BEAD

BRTS Evaluation and Design Tool *Version 1.60*

developed for

Institute of Urban Transport (India)

Interim Report

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FAZIO
ENGINEERWARE

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Explanation of Terms Used in this Report

PPHPD	Passengers per hour per direction
O-D	Origin to Destination; or Origin and/or Destination
Transfer or Interchange	Interchanging routes mainly between feeder and trunk route in a closed system
No Interchange	Refers to direct route moving both within the BRTS corridor and outside in mixed conditions.
BRTS	Bus Rapid Transit System
Tool	Referred to the BEAD tool
Straight Bus	Buses moving straight along the corridor at signalized intersection
Turning Bus	Buses turning off the corridor at signalized intersection
BPHPD	Buses per hour per direction
Xing	Crossing or Intersection, generally signalized
Common buses or common lane	Refers to buses in common lane or the lane hosting both straight moving and turning buses
FOB	(Pedestrian) Foot over bridge

1 Background

Bus Rapid Transit System or BRTS is a bus based transit system which allows higher speed, capacity and safety of buses by segregating them from other traffic on a roadway into a separated bus way. As more and more cities throughout the world opted for BRTS, further work into BRTS design and performance has made BRTS evolve into an advanced and optimized "bus" system with increasingly flexible and adaptable, operational and service characteristics. More than 150 cities in the world now operate BRTS corridors. No two systems are identical; their characteristics vary. Their uniqueness is because the system is flexible enough to allow variation and adaptation. A BRTS is custom built to the needs of the city. *However, BRTS uniqueness leads to debates on which features are better and in which manner is it better.*

The development of BRTS in India has been taken up on a large scale by more than 11 Indian cities and a total of more than 1250 km of BRTS is slated to be developed in the country mostly supported by the Ministry of Urban Development, Government of India (MoUD) under the JnNURM mission.

More than 100 parameters are involved in the design of BRT. About $1/3^{rd}$ are related to site conditions and hence fixed. The balance $2/3^{rd}$ parameters are variable and depend on design. There is a perennial controversy on several design features such as;

a) Dedicated lanes in the middle of the road or on the sides
b) Location of stations on the right hand or left hand side
c) Distance of station platform from the road intersection
d) Height of the station platform and the bus floor
e) Signal cycle phasing

Discussion on the merit and demerit of each alternative design feature is at present subjective and a rational decision is not possible.

Thus there exists an urgent need for an evaluation tool, which can provide quantified evaluation of alternative design features to the planners and engineers (or the consultants) and the Municipal and/or development authorities of the city; for a rational decision making.

This has led to the development of the Bus Rapid Transit System (BRTS) Evaluation and Design (BEAD) Tool. This is is a *.xls based interactive tool which allows engineers, planners, designers and decision makers to make a comparative evaluation against any proposed changes in the features (and their configuration) in a (BRT) system.

The tool provides the effect on journey speed, throughput capacity of the system and number of buses needed due to change in multiple design parameters. In a typical case the impact on the performance of the system due to the use of alternative design features can be evaluated due to comparative assessment. In addition the tool can be used to generate data for research and academic use.

2 Approach

The development of BEAD arises from the need for a tool which can provide planners/designers with a comparative evaluation of BRTS system before its implementation and operations. To allow this the exact details of the system need to be defined in a manner which can form the basis for application of standard public transport theories and formulas. The tool may then use the fed processes to calculate and present the expected performance of the system in a measurable format.

To do so the tool has been designed with three integrated parts which also form the stages of the estimation of final output. These are:

1. Input Fields
2. Calculation
3. Result Output

The project team undertook detailed discussions with its technical advisor, i.e. TRIPP, IIT Delhi on the finalization of the parts of the tool mentioned above. These were based on the experience of the team members in developing and assessing a number of BRTS projects as well as their understanding of best practices from a variety of case studies and other literature.

The second important step was to finalize the performance indicators which would be presented and compared in the output results. It is understood that the key performance indicators mainly focus on a global indicator (defined by agencies such as UNEP) which focuses on the reduction of green house gases (GHGs) and local (such as those set by project operators) who focuses on the increase in the passenger usage. These two are interconnected if the increase in passengers can be shown as a result of migration from private motorized modes or even if the current rate of migration to the private modes is shown to minimized.

This requires that the utility of the proposed BRT system be higher than what is derived from the use of private motorized modes. Transportation models such as proposed by Oort (1969) use the concept of maximizing utility by increasing work time, time for leisure, reducing expenditure (or increasing income) and reducing the unpleasantness of travel (or reducing the time spent in travel when not undertaken for leisure) (Sergio R.Jara-Diaz 303-19). Hence for most work trips served by public transport, utility can be maximized by minimizing the cost of travel, journey time and inconvenience or unpleasantness involved. In other words performance indicator of a good public transport mode can be defined as those which relate to reduced journey time, reduced cost, and increased comfort over private motorized (or more inefficient) modes; thereby maximising the chances of a migration to public transport leading to increased passenger demand (to match the local performance indicator) and increased efficiency leading to reduced GHGs (to match the global indicator).

The common factors affecting all these parameters are delays experienced by transit vehicles and passengers as well capacity of the system. These can be broadly categorized as:

- Faster door to door connectivity,

- Higher capacity for better convenience and comfort
- and resultant reduced out of pocket travel cost

Thus when systems or their features, reduced delays (directly leading to reduced journey time) and better capacity (subject to projected demand) can be used as effective indicators for evaluation.

The performance indicators have been broadly based on the delays involved in different parts of the journey and the expected capacity of the system. These have been broken down in to further details for easy and direct comparison by the users. Using these indicators along with the finalized filed and equipped with standard transit capacity, headway and frequency equations the first Beta version of the tool was based developed and the results validated using three well documented BRTS corridors, i.e. Delhi, Ahmadabad and Bogota.

Following this feedback of other experts and consultants in the field was collected as a part of the first BEAD workshop organized by IUT, at TRIPP, IIT Delhi on July 25, 2011 (Annexure 1). This was used to update the list of input fields and also to upgrade the calculations and processes in the tool, leading to the second Beta version of the tool.

This improved version was upgraded using the VBA script in the MS Excel software and allowed additional features of specifying multiple different segment designs on a single corridor to arrive at an overall and segmental corridor performance. The improved version was presented in a two day seminar organized by IUT in Goa on October 21-22, 2011 (Annexure 2). This workshop was attended by expected users of the tool including Municipal and Development bodies undertaking the development of BRTS in six different cities, consultants, operators, project regulating agencies (UTTIPEC) and NGOs (ITDP). The feedback collected from this workshop is currently being used to improve the presentation and usability of the results. For example as a part of the feedback received from the participants, the development team is undertaking a consultation with TRIPP, to finalize the Service Level benchmarking of an input design or a segment design based on the performance criterion.

3 Methodology – Working of BEAD Tool

The tool relies on inputs provided by the user. It combines this with pre-fed base data to generate a partial picture of the proposed design and all its features. To complete the picture, the signal phase plan of intersections involved and cross section design at bus shelters is required. The tool generates a signal design (phase plan and cycle length) along with a cross section design at station. The user can check and finalize these. Internal logic is used by the tool to generate behaviour of vehicles and passengers in the system based on average values (as defined in the user input or the base data). The tool then uses this behaviour inputs along with signal phase plan, cross section design, user inputs and base data to generate the expected capacity of the system, which is subsequently used to generate delays expected when the system operates at that capacity. These delays are generated both for within the system and outside the system (access delays) and can be used to generate the average speed of buses within the corridor as well the average journey time (for the average trip length in the city). The diagrammatic representation of this methodology has been presented in

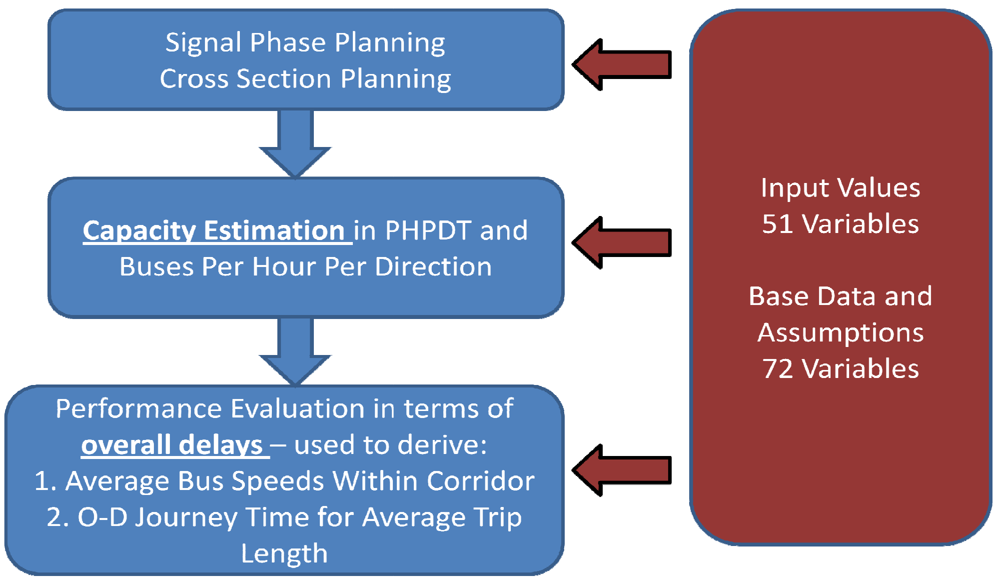


Figure 1: BRTS Evaluation and Design (BEAD) tool Methodology

The working of the tool required scores of complex interconnected processes, to allow estimation of the effect on performance against the use of all variables in all possible combination with each other. This required developing a detailed picture of the design. The project team concluded that the in order to make the tool user friendly, the input variables are required to be understood and easily provided by the user. To achieve this all inputs to the tool have been divided in to three parts. These are:

- User Input
- Default Variables (editable by user on demand)
- Base Assumptions

In addition the tool needed to fix the boundary limits of all values to ensure that the inputs comply with the broad BRTS planning and design principles. For this the, a set of principles or base log for the working of the tool has been defined. These principles have been listed below along with the list of Input fields used in the tool.

3.1 Principles or Base Logic behind the Working of BEAD

The tool is a Microsoft excel based mathematical model based on assessing **junction and station** access and delays. It is based on the principal that performance of vehicles (buses) in a controlled environment (such as segregated lane) is predictable through a simple analytical process. Main variable factors affecting this performance in a linear relationship are:

- Station Gaps
- Acceleration/Deceleration
- Peak speeds
- Signal Delays (based on signal cycle and crossing distances)
- Stacking delays (Based on capacity)
- Dwell time (based on steps to entry)

The broad listing of principles (in defined categories) used for establishing the platform for estimating the performance indicators in BEAD are as following:

3.1.1 Signal Cycle Design

- Signal phase design is required to assess bus and pedestrian crossing delays as well maximum and minimum throughput possible
- Total no. of phases shall be assessed from bus and vehicle turning requirement and arms at junction
- Signal cycle length shall be optimized from input to be in the range of 150 to 225 sec for 4 arm junction, 90 to 180 sec for 3 arm junction and up to 90 sec for mid block stations
- Cycle length optimization shall be based on bus phase length as min. 8% of cycle time within 12-21 sec range
- Multiple bus lanes at junction/intersection allow phase design with separate phases for straight and turning vehicles.
- In the absence of additional turn lanes (with turn requirements) for buses, phase design is sequential with common straight and turn phases for all arms.
- Model shall allow modification of output results.

3.1.2 Cross Section Design

- Cross section design is required for assessing crossing delays
- Cross Section design development shall assumes provision of bus lanes, car lanes, pedestrian paths, cycle tracks, service lanes, green belt, parking, turning pockets, medians segregators etc.
- It shall works on allocating a range of width to each, and starts from bus lanes and bus shelter width allocation based on station type and bus lane configuration input.

- It shall allocate width for remaining ROW in order of priority, allowing minimum width allocation to all primary functions, i.e. car lanes, pedestrian path and cycle infrastructure.
- The cross section design shall be editable by the user and the edited cross section design shall be used in the estimation of values for the performance indicators.

3.1.3 Capacity Estimation

- The tool shall to maximize capacity based on constraints such as:
  - Stacking length available before and/or after the intersection.
  - Cumulative green phase available to throughput buses.
- Capacity of the system is effected by the following (which impact minimum headway, frequency, etc.):
  - Signal Cycle design
  - Junction width
  - Bus length
  - Acceleration/Deceleration
  - Dwell time

Performance Estimation

- Performance shall be estimated based on point to point journey time of average motorized trip length in city
- Additional factors for estimating performance shall be:
  - Total walking distance per passenger in a return trip
  - Average speed within corridor (including delays faced by buses at signal)
  - Access delays to stations
  - Interchange Delays
  - Access delays to feeder buses
- In a closed system 100% of the trips shall be interchange trips. In an open system a specified percentage can be defined as interchange trips between the main corridor and feeder routes for access and egress.
- Fixed trip composition in terms of distance from corridor (ex. Avg. trip length more than 6.5km) is defined against the land use along the corridor (specified as user input) and the average motorized trip length for the corridor or for the city.
- Other factors that shall determine the performance of the system are:

– Average bus speeds in mixed condition
– Average walking speeds
– Average delays (based on feeder and main line frequencies), etc.
– Crossing distances and signal timings on the corridor and side roads

3.2 Input Fields

The tool relies on inputs provided by the user. It combines this with pre-fed base data to generate a partial picture of the proposed design and all its features. These input elements are been further categorized in three different levels. These levels are as follows:

3.2.1 User Inputs

These variables are necessary to be provided by the user and will vary from corridor to corridor and segment to segment within the corridor. These variables define a specific design and thus cannot be generalized.

1. Global
    a. System - Open or Closed
    b. City Profile – Average Speeds, Trip length
2. Macro
    a. Corridor – length, segments
    b. Bus Lanes – Type and location
3. Micro
    a. Station – Island, staggered, mid block, junction
    b. Junction – Signalized, roundabout, ped only, signal free
    c. Signal Design – Cycle length, special phase requirements, etc.
    d. Special – Off board ticketing, bus boarding doors.

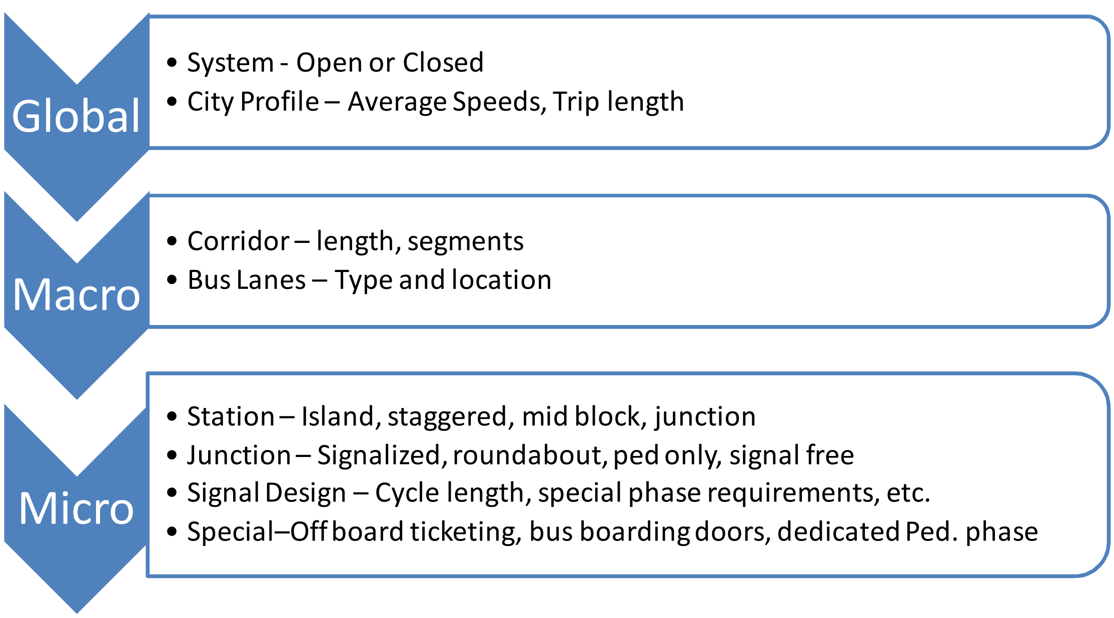


Figure 2: Categorization if Input fields for BEAD Tool

3.2.2 Default Variables

Apart from these above input data some default values are also been taken in consideration. These variables have been provided by default values as these can be generalized for all types of corridor designs. These values have been distributed under the following three categories:

1. Global – examples are:
    - **a.** Peak Speed of Buses (as per regulations)
    - **b.** O-D distance from corridor - % wise breakup of trips
    - **c.** % of direct route based trips as against interchanging trips
2. Vehicle & Infrastructure – examples are:
    - **a.** Bus Acceleration and Deceleration rate, Bus Dimensions and capacity
    - **b.** Junction width, distance of stop line from cross road edge
    - **c.** Level difference for grade separation options with climb rates and gradients
3. System &User – examples are:
    - **a.** Driver Reaction time
    - **b.** Walk Speeds
    - **c.** Inefficiency values in signal prioritization
    - **d.** Per person delay at turnstiles etc.

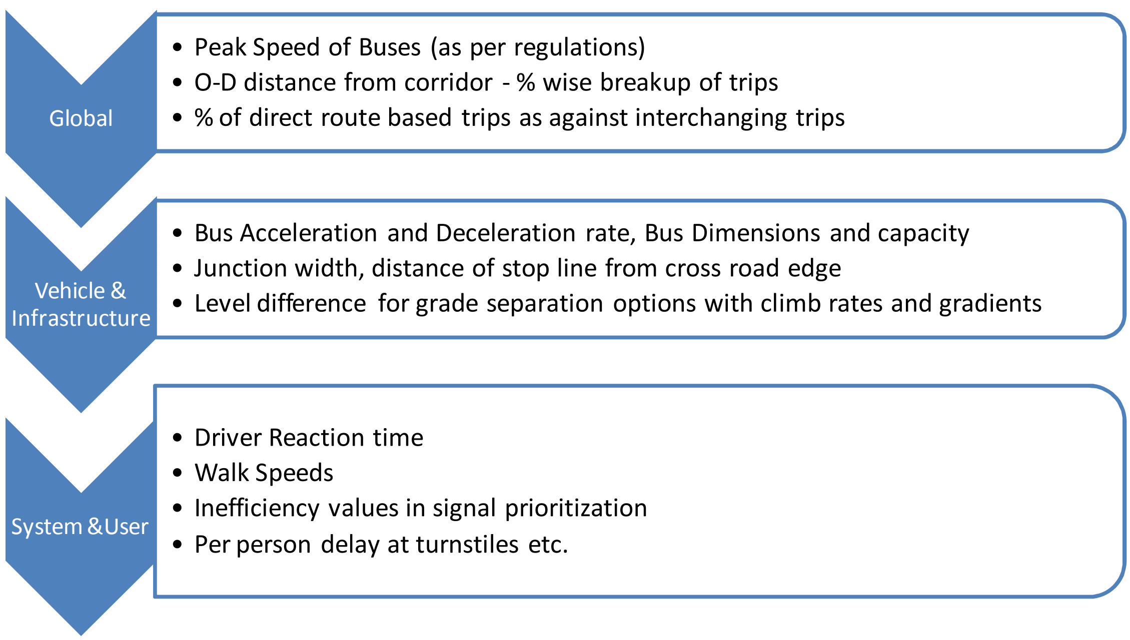


Figure 3: Categorization of default variables used in BEAD Tool

3.2.3 Assumptions

As a part of the process certain assumptions have been considered for the input data to the BEAD tool. These assumptions are as follows:

1. Multiple segments can be defined for each corridor
2. Design for each segment is treated and compared as a single unit, with a consolidated length
3. Each sub unit is a set comprising of one junction and one station
4. All results and comparisons are based on averages in normal distribution. For some parts weighted averages are used.

5. Nodes or cross roads are assumed as destinations for commuters, and delays estimated accordingly
6. The corridor is assumed with BRT only operations, no other parallel modes exist.
7. All interchange access and egress trips are assumed to be walk trips, to minimize travel cost.
8. Feeder trips longer than 0.5km are assumed as bus trips in mixed condition
9. Each dedicated bus phase is not more than 10-15% of signal cycle length
10. Fixed % of trips assumed for up to 0.5km from corridor, 0.5 to 1 km from corridor, 1-2km from corridor and 2-3km from corridor for different average trip lengths.
11. System capacity is independent of demand, and demand is not estimated by the tool.
12. All crossing distances for pedestrians are calculated from primary pedestrian paths or those which are adjacent to the carriageway and not those next to the building boundary.
13. Bus dwell time is estimated for average 10% passenger exchange for average bus capacity, with 2 second additional time each to account for reaction time for door opening/closing as well door opening and closing time each.

Figure 4 to Figure 12 below present an impression of the input forms as seen by the user of the BEAD tool. These forms have been categorized as per the above mentioned principles. The first or the base form allows user to define corridor specific parameters, whereas the following forms are repeated for each segment of the corridor to allow the user to input design parameters specific to each different segment on the corridor. Each segment on the corridor is defined by the difference in decisive design factors such as intersection, station or signal design, and similar design although separated on the corridor, can be clubbed as one segment under a sum total of their lengths. The tool allows and output showing individual segment results as well as combined or overall corridor performance results. A detailed list of all input variables and default values presented on the forms has been listed in Annexure 3.

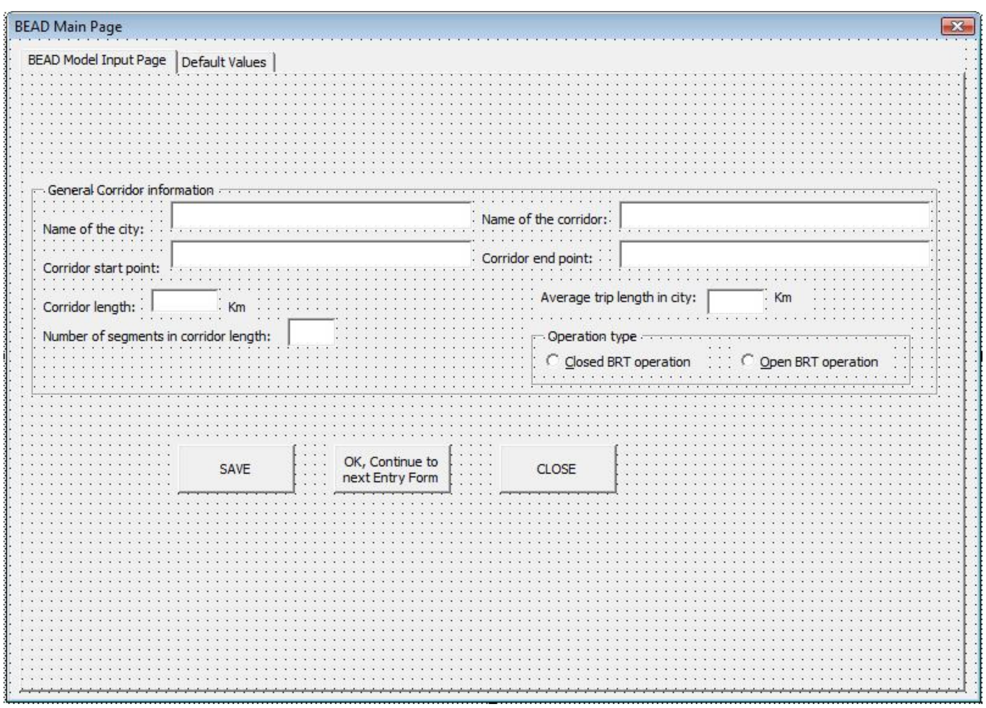
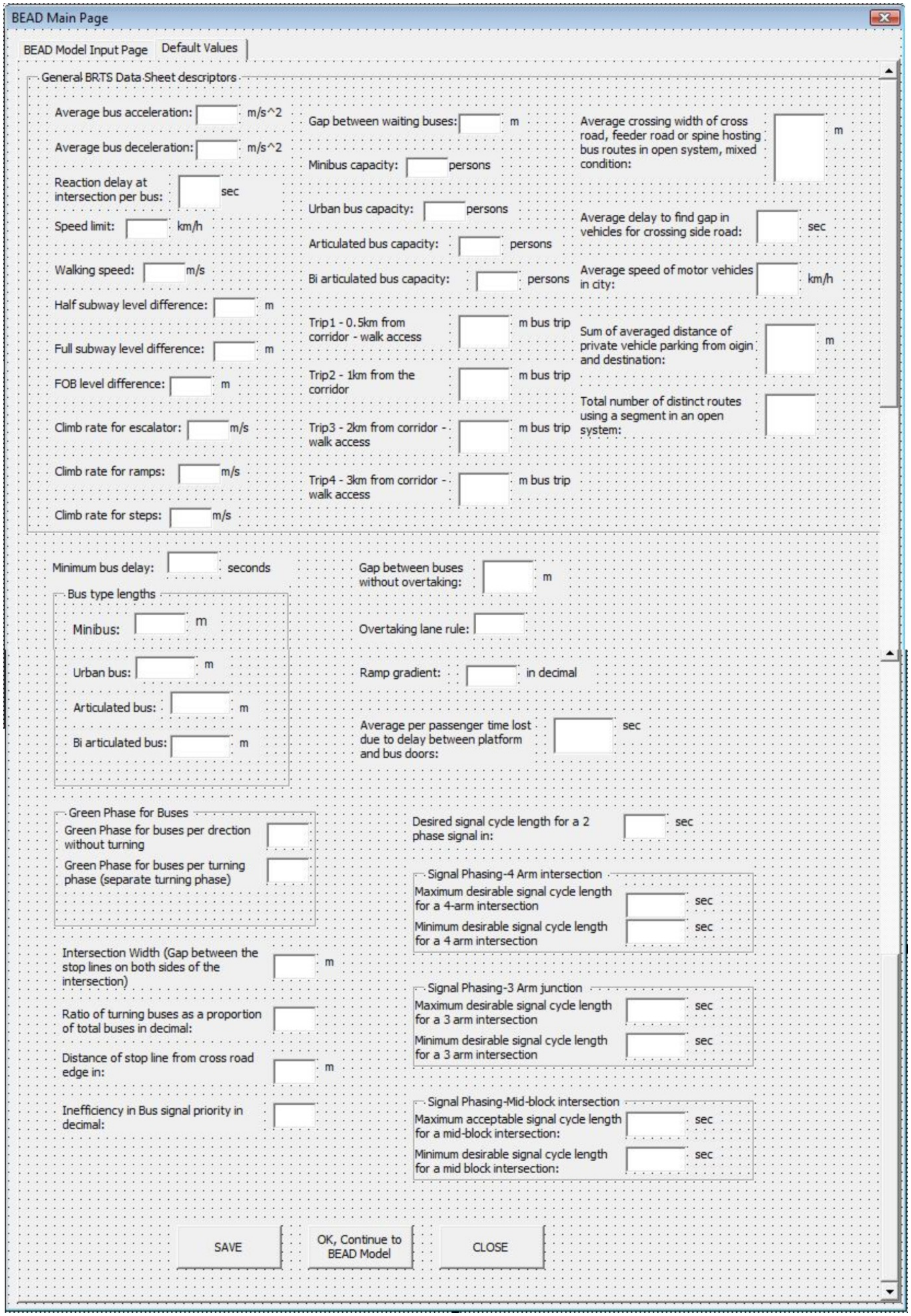


Figure 4: BEAD Tool – First Page form


BEAD Main Page

BEAD Model Input Page | Default Values

General BRTS Data Sheet descriptors

Average bus acceleration: m/s^2
Average bus deceleration: m/s^2
Reaction delay at intersection per bus: sec
Speed limit: km/h
Walking speed: m/s
Half subway level difference: m
Full subway level difference: m
FOB level difference: m
Climb rate for escalator: m/s
Climb rate for ramps: m/s
Climb rate for steps: m/s

Gap between waiting buses: m
Minibus capacity: persons
Urban bus capacity: persons
Articulated bus capacity: persons
Bi articulated bus capacity: persons
Trip1 - 0.5km from corridor - walk access m bus trip
Trip2 - 1km from the corridor m bus trip
Trip3 - 2km from corridor - walk access m bus trip
Trip4 - 3km from corridor - walk access m bus trip

Average crossing width of cross road, feeder road or spine hosting bus routes in open system, mixed condition: m
Average delay to find gap in vehicles for crossing side road: sec
Average speed of motor vehicles in city: km/h
Sum of averaged distance of private vehicle parking from oigin and destination: m
Total number of distinct routes using a segment in an open system:

Minimum bus delay: seconds

Bus type lengths
Minibus: m
Urban bus: m
Articulated bus: m
Bi articulated bus: m

Gap between buses without overtaking: m
Overtaking lane rule:
Ramp gradient: in decimal
Average per passenger time lost due to delay between platform and bus doors: sec

Green Phase for Buses
Green Phase for buses per drection without turning
Green Phase for buses per turning phase (separate turning phase)

Intersection Width (Gap between the stop lines on both sides of the intersection) m
Ratio of turning buses as a proportion of total buses in decimal:
Distance of stop line from cross road edge in: m
Inefficiency in Bus signal priority in decimal:

Desired signal cycle length for a 2 phase signal in: sec

Signal Phasing-4 Arm intersection
Maximum desirable signal cycle length for a 4-arm intersection sec
Minimum desirable signal cycle length for a 4 arm intersection sec

Signal Phasing-3 Arm junction
Maximum desirable signal cycle length for a 3 arm intersection sec
Minimum desirable signal cycle length for a 3 arm intersection sec

Signal Phasing-Mid-block intersection
Maximum acceptable signal cycle length for a mid-block intersection: sec
Minimum desirable signal cycle length for a mid block intersection: sec

SAVE | OK, Continue to BEAD Model | CLOSE

Figure 5: BEAD TOOL – Default variables form

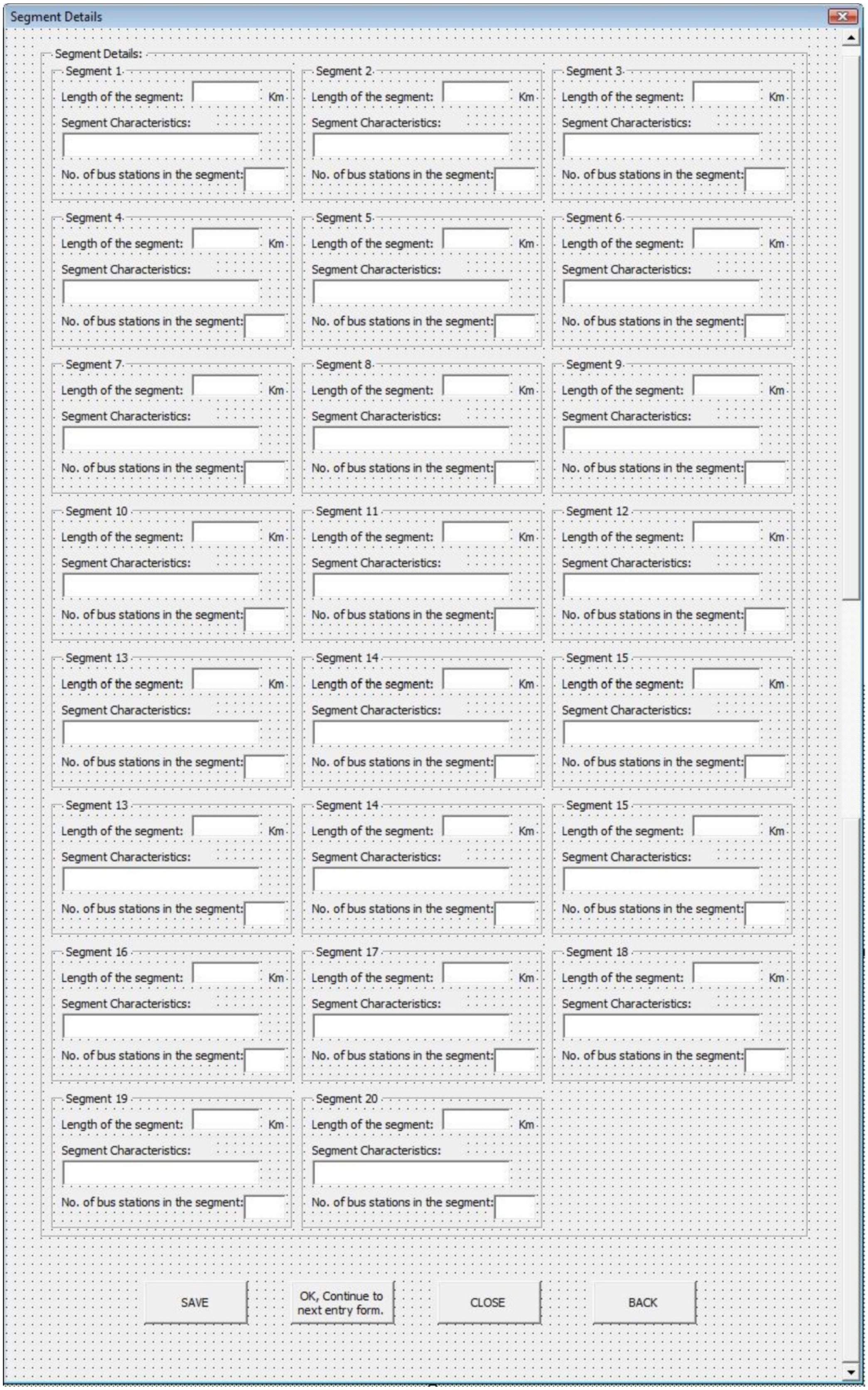


Figure 6: BEAD Tool - Segment Details form

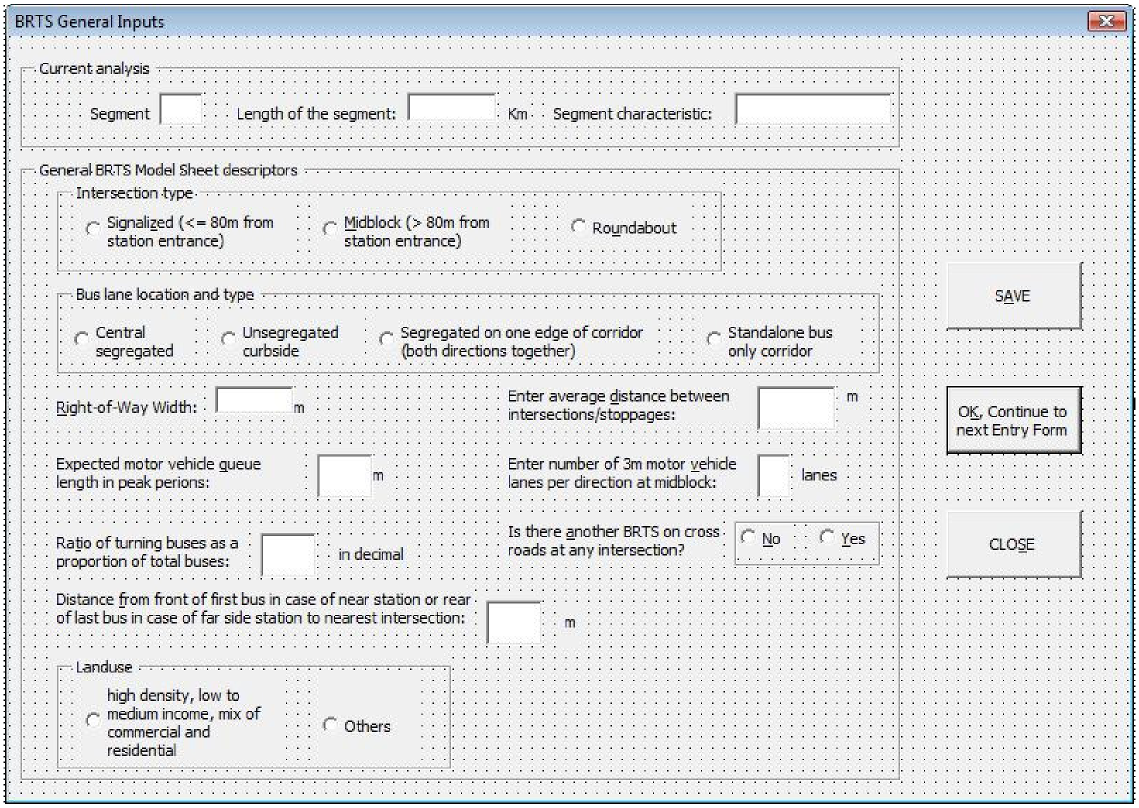


Figure 7: BEAD Tool – General inputs form

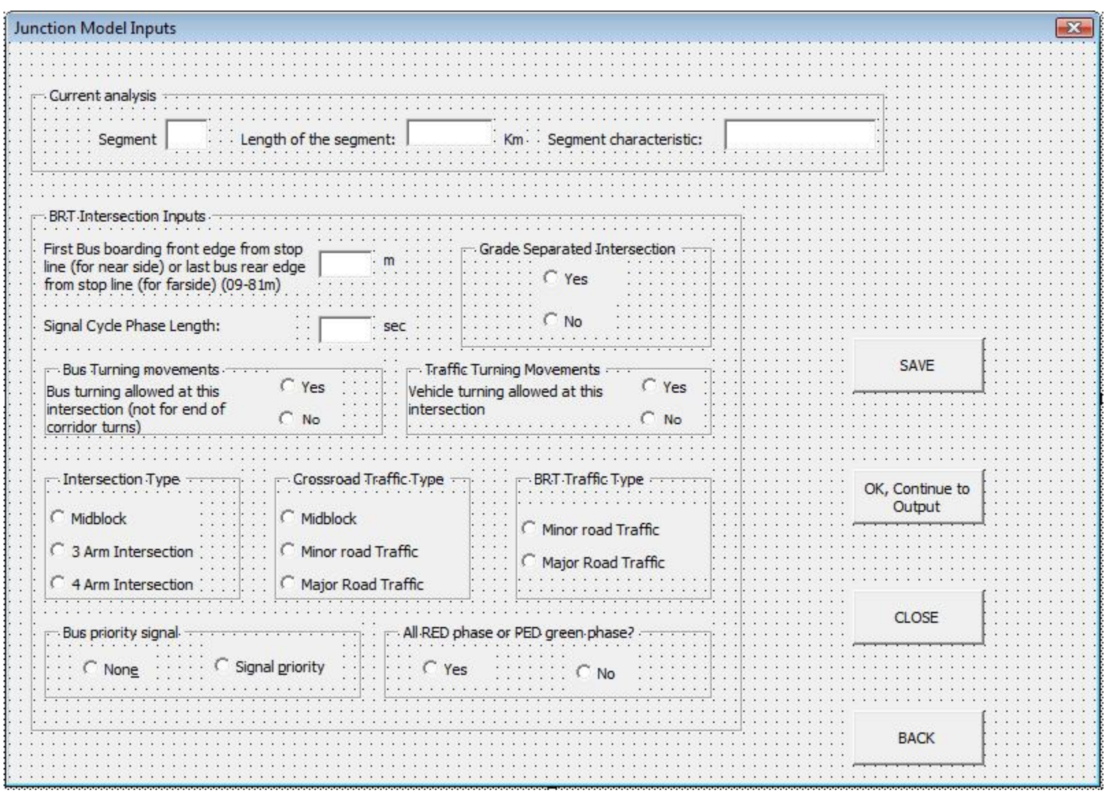


Figure 8: BEAD Tool - Intersection (for junction stations), input form

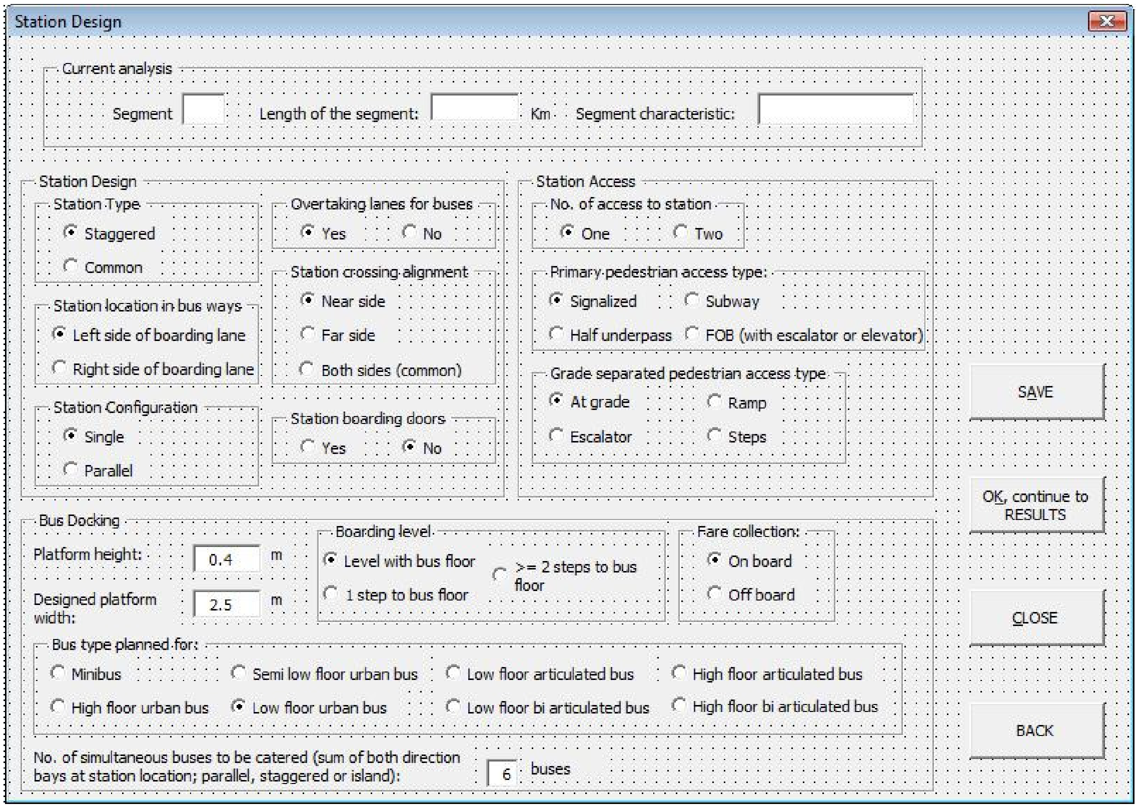


Figure 9: BEAD Tool – Station Design input form (common for junction or mid block stations)

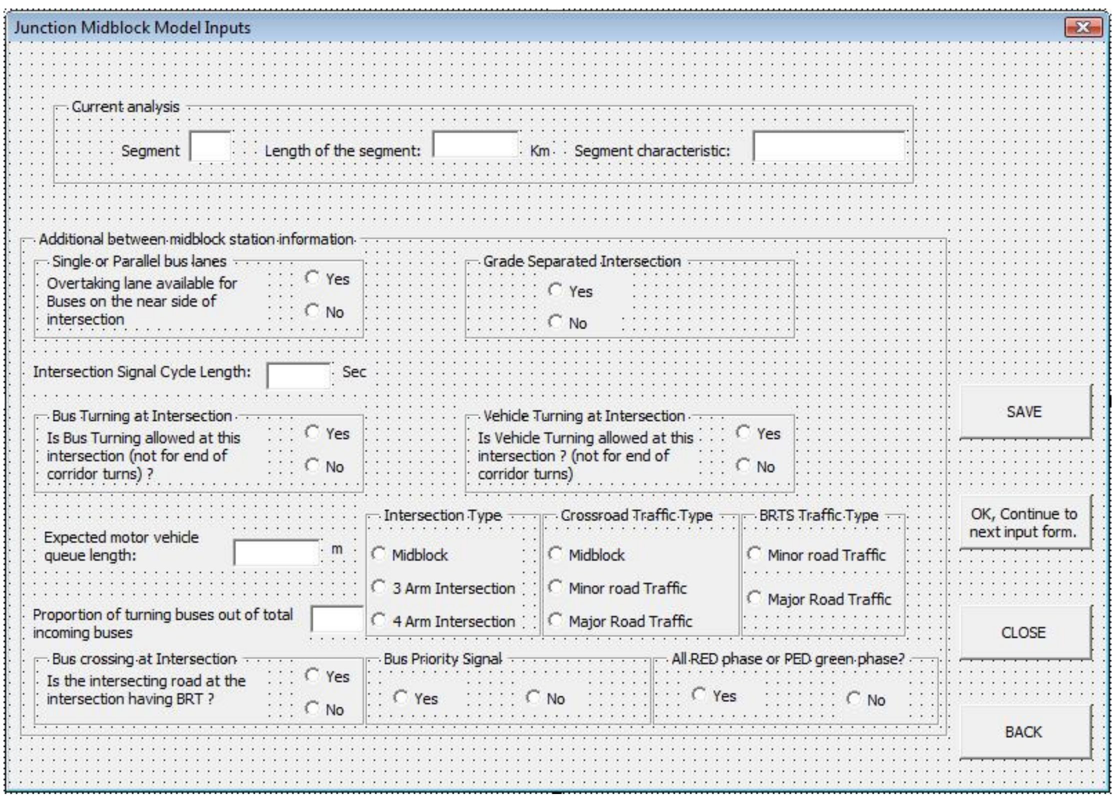


Figure 10: BEAD Tool - Additional junction input form, specific for junctions between mid block stations

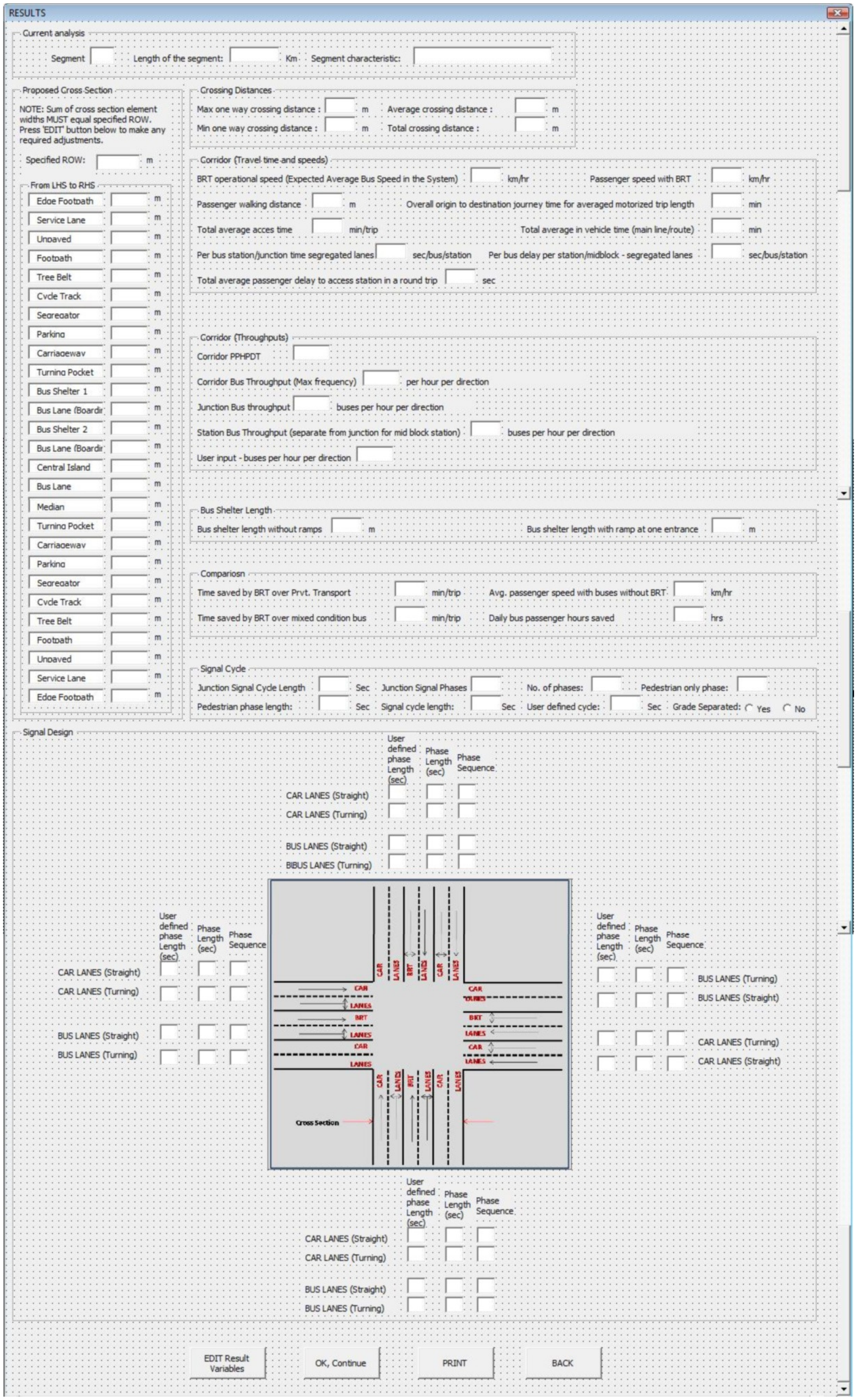


Figure 11: BEAD Tool – Results/Output sheet

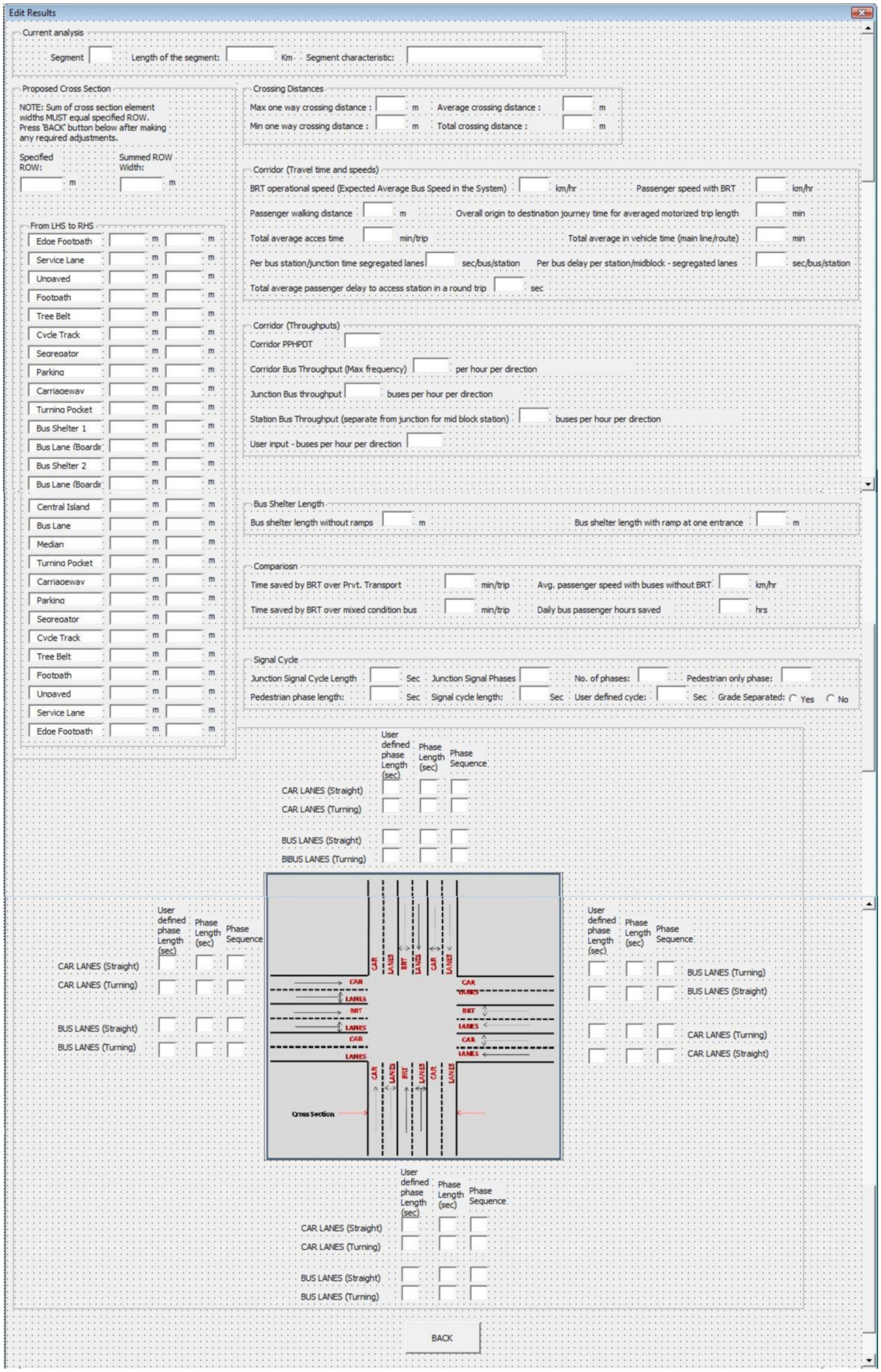


Figure 12: BEAD Tool – Edit results form

3.3 Background Processes and Calculations

This section explains the background processes and calculations undertaken by the tool, using the input data, principles and assumptions; in order to generate the output results. To understand these processes one needs to first understand the theoretical base of the system.

3.3.1 The Theoretical Base

This consists of the background formulas. All processes in the BEAD tool are based on these standard formulas and guidelines. Some of the formulas used are as following table:

Process	Formula
Line Capacity	$C = C_v * n * f * \alpha$ (at σ of 0.3)
Headway (in min)	$H = 60/f$
Min Headway (reaction time modified)	$H_{min} = t_s + (t_r * n_s) + n*l'/v + v(k + 1)/2b + \sqrt{(2*n_s*l'/a)}$
Operation Time for buses	$T_o = n_s (t_a + t_b + t_s) + \sum t_{vi}$
Operation Speed	$V_o = 3600 * L/T_o$
Min Gap between buses	$S_{min} = V^2 *(a+b)/(5*a*b)$
Poisson Distribution	$P(x) = e^{-\lambda} * \lambda^x / x!$

Where:

C	Line Capacity
C_v	Vehicle capacity in spaces per vehicle
n	No. of vehicles in each transit unit
f	Frequency in terms of transit units per hour per direction
α	Load Factor of vehicle
σ	Comfort Factor in terms of sq. m. per person for standing space in the vehicle
H	Headway in min.
H_{min}	Minimum headway possible (not including junction delays)
t_s	Station time in seconds (includes dwell time)
n_s	No. of stations on a line or on a corridor
t_r	Driver Reaction Time
l'	Vehicle length in m.
v	Approach velocity of vehicle approaching bus station
k	Safety constant (assumed as minimum spacing between buses = 1m)
a	Acceleration rate in m/s^2
b	Deceleration rate in m/s^2
T_o	Operational time in sec (total time consumed in operations on a line)
t_a	Time consumed during acceleration by the transit vehicle in seconds
t_b	Time consumed during deceleration by the transit vehicle in seconds
t_{vi}	Time consumed in sec during cruising of bus between two subsequent station intervals, i
V_o	Operational speed in km/hr
L	Total corridor length in km

V	Peak transit vehicle speed in km/hr.
S_{min}	Minimum distance in m, between two subsequent transit vehicles
$P(x)$	Probability of X
e	Exponential (constant =
λ	Rate of arrival of transit vehicles at a junction
x	No. of transit vehicles arriving at an intersection in a unit time

The above standard formulas and guidelines, are from **Urban Transit, Operations, Planning and Economics by Vukan R. Vuchic.** Standards for lane widths and other dimensions for cross section design have been used from 'Recommendations for **Traffic Provisions in built-up areas (ASVV) CROW', Record 15.**

In addition to using standard textbook formulas to achieve the results the tool uses data derived from primary survey conducted to estimate per passenger boarding alighting time for buses with varying floor height relative to bus platform height. The data collected as a part of this survey has been presented in Annexure 4 and the results have been presented below.

3.3.1.1 Boarding Alighting Time

A primary survey to collect the data of boarding and alighting time consumed per passenger for different types of buses using the BRTS corridor in Delhi was conducted between 05:00 to 06:30 pm at two different stations at Chiragh Delhi Bus Stop on November 04, 2011. The survey was conducted by counting the no. of boarding and alighting passengers for different buses and recording the total time consumed per door per bus. As a part of other details collected the type of bus and the no. of steps leading in to the bus after entry were counted. A total of 35 buses were surveyed of these 26 were low floor buses, 1 was a bus with entry plus 2 steps and eight buses had entry plus 3 steps.

The surveyor started the stop watch after opening of the doors and stopped when the last passenger boarded or off boarded. The data was analyzed for low floor or entry plus zero step and high floor i.e. entry plus two steps. The results have been presented in Table 1.

Table 1 : Results for boarding and alighting survey conducted at BRTS Delhi on Nov 4, 2011

	Time (sec)		No. of Passengers	
	Level Board	3 Steps	Level Board	3 Steps
Minimum	0.83	1.00	1.00	1.00
Maximum	3.00	4.00	8.00	6.00
Average	1.67	2.17	4.04	3.50
85th Percentile	2.00	2.66	6.55	5.95
15th Percentile	1.25	1.50	2.00	1.05

Since both front and rear doors were used for boarding and alighting the data represents per person boarding/alighting time per door. Low floor Urban buses are 1.2m wide, and theoretically use 2 channels per door for boarding and alighting. However the surveyor only recorded the data from buses where people boarding or alighting used a single channel even in low floor buses. This was done for easy comparison with high floor buses which had single channel of passenger movement on each door due to reduced width. Also since the data is only available for zero or three steps inside the bus; the average per passenger time required for boarding and alighting have been interpolated for one and two steps inside the bus. This has been presented in Table 2

Table 2 : Average per passenger time required for boarding or alighting low floor (level boarding), one step inside two steps inside and three steps inside the bus.

	Time in Sec
Level Board	1.67
1 step	1.83
2 step	2.00
3 Step	2.17

The data has primarily been collected from standard and urban buses. These have 2 channels for boarding and alighting. The average capacity of these buses is assumed to be 60 on the basis of at σ of 0.3. The assumed that on an average 10% passenger exchange takes place at each station, i.e. 6 boarding and 6 alighting passengers from each channel. Using this and a 2 second time penalty for opening and closing of doors and reaction time on part of the driver to do so, the following dwell time values are generated for buses with varying floor height with respect to platform level:

- Level Boarding or no steps inside the bus = 1.67*6 + 4 = 14 sec
- Boarding with 1 step inside the bus = 1.83*6 + 4 = 15 sec
- Boarding with 2 steps inside the bus = 2.00*6 + 4 = 16 sec
- Boarding with 3 steps inside the bus = 2.17*6 + 4 = 17 sec

Since no. of channels increase proportionately with the size of the transit vehicle, it is assumed that vehicle type has no impact on the dwell time, and it is only dependent on the no. of steps encountered by the passengers on entering the bus. Thus the tool uses a one second penalty for every step added after entering the bus or as a result of level difference between the bus floor and the platform height.

3.3.2 Description of Processes

The equations and assumptions explained above have been built into a number of sequential processes, which generate the output of the tool. As per the overall methodology represented in Figure 1 above, the eventual estimation of delays, used in the output, requires the system capacity as the input while estimation of system capacity require the signal phase design and cross section design as the input, along with other user input and default variables that are used selectively in all processes. Thus the processes designed in tool follow this sequence, i.e. signal and cross section design, followed by capacity estimation, followed by delay estimation. However for the purpose of explanation the processes presented in Annexure 5 and explained below have been described from the final output backward.

The tool uses close to 200 interrelated processes, of which 76 have been presented in Annexure 5. Some of the critical logic or processes used in the tool have been explained below under three heads:

- Vehicle Bus Behaviour Logic and Processes applied in the tool
- Commuter Behaviour Logic (outside the vehicle)
- Signal Cycle Design Logic

Before getting in to the description of these processes, it is important to discuss the potential and the limitations of the tool. The tool in its current form is a 'vba' script based tool written on the base Microsoft Excel software. The tool allows the user to define the corridor as a sum of distinctly different segments, each of which can be defined in detail using a set of input forms (separate for each segment). This is why though for a closed system, the user is prompted to not select bus turning option at intersections, for an open system, some segments can be chosen with bus turning at intersection, while others can be without bus turning option, allowing one to generate a hybrid system design.

After inputting the data for each segment the tool presents the performance of the segment design as an output sheet which can be printed. When the user chooses to fill or define the next segment of the corridor design in the tool the output results of the first tool are saved by the tool, and the process follows for all designed segments. At the end of this process the tool prompts the user to save an output file at a user prescribed location. The output file is generated in an 'xls' format to allow the users to use the result for any further analysis. The output file, present s all input values for all segments along with the summary of results for each segment along with an overall result for the combined corridor (considering the effect of all corridors on important performance indicators such as corridor capacity, passenger speeds, operational speeds etc. The output results have been explained in detail in section 3.4 of this report.

3.3.2.1 Vehicle/Bus Behaviour Logic applied in the Tool

The following logic has been used for vehicle behaviour in the processes generated by the tool.

