REPRESENTING PUBLIC TRANSPORT SERVICES IN A REGIONAL TRAVEL MODEL

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ABSTRACT

The Western Cape Travel Model (WCTM) is a multi-modal process that includes both traditional fixed-route public transport (PT) and an extensive minibus-taxi (MBT) network. The PT services are represented in the model by coding traditional routes, frequencies, and fares in the Cube software package. This includes Golden Arrow Bus System, MyCiti, Jammie Shuttle (UCT students), Metrorail, and GoGeorge.

The coded PT network is a simplified representation of the routes of the real system, consistent with the zones and the roadway network of the model. Many of the data characterizing the supply of the PT services were not readily available and the existing information required considerable processing before the routes could be coded. The coded network provides a systematic way of calculating the zone-to-zone travel time by PT.

The MBT service has hundreds of individual flexible routes that operate without fixed schedules and service is nearly ubiquitous. This is similar to informal transit services that exist in other cities in developing countries: colectivos in Buenos Aires and jeepneys in Manila. To represent this service, the authors developed an innovative route density-based procedure, which is used to calculate walk and wait times for each zone. This is combined with travel impedances from the roadway network to describe MBT service to the travel model. A similar method is used for metered taxicabs and Transport Network Company services (Uber, Bolt [formerly Taxify]).

1. BACKGROUND

A new travel demand and land use model has been created for Western Cape Province (1). This is a strategic, synthetic model that allocates provincial growth by Traffic Analysis Zone (TAZ) which is then input to models of person travel and goods movement to estimate traffic volumes and transit ridership at the link level. That information is then used to update the land use model in an integrated process that establishes the equilibrium between development and travel demand.

The model has been created by Bentley Systems (formerly Citilabs) and Esri SA for the Western Cape Government Department of Transport and Public Works (DTPW). The model covers the entire province with greater detail in the City of Cape Town, using around 4000 zones and a base year of 2016. The model is applied using the Cube software package, including Voyager for person travel, Cargo for goods movement, and Land for land use estimation. Since a travel demand model exists in the City of Cape Town, every effort has been made to coordinate the data used by the two models. The principal use of the Western Cape Land Use/Transport Interaction (WCLUTI) model will be mid-to-long term planning-level analysis of transport and land use strategies.

2. PUBLIC TRANSPORT SERVICES

A principal input to any such travel model is a description of the public transport (PT) services. In this model, the PT system has several submodes that have been treated in two different ways in the WCTM.

The following submodes have been treated as conventional fixed-route/fixed-schedule services coded within the PT network:

- MyCiti bus, operated by Transport of Cape Town to provide relatively higher speed bus service.
- Golden Arrow Bus System, a privately-operated system that is subsidised by the province.
- Metrorail, a network of commuter and suburban rail lines in and around the metropolitan area of Cape Town, operated by the Passenger Rail Agency of South Africa (PRASA).
- Jammie Shuttle, the bus system serving the University of Cape Town.
- GoGeorge, the bus system serving the City of George.

There are also intercity rail services (e.g., Shosholoza Meyl) and intercity bus (Greyhound, Baz Bus, etc.) that connect Cape Town with Kimberley and Johannesburg but these are relatively infrequent services that are not currently included in the model, and will be examined as a future model enhancement.

The following “flexible” submodes have been treated at the demand model level and therefore are not included within the coded PT network:

- Minibus Taxis (MBT).
- Metered Taxis / Uber / Bolt.
- School Buses.

2.1 PT Network Coding for Fixed-Route Services

The PT services must be represented in the travel model, in order to represent the choices that each traveller has in going between origin and destination zones. For the conventional fixed-route/fixed-schedule services, each PT line is *coded* in the PT network. PT coding in Cube consists of defining six main components in the PT network/system:

- The description of the **PT system**, with the definition of the Transit and Non-Transit modes available to the passengers, the operators of the services, and other general elements defining how the PT system works.
- The services’ routes, named **PT lines**, with the definition of the average service frequency by period and other attributes specific to each service.
- The definition of the **fare system** implemented for each PT mode/operator and associated to each line.
- The access/egress links and transfer links, named **Non-Transit Legs**. In the WCTM only walk NT-Legs are coded, because drive access is treated separately in the demand model with a specific Park & Ride model.
- The specification of how to calculate the actual **travel time** along the PT network for each service.

