BEAD

BRTS Evaluation and Design Tool *Version 1.69*

developed for

Institute of Urban Transport (India)

Final Report

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SGArchitects

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FAZIO
ENGINEERWARE

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Transportation Research and Injury Prevention Program, IIT Delhi

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SGArchitects, 6151/8, Sector D, Pocket 6, Vasant Kunj, New Delhi – 110070

Tel: - +91 11 42147521, Email – design@sgarchitects.in, Web: www.sgarchitects.in

Executive Summary

The BRTS Evaluation and Design (BEAD) Tool has been developed to provide Bus Rapid Transit System (BRTS) planners and designers with the means to predict the performance of a designed/planned system and compare the same against alternate options. Unlike existing, commercially available modelling software which focuses on BRTS vehicle performance such as bus operational speed in the corridor, as a part of the road system, BEAD generates average performance values for passenger centric parameters such as passenger speeds and door to door travel times. This allows more appropriate performance evaluation of systems based on its benefits in terms of attracting use and effecting long term modal shift in favour of public transport.

In addition, the tool allows users to define detailed BRT system design including different operational and infrastructure design characteristics in different segment of the same corridor. Up to 20 different segments can be defined for a single corridor and aggregate corridor performance generated along with detailed performance for each segment. This flexibility allows designers the means for effective intervention to achieve improvements. The tool is sensitive to minor design details and any changes in elements such as crossing type, or gradients of access ramps, driver reaction time can be seen in the overall performance. The tool brings out these changes in two distinct categories important for public transport design, viz. access and In-vehicle time and performance.

This tool has gone through various stages of development which included seeking feedback from various stakeholders and prospective users. This was achieved through two workshops held on the subject, which was attended by different consultants, representatives from advocacy groups, city officials involved with BRTS project implementations, representatives from Public Transport Operators/regulatory bodies and representatives from planning regulatory bodies responsible for approving such project. The tool has been calibrated and validated using three case studies including, Delhi, Ahmadabad and Bogota. It has been tested against different BRTS corridor design development processes, to assess its capabilities in replicating all possible BRTS designs and configurations. A draft final version of the tool was sent to various stakeholders and experts for final review. The tool was presented to Delhi Integrated Multi Modal Transport System (DIMTS) Ltd and other stakeholders through three presentations held in IIT, Delhi. The comments received during these presentations and from the review were included in the revised (final) version 1.69 of the tool.

The validation study of the tool has yielded good results and has provided operational speed and capacity measures within 94 to 99% accuracy of the field measurements and/or performances predicted in other documents/models. For example, BEAD predicts Delhi BRTS to have a capacity of 160 buses per hour per direction and an average operational speed of 16.9 km/hr as against the observed operational speed of 18km/hr and average observed demand of 120 buses per hour and predicted capacity of 120-150 buses per hour per direction. Similarly, Ahmadabad's BRTS is predicted to have a capacity of 15000 to 20000 PPHPDT with current observed speeds of 25 km/hr at a current demand of about 2500-3000 PPHPDT and BEAD models the system to have a peak capacity of 18000 PPHPDT, and operational speed of 24.8 km/hr at current volumes. For Bogota, the comparison is 300 buses per hour per direction as expected capacity and observed speed of 26.0 km/hr, against 300 buses per hour per direction as BEAD predicted capacity and operational speeds at capacity as 26.7 km/hr

The tool has also been able to replicate a variety of BRTS configuration, and it allows users to define up to four different bus lane types, and 37 different BRTS station designs with per directions simultaneous bus boarding options ranging from one to 20 buses for each type. It allows users to choose from up to eight different bus types for the BRTS fleet; each with different boarding level options. Users can also adjust bus station height, distance from the junctions, signal cycle design, BRTS cross section design, walking speeds, reaction time, intersections widths, etc.

BEAD is a useful evaluation tool for decision makers, both at the level of funding/approval and implementation. BEAD is an important design tool for consultants, including planners, designers and engineers. It can be used both at the conceptual system design level as well as detailed infrastructure design level to test various options of operational and infrastructure design and select an optimum design for a given context/city. BEAD is also useful for Public Transport Operators and can help in the design of optimum service plans, headways, operational plans etc.

With these capabilities BEAD can serve an important role in improving the benefits of investments made by the cities, and central government schemes (such as the JnNURM) in Public Transport, and help effectively realize the policy objectives such as those listed in the National Urban Transport Policy (NUTP).

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Project Team

SGArchitects

Sandeep Gandhi

AnkurDadheech

Fazio Engineerware

Dr. Joseph Fazio

I-Trans

Ravi Gadepalli

Technical Advisor

TRIPP, IIT Delhi

Prof. Geetam Tiwari

Pushkar Makarand Dhawale

Explanation of Terms Used in this Report

BEAD	BRTS Evaluation and Design Tool
BPHPD	Buses per hour per direction
BRTS	Bus Rapid Transit System
Bus Lanes	Lanes designated for use by buses only.
Common buses or common lane	Refers to buses in common lane or the lane hosting both straight moving and turning buses
Corridor	Is the entire length of the proposed BRTS infrastructure along a road or a series of roads, and can contain more than 1 segment of differing designs.
FOB	(Pedestrian) Foot over bridge
GHGs	Green house gases
MV Lanes	Lanes designated for use by general motor vehicle traffic other than buses.
No Interchange	Refers to direct route moving both within the BRTS corridor and outside in mixed conditions.
O-D	Origin to Destination; or Origin and/or Destination
PPHPD	Passengers per hour per direction
Segment	Refers to a component or part length of the corridor which is classified as one segment as it has a uniform design of infrastructure and operations across its length. A segment may differ from another segment as one or more of the performance determining design features are differing.
Straight Bus	Buses moving straight along the corridor at signalized intersection
Tool	Refers to the BEAD tool
Transfer or Interchange	Interchanging routes mainly between feeder and trunk route in a closed system
Turning Bus	Buses turning off the corridor at signalized intersection
Xing	Crossing or Intersection, generally signalized

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 than150 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 is emerging on a large scale by more than 11 Indian cities. More than 1250 km of BRTS is slated to be developed in India. Most development is supported by the Ministry of Urban Development, Government of India (MoUD) under the Jawaharlal Nehru Urban Renewal Mission (JnNURM) mission.

More than 100 parameters are involved in BRTS design. Approximately one-third of parameters is related to site conditions and hence fixed. The remaining two-thirds of parameters are variable and depend on design. Perennial controversies exist 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, an urgent need exists for an evaluation tool, which can provide quantified evaluation of alternative design features to planners, engineers, consultants, contractors, and the Municipal and/or development authorities of the city for rational decision making.

This urgent need has led to the development of the Bus Rapid Transit System (BRTS) Evaluation and Design (BEAD) Tool. BEAD is a macro-enabled, Microsoft Excel file, i.e., an xlsm file, based interactive tool that allows engineers, planners, designers, and decision makers to make a comparative evaluation against any proposed changes in 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 of proposed alternative design features can be evaluated using comparative assessment. In addition, one can use the tool to generate data for research and academic purposes.

2 Approach

BEAD development arises from the need for a tool which can provide planners, engineers, and 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. BEAD may then be used to feed processes to calculate and present the expected performance of the system in a measurable format.

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

1. Input Fields
2. Calculation
3. Result Output

The project team undertook detailed discussions with its technical advisor, i.e. Transportation Research and Injury Prevention Programme (TRIPP), IIT Delhi, on the finalization of BEAD components mentioned above. The finalization was based on the experience of 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 performance indicators that would be presented and compared in output results. Key performance indicators mainly focus on a global indicator as defined by agencies such as UNEP that focuses on the reduction of green-house gases (GHGs) and local indicators such as those set by project operators who focus on the increase in passenger usage. These two types of indicators 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 be minimized.