1. Vehicle movement is simplified for estimation purposes, hence the following logic is used:
    a. Vehicles/Buses accelerate and decelerate at a constant rate.
    b. The acceleration and deceleration of buses has been set as 1 m/s^2 in the default sheet and can be modified to have a value of between 0.5 to 1.5 m/s^2
2. Vehicle movement is governed by efforts to minimize delay. To achieve this following logic is used.
    a. Vehicles try to achieve the peak speed (as defined in the default input data) after acceleration. Vehicles never cross the speed limit and may remain slightly below it (for cruising calculations) due to estimation processes.
    b. Peak bus speed is considered as the desirable speed limit in bus lanes. This is set as 40km/hr. (for safety considerations) in the default input sheet.
    c. Vehicles try to accelerate (at defined constant acceleration rate) to a maximum speed even for short distances, thus vehicles will switch from acceleration to deceleration without moving on constant speed when short distance are to be covered.

d. Start up delay on account of reaction time for bus drivers is assumed to be 2 seconds.
e. Buses occupy the first empty bay while approaching bus station. Bus speeds and delays are estimated based on average delays at bus stations and intersections.
f. For delay estimation, the tool estimates the combined delay of station and signal for junction stations (because of their close proximity they work as one system), whereas for mid block stations the station delay is estimated along with the delay at the pedestrian signal (in case of the signalized crossing because of their expected close proximity), whereas the intersection (between mid block stations) delay is estimated independently and combined with the station delay to arrive at an estimate of an overall delay (for buses at stations and intersection). For situations where mid block stations falls within two junction stations, the segments of the corridor (as defined in the master corridor input data form, by the user) explaining the mid block design considers the junction between two mid block stations as signal free and its location or distance from the mid block station is termed as the average distance to a major road meeting the corridor (where only left turns are allowed as no intersection for bus or vehicular turning exists).
g. Delays are estimated based on the smallest unit of length between two stations (based on average gap between stations input by users). This unit of design is constructed for each specific segment of the corridor on the basis of inputs by the user in the global variables, user input form. This unit length covers one station, and one signalized intersection, based on the assumption that between each set of mid block stations lies a single signalized intersection, whereas between junction stations lies no mid block station. In this manner the tool compares smallest unit of design, and indicates the impact of corridor (in terms of travel time and capacity) assuming a uniform reproduction of the defined unit throughout the segment. Distinctly different design sections of the corridor may be defined as different segments in the master sheet, and the tool will allow the user to subsequently input uniform values for different segments, and the combined corridor performance is presented in the output xls file.
h. Bus delays are estimated on the basis of per bus delay assessment at a signal. This is based primarily on the weighted average delay experienced due to the red phase of the signal. The weighted average is derived to account for zero delay for buses arriving during the green phase of the signal (this is why average value of the total red phase is not used).
i. Average bus speed of buses in mixed condition (refer Figure 55) is estimated on the basis of average vehicular speed in mixed condition discounted for the lower acceleration and deceleration of buses (than motorized four and two wheelers) and the frequent stops. To assess this the following assumptions are made:
    i. Average distance between stations in mixed condition is assumed to be the same as that specified for the corridor.
    ii. Average running speed of buses in mixed conditions (including delays at junctions) is assumed to be 80% of the average vehicular speed in the city.
    iii. Buses docking at curb side station in mixed condition are assumed not to be delayed due to a queue of buses waiting to dock at the station (as in practice

buses spill-over on to the general vehicular lanes or use the same for overtaking). Hence at a time only one bus is assumed to arrive at the bus stop and thus the acceleration deceleration time and the dwell time is accounted for accordingly in the average speed estimation

iv. The average dwell time of buses in the mixed condition is assumed to be the same as the dwell time of buses estimated for the corridor.

j. Average delay experienced by each bus per signal cycle per direction is used as an important means to estimate the overall system delays and the resultant travel time and average speed of buses in the corridor. Different principles are used for the assessment of this junction delay for buses for different station-junction configurations. These are as following:

   i. **For Near side (staggered) stations (both for junction or mid block) (Figure 57)** – In case of junction stations the common pedestrian cum vehicular crossing signal design is used for assessment, while in case of mid block stations the pedestrian signal design (where used) is used for the assessment of delay. For all station configurations, the capacity is based on the throughput possible in one signal cycle. Hence for delay estimates and important understanding is that the bus delay is in no condition longer than the signal cycle. For near side stations the bus must board and offload passengers before passing through the junction, and hence minimum delay is the dwell time and the reaction time involved. Add to this the necessary time lost in acceleration and deceleration of the bus. Thus even if the bus is ready to leave within the green phase of the signal (signal delays are zero), the minimum delay is the dwell time + reaction time + acceleration and deceleration time lost. Additional delays can be the delay caused by waiting at the signal and the delay caused because of waiting outside the station in a queue of buses. Thus in the worst case scenario the delay shall be dwell time + reaction time + acceleration and deceleration time lost + time lost in waiting for a boarding slot at the station (buses queuing to enter station) + delay at the signal during the red phase. Since all buses must pass through during one signal cycle the maximum red phase delay has to be longer than or account for the time lost in waiting for a boarding slot at the station (buses queuing to enter station). In other words for the average delay (or in a controlled scenario) buses will find a boarding slot within the red phase of the signal. Thus the maximum delay can be calculated by dwell time + reaction time + acceleration and deceleration time lost + maximum delay at the signal during the red phase. Thus average per bus delay at the signal can be estimated by - dwell time + reaction time + acceleration and deceleration time lost + average delay at the signal during the red phase. However average delay at the signal phase is weighted to account for the green phase duration and hence the weighted average signal delay is used. The delay is estimated separately for straight moving and turning buses (Figure 58). Turning bus delay differs from straight moving buses as in case of overtaking lanes the signal delay for turning buses is different from that of straight moving buses.

ii. **Far side stations** – In case of far side stations, delay at station (including the delay at signalized pedestrian and/or vehicular crossing) has to estimated on the basis of whether the station is with or without overtaking lane, and separately for turning and straight buses (Figure 61 –straight moving bus delay at far side stations with overtaking lane, Figure 62 – turning bus delay at far side stations with overtaking lane, Figure 65 – straight moving bus delay at far side station without overtaking lane, Figure 66 – turning bus delay at far side stations without overtaking lanes). This is because the stations with overtaking lanes allow additional stacking of buses in the overtaking lane and thus allow higher capacity. The tool assumes that the boarding lane is used for stacking of straight arriving buses while the overtaking lanes is used by buses which have turned in to the corridor from cross roads (in case where turning at junctions is allowed). Thus this effect the station length as the no. of boarding bays are divided into bays serving straight arriving and turned in buses, and the two sets are separated by a length equivalent to the bus length + 3 m (to allow manoeuvring of buses). Thus in case of stations with overtaking lanes on the far side the station length also gets effected thereby impacting the acceleration/deceleration delays and capacity. Here increased capacity in turn results in increase delays as all buses stack during green phases of different arms. But they are processed gradually and hence the stacked buses experience delay which is directly proportional to the total buses waiting in the queue, thereby increasing the average delay considerably.

iii. **Common or Island Stations** – Since at island stations, buses for both direction dock at the same platform (that is why it is known as a common station), it is located such that it is on the near side of junction for one direction of bus movement and on the far side for the other direction. Hence the average per bus delay expected for straight moving buses is the average of delay expected at near side station and that expected at far side stations for the capacity calculated by the tool for common stations. This is achieved separate for straight buses at stations with (Figure 69) and without overtaking lane(Figure 70) as well turning buses at common station with (Figure 71) and without overtaking lanes (Figure 72).

3. Intersection signal phasing plays an important role in estimating bus delays, which effect average operational and passenger speeds in the corridor in the corridor. The delays at signal are estimated per bus, based on averages. The following logic is used to assess delays at signalized intersections (with cross roads, i.e. 3 or 4 arm junction):
    a. Weighted average of bus delay per cycle is used to estimate average per bus delay at the signal.
    b. If the design allows the use of priority signal for buses, the tool estimates the reduction in signal delay on the basis of calling an early green phase for buses as soon as all buses as per the system capacity or the demand for which the system is designed (in terms of buses per cycle) arrive at the junction and are ready to leave. This leads to estimation of probabilities of buses arriving in red and green phase and also of buses (throughput in each cycle) being stacked together with minimum

headway verses their arrival rate being equally distributed in the entire red phase at the signal (for buses).

4. The tool tries to maximize the capacity in terms of number of passengers' throughput/processed by the system per hour per direction. This is based on:
   a. The number of buses throughput in one hour, which is calculated on the basis of number of buses throughput in each cycle at a signalized intersection, mid block station or a roundabout. Where no signals exist the system assumes as signal cycle length as 3600 seconds and calculates the throughput in one hour.
   b. If vehicular intersections and stations are separate (in case of mid block station) the capacity of the system is governed by the minimum throughput of the two locations.
   c. For junction stations (signalized junctions and roundabouts), the bus throughput per cycle is estimated after accounting for the effect of both station and the intersection, treated as common unit.
   d. For mid block stations, the capacity is estimated on the basis of the lower value of throughputs possible at the mid block signal and a signalized junction between mid block stations. For this per cycle per direction assessment of straight and turning bus throughput is made at the pedestrian signal at mid block station. This is then used as the maximum no. of vehicles that will arrive at the following signalized junction (based on the no. of pedestrian signal cycles that can be completed within one junction signal cycle). The tool then asses the maximum no. of buses that can be throughput during the green phase at the signalized junction (separately for straight and turning). The minimum of the two values (i.e. buses arriving at the junction and the buses that can be throughput during the green phase) is used (after doing a weighted average of straight and turning buses) to arrive at the throughput of buses per cycle per direction in a system with mid block stations. This can be extrapolated over an hour to get an hourly capacity (BPHPD) using the intersection signal cycle length.
   e. The system estimates the total throughput of buses per cycle per direction separately for near and far side staggered station types (mid block or junction) by determining separately the throughput possible for straight and turning buses per cycle and then totalling them. For island stations the capacity is estimated by selecting the minimum of the throughput values for near and far side stations. This is because the island station has one direction as near side while the other is far side. In a round trip the total capacity would be determined by the minimum throughput capacity of either the far side direction or the near side direction.
   f. The throughput of straight (Figure 59) or turning (Figure 60) buses per signal cycle for near side stations is dependent on how many buses can be throughput in green phase length (for straight and for turning buses). The no. of buses throughput can be of two types. These are either buses that are stacked, i.e. they have finished their boarding/alighting cycle and are ready to go; or the buses which are yet to undertake there boarding/alighting cycle and they will undertake that during the green phase after the stacked buses vacate boarding bays. The no. of buses that can be throughput depends on the length of the green phase. If the green phase is short, part of the stacking capacity of the station can be vacated and this defines the no. of uses that can be throughput in a signal cycle. If the green phase is long apart from

stacked buses, additional buses can board and depart within the length of the additional green phase time (time in excess of that required to clear the stacked buses).

   g. In case of far side stations, the bus throughput capacity is the sum of buses from all arms, entering the far side bus lane/station. The throughput of straight (Figure 63) and turning (Figure 64) buses at far side stations is governed by three factors. This includes the no. of buses that can be stacked (including any bus completing its boarding and alighting cycle) in the green phase (accounting for all three arms, separately for straight and turning phases), the no. of buses that can be throughput in the green phase from each of these arms (based on the limitation of the length of green phase for each arm) and the no. of buses that can be processed in one signal cycle by the far side station (based on the limitation of no. of bays available and the length of the signal cycle). Here the minimum of the three limitations governs the capacity at the station.

5. Stations can be junction (either signalized junction or roundabout) or mid block. The tool considers stations with first boarding bay less than 80m from the stop line as junction station while others are considered as mid block stations. This is based on the estimated length of vehicular queue that can be throughput in each green phase at the intersection signal.
6. Stations can be parallel (2 stations each served by a bus lane) or single with or without an overtaking lane. Parallel stations are treated as two single stations working simultaneously. Hence for capacity estimation and station delays, estimations are made by extrapolating the functioning of a single station and logic of single stations is applied for these calculations.
7. Stations can be near side or far side. For staggered stations each direction has the same type of stations, i.e. near side or far side. In case of island or median stations near intersections, one direction has all or most near side stations while the other has mostly far side. This arrangement can be different for the two directions at different stations, however for estimation, the total no. of station near side and far side will remain the same, and hence for island stations the results for delay is based on an average of near and far side station delays, while for capacity the minimum capacity of near and far side stations is selected (as in a closed loop system the overall bus throughput will be equivalent to the least amount of buses that can be throughput from any point). The following logic is applied by the tool to calculate the delays at intersections or junction stations based on whether they are near side or far side:
   a. Near Side Stations
      i. Near Side Stations with single lane(without overtaking lane) - Based on whether the input values specify turning at junctions or not, the tool designs the signal phasing as a dedicated bus phase per direction or a combined phase with straight moving motorized vehicles.
      ii. Near Side Station with overtaking lane – Based on whether the system allows turning at junctions or not, the tool designs the signal phasing with the overtaking lane as a dedicated turning lane (with common bus turning phase for both directions) and the bus boarding lane as straight bus movement lane with a common phase with straight moving vehicles; or both

lanes moving together in a common phase with straight motor vehicles (for a closed system).

iii. The delay estimate for near side station with or without overtaking lane (either mid-block or junction station) uses common logic stream. This is based on the buses being stacked before the stop line (either a junction signal in case of intersection stations or pedestrian signal in case of mid block stations) after being finishing boarding alighting within the red phase of the signal. During the green phase buses are throughput based on the reaction time, bus acceleration, bus queue length, etc.

iv. For near side stations without overtaking lane, all bus boarding areas are designed to be segregated by a gap of 3m. Each bus boarding bay is equivalent to the length of the bus length selected for the system based on the user input. In case of stations with overtaking lanes (for both open and closed system) the tool provides an overtaking length equivalent to one bus bay plus 3m is between two equivalent no. of bus boarding bays. For opens system the rear set of bus boarding bays (i.e. behind the overtaking length) is dedicated for turning buses while the front set (i.e. ahead of overtaking length) is dedicated for straight buses.

v. The gap of the first boarding bay from the stop line is based on user input.

vi. These distances (discussed in 'd' and 'e' above) are used to estimate bus stacking during red phase of the signal (to estimate capacity) and also to arrive at throughputs and station delays (for near side stations).

b. Far Side Stations

i. For far Side Stations, the assumption is that the no. of bus lanes at near side of the junction is always the same as the number of lanes provided for the station. This is because if a turn lane is provided at a station, then the same would need to be provided at the intersection, and since for far side stations the bus stopping for boarding/alighting and that for the signal is on either side of the junction (unlike in near side stations) and thus similar lane configuration is required on both sides.

ii. In a system or segment with single bus lane(without overtaking lane) - based on whether the input values specify turning at junctions or not, the tool designs the signal phasing as a dedicated bus phase per direction or a combined phase with straight moving motorized vehicles.

iii. Far Side Station with overtaking lane – Based on whether the system allows turning at junctions or not, the tool designs the signal phasing with the overtaking lane as a dedicated turning lane (with common bus turning phase for both directions) and the bus boarding lane as straight bus movement lane with a common phase with straight moving vehicles; or both lanes moving together in a common phase with straight motor vehicles (for a closed system).

iv. The delay estimate for far side station with or without overtaking lane (either mid-block or junction station) uses common logic stream. This is based on the buses being stacked backward all the way from first boarding bay (farthest after crossing the junction) all the way up to the stop line location (for near side on the same arm).The stacking can happen throughout the signal cycles as buses in an open system (for junctions where turns are allowed) will be pushed in to the bus lane during different phases. However the system does not allow the number of buses input in to the bus lane to exceed more than the number that can be processed by the (number of) boarding bays provided. This allows higher capacity then near side stations if the bus stops are located at a sufficient distance from the junction, however the delays increase substantially as, unlike in near side stations where the maximum delay is the length of red (bus) phase, in case of far side the maximum delay is defined as the signal cycle length.

v. For far side stations without overtaking lane, all bus boarding areas are designed to be segregated by a gap of 3m. Each bus boarding bay is equivalent to the length of the bus length selected for the system based on the user input. In case of stations with overtaking lanes (for both open and closed system) the tool provides an overtaking length equivalent to one bus bay plus 3m is between two equivalent no. of bus boarding bays. For opens system the rear set of bus boarding bays (i.e. behind the overtaking length) is dedicated for turning buses while the front set (i.e. ahead of overtaking length) is dedicated for straight buses.

vi. The gap of the last boarding bay (or that nearest to the intersection) from the stop line is based on user input.

vii. These distances (discussed in 'v' and 'vi' above) are used to estimate bus stacking during red phase of the signal (to estimate capacity) and also to arrive at throughputs and station delays (for near side stations).

3.3.2.2 Commuter Behaviour Logic (Outside the Bus)

Commuters try to minimize their delay. The tool works on the logic that each passenger attempts to minimize its delay. The delay estimation of passenger uses the following logic:

1. The tool derives an average travel time for all commuters using a breakup of trips in 4 categories (i.e. 0-500m, 500-1000m, 1000-2000m, 2000-3000m), and using the average trip length in the city (input by user) and the average distance between stations (input by the user). Based on this the access distances for each category and resultant delays are calculated and averaged using the following logic:
    a. Based on the access distance (for each category) the average trip length is broken in to journey by walk, by bus or IPT (considered at same average speed) in mixed condition and journey by bus in the corridor.
    b. It is assumed that walk trips are no longer than within 500m radius of the bus stops, and each end of the journey a total of 1000m is deducted from the average trip length and the remaining distance is allocated for travel by motorized mode (including main corridor and feeder mode).
    c. All trips by feeder modes are estimated by a bus (or a motorized IPT such as a three wheeled auto rickshaw) in mixed condition
    d. Average walk trip delay is based on length calculated on the basis of perpendicular walking distances from within a neighbourhood to the main spine or arterial which is

either the corridor or a road leading to the corridor which is served by a bus route linking to the corridor; plus the walking distance along the corridor to the bus stop.

e. The walk trips distance are calculated as a sum of average depth (of O-D) from the corridor or main road served by a bus route or IPT (this is taken as an average of 0 to 500m, which is 250m) and average walking distance along the corridor (which is taken as $1/4^{th}$ the average distance between two stations as input by the user).
f. The overall passenger delay is estimated as a sum of passenger delay in accessing the feeder (for closed system) or direct route station (for open system) outside the corridor, the travel time for feeder or direct route bus in mixed conditions, the delay in accessing the BRTS station (in case of closed system) from the feeder route station and the travel time of direct route bus or trunk line (for closed system) in the dedicated bus lanes of the BRT corridor.
g. Access delay to feeder or direct route station outside the corridor is estimated as a sum of time consumed in average walking distance, average crossing delay (to access the feeder station) and the average wait time for feeder or direct route bus.
h. The bus frequency outside the corridor is assumed to be the same as that within the corridor. The average spacing between bus stations outside the corridor is also assumed to be the same as the average spacing of stations within the corridor.
i. The bus speed in mixed condition is necessary to estimate the travel time by feeder bus or a direct route bus in mixed condition. This is estimated from the average speed of vehicles in the city, inserted in the predefined data sheet as 22km/hr. (as per average speed of vehicles in Delhi as listed in CTTS study by Rites). The speed is discounted by a factor of 4/5 to account for lower acceleration and deceleration of buses in the mixed condition. In addition bus dwell time (assumed to be the same as swell time for buses in the corridor) as well acceleration deceleration delay (for station access) is added to the time it would take (at the discounted average speed) for the bus between two stations (as per the average distance between stations input by the user). The resultant time is then used to derive the average speed of bus in mixed condition.
j. Travel time by bus in mixed condition is estimated up to the stop line of the perpendicular road at the BRTS corridor junction
k. The BRTS station access delay is estimated from the feeder station (and hence only used for estimation in case of a closed system) on the perpendicular road, and includes the walking distances from the feeder station up to the middle of the BRTS station (as an average walking distance), the average delay in crossing the side road (assumed as average delay in crossing the main BRTS corridor), the average delay in crossing the BRTS corridor to access the station and the average wait time for a BRTS bus on the corridor.
l. For closed system passenger delay estimation, the walking distance from the feeder station till the BRTS corridor edge (or the stop line) is deducted from the distance travelled by the feeder bus in mixed condition (as the feeder bus travel time is estimated up to the stop line of the perpendicular road while the station is at a set distance before the stop line).
m. The distance of feeder station from the BRTS corridor edge is assumed as 150m. This is based on the assumption that the minimum distance of a bus station to the

corridor in mixed condition is 50m and the maximum is 250m. However in metropolitan areas such as Delhi the minimum distance defined by administration is 150m, and the maximum distance is 650m where flyovers or vehicular underpasses are constructed. Hence in case of large metropolitan cities this predefined value may need to be changed to 400m. However since 150m also coincides with the minimum distance for cities like Delhi, this value is used in the model.

n. The travel time by bus in the BRTS corridor is based on the average system of buses in the proposed value which is derived by a different process.

o. One of the components effecting delay for passengers is the waiting time for the bus at a station. This is dependent on bus frequency. To estimate the wait time for a bus the tool uses the maximum capacity of the system and works out the average waiting time for a bus. In a closed system, since all buses move on the same route, this is estimated through a simple calculation of averaging the maximum and minimum waiting time. In an open system the tool makes a calculation on the basis of 5 routes using the corridor and hence delay in waiting for a direct route is estimated as five times the delay in a closed system.

3.3.2.3 Signal Cycle Design Logic

Signal cycle at intersections or at mid block pedestrian crossing effect both the vehicle (bus) and the passenger delay on the corridor. Lower signal cycle lengths lead to lower delays for buses and passengers. The tool works around this principle to minimize signal cycle length on the basis of desirable signal cycle length input by the user, and subsequently proposes a phase design to fit the optimized cycle length. The tool also provides the user an option to override the system designed signal cycle and phase design, by allowing a user input for the same. The user inputs override system proposed cycle design and all estimates in the tool, use user inputs when the same are defined in the results sheet. However the system design of signal cycle is an essential start point and forms the basis os the initial result which can be modified by modifying cycle design, by the user if required. The tool uses the following logic to design the signal cycle and phase sequence/length etc.:

1. The tool has two signal cycle design sub-components.
    a. One of the components deals with the design for the station access signal; which is a pedestrian only signal for mid block stations or a combined pedestrian and vehicular signal for junction stations.
    b. The other component or sub-tool deals with the intersection signal design for junctions located between mid block stations.

    Hence for junction stations only the first or the station access signal design component is activated, whereas for the mid block stations, the delay and capacity contribution of both signals are taken in to account. For the latter the delay estimate is accumulation of both signals whereas the capacity estimation is the minimum throughput possible at either of the two signals.

2. The input value of desirable signal cycle is verified/ modified to produce an optimum signal cycle length. This is achieved by:
    a. Estimating the number of phases that are required based on the given design and other intersection information input by the user.

b. In addition the tool estimates the minimum signal cycle length required to process all phases as per design features input by the user.
c. Following this the tool checks if the user input value is too less for the design, or is it too high to be efficient. Low values are increased based on the no. of phases estimated by the tool, while high values are brought down based on the ratio of the input value and the minimum desirable value for the no. of arms at the junction (as input by the user). The tool has inbuilt values for the minimum and maximum desirable signal cycle length which is as following:
    i. Minimum and maximum signal cycle lengths are defined in the tool as following:
    ii. The system Maximum permissible cycle length is 225sec long
    iii. Minimum and maximum desirable cycle length for 4 arm junction is 150 sec and 180 sec respectively.
    iv. Minimum and maximum desirable cycle length for 3 arm junction is 120 sec and 150 sec respectively.
    v. Minimum and maximum desirable cycle length for 2 arm location (or mid block station with a pedestrian signal) is 60 sec and 90 sec respectively.
d. The above minimum and maximum and desirable cycle lengths are a part of default values which can also be modified by the user (in the default value form) if required.

3. User defined signal cycle length are also subject to a maximum and minimum range and which is between 30 to 300 seconds for different types of junction types.

3.4 Results

The BEAD tool presents results or performance values of different indicators of the design in two stages:

- Segment Wise Results
- Overall Aggregated Results for the Entire Corridor

The results for both the above categories are presented under same heads. However segment wise results are presented after the inputs for each segment have been fed in the tool. These include additional signal and cross section design information specific to the input segment and can be printed using a print button. Overall corridor results are saved in an output xls file when all segments are input in the tool. It is also important to note that users have the flexibility to edit defining values in the output sheet for each segment, and generate revised values; however the same is not permit in the aggregate output of the corridor. The users can though use the output xls file to load data

3.4.1 Result Categories

The results presented under both the stages discussed above are classified and presented under the following categories (Annexure 3) :

3.4.1.1 Cross Section Design

Here the width and order of arrangement of each road component such as service lane, footpath, cycle track, green belt, service belt, IPT Parking, carriageway for motorized vehicles, bus lanes, bus stop etc. The cross section designs are presented in two parts, viz., system designed and user defined. The cross section design is generated for the most critical location, i.e. the bus station. As default the output sheet uses the above defined processes to generate a cross section design which is presented both as same under system and user defined head. The user has the flexibility to edit these cross section design values using the edit results button. Here the user can input/change all the individual cross section design elements. These will be totalled and checked against the ROW width input by the user in the user forms, and an error message returned till the same is corrected. The evaluation of crossing distances are estimated based on the user input values which over-ride the system defined design.

3.4.1.2 Signal Design

This component displays the results of a system designed signal cycle and phase sequencing as well distribution. The signal cycle design is based on background process mentioned above and allows the user to edit the same (system overrides the system designed signal cycle with user defined one), using an edit button on the first results/output sheet. This leads the user to a result editing sheet.

As discussed in the previous section, user can defined specific signal cycle and phase group lengths, which are checked by the system and an error message returned till the time all errors in the input are removed. On pressing the back button which brings displays the edit sheet presenting the output results based on the inputs/editions provided by the user.

3.4.1.3 Corridor Travel Time and Speed

This category presents all speed and travel time related outputs as estimated for the unput design, by the BEAD tool. These results are presented under the following sub heads:

1. BRT operational speed (Expected Average Bus Speed in the System)
2. Passenger speed with BRT
3. Passenger walking distance
4. Overall origin to destination journey time (using BRTS) for average motorized trip length
5. Total average access time
6. Total average in vehicle time (main line/route)
7. Per bus delay per station/junction in segregated lanes
8. Per bus delay per midblock station in segregated lanes
9. Total average passenger delay in the sytem

BRT Operational Speed – This is the expected average bus speed in the system, after accounting for all station, signal and acceleration/deceleration related delays. It is affected by the spacing between intersections, signal cycle length, station set back from intersection etc. The operational speed of buses in the BRTS system is presented on the output sheet in Km/h.

Passenger Speed with BRT – This value in the output sheet indicates average speed in km/h experienced by the passenger in undertaking the total journey including walk trips, feeder bus trip and transit trip. This is considered and important measure in the performance of the system as it aggregates the delay experienced by the passenger in the entire journey (and not just the journey within the BRTS corridor – which is represented by operational speed and which does not account for important factors such as access and egress delays) and presents it as speed for easy comparison with other modes such as private motorized modes.

Passenger Walking Distance – Total passenger walking distance in meters (averaged over different trip types) in a one way trip are estimated and presented by the tool in the output sheet. This is an important indicator for comparison between different designs as it directly relates to passenger inconvenience and perceived time. This value is majorly dependent on average spacing between stations, crossing widths, crossing type (grade separated pedestrian crossing facilities with ramps add to walking distances), etc.

Overall origin to destination journey time (using BRTS) for average motorized trip length – Under this head the overall passenger journey time between origin and destination is estimated by the tool and presented in minutes. The journey time is estimated after accounting for passenger speed in different trip components or using different modes, waiting delays, crossing delays, etc.

Total Average Access Time – The point to point journey time for an average passenger undertaking a trip equivalent to average trip length in the city or along the corridor; is broken in to two components, i.e. 'Total Access and Egress Time' and total in vehicle time. Total Access and egress time is presented under this head in minutes, and includes time spent in any feeder bus to access the transit station and also accounts for any changeover delays.

Total Average In-Vehicle Time – Total average in-vehicle time is the time spent on the main line transit vehicle. In an open system it includes the journey (for direct routes) outside the BRTS corridor. This time is estimated after subtracting the total access and egress time from the total journey time (discussed above) and presented in minutes.

Per bus delay per station/junction in segregated lanes – This head presents the delay experienced by an average bus per station junction combination for junction stations or just junction delay for intersections between mid block stations (as per user inputs defining BRTS design in the user input forms). These values are presented in seconds.

Per bus delay per midblock station in segregated lanes – This heads presents the delay experience per bus per mid block station (in combination with a pedestrian signal delay if defined in the user input). This delay is presented in seconds. In case of junction stations this delay value appears as '0', whereas in case of mid blocks stations this delay is aggregated with the junction delay (explained) above for the specified number of stations (derived from the average station spacing input by the user).

Total Average Passenger Delay in the System – This head presents average passenger delay encountered for an average trip length, excluding time spent in walking, but including time lost for waiting the bus, crossing the road, and reaching the bus boarding bay from the middle of the cross road.. This value is presented in seconds.

3.4.1.4 Corridor Throughput

This category presents results under the following sub heads:

1. Corridor PPHPDT
2. Corridor Bus Throughput (Max frequency)
3. Junction Bus throughput
4. Station Bus Throughput (separate from junction for mid block station)
5. User input - buses per hour per direction

Corridor PPHPDT – Corridor PPHPDT implies Peak per Hour per Direction Trips transported by the BRTS system as per the specified corridor design, and relates to the peak hour peak direction capacity (in terms of passengers) offered by the corridor. This typically varies between 4000 to 20000.

Corridor Bus Throughput (Max Frequency) – Peak passenger carrying capacity is derived from the vehicle type (specified by the user in the user forms) and the peak corridor bus throughput. This value is presented separately so as users can relate to the fleet volume handling capacity of the system.

Junction Bus Throughput – Corridor bus throughput is derived from the per cycle throughput of buses, which is based on the minimum headway calculations for the data input by the user. This value is presented separately for mid block throughput (at pedestrian signal cycles) and at junction throughput (for junctions between mid block stations or junction stations).

Station Bus Throughput – This is the same as junction bus throughput for junction stations (as it acts as a combined unit) whereas for mid block stations it is presented separately. This is also based on the minimum headway estimates calculated from the user input.

Bus Demand User Input – By default this value is set the same as Corridor Bus Throughput or Maximum Frequency derived by the tool. However the user can use the edit results button and set this to a lower value as per estimated design. This will override the Maximum frequency value derived by the system and other performance measures such as delay, speeds etc. are recalculated as per the user input value.

3.4.1.5 Bus Shelter Length

This category presents the calculated length of the bus station, with and without ramps. When combined with the station width generated by the cross section design utility of the tool, the user can estimate the station and ramp sq. M. area, which is useful in determining a rough estimate of costs involves.

3.4.1.6 Comparisons

The tool presents the following additional data/results for comparison with the proposed system performance:

1. Time saved by BRT over Private Transport
2. Avg. passenger speed with buses without BRT
3. Time saved by BRT over mixed condition bus
4. Daily bus passenger hours saved

Time Saved over Private Transport – This uses the average motor vehicle speed in the corridor or the city (from default values – set as 20km/h but editable by the user) and estimates the passenger speed on the basis of walking distance to access parked vehicle (50m in the default values). It then compares this with the passenger speeds estimated by the tool for the proposed BRTS design. The difference time per passenger trip is presented as the time saved by using BRTS over private transport.

Average Passenger Speed with Buses without BRTS – Under this head the passenger speed for bus transit in mixed conditions is estimated as per the process defined above. The values are presented in Km/h.

Time Saved by BRT over mixed condition bus – Under this sub head the time savings are calculated in daily hours saved. This is done by deriving the time difference (in hours) per passenger trip (using passenger speed values derived by the tool) between buses using the BRTS system and those moving in mixed condition.

Daily Bus Passenger Hours Saved - This value is multiplied by the total passenger trips expected in the segment (using the corridor PPHPDT value estimated by the tool and multiplying it by 10 * 2 to arrive at daily two directional trips) to arrive at a an estimate of total hours saved per day.

3.4.1.7 Level of Service (LOS) as an Overall Performance Indicator

BEAD tool employs a sub LOS estimator tool, which derives the values from the output sheet under 10 different heads, and the same are divided in to three categories, based on the main recipient of benefits under that head. These categories are:

- Societal
- User
- Operator

The LOS estimator assigns weights to each of the 10 indicators based on the relative weights of the category under which they fall and the relative weights of indicators within each category. These indicators are:

1. **Attractiveness for Public Transport Users** – This indicator uses the ratio of passenger speed in the proposed BRTS system and that in the existing bus based or IPT based public transport. A higher ratio indicates better performance.

2. **Passenger Speed** – This indicator uses the absolute value of passenger speed (ratio of total O-D distance by total time spent by the passenger in the journey). A higher passenger speed indicates better performance

3. **Safety** – Empirical evidence shows that 1% increase in speed of motorized vehicles results in 4% increase in chances of a fatal accident. This is why the peak cruising speed limit of transit vehicle plays an important role in ensuring safety of pedestrians and other road users. Thus a lower peak speed limit for buses using BRTS is considered a better, as an indicator of safety.

4. **Walking Distance** – Longer walking or access/egress distances increase inconvenience which results in a higher perceived time (than actual time), reducing the attractiveness of public transport. Thus reduced walk distances are considered better in the overall performance of the BRT system being evaluated.

5. **Attractiveness for Private Two Wheelers** – Buses and typically BRTS systems present travel costs similar to the operational cost of motorized two wheelers. Thus a reduced passenger time in the BRTS than motorized modes is likely to attract mode shift from motorized two

wheelers. Thus the ratio of passenger speed in buses to that of motorized two wheelers is considered as an indicator of the performance of the BRT system. A higher ratio indicated better performance.

6. **Capacity** – BRTS systems improve operational efficiency and attractiveness of bus transport by allowing a higher capacity than buses moving in mixed condition. Thus higher capacity is an indicator of better performance of BRT system

7. **Total Passenger Delay** – Passenger delay in the system directly effects inconvenience experienced by the user. Hence higher delays lead to lower attractiveness of public transport.

8. **Total Bus Delay (Station + junction time)** – Delay of buses in the system increases both actual and perceived (higher than actual) passenger travel time thereby reducing the attractiveness of the system. Thus lower average delays of buses are an indicator of better performance of the system.

9. **Operational Speed –** Higher average operational speeds reduce perceived passenger travel time though its effect on the actual travel time may be limited. Thus higher operational speeds are indicators of better performance of a BRTS system.

10. **Ratio of in-vehicle to access time** – Because walking speeds are less longer and effort involved is considerably higher than the speed of a feeder service in mixed condition which is considerably lower than the speeds of transit in the BRTS corridor; it is considered that access time should be comparatively shorter than in vehicle time. Therefore a higher than 1 ration of in-vehicle time to access time is an indicator of better performance by the system.

To estimate the overall LOS, the performance under each indicator needs to be benchmarked. This has been done by giving a score, ranging from 'A to F' to each indicator. 'A' is for best performance and 'F' for worst. The expected performance of each indicator (from the assessment of results derived from BEAD) has been broken in to six parts (corresponding to each score), so as the performance value generated by the Tool can be used to rate that indicator as per the score card. The range of performance values relative to each score along with their individual weightages (Annexure 6), has been listed for each indicator in the Table 3 below.

Table 3: Categorization of performance indicators by score ranging from 'A' to 'F'

Indicators	Score	A	B	C	D	E	F	Units/ Description
	Weightage	1	0.8	0.6	0.4	0.2	0	
Attractiveness for Public Transport Users	0.083222	>= 1.5	1.49 - 1.3	1.29 - 1.15	1.14 - 1.05	1.04 - 1.01	<= 1	Ratio of Passenger speed in BRT to that in regular bus service
Passenger Speed	0.0389536	>= 13	12.9 - 11.5	11.4 - 10	9.9 - 8	7.9 - 6	< 6	Overall Journey speed in Km/h

Indicators	Score	A	B	C	D	E	F	Units/ Description
	Weightage	1	0.8	0.6	0.4	0.2	0	
Safety	0.3875091	< = 40	41 - 45	46 - 50	51 - 55	56 - 60	> 60	Peak Bus Speed in Km/h
Walking Distance	0.1399425	< = 900	901 - 1050	1051 - 1200	1201 - 1350	1351 - 1500	> 1500	m
Attractiveness for Private Two Wheelers	0.1937545	> = 1.1	1.09 - 1	0.99 - 0.9	0.89 - 0.8	0.79 - 0.65	< 0.65	Ratio of Passenger speed in BRT to that in private vehicles
Capacity	0.0450520	>= 20000	19999 - 12000	11999 - 8000	7999 - 6000	5999 - 4000	< 4000	PPHPD
Total Passenger Delay	0.0241945	<= 150	151 - 200	201 - 250	251 - 350	351 - 450	>450	Total delay for crossing, waiting, access, etc. in Sec
Total Bus Delay (Station+junction time)	0.0286141	<= 30	31 - 50	51 - 75	76 - 105	106 - 150	> 150	Sec
Operational Speed	0.0359199	>= 23	22.9 - 20	19.9 - 18	17.9 - 15	14.9 - 12	< 12	Km/Hr
Ratio of In-vehicle to access time	0.0228386	1.5	1.25	1	0.75	0.5	0	Ratio

Each score from A to F has been assigned a numerical value between 0 and 1 to allow an overall estimate of score for the design. This score

Total Score is derived by multiplying the individual score for each measure as per the benchmarks and scores shown in columns by their individual weights (under the weightage column), and taking the sum of these values.

The numerical value achieved is represented as an overall score between 'A' to 'F' on the basis of following breakup:

1 - 0.75	0.74 - 0.6	0.59 - 0.45	0.44 - 0.3	0.29 - 0.15	0.14 - 0
A	B	C	D	E	F

3.4.2 Application of Results

Results derived from BEAD can be compared against design changes by toggling input values provided by the user. The comparative results are useful in guiding the user to refine the design with an objective of overall performance improvement. Here the most significant contribution of the tool is that it is passenger and not vehicle focused, and thus reflects direct impact on end user of the proposed system. This is possible as the tool allows passenger speeds and journey time comparison against the prevalent vehicle or operator oriented operational speed and capacity based comparisons.

In addition the Tool will be provided with a comprehensive user manual (currently under development) which standard trend charts using results, derived for different design combinations, from the BEAD tool. The charts would be useful in guiding the user on what features to adjust to achieve specific design performance improvements.

To develop these charts a standard set of parameters (listed in Table 4) have been defined in the BEAD Tool to derive results for 16 different design options. These options differ from each other through following combination of features:

1. System or operations type, i.e. open or closed
2. Station type, i.e. island or staggered
3. Presence or absence of an overtaking lane at the station
4. Station Location, i.e. island or mid block

Table 4: The standard values of parameters used for each of the 16 design types defined in BEAD Tool

Parameter	Standard Value	Variations	Unit
Average Distance Between Stations	600	500 to 1000	m
Designed or Desired Frequency (Demand)	2500	2500 to 22500	PPHPDT
1st bus boarding distance From Stop Line	26	13 to 78	m
Signal Cycle Length	150 for intersection 60 for mid block	120 to 300 for Intersections	Seconds

The results were derived from BEAD for each of the 16 designs separately, and then compared against variations in the standard value within a range (Table 4). The data derived from this exercise was plotted as trends. Some of these charts have been presented in Annexure 7 of this report.

In addition the tool can be used to derive policy level indicators on an optimum design for different city conditions (instead of proposing a blanket design for all cities). In one way this can be achieved is by using passenger journey time as an indicator of the corridor design performance and comparing its trend with varying average trip lengths (along the corridor or for the city), peak speeds of buses in segregated conditions and average spacing of stations in the corridor. Figure 13 to Figure 17, present these charts for two broad design categories, i.e. closed systems with island stations located 50m from the stop line and staggered stations with island stations located 13m from stop line (in both cases no overtaking lane is provided). These charts can be used as a basis of important conclusions effecting design and planning decisions at policy and conceptualization levels; such as:

1. Peak speed of buses higher than 40km/h in the corridor provides little or no advantage in terms of passenger journey time saving; however the adverse impact of this increase is known to be significant on the safety of community where such systems are planned. Hence it can be recommended that the peak speed limit of buses within BRTS corridors should be retained as per the current motor vehicle norms, at 40km/h.
2. Closed systems show very little sensitivity to average spacing between bus stations on the corridor. However in case of open systems, the passenger journey time savings are significant for station spacing around 750m, than those at 500 or 1000m. Even for closed system designs 750m spacing allows the maximum travel time saving (though this saving is

lesser in terms of absolute numbers) and hence it can be suggested that average bus stop spacing of about 750m is desirable for all types of BRTS corridor designs with junction stations.

3. There is no significant gain to existing public transport users if the current or horizon year average speeds on the corridor (in mixed condition) are more than 20-25km/h.
4. Closed systems (with or without the use of island stations) provide significantly higher operational speeds of buses in the corridor, than the open systems. Though this operational speed advantage does not translate in to journey time savings; and open systems provided faster journey time than closed system for up to 10-12km trip length while closed systems prove advantageous for longer trips.

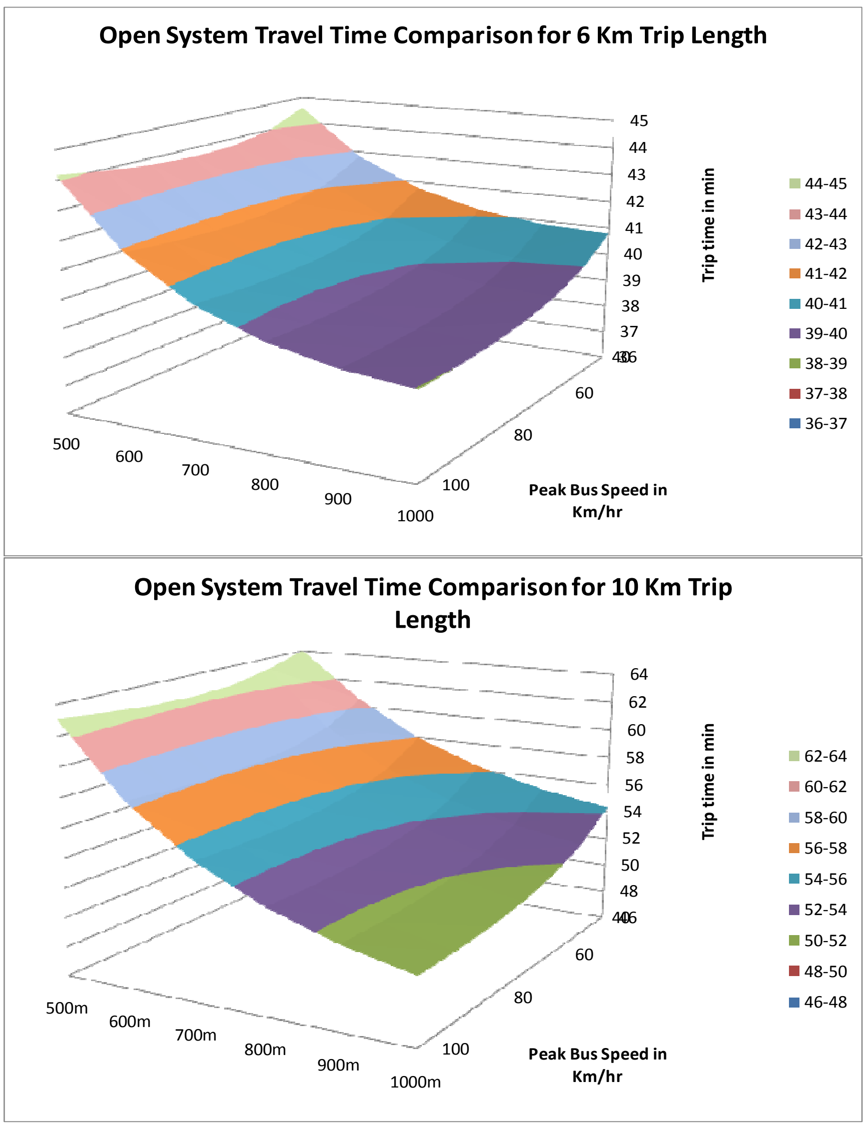
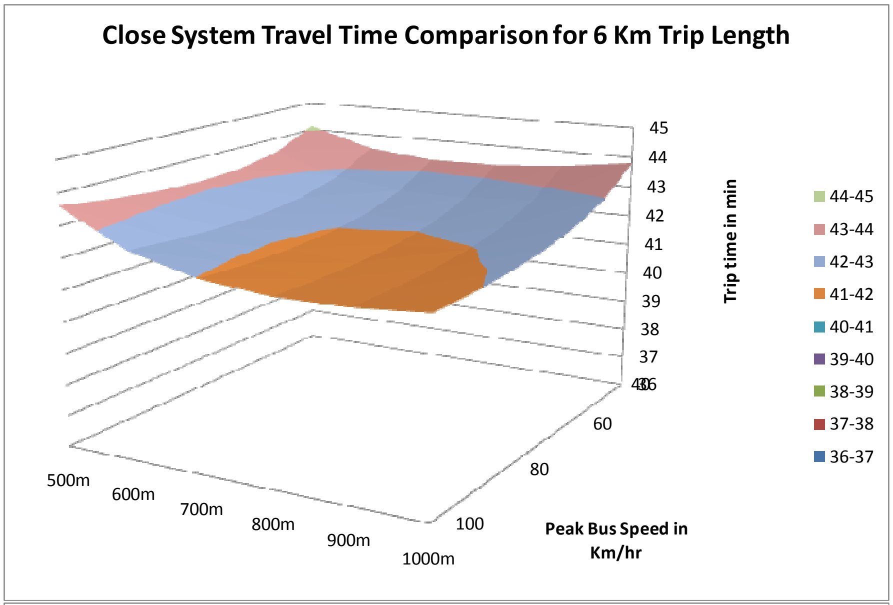


Figure 13: Comparison of trends for journey time changes (for 6 and 10km trip lengths using BRTS system) in an open system with staggered junction stations (based on results derived from BEAD Tool).



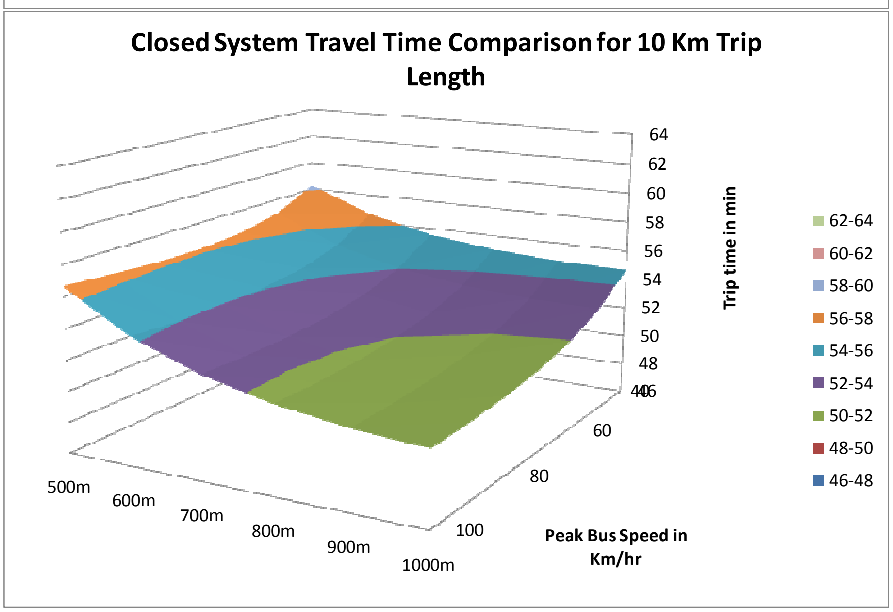


Figure 14: Comparison of trends for journey time changes (for 6 and 10km trip lengths using BRTS system) in a closed system with island junction stations (Based on results derived from BEAD Tool).

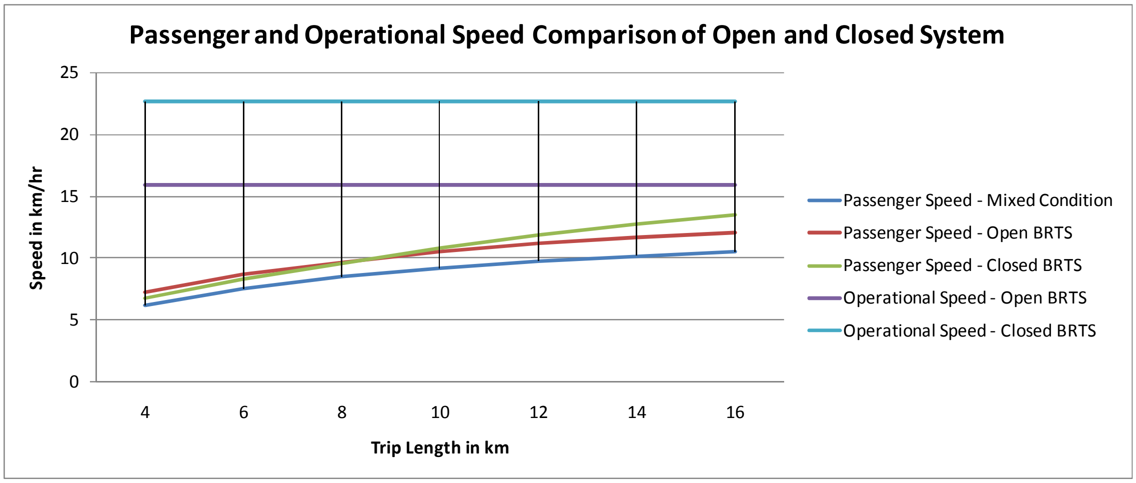
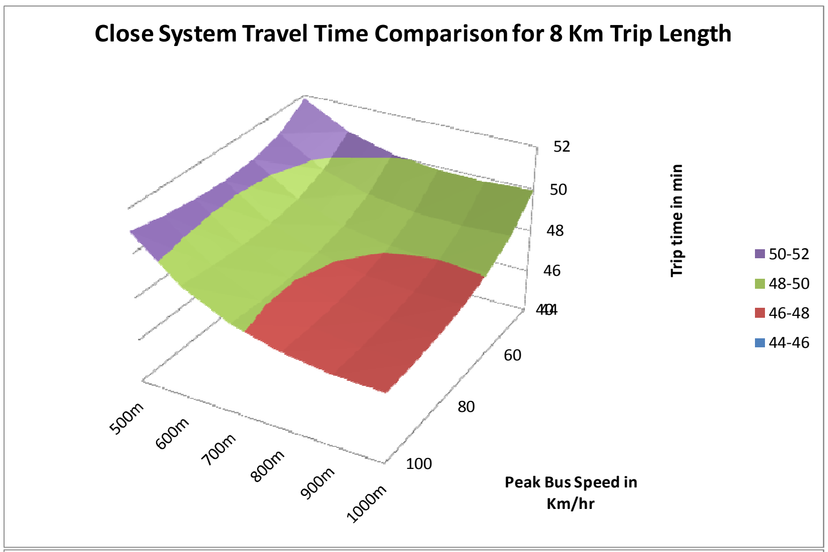


Figure 15: Passenger and operational speed comparison between open and closed system for different trip lengths



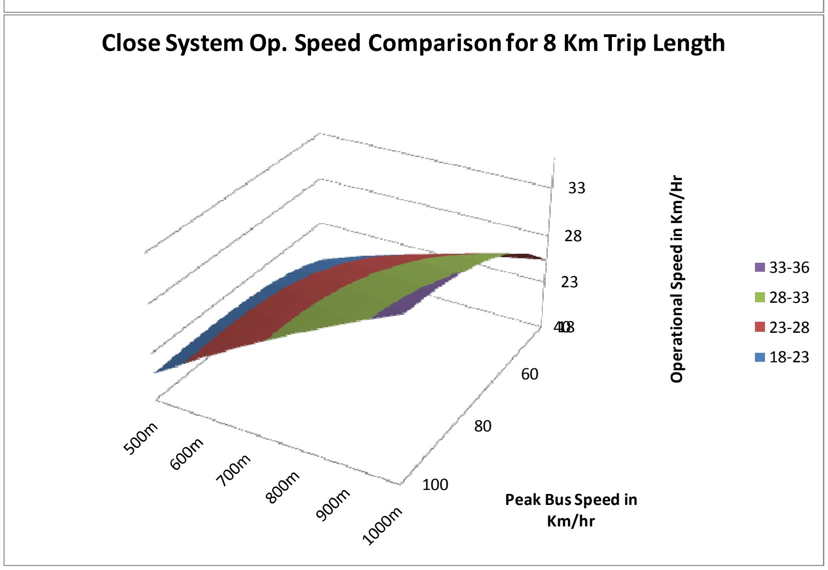
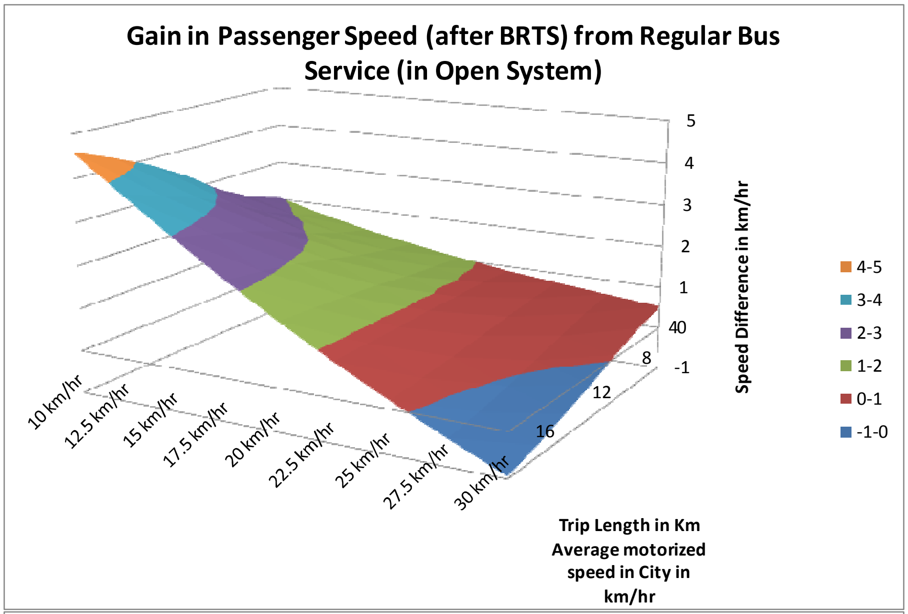


Figure 16: Operational and passenger speed comparison for closed system (with island stations) for a trip length of 8 km and varying stations spacing as well peak bus speeds in the corridor.



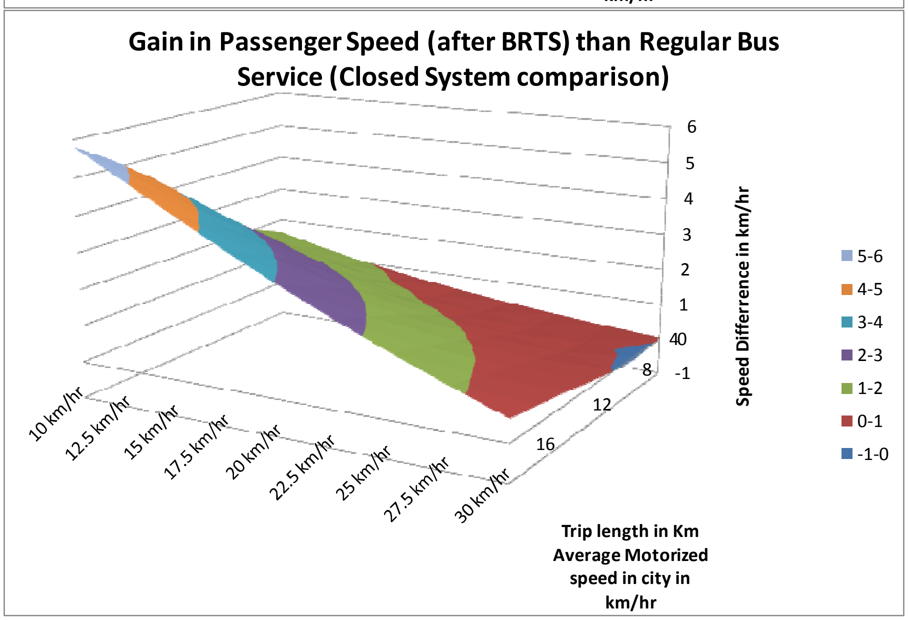


Figure 17: Time gain for passengers in BRTS over regular bus service (in mixed condition) compared for open and closed system against varying trip lengths and average speed of motorized vehicles in mixed traffic (on the corridor or in the city).

4 Validation of Results

The performance of the tool in accurately evaluating a BRTS system design has been established by validating the results between modelled and known/documented performance of three BRTS systems. These are:

1. Delhi BRTS pilot corridor from Ambedkar Nagar to Moolchand
2. Ahmadabad BRTS corridor from RTO junction to Shivrajani
3. Bogota BRTS – Caracas Corridor

Since most documentation on these corridor focuses on vehicles performance rather than passenger indicators, the operational speeds and expected peak system capacities were compared for validations.

4.1 Delhi BRTS

The Delhi BRTS corridor uses an open bus operations design with staggered parallel stations at intersections (Figure 18). It has a total of 9 stations (including end stations) over a length of about 5.6km. The Average distance between stations is about 730m. Though the corridor has 2 mid block stations and 7 junction stations, the tool defined the corridor as a uniform design with junction stations with 180 second signal cycle with a total of 6 phases (with 2 dedicated bus phases). The distance of the first boarding bus from stop line on the current corridor is 20m.

Figure 18: Aerial view (Google Earth) of Siri Fort Junction Station, Delhi BRTS corridor

The comparative results, between the tool output and the actual site studies generated by DIMTS Ltd., have been presented in Table 5.

Table 5: Validation of Results for Delhi BRTS Corridor

Data from Studies/Surveys	Model Results
Current Demand – 120-150 buses, 13500PPHPD (Geetam Tiwari and Deepty Jain)–100 pas/bus	Current Demand – 160 buses, 16000 PPHPD (100 pas/bus)
Average Corridor Speed (in current demand)– 18 Km/hr (Geetam Tiwari and Deepty Jain)	Average Corridor Speed (with current demand) – 16.92Km/hr
Peak Capacity – 200-240 Buses, 20000-24000PPHPD (Geetam Tiwari and Deepty Jain) (100 pas/bus)	Peak Capacity – 320 Buses, 32000 PPHPD (100 pas/bus)
Avg. Corridor Speed (Peak Capacity) - ?	Avg. Cor. Speed (Peak Capacity) – 20.74 Km/h (for modified signal cycle option)

4.2 Ahmadabad BRTS

The 8km long first Ahemedabad BRTS corridor from RTO to Shivrajani (Figure 19) uses closed bus operations with island stations. It has an average station spacing of about 800m and deploys 12m long high floor urban buses, with a possibility of maximum two simultaneous boarding's at each station. The first bus boards about 50-60m from the stop line and the junction signal cycle is about 120 seconds, with 4 phases.

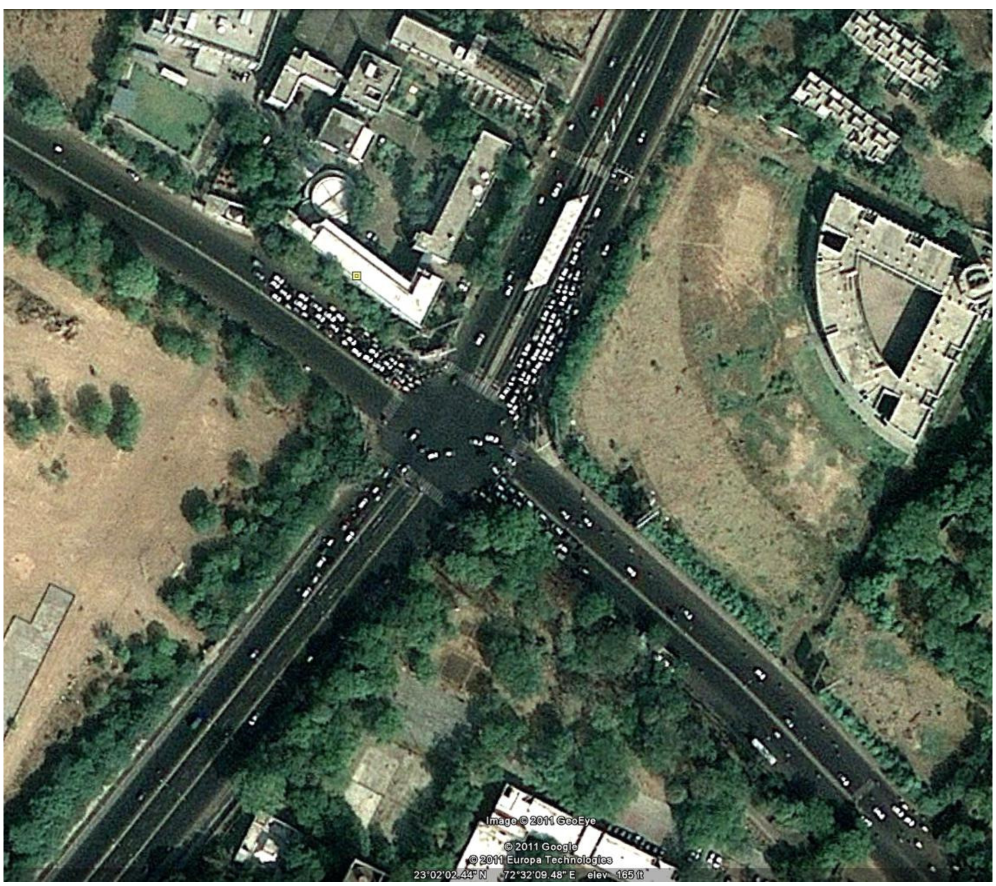


Figure 19: Aerial view of Ahmedabad BRTS corridor

The comparative results, between the tool output and the actual site studies generated by 'Janmarg' have been presented in Table 6.