- The definition of the **factors characterising passengers' behaviour** along the PT system (perception of costs and time, generalised cost calculation, route choice behaviour).

Only weekday services are modelled, by these periods: AM peak, midday, PM peak, night.

The coded PT network is a simplified representation of the real system, consistent with the zones and the roadway network of the model:

- Bus routes are coded using the links and nodes in the roadway network and speeds affected by traffic congestion.
- Rail routes are coded by adding specific rail-only links and nodes to the roadway network, with speeds obtained from the available timetables.

It is important to note that this is a strategic planning-level model, so the service is represented in terms of *frequency* coding, rather than *timetable* coding. The latter method is used with low-frequency and highly-synchronized services, by operating agencies to represent and optimize bus scheduling detail. DTPW does not need that level of detail, which is a significant burden on the model user. Moreover, the nature of the PT system in Western Cape is more appropriately approximated in terms of its average frequency for each period and the routing is based on the most common route. No attempt is made to represent *trippers* or other unique, specific bus runs.

The result is the number of routes by submode shown in Table 1, whilst Figure 1 shows an example of a coded MyCiti line and stop nodes.

Table 1: One-way PT Lines

Service	Routes
MyCiti	84
GABS	433
Metrorail	65
Jammie Shuttle	18
GoGeorge	34

Figure 1: Coded Route Example (MyCiti trunk line T01dR: Civic – Danoon)

Together with the route coding, the other fundamental component is the access/egress/transfers coding, or more generally and with Cube terminology the generation of the NT-Legs (NT = Non-Transit; Leg = sequence of links). This consists of the links that connect the zonal centroids to the PT system at both ends of the trip (access and egress), and the links that connect stop nodes belonging to different lines.

The pedestrian network is necessary to create the connections between the zone and the PT system and vice versa, and to transfer between different services. It is important to notice that no “walk-only” connections are created “automatically” in the path-building process. The Non-Transit Legs are created with a distance/submode based controlled procedure for the WCTM, checking the distribution of walk-distances that derives from the process. It was necessary to refine the walk network locally to allow better walk connections than through the HW network in some cases. Because in WC people walk almost everywhere, it has been agreed with WCG to only exclude very few links from the "walkable" network (freeways and railways), and it was necessary to create some walk-connections parallel to the railway network where people can walk.

2.2 Challenges in Coding the Fixed-Route Services

The first challenge with coding the fixed-route services was the definition of the services actually running in the system and their actual schedule. Indeed, only MyCiti and GoGeorge services were clearly defined from publicly available sources.

Another interesting aspect of PT service in Western Cape is that virtually no service is provided in the evenings, after about 19.00. This may be due to local custom, but it is likely that concern for personal security is a key reason as well.

It is also a local custom that the level of PT service is much different on Fridays than on other weekdays. It is common on Friday for workers to go to work and return home an hour or two earlier than on other days and this is reflected in the published PT timetables. No attempt has been made to reflect this in the coded network, which represents the Monday – Thursday scheduling.

2.2.1 Metrorail

A particular challenge was related to the rail services. In recent years (including this project’s base year of 2016), the Metrorail system has suffered significant acts of vandalism. These incidents have not only complicated the coding of accurate service levels, but they have also substantially affected the ridership, both in terms of reduced service levels due to fewer cars available and in discouraging travellers from using the rail system.

2.2.2 GABS

The GABS service proved to be a special case. The GABS service is highly irregular in time and space. Many routes have a significant number of branches and in many cases, service is not uniform or symmetrical between AM and PM, for example. As a private operator, GABS has a greater incentive to match supply to demand and thus operates services that closely align with unique highly localised patterns of bus ridership. In order to better understand the GABS operation, a survey of the bus services was commissioned. This survey identified more than 10 000 individual “pieces of work”, indicating the complexity of the schedule. Several weeks have been spent examining these service fragments, in order to create an approximation of a uniform schedule that could be coded in the software.