This interconnectivity 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, increasing income, reducing the unpleasantness of travel, and reducing the time spent in travel when not undertaken for leisure (Sergio R.Jara-Diaz 303-19). 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(s) 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 factors 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

Systems or their features such as reduced delays that directly lead 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 delays and capacity have been broken down in to further details for easy and direct comparison by the users. Using these indicators along with the finalized file and equipped with standard transit capacity, headway and frequency equations the first Beta version of the tool was formulated, developed, and 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 was used to improve the presentation and usability of the results. For example, as a part of the feedback received from workshop participants, the development team undertook consultation with TRIPP and finalized the Service Level benchmarking of an input design or a segment design based on the performance criterion. Further on, after incorporating the comments and feedbacks from all the workshops and various presentations the tool was refined. A draft final version of the tool was sent to various stakeholders and experts for final review. The tool was presented to Delhi Integrated Multi Modal Transport System (DIMTS) Ltd. Three other meetings were held in IIT, Delhi where BEAD Version 1.68tool was presented. The comments received during these presentations have been included in the revised version of the tool. Also, through review process two written review comments were received by the development team and the response to same have been presented in Annexure 8 to 11.

The comments received in the reviews and meetings were incorporated in the tool and the tool was upgraded as BEAD Version 1.69. The improvements and modifications made in the tool were:

1. The upper limit of Signal Cycle Length was increased from 300 to 600 seconds.

2. Bus Dwell Time calculator form was added by which users can calculate the actual bus dwell time. This is an added improvement to the option of editing the bus dwell time in default values.
3. Average distance between stoppages is calculated based on the user input of segment length and number of bus stops. The value can be edited based on the user's requirement.
4. Reliability component of Passenger Waiting Time was improved by incorporating standard deviation of bus headway. This allows the user to estimate the impact of unreliable service on total passenger waiting time.

3 Methodology – Working of BEAD Tool

The tool requires the necessary environment in order to function. BEAD is a Microsoft Excel based tool. To use BEAD, the user should use a PC. The tool will work in Windows XP, Windows Vista or Windows 7 operating systems. BEAD does not work in early Service Packs of Windows XP. The BEAD tool requires 3 MB of storage. If hard drive space is limited, one can use the BEAD tool from a USB memory stick with at least 10 MB of free space. The BEAD tool will automatically adjust to most screen resolutions. In cases in which BEAD scroll bars and buttons are not visible, the user must exit BEAD and enter Windows Control Panel to change the screen resolution. One should select 1280 x 800 dpi or 1024 x 768 dpi resolution. Software required are MS Excel 2007 or higher version and the BEAD .xlsm file. The BEAD tool requires an opening password to use. If one is authorized to use the BEAD tool, one can contact SGA to obtain the necessary opening password. The BEAD tool will work in any subdirectory except virtual ones such as Windows 7 "Library." External BEAD xlsx files that can be loaded into BEAD must also reside in non-virtual subdirectories such as the "Documents" subdirectory. BEAD makes use of VBA script and macros in MS Excel. To run BEAD one needs to enable macros.

The tool relies on inputs provided by the user. It combines this with pre-fed base data to generate a 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 that includes a 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 these 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, i.e., 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.

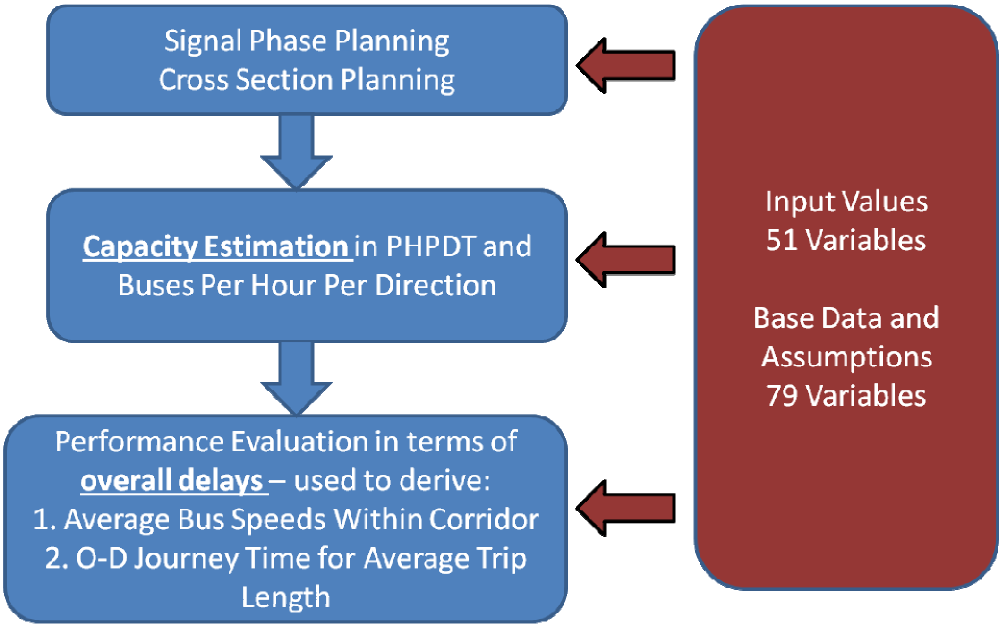


Figure 1: BRTS Evaluation and Design (BEAD) tool Methodology

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 set the boundary limits of all values to ensure that user inputs comply with the broad BRTS planning and design principles as well as calibration data from existing Indian BRTS. For these boundary limits, 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/intersection and station** access and delays. It is based on the principal that vehicle performance including buses in a controlled environment such as segregated lane is predictable through a simple analytical process. This primarily relies on generating a third order motion profile for buses. Variable factors affecting this profile and resultant performance 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 that is possible
- Total number 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 midblock 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 for commuters.
- 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. The user can remove one or more of these provisions by adjusting their cross-section widths to zero meters.
- 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, and impacts minimum headway, frequency, etc.:
  - Signal Cycle design
  - Junction/Intersection width
  - Bus length
  - Acceleration/Deceleration
  - Dwell time

3.1.4 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 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, e.g., average 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. The user is required to fill in a total of 28 to 51 input fields depending on the design being defined. For following segments user only needs to change inputs specific to differing design features as the tool reflects values of previous segment in subsequent segment forms. Figure 2 illustrates the categorization of the variables.

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, midblock, junction/intersection
   - **b.** Junction/Intersection – Signalized, roundabout, pedestrian only, traffic signal free
   - **c.** Signal Design – Cycle length, special phase requirements, etc.
   - **d.** Special – Off board ticketing, bus boarding doors.