Table 6: Validation of results for Ahmadabad BRTS corridor

Data from Studies/Surveys	**Model Results**
Current usage – 2350-2600 PPHPD (Janmarg: BRTS Ahmedabad (8th Month MIS))	Input usage – 3000 PPHPD (100 pas/bus)
Average Corridor Speed (in current demand)– 25 Km/hr (Janmarg: BRTS Ahmedabad (8th Month MIS))	Average Corridor Speed (with current demand) – 24.77Km/hr
Peak Capacity – 15000-20000 PPHPD (Janmarg: BRTS Ahmedabad (8th Month MIS)) (100 pas/bus)	Peak Capacity – 18000 PPHPD (100 pas/bus)
Avg. Corridor Speed (Peak Capacity) - ?	Avg. Cor. Speed (Peak Capacity) – 22.03 Km/Hr

4.3 Bogota BRTS

The Caracas corridor in Bogota is based on closed bus operations with island stations mostly provided with an overtaking lane. It has an estimated average station spacing of about 720m (measured from Google Earth). Each station boards three simultaneous bi-articulated buses, and the first bus boarding distance from stop line is 28m. The signal cycle at intersections is 60 seconds and uses a two phase signal.

Figure 20: Aerial view of (Google Earth) Bogota BRTS – Caracas Corridor

The comparative results, between the tool output and the actual site studies generated by ITDP have been presented in Table 7.

Table 7: Validation of results for Bogota BRTS corridor

Data from Studies/Surveys	Model Results
PPHPDT – 45000 (Walter Hook) (150 pas/bus) (300 buses/hr/dir)	PPHPDT – 48000 (160 pas/bus) (300 buses/hr/dir)
Average Corridor Speed – 26 Km/hr (Express Service), 21 Km/hr. (all stop service)	Average Corridor Speed – 26.70 Km/hr

Annexure 1: First BEAD Workshop – Finalization of Input Variables

Objective of the workshop:

To discuss and get feedback on establishing and identifying important input variables as well their relationship in determining system performance as measured by its capacity and various delays for the development of the Bus Rapid Transit System (BRTS) Design and Evaluation Tool (BEAD)

Participants:

1. Institute for Urban Transport (IUT)
2. Transportation Research and Injury Prevention Program (TRIPP), IIT Delhi
3. Shakti Sustainable Energy Foundation (SSEF)
4. Delhi Integrated Multi Modal Transport Systems Ltd (DIMMTS)
5. Urban Mass Transit Company (UMTC)
6. Capita Symonds
7. Innovative Transport Solutions (i-Trans)
8. S G Architects (SGA)
9. Dr. Joseph Fazio

Comments:

- Allow users to choose pedestrian crossing options at junctions. 'Walk With' or 'All Red' policy.
- Include 'Land Use Pattern' as one of the variables as it would affect model output.
- In assumptions - the ROW up to 120m may be added.
- Constant spacing of stops (770m) needs some alteration to fit in more mid block stations.
- Mid block stops not present right now. Can be included.

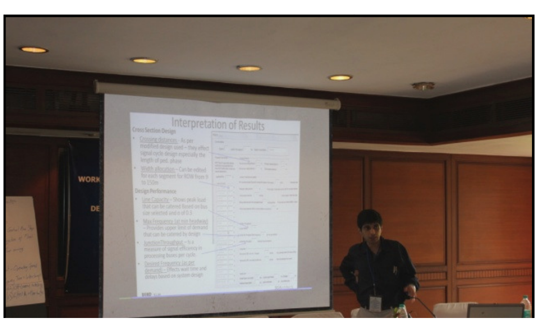
Annexure 2: Second BEAD Workshop – Finalization of Output Variables and Discussions on the Working of the Tool

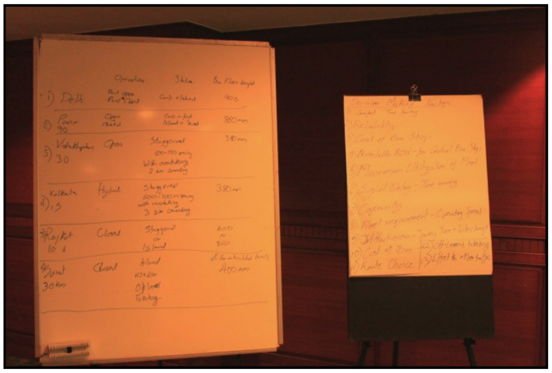
Objective of the workshop:

The objective of this workshop was to present the BETA version of the tool and its working, and collect feedback on the user friendliness of the tool as well as the utility and application of results generated by the same

List of Participants:

1. Institute for Urban Transport (IUT)
2. Transportation Research and Injury Prevention Program (TRIPP), IIT Delhi
3. Shakti Sustainable Energy Foundation (SSEF)
4. Delhi Integrated Multi Modal Transport Systems Ltd (DIMMTS)
5. Innovative Transport Solutions (i-Trans)
6. S G Architects (SGA)
7. Pune Municipal Coporation (PMC)
8. Greater Vishakapatnam Municipal Coporation (GVMC)
9. Rajkot Municipal Corporation (RMC)
10. Surat Municipal Coproration (SMC)
11. Institute for Transportation & Development Policy
12. UTTIPEC, DDA (Delhi Development Authority)
13. Kolkata Metropolitan Development Authority (KMDA)
14. IL&FS Infrastructure Development Corporation Ltd.
15. Voyants Solutions Pvt. Ltd.
16. PWD, Govt. Of NCT, Delhi





Comments provided by Participants during the two day session at the Workshop:

- Hybrid system selection option should be given along with open and closed systems
- Effect of set back at the far-side station should be explained in the manual
- Bus shelter/ Bus station a more appropriate word than Bus stop. The main station can be called as a Bus terminal
- Can the mid-block station take a signal?
- Can we see the performance of the BRT as a function of its demand as demand also includes performance?
- Fixing 10-15% of the junction signal cycle for buses might not be correct because at smaller junctions the % may be more and at bigger junctions it might be lesser. But the bus accumulation in smaller junctions is also small due to smaller cycles hence the bigger junctions might be the issue.
- Area (m^2/pass)should be related for various LOS
- Can we have different corridor designs and integrate them in this software?
- A glossary of definitions of technical terms used in BEAD to help the users
- Make a user manual and explain how the dummy variables can be changed to get required results.
- The signal phasing diagram should change for different designs. Right now it is constant for all designs.
- In the output, colour the various results obtained to show whether the result is correct or wrong to make it easier for the users to evaluate a design.
- Assign a LOS to the output obtained and make this decision city specific. Can we have the LOS based on NMT infrastructure availability and access?
- If there is a green phase for Buses and Boarding and alighting is still in progress at the station, is the delay caused accounted for in BEAD??
- Access trips' trip length frequency distribution to be considered for different access types
- Access trip by cycle parking also should be included
- Is the delay in access difference between Low floor and high floor buses considered?
- What about V/C ratios in MV lanes. A lot of opposition to BRT is from the car lobby and the tool should assess MV lane performance for various designs also.
- Turnstiles and ticket vending can be staggered to make way for 2 turnstiles at the same time

Feed back provided by the Participants

IUT:

- About one-third of the variables are fixed and the remaining are variable
- Output should be specific to Users, operators and the owner of the system
- User manual should contain details on what specific inputs need to be changed for what specific output required
- Impact on other road users, apart from bus users also to be given in output

Different user groups

Designers/ Consultants

- BEAD in its current form can be used for evaluating but not designing a new system from scratch
- Existing designs can be altered and their effects can be observed using BEAD
- Benchmarking of different designs required to define an optimum design

Operators

- Open system better than closed. We can't have buses operating like Metro.
- Station location (island/ staggered) also plays a role
- Travel without ticket involves queues at checking points and that can also be included

ULBs who evaluate the BRT designs

- Detailed training required for ULBs, one 2-day session insufficient (VIzag, Rajkot)
- Glossary required so that BEAD can be used on their own (Pune)
- Useful, but only after more practice (Pune, Vizag, Surat)
- In case of Metro running parallel to BRTS, some of the variables are fixed and same as Metro, can BEAD function in such a scenario (Kolkata)
- Impact of BRT on motorised vehicles is important (Delhi PWD)

Annexure 3: List of Input Variables and Output Fields Used in the Tool

Parameters involved in the design of BRT

Sr.No.	Input Variables Category
1	Mid block, Signalized or roundabout junction station
2	System Operation Type
3	Use of physically segregated bus ways or dedicated lanes
4	Staggered or common station
5	Station is Left or right side of bus boarding lane
6	Parallel or single station
7	With or without overtaking lanes
8	First Bus boarding front edge from stop line (for near side) or last bus rear edge from stop line (for far side)
9	No. of Simultaneous buses to be catered (total for both directions)
10	Platform Height
11	Designed platform width (each)
12	Grade separated Junction (no signal delay for buses)
13	Junction signal cycle
14	Near side or far side
15	With or without doors
16	Bus Type planned for
17	Off board fare collection
18	Bus Turning allowed at this junction (not for end of corridor turns)
19	Vehicle turning allowed at junction
20	Pedestrian access type
21	Grade Separated Pedestrian crossing access type
22	Row Width
23	Average distance between junctions/stoppages
24	Expected motor vehicular queue length in peak hours
25	No. of MV lanes desired per direction at mid block
26	Ratio of turning buses as a proportion of total buses
27	Is there BRTS on cross roads at intersection
28	Junction Type
29	Cross Road traffic type
30	BRTS corridor Traffic Type
31	Distance from first bus front (in case of near station) or last bus rear (in case of far side station) to nearest Intersection
32	Boarding level
33	No. of access to the station
34	Corridor Length
35	Average Motorized Trip length in the city
36	Bus priority signal
37	All Red phase for vehicles or dedicated pedestrian green phase
38	Land use along the corridor
	Additional Corridor Junction Information for Mid block Stations

39	Single or parallel lanes on near side of intersection
40	Grade separated Junction (no signal delay for buses)
41	Junction signal cycle
42	Bus Turning allowed at this junction (not for end of corridor turns)
43	Vehicle turning allowed at junction
44	Expected motor vehicular queue length in peak hours
45	Ratio of turning buses as a proportion of total buses
46	Is there BRTS on cross roads at intersection
47	Junction Type
48	Cross Road traffic type
49	BRTS corridor Traffic Type
50	Bus Priority Signal
51	All Red phase for vehicles or dedicated pedestrian green phase
52	Jurisdiction of BRTS corridor
53	BRTS Corridor name
54	Begin point of BRTS corridor
55	End point of BRTS corridor
56	Number of segments in corridor length

Sr.No.	Default Variables Category (Editable)
1	Green phase for buses per direction without turning
2	Green phase for buses per direction turning phase (separate turning phase)
3	Minimum bus delay
4	Average bus acceleration
5	Average Bus Deceleration
6	Junction width
7	Minibus length
8	Urban Bus length
9	Articulated bus length
10	Bi articulated bus length
11	Gap between bus without overtaking
12	Gap between buse with overtaking
13	Ratio of turning buses as a proportion of total buses
14	Overtaking lane rule
15	Pedestrian Ramp gradient
16	Walking speed
17	Half Subway level difference
18	Full subway level difference
19	FOB level difference
20	Climb rate for Escalator
21	Climb rate for Ramps
22	Climb rate for steps
23	Gap between waiting buses
24	Minibus Capacity
25	Urban Bus Capacity
26	Articulated bus Capacity

27	Bi articulated bus Capacity
28	Distance of stop line from cross road edge
29	Trip1 - 0.5km from corridor - walk access
30	Trip2 - 1km from the corridor
31	Trip3 - 2km from corridor - walk access
32	Trip4 - 3km from corridor - walk access
33	Avg. crossing width of cross road, feeder road or spine hosting bus routes in open system, mixed condition
34	Average delay to find gap in vehicles for crossing side road
35	% inefficiency in bus signal priority
36	Desired signal cycle length for 2 phase signal
37	Maximum desirable signal cycle length
38	Min desirable signal cycle length for 4 arm BRT corridor
39	Maximum desirable signal cycle length for 3 artm junction
40	Minimum desirable signal cycle length for 3 arm junction
41	Maximum desirable signal cycle length for 2 arm or mid block junction
42	Minimum desirable signal cycle length for 2 arm or mid block junction
43	Avg. Per passenger time lost due to delay between platform and bus doors
44	Sum of average Distance of Pvt. Vehicle parking from Origin and destination
45	Total No. of Distinct routes using a segment in an open system

Result Categories

A. Crossing Distances:

1. Max. one way crossing distance
2. Min. one way crossing distance
3. Average crossing distance
4. Total crossing distance

B. Corridor Travel Time and Speeds:

10. BRT operational speed (Expected Average Bus Speed in the System)
11. Passenger speed with BRT
12. Passenger walking distance
13. Overall origin to destination journey time for averaged motorized trip length
14. Total average access time
15. Total average in vehicle time (main line/route)
16. Per bus station/junction time segregated lanes
17. Per bus delay per station/midblock - segregated lanes
18. Total average passenger delay to access station in a round trip

C. Corridor Throughputs:

1. Corridor PPHPDT
2. Corridor Bus Throughput (Max frequency)
3. Junction Bus throughput

4. Station Bus Throughput (separate from junction for mid block station)
5. User input - buses per hour per direction

D. Bus Shelter Length:

1. Bus shelter length without ramp
2. Bus shelter length with ramp at one entrance

E. Comparison:

5. Time saved by BRT over Private Transport
6. Avg. passenger speed with buses without BRT
7. Time saved by BRT over mixed condition bus
8. Daily bus passenger hours saved

F. Signal Cycle:

1. Junction signal cycle length
2. Junction signal phases
3. No. Of phases
4. Pedestrian only phase
5. Pedestrian phase length
6. User defined signal cycle
7. Junction is grade separated or not

G. Proposed Cross Section (From LHS to RHS)

1. Edge Footpath
2. Service Lane
3. Unpaved
4. Footpath
5. Tree Belt
6. Cycle Track
7. Segregator
8. Parking
9. Carriageway
10. Turning Pocket
11. Bus Shelter 1
12. Bus Lane (Boarding 1)
13. Bus Shelter 2
14. Bus Lane (Boarding 2)
15. Central Island
16. Bus Lane
17. Median
18. Turning Pocket
19. Carriageway
20. Parking Segregator
21. Cycle Track
22. Tree Belt
23. Footpath

24. Unpaved
25. Service Lane
26. Edge Footpath

Annexure 4: Boarding Alighting Survey Data

Data for buses with three steps:

Bus type	Door	No. of Steps	Time in Sec		No. of passengers	Boarding or Alighting	Average Per Pass. Time in Sec
			Rear Door	Front Door			
DTC H	Open	3	4		1	down	4
DTC H	Open	3		12	6	down	2
DTC H	Open	3		5	2	down	2.5
DTC H	Open	3		8	3	up	2.66666667
DTC H	Open	3	11		5	up	2.2
DTC H	Open	3		9	6	down	1.5
DTC H	Open	3	6		4	down	1.5
DTC H	Open	3		1	1	down	1

Data for buses with level boarding

Bus type	Door	No. of Steps	Time in Sec		No. of passengers	Boarding or Alighting	Average Per Pass. Time in Sec
			Rear Door	Front Door			
DTC L	Closed			5	3	down	1.666667
Orange	Closed			3	2	down	1.5
DTC L	Closed			15	8	down	1.875
Orange	Closed		8		4	down	2
DTC L	Closed		6		4	down	1.5
Orange	Closed		9		5	down	1.8
DTC L	Closed			3	1	down	3
DTC L	Closed			3	2	down	1.5
DTC L	Closed			5	4	down	1.25
DTC L	Closed			5	3	down	1.666667
Orange	Closed		6		3	up	2
Orange	Closed			10	6	down	1.666667
DTC L	Closed			8	6	down	1.333333
DTC L	Closed			10	8	down	1.25
DTC L	Closed			9	7	down	1.28571

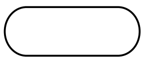
Bus type	Door	No. of Steps	Time in Sec		No. of passengers	Boarding or Alighting	Average Per Pass. Time in Sec
			Rear Door	Front Door			
							4
DTC L	Closed			2	1	down	2
Orange	Closed		7		3	up	2.333333
DTC L	Closed			6	3	down	2
DTC L	Closed		5		4	down	1.25
Orange	Closed			5	6	down	0.833333
DTC L	Closed			3	2	down	1.5
DTC L	Closed			9	7	down	1.285714
DTC L	Closed		3		3	down	1
DTC L	Closed		5		2	up	2.5

Annexure 5: Flow Charts for Important Processes used in the BEAD Tool

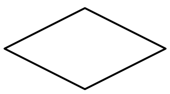
The following pages present flow diagrams of some of the processes used in the BEAD Tool. The symbols used in the diagram are as following:

Process

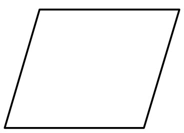
Alternate Process



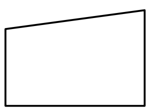
Terminator



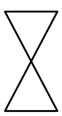
Decision



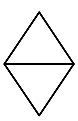
Data



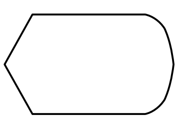
Manual Input



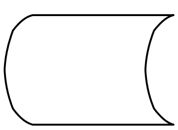
Collate



Sort



Display



Stored Data

Figure 21 – Process 1: Journey time for average trip in the city, in mins

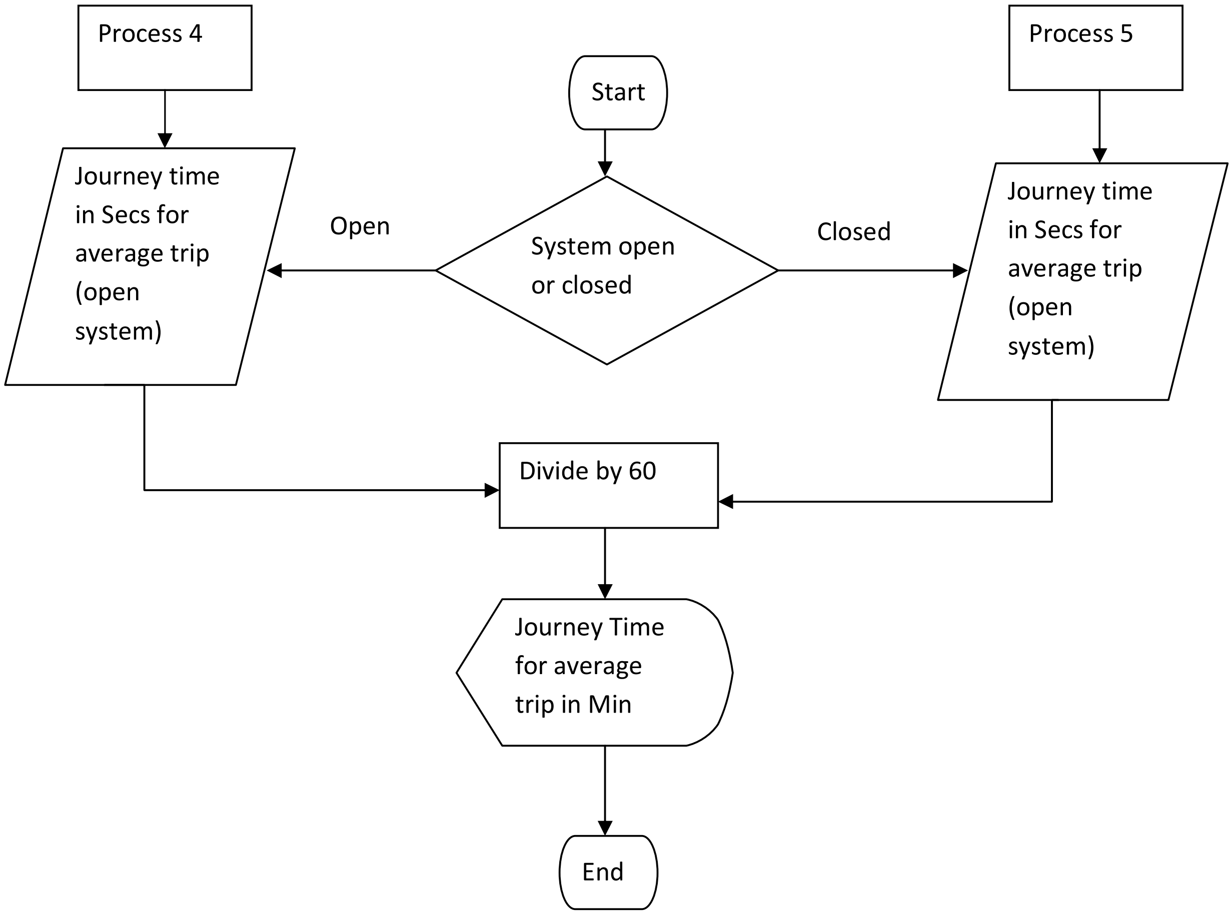


Figure 22 – Process 2: Determining average bus speed in the BRTS corridor

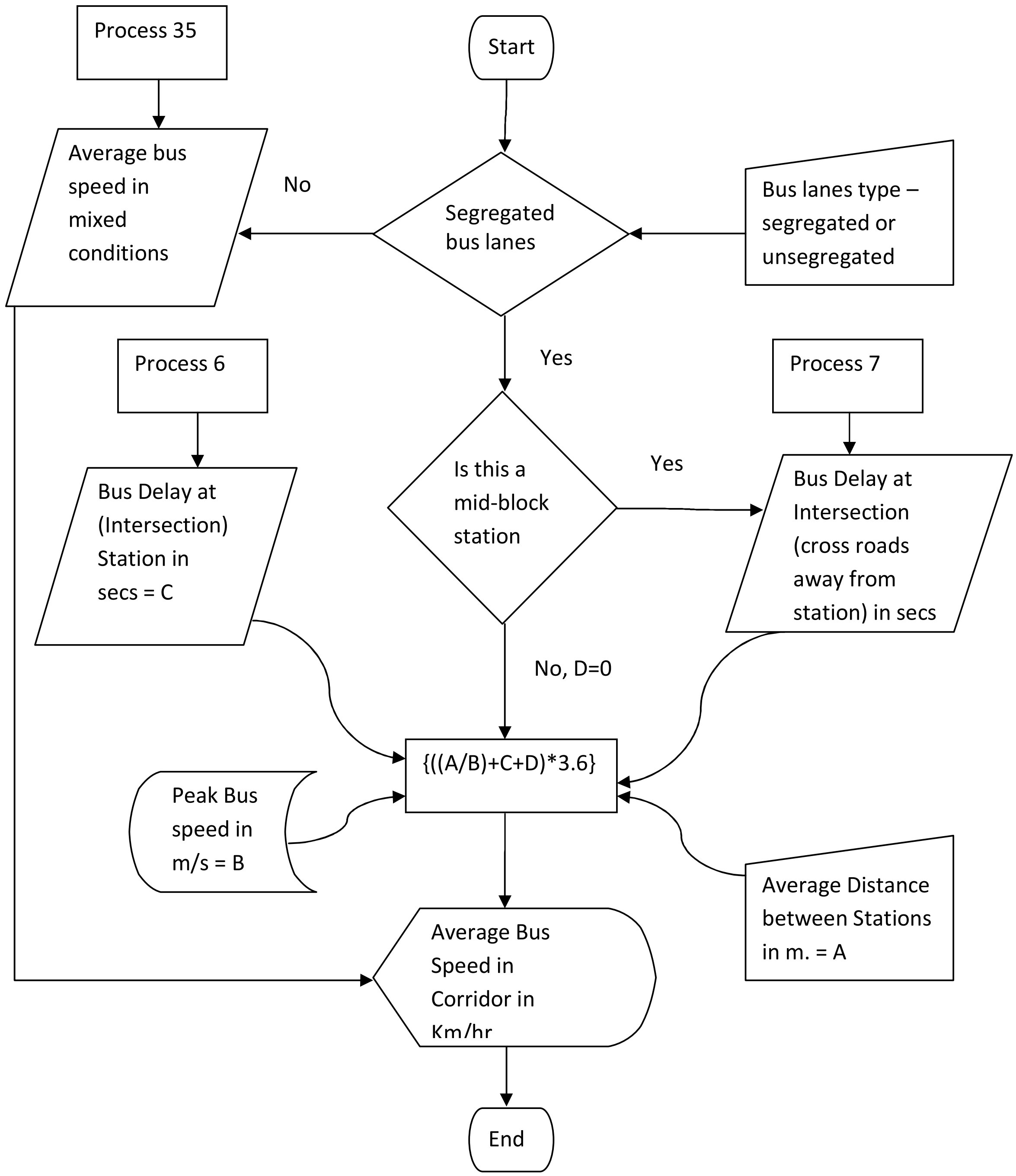


Figure 23 – Process 3: Determining Capacity of the BRTS Corridor/Segment

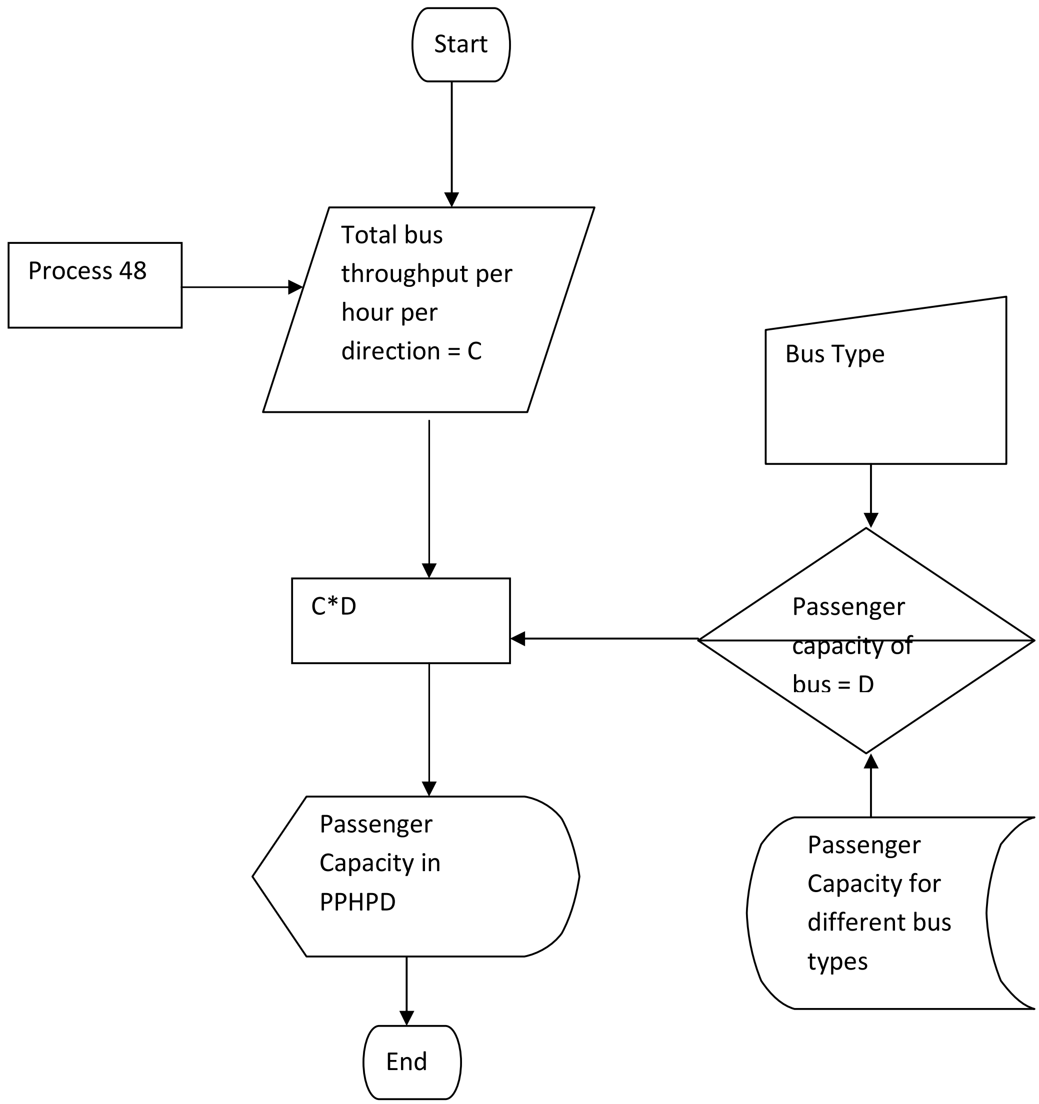


Figure 24: Process 4 – Journey time in secs for average trip in open system

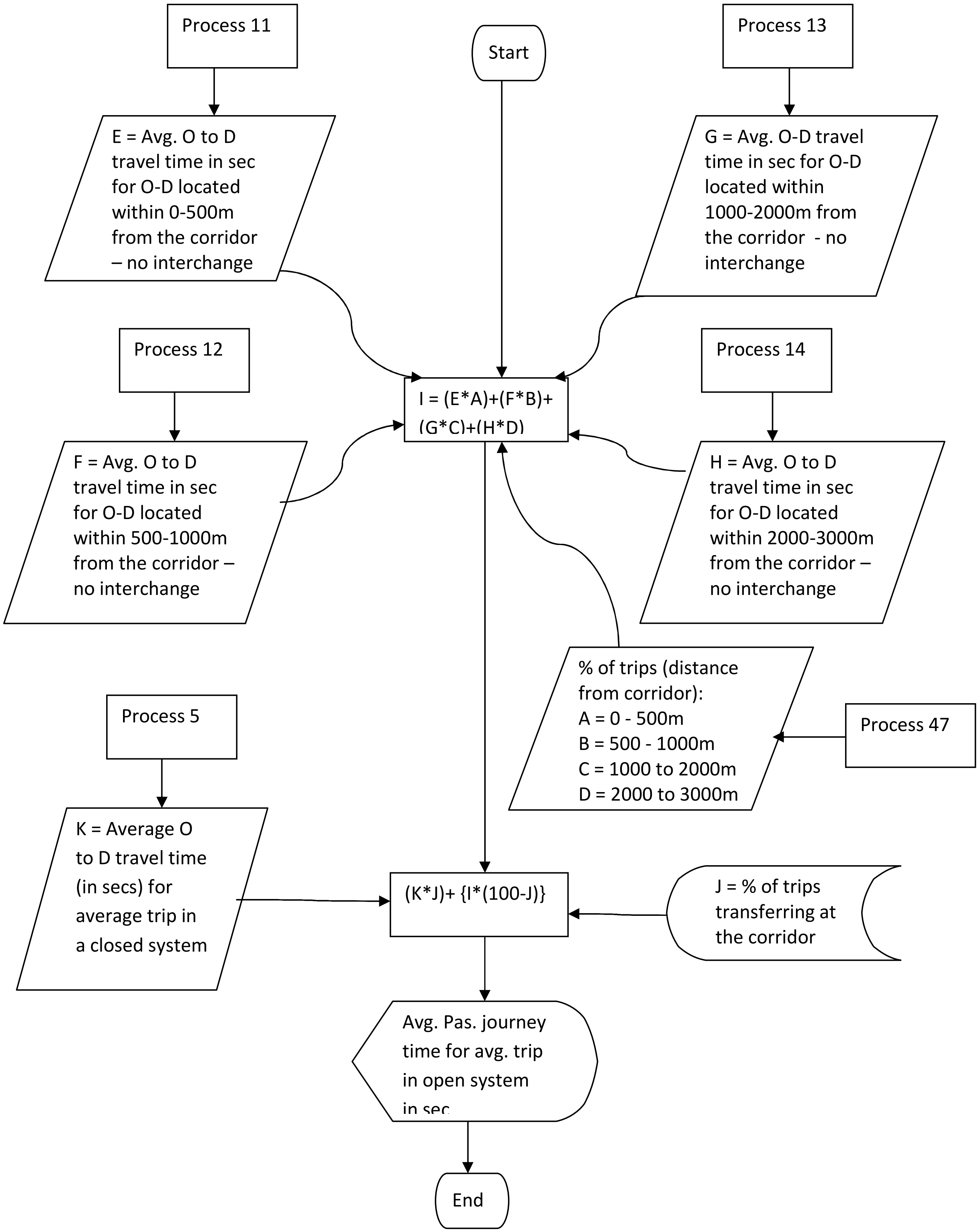


Figure 25 – Process 5 – Average journey time in secs for average trip length in a closed system

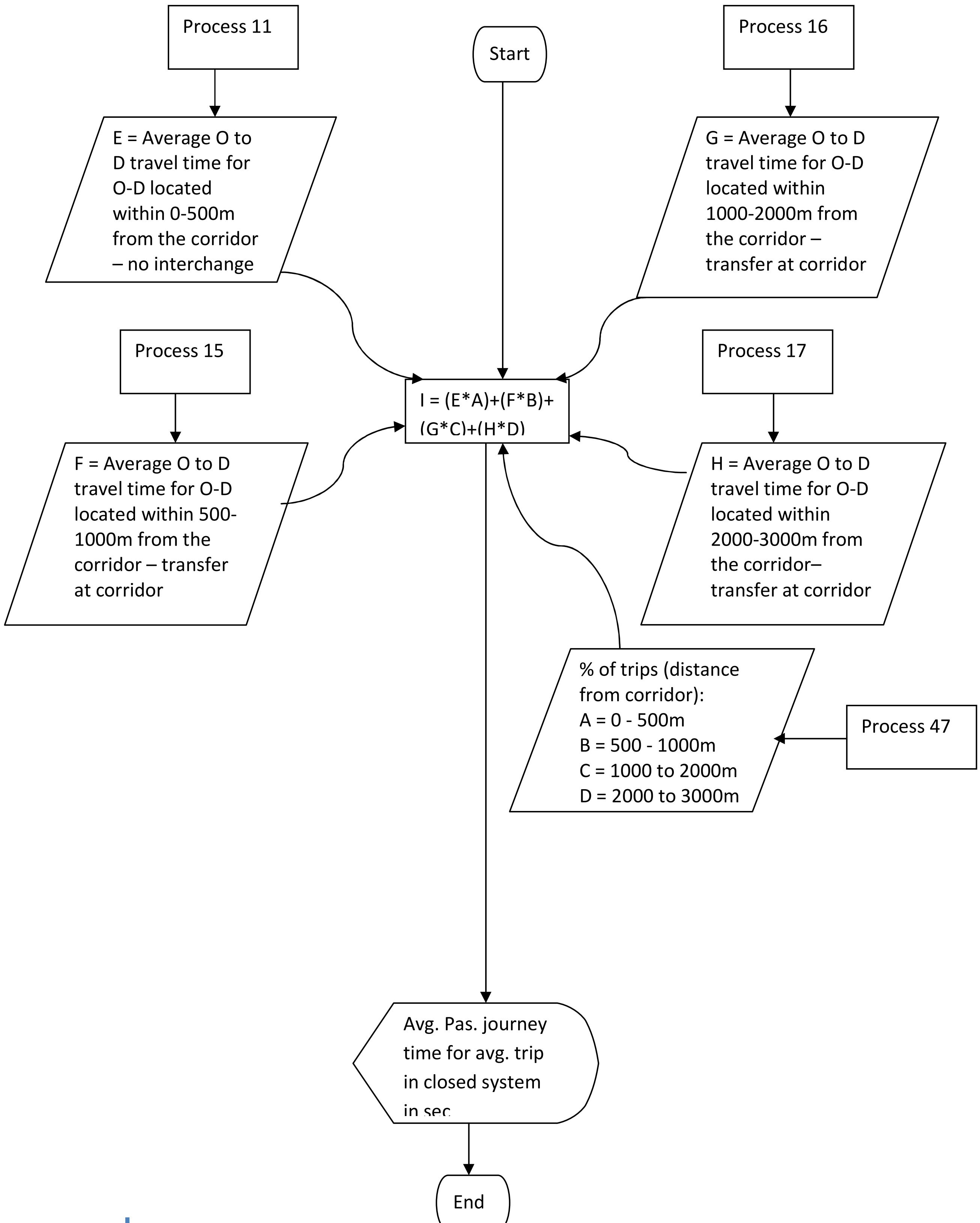


Figure 26 – Process 6: Bus delay at stations including signal delay (pedestrian signal delay at mid block stations)

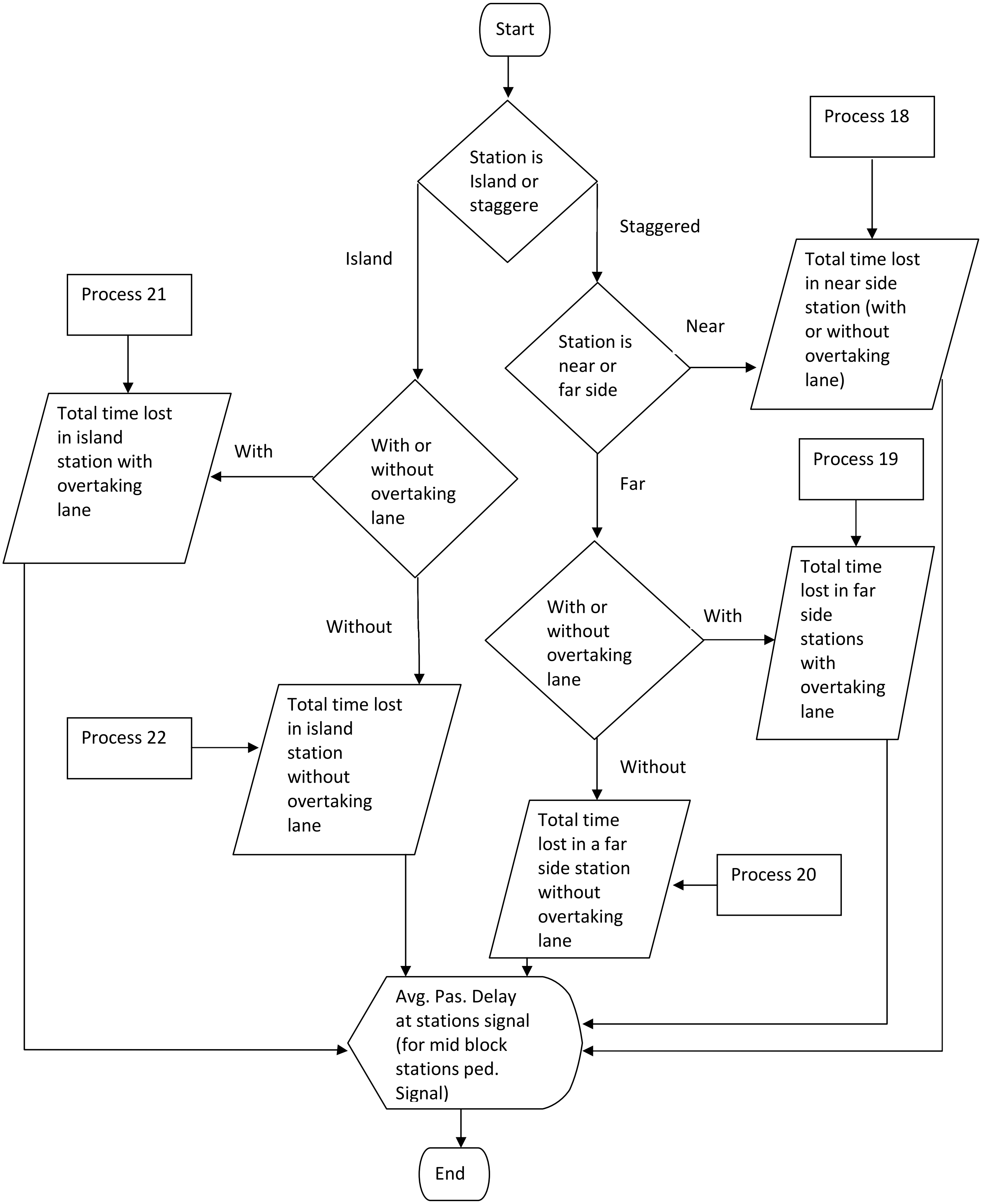


Figure 27 – Process 7: Bus delay at intersection (cross roads) on corridors with mid block stations

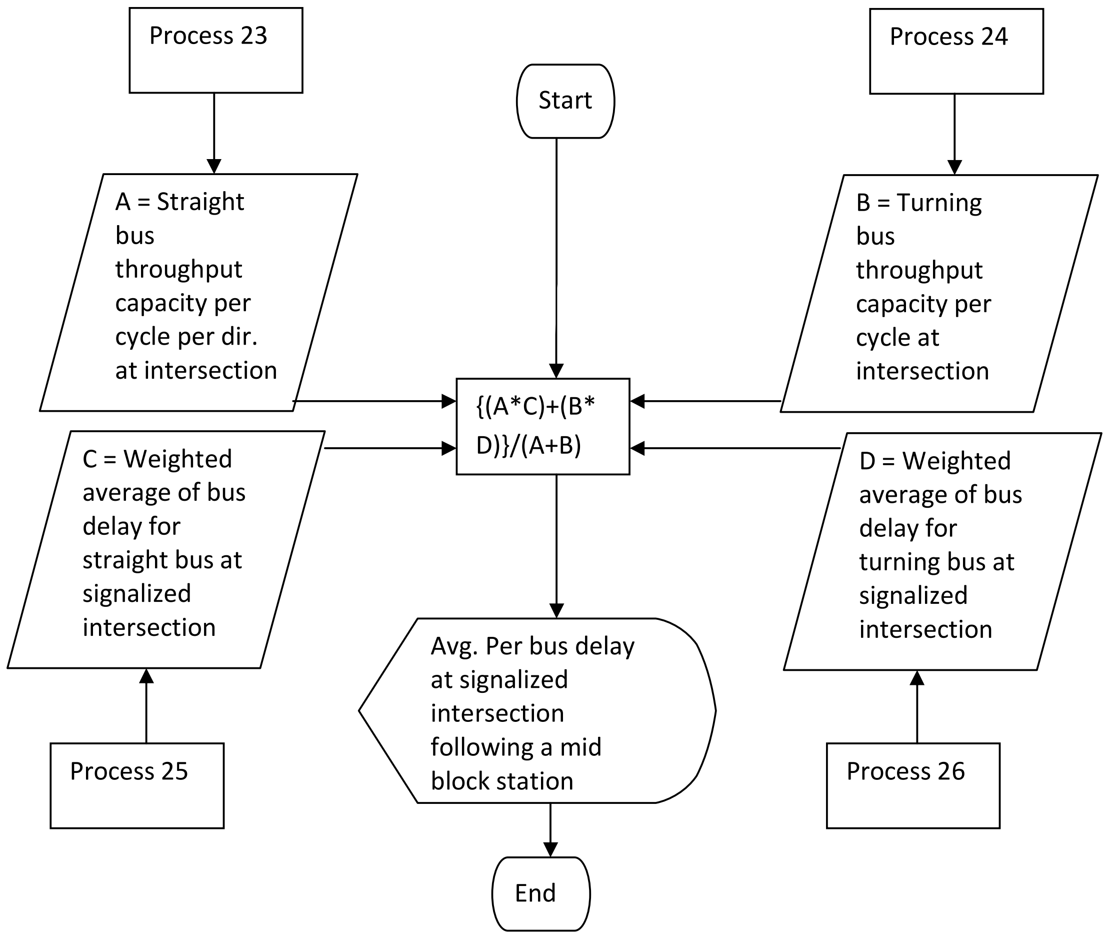


Figure 28: Flow chart for Process 8 - Bus throughput per signal cycle per direction from station including intersections throughput for junction stations (roundabout or signalized).

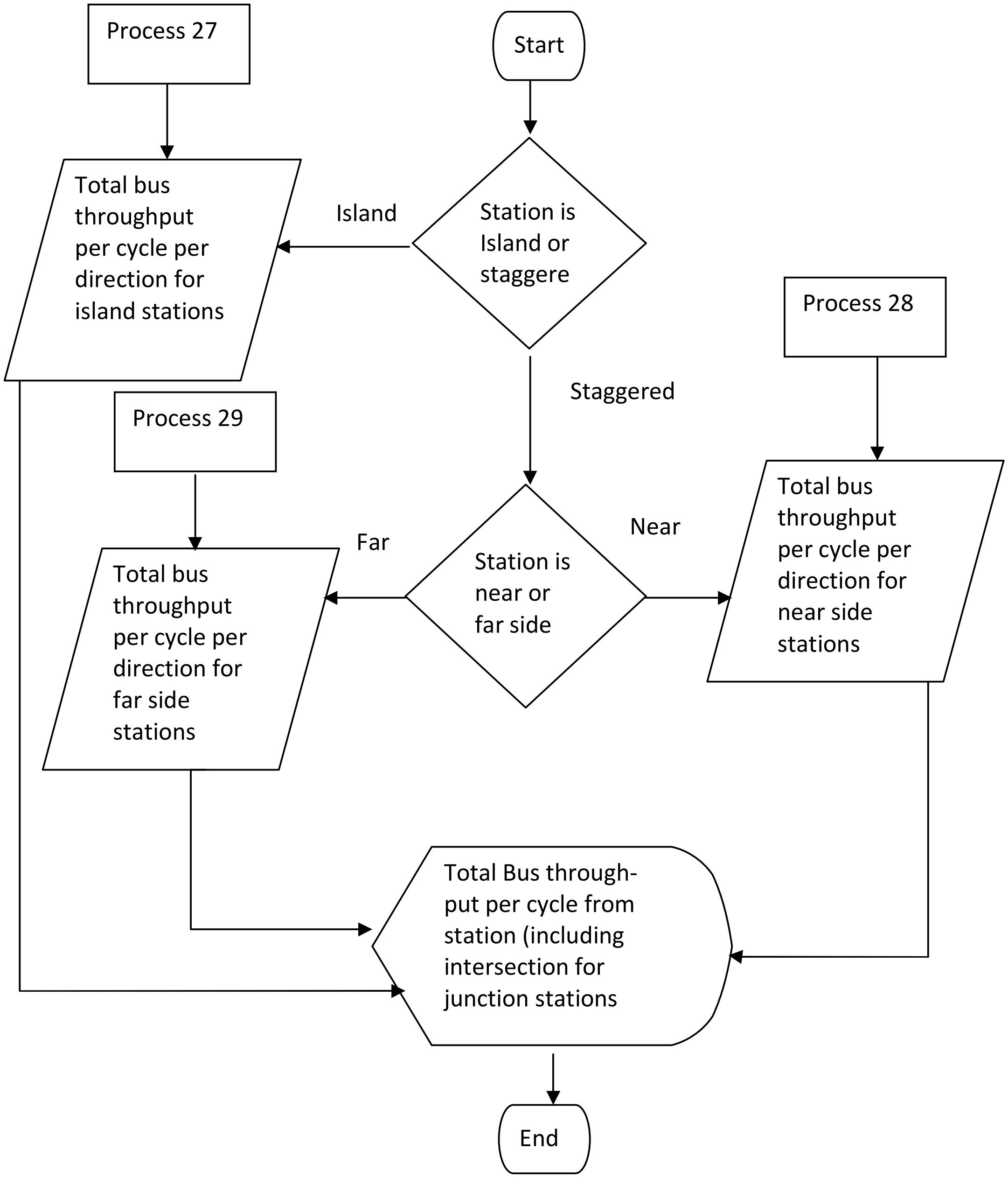


Figure 29: Flow chart for Process 9 - Total Buses Throughput per signal cycle per direction from intersection (for mid block station)

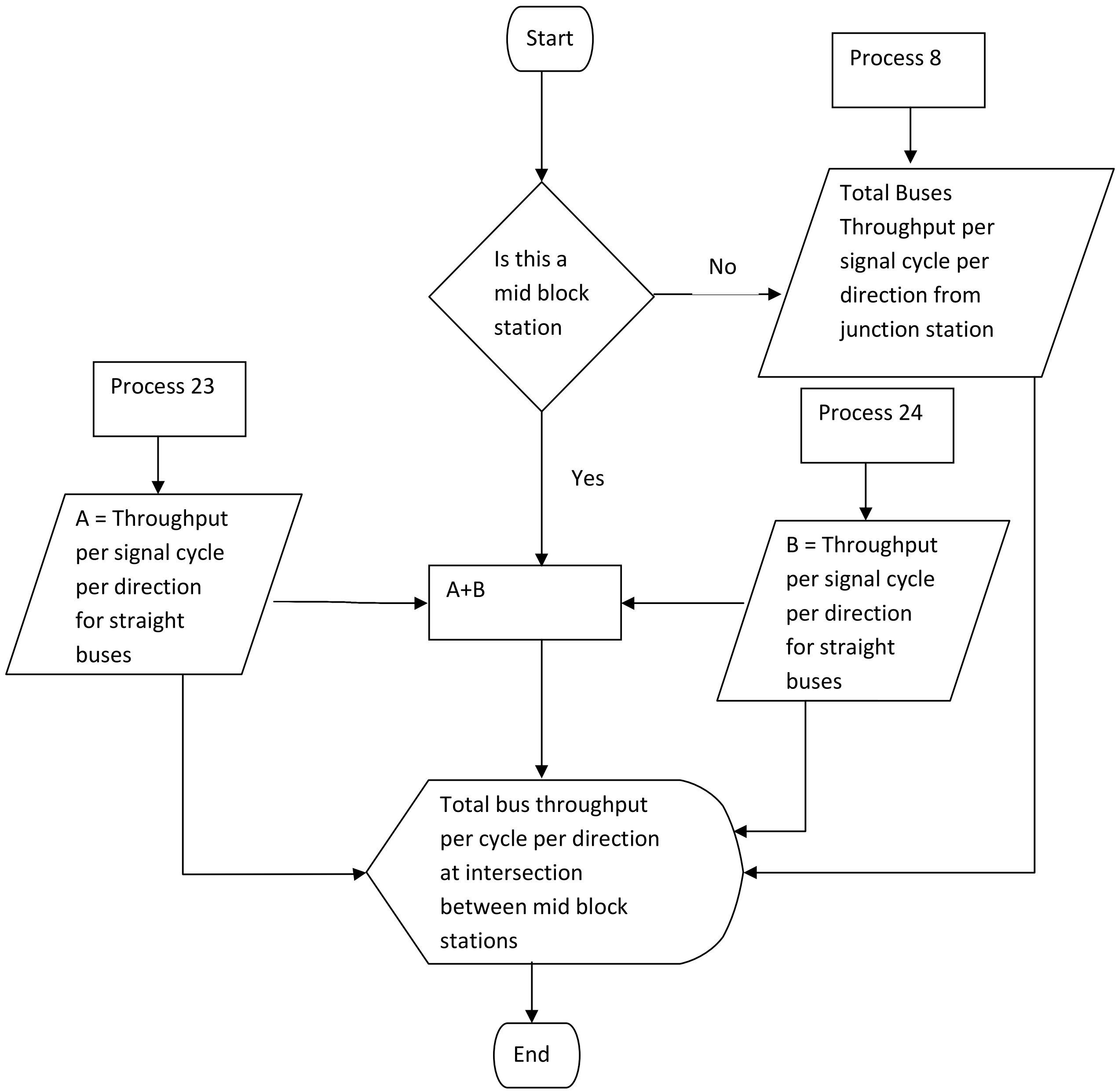


Figure 30: Flow chart for Process 10 – Signal cycle length in secs at intersection.

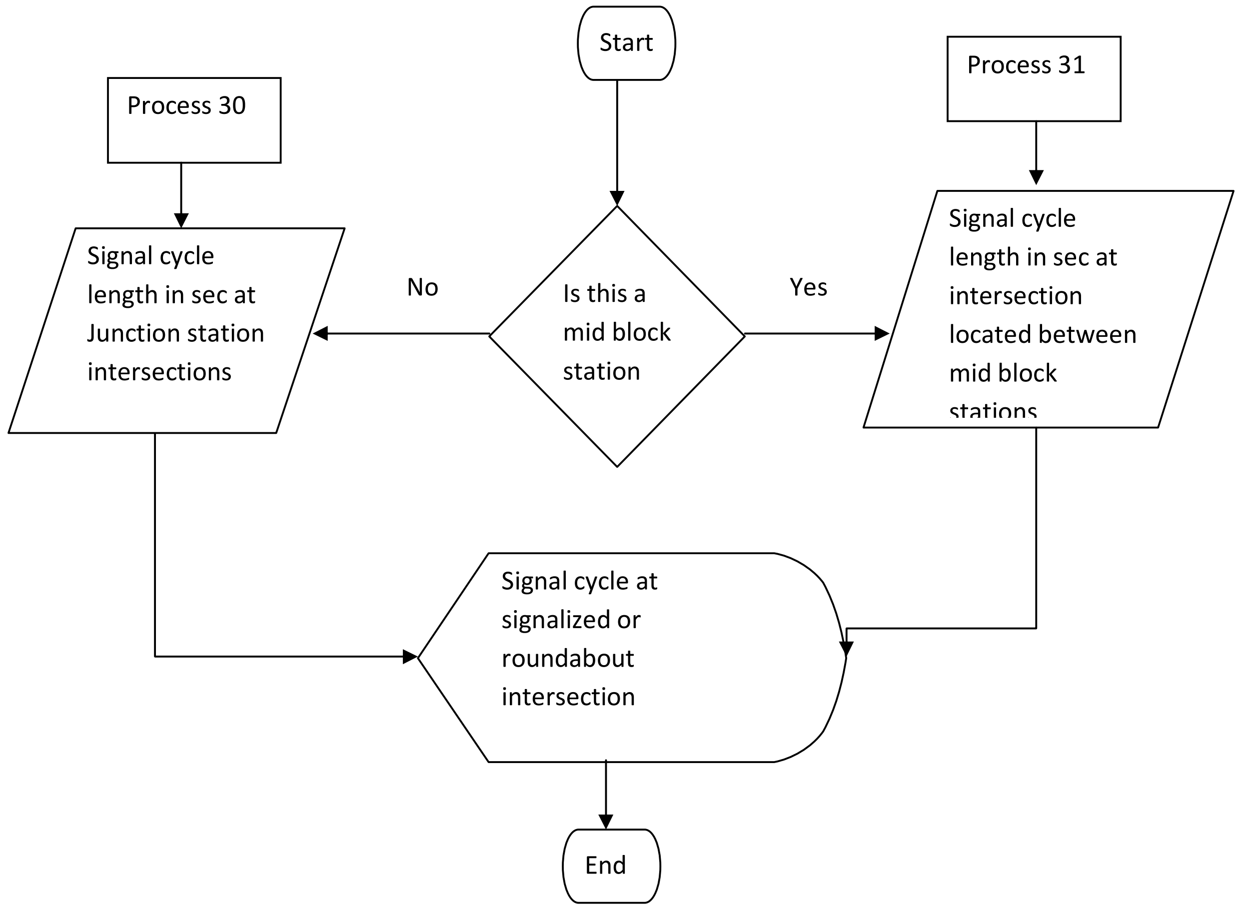


Figure 31: Flowchart for Process 11 - Average O to D travel time for O-D located within 0-500m from the corridor – no interchange (in an open or closed system)

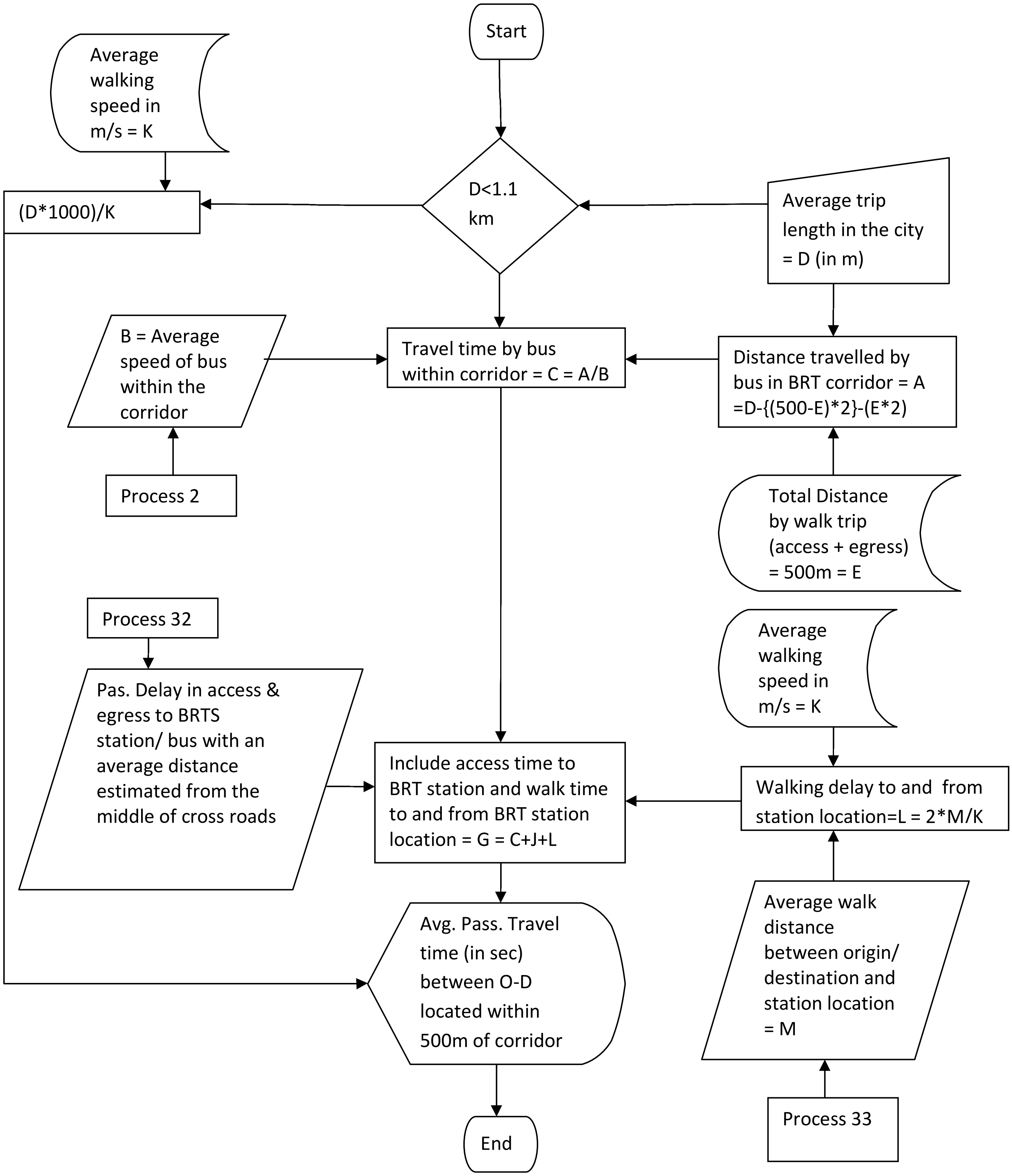


Figure 32: Flowchart for process 12 – Average O to D travel time for O-D located within 500-1000m from the corridor – no interchange (in an open system)

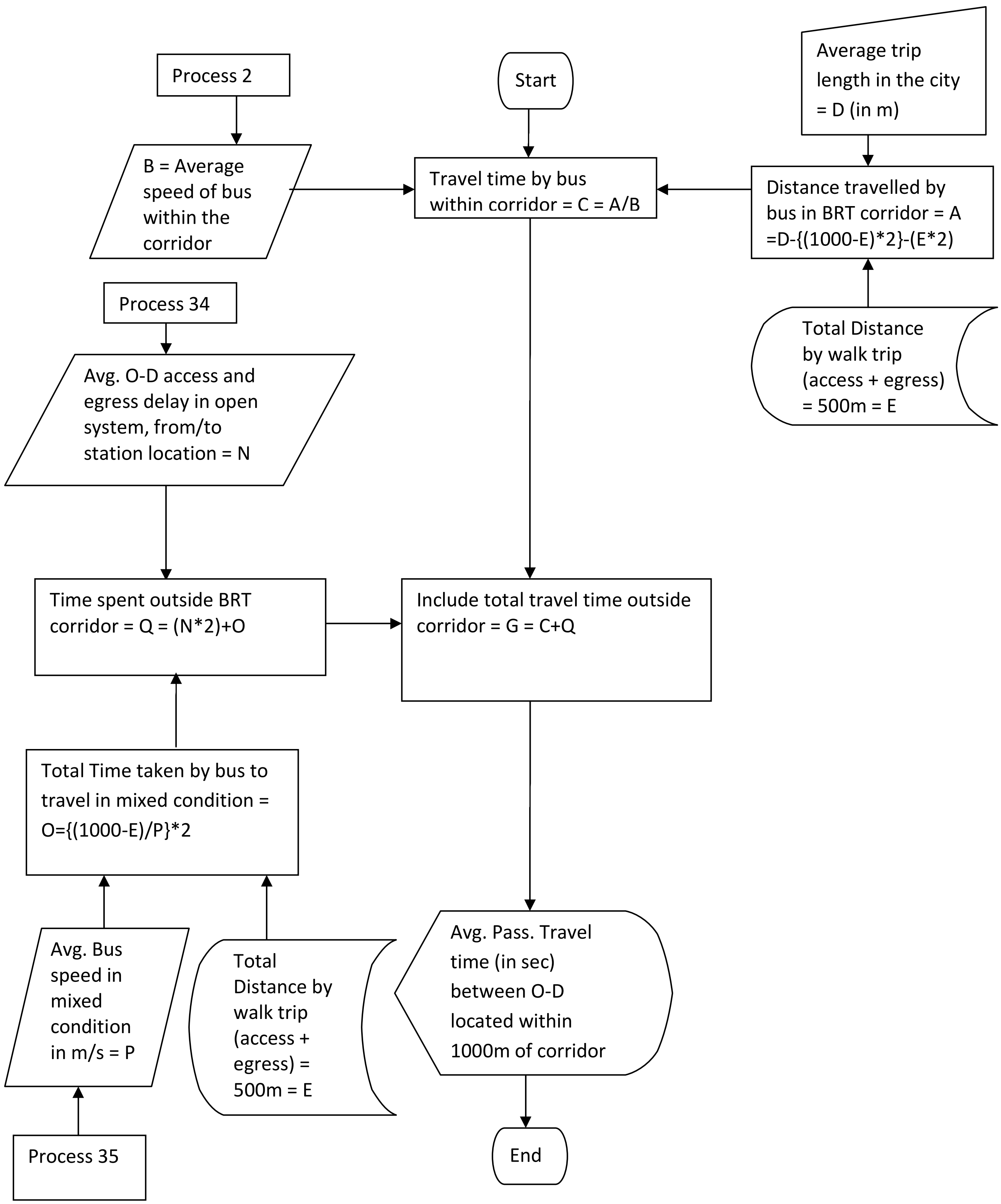


Figure 33: Flowchart for process 13 – Average O to D travel time for O-D located within 1000-2000m from the corridor – no interchange (in an open system)

