaining the specified efficacy level of meeting the parking demand.

Overall, the optimal dock configuration recommended by the optimisation solver does not only focus on satisfying the estimated parking demand, but also consider minimising the overall area of the dock and other supporting regulations such as specified minimum number of loading spaces for medium and/or large vehicles. Hence, the multi-criteria perspective applied in the decision-support process facilitates considering the various requirements and expectations of the different stakeholders.

Figure 4. Snapshot of the Optimisation Solver outputs

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BUILDING CHARACTERISTICS		
INPUT	VALUE	COMMENT
Number of floors	26	
Commercial area, m2	23000	
Residential area, m2	0	
Number of apartments		leave empty if unknown (for a primarily commercial building)
Retail area, m2	500	
Availability of a dedicated elevator	no	if uncertain, select "no"
Primary use type	commercial	

PEAK DAILY DEMAND	
Vehicle class	Peak demand
Small	10.1
Medium	2.2
Large	1.4

ANALYSIS SETTINGS		
PARAMETER	VALUE	COMMENT
Minimum required efficacy (average % of vehicles to be accomodated during the day)	80	Optimal numbers of small, medium and large spaces are found by minimizing the total area of the parking lot while maintaining minimum efficacy (average % of vehicles to be accomodated during the day) at least at this level
Area of 1 small space	18	m²
Area of 1 medium space	24.5	m²
Area of 1 large space	31.5	m²
Minimum number of small spaces	0	
Minimum number of medium spaces	0	
Minimum number of large spaces	0	increase if you find the optimal number to be unacceptably small
Maximum number of small spaces	100	
Maximum number of medium spaces	100	
Maximum number of small spaces	100	
Maximum total number of spaces	100	decrease if you find the optimal number to be unacceptably large

OPTIMAL SOLUTION	
SIZE	OPTIMAL NUMBER
SMALL	5
MEDIUM	1
LARGE	0
SOLUTION'S CHARACTERISTICS	
Total spaces	6
Average accomodated vehicles	2.0
Average demand	2.4
EFFICACY (average % of vehicles to be accomodated during the day)	82.4
TOTAL PARKING AREA, m²	114.5

USER-SPECIFIED SCENARIO	
SIZE	NUMBER
SMALL	3
MEDIUM	1
LARGE	1
SOLUTION'S CHARACTERISTICS	
Total spaces	5
Average accomodated vehicles	1.9
Average demand	2.4
EFFICACY (average % of vehicles to be accomodated during the day)	79.3
TOTAL PARKING AREA, m²	110

5.2 Description of Dashboard

The Dashboard calculates various metrics for a given parking configuration by determining demand numbers, the number of spaces used, and the number of vehicles accommodated from simulated demand. The following table describes the main features of the Dashboard.