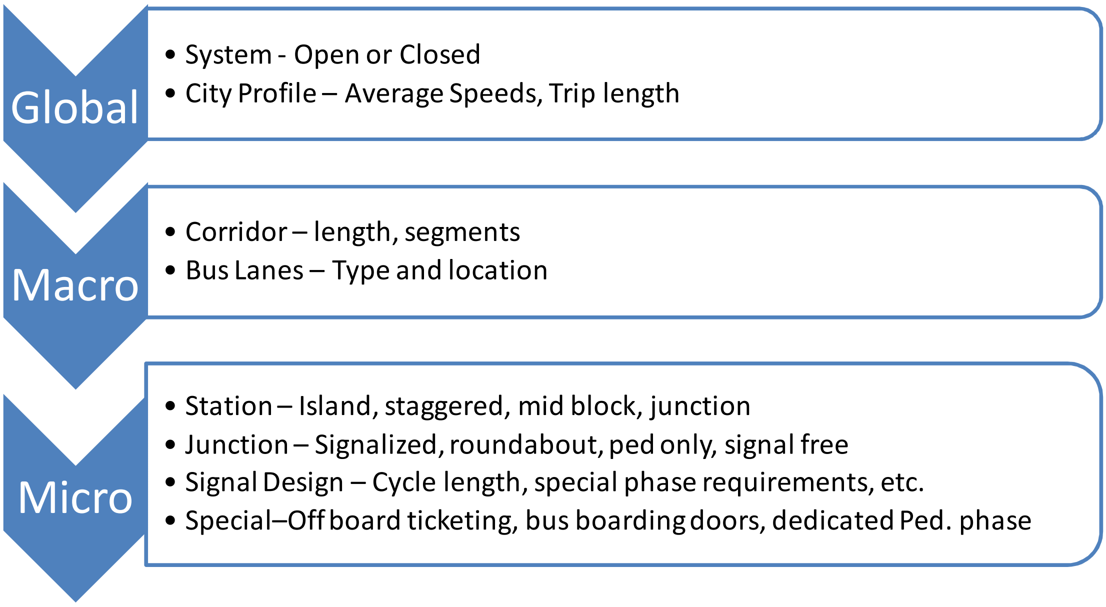


Figure 2: Categorization if Input fields for BEAD Tool

3.2.2 Default Variables

Apart from above user input data, some default values are also been taken in consideration. These variables have been defined as default values as they have been derived from different primary and secondary sources to calibrate the tool and can be generalized for all types of corridor designs. However the tool provides the flexibility to edit these values so as it could calibrated for varied contexts. 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 and Infrastructure – examples are:
   - **a.** Bus Acceleration and Deceleration rate, Bus Dimensions and capacity

   - **b.** Junction/Intersection width, distance of stop line from cross road edge
   - **c.** Level difference for grade separation options with climb rates and gradients

3. System and 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 shows the categorization.

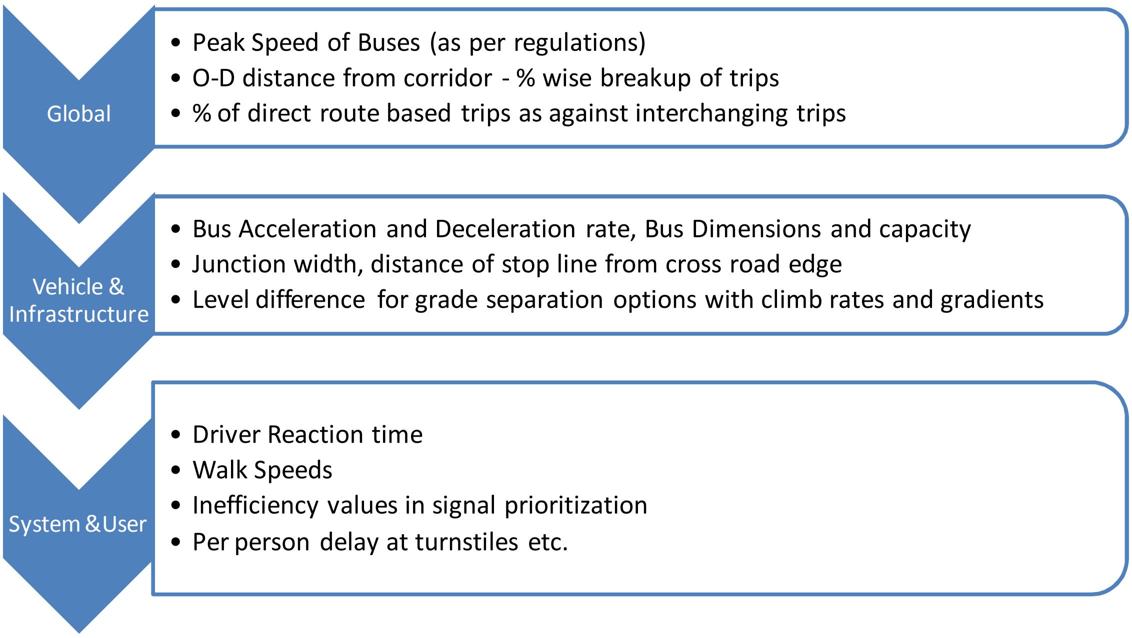


Figure 3: Categorization of default variables used in BEAD Tool

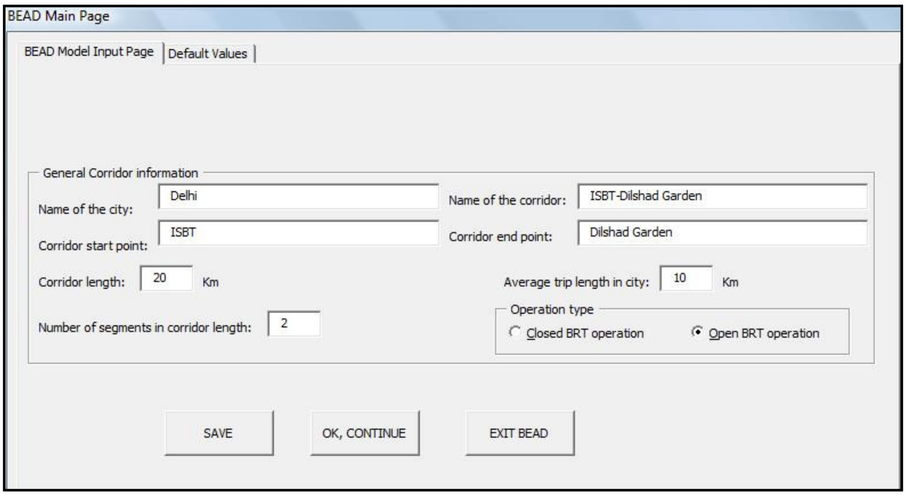
3.2.3 Assumptions

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

1. A corridor is composed of one or more segments. Each segment is different from the other by at least one of the many design features which constitute a corridor. Thus 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/intersection 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 and land use type (refer figure 67).
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.

Figure 4throughFigure 13below 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.