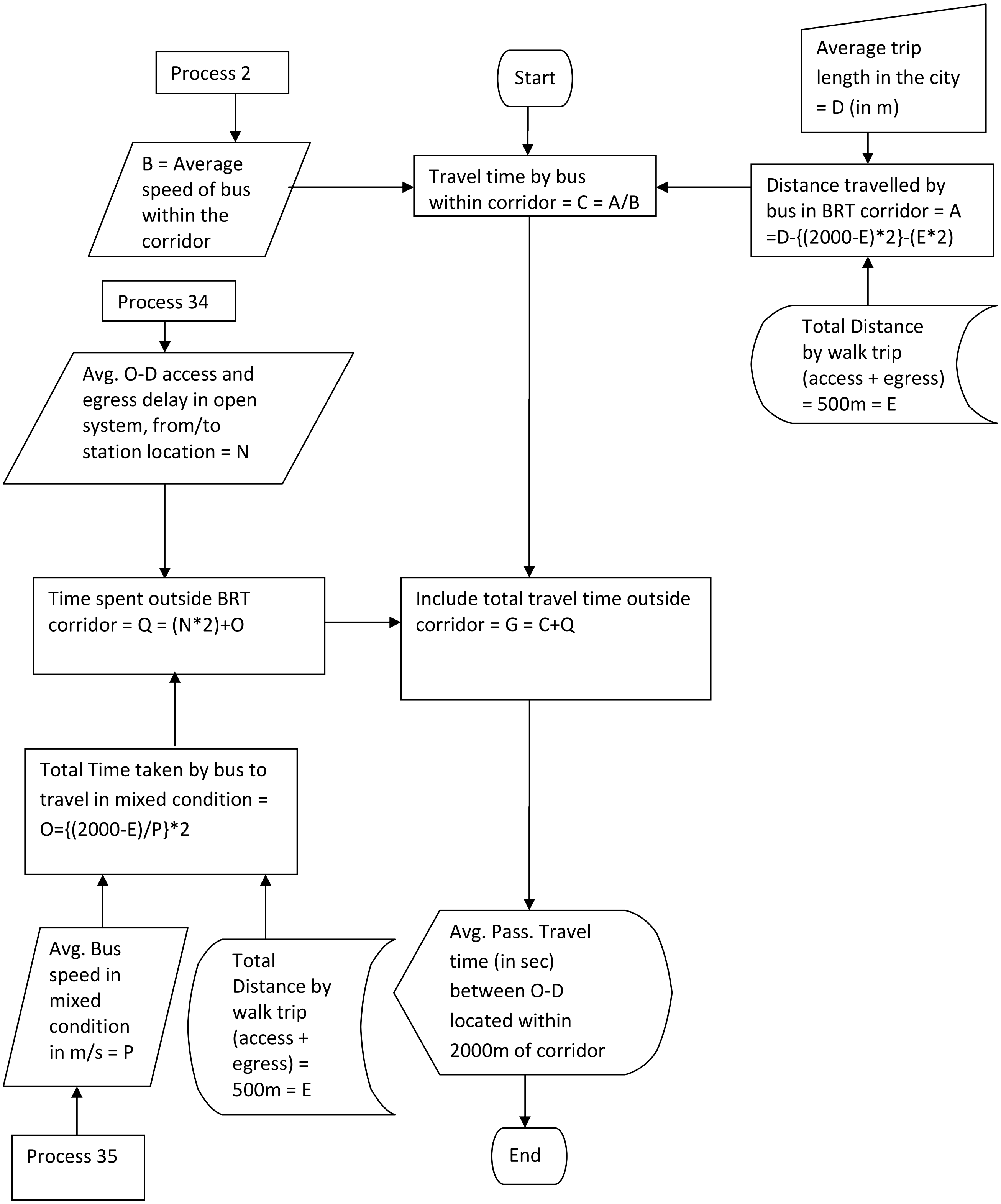


Figure 34: Flowchart for process 14 – Average O to D travel time for O-D located within 2000-3000m from the corridor – no interchange (in an open system)

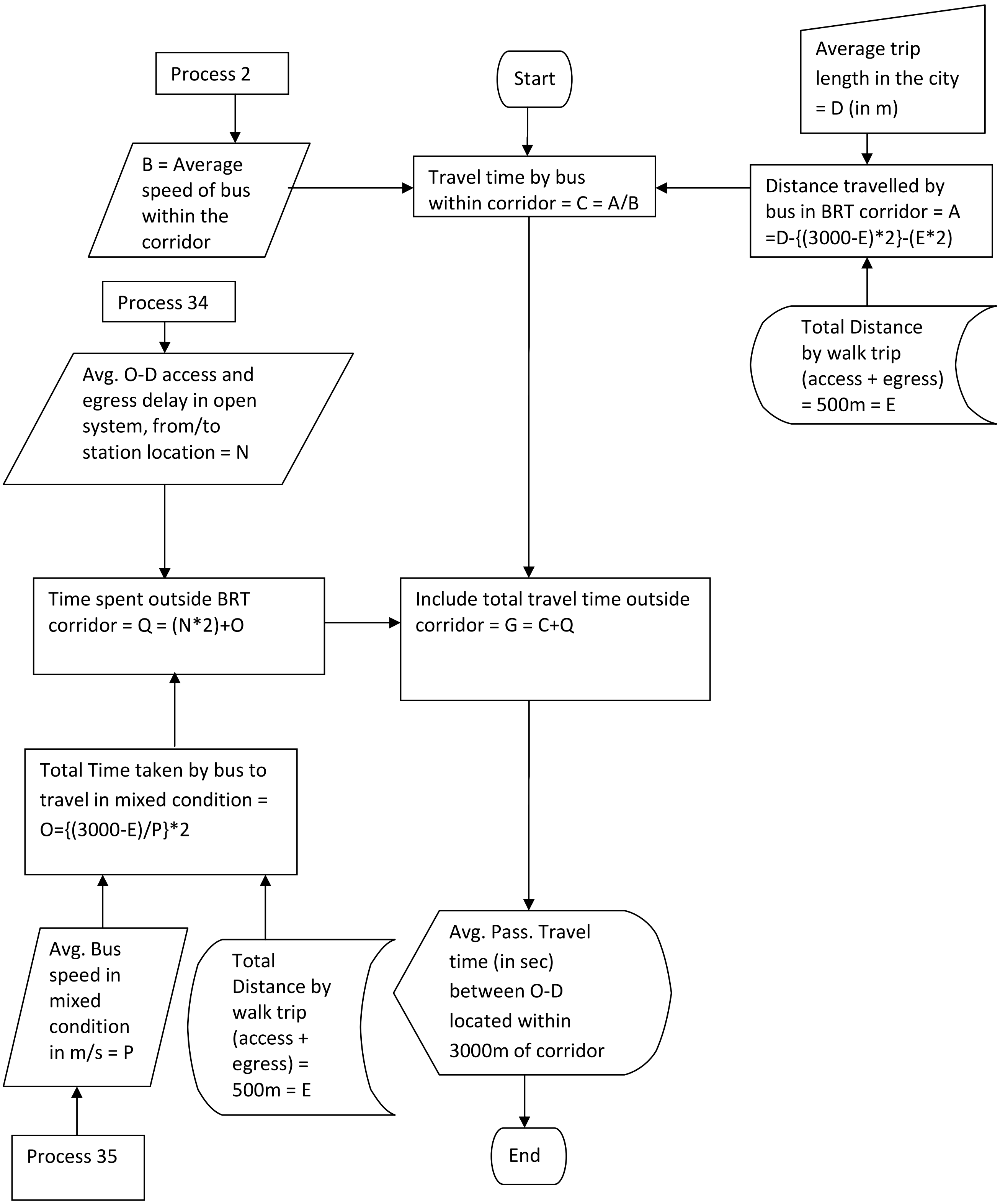


Figure 35: Flowchart for Process 15 - Average O to D travel time for O-D located within 500-1000m from the corridor in a closed system

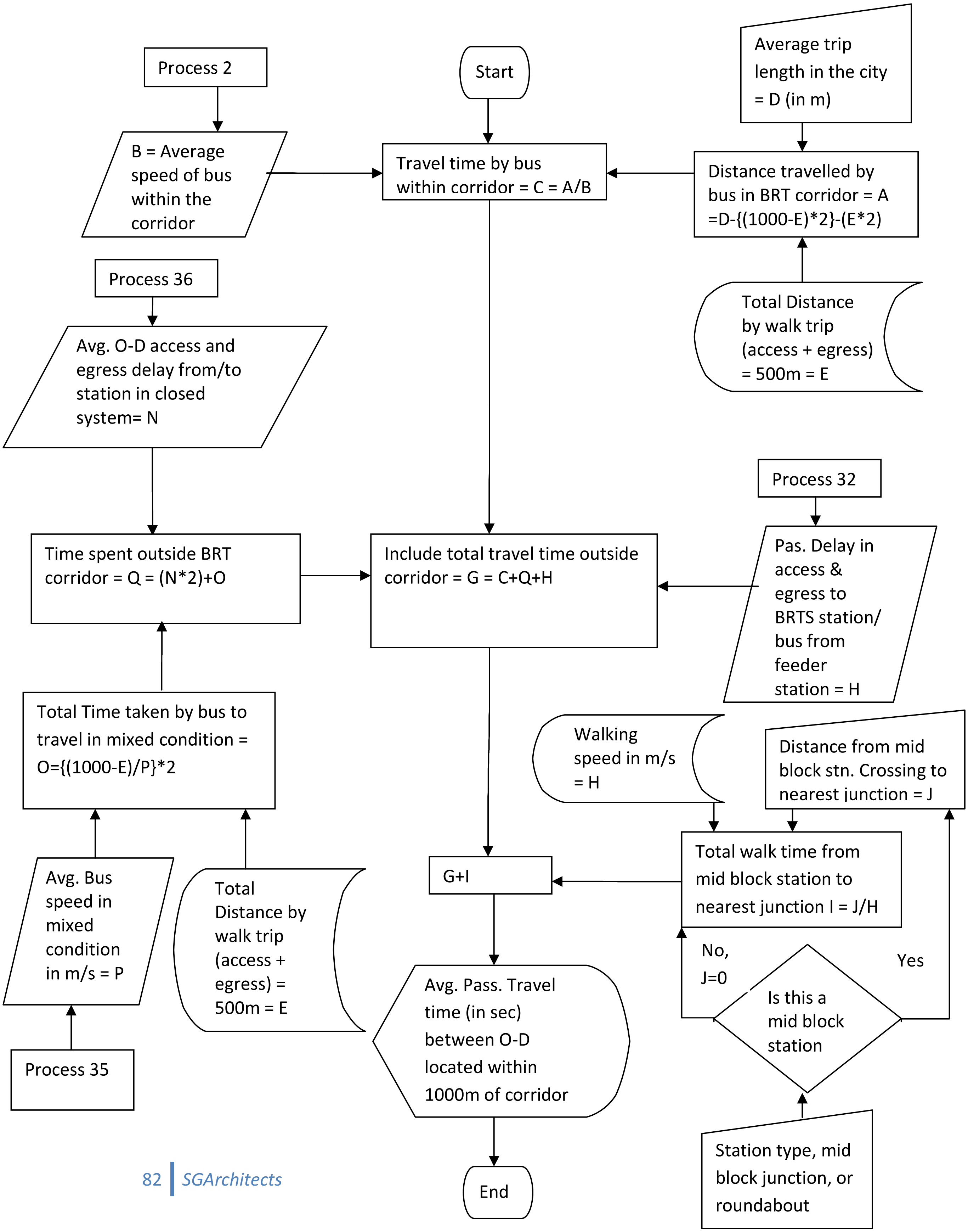


Figure 36: Flowchart for Process 16 - Average O to D travel time for O-D located within 1000-2000m from the corridor in a closed system

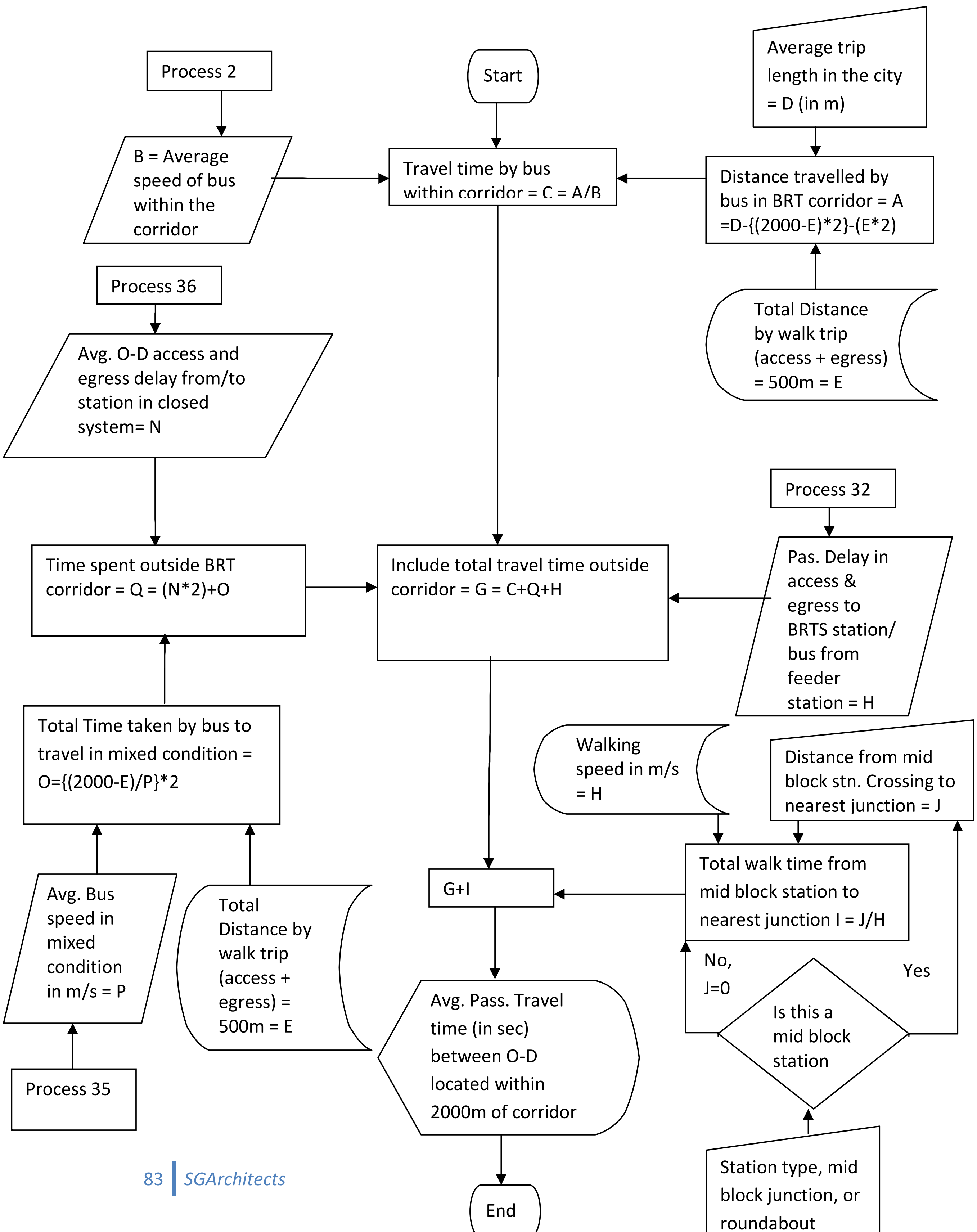


Figure 37: Flowchart for Process 17 - Average O to D travel time for O-D located within 2000-3000m from the corridor in a closed system

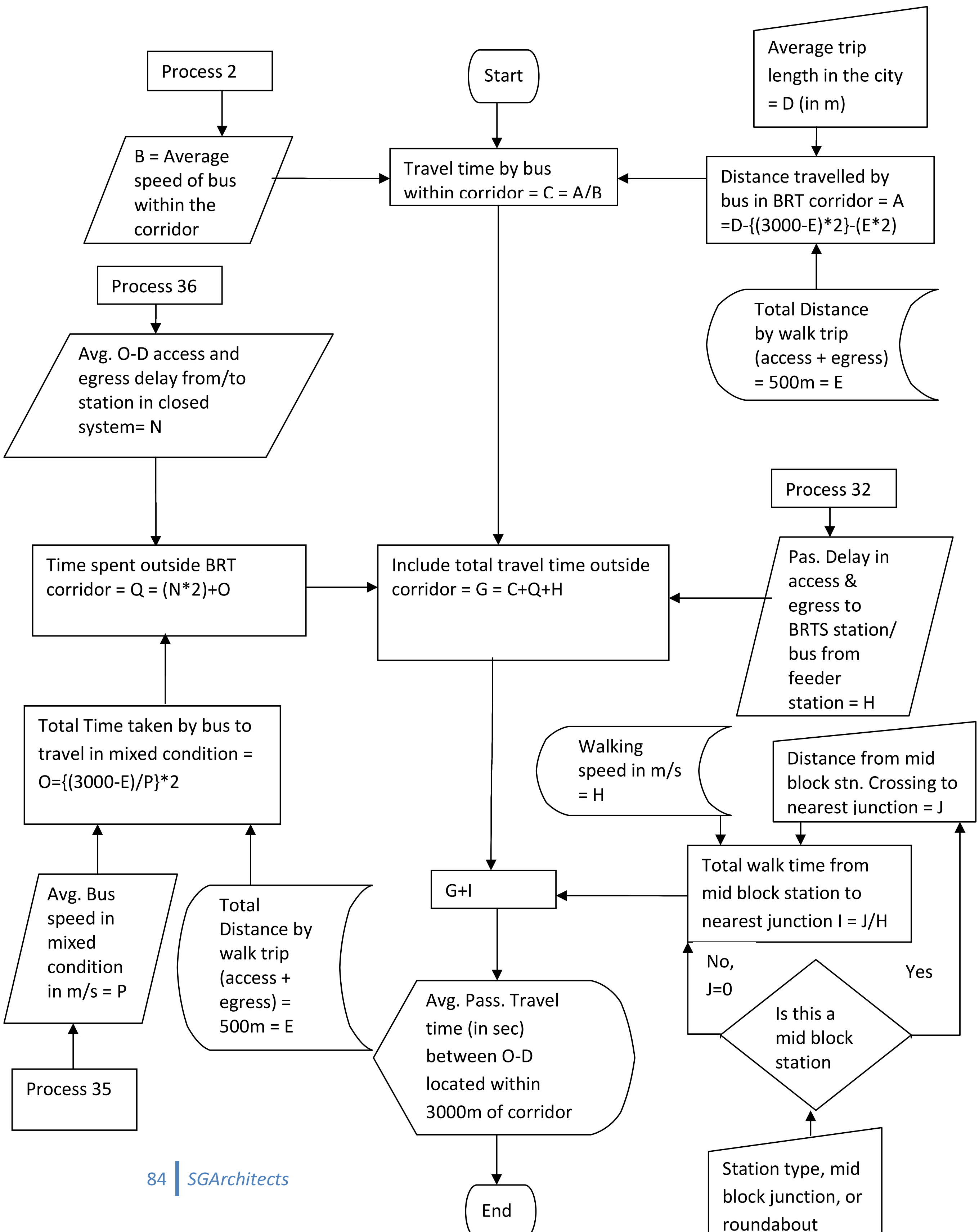


Figure 38: Flow chart for Process 18 - Average per bus delay at near side (staggered) junction stations (including junction delay) in secs (with or without overtaking lane)

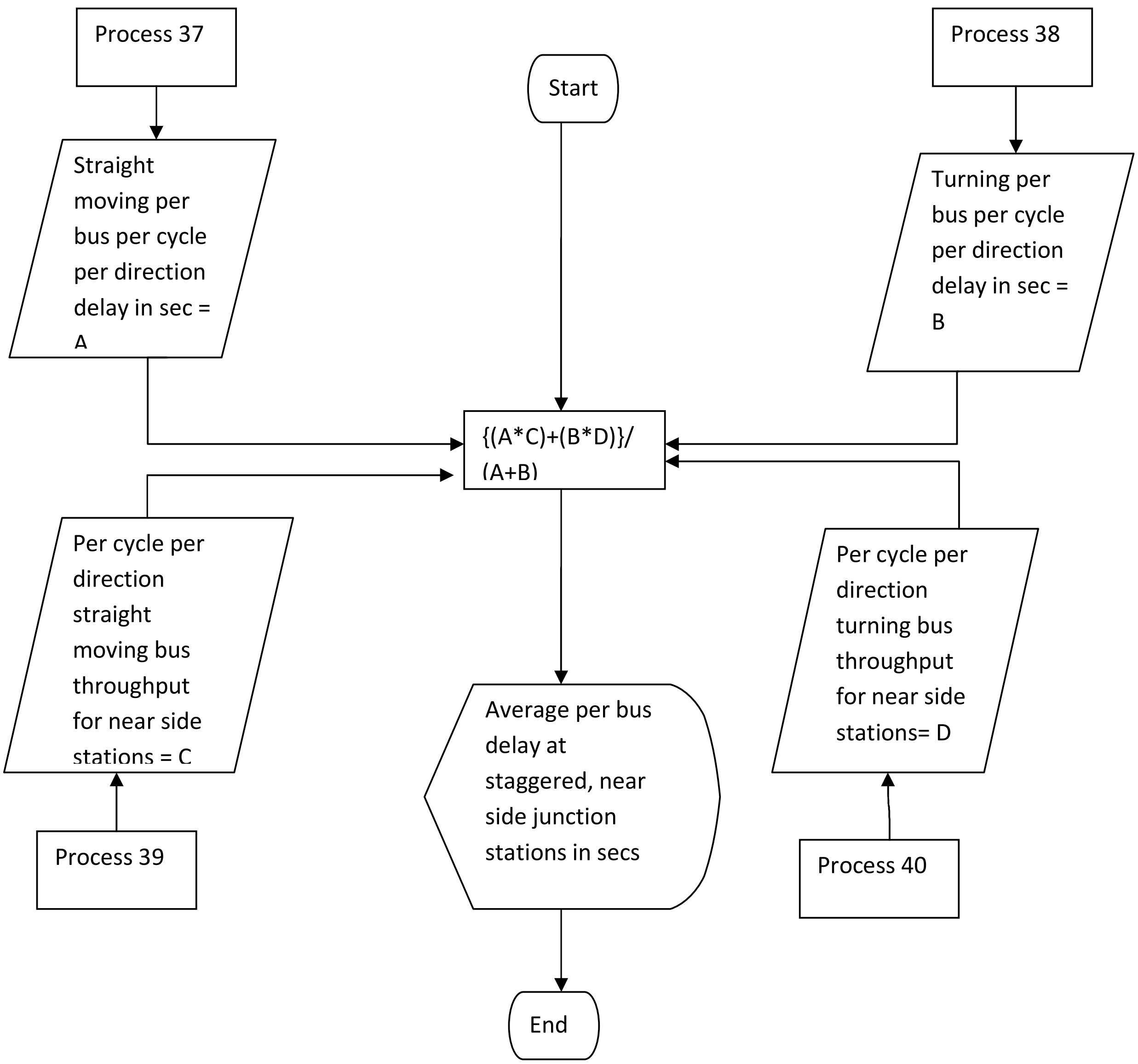


Figure 39: Flow chart for Process 19 - Average per bus delay at far side (staggered) junction stations (including junction delay) in secs (with overtaking lane)

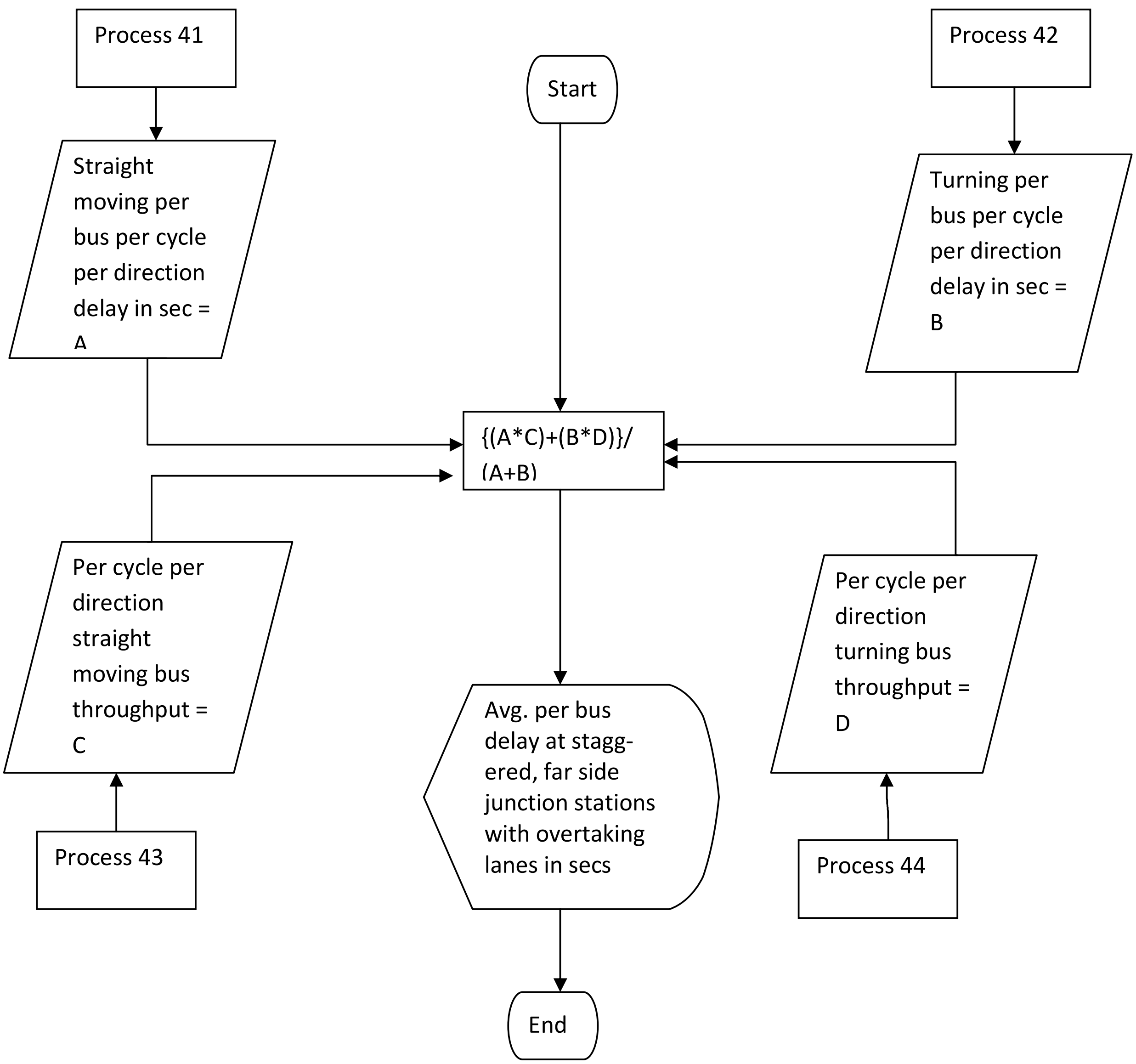


Figure 40: Flow chart for Process 20 - Average per bus delay at far side (staggered) junction stations (including junction delay) in secs (without overtaking lane)

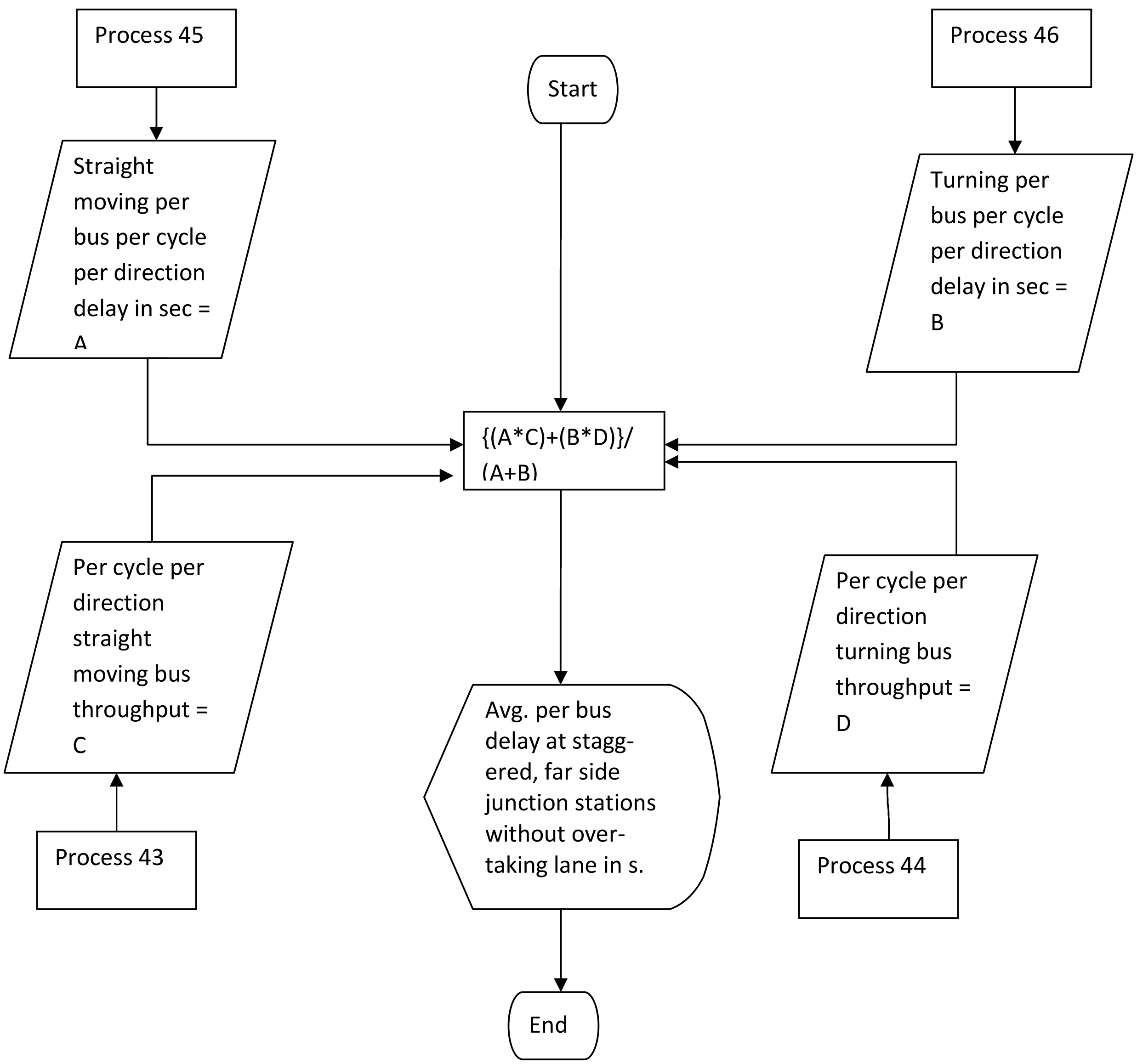


Figure 41: Flow chart for Process 21 - Average per bus delay at Junction Island stations with overtaking lane

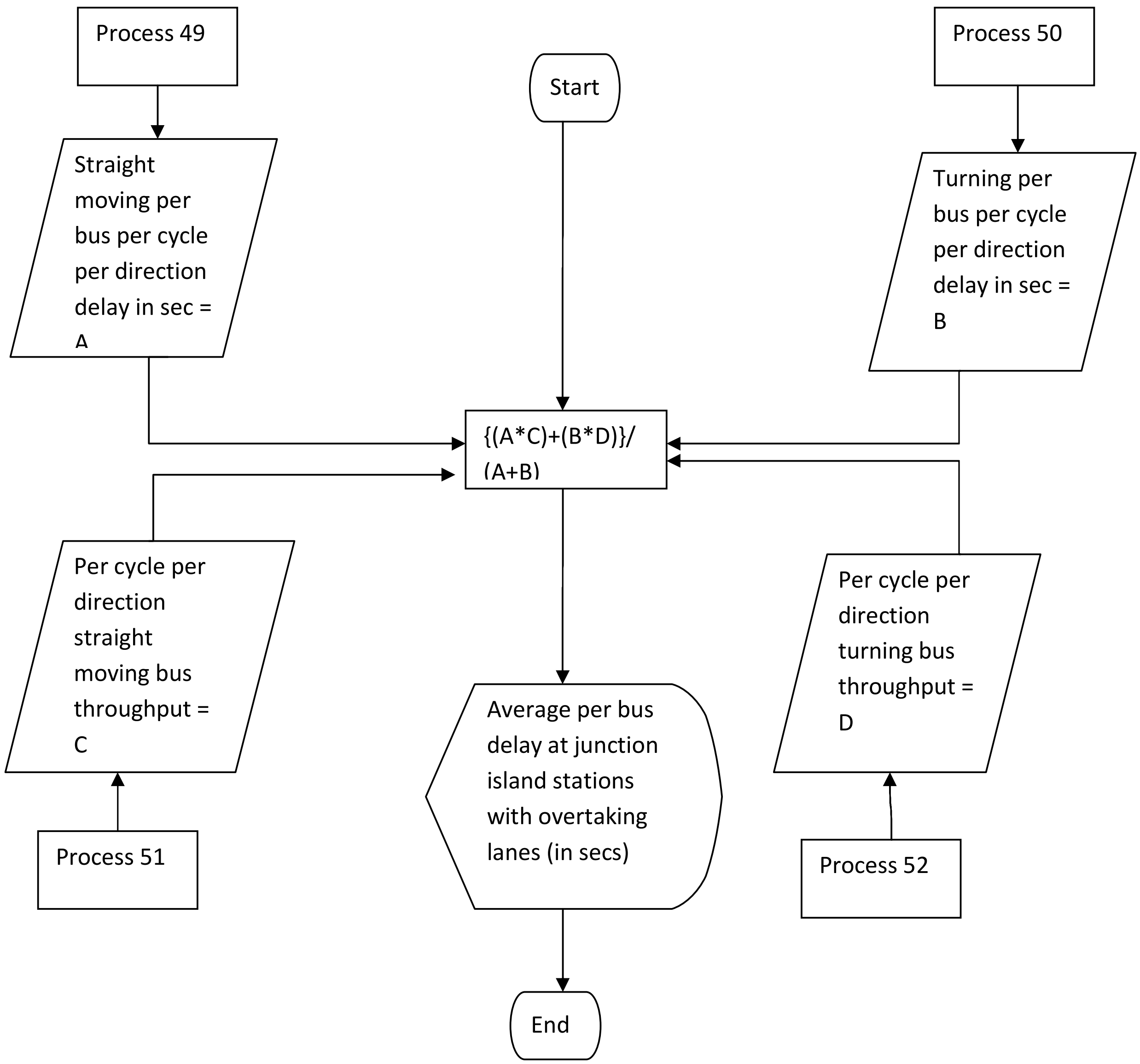


Figure 42: Flow chart for Process 22 - Average per bus delay at Junction Island stations without overtaking lane

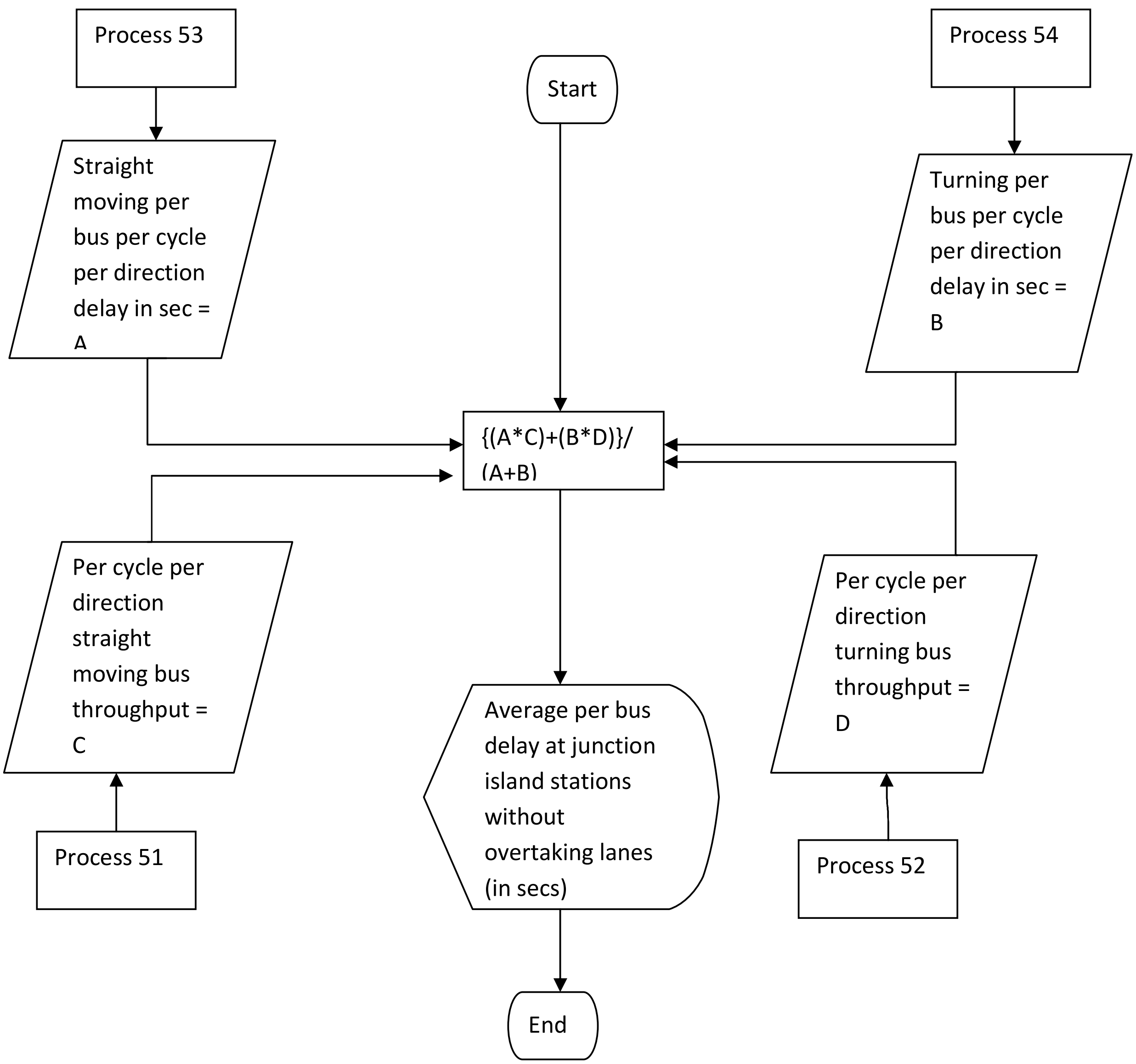


Figure 43: Flowchart for process 23 – Straight bus throughput per cycle per direction at intersections (between mid block stations).

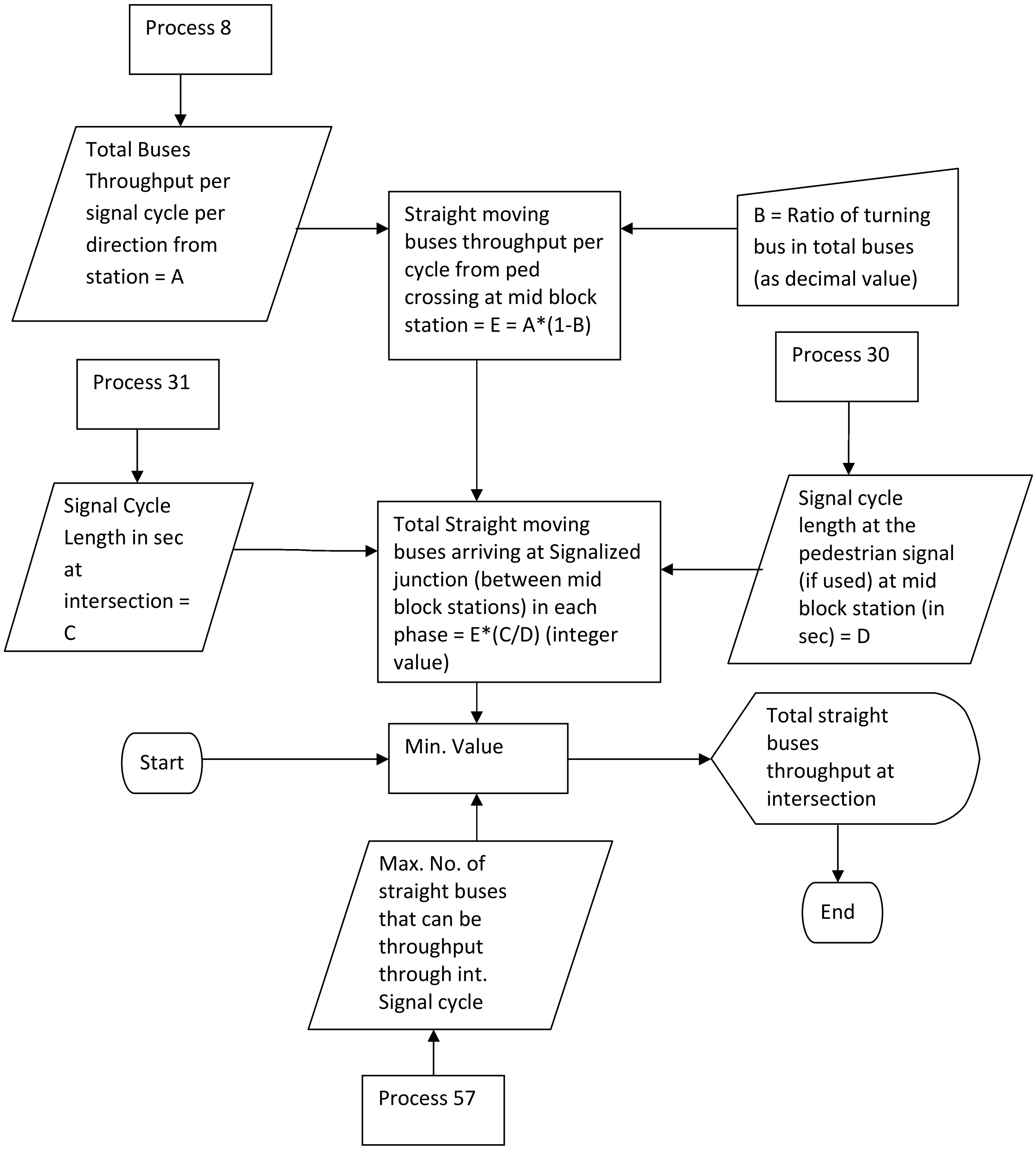


Figure 44: Flowchart for process 24 – Turning bus throughput per cycle per direction at intersections (between mid block stations).

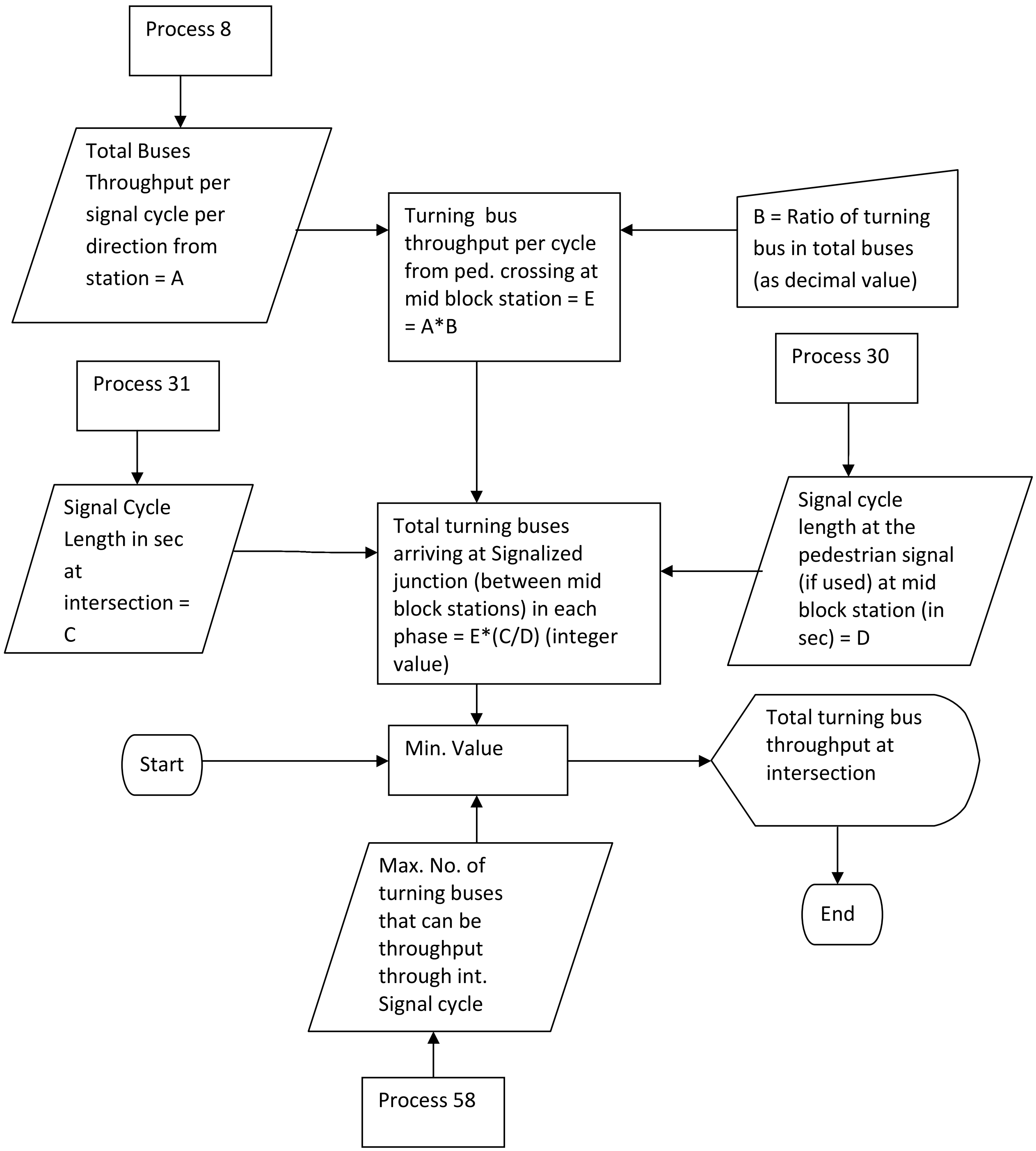


Figure 45: Flowchart for process no. 25 – Weighted average of bus delay for straight moving bus at a signalized intersection between bid block stations.

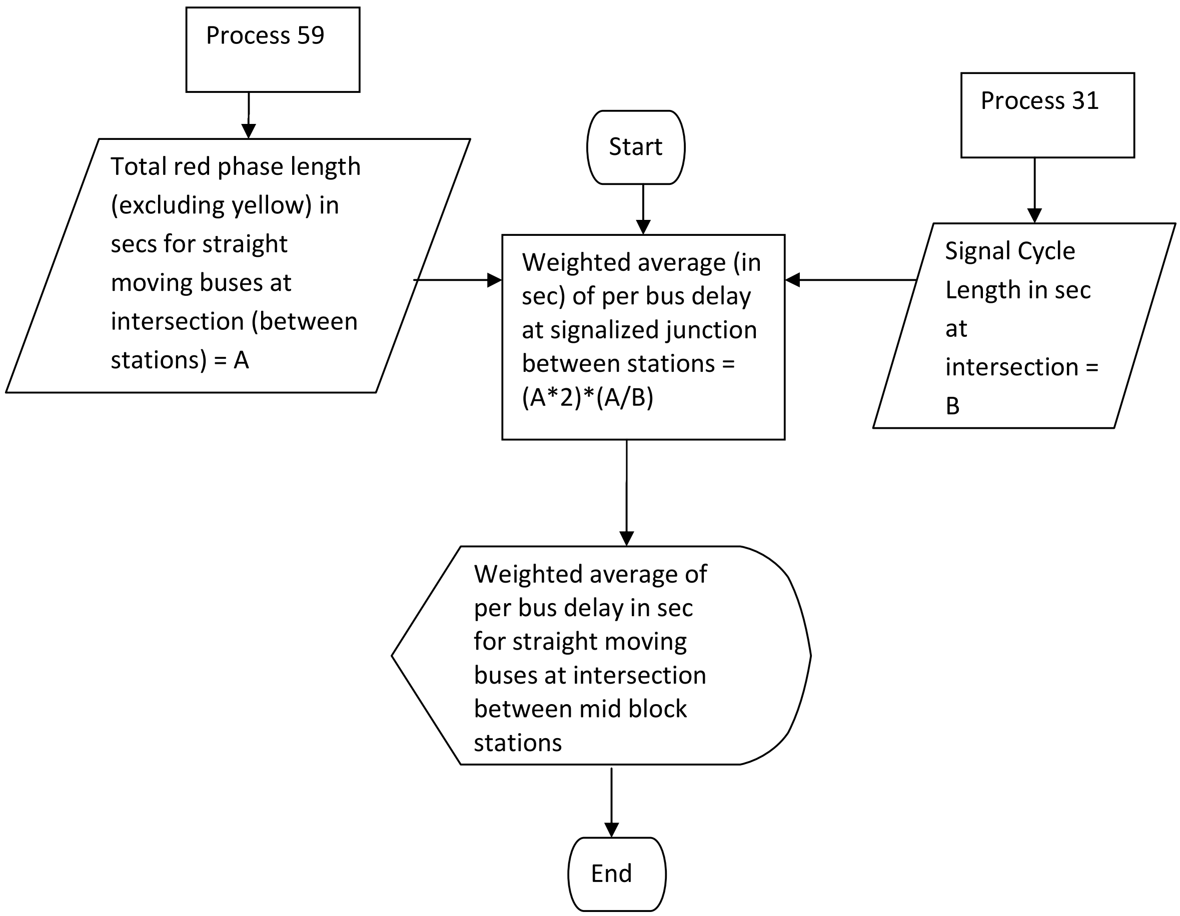


Figure 46: Flowchart for process no. 26 – Weighted average of bus delay for turning bus at a signalized intersection between bid block stations.

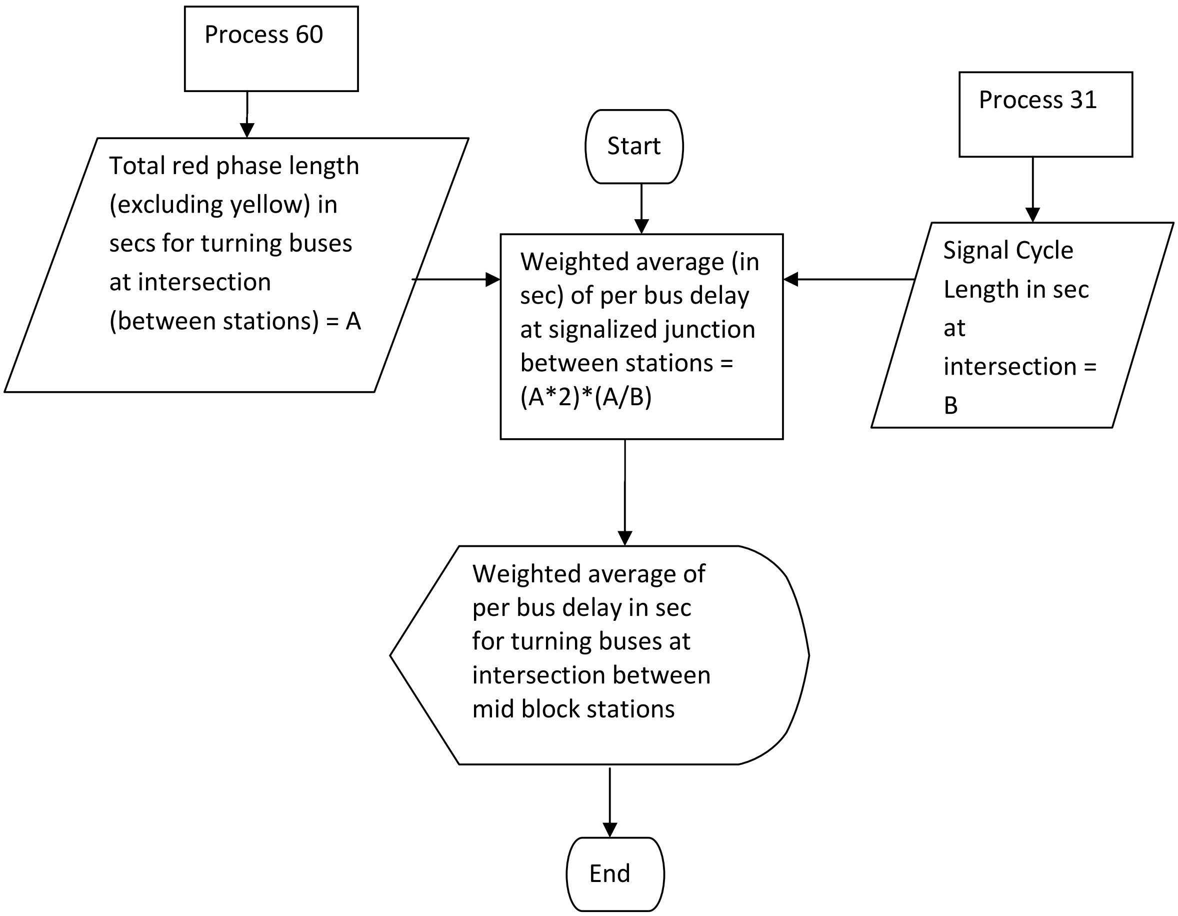


Figure 47: Flowchart for Process 27 – Total bus throughput per signal cycle per direction at (junction or mid block) island stations

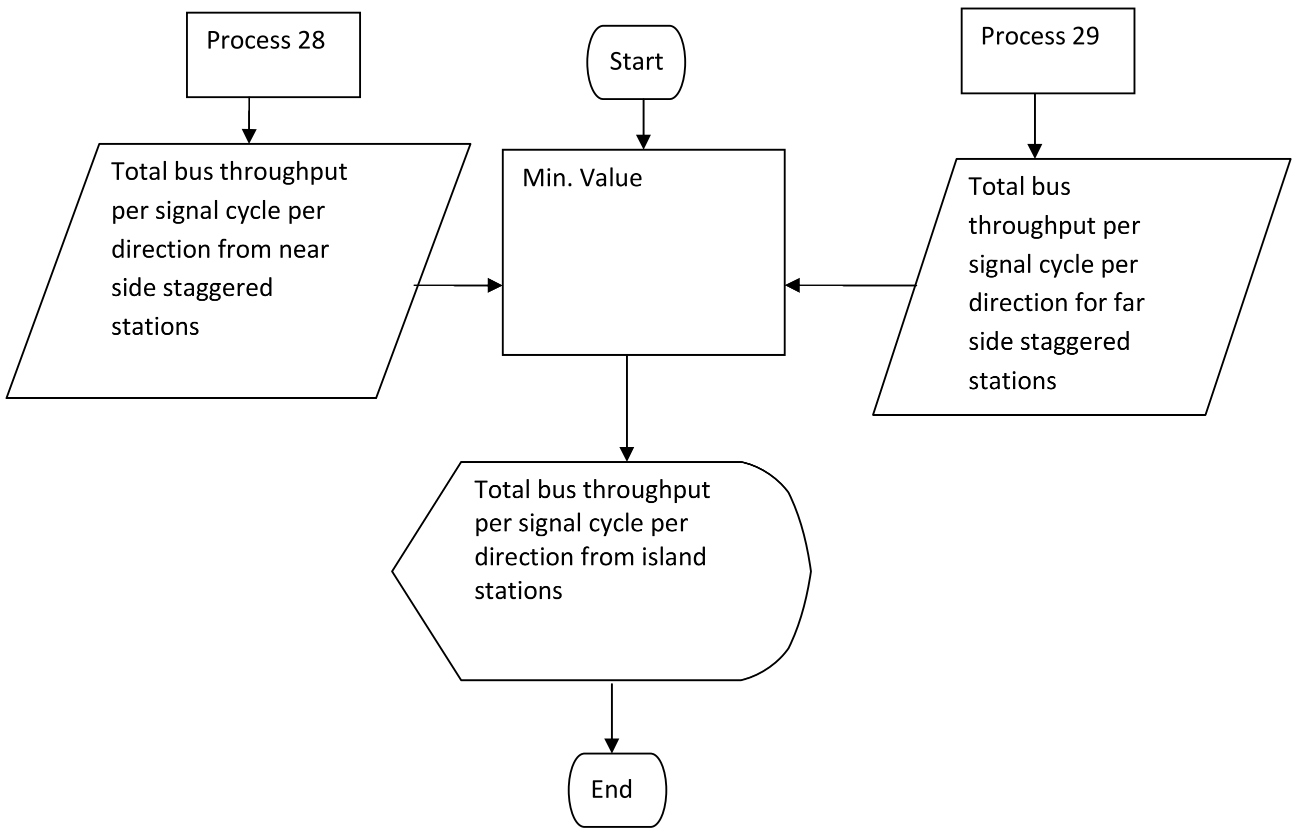


Figure 48: Flowchart for Process 28 – Total bus throughput per signal cycle per direction at (junction or mid block) staggered, near side stations

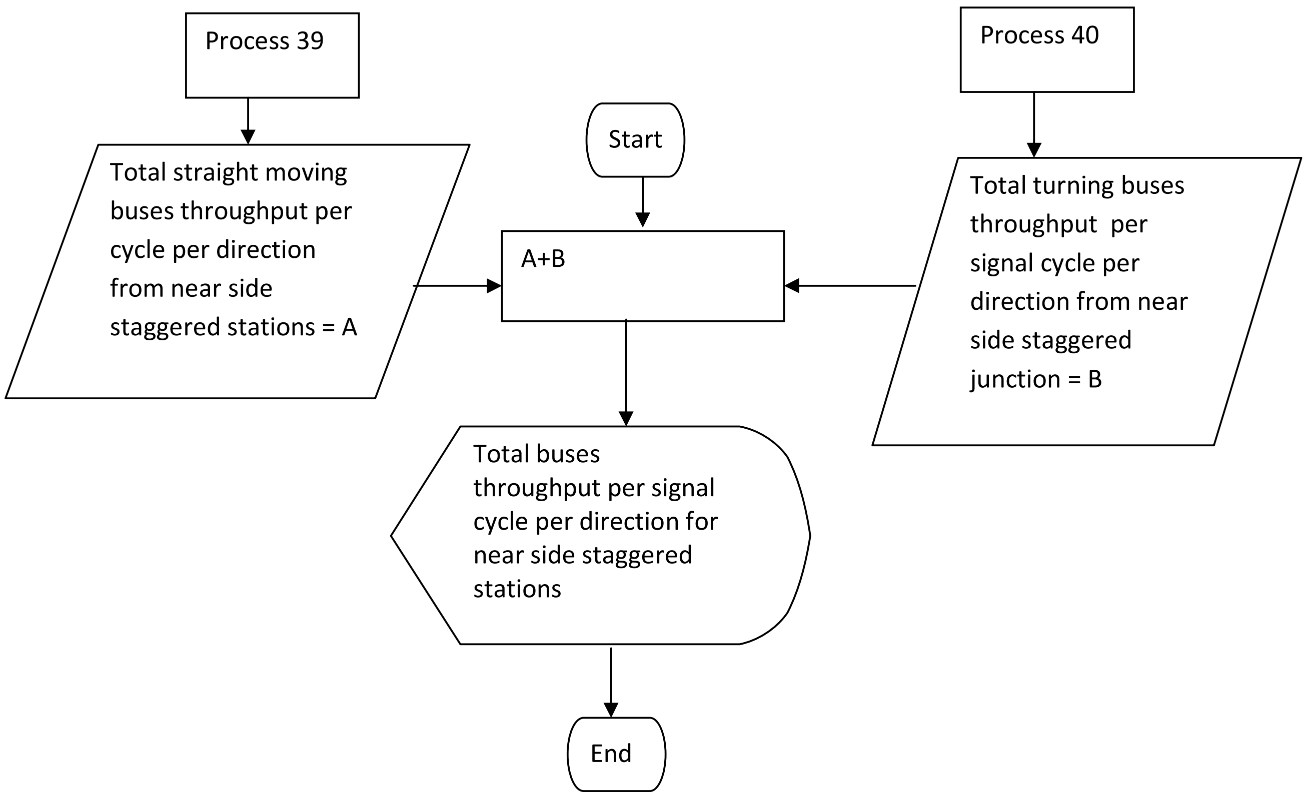


Figure 49: Flowchart for Process 29 – Total bus throughput per signal cycle per direction at (junction or mid block) staggered, far side stations