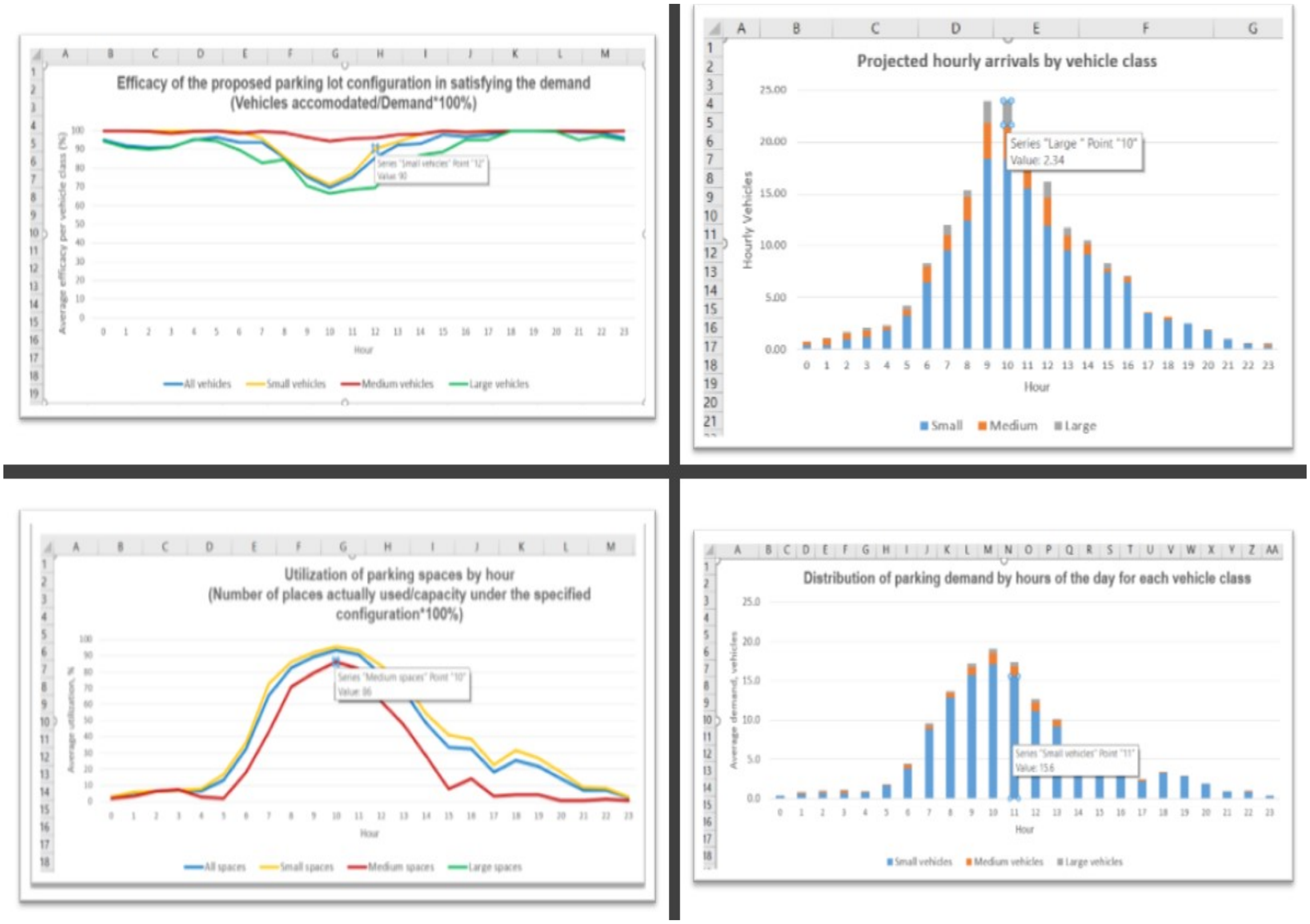
Table 2. Dashboard features description

Tab	*Description*
ARRIVALS	▪ *Vehicle arrivals are computed using daily trip rates (i.e. movements per 100 apartments, 100m2 of retail and commercial area) derived using the calculated "TRIP RATES" and hourly distribution of arrivals for the primary use type* ▪ *Projected daily arrivals of each vehicle type are computed*
DEMAND	▪ *Charts and tables summarise simulated absolute demand (in vehicles) by aggregating it to the hourly level*
UTILISATION	▪ *Charts and tables summarise utilisation by aggregating it to the hourly level. Utilisation at any given time point was found by comparing the number of places occupied and the capacity under the specified configuration*
EFFICACY	▪ *Charts and tables summarise efficacy by aggregating it to the hourly level. Efficacy at any given time point was found by dividing the number of vehicles accommodated and the demand at that point in time*

ARRIVALS ATTRIBUTION	▪ *Displays the estimated vehicle arrivals per land-use units in the building i.e. vehicles per commercial area, vehicles per retail area etc.*
PARKING DURATION	▪ *Displays the estimated hourly average parking duration per vehicle class and the estimated hourly average parking duration per activity type*

Based on the inputs, the Dashboard template would generate the key outputs and parameters, which covers hourly parking demand, hourly vehicle arrivals, the efficacy of the recommended dock configuration, capacity utilisation of the recommended dock configuration, average parking duration.