General Corridor information

Name of the city: Delhi

Name of the corridor: ISBT-Dilshad Garden

Corridor start point: ISBT

Corridor end point: Dilshad Garden

Corridor length: 20 Km

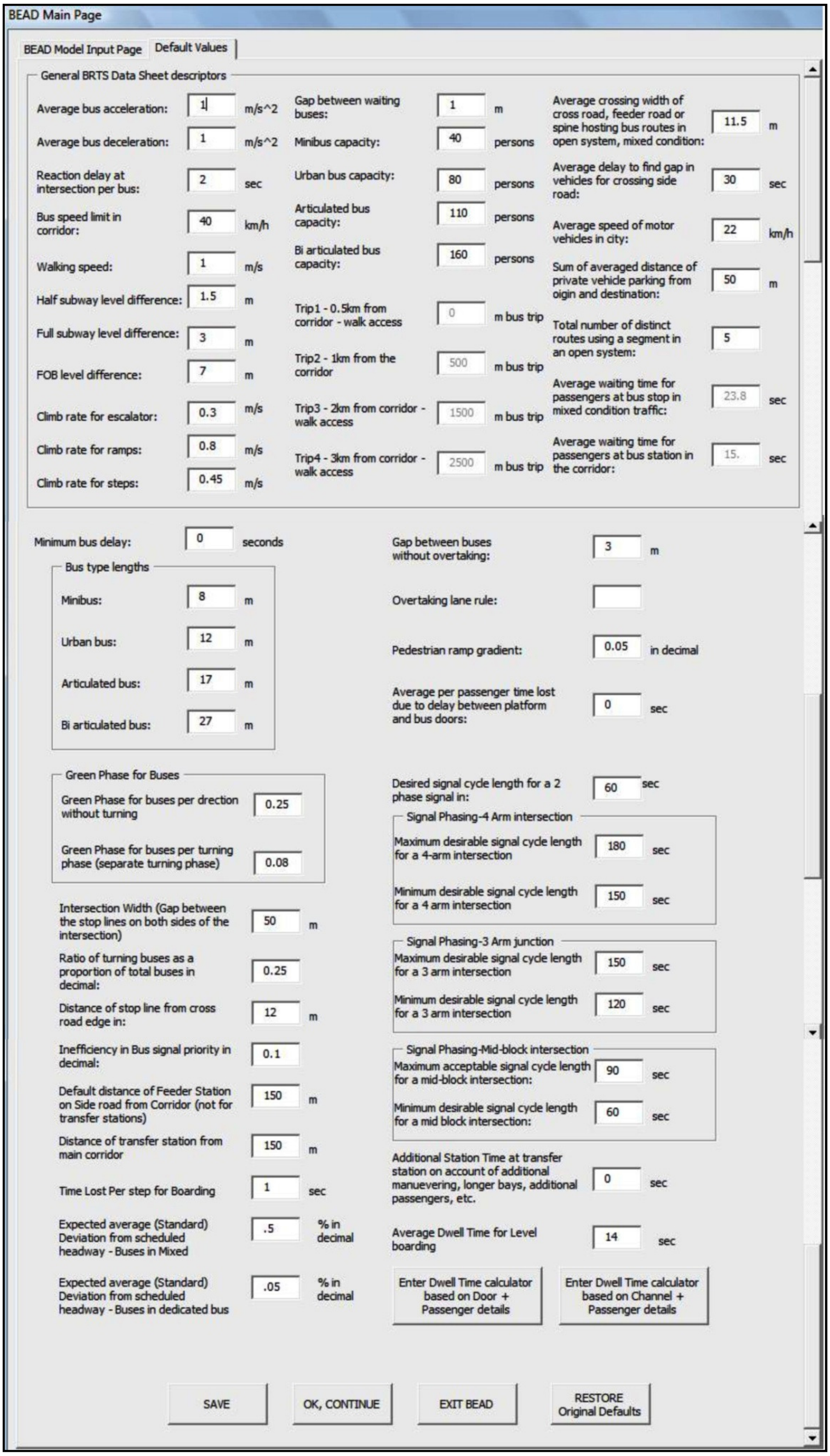
Average trip length in city: 10 Km

Number of segments in corridor length: 2

Operation type

○ Closed BRT operation ● Open BRT operation

Figure 4: BEAD Tool – First Page form



General BRTS Data Sheet descriptors

Average bus acceleration: 1 m/s^2
Average bus deceleration: 1 m/s^2
Reaction delay at intersection per bus: 2 sec
Bus speed limit in corridor: 40 km/h
Walking speed: 1 m/s
Half subway level difference: 1.5 m
Full subway level difference: 3 m
FOB level difference: 7 m
Climb rate for escalator: 0.3 m/s
Climb rate for ramps: 0.8 m/s
Climb rate for steps: 0.45 m/s
Gap between waiting buses: 1 m
Minibus capacity: 40 persons
Urban bus capacity: 80 persons
Articulated bus capacity: 110 persons
Bi articulated bus capacity: 160 persons
Trip1 - 0.5km from corridor - walk access 0 m bus trip
Trip2 - 1km from the corridor 500 m bus trip
Trip3 - 2km from corridor - walk access 1500 m bus trip
Trip4 - 3km from corridor - walk access 2500 m bus trip
Average crossing width of cross road, feeder road or spine hosting bus routes in open system, mixed condition: 11.5 m
Average delay to find gap in vehicles for crossing side road: 30 sec
Average speed of motor vehicles in city: 22 km/h
Sum of averaged distance of private vehicle parking from oigin and destination: 50 m
Total number of distinct routes using a segment in an open system: 5
Average waiting time for passengers at bus stop in mixed condition traffic: 23.8 sec
Average waiting time for passengers at bus station in the corridor: 15. sec

Minimum bus delay: 0 seconds

Bus type lengths

Minibus: 8 m
Urban bus: 12 m
Articulated bus: 17 m
Bi articulated bus: 27 m

Green Phase for Buses

Green Phase for buses per drection without turning 0.25
Green Phase for buses per turning phase (separate turning phase) 0.08

Intersection Width (Gap between the stop lines on both sides of the intersection) 50 m
Ratio of turning buses as a proportion of total buses in decimal: 0.25
Distance of stop line from cross road edge in: 12 m
Inefficiency in Bus signal priority in decimal: 0.1
Default distance of Feeder Station on Side road from Corridor (not for transfer stations) 150 m
Distance of transfer station from main corridor 150 m
Time Lost Per step for Boarding 1 sec
Expected average (Standard) Deviation from scheduled headway - Buses in Mixed .5 % in decimal
Expected average (Standard) Deviation from scheduled headway - Buses in dedicated bus .05 % in decimal

Gap between buses without overtaking: 3 m
Overtaking lane rule:
Pedestrian ramp gradient: 0.05 in decimal
Average per passenger time lost due to delay between platform and bus doors: 0 sec

Desired signal cycle length for a 2 phase signal in: 60 sec

Signal Phasing-4 Arm intersection

Maximum desirable signal cycle length for a 4-arm intersection 180 sec
Minimum desirable signal cycle length for a 4 arm intersection 150 sec

Signal Phasing-3 Arm junction

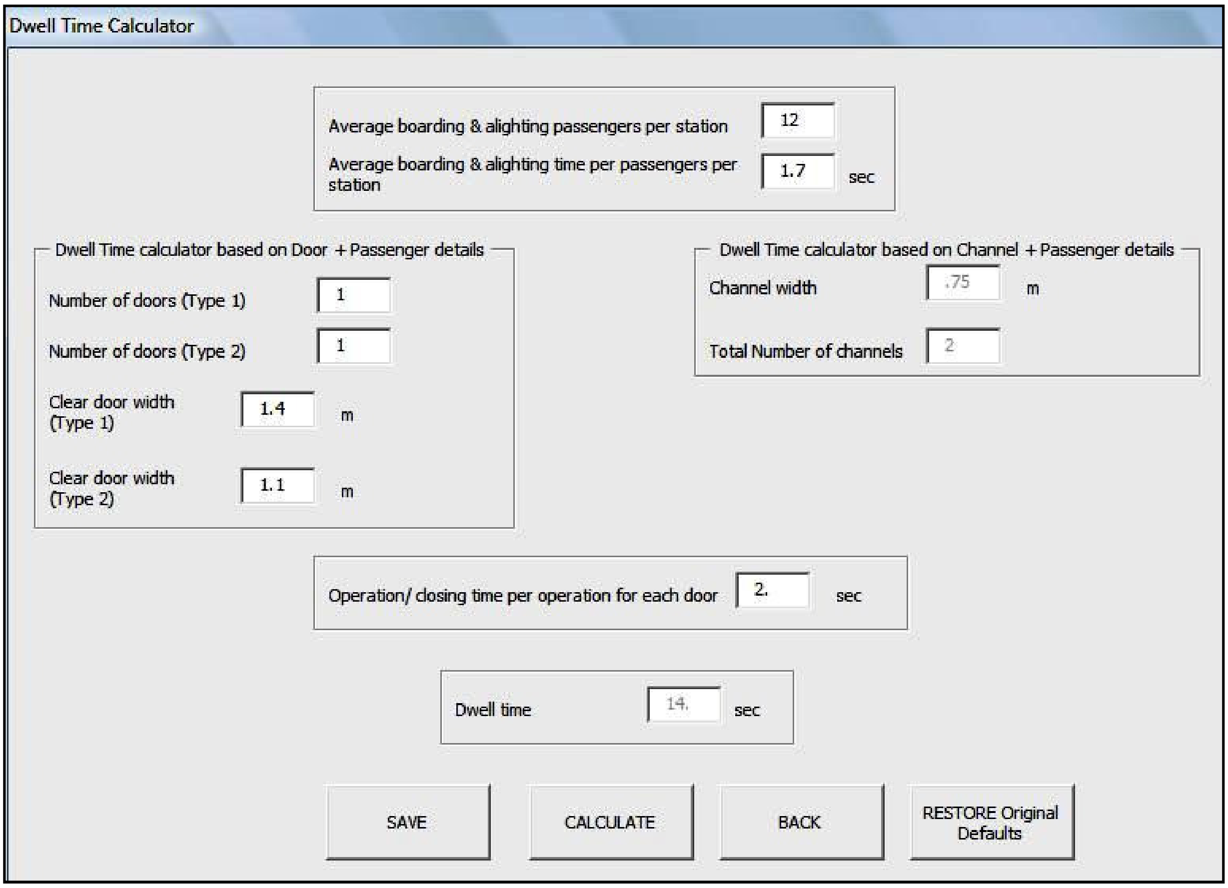
Maximum desirable signal cycle length for a 3 arm intersection 150 sec
Minimum desirable signal cycle length for a 3 arm intersection 120 sec