2.3 Flexible PT Services

2.3.1 MBT

A significant component of service is the minibus-taxi system (*MBT*). MBT is very similar to other informal transit services that exist in large cities in developing countries, such as Buenos Aires (*colectivo*), Mexico City (*pesero*), Manila (*jeepney*), and Bangkok (*tuk-tuk*). This service is provided by thousands of individual drivers, operating vans that carry 10-14 passengers. Many of these drivers work for private companies or driver associations while others are individual drivers. These services are licenced by the province to operate on a fixed route for a specified number of hours per day but deviating from the route to serve demand is common. MBT service is also characterised by overcrowded vehicles, unsafe driving, and haphazard operations. MBT provides service to areas that are poorly served (or unserved) by fixed-route transit and appeals mainly to a segment of the population that have limited options.

The flexible (and unpredictable) nature of the routes and frequencies and the large number of routes (several hundred) make it extremely difficult to code this service in the same manner as the fixed-route services. An alternative method was developed to represent this service level in an approximate manner.

The model requires the in-vehicle travel time between all pairs of traffic analysis zones. It is assumed that MBT drivers know their areas, are very efficient, and generally operate at the same speed as other traffic. Many MBT drivers are quite aggressive, suggesting that they drive faster than the general flow of traffic and often violate traffic laws and government regulations in the interest of saving time. However, they also must stop for passenger boarding and alighting. It also appears that their deviations from their assigned routes are unpredictable. The MBT zone-zone travel time can be derived from the coded highway network. This represents the travel time by private auto and is stratified by AM peak and midday for most purposes in the model. The model assumes that the MBT in-vehicle time is the same as the private auto driving time for each O/D pair with an adjustment to reflect pickups and drop-offs.

The model also requires the out-of-vehicle travel time between all pairs of traffic analysis zones. This consists of the time to walk from the origin to the MBT boarding stop, the time to walk from the MBT alighting stop to the destination, and the wait time for the initial MBT vehicle and all other MBTs that are transferred to. These average walk and wait times are needed for each zone-zone movement and it is typical to estimate them as an average value for each zone (finer geographic detail than that is not necessary). Generally, these parameters are highly influenced by the size and development density of the zone (population and employment density) and, more specifically, the *route density* of the zone. A common way of measuring route or service density is to sum the number of kilometers for all MBT routes in a zone and divide that by the zonal area in square kilometers. WCG provided data describing the MBT service as of 2016, in the form of a GIS map of routes. The consultant tabulated that data in terms of number of routes and number of vehicles serving each route. This analysis accounts for routes that have been approved but which currently have no service. It also accounts for the different types of route, stratified by route length, using weighting factors as shown in Table 2. Long-distance routes that operate infrequently are given a lower weight and “regular” routes are weighted the highest.

Table 2: Minibus-Taxi Weighting Factors

Route Length	Weight
< 60 km	1.0
60 – 200 km	0.8
200 – 500 km	0.2
> 500 km	0.0

This data was geoprocessed in order to determine the approximate number of route-kilometers and bus-kilometers that operate in each zone. These are divided by the zone's area to determine the *service density*. If a zone had no routes operating within the zone's boundary, but it would be possible for travellers to easily walk to a nearby zone, that zone was considered to have service. The resulting data was normalised and rounded to produce index values of 0 – 100 for each zone. A value of zero means that the MBT mode is unavailable for trips to/from that zone. A value of 1 means that some MBT service exists, but it could be at a very low level of service. Values of 2 – 100 represent the relative level of MBT service available to travellers in the zone. Two values are calculated for each zone: route density index and a bus density index.

- The route density index represents the relative proximity of service and is used to estimate the average walk time to/from an MBT route.
- The bus density index provides a measure of service frequency and so is used to estimate the average initial wait time for an MBT vehicle.

Figure 2 illustrates the relationship between the service indices and the MBT walk and wait times. The walk time relationship is slightly different between the origin walk and the destination walk.

Figure 3 illustrates the extent of MBT service in Western Cape.