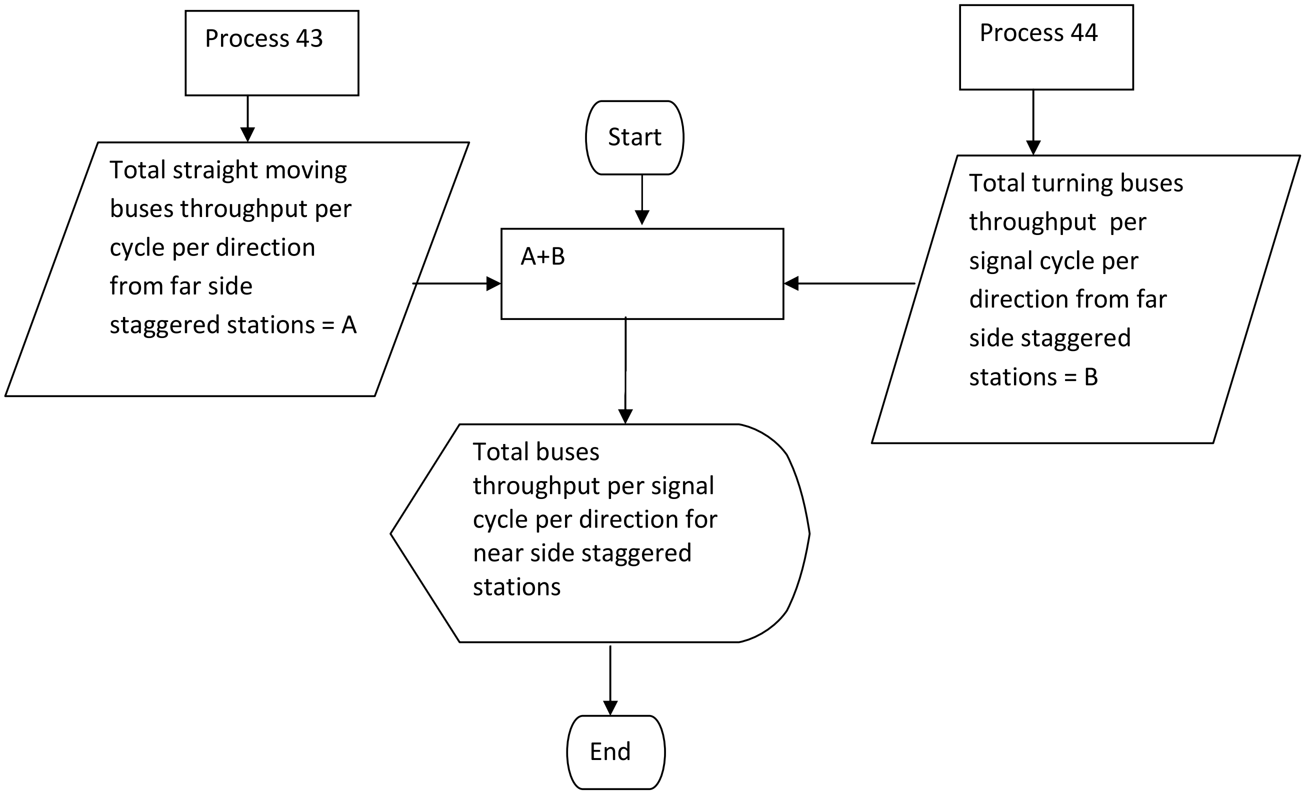


Figure 50: Flow chart for process 30 – Signal cycle length in sec for junction station intersections

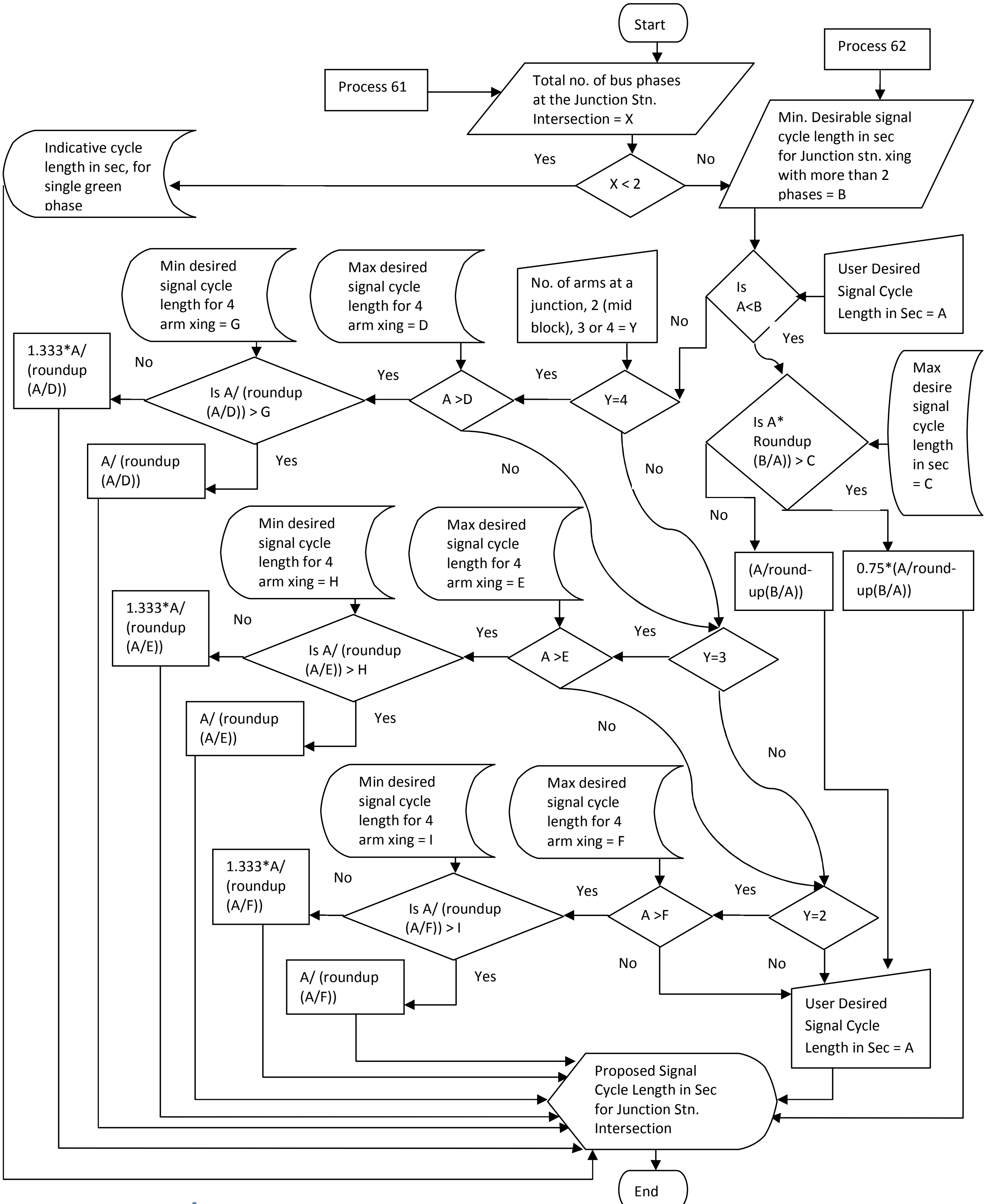


Figure 51: Flow chart for process 31 – Signal cycle length in sec for Mid Block station intersections

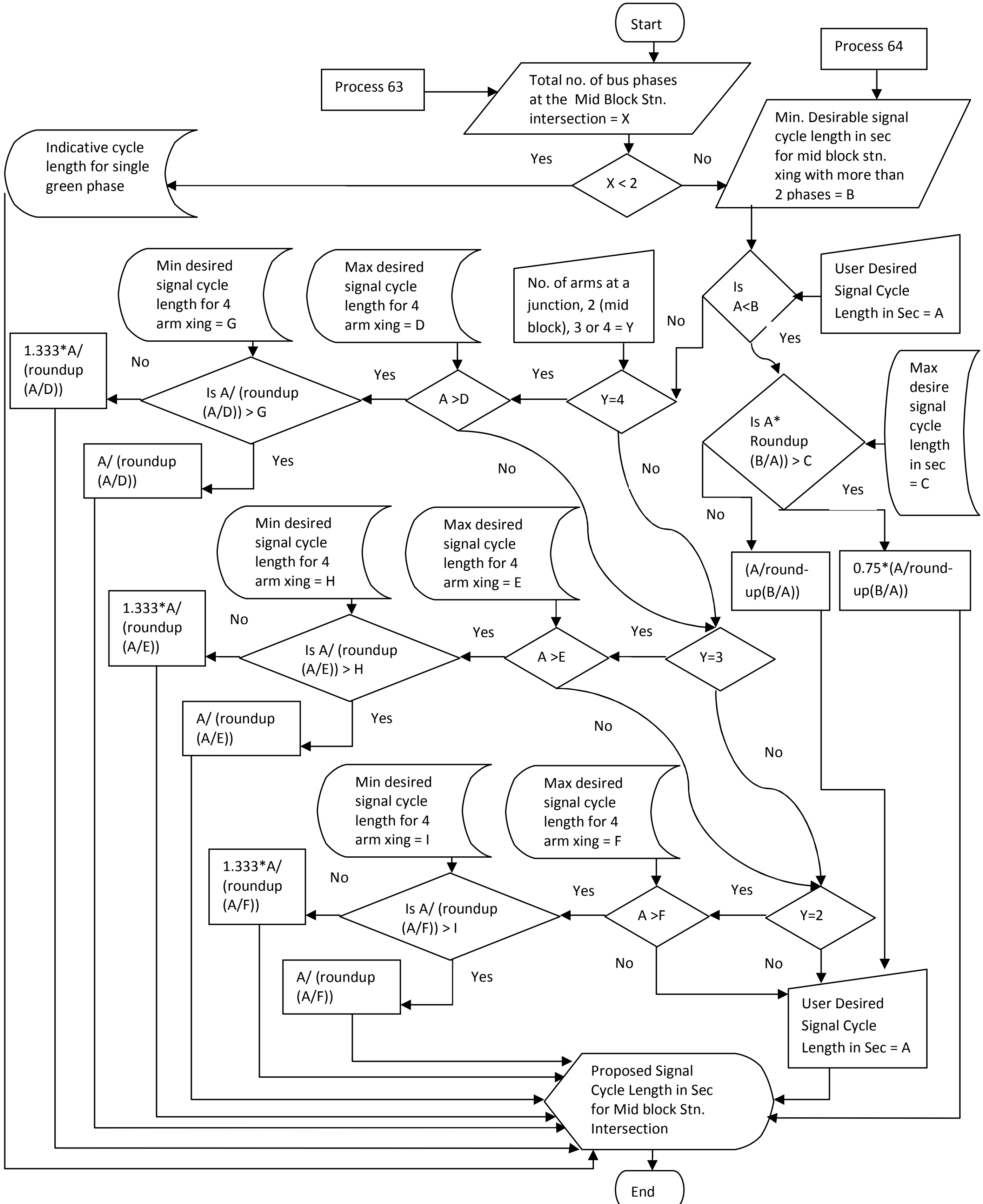


Figure 52: Flowchart for Process No. 32 – Passenger access delay for a BRTS bus based on average walking distance from median on the cross roads.

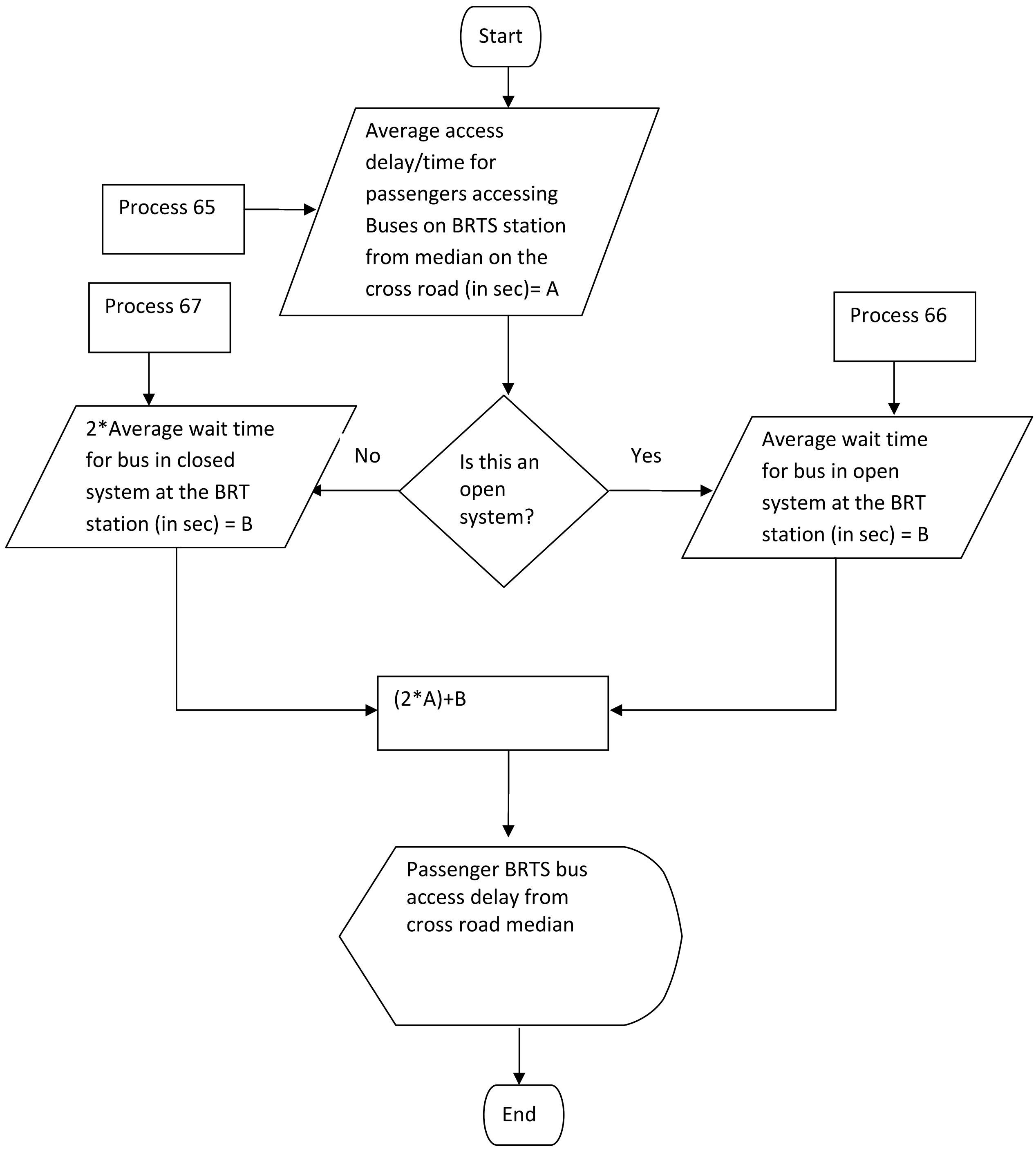


Figure 53: Flow chart for Process no. 33 – Average walking distance in m. from origin/destination point to the BRTS or feeder station location.

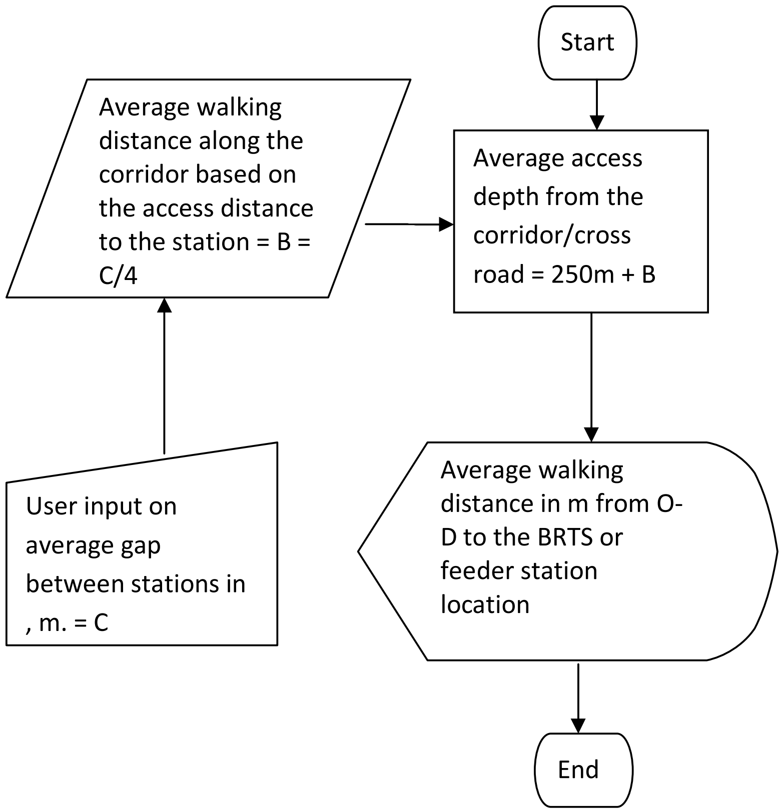


Figure 54: Flowchart for process no. 34 – Average total access delay to bus outside the corridor in an open system

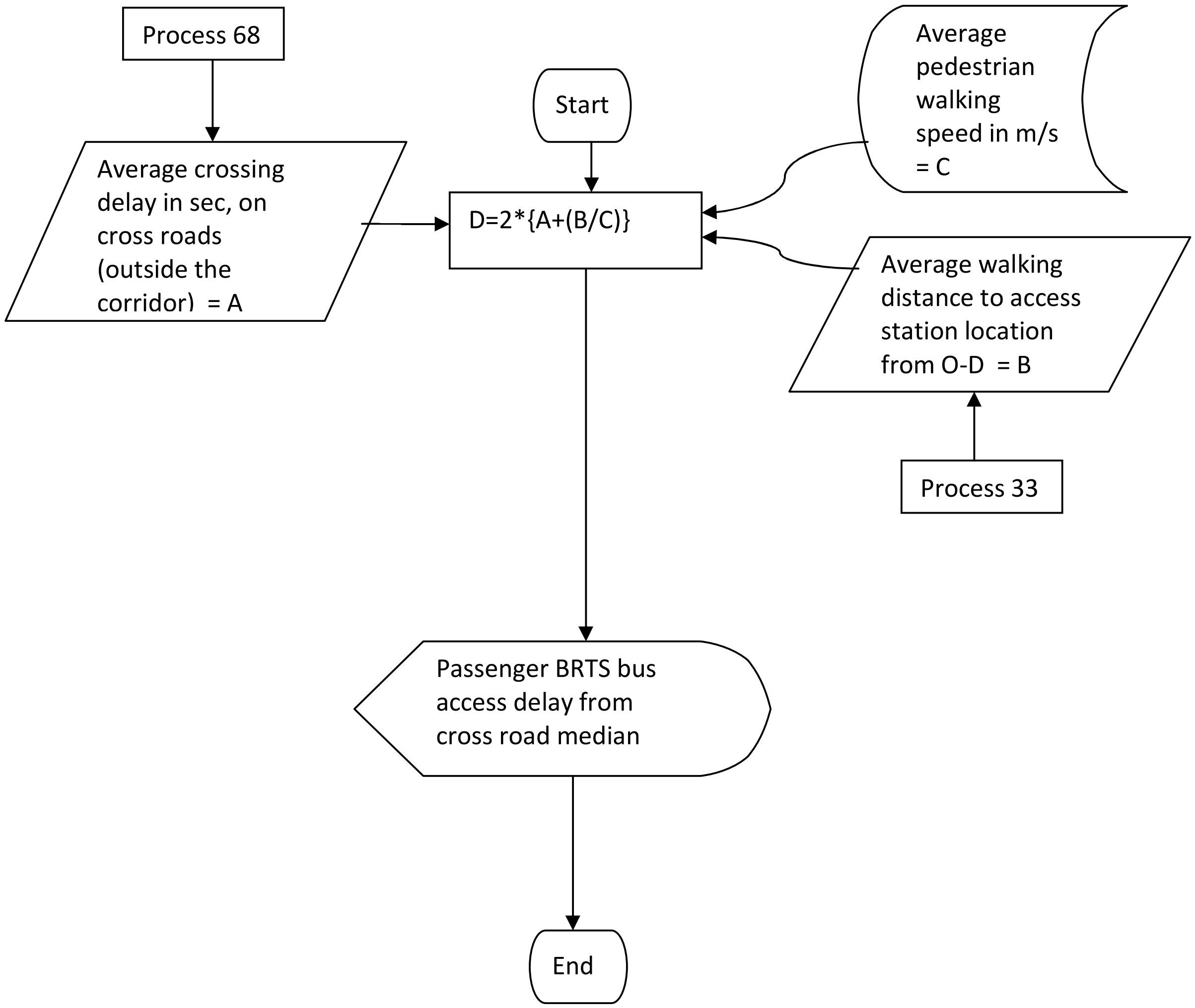


Figure 55: Flowchart for Process no. – Average bus speed in mixed conditions in m/s.

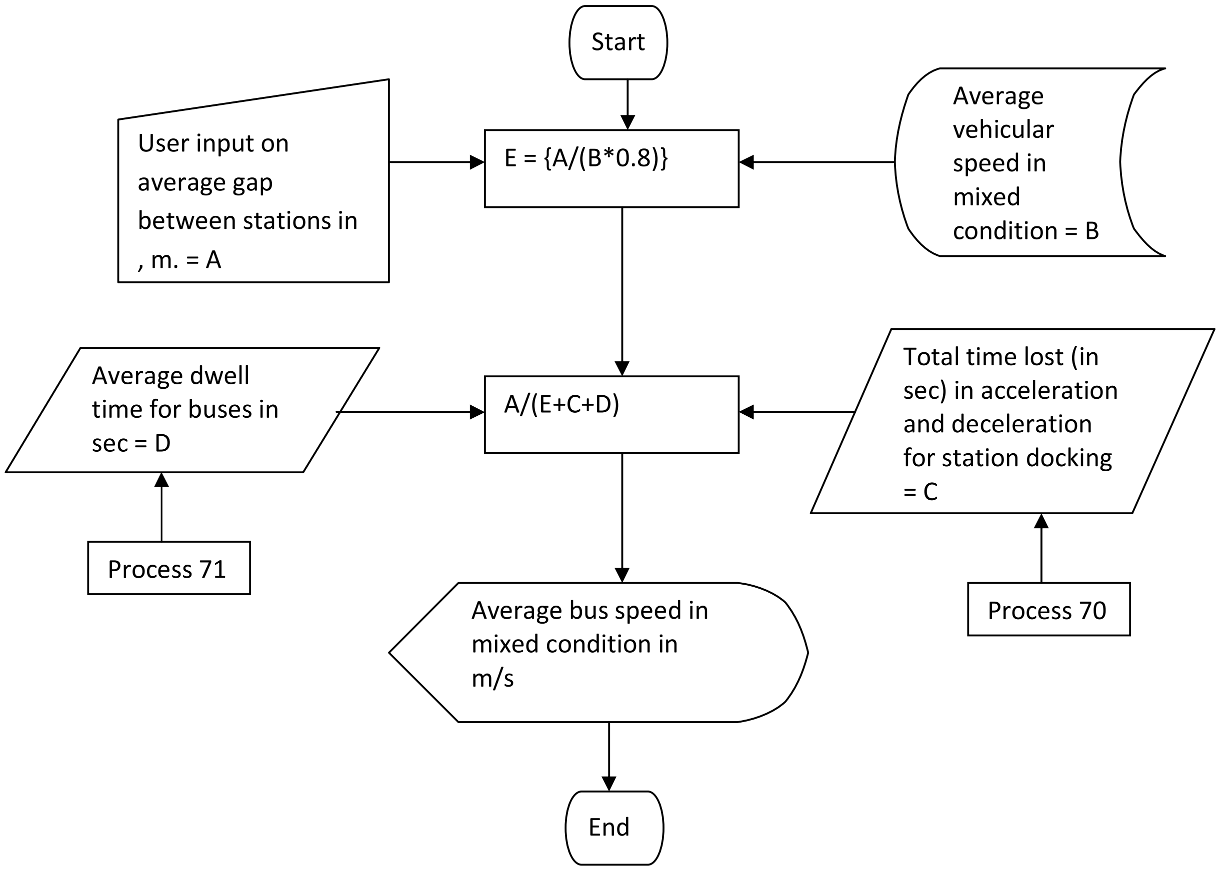


Figure 56: Flowchart for Process no. 36 - Average total access delay to bus outside the corridor in closed system

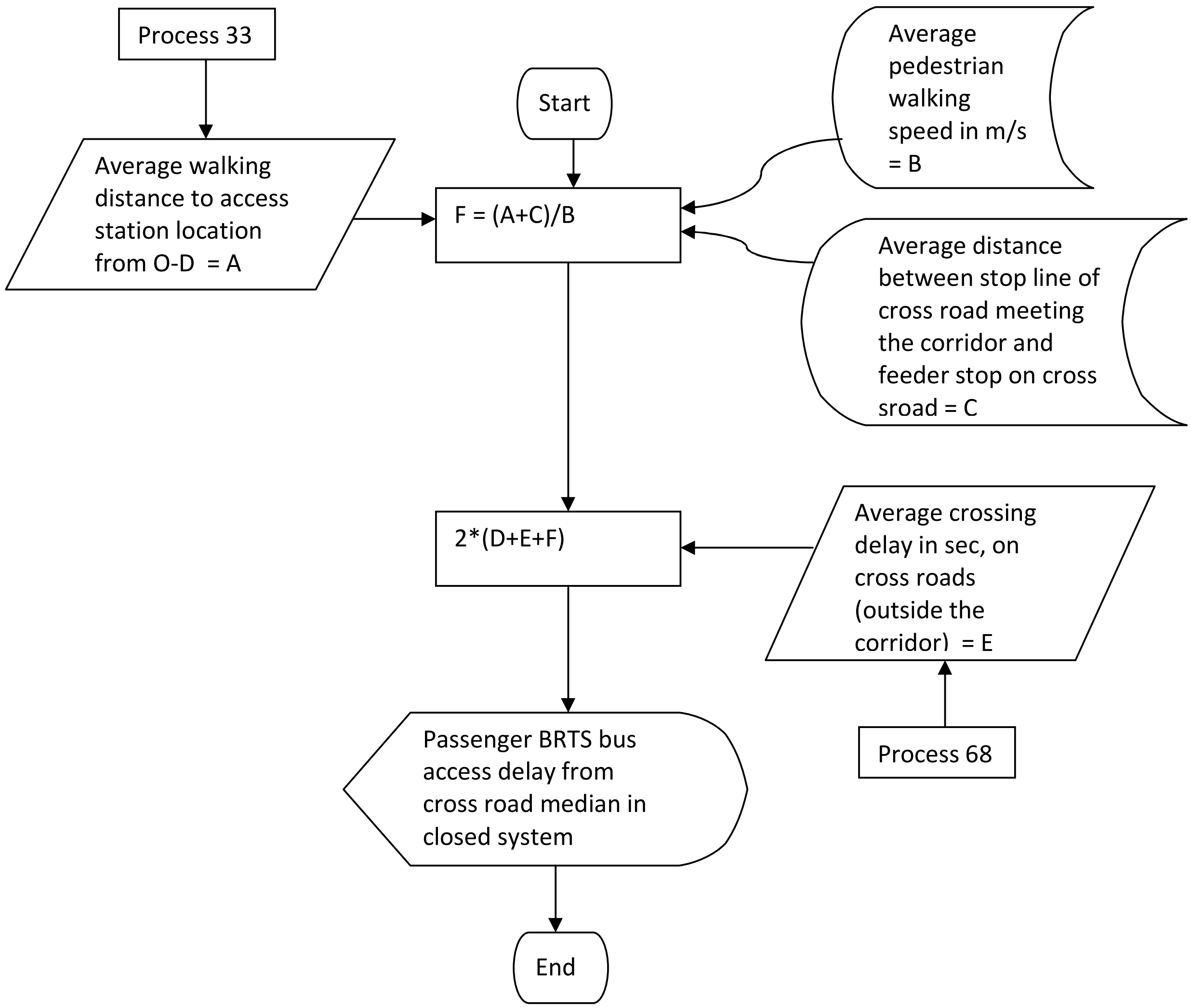


Figure 57: Flow chart for process 37 – Straight moving per bus per cycle per direction delay for buses at near side (staggered stations) in secs.

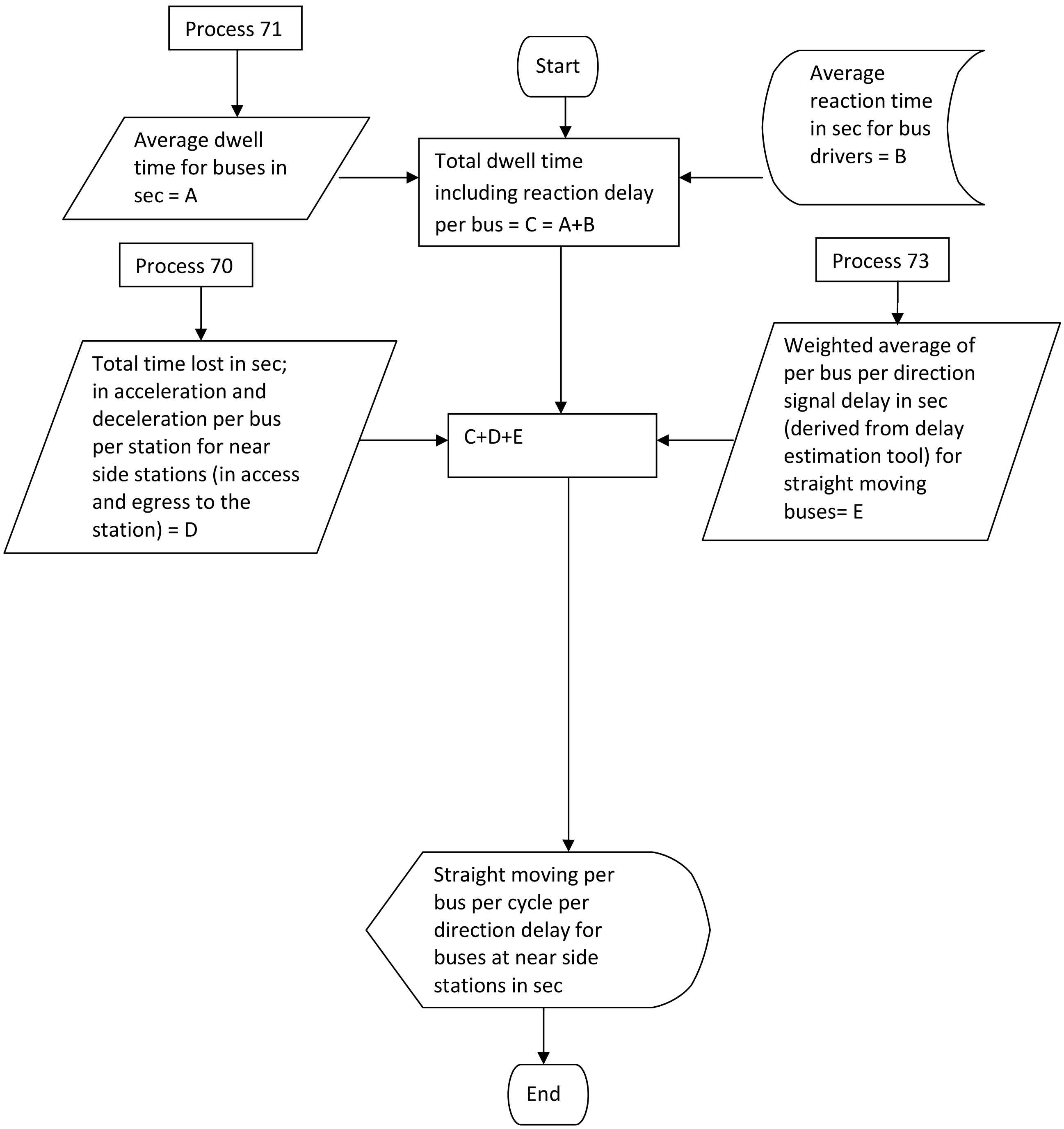


Figure 58: Flowchart for process 38 - Turning per bus per cycle per direction delay for buses at near side (staggered stations) in secs.

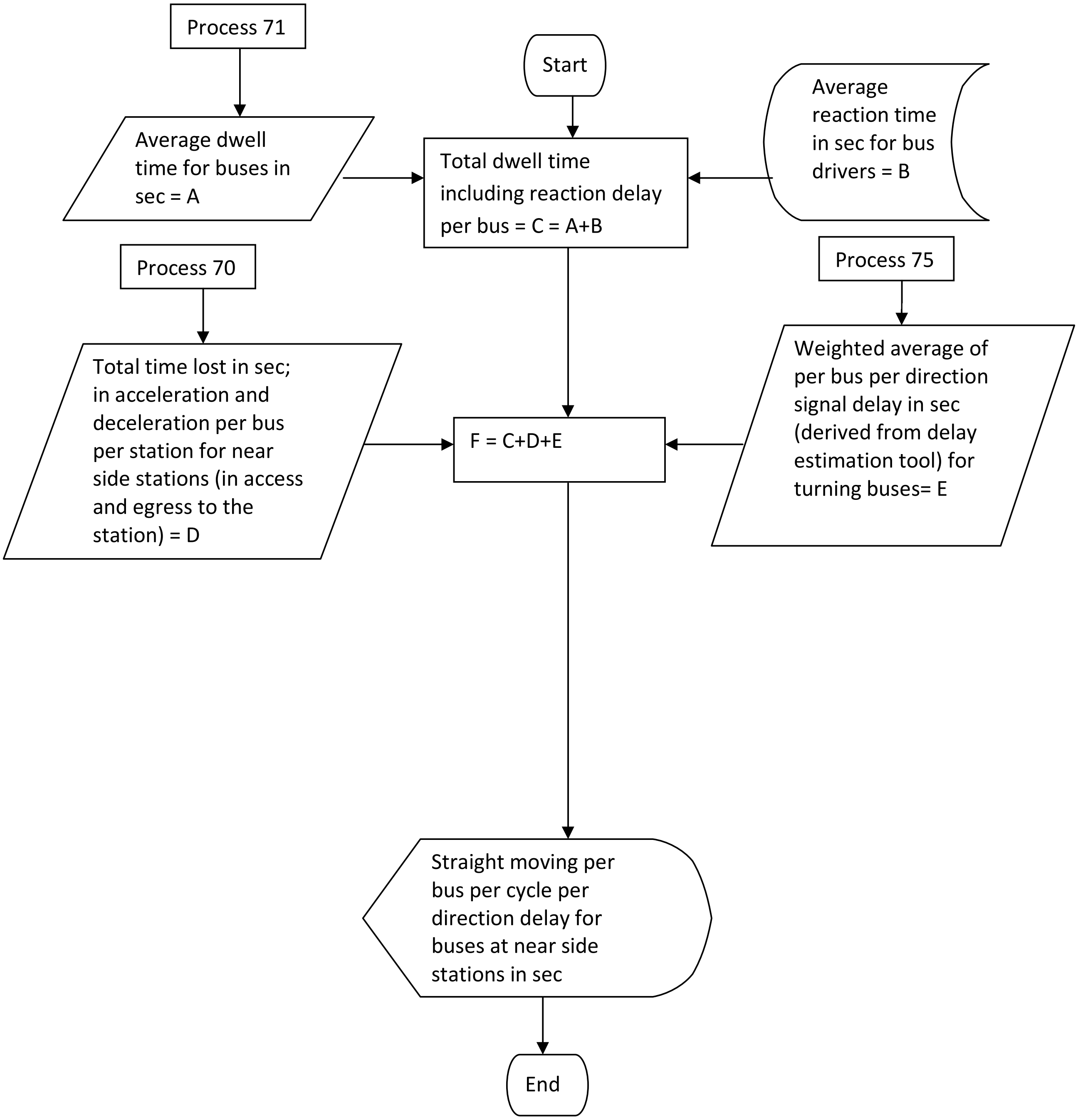


Figure 59: Flow chart for process 39 – Straight moving bus throughput per direction per signal cycle for near side stations

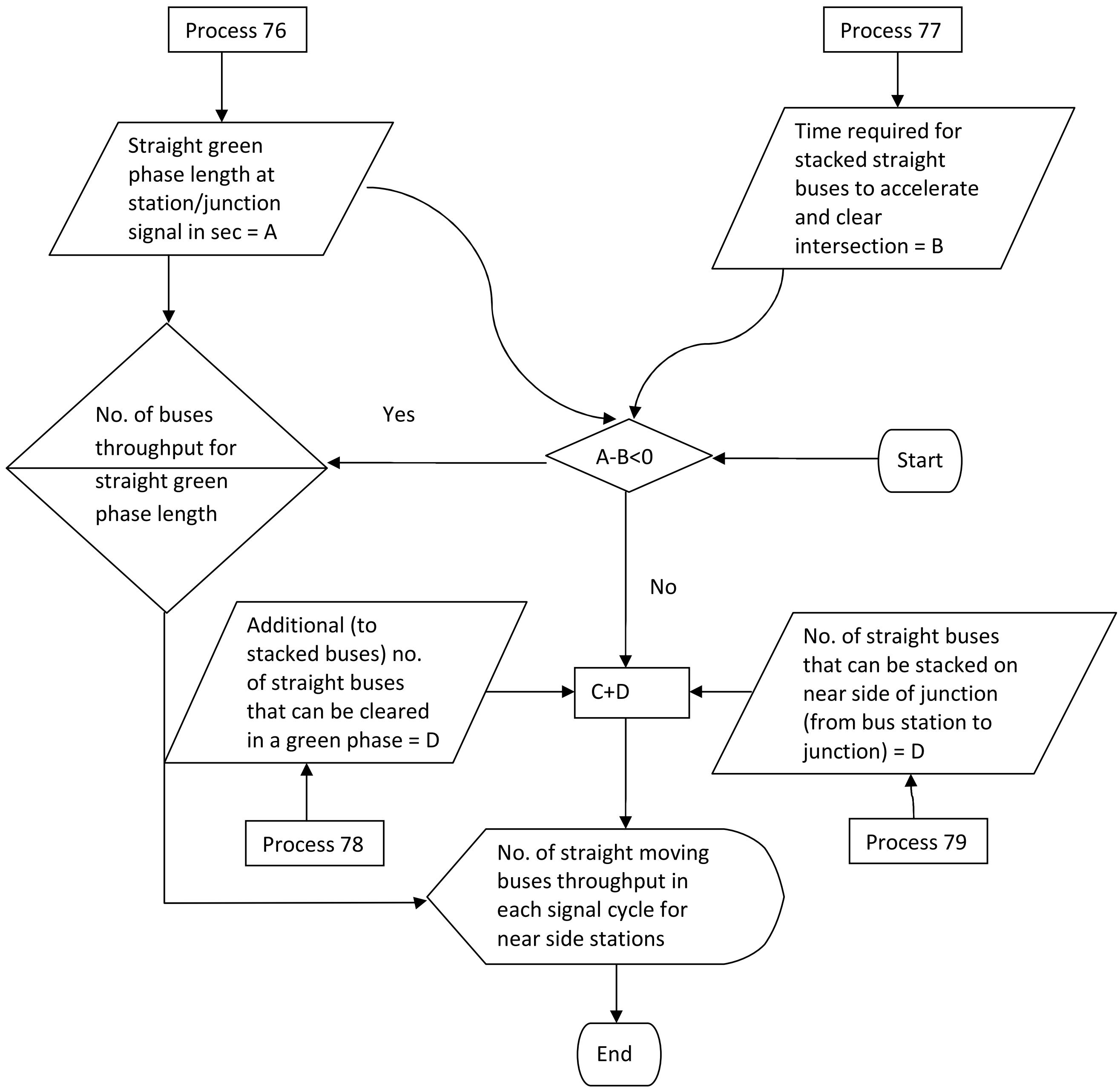


Figure 60: Flowchart for process 40 - Turning bus throughput per direction per signal cycle for near side stations

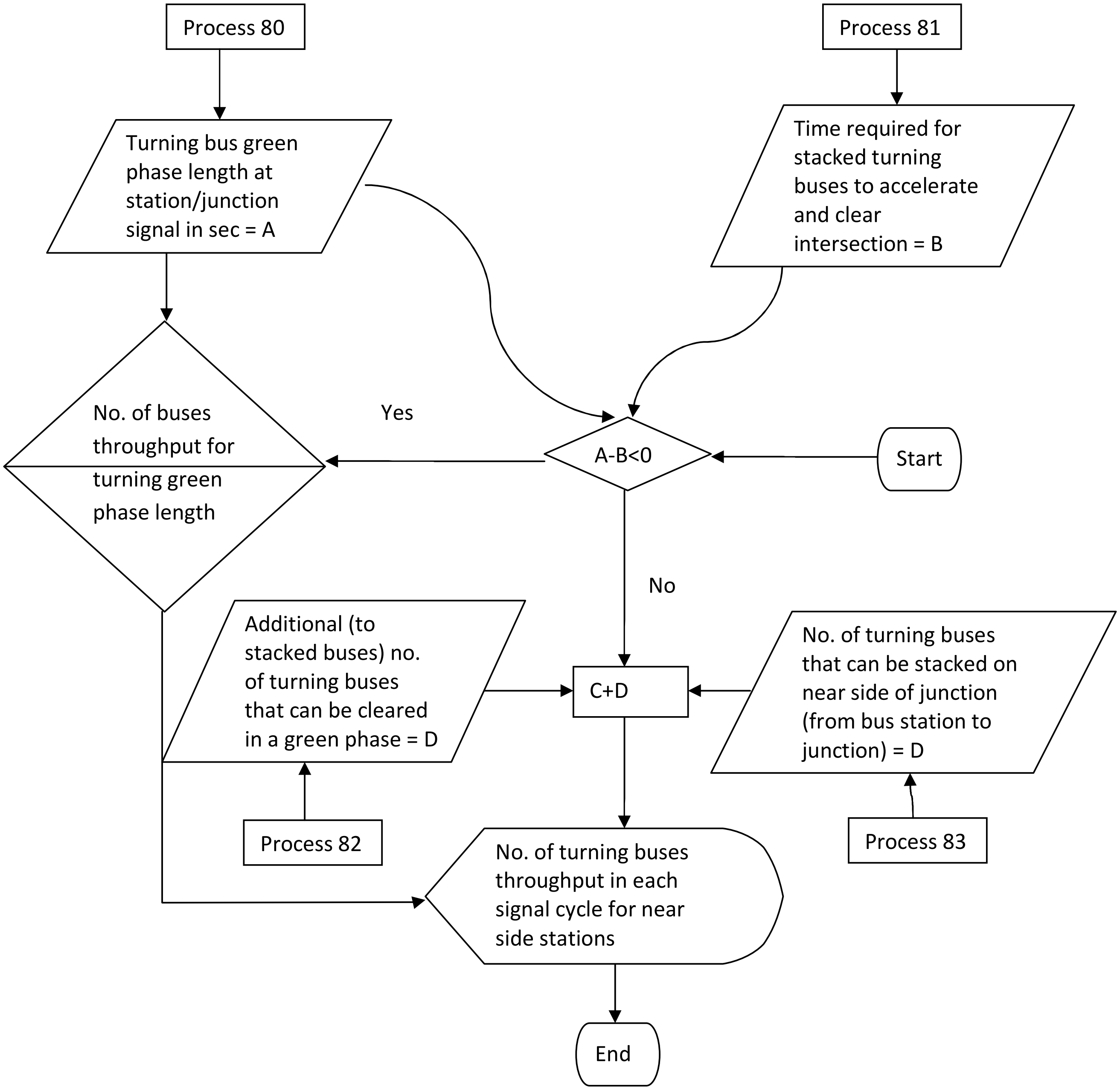


Figure 61: Flow chart for process 41 - Straight moving per bus per cycle per direction delay for buses at far side (staggered stations) with overtaking lanes in secs.

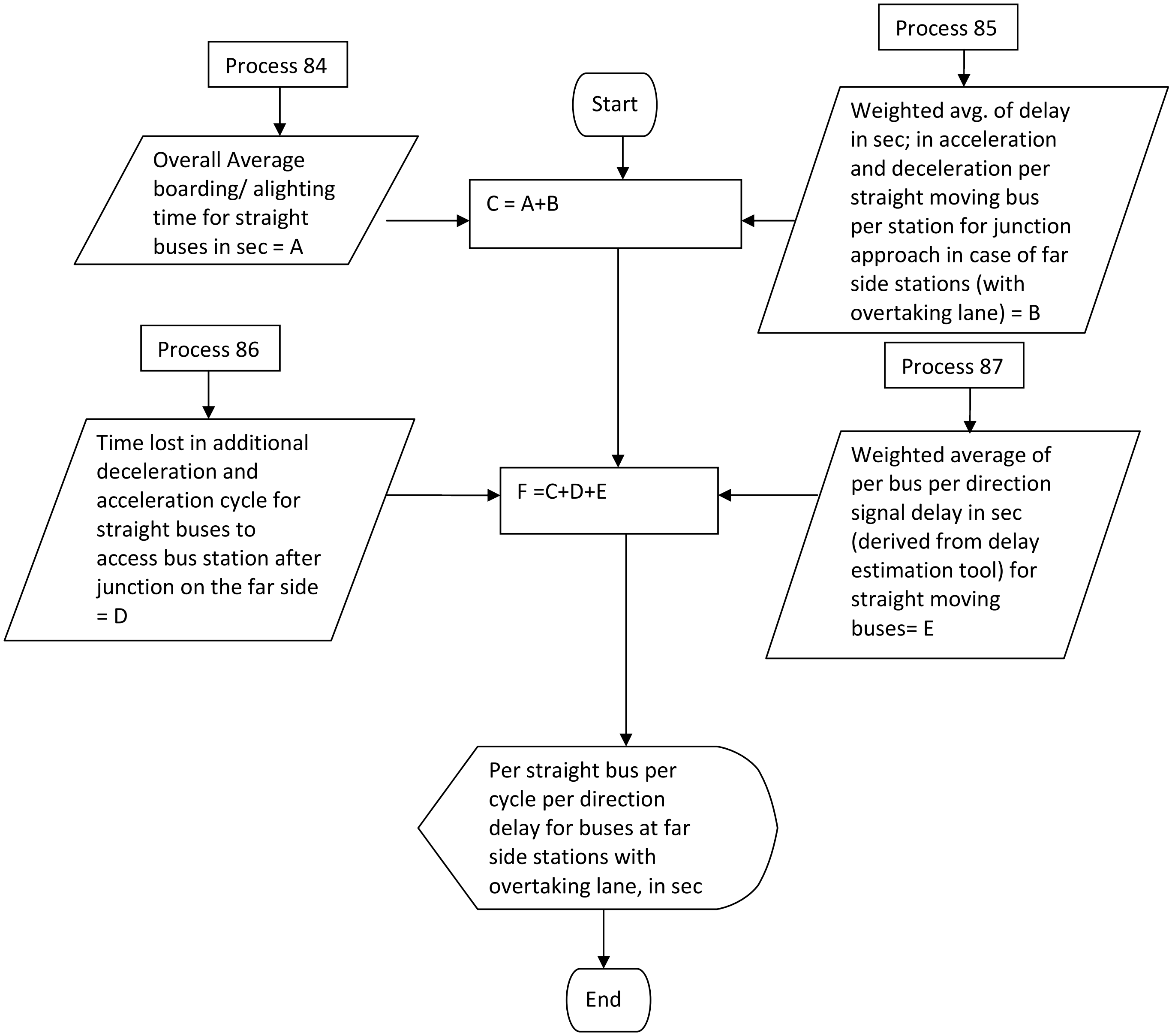


Figure 62: Flow chart for process 42 –Per bus per cycle per direction delay for turning buses at far side (staggered stations) with overtaking lanes in secs.

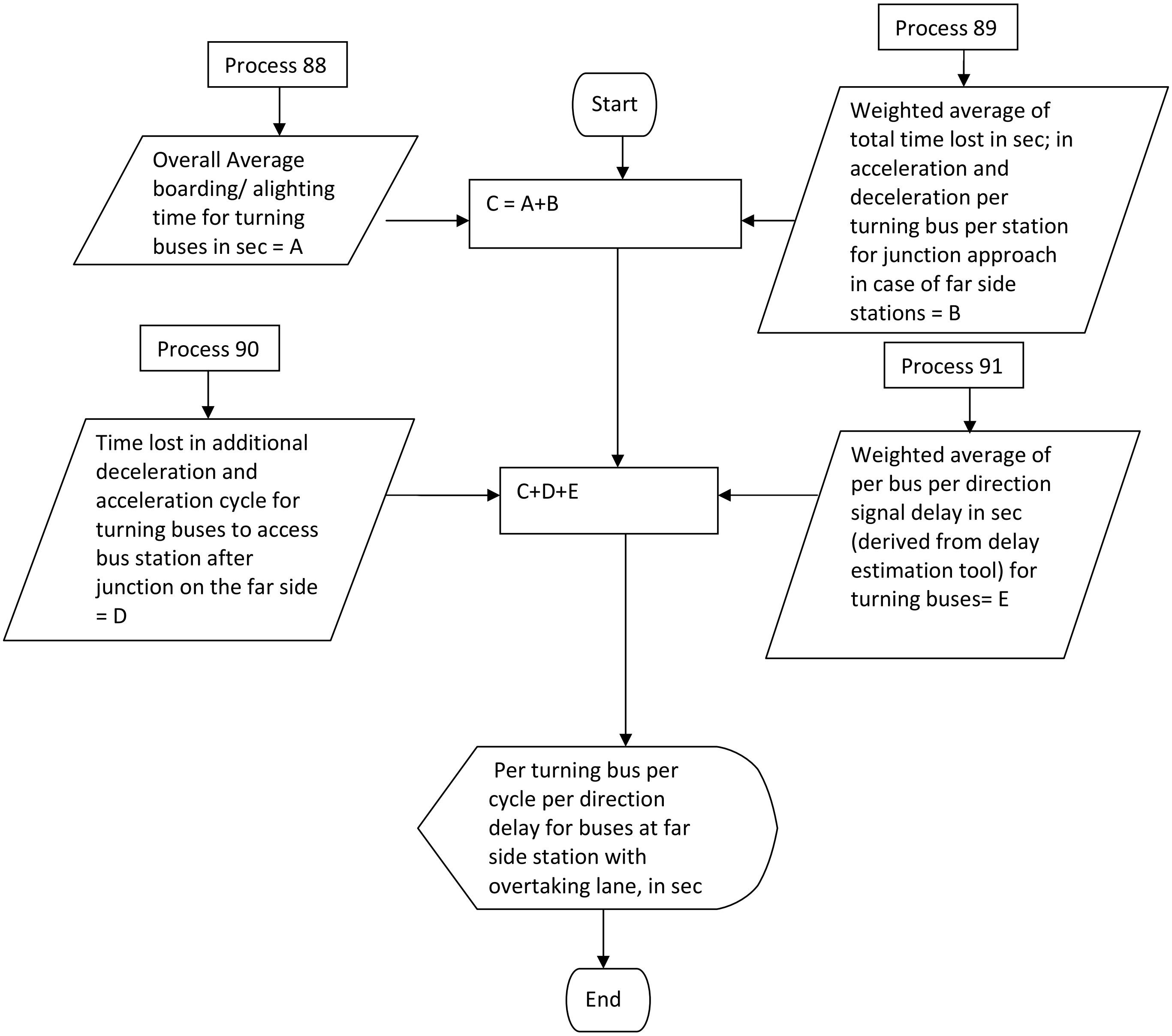


Figure 63: Flow chart for process 43 – Per cycle per direction straight moving bus throughput for far side stations with or without overtaking lanes

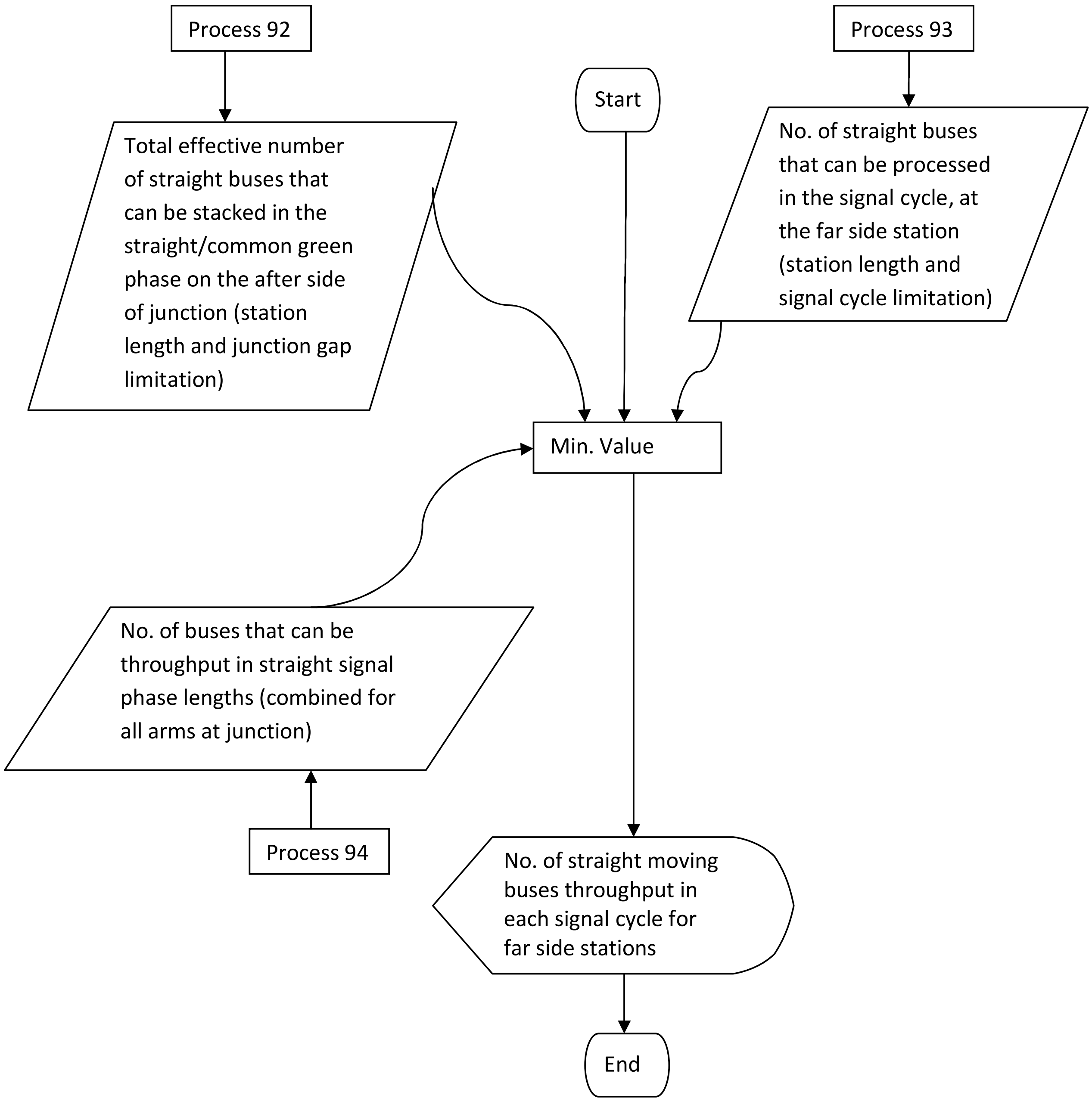


Figure 64: Flow chart for process 44 – Per cycle per direction turning bus throughput for far side stations with overtaking lanes

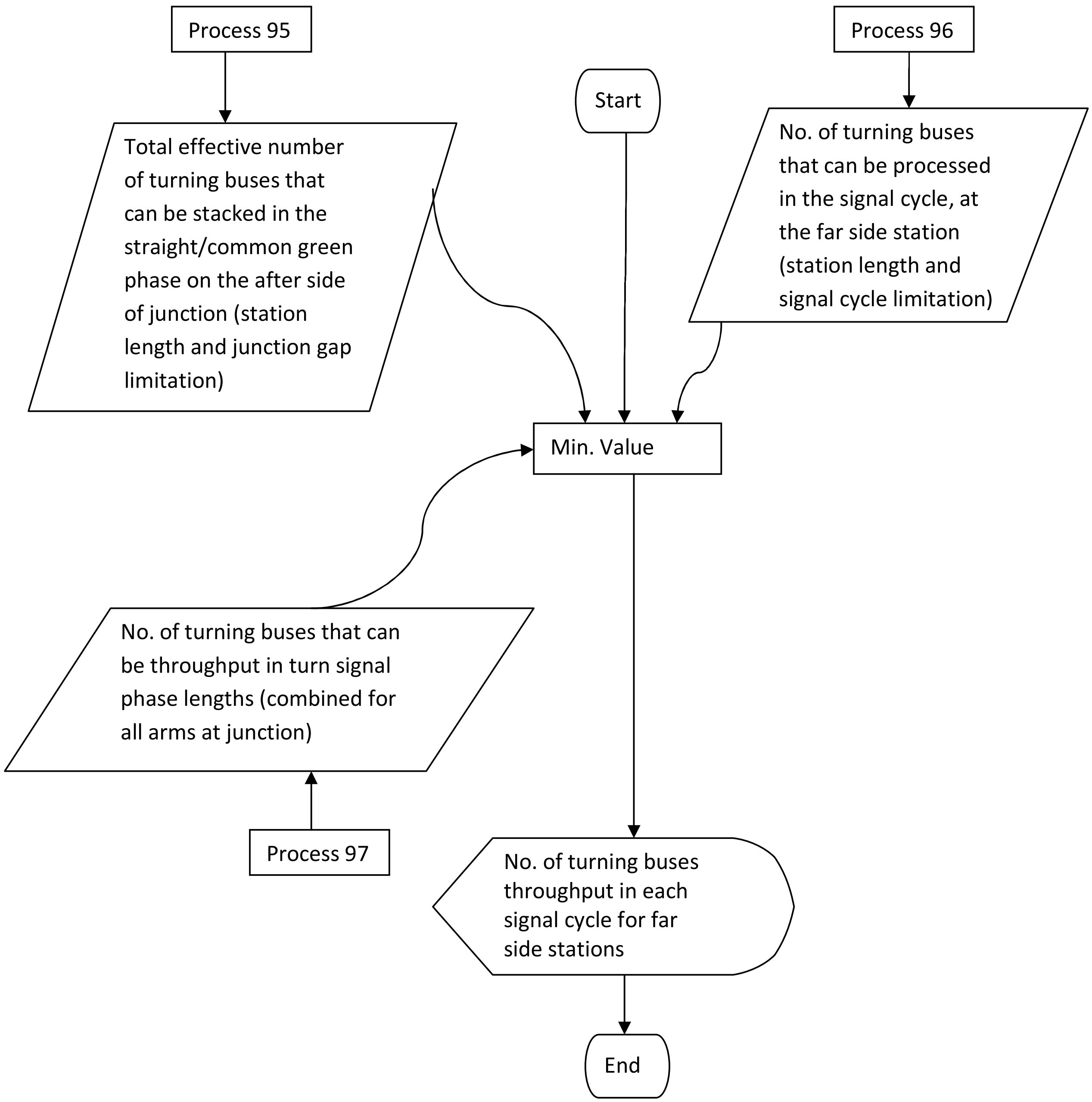


Figure 65: Flow chart for process 45 - Straight moving per bus per cycle per direction delay for buses at far side (staggered stations) without overtaking lanes, in secs.