Signal Phasing-Mid-block intersection

Maximum acceptable signal cycle length for a mid-block intersection: 90 sec
Minimum desirable signal cycle length for a mid block intersection: 60 sec

Additional Station Time at transfer station on account of additional manuevering, longer bays, additional passengers, etc. 0 sec
Average Dwell Time for Level boarding 14 sec

Figure5: BEAD TOOL – Default variables form



Average boarding & alighting passengers per station: 12

Average boarding & alighting time per passengers per station: 1.7 sec

Number of doors (Type 1): 1

Number of doors (Type 2): 1

Clear door width (Type 1): 1.4 m

Clear door width (Type 2): 1.1 m

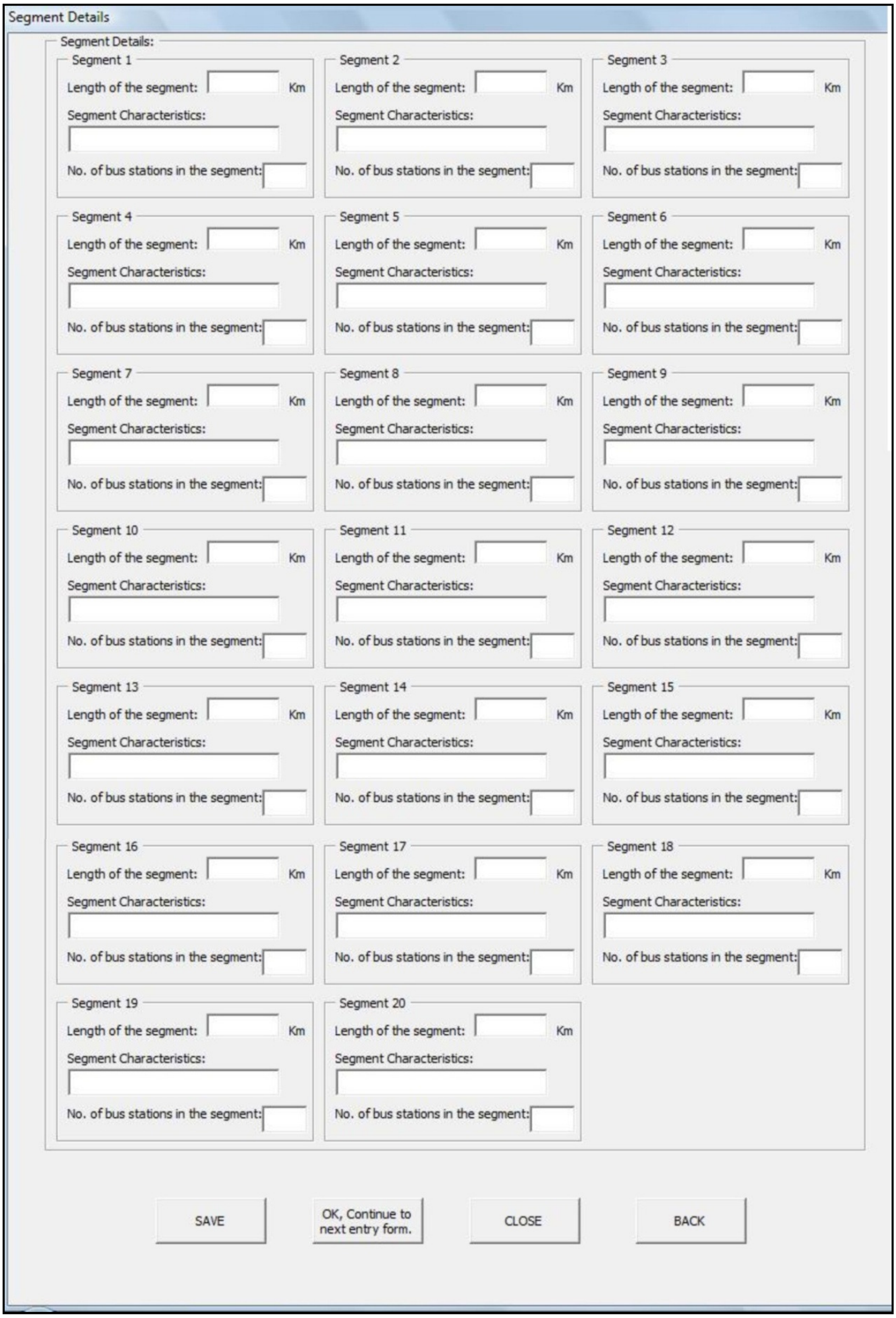
Channel width: .75 m

Total Number of channels: 2

Operation/ closing time per operation for each door: 2. sec

Dwell time: 14. sec

Figure 6: Dwell Time Calculator Form



Segment Details

Segment Details:

Segment 1
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 2
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 3
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 4
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 5
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 6
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 7
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 8
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 9
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 10
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 11
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 12
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 13
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 14
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 15
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 16
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