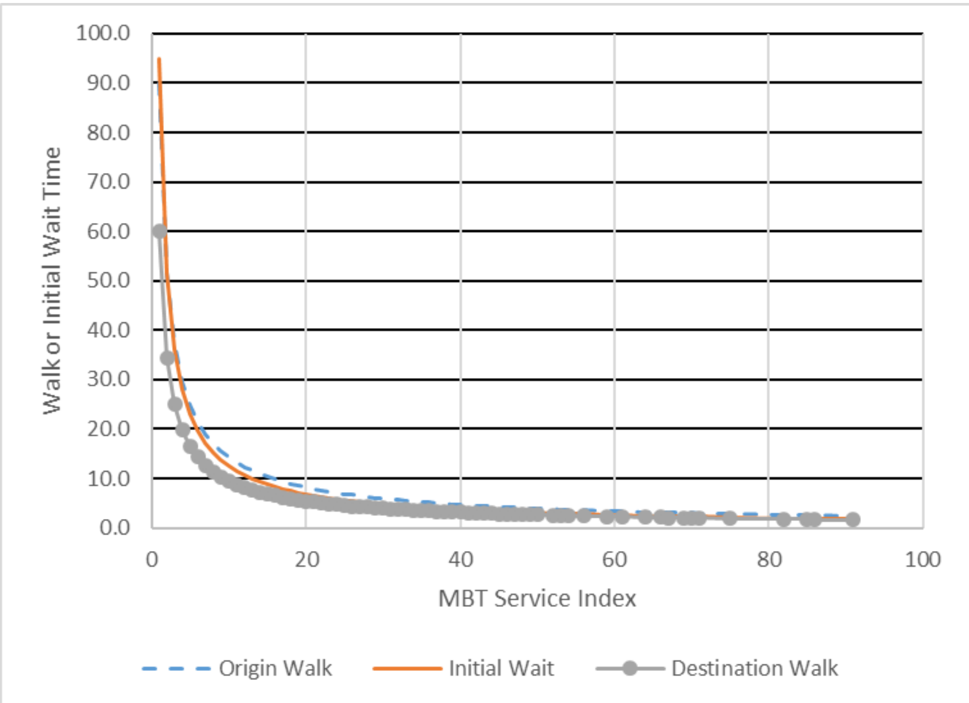

Figure 2: Minibus-Taxi Walk/Wait Time

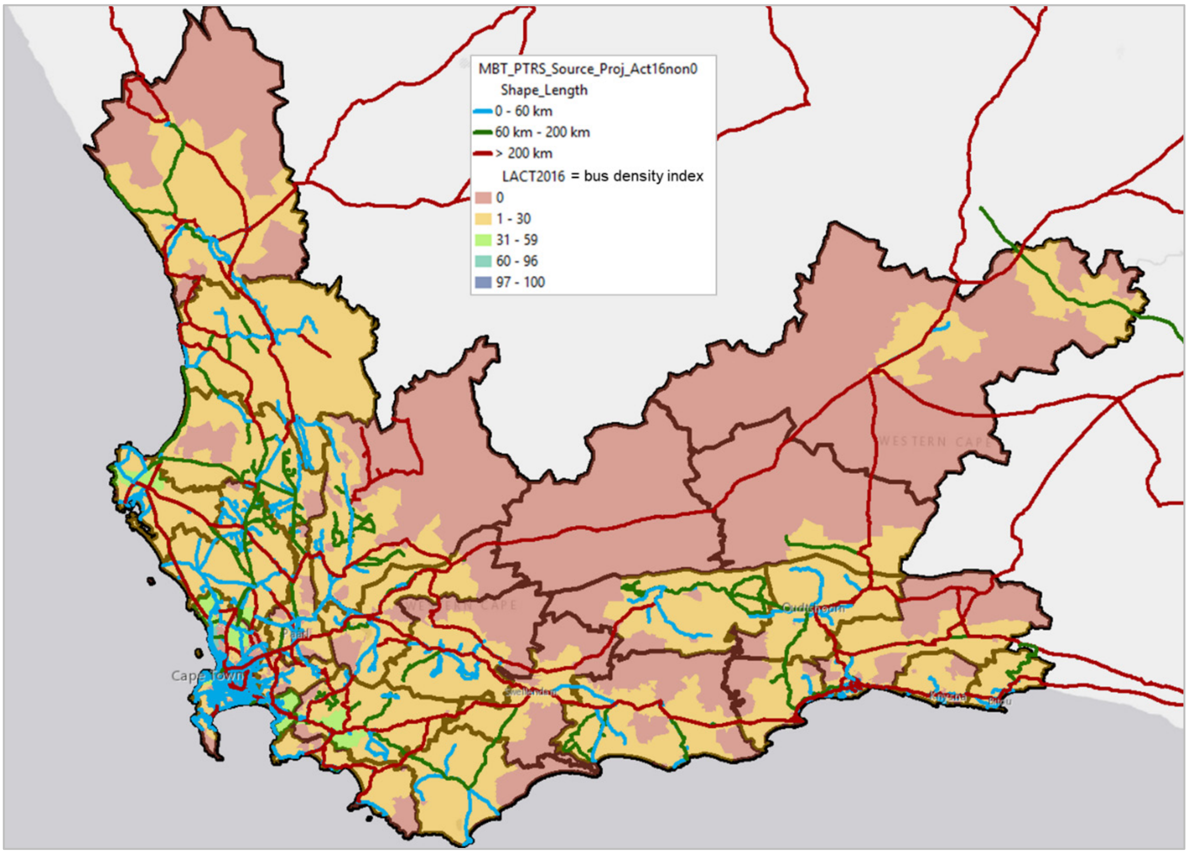

Figure 3: Minibus-Taxi Service Coverage

Table 3 shows the resulting peak period values for a sample of zones.

Table 3: Sample MBT Walk/Wait Times

Area	Zone	Route Index	Bus Index	Origin Walk Time	Destination Walk Time	Wait time
Lamberts Bay	110	17	12	9.3	6.2	10.7
Paarl	439	54	54	3.7	2.5	2.8
Stellenbosch	600	5	5	24.8	16.6	23.0
Swellendam	760	2	5	51.7	34.5	23.0
Mossel Bay	1200	5	3	24.8	16.6	36.1
Oudtshoorn	1460	2	1	51.7	34.5	85.0

The population-weighted average for all zones in the province is walk time = 8.7 min, wait time = 7.8 min. These are consistent with values reported in the 2013 National Household Travel Survey (3) for actual MBT users (walk: 8.2 min, wait: 6.8 min). Figures 4 and 5 show the estimated vs. observed distributions of MBT walk and wait times.

The figures in Table 3 represent the wait time for the *initial* vehicle. It is assumed that the typical MBT trip is fairly short – on the order of 10 km. So a longer trip would require one or more transfers to different MBT routes. It is very difficult to accurately estimate the wait time for each of the subsequent vehicles, as it depends entirely on the length and geography of the trip. As an average, the model will add 5 min of wait time for each 10 km of trip distance, or part thereof. These are the model's current assumptions. Validation of these figures and further examination of their impact on model accuracy must await the availability of more detailed data on MBT ridership, such as would be available from a rider survey (2).