Figure 5. Snapshot of the dashboard outputs



Some key inferences which are derived from the outputs of the Dashboard include:

- Accommodated vehicles "small, medium and large" in each hour interval by the recommended dock configuration is illustrated in the efficacy chart. For instance, it is estimated that about 70-75% of all vehicle arrivals during 9-12 with large vehicles having the most parking availability issue in the example building shown in Figure 6. Hence, detailed insights are provided for the efficacy of the recommended dock configuration in meeting the parking demand for each vehicle class.
- Additionally, the capacity utilisation chart illustrates the most utilised and underutilised loading spaces in each hour interval by each vehicle class. Accordingly, the users can decide what actions and/or regulations should be encouraged to better support the utilisation of the recommended dock configuration.
- The detailed insights provided in Arrivals charts display the peak hour for vehicle arrivals from each vehicle class and each activity visit as well as the estimated arrival count in each hour interval. Additionally, the highest number of vehicle arrivals or lowest number of vehicle arrivals for each hour interval provides a valuable figure regarding the number of vehicles present at the dock. Accordingly, characterisation of the

vehicle class and activity type that occupy the dock in each hour interval are provided for better decision-making and analysis.

- The average parking duration for each vehicle class and activity visit provides detailed analysis of time spent at loading spaces throughout the different hour intervals. Hence, the users are better informed regarding which vehicle class and/or activity visit might adversely affect the efficiency of the dock by parking longer or shorter.
- The estimated vehicle trip rates by each land-use type "commercial, residential and/or retail" provide detailed analysis of the freight generation produced by these land-use and indicate which land-use type generates the most or least vehicle movements.
- Overall, the insights provided in the Dashboard facilitate an improved understanding and knowledge of the utilisation and suitability of the recommended dock configuration. Hence, the users can make better-informed decision about any trade-offs related to the dock configuration, if necessary.

The Dashboard provides many additional valuable insights into the loading dock's operations and efficiency through several parking characteristics. This has many use cases to understand the performance of the operations, occupancy of the dock, peak requirements, parking availability at the time of the day. For instance, the efficacy of different dock configurations can be compared in terms of the likely success of the recommended loaded spaces in meeting a different threshold of parking demand. Additionally, the highest and lowest hour intervals are identified in terms of highest parking demand, vehicle arrivals, vehicle classes and activity visits, success and/or failure to accommodate incoming vehicles.

Different stakeholders could directly utilise these outputs to optimise further (as an example, any new delivery vehicles could be provided with an appropriate time slot when the overall activity levels are low in the day. These insights provide an ability to develop a booking management system to schedule freight and service vehicle trips.

Table 3. Description of the data variables generated after feature extraction

Parking Characteristics	Description of the Variable
Parking accumulation	▪ *the number and type of vehicles parked at an interval of time*
Occupancy factor	▪ *the total number of parked vehicles at a specified duration, indicating how effectively the loading dock is being utilised*
Peak parking saturation	▪ *the number and type of vehicles parked at peak time to the total number of parking space available*
Vehicle Arrival Profile	▪ *Detailed characterisation of the vehicles that used the dock through generating the vehicle volumes by time of the day*
Vehicle Type and Size	▪ *Detailed characterisation of the vehicles that used the dock through generating the vehicle volumes by type and size*
Parking Duration Distribution	▪ *Distribution of dwell time (average and percentile distribution) for different type and size of vehicles for all the activity type for all the hourly intervals across the day*
Activity Profile	▪ *This insight provides an additional detailed characterisation of the activity type that uses the dock, i.e. common activity type used during peak, off-peak hours, parking duration for each activity type.*
Parking availability	▪ *This insight provides an additional detailed characterisation of parking availability during different hour intervals based on the estimated capacity utilisation. The times when the overall dock is over-utilised or underutilised could be established. We can use this insight to highlight the space type that might be the most problematic from a capacity perspective.*
Dock Efficacy	▪ *Efficacy of the proposed parking lot configuration in satisfying the parking demand by vehicle size*
Dock Utilisation	▪ *The utilisation of parking spaces by size (i.e. small, medium and large) for each hour*

6. Discussion and Implications

This section briefly summarises the merits and usability of the model. It outlines various stakeholders who can use the model to provide better freight and service operations and minimise the associated negative impacts.