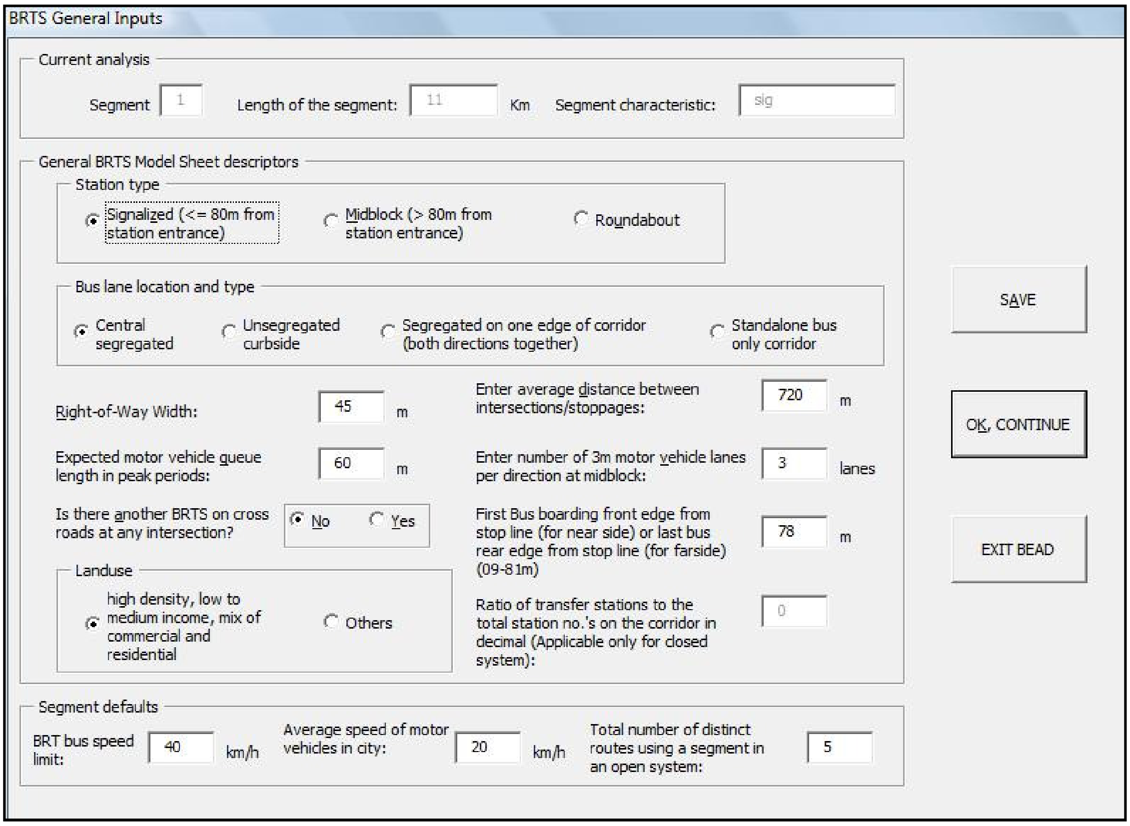
Segment 17
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 18
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 19
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Segment 20
Length of the segment: Km
Segment Characteristics:
No. of bus stations in the segment:

Figure 7: BEAD Tool - Segment Details form



BRTS General Inputs

Current analysis

Segment: 1
Length of the segment: 11 Km
Segment characteristic: sig

General BRTS Model Sheet descriptors

Station type: ● Signalized (<= 80m from station entrance) ○ Midblock (> 80m from station entrance) ○ Roundabout

Bus lane location and type: ● Central segregated ○ Unsegregated curbside ○ Segregated on one edge of corridor (both directions together) ○ Standalone bus only corridor

Right-of-Way Width: 45 m
Enter average distance between intersections/stoppages: 720 m
Expected motor vehicle queue length in peak periods: 60 m
Enter number of 3m motor vehicle lanes per direction at midblock: 3 lanes
Is there another BRTS on cross roads at any intersection? ● No ○ Yes
First Bus boarding front edge from stop line (for near side) or last bus rear edge from stop line (for farside) (09-81m): 78 m

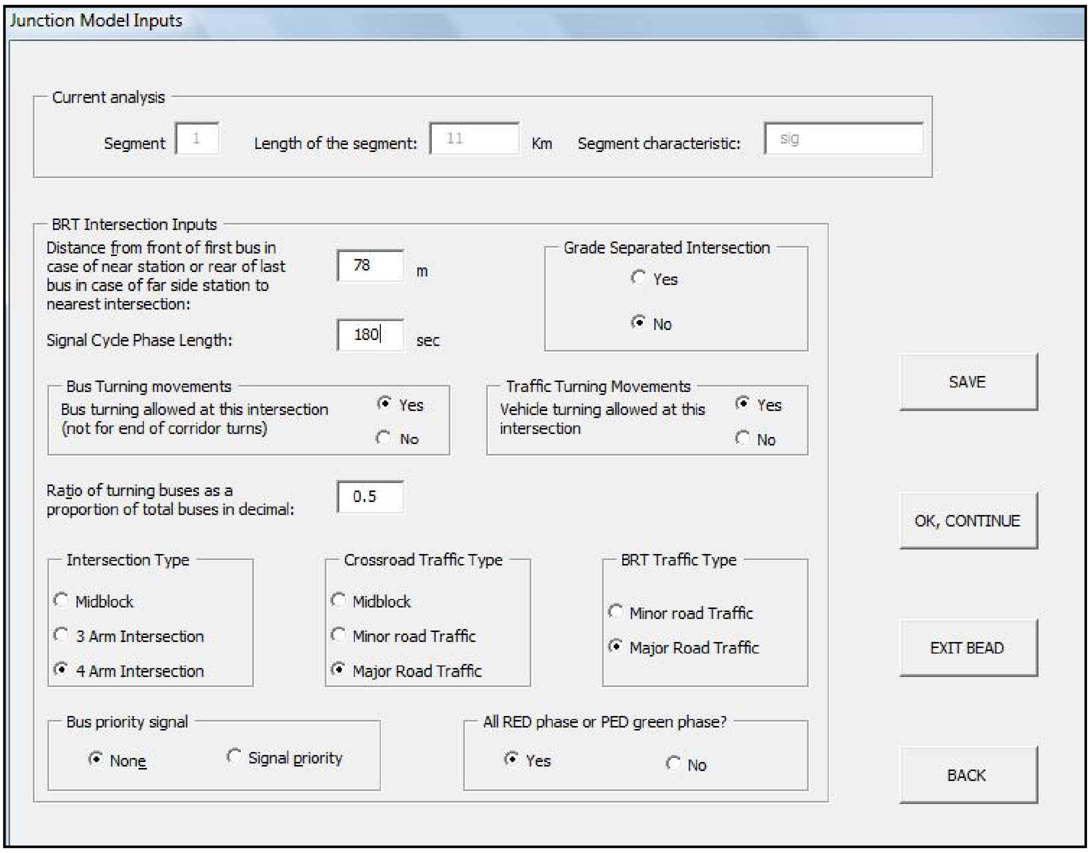
Landuse: ● high density, low to medium income, mix of commercial and residential ○ Others

Ratio of transfer stations to the total station no.'s on the corridor in decimal (Applicable only for closed system): 0

Segment defaults

BRT bus speed limit: 40 km/h
Average speed of motor vehicles in city: 20 km/h
Total number of distinct routes using a segment in an open system: 5

Figure 8: BEAD Tool – General inputs form



Junction Model Inputs

Current analysis

Segment: 1
Length of the segment: 11 Km
Segment characteristic: sig

BRT Intersection Inputs

Distance from front of first bus in case of near station or rear of last bus in case of far side station to nearest intersection: 78 m
Signal Cycle Phase Length: 180 sec

Grade Separated Intersection: ○ Yes ● No

Bus Turning movements: Bus turning allowed at this intersection (not for end of corridor turns) ● Yes ○ No

Traffic Turning Movements: Vehicle turning allowed at this intersection ● Yes ○ No