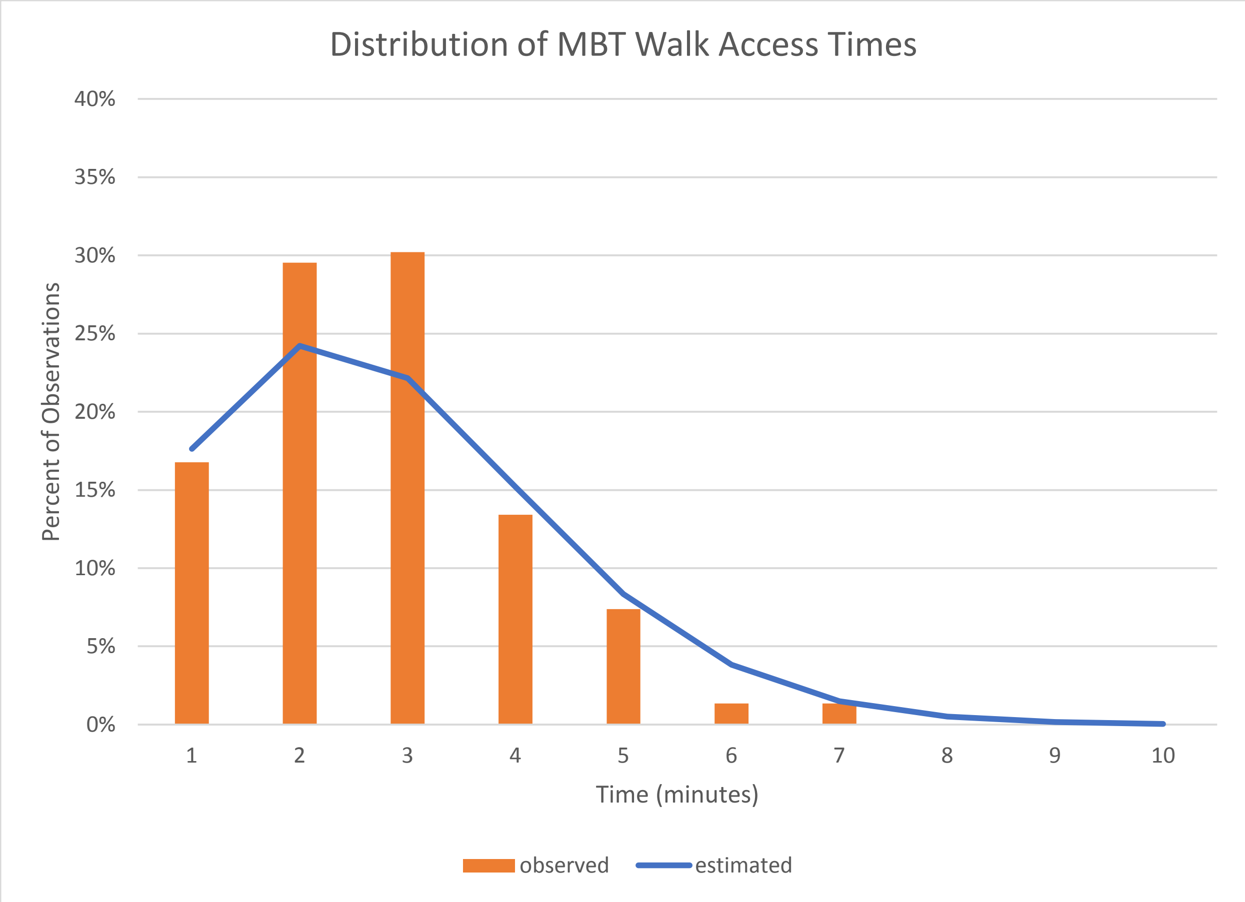

Figure 4: MBT Walk Times

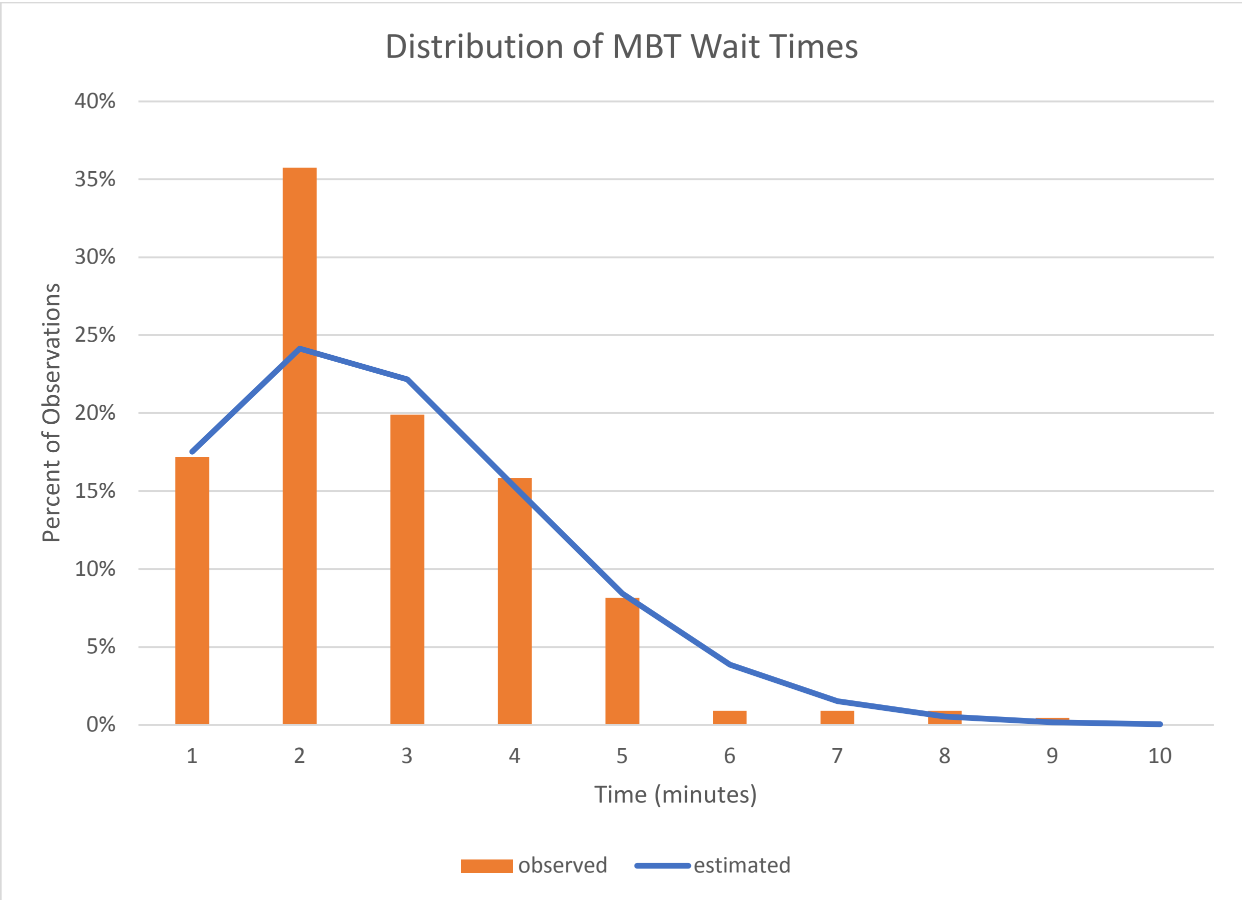

Figure 5: MBT Wait Times

MBT mainly uses a fixed fare system based on trip distance. This approach represents a reasonable balance between system detail and the burden on the model user. Most routes charge R7 per trip. Some longer routes charge as much as R15 and it appears that no transfers are free. If a trip requires three separate MBT routes, the rider pays three separate fares. The model will use a similar method as for the wait time. The estimated fare for a specific trip would be R7 for the first 10 km and R7 for each additional block of 10 km.

MBT is treated as a separate mode in the mode-choice model.

This method of handling MBT impedance is not without its drawbacks. The principal disadvantage is that it is infeasible for the model to estimate ridership impacts from detailed changes in MBT routing, many types of changes in fare structure, or other specific changes in MBT operation. However, MBTs are loaded separately onto the network and so creating exclusive lanes or allowing MBTs to use reserved bus lanes can be modelled. The authors hope to be able to improve the model’s handling of MBT service in the near future.

2.3.2 Other Submodes

Metered taxis and Transport Network Companies (TNC) are integrated in the model as a separate mode at the mode-choice level.

Metered taxis include conventional licenced taxi services and service provided through TNCs include services such as Uber and Bolt. The impedance for this mode includes a weighted average fare between those two types of service.