6.1 Merit and usability of the model

Regression and clustering analysis techniques are used to develop the predictive modelling methodology used in the development of the DSS. This modelling approach promotes a versatile and scalable model input system that allows different datasets and variables to be used (e.g. different land-use types and/or vehicle types). Due to its value and applicability, this method is ideal for the most common land use forms and sizes. The predictive model was not intended for a certain form or size of a building. The transferability of the environment/platform modelling allowed the model to be externalised and readily shared with all the relevant external stakeholders. Additionally, the inclusion of a diverse and representative list of buildings with different mix of land-use types “commercial, residential and retail” in the collected parking surveys and model inputs facilitates producing valid and reliable estimates for most common building types and sizes that are common in CBDs.

The model could be shared in an interactive tool using publicly accessible analytics tools on the market. Prescriptive analytics can help decision-makers choose a course of action and make relevant recommendations based on potential forecasts, inferred findings, and patterns in datasets. The model template will be presented in an interactive and sharable/transferrable template (preferably Excel spreadsheet or an open-source online platform/dashboard) to be used by multiple members in different locations to input the parameters and generate the results that have been described in the previous sections

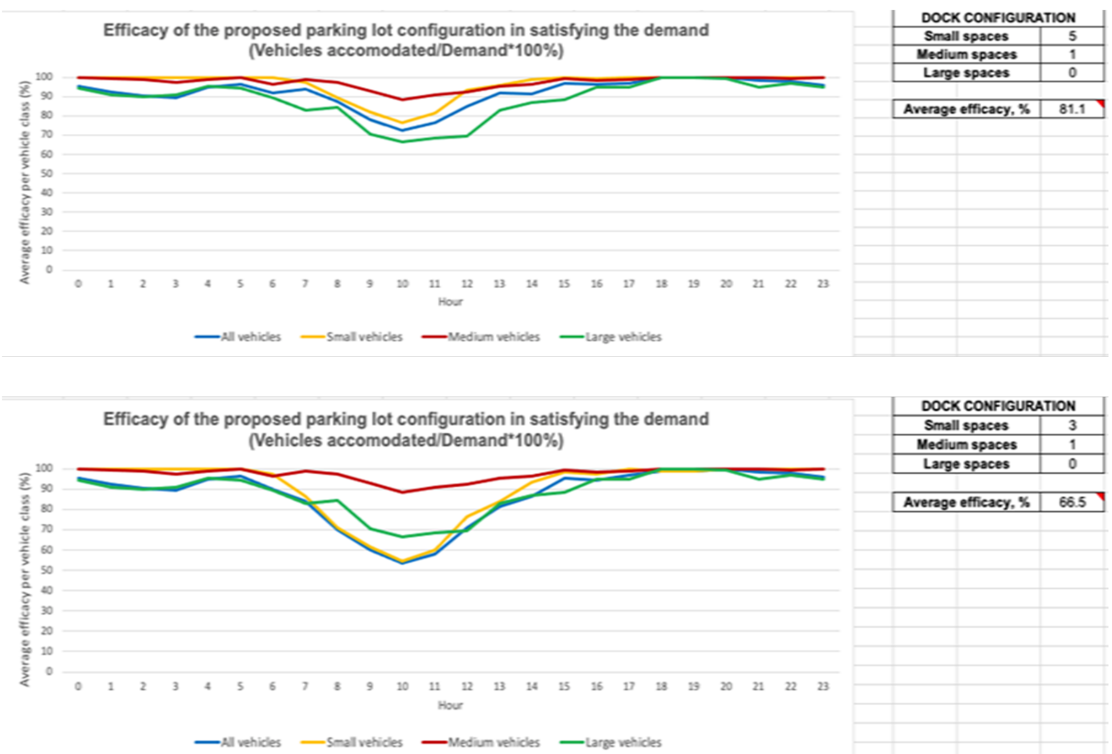
6.2 Model Applicability and Further Potential

Two main output, in the form of templates, were generated as a result of using the predictive modelling method to construct the DSS (the Optimisation Solver and the Dashboard). Via a variety of parking characteristics, the Dashboard offers a wealth of additional information about the loading dock's operations and performance. This can be used to understand operations efficiency, dock occupancy, peak requirements, and parking availability at different times of the day. Various stakeholders could use these outputs directly to improve efficiency (for example, any new delivery vehicles could be assigned to a time slot when overall activity levels are low during the day). These findings allow the development of a booking management system for freight and service vehicle trips. The delivery and service vehicles can book an arrival slot in the premises and allocate a parking space based on hours of operations, available parking bay supply and requested dwell time requirements.