Ratio of turning buses as a proportion of total buses in decimal: 0.5

Intersection Type: ○ Midblock ○ 3 Arm Intersection ● 4 Arm Intersection

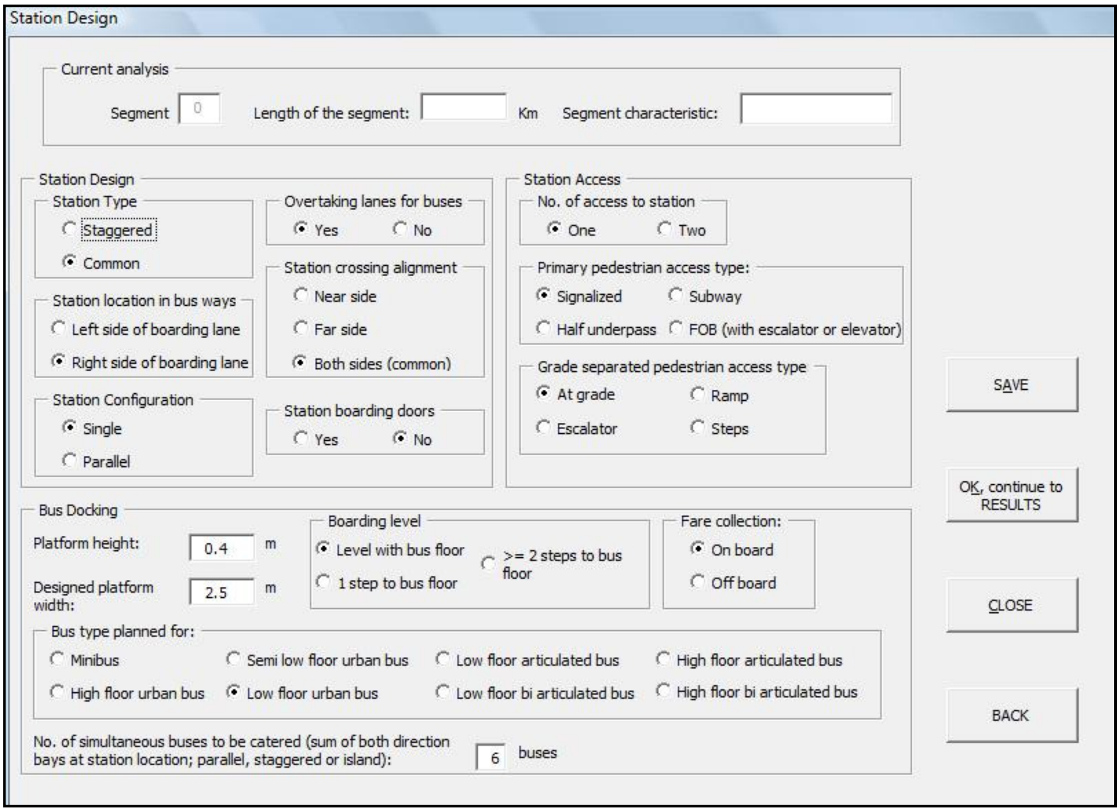
Crossroad Traffic Type: ○ Midblock ○ Minor road Traffic ● Major Road Traffic

BRT Traffic Type: ○ Minor road Traffic ● Major Road Traffic

Bus priority signal: ● None ○ Signal priority

All RED phase or PED green phase? ● Yes ○ No

Figure 9: BEAD Tool - Intersection (for junction stations), input form



Station Design

Current analysis
Segment: 0
Length of the segment: Km
Segment characteristic:

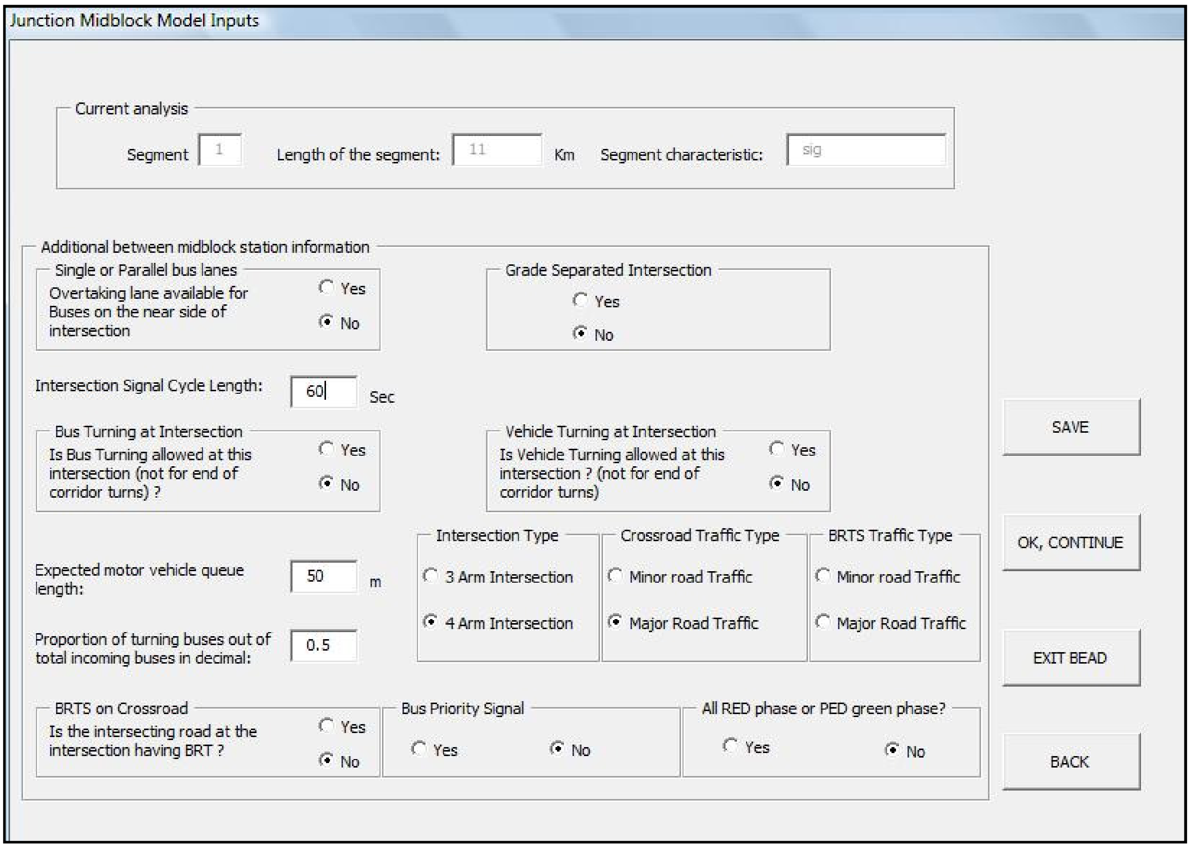
Station Design
Station Type: ○ Staggered ● Common
Overtaking lanes for buses: ● Yes ○ No
Station crossing alignment: ○ Near side ○ Far side ● Both sides (common)
Station location in bus ways: ○ Left side of boarding lane ● Right side of boarding lane
Station Configuration: ● Single ○ Parallel
Station boarding doors: ○ Yes ● No

Station Access
No. of access to station: ● One ○ Two
Primary pedestrian access type: ● Signalized ○ Subway ○ Half underpass ○ FOB (with escalator or elevator)
Grade separated pedestrian access type: ● At grade ○ Ramp ○ Escalator ○ Steps

Bus Docking
Platform height: 0.4 m
Designed platform width: 2.5 m
Boarding level: ● Level with bus floor ○ 1 step to bus floor ○ >= 2 steps to bus floor
Fare collection: ● On board ○ Off board
Bus type planned for: ○ Minibus ○ High floor urban bus ○ Semi low floor urban bus ● Low floor urban bus ○ Low floor articulated bus ○ Low floor bi articulated bus ○ High floor articulated bus ○ High floor bi articulated bus

No. of simultaneous buses to be catered (sum of both direction bays at station location; parallel, staggered or island): 6 buses

Figure 10: BEAD Tool – Station Design input form (common for junction or midblock stations)