For School trips only, the School Bus mode is available at the mode-choice level, depending on the length of the trip.

3. PARK-AND-RIDE CODING

Although using a private vehicle to access public transport is not a significant travel mode in Western Cape today, this could be expected to change in the future. In many models, modelling this travel option requires the user to define a “travel shed” for each park-and-ride (PnR) lot and to code access connectors for the zones in each shed. In order to ease the coding burden on the user and to provide for greater accuracy, the consultant has developed an alternative approach. In this approach, the user need only create a list of PnR lots and identify the zone number for each one. The model includes a Cube Voyager step that uses the travel times from the roadway network to identify the most likely PnR lot that would be used to go from each origin zone to each destination zone via PT. This procedure follows certain rules and logic checks. These are needed to ensure that only logical, reasonable drive-access paths are identified:

- The optimal origin-lot-destination path is defined by the equivalent time. This is defined as in-vehicle time + 2.5*(walk + wait + transfer time) + fare/VOT, where VOT for this purpose is defined as 0.2361 rands/minute for Work and 0.1181 rands/minute for non-work.
- For any O/D pair, a PnR lot can be used only if PT service is available from the lot to the destination zone.
- If the origin-lot distance exceeds the origin-destination distance, the lot is skipped.
- If the origin-destination drive-to-transit time is more than twice the origin-destination walk-to-transit time, the lot is skipped.