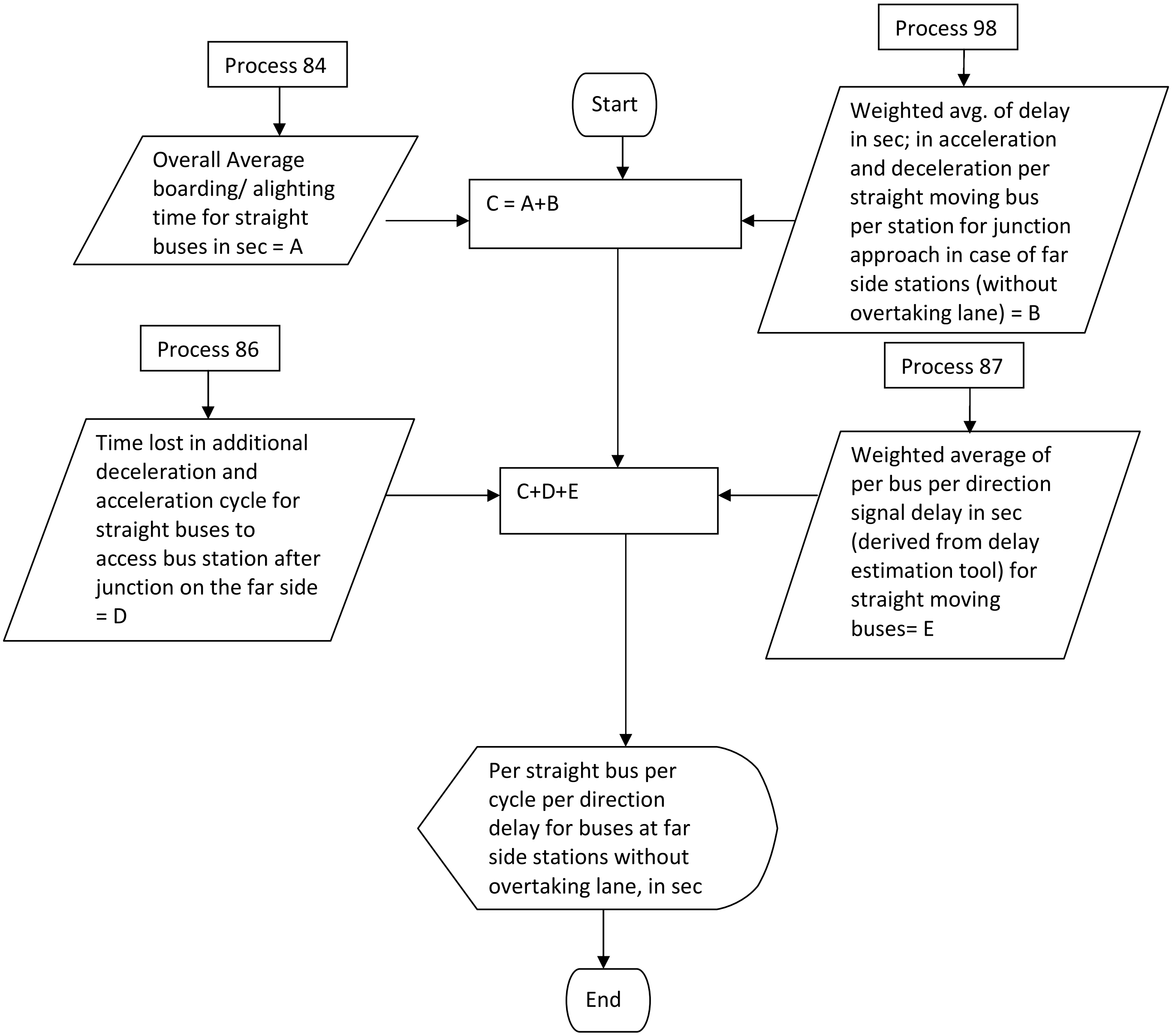


Figure 66: Flow chart for process 46 –Per bus per cycle per direction delay for turning buses at far side (staggered stations) without overtaking, lanes in secs.

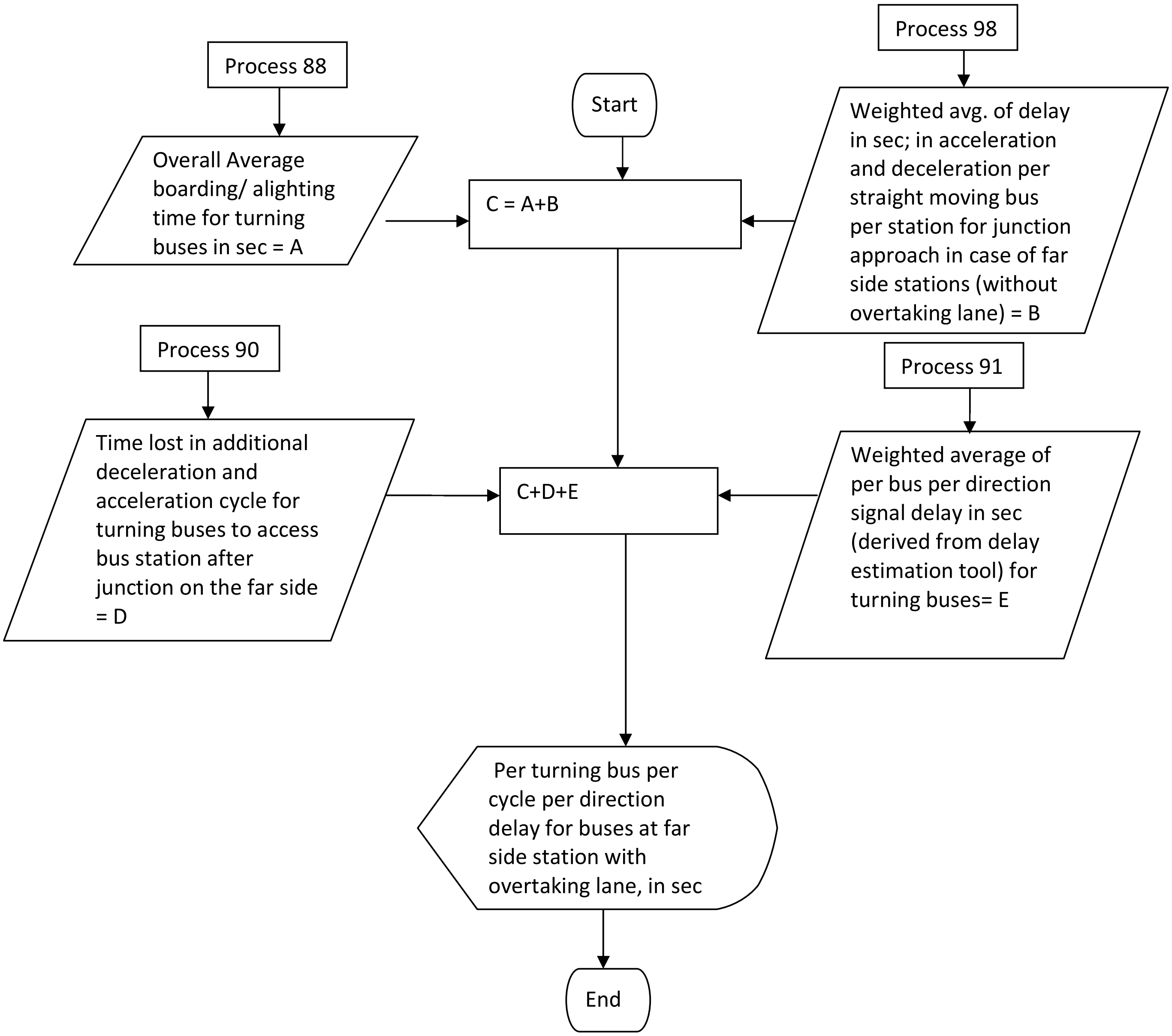


Figure 67: Flow chart for process 47 – Percentage of trips with varying distance of O-D situated of the corridor on the basis of average motorized trip length in the city

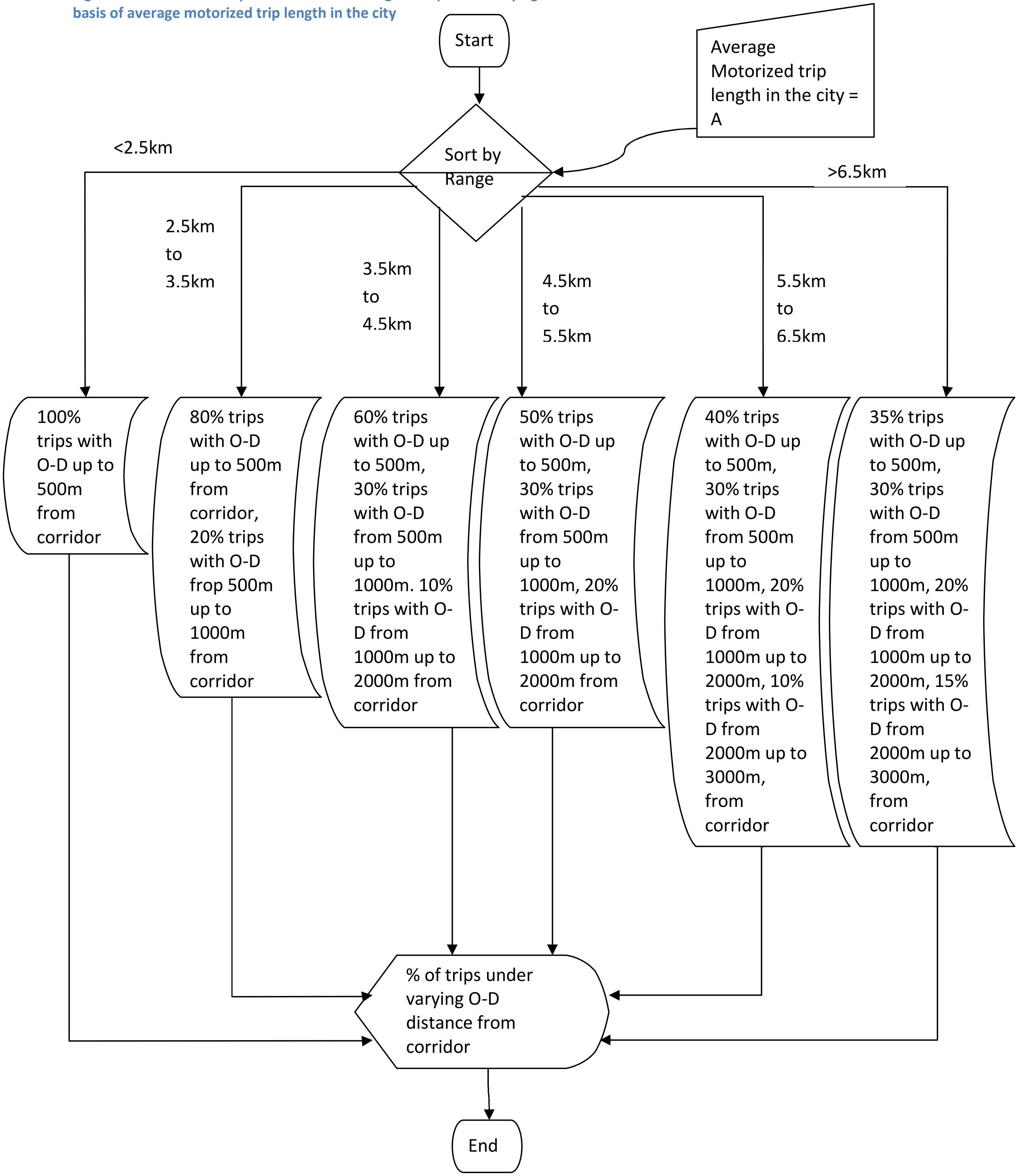


Figure 68: Flowchart for process 48 – Total bus throughput per hour per direction capacity of the corridor.

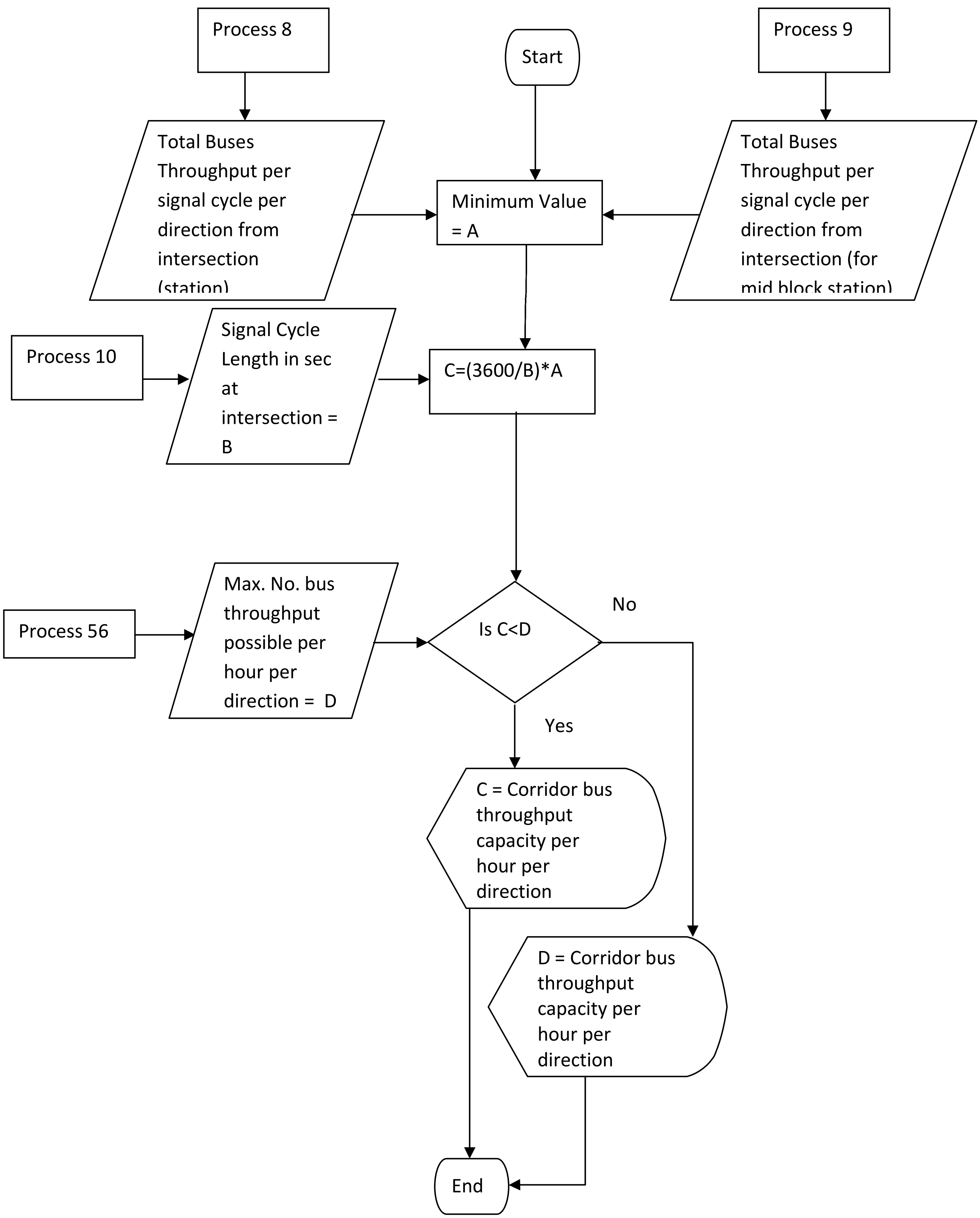


Figure 69: Flow chart for process 49 – Average per bus delay for straight moving buses at common or island stations with overtaking lanes.

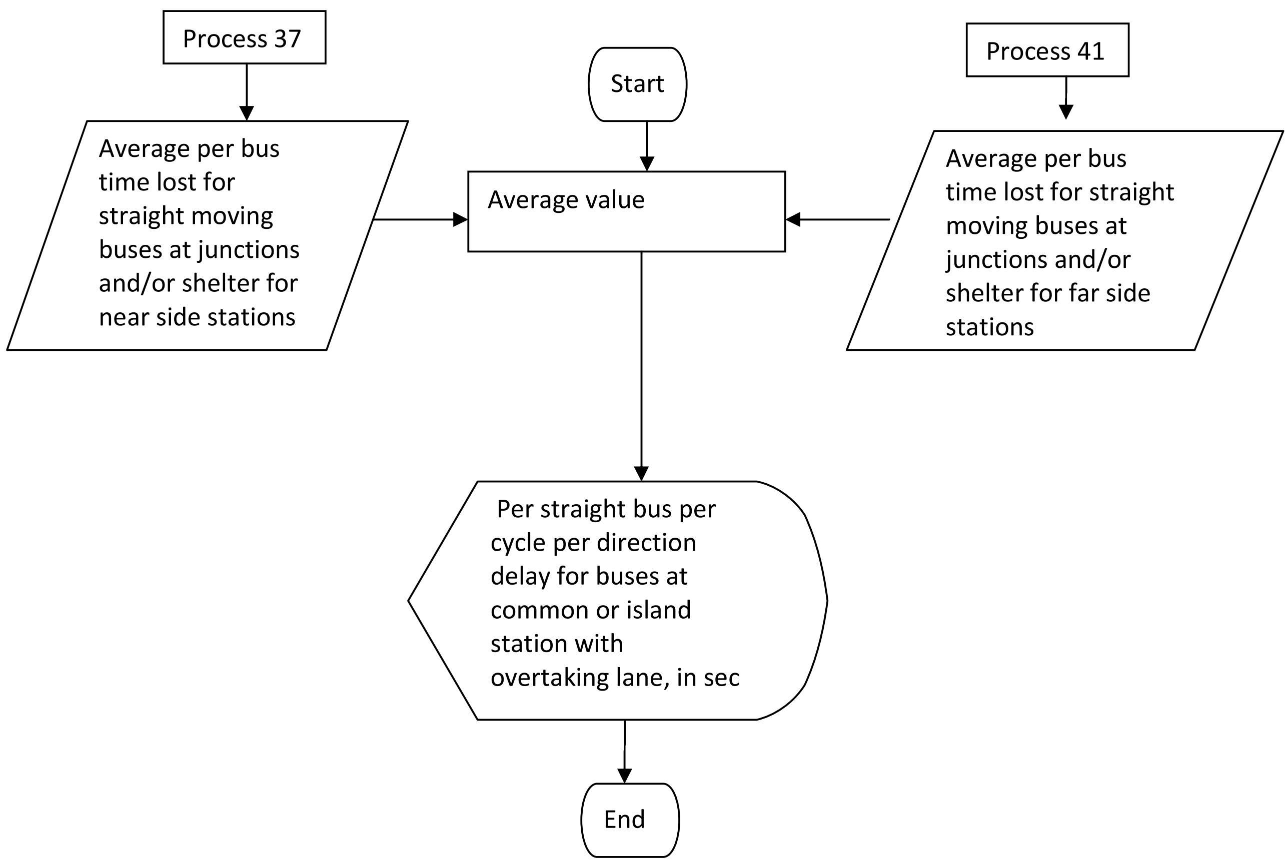


Figure 70: Flow chart for process 50 – Average per bus delay for turning buses at common or island stations with overtaking lanes.

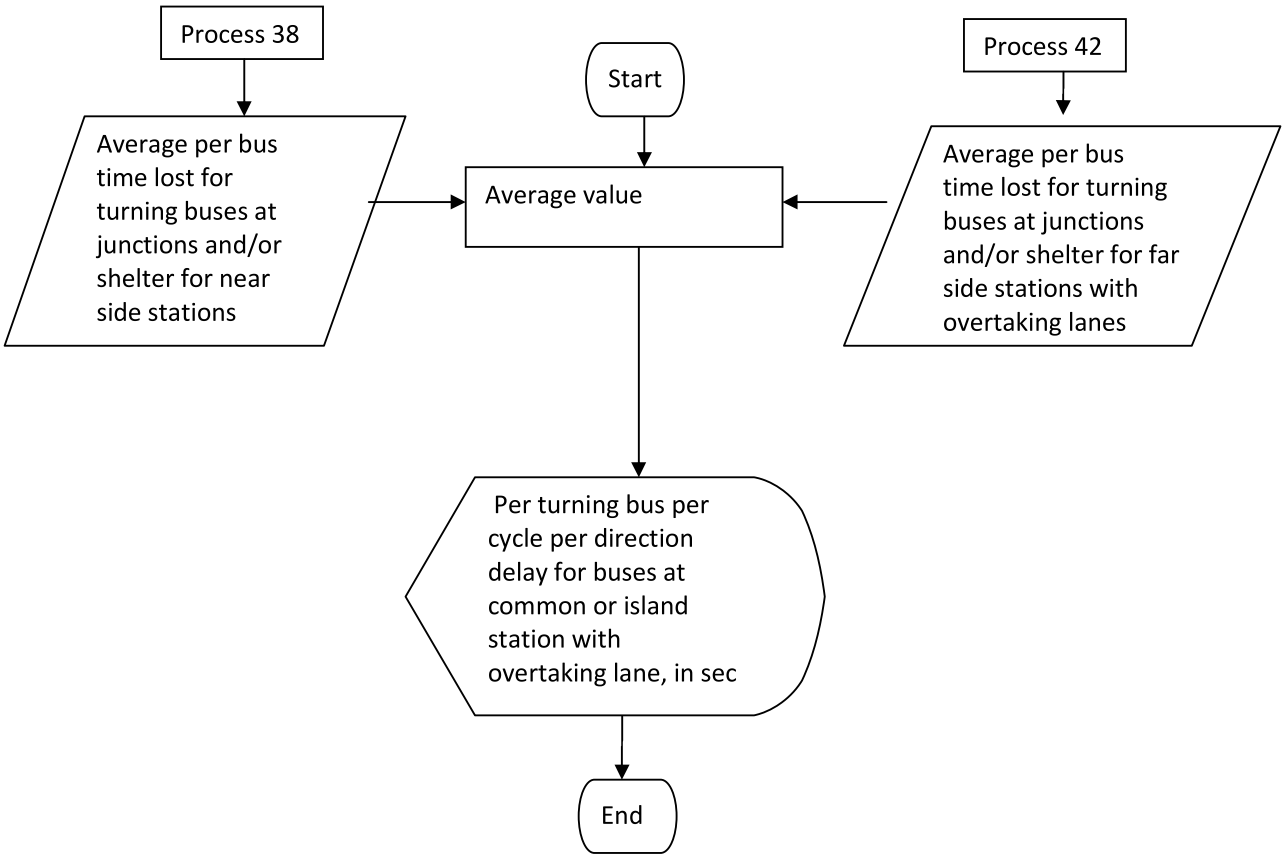


Figure 71: Flow chart for process 51 - Per cycle per direction straight moving bus throughput for common/island stations with or without overtaking lanes

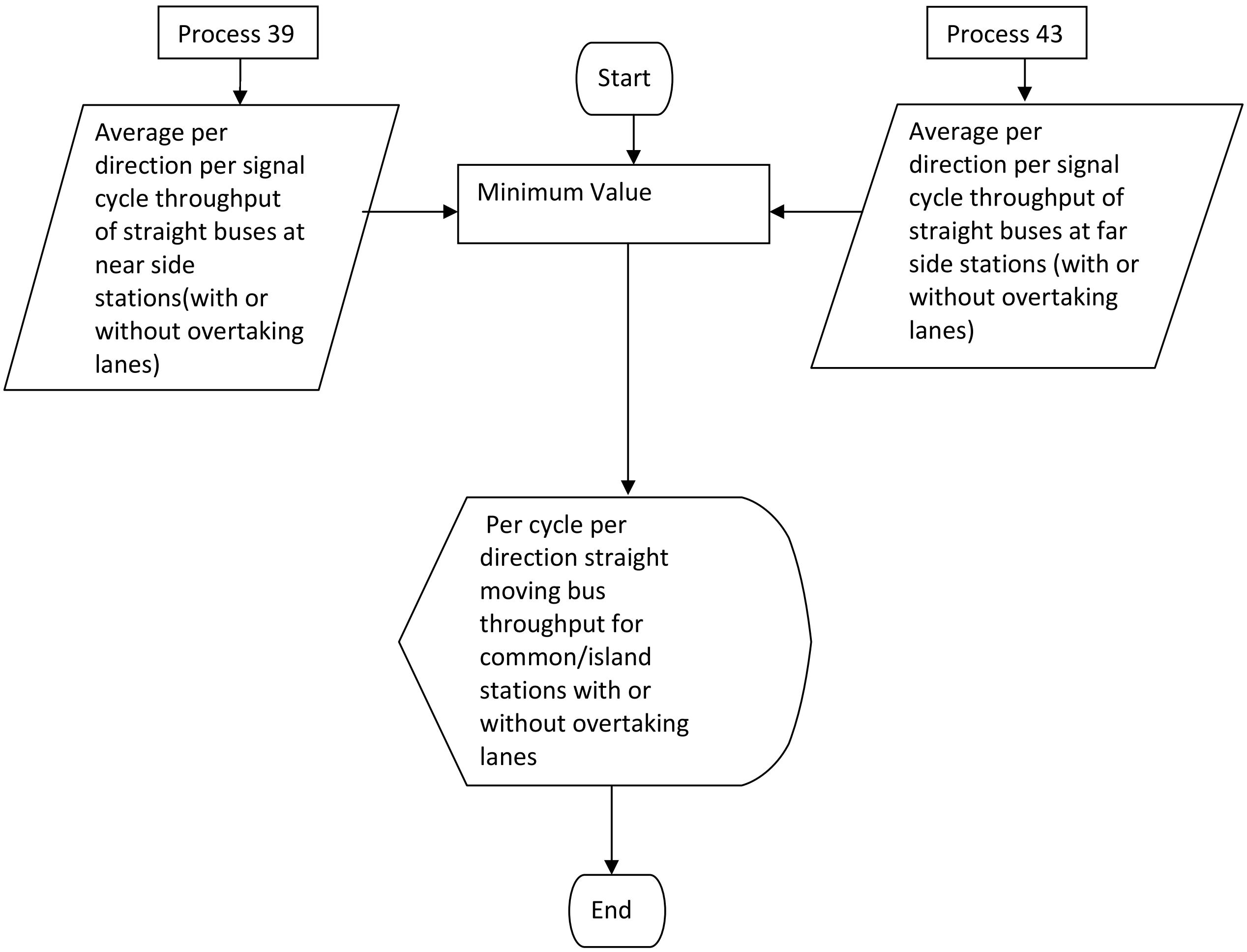


Figure 72: Flow chart for process no. 52 - Per cycle per direction turning bus throughput for common/island stations with or without overtaking lanes

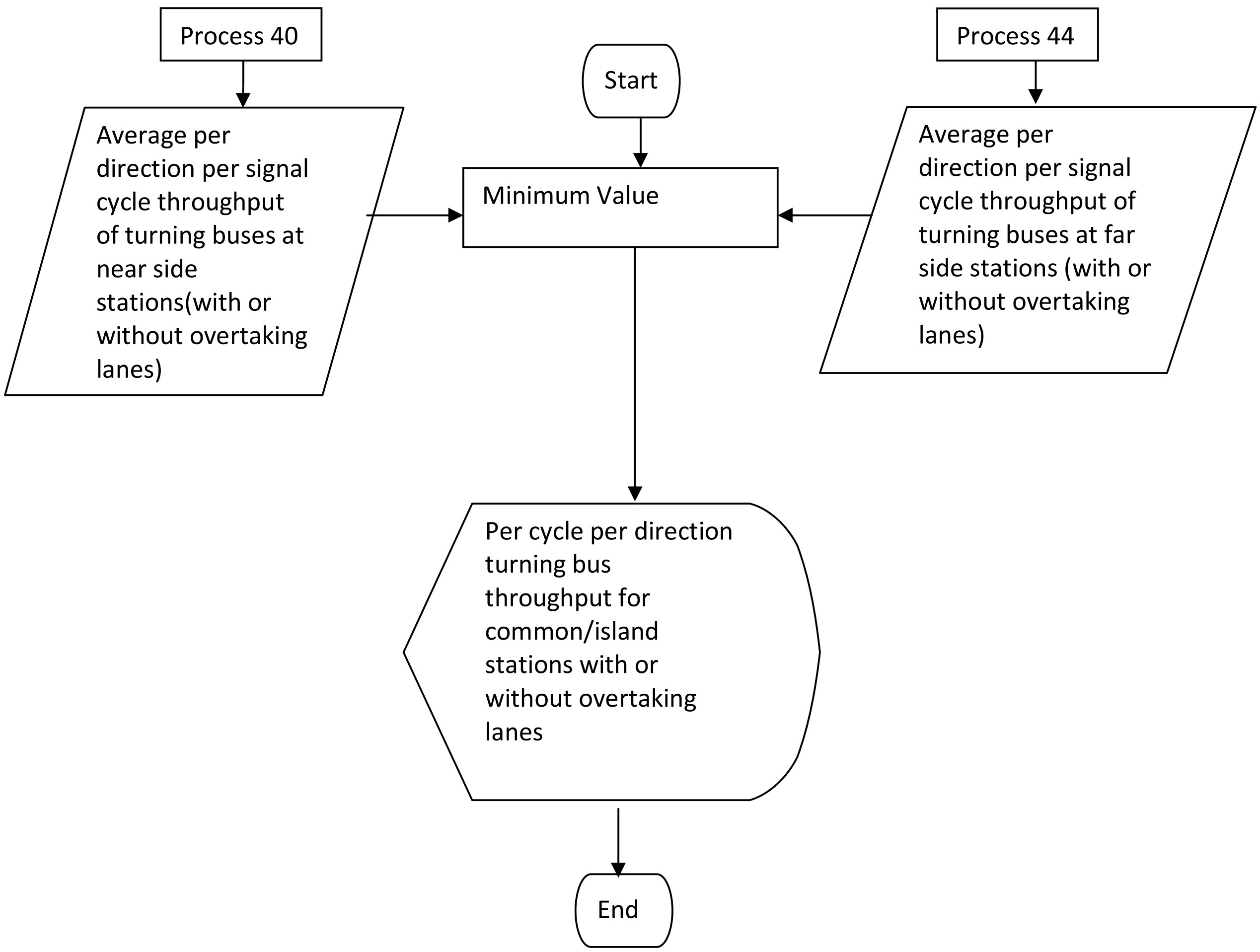


Figure 73: Flowchart for Process no. 53 - Straight moving average per bus per cycle per direction delay in sec for island stations without overtaking lanes.

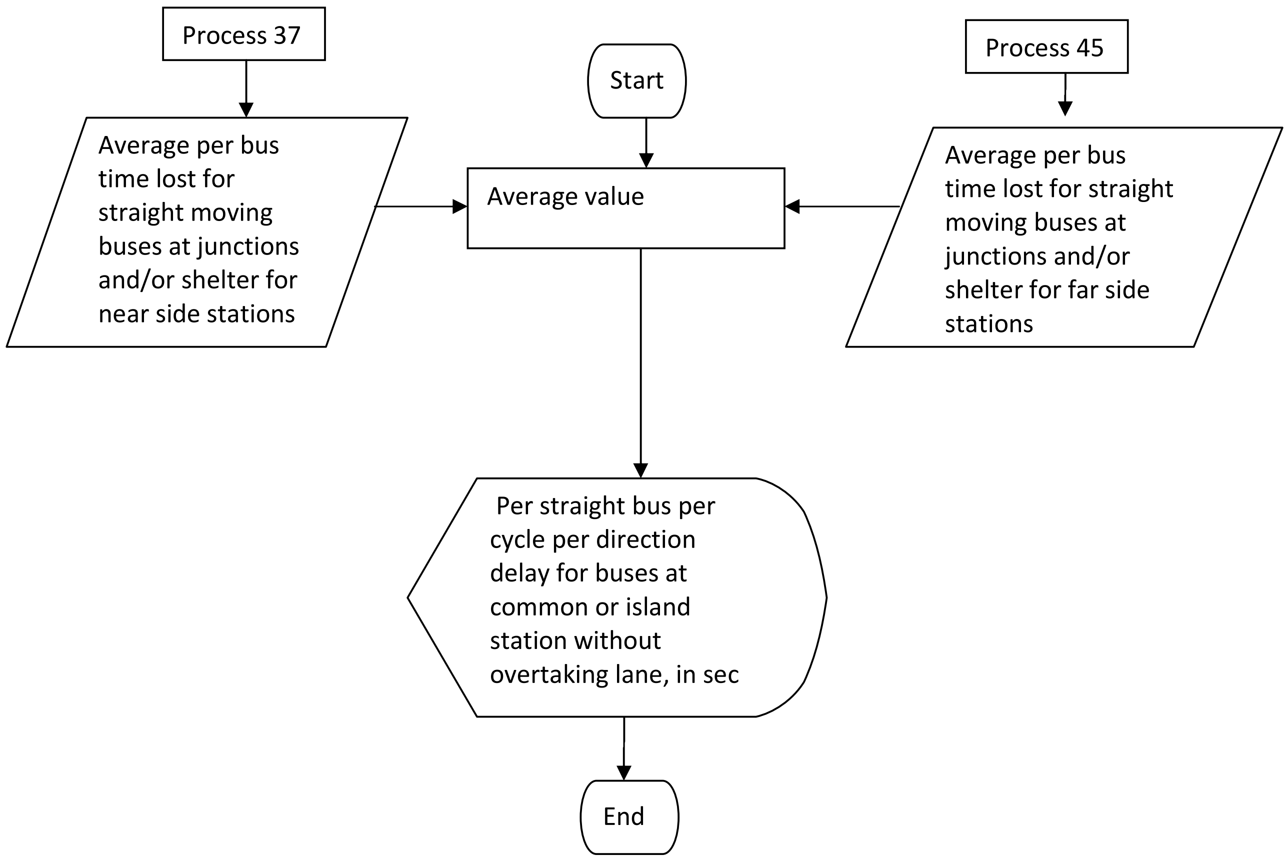


Figure 74: Flowchart for process no. 54 - Average per bus per cycle per direction delay in sec for island stations without overtaking lanes for turning buses.

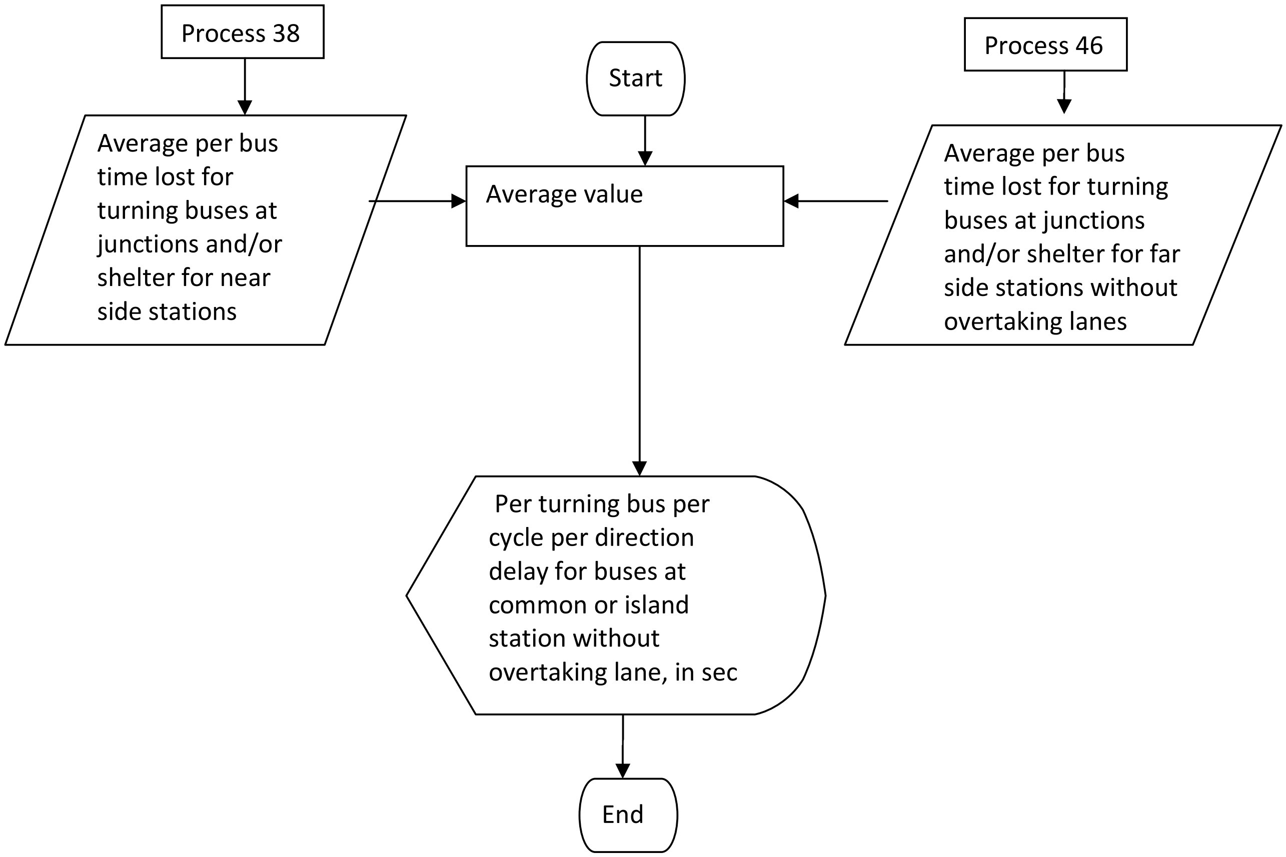


Figure 75: Flowchart for process 55 – Safe gap between buses on the corridor

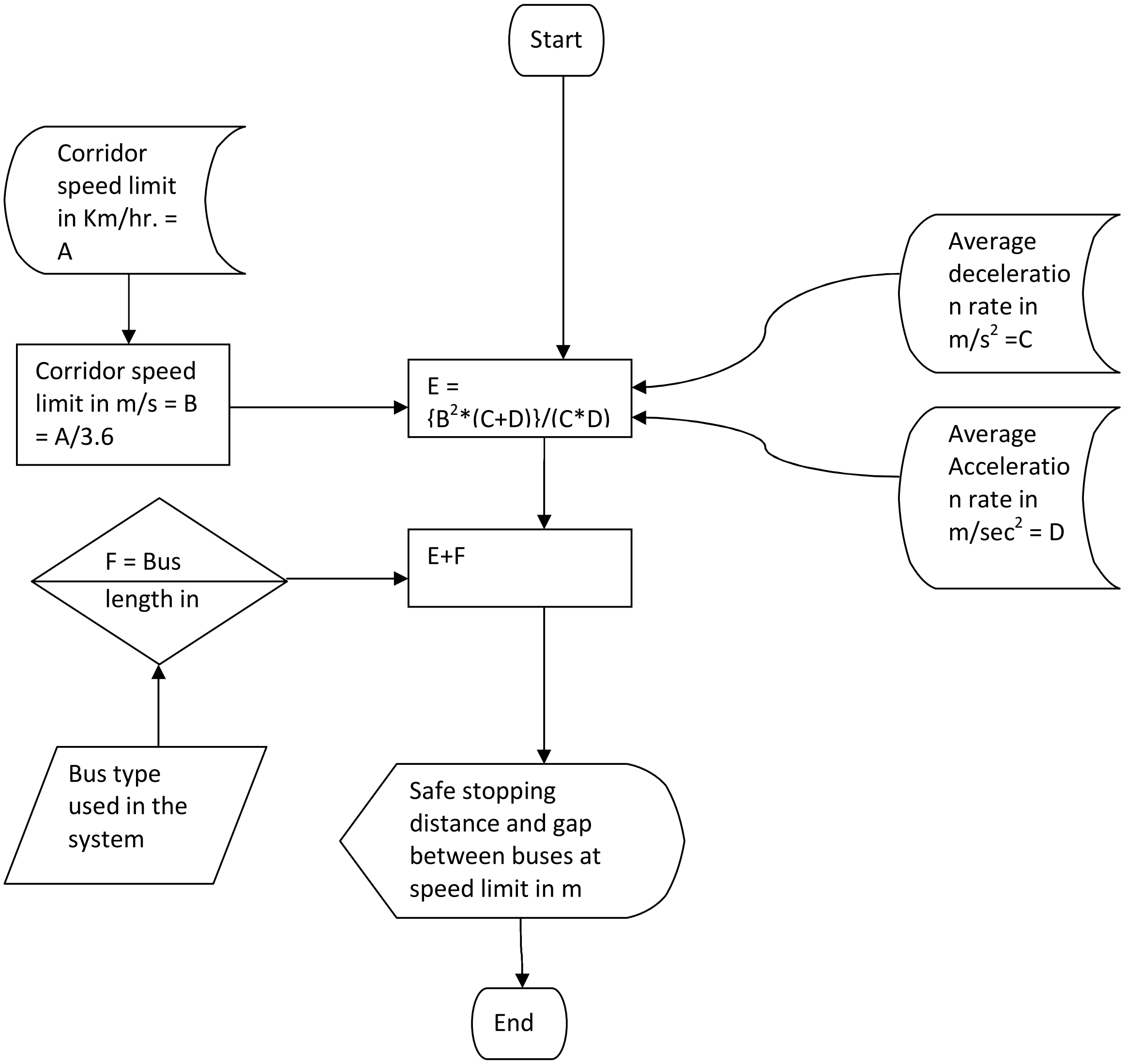


Figure 76: Flow chart for process 56 – Maximum no. of buses (per hour per direction) that can cruise in the corridor safely (maintaining safe gap between buses)

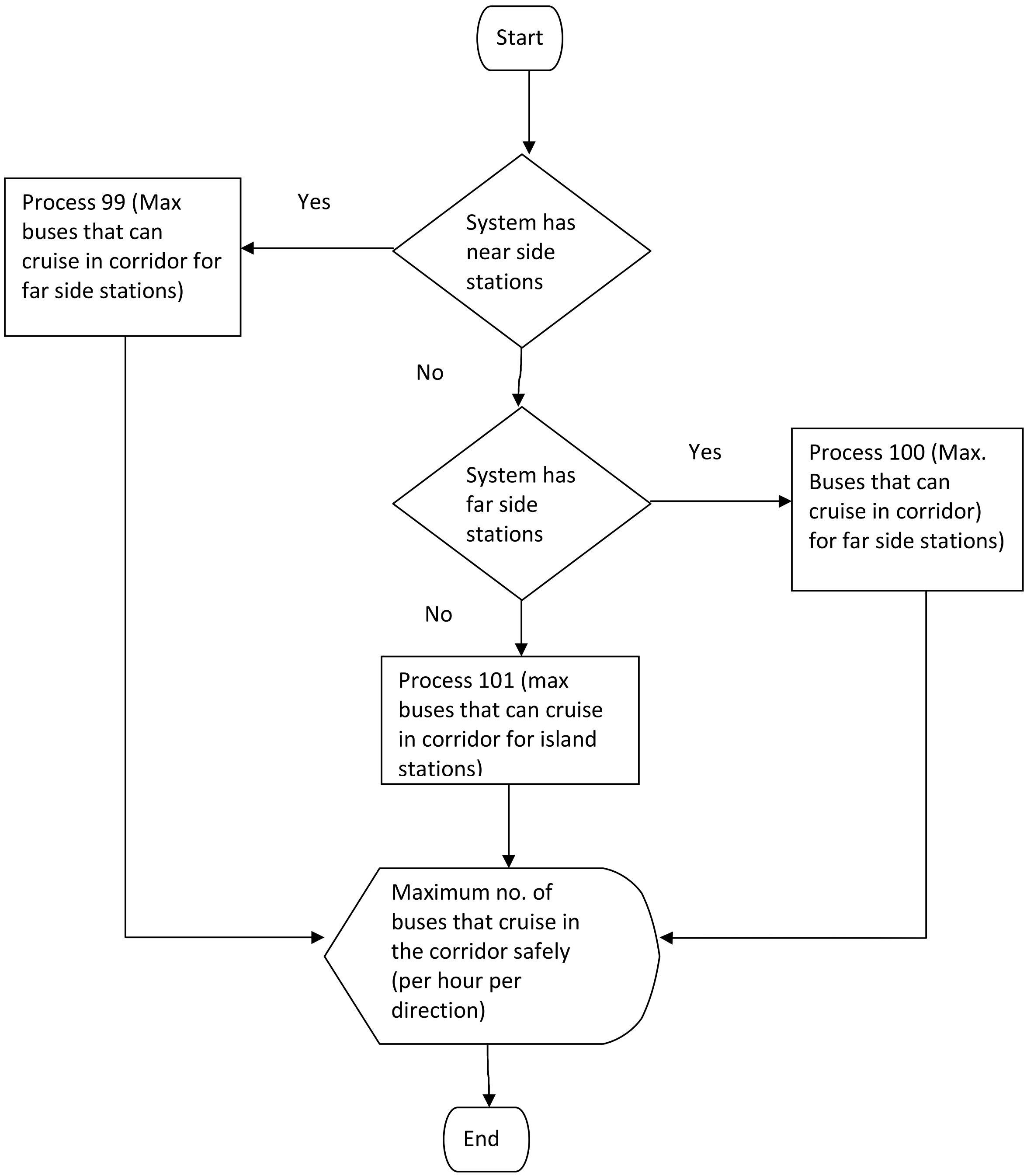


Figure 77: Flowchart for Process 57 – Maximum number of straight buses that can be throughput at an intersection signal cycle between two mid block stations.

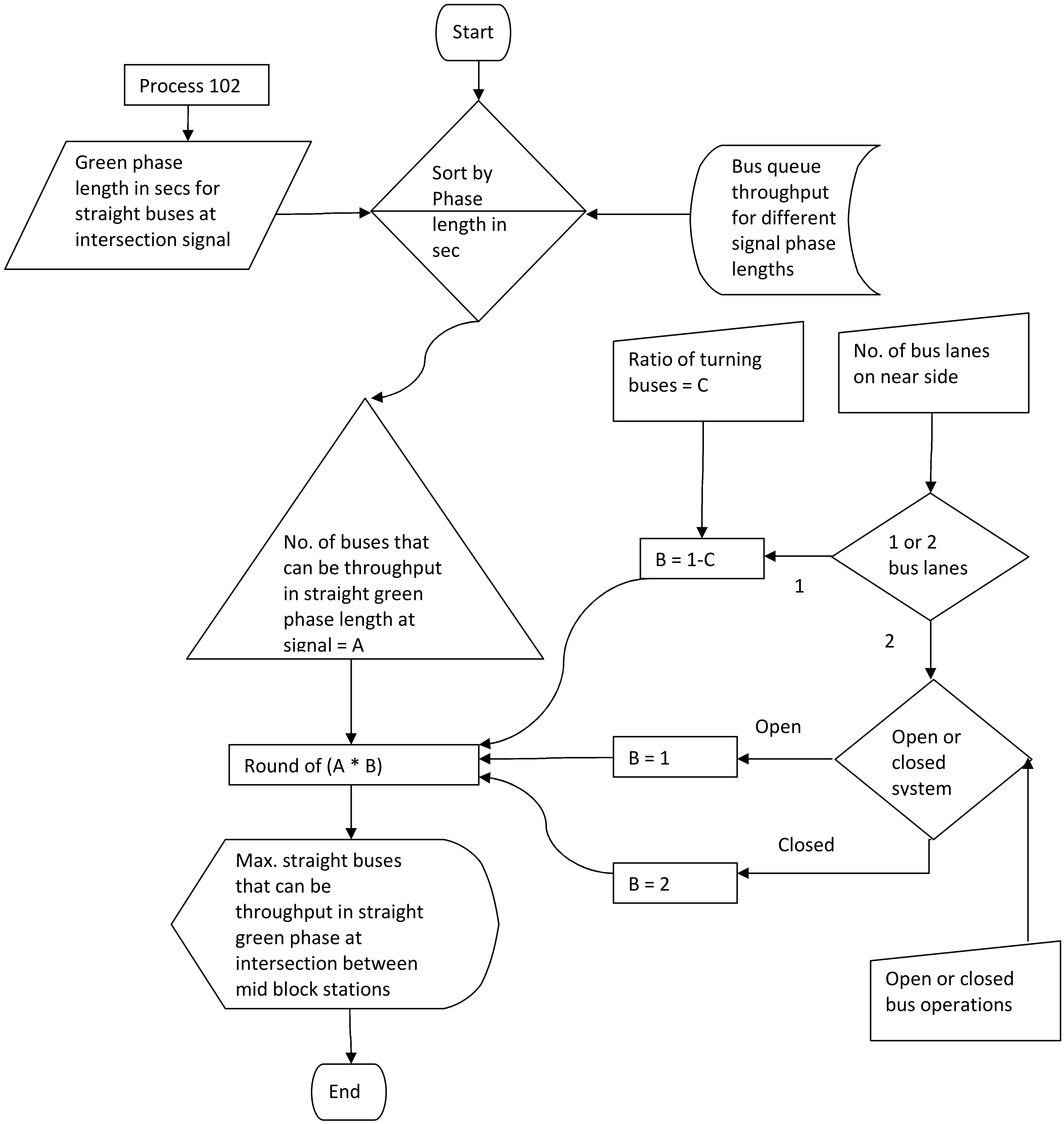


Figure 78: Flowchart for process no. 58 - Maximum number of turning buses that can be throughput at an intersection signal cycle between two mid block stations.

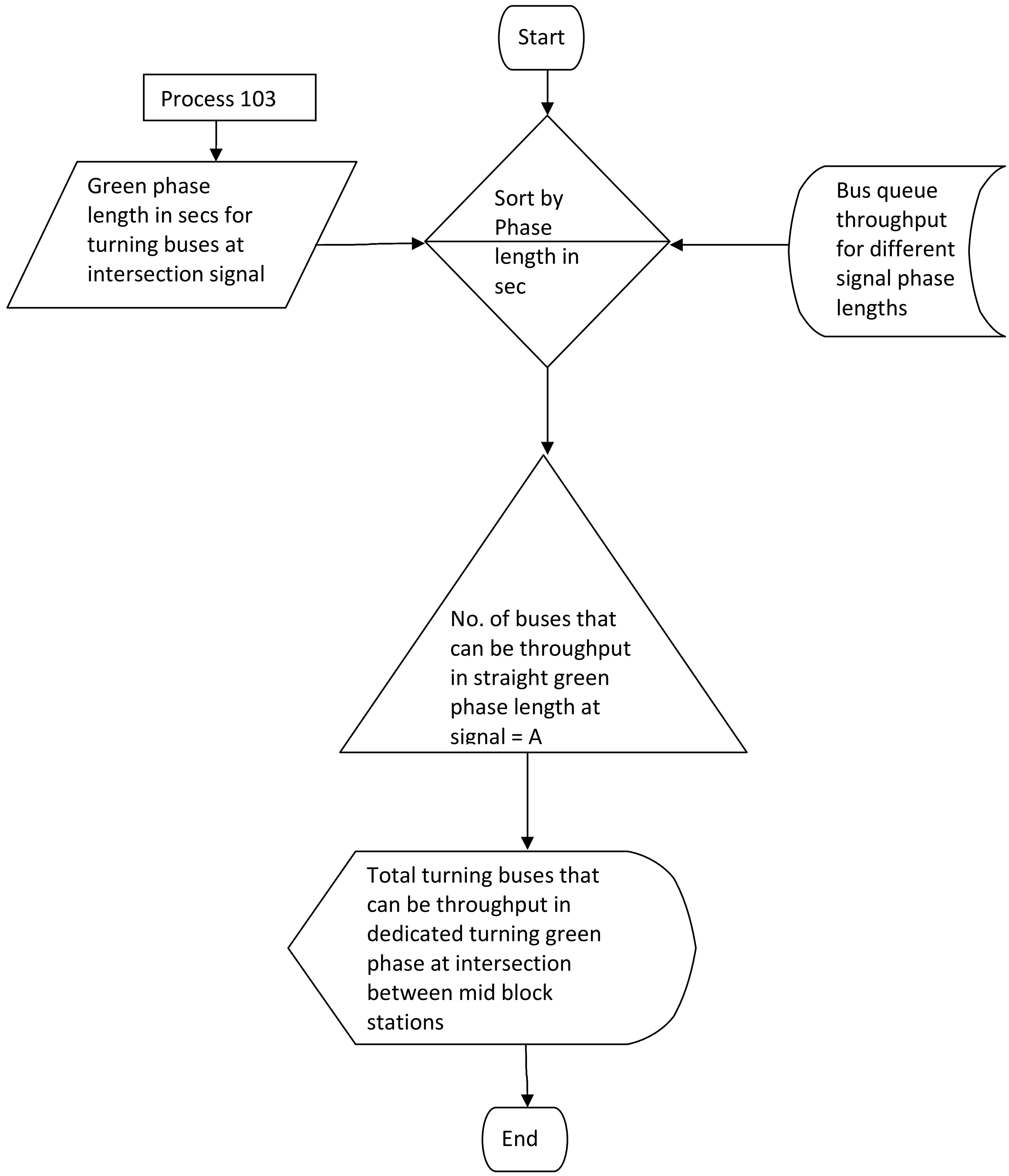


Figure 79: Flow chart for process no. 59 – Total red phase length for buses (excluding yellow) in seconds, for straight buses at vehicular intersection between two mid block stations.

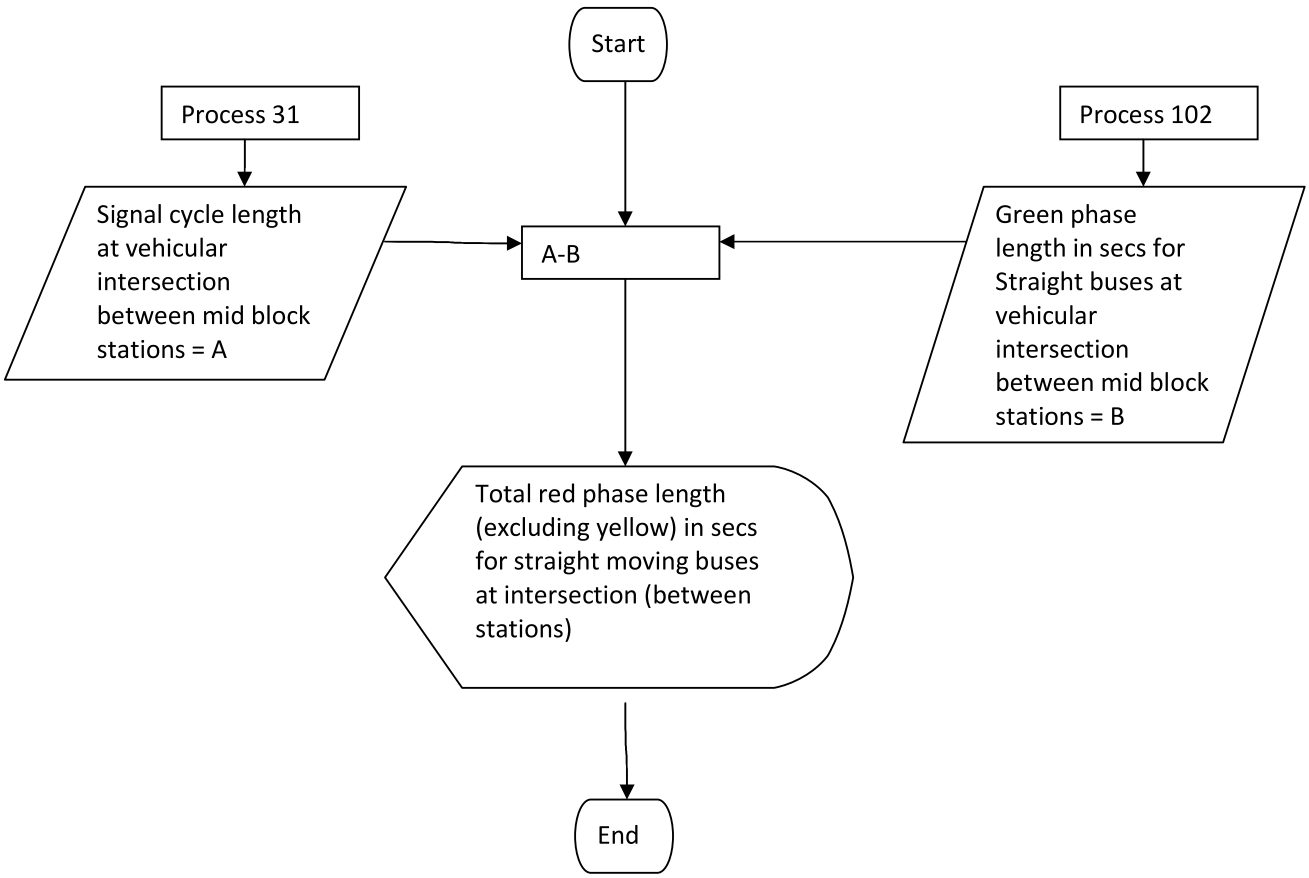


Figure 80: Flow chart for process 60 - Total red phase length for buses (excluding yellow) in seconds, for turning buses at vehicular intersection between two mid block stations.