Property developers often complain that the parking rates in planning regulations are too high and irrelevant, while local authorities argue that property developers fight to minimise the number of spaces without taking into consideration the operational practices of F&S vehicles. It can be argued that most developers mainly focus on minimising the infrastructural costs of establishing on-site loading docks with far less emphasis placed on carrying out comprehensive assessment studies of existing loading docks and applying robust models to properly determine the best design of new docks. This is a critical oversight given that the efficacy of loading docks is inextricably linked to understanding how they are utilised and assessing their suitability. Thus, this ill-advised and problematic decision-making process by many developers compels local authorities to reject the initial number of loading spaces in most building approval applications. Hence, the planning process goes over multiple rounds of negotiations between transportation authorities and property developers as the recommended loading dock is not decided based on a sound and representative approach that reflects the actual use of loading docks and operational practices of F&S vehicles.

However, the acquired knowledge and insights from existing loading docks presented in this project facilitate an enhanced understanding and depict an accurate picture of the current utilisation of docks by F&S vehicles. Moreover, the data-adjusted decision-support tool developed in this project overcomes the shortcomings of existing dock provision approaches and provides all the stakeholders involved in new building approval applications with an enhanced understanding and confidence about the optimal configuration of loading docks in new major developments. For instance, the model outputs offer detailed characterisation scenario analysis of the likely efficiency of different dock configurations, as shown in the Figure 7 below. The model templates allow the users to compare the suitability and efficacy of different dock configurations in terms of accommodating the estimated parking demand and vehicle arrivals. This will potentially contribute to greater confidence and less contention between different stakeholders within the building planning and approval process. Moreover, the model would help plan an optimal loading dock configuration that keeps a balance between the amount of space required and fulfils the freight and service vehicle demand optimally. Thus, eliminating the issues around long queueing times, a large share of vehicles parking illegally, and road safety concerns when the drivers load and unload goods on the street. Urban planners may take a proactive approach to incorporate the derived knowledge on vehicle movements and parking demand in the land-use ordinances of on-site loading docks for sustainable integration with sensitive surrounding uses. Additionally, the outputs from the model could also allow local authorities to recommend supporting measures and regulations to accommodate these vehicles' different operational requirements and practices. For example, off-peak delivery programs could be considered to encourage F&S vehicles to utilise loading docks during quiet business hours with a broader aim to reduce non-essential traffic from the road network during peak hours. The idea of creating a consolidated logistics centre where the F&S operations of several adjacent but inter-connected developments could be consolidated should be pursued further. These criteria are supported by the model as most activities happen during peak hours, which may be used to explicitly promote the evaluation of such proposals, including testing off-peak delivery schedules.

Figure 6. Efficiency of Different Dock Configuration (different combination of loading spaces)



The model may be further enhanced by including new datasets from other building types in a future. Efforts are also required to create a template that would capture the operational setup of a loading dock and the underlying building regulations and business requirements of building tenants as these factors considerably affect the loading dock efficiency and the capacity of loading spaces in meeting the functional requirements of incoming vehicles.