- If the lot is in the destination zone, the lot is skipped.
- If the origin-lot drive access time is more than 10 times the lot-destination PT ride time, the lot is skipped.

For both AM peak and midday periods, this process produces a travel time matrix with eight tables: 1) walk time, 2) initial wait time, 3) transfer wait time, 4) PT ride time, 5) number of transfers, 6) drive time, 7) lot number (zone). For 2016, the list of PnR lots is shown in Table 4.

Table 4: Park & Ride Lots

Zone	Location	Zone	Location
5	Cape Town	830	Oosterzee
121	Akasiapark	981	Ottery
122	Century City	1157	Kraaifontein
131	Pinelands	1210	Kuilsrivier
473	Athlone	1293	Mitchell's Plain
477	Lansdowne	1298	Kapteinsklip
515	Claremont	1439	Blackheath
553	Plumstead	1440	Eerste River
784	Bellstar Junction	1636	Strand
822	Stikland		

4. PT PERCEPTION FACTOR

A special variable was added to the top level model to reflect rider perception about the safety, security, and quality of the PT system. This is called the Perception Factor (PF) and it ranges from 0 (poor) to 10 (excellent). The main use of this variable in the model is to represent the loss in ridership over the past few years that has resulted from the difficulties that the rail operator (PRASA) has experienced with system vandalism and the loss of rail cars. This variable is mainly qualitative in nature and the value used for any model run is subject to interpretation. The coefficient on PF was selected such that the difference between a PF of 8 and a PF of 3 should be approximately 15%, which is what could be derived from the available data in terms of actual ridership decrease from 2016 to 2018. For the 2016 base case, a value of 8 is being used. This reflects news reports that rail vandalism started to become more serious in the period 2012-16. Since 2016, this vandalism has increased, and this should be reflected in future values of PF. In future years, PRASA should address this issue and the PF could improve for such scenarios.

The original PT Perception Factor is a single value, referring to the regional public transport system as a whole. Separate PF values for MyCiti, GABS, GoGeorge, and Metrorail will be considered in the version of the model currently under revision.

5. PATH-BUILDING AND ASSIGNMENT

The selection of routes within the PT system is called path-building. The implemented PT path-building and assignment process considers a constrained multi-routing approach, with small spread of routes between pair of zones.

All cost components are converted to the same units: equivalent travel time (minutes). Each user class that the program references must have a separate set of factors characterising its behaviour in terms of route choice. Typically, the “user class” reflects the trip purpose. However, in a discrete model such as this one, it might also be possible in the future to reflect specific traveller attributes such as worker/non-worker, HH income, or traveller age group.

Small values of path-spreading have been used to ensure faster model run times, along with checking for O/D connectivity to ensure the proper level of connectivity. Also the number of transfers have been checked against data available from the National Household Travel Survey. Boarding and transfer penalties and run time factors have been applied and refined through O/D connectivity checks.

The PT validation has not yet been fully completed due to difficulties in obtaining consistent and reliable data on actual 2016 transit ridership during the first phase of model development. Data collection on PT ridership has now been finalised and the revision and calibration of the PT path-building and assignment is in process for the Base Year.

6. CONCLUSIONS

The PT system has been represented in the model with the aim of reaching a balance between a sufficient level of detail to simulate the complex system in the region and the capability of keeping model run time and coding effort acceptable.

The conventional PT submodes (MyCiti, GABS, Metrorail, GoGeorge and Jammie Shuttles) have been coded in detail in the PT network and simulated through a controlled multi-routing path-building and assignment process within the Cube Voyager software.

More flexible PT submodes have not been coded as conventional modes, but have been represented at the zonal level. Particular attention has been given to the representation of the Minibus-Taxis, through a zonal density approach, based on a zonal index representing services availability. The effort of coding every single MBT service as a traditional PT submode is not advisable or necessary in this case, due to the high degree of flexibility of the service and the very high density of MBT routes, establishing a quite continuous service in spatial and temporal terms.

Several challenges have been faced in the development of the PT model, particularly related to data collection and the informal way in which some of the system operates. A perception factor has been introduced in the modelling formulation to take into account rider perception about the safety, security, and quality of the PT system, representing non-measurable aspects affecting PT ridership.

Further data collection and these innovative methodological approaches allow the refinement and re-validation of the PT model, which is currently under way.

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