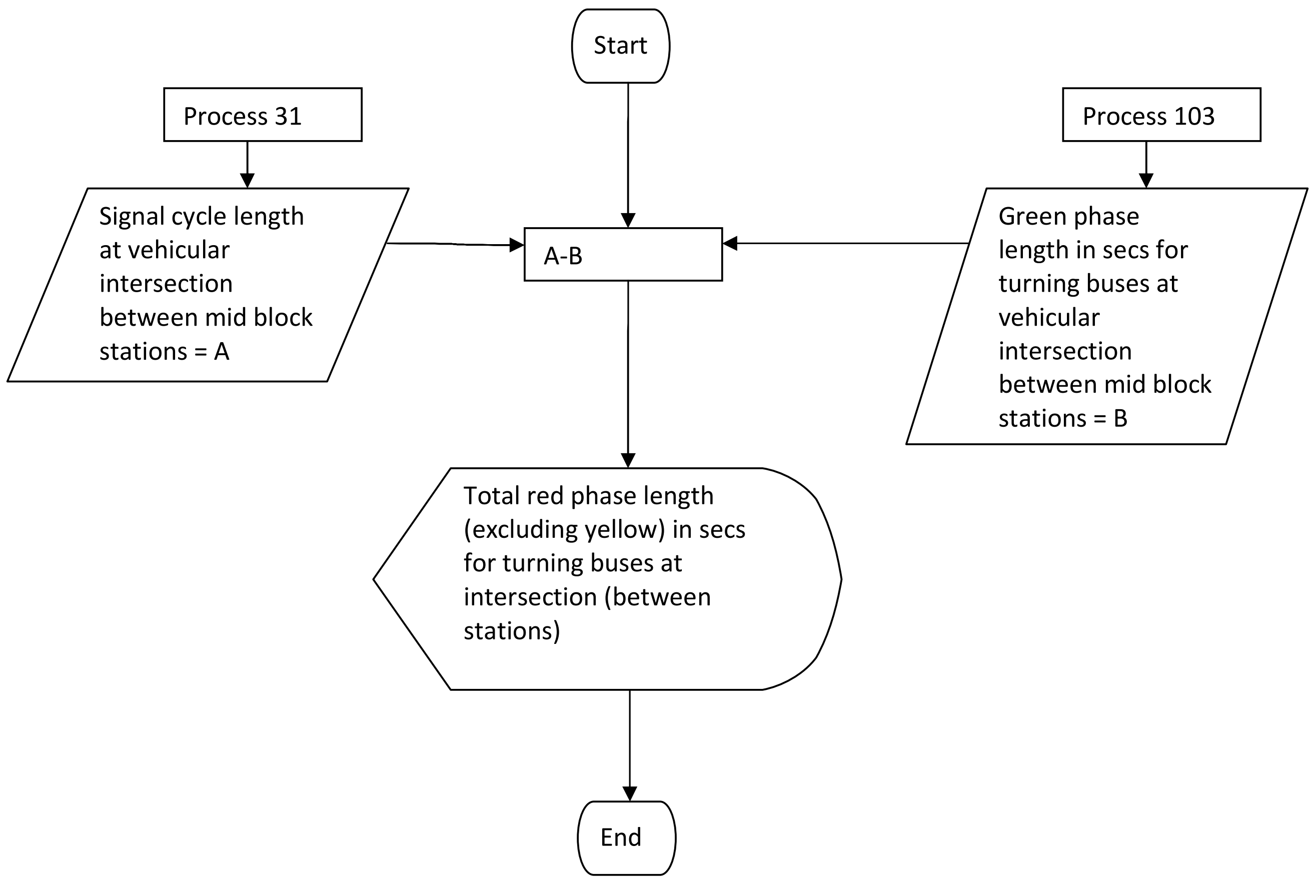


Figure 81: Flow chart for process 61 – Total no. of phases at Station Crossing Signal/ intersection signal

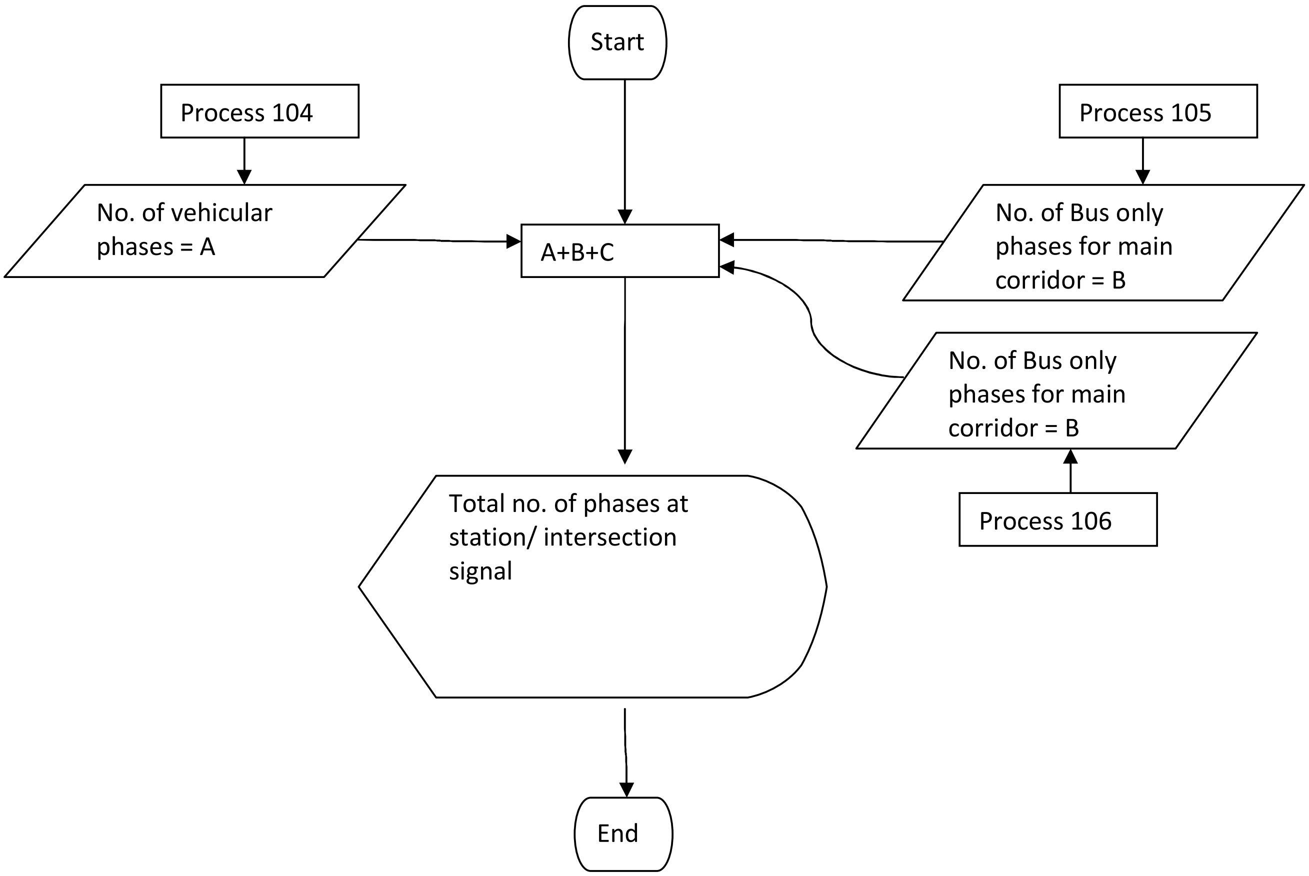


Figure 82: Flow chart for process 62 - Minimum Desirable signal cycle length in sec for station/junction signal with more than 2 phase signal cycle

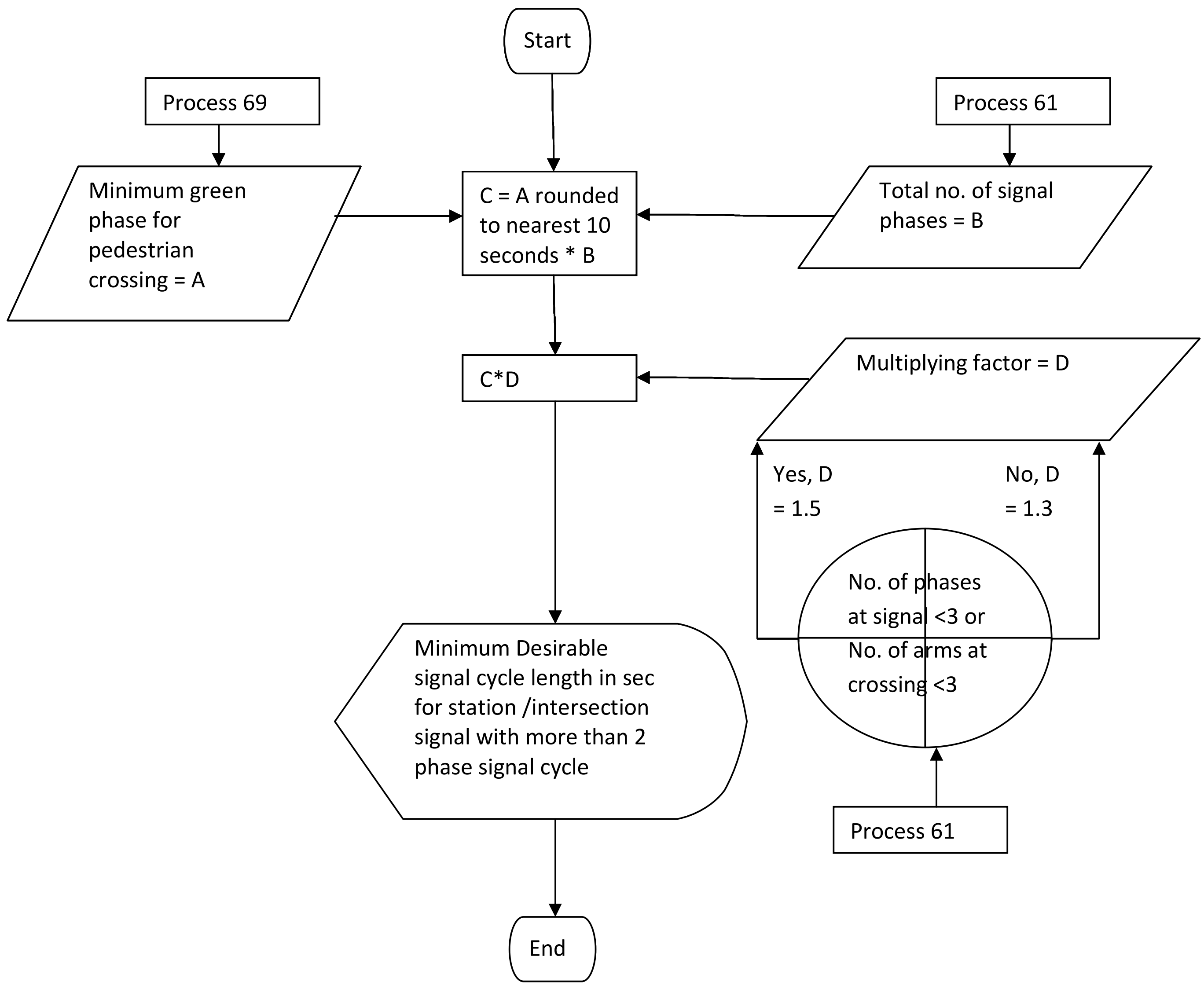


Figure 83: Flow chart for process 63 – Total no. of phases at Junction Signal between two mid block stations

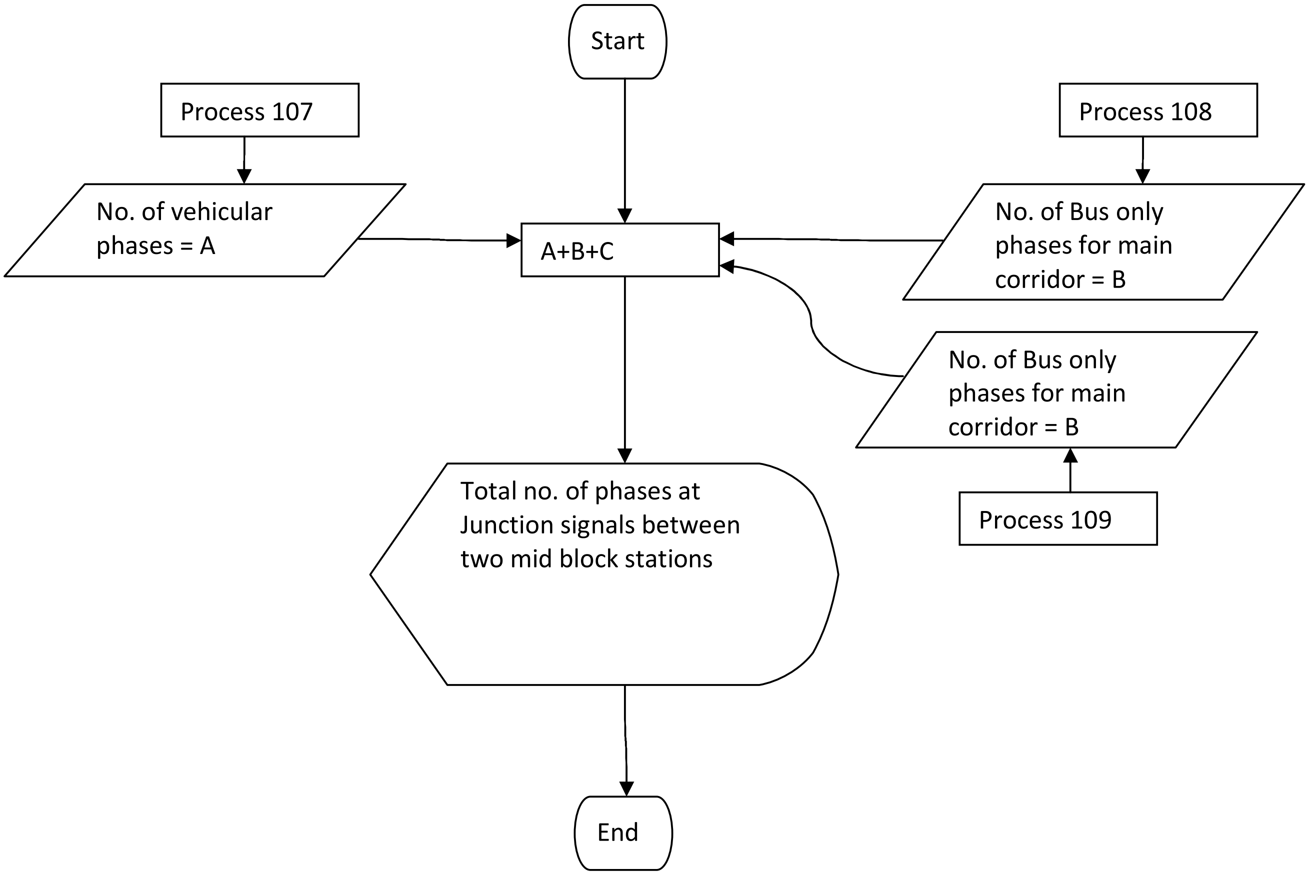


Figure 84: Flow chart for process 64 - Minimum Desirable signal cycle length in sec for station/junction signal with more than two phase signal cycle

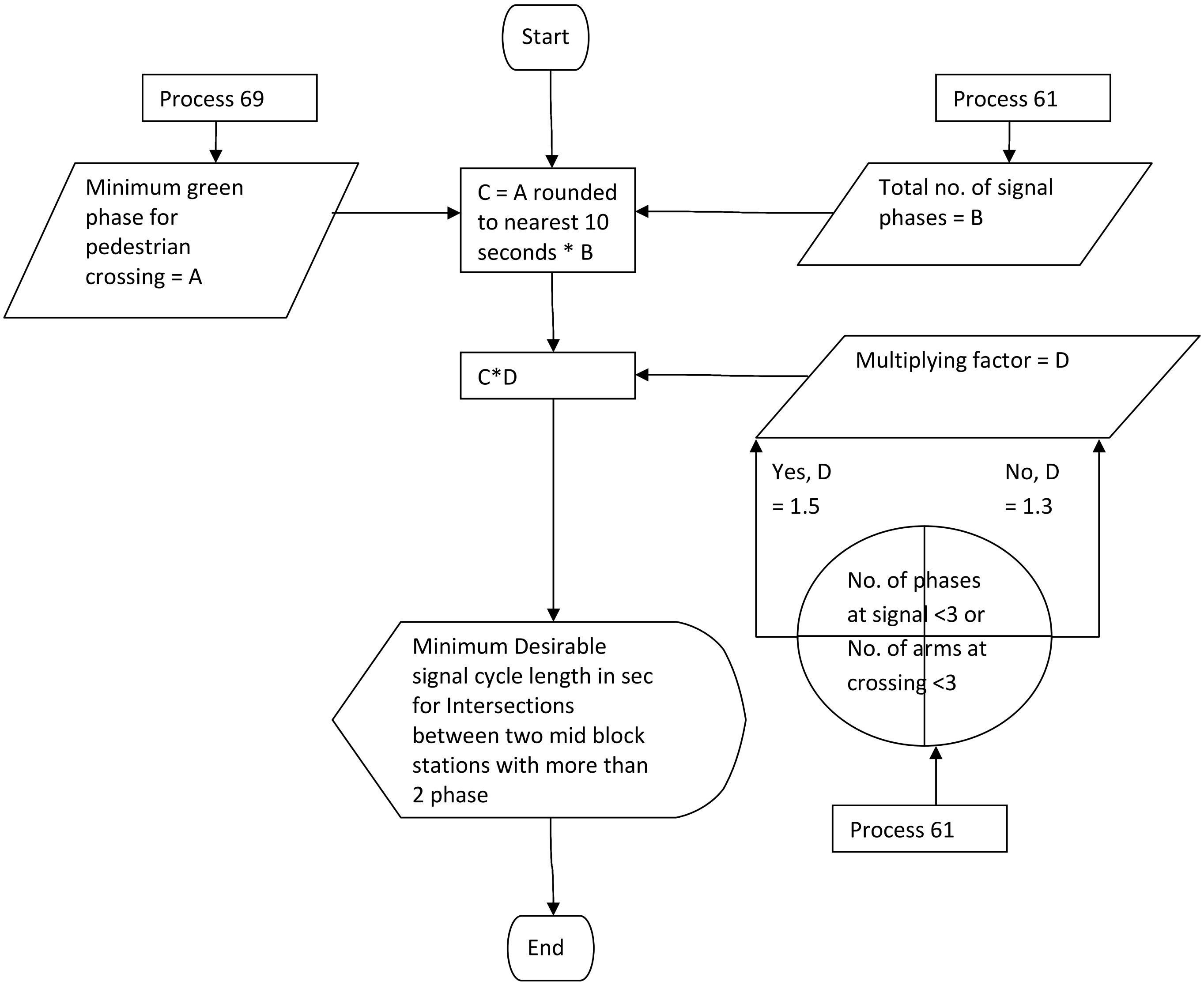


Figure 85: Flow chart for process 65 - Average one way access delay/time for passengers accessing Buses on BRTS station from median on the cross road (in sec)

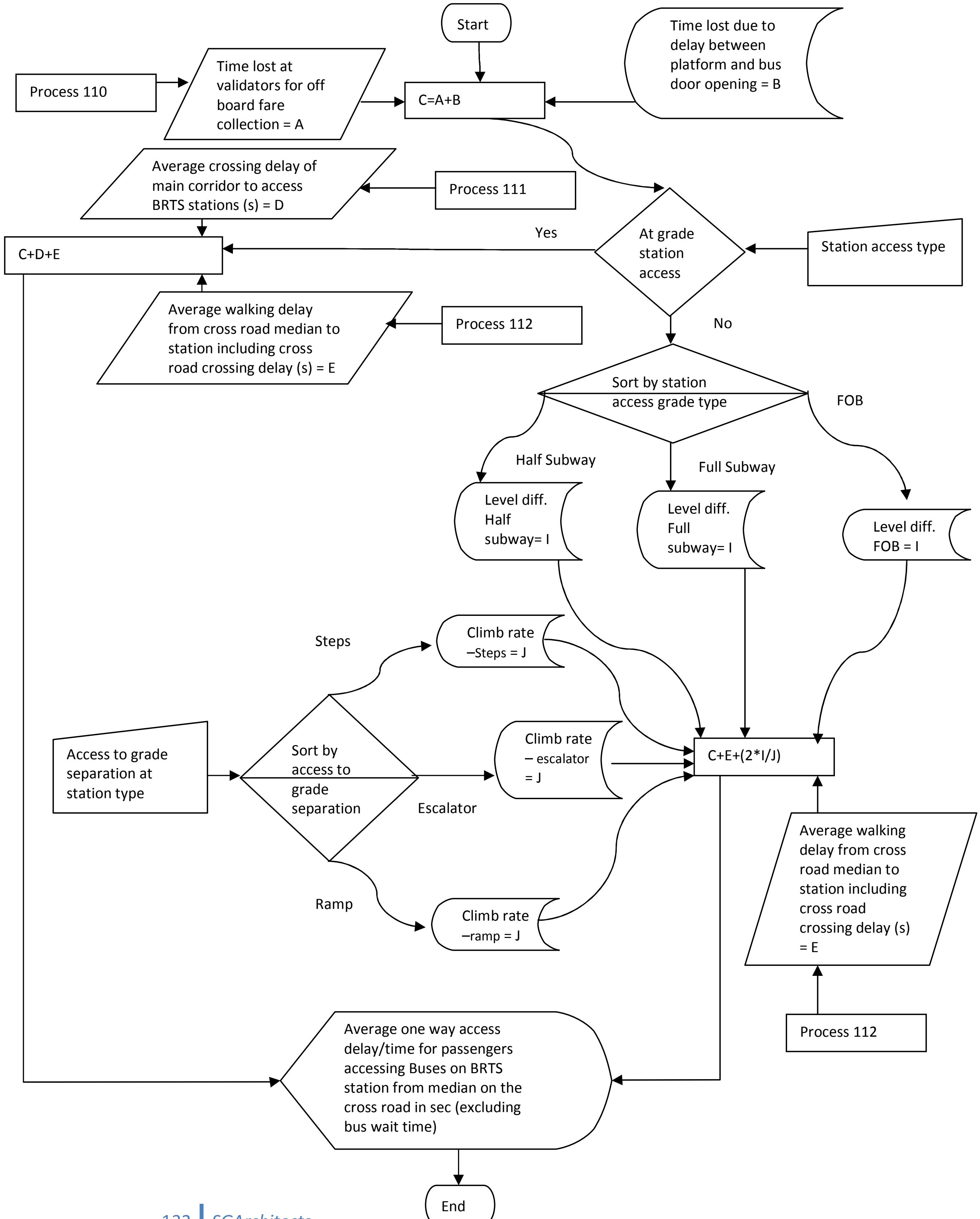


Figure 86: Flowchart for process 66 – Average wait time for buses (in sec) in open system

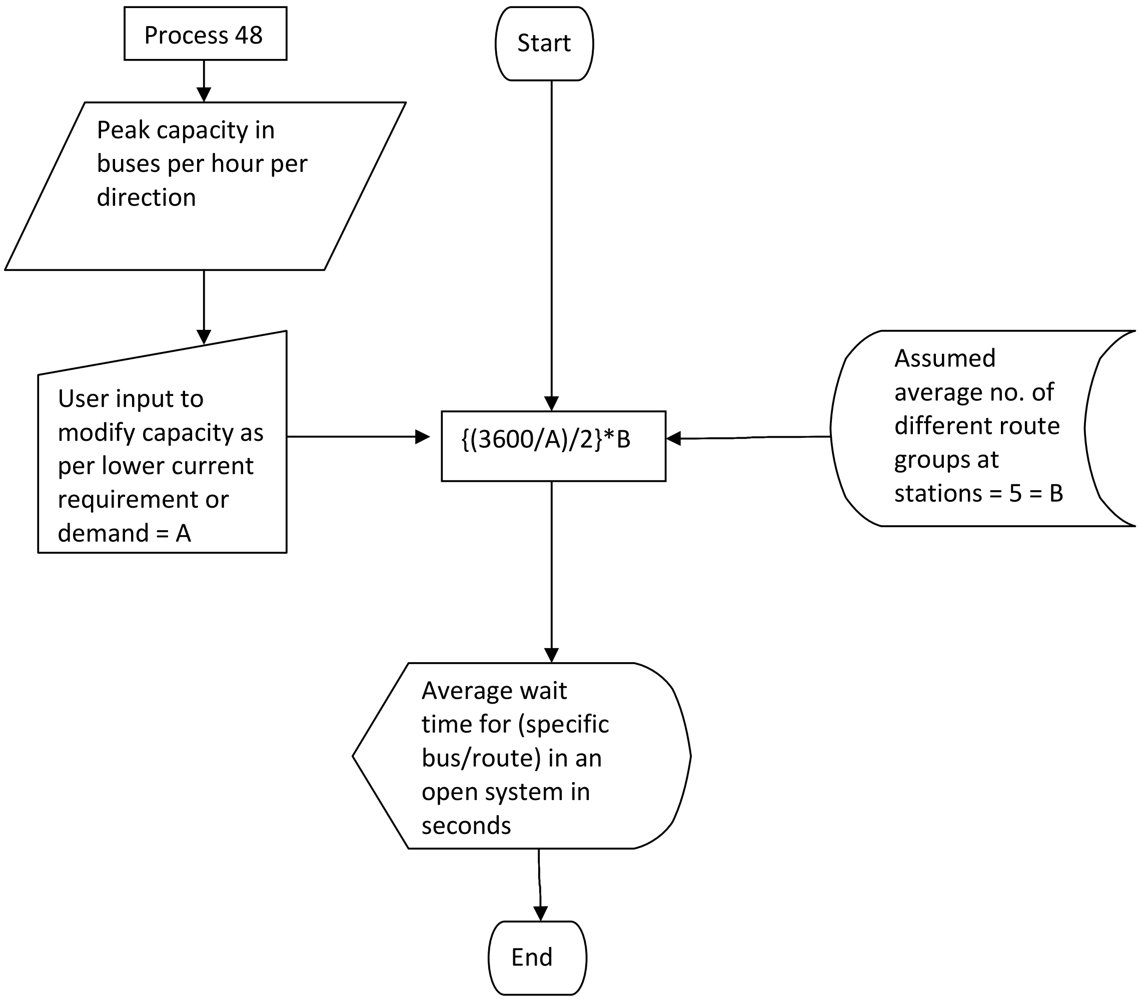


Figure 87: Flowchart for process 67 – Average wait time for buses (in sec) in closed system

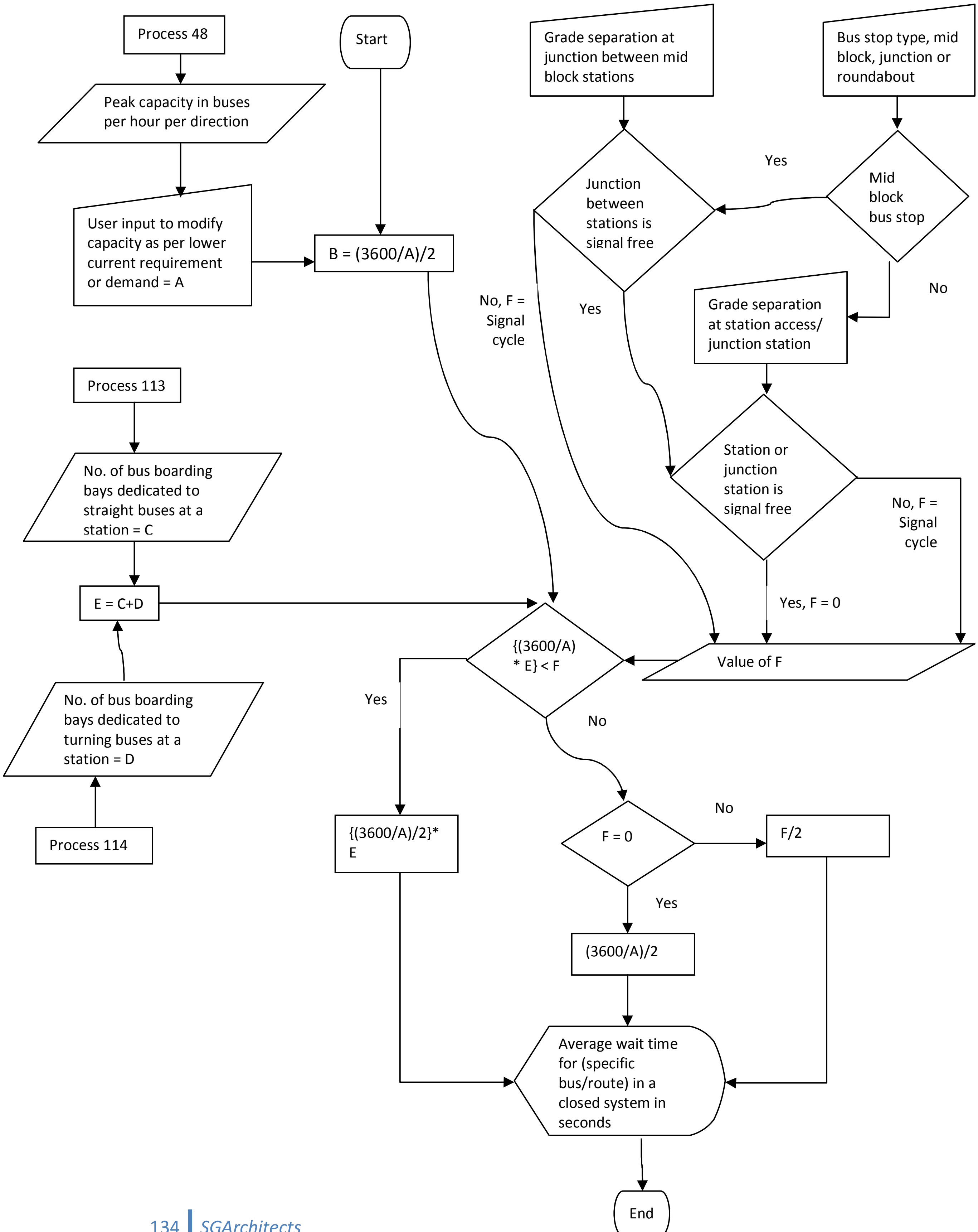


Figure 88: Flowchart for process 68 – Average crossing delay in sec, on cross roads (outside the corridor)

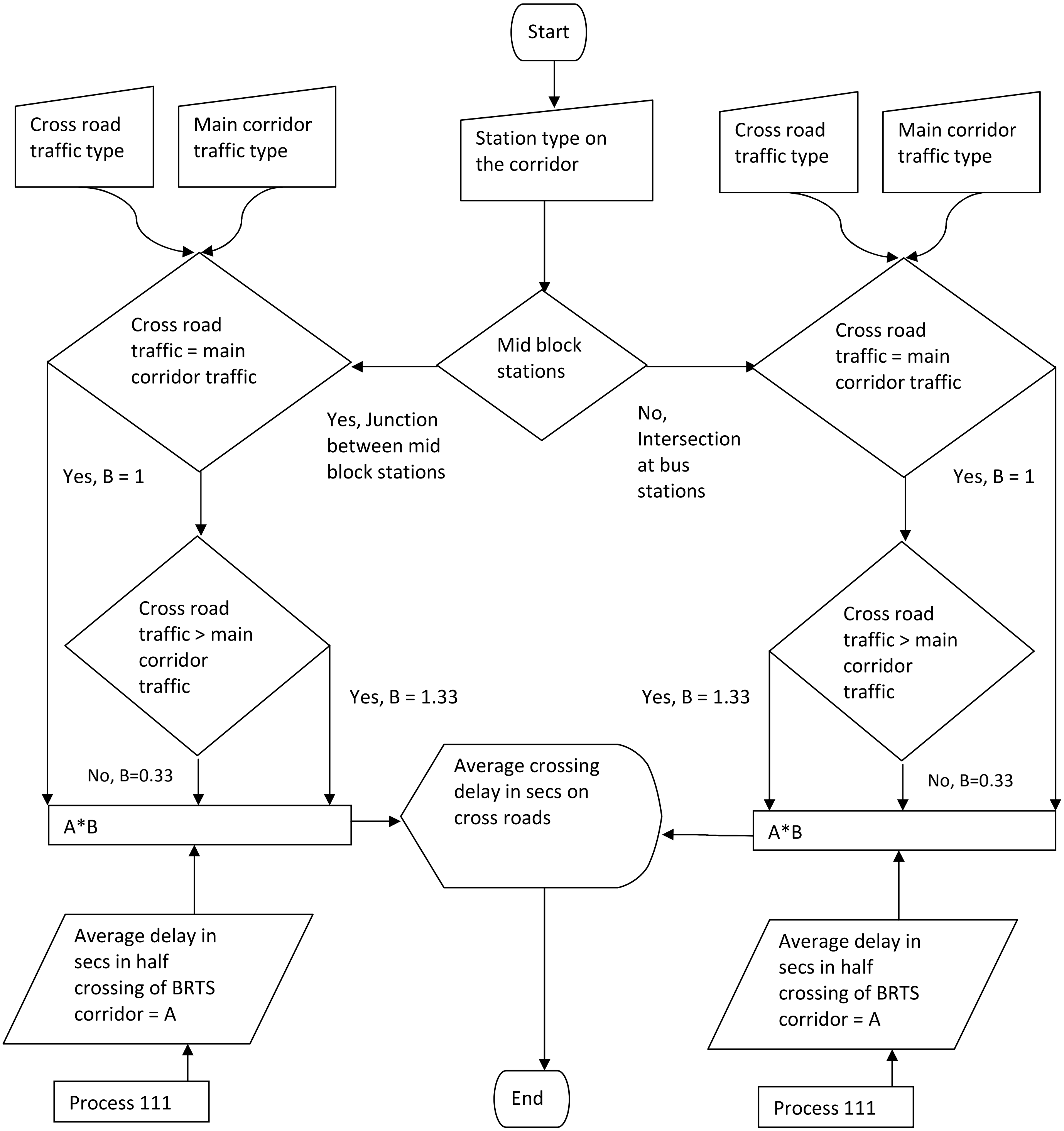


Figure 89: Flowchart for process 69 – Minimum green phase length for pedestrian crossing requirements in seconds.

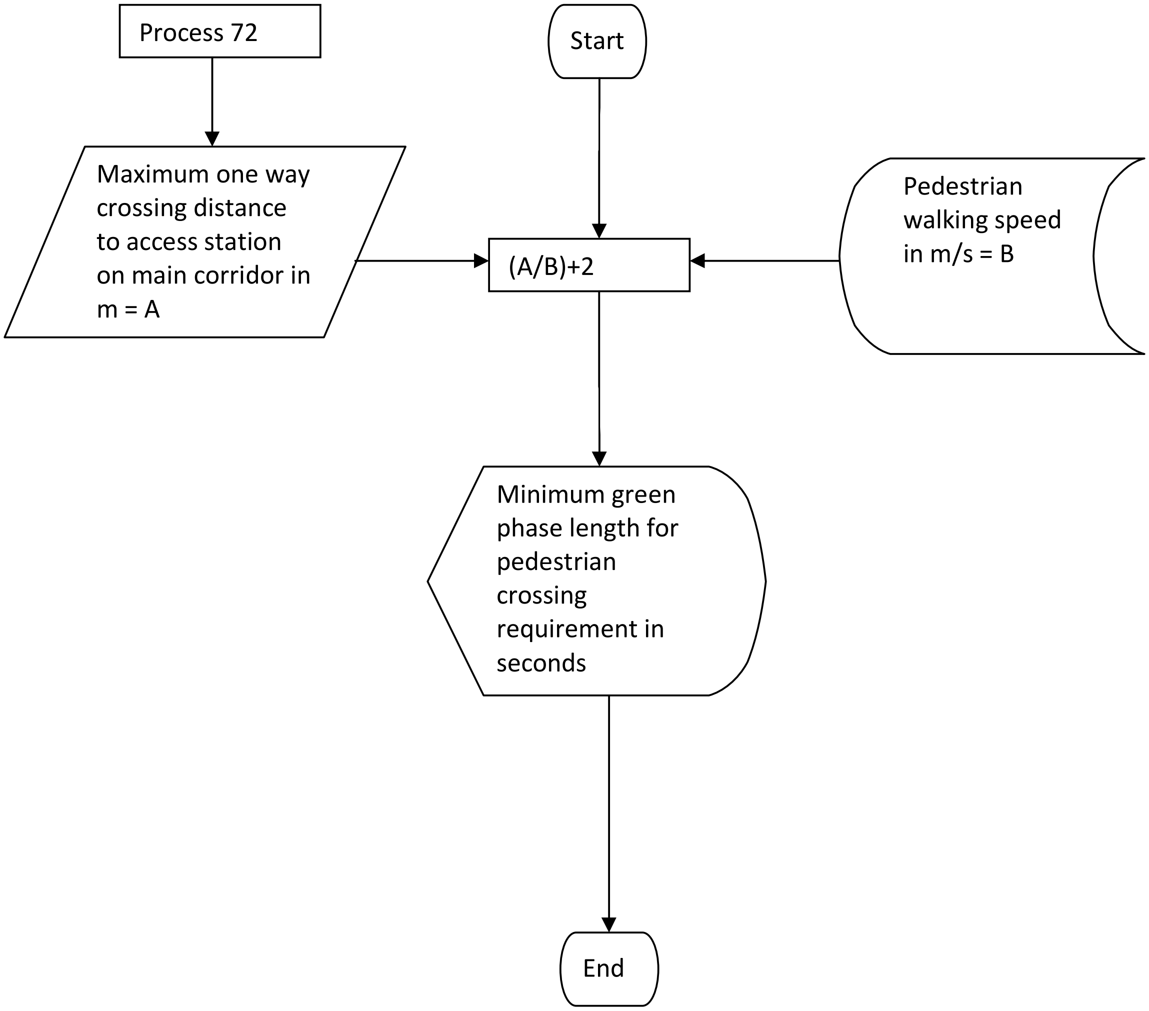


Figure 90: Flowchart for process 70 – Total time lost (in seconds) in acceleration and deceleration of bus to and from peak speed

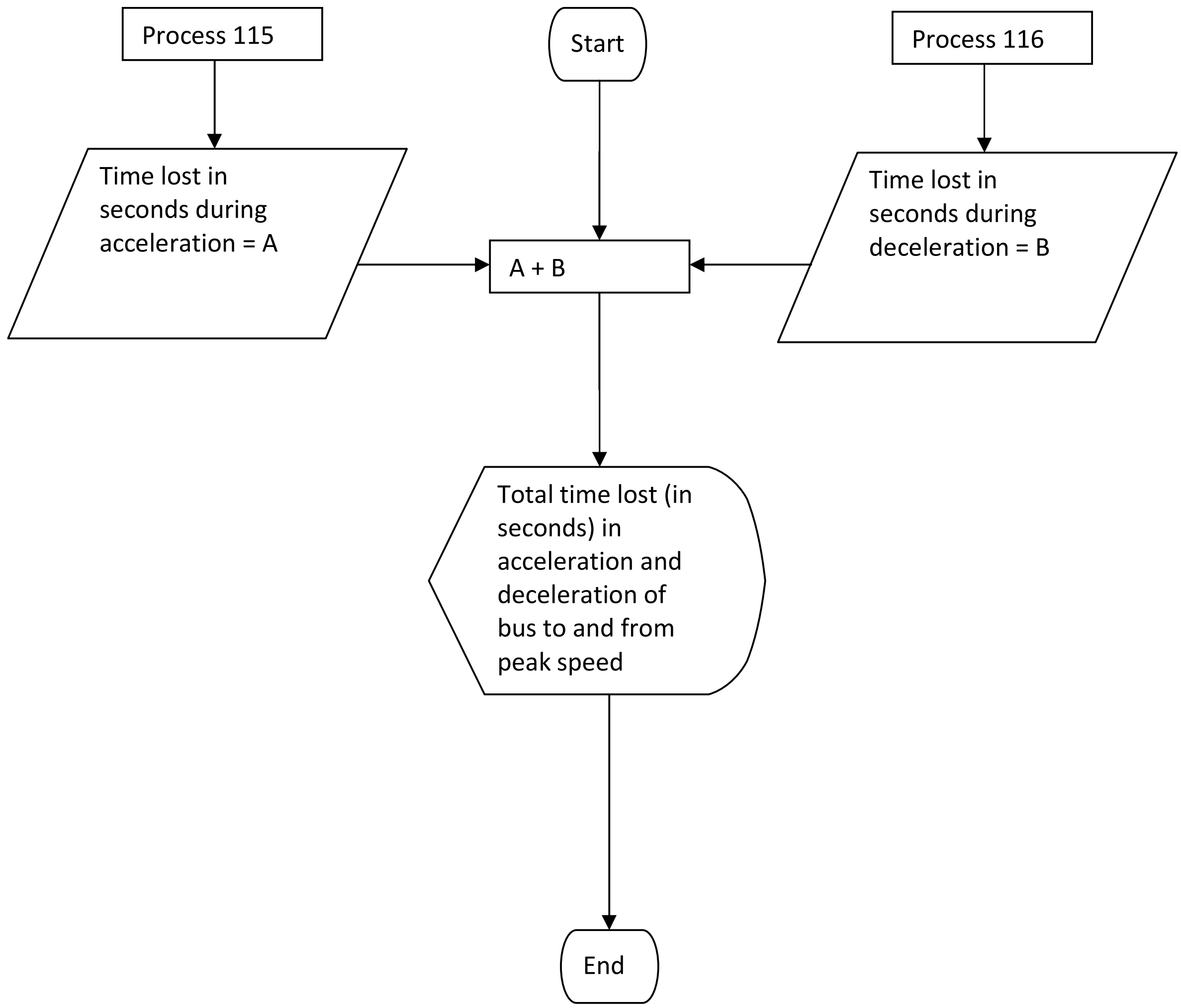


Figure 91: Flowchart for process 71 – Average dwell time for buses in seconds

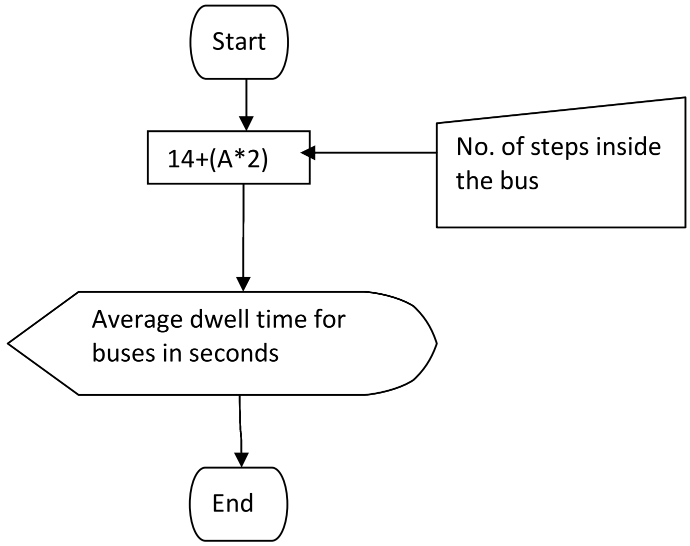


Figure 92: Flowchart for process 72 – Maximum crossing or access distance (in m) for passengers, in order to access the bus stop

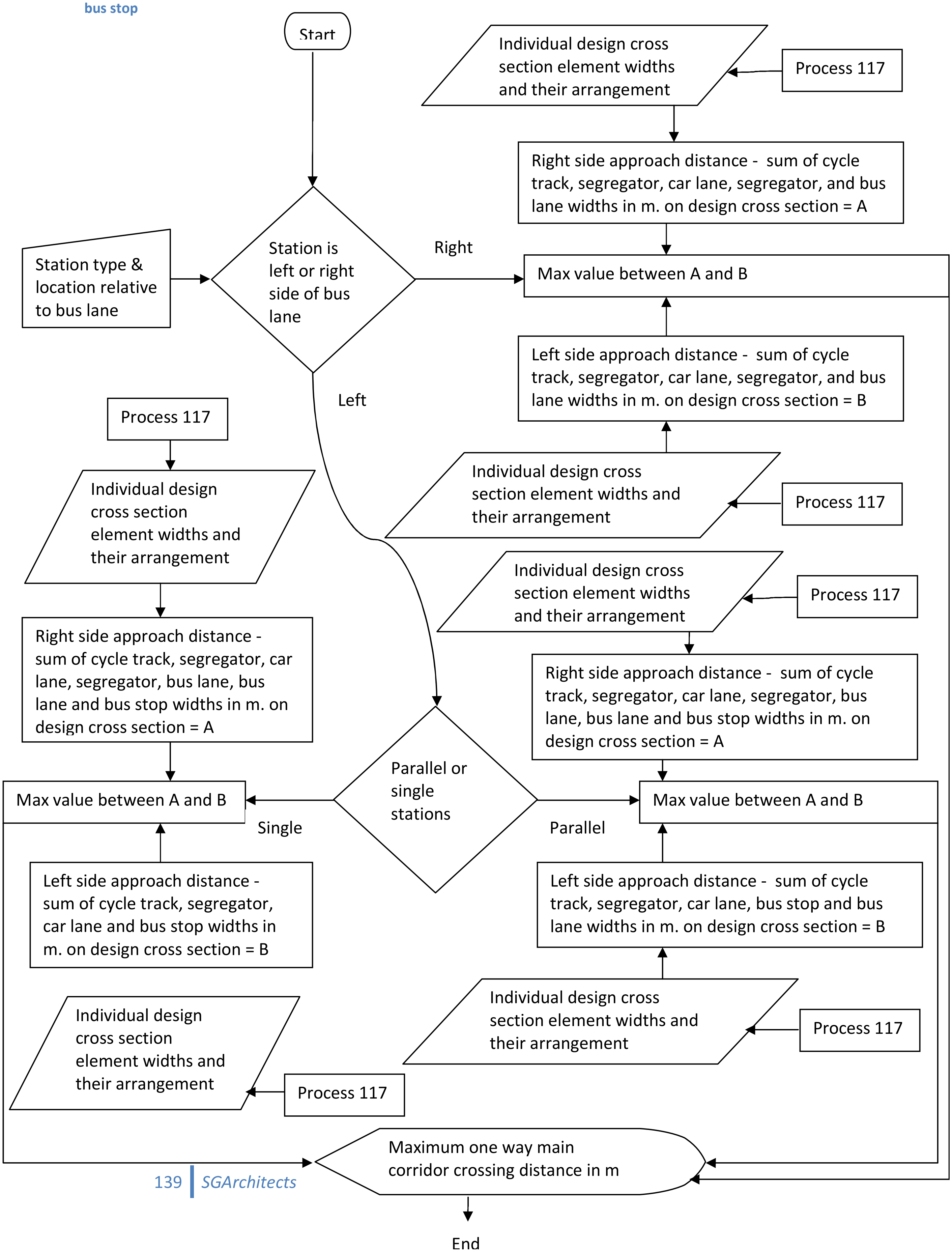


Figure 93: Flow chart for process 73 – Weighted average of straight moving bus delay at bus stop or junction bus stop signal.

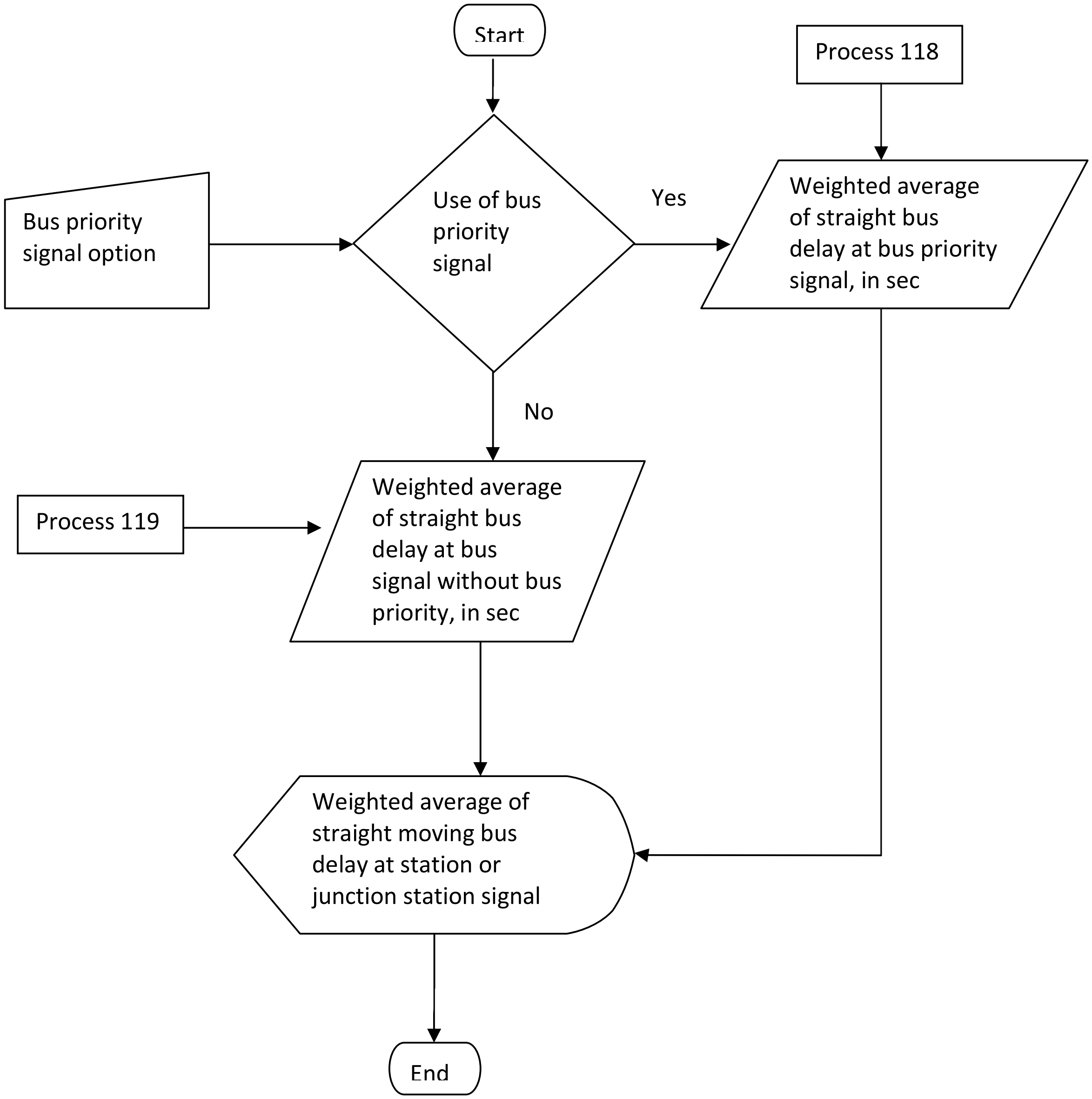
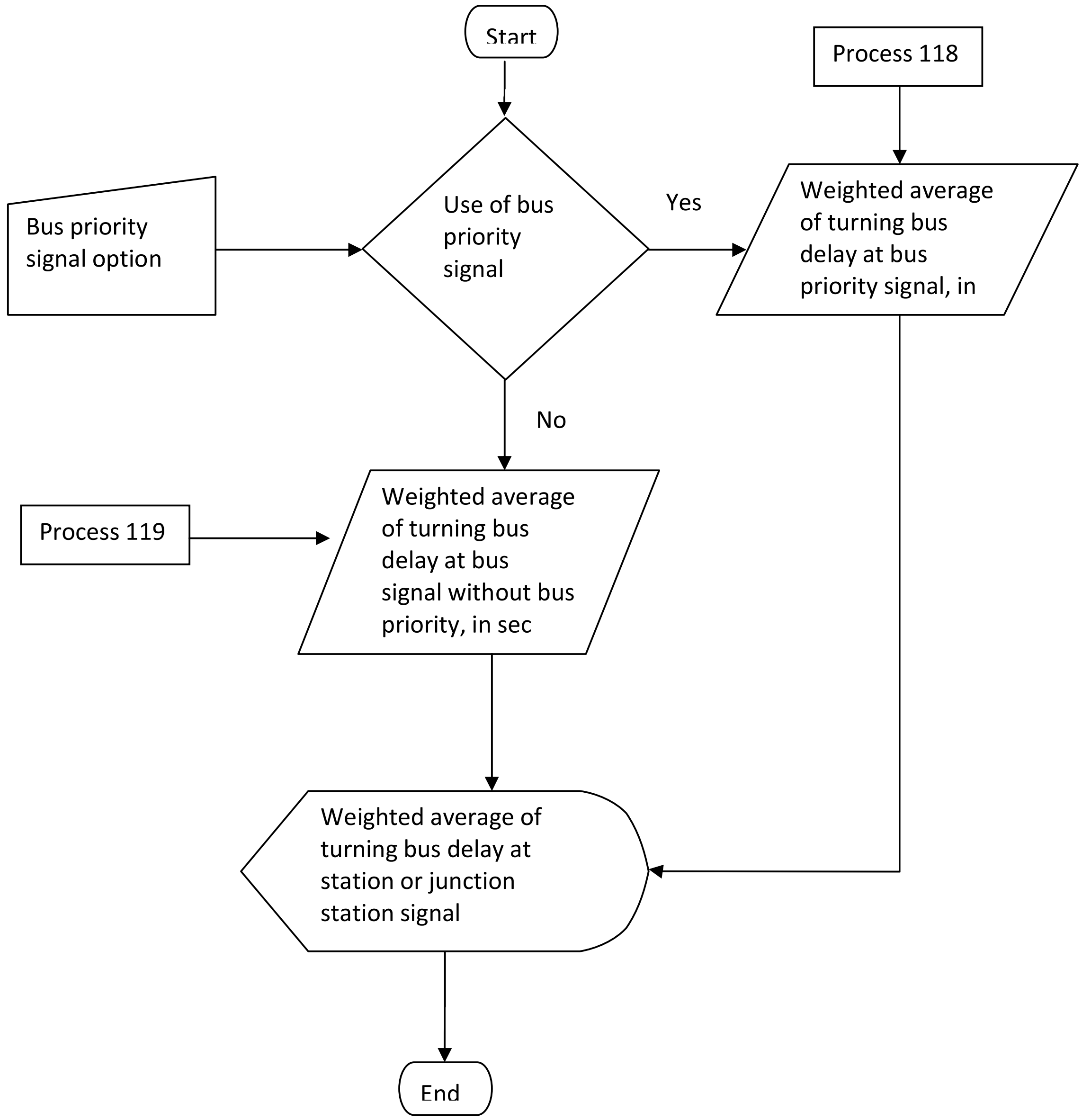


Figure 94: Flow chart for process 75 – Weighted average of turning bus delay at bus stop or junction bus stop signal.



Annexure 6: Methodology for Deriving Weightage for Different Performance Indicators Used for Determining Overall BRT System LOS by the Tool

Categorization of Performance Indicators in BEAD Tool

A total of 10 different performance indicators have been selected to contribute to the LOS value of the BRTS system being evaluated by the tool. These are:

11. **Attractiveness for Public Transport Users** – This indicator uses the ratio of passenger speed in the proposed BRTS system and that in the existing bus based or IPT based public transport. A higher ratio indicates better performance.

12. **Passenger Speed** – This indicator uses the absolute value of passenger speed (ratio of total O-D distance by total time spent by the passenger in the journey). A higher passenger speed indicates better performance

13. **Safety** – Empirical evidence shows that 1% increase in speed of motorized vehicles results in 4% increase in chances of a fatal accident. This is why the peak cruising speed limit of transit vehicle plays an important role in ensuring safety of pedestrians and other road users. Thus a lower peak speed limit for buses using BRTS is considered a better, as an indicator of safety.

14. **Walking Distance** – Longer walking or access/egress distances increase inconvenience which results in a higher perceived time (than actual time), reducing the attractiveness of public transport. Thus reduced walk distances are considered better in the overall performance of the BRT system being evaluated.

15. **Attractiveness for Private Two Wheelers** – Buses and typically BRTS systems present travel costs similar to the operational cost of motorized two wheelers. Thus a reduced passenger time in the BRTS than motorized modes is likely to attract mode shift from motorized two wheelers. Thus the ratio of passenger speed in buses to that of motorized two wheelers is considered as an indicator of the performance of the BRT system. A higher ratio indicated better performance.

16. **Capacity** – BRTS systems improve operational efficiency and attractiveness of bus transport by allowing a higher capacity than buses moving in mixed condition. Thus higher capacity is an indicator of better performance of BRT system

17. **Total Passenger Delay** – Passenger delay in the system directly effects inconvenience experienced by the user. Hence higher delays leads to lower attractiveness of public transport.

18. **Total Bus Delay (Station + junction time)** – Delay of buses in the system increases both actual and perceived (higher than actual) passenger travel time thereby reducing the attractiveness of the system. Thus lower average delays of buses are an indicator of better performance of the system.

19. **Operational Speed –** Higher average operational speeds reduce perceived passenger travel time though its effect on the actual travel time may be limited. Thus higher operational speeds are indicators of better performance of a BRTS system.

20. **Ratio of in-vehicle to access time** – Because walking speeds are less longer and effort involved is considerably higher than the speed of a feeder service in mixed condition which is considerably lower than the speeds of transit in the BRTS corridor; it is considered that access time should be comparatively shorter than in vehicle time. Therefore a higher than 1 ration of in-vehicle time to access time is an indicator of better performance by the system.

The above indicators can be broadly divided in to three categories, that is societal indicators, user indicators and operator indicators. Societal indicators are those where the better performance results in the benefit to the society on the whole. User and operator indicators are those which benefit passenger and operators respectively. The above 10 indicators have accordingly been divided in to the three categories below.

1. **Societal Indicators**

    a. Safety – As road users outside the vehicle stand to gain from reduced risk of accident

    b. Attractiveness for Private two wheelers – As population on the whole will benefit from reduced, air and noise pollution, reduced sprawl etc.

2. **User Indicators**

    a. Attractiveness for Public Transport Users – As existing public transport users benefit

    b. Passenger Speed – As user travel time reduces

    c. Walking Distance – As user inconvenience reduces

    d. Total Passenger Delay – Reduced delay reduces user perceived journey time

    e. Ratio of in vehicle to access time – As a higher ratio increases attractiveness for use by passengers, due to reduced inconvenience and journey time.

3. **Operator Indicators**

    a. Capacity – Higher capacity will result in reduced fleet size and higher operational efficiency

    b. Total Bus Delay – Reduced delay will reduce fuel consumption, improve driving cycle and operational efficiency

    c. Operational Speed – Higher operational speed will reduce fleet requirement, and result in higher operational efficiency

Assigning Weights to Indicators

Weights have been assigned using the Analytical Hierarchy Process (AHP) to by first assigning relative weights on a scale of 1 to 9 to each category and then using the process to assign the weights to each indicator within the category. These have been then assimilated using AHP to arrive at the overall weight for each indicator. The relative scales used are as follows:

1 – Indicates equal weightage

3 – Indicates moderately preferred

5 – Indicates strongly preferred

7 – Indicates Very Strongly Preferred

9 – Indicates Extremely Strongly Preferred

Assigning Weights to Each Category

In assigning weights to each category it is understood that the highest weights should be given to societal indicators, followed by user indicators and lastly to operator indicators. This is because the scale and type of benefit follows this trend from the overall population to the bus user set to a few individuals/companies which gain commercial advantage.

The categories are compared as the following sets and the comparative results presented in a matrix for each set:

- Societal Indicator – User Indicator
- User Indicator - Operator Indicator
- Societal Indicator – Operator Indicator

Societal Indicators to User Indicators Comparison

Here Societal indicator is moderately preferred to User indicator as when compared in the city the size of bus user population is substantial ratio of the city population.

User Indicators to Operator Indicator Comparison

Here user indicator is strongly preferred to operator indicator as patronage of a transit system by the user also has a strong effect on the operational efficiency of the system. Thus patronage of a public transport system would improve fare box collection and reduce dependence on subsidies.

Societal Indicators to Operator Indicators Comparison

Here Societal indicator is very strongly preferred to operator indicator as when compared in the city the advantage to the overall population should be considered much higher than the commercial advantage to a few. It is also important that the advantage toe population also has a relationship to the performance of the operators, and there dependence on external subsidies.

Using these relative score the weights of each category can be derived using AHP, as following:

[Categories]

	Societal	User	Operator
Societal	1	2	5
User	0.5	1	3
Operator	0.2	0.333333	1
Sum	1.7	3.333333	9

[N]

Societal	0.588235	0.6	0.555556	0.581264
User	0.294118	0.3	0.333333	0.30915
Operator	0.117647	0.1	0.111111	0.109586

Assigning Weights to Indicators within Each Category

Societal Indicators

When comparing safety to 'attractiveness to private motor vehicle users' safety should get higher priority as it results in direct impact on fatalities. The impact of shift from private transport is considered moderately to low to equal weightage as the impact on public health in that case is not measurable directly and also because the shift is considered from lesser polluting two wheelers and not private cars (although the overall numbers of two wheeled motorized vehicles is large). Hence the relative weightage of the two indicators under societal indicators category can be derived as following:

[Societal]

	Safety	Shift from Pvt. 2 Wheelers
Safety	1	2
Shift from Pvt. 2 Wheelers	0.50	1
Sum	1.5	3

[N]

Safety	0.666667	0.666666667	0.666667
Shift from Pvt. 2 Wheelers	0.333333	0.333333333	0.333333

User Indicators

The user indicators have been compared to each other as following:

Attractiveness to Public Transport User to passenger Speed – Though these two indicators are dependent on the passenger speed the attractiveness to public transport user is dependent on relative increase in passenger speed on BRTS than the regular transport mode. Thus attractiveness to public transport user is strongly preferred to passenger speed

Attractiveness to public transport users to walking distances – Walking distances involve physical effort and thus lead to very high perceived time as compared to actual time saving that may be achieved by BRTS over regular public transport. Thus walking distances are moderately preferred over attractiveness to public transport users.

Attractiveness for Public Transport Users to total passenger delay – Attractiveness to regular public transport users depend on passenger speed which is dependent on walking distances involved. Whereas passenger delay is static delay and its impact on attractiveness of public transport is considered relatively less. Thus attractiveness to public transport is moderate to equally preferred to passenger delay

Attractiveness for public transport users to ratio of access to in-vehicle time – Attractiveness to public transport forms a part of a wider goal and intent for developing BRTS. Ratio of access to in vehicle time also contributes to this attractiveness. Thus attractiveness to public transport is strongly preferred over ratio of access to in-vehicle time

Passenger Speed to Walking Distances – Walking distances form a major contributor in passenger speed, and it is not the other way round. Thus walking distances are strongly preferred to the passenger speed.

Passenger Speed to Total Passenger Delay – Passenger delay is a component or sub set of passenger speed. Thus passenger speed is moderately preferred to passenger delay

Passenger Speed to ratio of access to in-vehicle time – Overall passenger speed and the ratio of access to in-vehicle time contribute to the perceived time for the passenger. However Passenger speed also is an indicator of better actual time. Hence passenger speed is moderate to equally preferred, to ratio of access to in-vehicle time.

Walking Distance to Total Passenger Delay – Walking distances involve physical effort and hence are much more critical to the attractiveness of transport than static delays, which may even involve seated passengers. Also in terms of perceived time, physical effort involved in walking will lead to much longer perceived time than static waiting at the stations. Thus Walking distances are strongly preferred to Passenger delays

Walking distance to Ratio of Access to in-vehicle time for passengers – Both these factors are indicators of perceived time. However because walking distances involve physical effort, it is strongly to moderately preferred to ratio of access to in-vehicle time.

Passenger Delay to Ratio of access to in-vehicle time – Both passenger delay and ratio of access to in vehicle time generate perceived time penalty. However the ratio of access to in-vehicle time relates to walking distance or physical effort while passenger delay contributes to actual journey time delay. Thus both these indicators are equally preferred.

Using the scores from the above comparison, weights of individual indicators in this category are determined as following:

[User]

	Attractiveness to PT Users	Pass. Speed	Walk Dist.	Pass. Delay	Ratio of Access to in-vehicle Time
Attractiveness to PT Users	1	5	0.333	2	5
Pass. Speed	0.2	1	0.2	3	2
Walk Dist.	3	5	1	5	4
Pass. Delay	0.5	0.3333	0.2	1	1
Ratio of Access to in-vehicle Time	0.2	0.5	0.25	1	1
Sum	4.9	11.833	1.983	12	13

[N]

Attractiveness to PT Users	0.204081633	0.4225	0.168	0.16666667	0.384615385	0.269193
Pass. Speed	0.040816327	0.0845	0.101	0.25	0.153846154	0.126002
Walk Dist.	0.612244898	0.4225	0.504	0.41666667	0.307692308	0.452668
Pass. Delay	0.102040816	0.0282	0.101	0.08333333	0.076923077	0.078261
Ratio of Access to in-vehicle Time	0.040816327	0.0423	0.126	0.08333333	0.076923077	0.073875

Operator Indicators

The indicators in the operator indicator category have been compared and assigned relative scores as per AHP, below.

Capacity to Total Bus Delay – Capacity of the system is an indicator which is dependent on demand. The capacity is essential to meet demand, and excess capacity is of little use for the operator or in the overall performance of the system. However totals bus delay also impacts the fleet requirement and the delay to passengers and perceived travel time for passengers. On the other hand is the system does not possess capacity to handle the required demand the impact is negative both for the operator, passenger and society. Thus capacity is moderately to equally preferred to total delay.

Capacity to Operational Speed – Operational speed of buses directly impacts fleet requirement. However the capacity to meet the system demand is essential both for passengers, society and the operator. However as mentioned above, excess capacity is of little or no use to either society, user or operator. Thus capacity is equally preferred to operational speed.

Total Bus Delay to operational Speed – Both the factors effect fleet requirement and operational efficiency, and are also related to each other. Thus operational speed is equally preferred to bus delay.