6.3 Target Stakeholders

The decision support system provides all stakeholders and decision-makers in the planning phase with a comprehensive tool to incorporate the F&S delivery processes into the facility planning's core requirements at the early stages of the project. The model has many practical applications and uses for a variety of stakeholders:

Some of the key stakeholders include:

Primary Stakeholders

- **Transport Authorities** – Ensure that any freight and service-related activity is not utilising the public roads and infrastructure (e.g. on-street parking/staging) and thus requiring lesser maintenance efforts. Also, it would ensure that the local road congestion due to freight and service delivery operations is minimised.
- **Planning Authority** – Overall adherence to space standard and planning guidelines at a state planning level. Support in approval of planning applications.
- **Local Councils** – The councillor working for the local government could be assured that any new development in their council areas would cater for all the requirements of the docking operations within site itself, thus enhancing the local environment. The overall aim is to ensure the city is attractive and liveable for citizens and businesses alike, with minimum hindrance, through effective and efficient transport operations.
- **Property Developers** – Property Developers can integrate the model outputs when planning for the development. This way, they can estimate the amount of space that should be reserved for F&S operations planning. This would support the planning and development application and provide an opportunity to increase the market attractiveness and future potential of the proposed development.

Secondary Stakeholders

- **Delivery Companies** – The delivery companies are ensured that they get a parking spot when needed, thus optimising the time spent by the delivery vehicle and person. The driver could be assigned a specific position inside the loading dock, thus eliminating the need to look for an illegal parking spot, whether inside a loading dock or outside in on-street parking spaces.
- **Property Tenants** – Tenants of the property are assured that the building has its own efficiently dedicated space for the F&S delivery operations. There is no day-to-day hassle to manage these operations.
- **Resident Wellbeing** – for residential buildings, having a dedicated and segregated (from other core activities within the residential development) presents a good image of the property, thus enhancing the market attractiveness.

7. Conclusion and Outlook

Freight and service vehicles need to park close to their customers, and they require an operationally effective loading dock to perform their services in buildings. However, an onsite-loading dock becomes a viable solution only when enough spaces are present. If there is a gap between available parking and demand, more innovative and dynamic approaches need to be considered. This is not only an enforcement issue, as quite frequently, but the number of parking spaces available is simply not enough to satisfy the needs of incoming vehicles. Hence, the freight demand management solutions should be considered to enhance the operational environment for incoming F&S vehicles. They aim to improve freight management by modifying the underlying demand by adjusting the frequency, timing, and freight and goods delivery mode. The goal of such an approach is to change behaviour and operations primarily through policy intervention. The parties involved are incentivised or taxed (for positive or negative behaviour) so that the recipient is motivated to choose a more appropriate time.

In terms of model implementations, stakeholders should be mindful of data quality and coverage. The stronger the input data (in terms of data quality, coverage, survey program size and scale, various building types covering all sizes and activity types), the higher the predicted degree of model robustness. Other variables that may influence data inputs include seasonality, holiday times, and other factors such as demographics of property tenants, which affects the length and demand for service vehicles.

The infrastructure design and planning for the loading dock's operations should consider other activities in the area, as well as the primary development zoning/land use segregation principles. The loading dock, for example, should preferably be situated away from the customer-facing areas (ideal location could be at the backside of the development with separate roadway access away from the main traffic route or in the basement if the height restrictions allow for it).

The following figure provides an assessment of the main supporting solutions and measures that may enhance the efficiency and utilisation of on-site loading docks in large developments.

Figure 7. Proposed Solutions and their qualitative efficiency

Criterion	Solution				
	Delivery & Service Plan	Consolidation Schemes	Booking Scheme	Staging Area	Off-hour Delivery
Changes	◕	◕	◕	○	●
Required Coordination	●	◕	◔	◔	◑
Cost	◑	○	◕	●	◕
Benefit	●	◔	◕	◑	◑
Potential Compliance	◑	●	◑	◕	◔
Potential Conflict	◔	○	◑	◔	●
Risk	○	◕	○	●	◕
Suitability	◕	◕	●	◔	◔
Responsibility (Initiator)	Bldg. Management	Receivers	Bldg. Management	Bldg. Management	Bldg. Management & couriers
Stakeholders	Dock managers, shippers, couriers & receivers	Receivers & carriers	Dock managers, couriers, receivers & application provider	Dock managers, couriers & 3rd party operator	Dock managers, shippers, couriers & receivers

Efficiency Index	Low	Relatively moderate	Moderate	High	Very high
	○	◔	◑	◕	●

8. Funding

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