Using the scores from the above comparison, weights of individual indicators in this category are determined as following:

[Operator]

	Capacity	Operational Speed	Bus Delay
Capacity	1	1	2
Operational Speed	1	1	1
Bus Delay	0.5	1	1
Sum	2.5	3	4

[N]

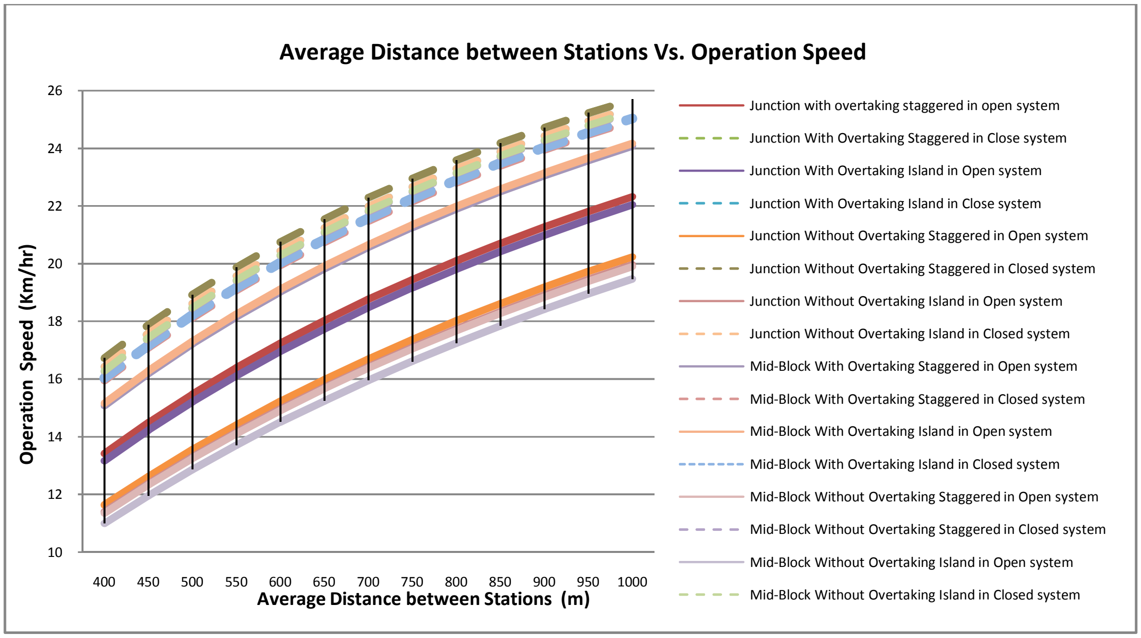
Capacity	0.4	0.333333333	0.5	0.4111111
Operational Speed	0.4	0.333333333	0.25	0.3277778
Bus Delay	0.2	0.333333333	0.25	0.2611111

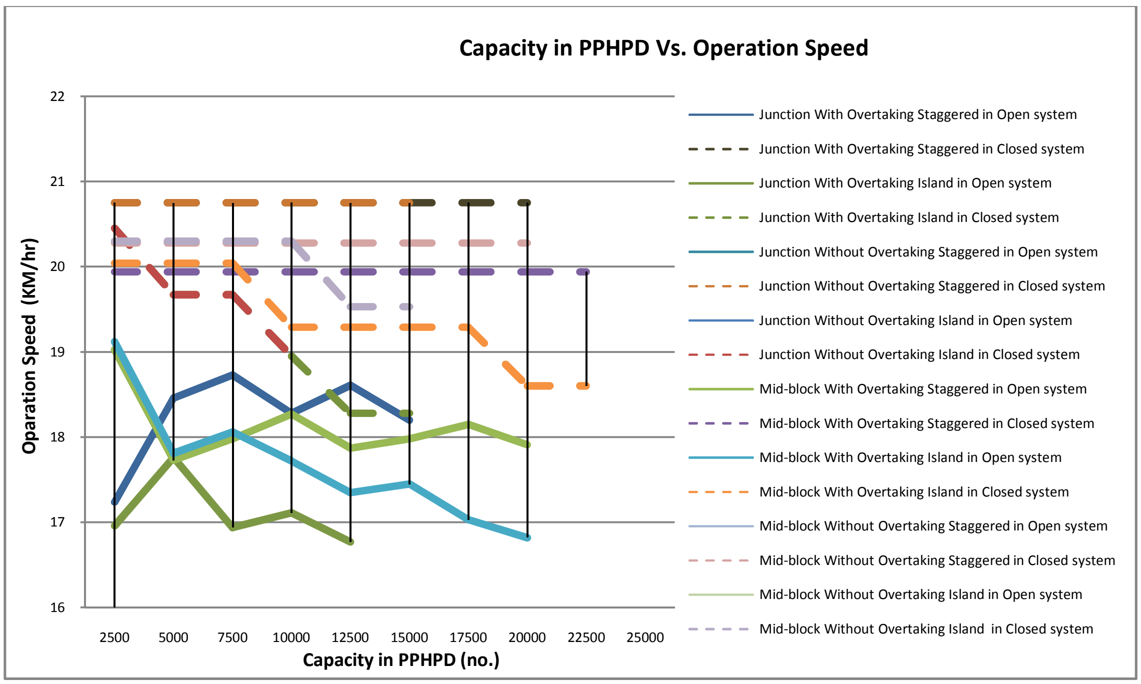
Determination of Overall Weightage of all Indicators

The weights of each indicator in each category is weighted by the weight of the category to determine the overall weights of indicators to be used in the BEAD Tool LOS estimator tool. These weights are listed in the table below.

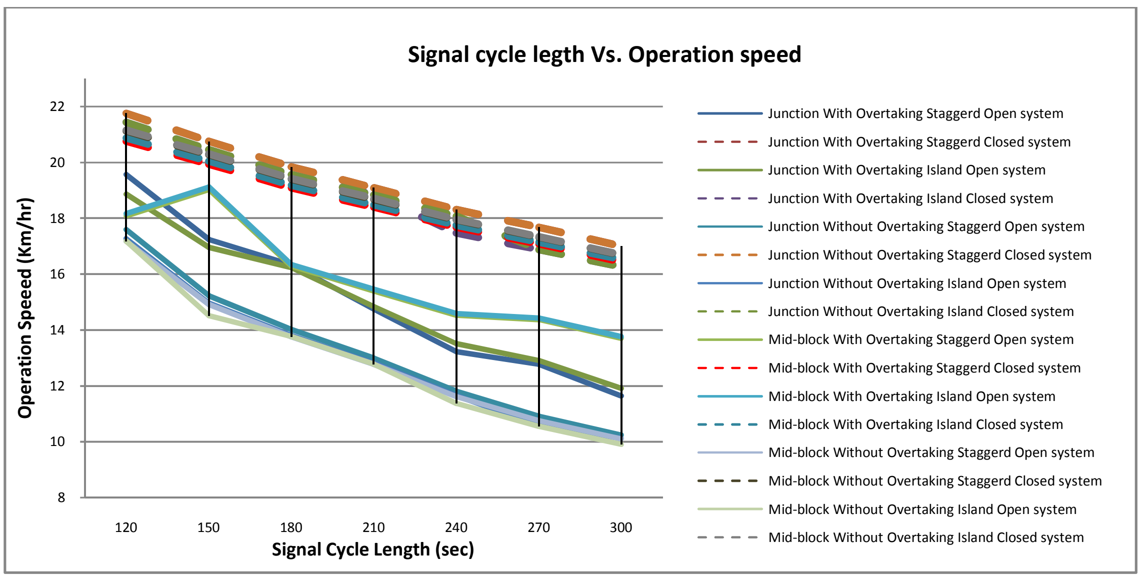
Safety	0.38750908
Shift from Pvt. 2 Wheelers	0.19375454
Attractiveness to PT Users	0.08322117
Pass. Speed	0.03895355
Walk Dist.	0.13994251
Pass. Delay	0.02419451
Ratio of Access to in-vehicle Time	0.02283858
Capacity	0.04505205
Operational Speed	0.03591987
Bus Delay	0.02861414
Total	1

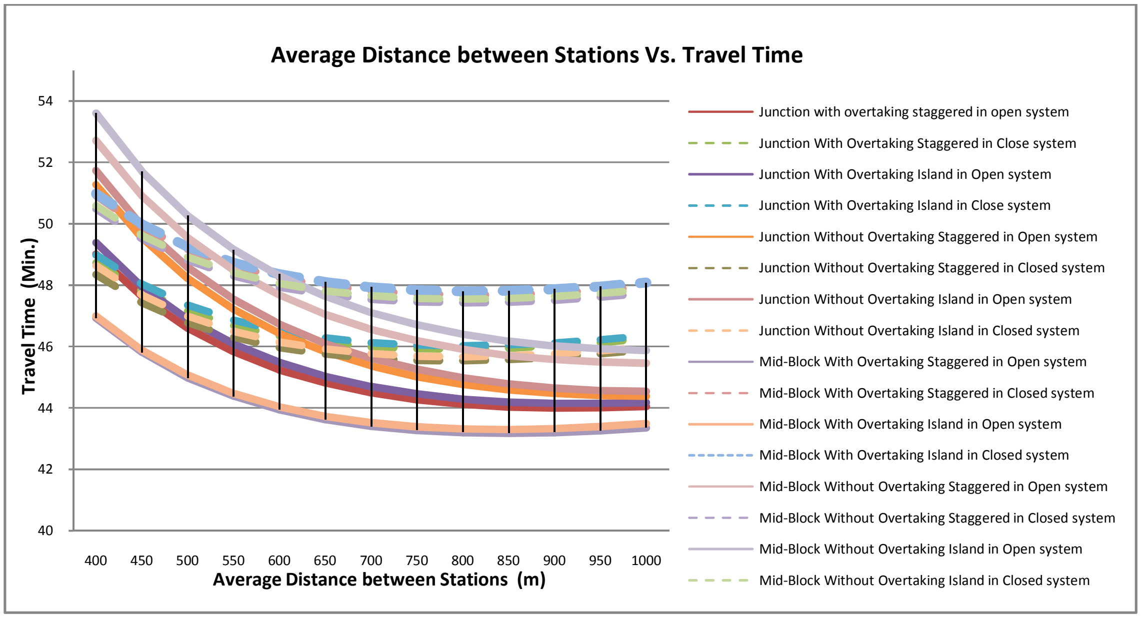
Annexure 7: Comparative graphs using BEAD Tool Generated Results

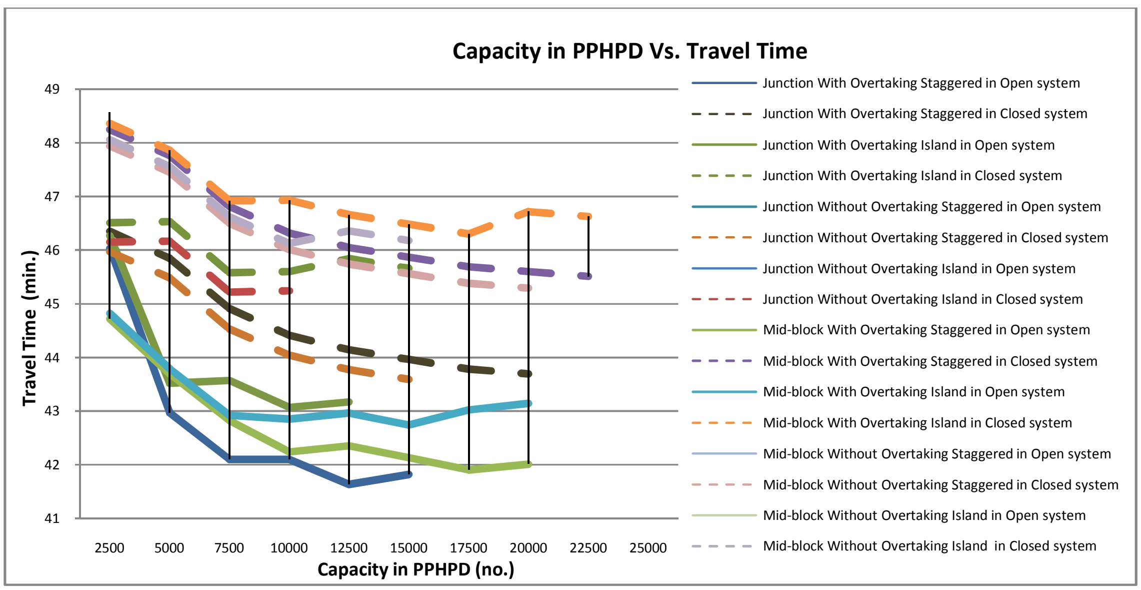


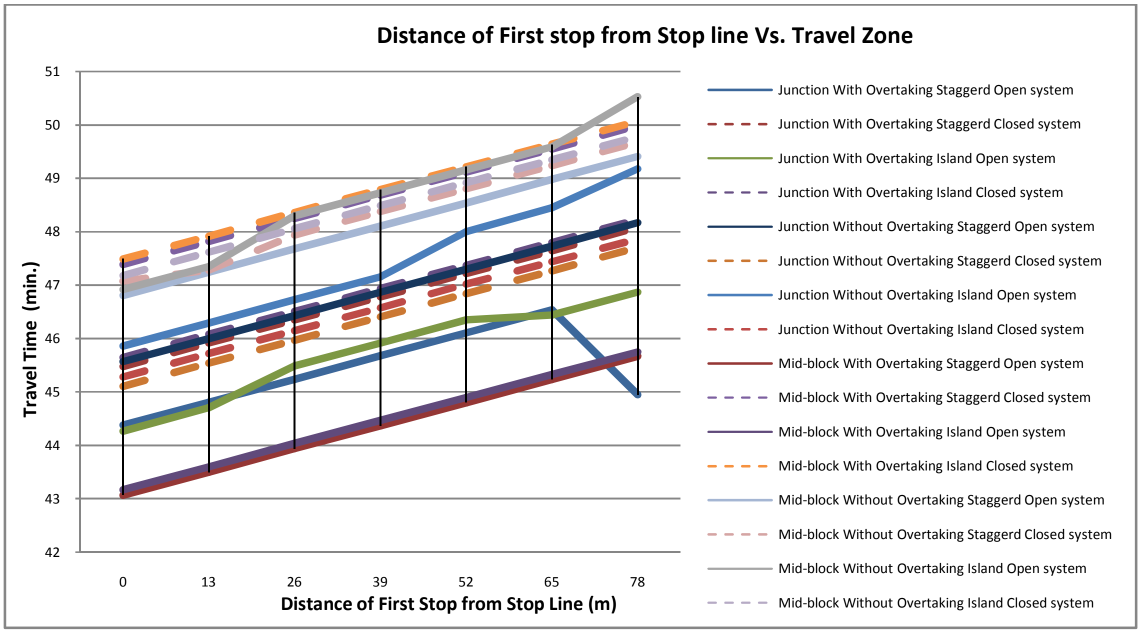


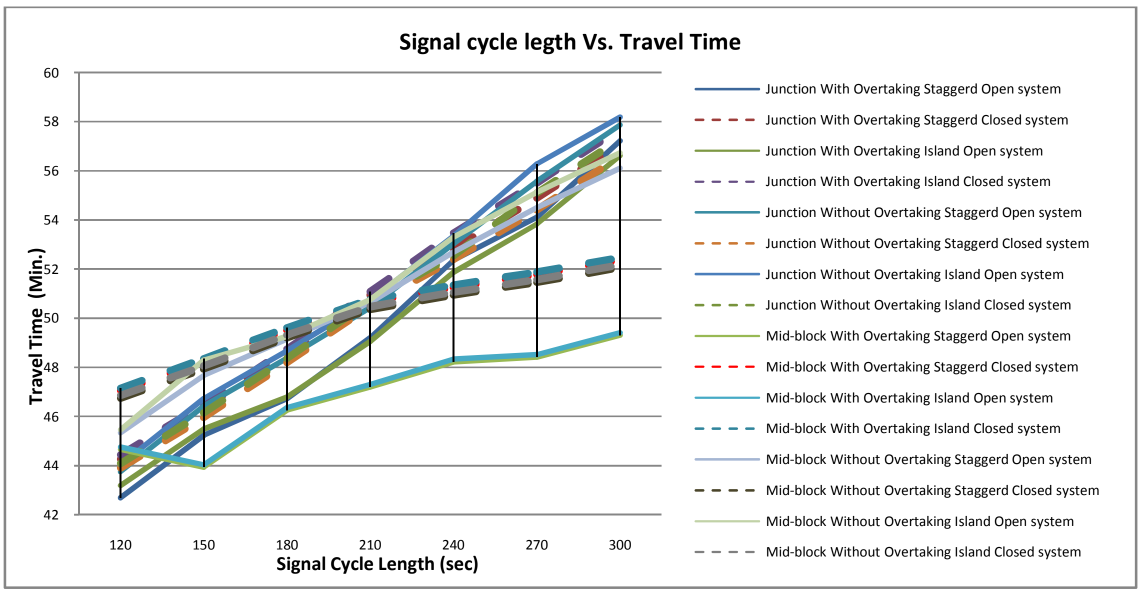

Distance of First stop from Stop line Vs. Operation Speed
Oparation Speed (KM/hr)
21
20
19
18
17
16
15
14
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

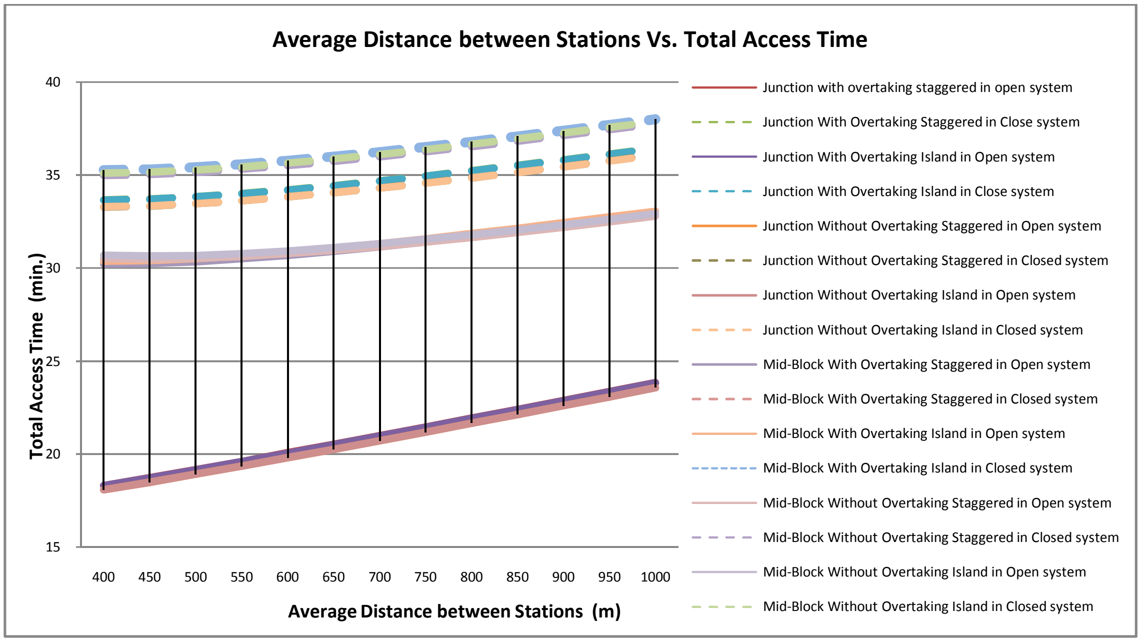

Signal cycle legth Vs. Operation speed
Operation Speeed (Km/hr)
22
20
18
16
14
12
10
8
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

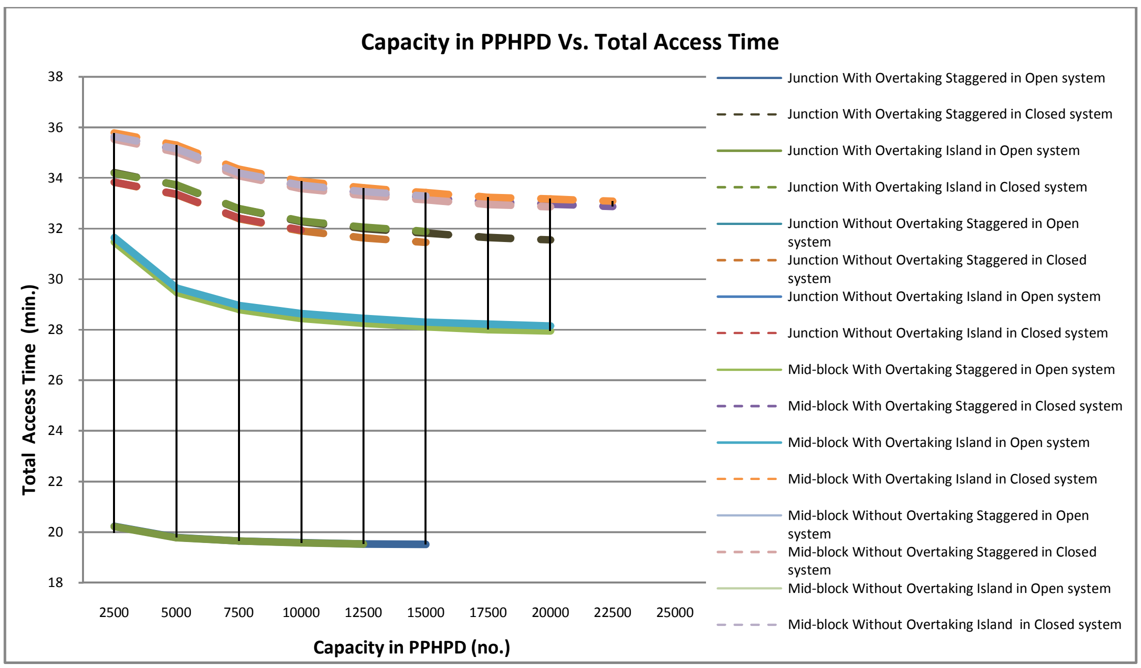

Average Distance between Stations Vs. Travel Time
Travel Time (Min.)
54
52
50
48
46
44
42
40
400
450
500
550
600
650
700
750
800
850
900
950
1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Close system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-Block With Overtaking Staggered in Open system
Mid-Block With Overtaking Staggered in Closed system
Mid-Block With Overtaking Island in Open system
Mid-Block With Overtaking Island in Closed system
Mid-Block Without Overtaking Staggered in Open system
Mid-Block Without Overtaking Staggered in Closed system
Mid-Block Without Overtaking Island in Open system
Mid-Block Without Overtaking Island in Closed system

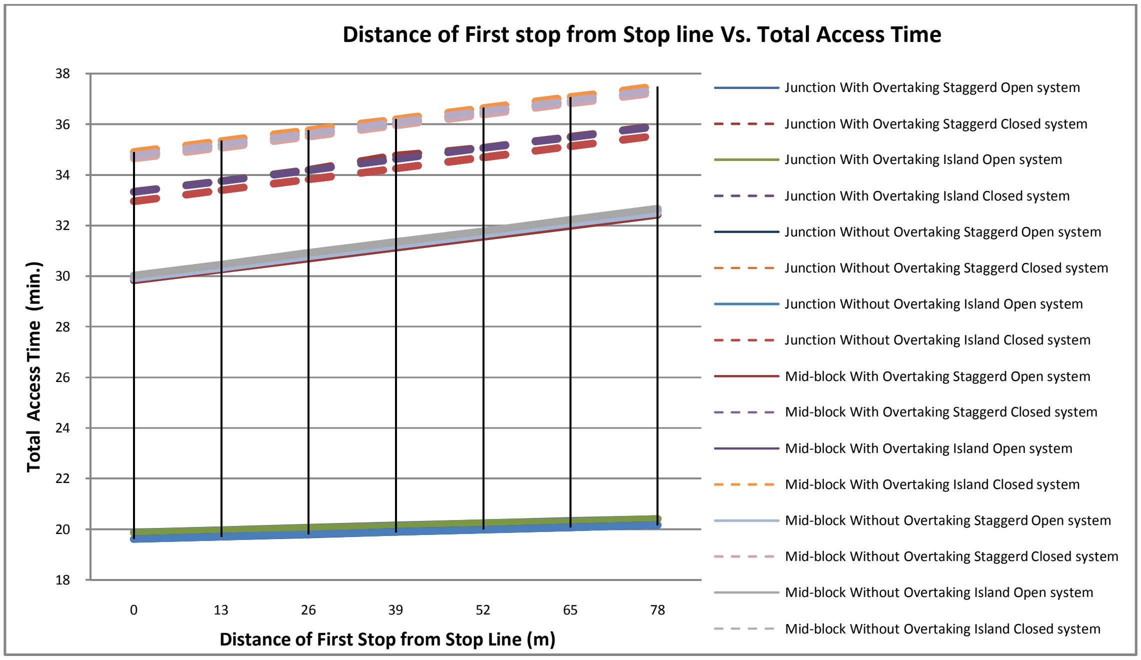

Capacity in PPHPD Vs. Travel Time
Travel Time (min.)
49
48
47
46
45
44
43
42
41
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
Capacity in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Closed system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-block With Overtaking Staggered in Open system
Mid-block With Overtaking Staggered in Closed system
Mid-block With Overtaking Island in Open system
Mid-block With Overtaking Island in Closed system
Mid-block Without Overtaking Staggered in Open system
Mid-block Without Overtaking Staggered in Closed system
Mid-block Without Overtaking Island in Open system
Mid-block Without Overtaking Island in Closed system

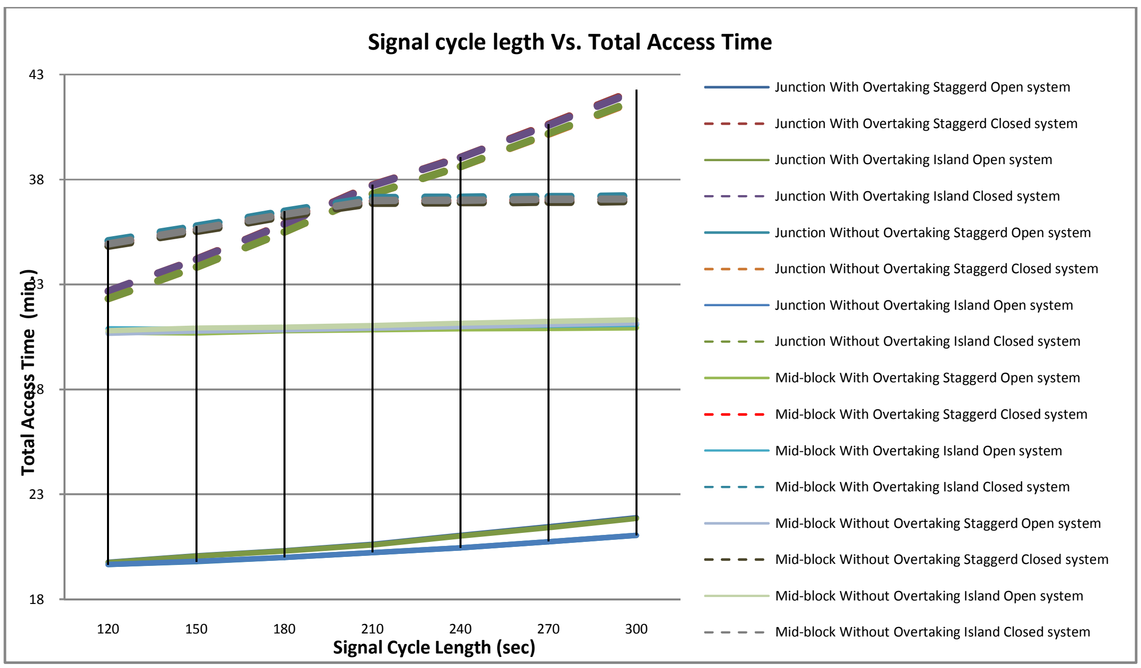

Distance of First stop from Stop line Vs. Travel Zone
Travel Time (min.)
51
50
49
48
47
46
45
44
43
42
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

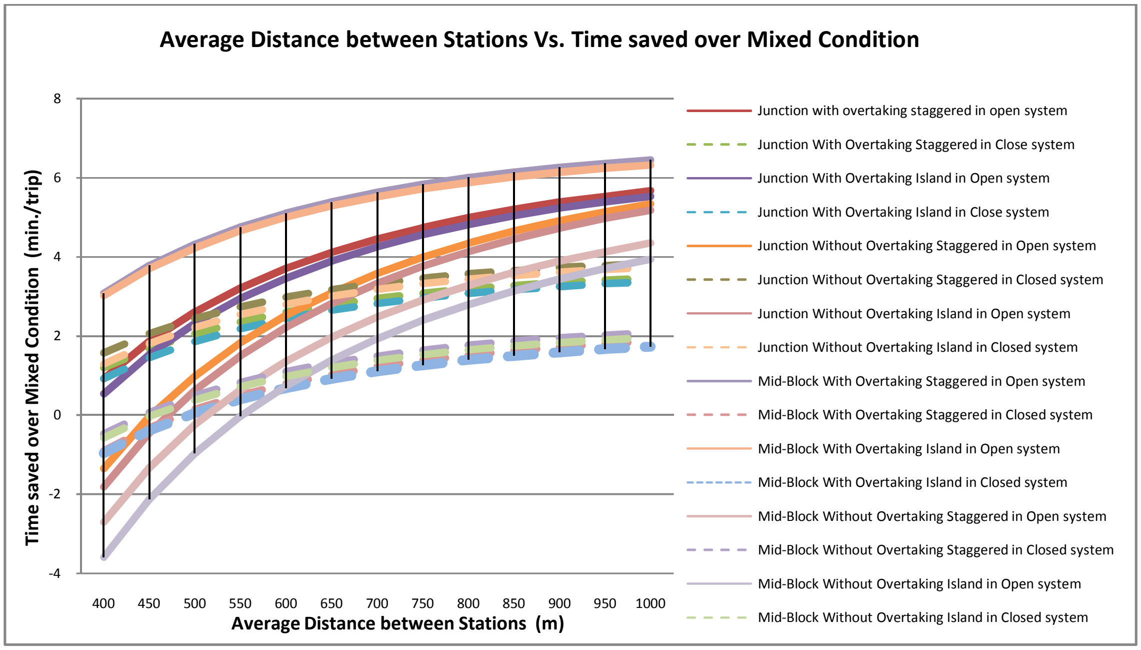

Signal cycle legth Vs. Travel Time
Travel Time (Min.)
60
58
56
54
52
50
48
46
44
42
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

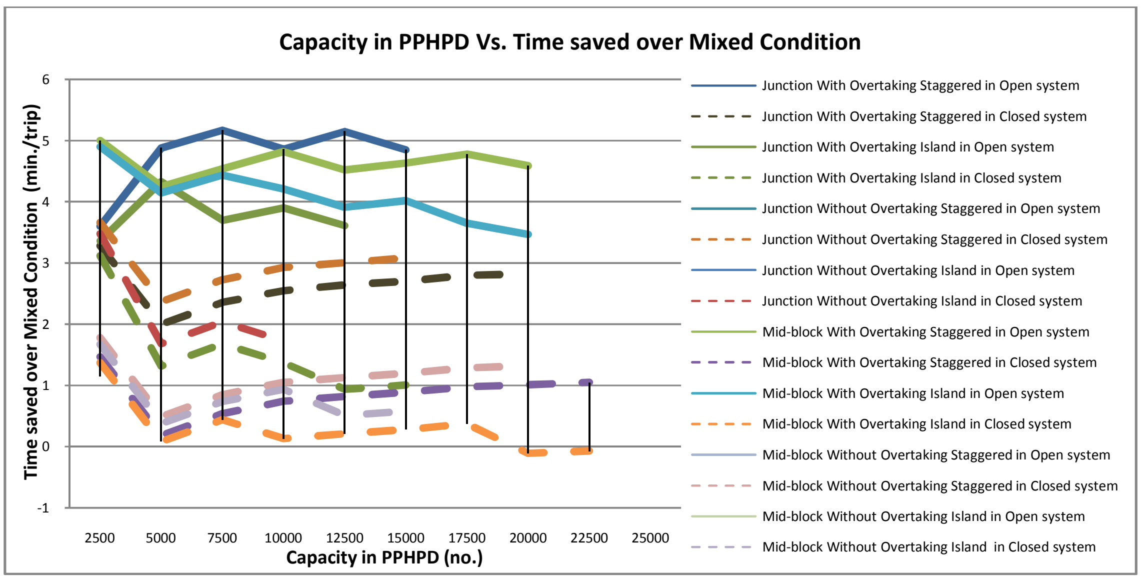

Average Distance between Stations Vs. Total Access Time
Total Access Time (min.)
40
35
30
25
20
15
400
450
500
550
600
650
700
750
800
850
900
950
1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Close system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-Block With Overtaking Staggered in Open system
Mid-Block With Overtaking Staggered in Closed system
Mid-Block With Overtaking Island in Open system
Mid-Block With Overtaking Island in Closed system
Mid-Block Without Overtaking Staggered in Open system
Mid-Block Without Overtaking Staggered in Closed system
Mid-Block Without Overtaking Island in Open system
Mid-Block Without Overtaking Island in Closed system

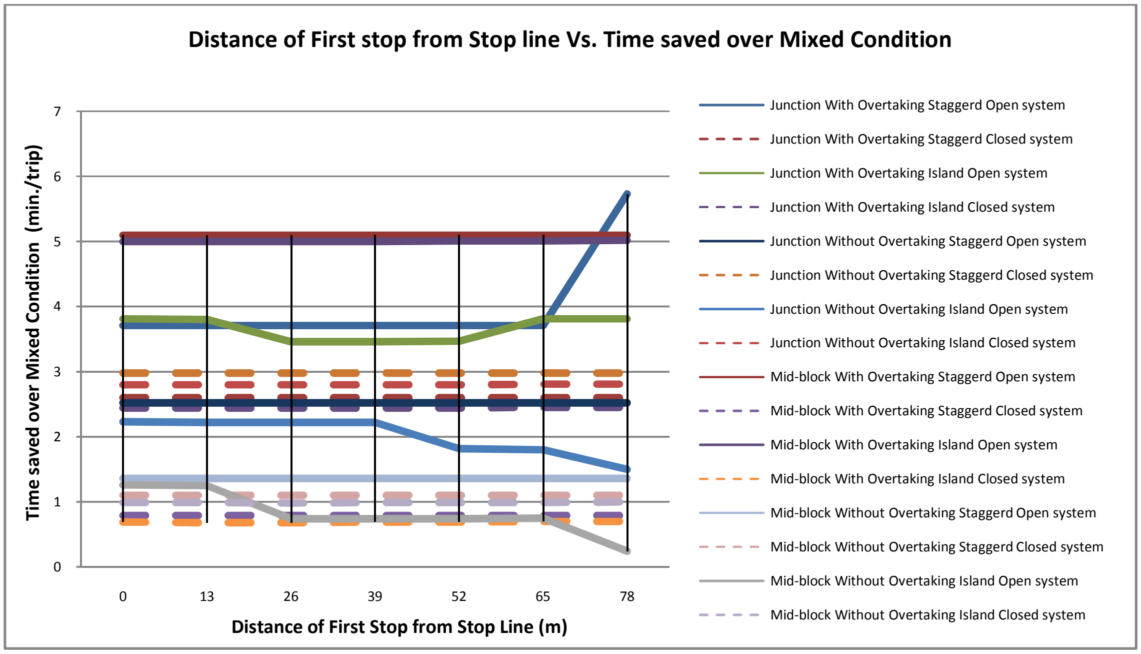

Capacity in PPHPD Vs. Total Access Time
Total Access Time (min.)
38
36
34
32
30
28
26
24
22
20
18
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
Capacity in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Closed system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-block With Overtaking Staggered in Open system
Mid-block With Overtaking Staggered in Closed system
Mid-block With Overtaking Island in Open system
Mid-block With Overtaking Island in Closed system
Mid-block Without Overtaking Staggered in Open system
Mid-block Without Overtaking Staggered in Closed system
Mid-block Without Overtaking Island in Open system
Mid-block Without Overtaking Island in Closed system

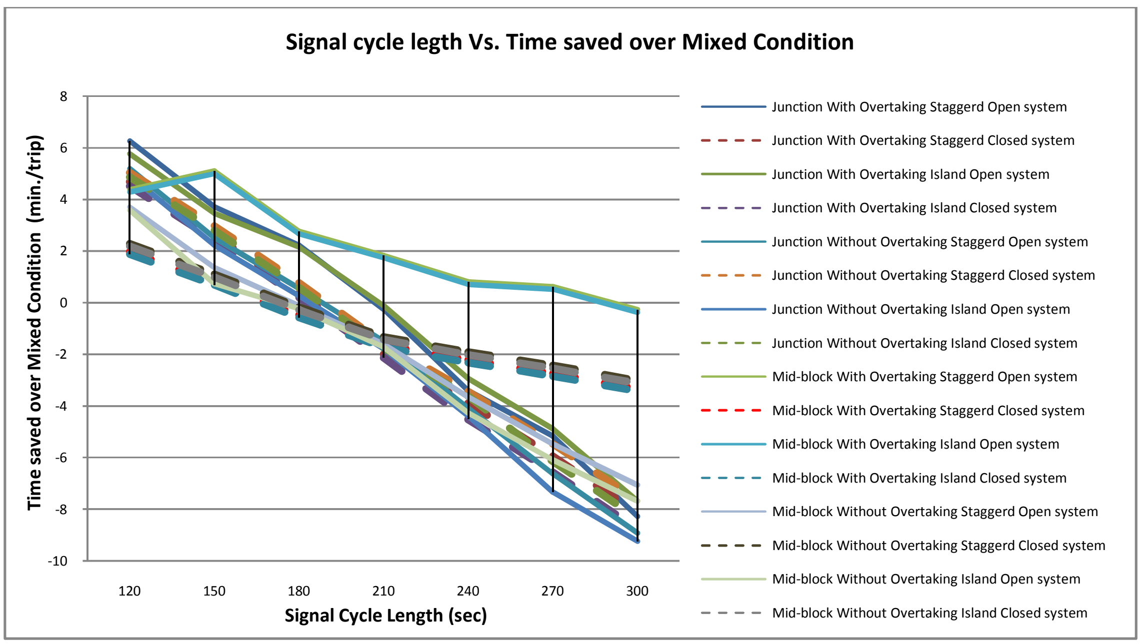

Distance of First stop from Stop line Vs. Total Access Time
Total Access Time (min.)
38
36
34
32
30
28
26
24
22
20
18
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

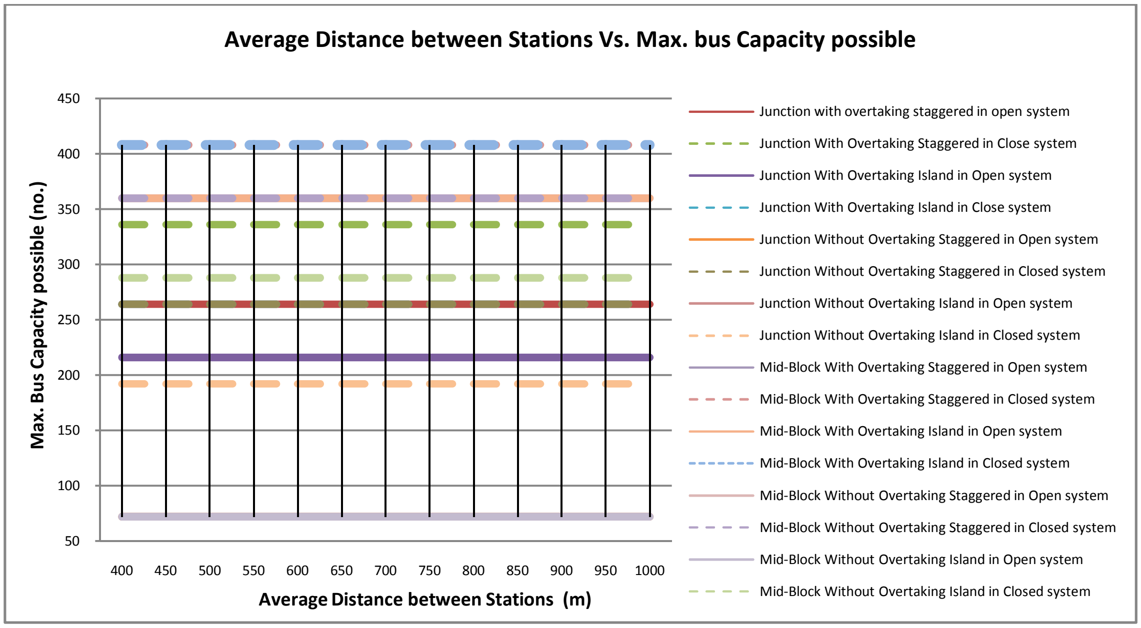

Signal cycle legth Vs. Total Access Time
Total Access Time (min.)
43
38
33
28
23
18
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

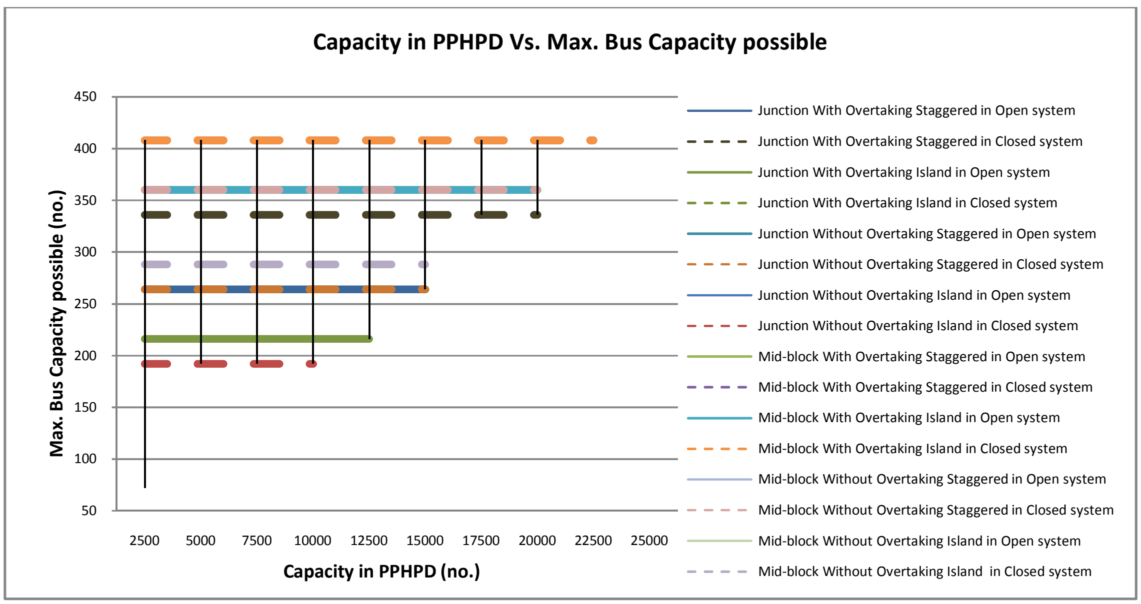

Average Distance between Stations Vs. Time saved over Mixed Condition
Time saved over Mixed Condition (min./trip)
8
6
4
2
0
-2
-4
400 450 500 550 600 650 700 750 800 850 900 950 1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Close system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-Block With Overtaking Staggered in Open system
Mid-Block With Overtaking Staggered in Closed system
Mid-Block With Overtaking Island in Open system
Mid-Block With Overtaking Island in Closed system
Mid-Block Without Overtaking Staggered in Open system
Mid-Block Without Overtaking Staggered in Closed system
Mid-Block Without Overtaking Island in Open system
Mid-Block Without Overtaking Island in Closed system

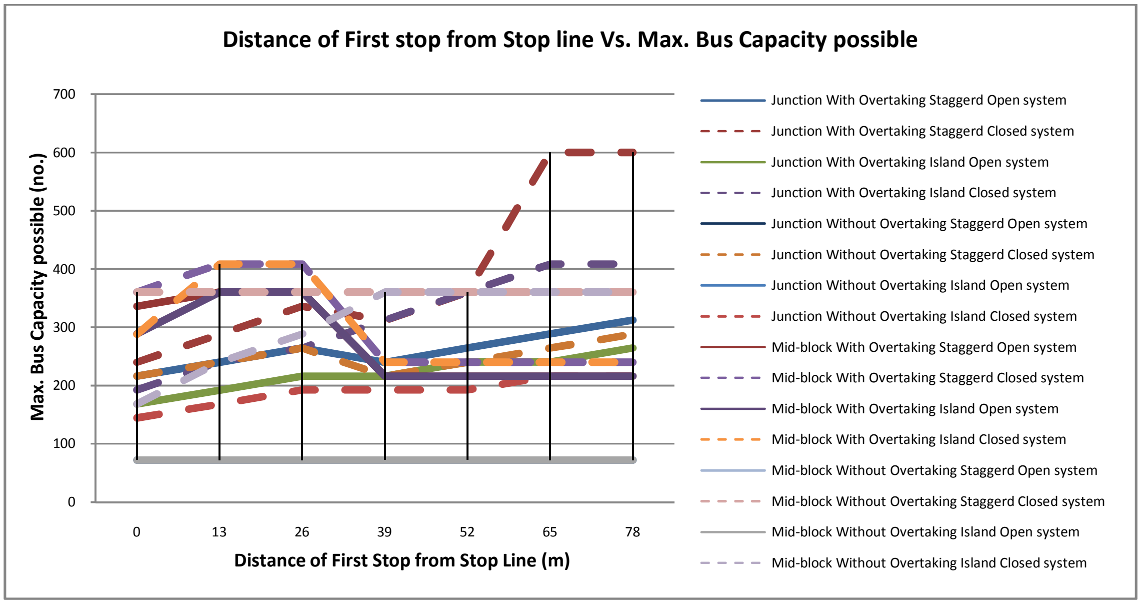

Capacity in PPHPD Vs. Time saved over Mixed Condition
Time saved over Mixed Condition (min./trip)
6
5
4
3
2
1
0
-1
2500 5000 7500 10000 12500 15000 17500 20000 22500 25000
Capacity in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Closed system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-block With Overtaking Staggered in Open system
Mid-block With Overtaking Staggered in Closed system
Mid-block With Overtaking Island in Open system
Mid-block With Overtaking Island in Closed system
Mid-block Without Overtaking Staggered in Open system
Mid-block Without Overtaking Staggered in Closed system
Mid-block Without Overtaking Island in Open system
Mid-block Without Overtaking Island in Closed system

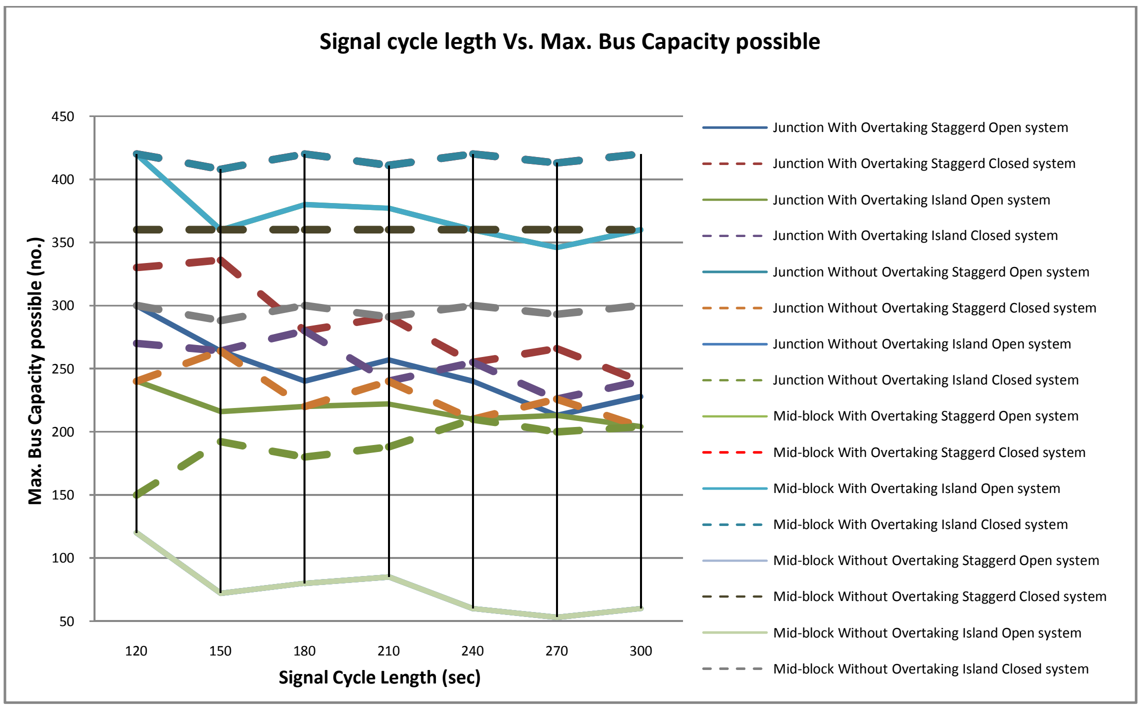

Distance of First stop from Stop line Vs. Time saved over Mixed Condition
Time saved over Mixed Condition (min./trip)
0
1
2
3
4
5
6
7
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

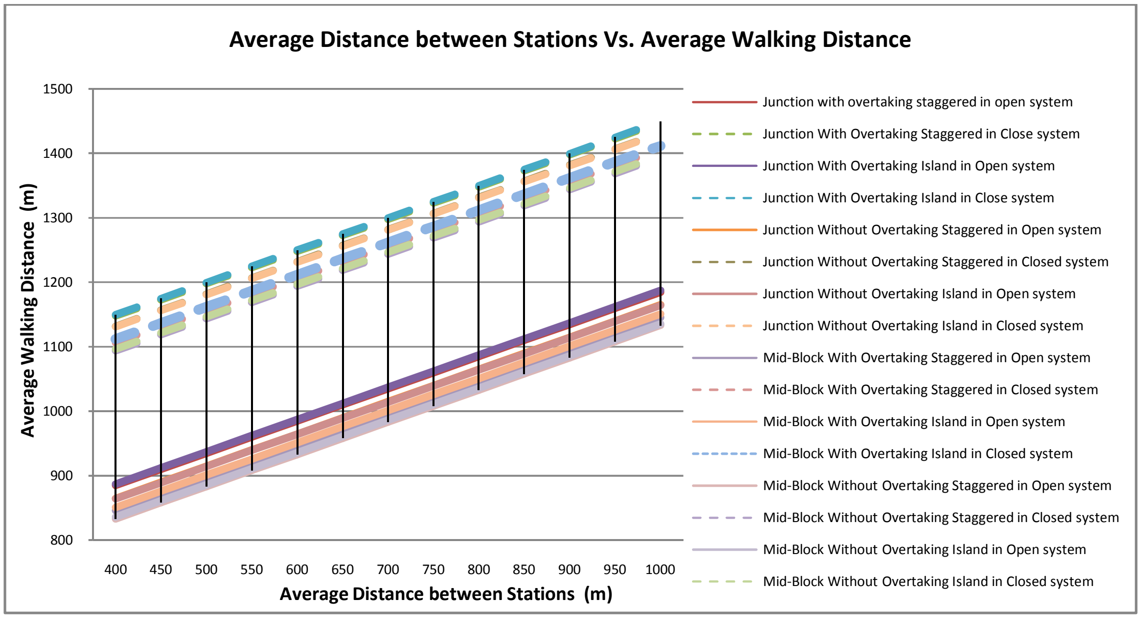

Signal cycle legth Vs. Time saved over Mixed Condition
Time saved over Mixed Condition (min./trip)
-10
-8
-6
-4
-2
0
2
4
6
8
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

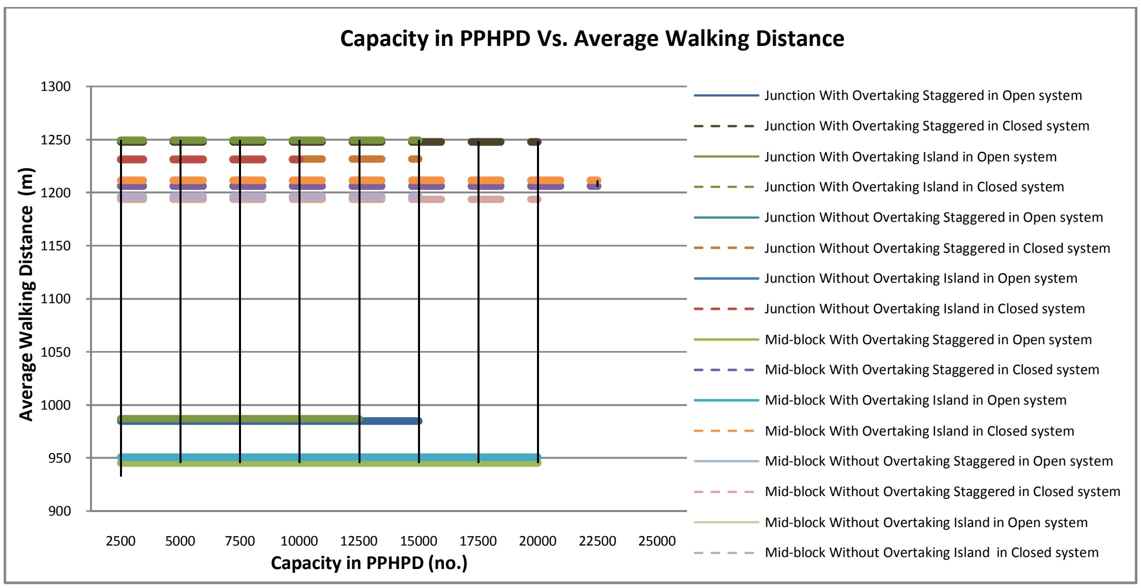

Average Distance between Stations Vs. Max. bus Capacity possible
450
400
350
300
250
200
150
100
50
Max. Bus Capacity possible (no.)
400 450 500 550 600 650 700 750 800 850 900 950 1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Close system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-Block With Overtaking Staggered in Open system
Mid-Block With Overtaking Staggered in Closed system
Mid-Block With Overtaking Island in Open system
Mid-Block With Overtaking Island in Closed system
Mid-Block Without Overtaking Staggered in Open system
Mid-Block Without Overtaking Staggered in Closed system
Mid-Block Without Overtaking Island in Open system
Mid-Block Without Overtaking Island in Closed system

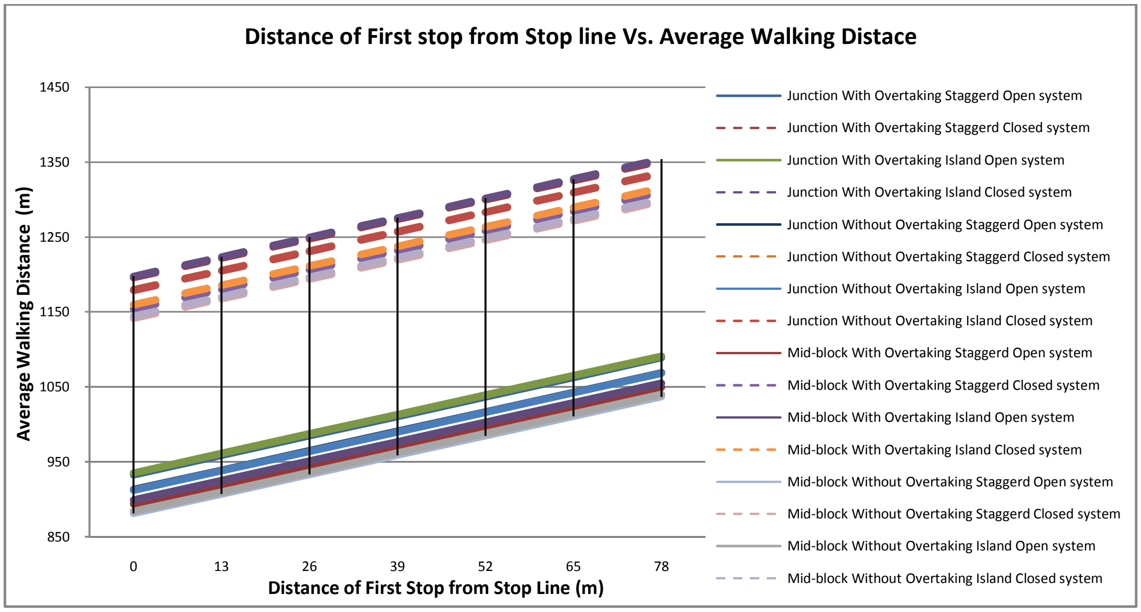

Capacity in PPHPD Vs. Max. Bus Capacity possible
450
400
350
300
250
200
150
100
50
Max. Bus Capacity possible (no.)
2500 5000 7500 10000 12500 15000 17500 20000 22500 25000
Capacity in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Closed system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-block With Overtaking Staggered in Open system
Mid-block With Overtaking Staggered in Closed system
Mid-block With Overtaking Island in Open system
Mid-block With Overtaking Island in Closed system
Mid-block Without Overtaking Staggered in Open system
Mid-block Without Overtaking Staggered in Closed system
Mid-block Without Overtaking Island in Open system
Mid-block Without Overtaking Island in Closed system

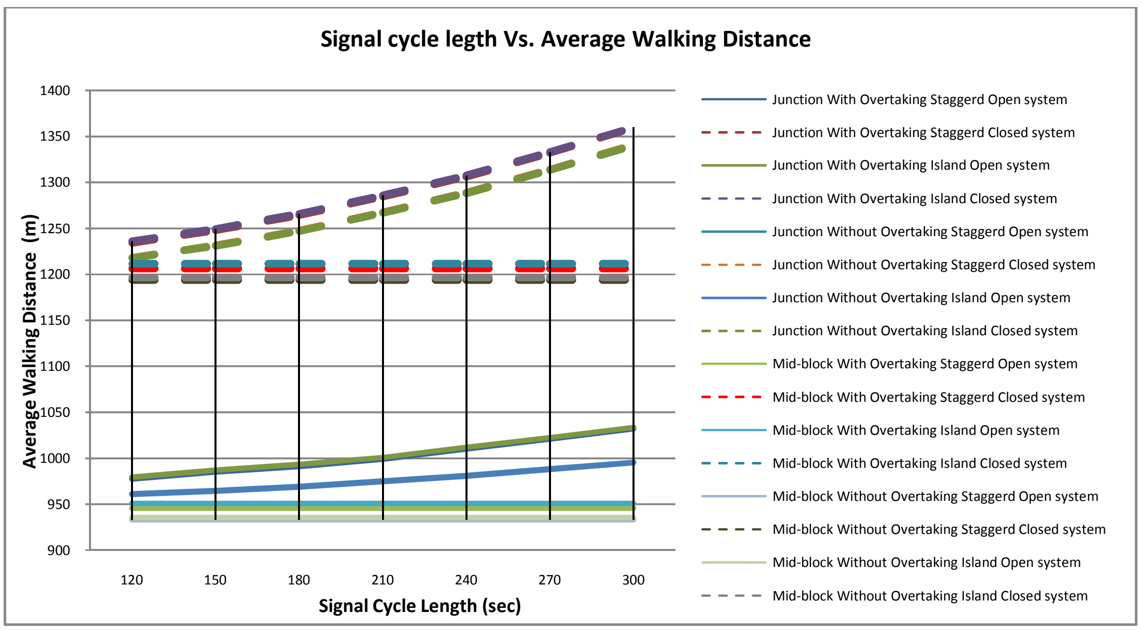

Distance of First stop from Stop line Vs. Max. Bus Capacity possible
Max. Bus Capacity possible (no.)
700
600
500
400
300
200
100
0
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system


Signal cycle legth Vs. Max. Bus Capacity possible
Max. Bus Capacity possible (no.)
450
400
350
300
250
200
150
100
50
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system


Average Distance between Stations Vs. Average Walking Distance
Average Walking Distance (m)
1500
1400
1300
1200
1100
1000
900
800
400 450 500 550 600 650 700 750 800 850 900 950 1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Close system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-Block With Overtaking Staggered in Open system
Mid-Block With Overtaking Staggered in Closed system
Mid-Block With Overtaking Island in Open system
Mid-Block With Overtaking Island in Closed system
Mid-Block Without Overtaking Staggered in Open system
Mid-Block Without Overtaking Staggered in Closed system
Mid-Block Without Overtaking Island in Open system
Mid-Block Without Overtaking Island in Closed system


Capacity in PPHPD Vs. Average Walking Distance
Average Walking Distance (m)
1300
1250
1200
1150
1100
1050
1000
950
900
2500 5000 7500 10000 12500 15000 17500 20000 22500 25000
Capacity in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking Island in Open system
Junction With Overtaking Island in Closed system
Junction Without Overtaking Staggered in Open system
Junction Without Overtaking Staggered in Closed system
Junction Without Overtaking Island in Open system
Junction Without Overtaking Island in Closed system
Mid-block With Overtaking Staggered in Open system
Mid-block With Overtaking Staggered in Closed system
Mid-block With Overtaking Island in Open system
Mid-block With Overtaking Island in Closed system
Mid-block Without Overtaking Staggered in Open system
Mid-block Without Overtaking Staggered in Closed system
Mid-block Without Overtaking Island in Open system
Mid-block Without Overtaking Island in Closed system


Distance of First stop from Stop line Vs. Average Walking Distace
Average Walking Distance (m)
1450
1350
1250
1150
1050
950
850
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system


Signal cycle legth Vs. Average Walking Distance
Average Walking Distance (m)
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking Island Closed system
Junction Without Overtaking Staggerd Open system
Junction Without Overtaking Staggerd Closed system
Junction Without Overtaking Island Open system
Junction Without Overtaking Island Closed system
Mid-block With Overtaking Staggerd Open system
Mid-block With Overtaking Staggerd Closed system
Mid-block With Overtaking Island Open system
Mid-block With Overtaking Island Closed system
Mid-block Without Overtaking Staggerd Open system
Mid-block Without Overtaking Staggerd Closed system
Mid-block Without Overtaking Island Open system
Mid-block Without Overtaking Island Closed system

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