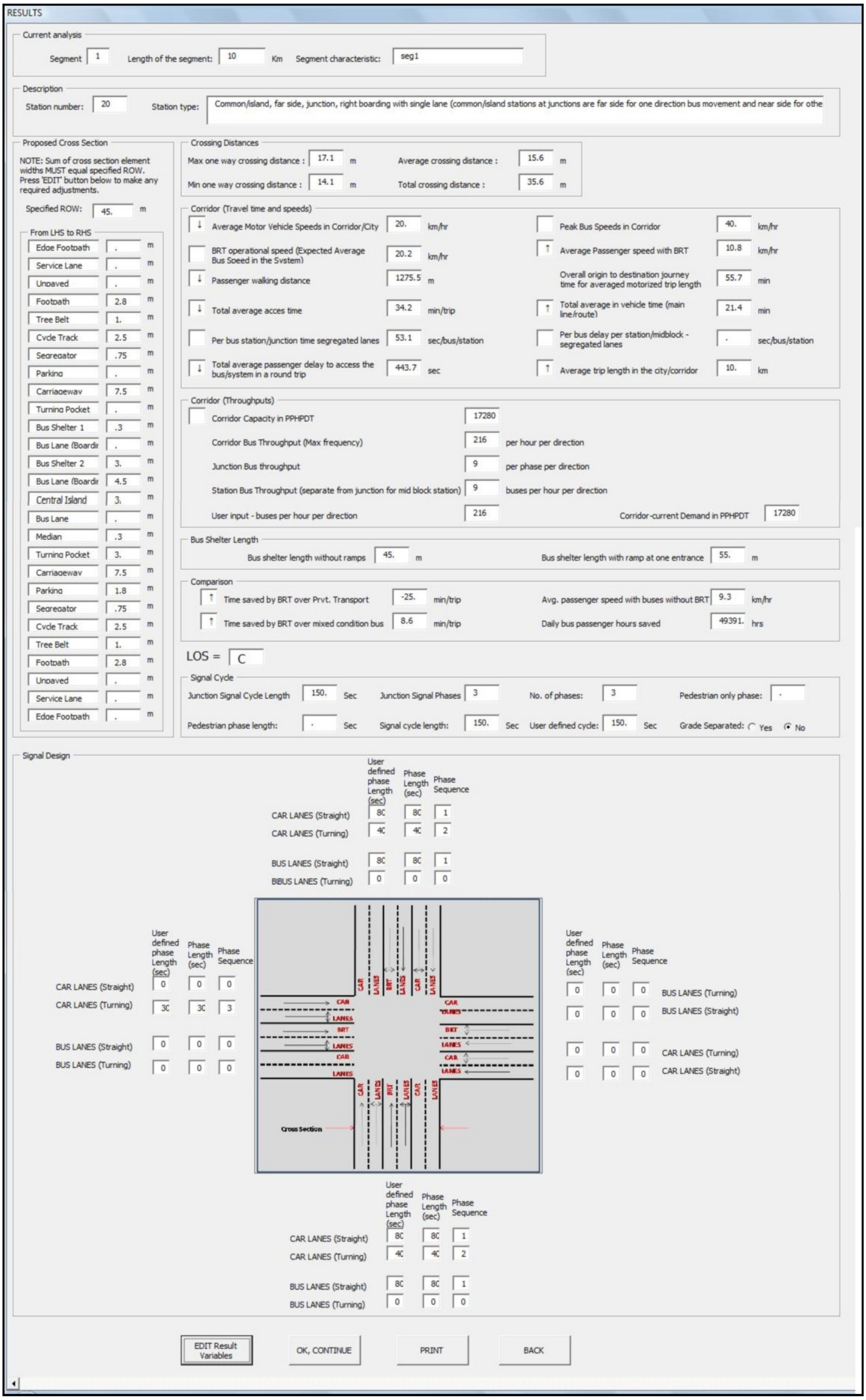


Junction Midblock Model Inputs

Current analysis
Segment: 1
Length of the segment: 11 Km
Segment characteristic: sig

Additional between midblock station information
Single or Parallel bus lanes – Overtaking lane available for Buses on the near side of intersection: ○ Yes ● No
Grade Separated Intersection: ○ Yes ● No
Intersection Signal Cycle Length: 60 Sec
Bus Turning at Intersection – Is Bus Turning allowed at this intersection (not for end of corridor turns) ?: ○ Yes ● No
Vehicle Turning at Intersection – Is Vehicle Turning allowed at this intersection ? (not for end of corridor turns): ○ Yes ● No
Expected motor vehicle queue length: 50 m
Proportion of turning buses out of total incoming buses in decimal: 0.5
Intersection Type: ○ 3 Arm Intersection ● 4 Arm Intersection
Crossroad Traffic Type: ○ Minor road Traffic ● Major Road Traffic
BRTS Traffic Type: ○ Minor road Traffic ○ Major Road Traffic
BRTS on Crossroad – Is the intersecting road at the intersection having BRT ?: ○ Yes ● No
Bus Priority Signal: ○ Yes ● No
All RED phase or PED green phase?: ○ Yes ● No

Figure 11: BEAD Tool - Additional junction input form, specific for junctions between mid block stations



RESULTS

Current analysis

Segment: 1 | Length of the segment: 10 Km | Segment characteristic: seg1

Description

Station number: 20

Station type: Common/island, far side, junction, right boarding with single lane (common/island stations at junctions are far side for one direction bus movement and near side for othe

Proposed Cross Section

NOTE: Sum of cross section element widths MUST equal specified ROW. Press 'EDIT' button below to make any required adjustments.

Specified ROW: 45. m

From LHS to RHS

Edge Footpath	.	m
Service Lane	.	m
Unpaved	.	m
Footpath	2.8	m
Tree Belt	1.	m
Cycle Track	2.5	m
Segregator	.75	m
Parking	.	m
Carriageway	7.5	m
Turning Pocket	.	m
Bus Shelter 1	.3	m
Bus Lane (Boardir	.	m
Bus Shelter 2	3.	m
Bus Lane (Boardir	4.5	m
Central Island	3.	m
Bus Lane	.	m
Median	.3	m
Turning Pocket	3.	m
Carriageway	7.5	m
Parking	1.8	m
Segregator	.75	m
Cycle Track	2.5	m
Tree Belt	1.	m
Footpath	2.8	m
Unpaved	.	m
Service Lane	.	m
Edge Footpath	.	m

Crossing Distances

Max one way crossing distance : 17.1 m

Average crossing distance : 15.6 m

Min one way crossing distance : 14.1 m

Total crossing distance : 35.6 m

Corridor (Travel time and speeds)

↓	Average Motor Vehicle Speeds in Corridor/City	20.	km/hr
☐	BRT operational speed (Expected Average Bus Speed in the System)	20.2	km/hr
↓	Passenger walking distance	1275.5	m
↓	Total average acces time	34.2	min/trip
☐	Per bus station/junction time segregated lanes	53.1	sec/bus/station
↓	Total average passenger delay to access the bus/system in a round trip	443.7	sec
☐	Peak Bus Speeds in Corridor	40.	km/hr
↑	Average Passenger speed with BRT	10.8	km/hr
	Overall origin to destination journey time for averaged motorized trip length	55.7	min
↑	Total average in vehicle time (main line/route)	21.4	min
☐	Per bus delay per station/midblock - segregated lanes	.	sec/bus/station
↑	Average trip length in the city/corridor	10.	km

Corridor (Throughputs)

☐	Corridor Capacity in PPHPDT	17280	
	Corridor Bus Throughput (Max frequency)	216	per hour per direction
	Junction Bus throughput	9	per phase per direction
	Station Bus Throughput (separate from junction for mid block station)	9	buses per hour per direction
	User input - buses per hour per direction	216	
	Corridor-current Demand in PPHPDT	17280	

Bus Shelter Length

Bus shelter length without ramps: 45. m

Bus shelter length with ramp at one entrance: 55. m

Comparison

↑	Time saved by BRT over Prvt. Transport	-25.	min/trip
↑	Time saved by BRT over mixed condition bus	8.6	min/trip
	Avg. passenger speed with buses without BRT	9.3	km/hr
	Daily bus passenger hours saved	49391.	hrs

LOS = C

Signal Cycle

Junction Signal Cycle Length: 150. Sec

Junction Signal Phases: 3

No. of phases: 3

Pedestrian only phase: .

Pedestrian phase length: . Sec

Signal cycle length: 150. Sec

User defined cycle: 150. Sec

Grade Separated: ○ Yes ● No

Signal Design

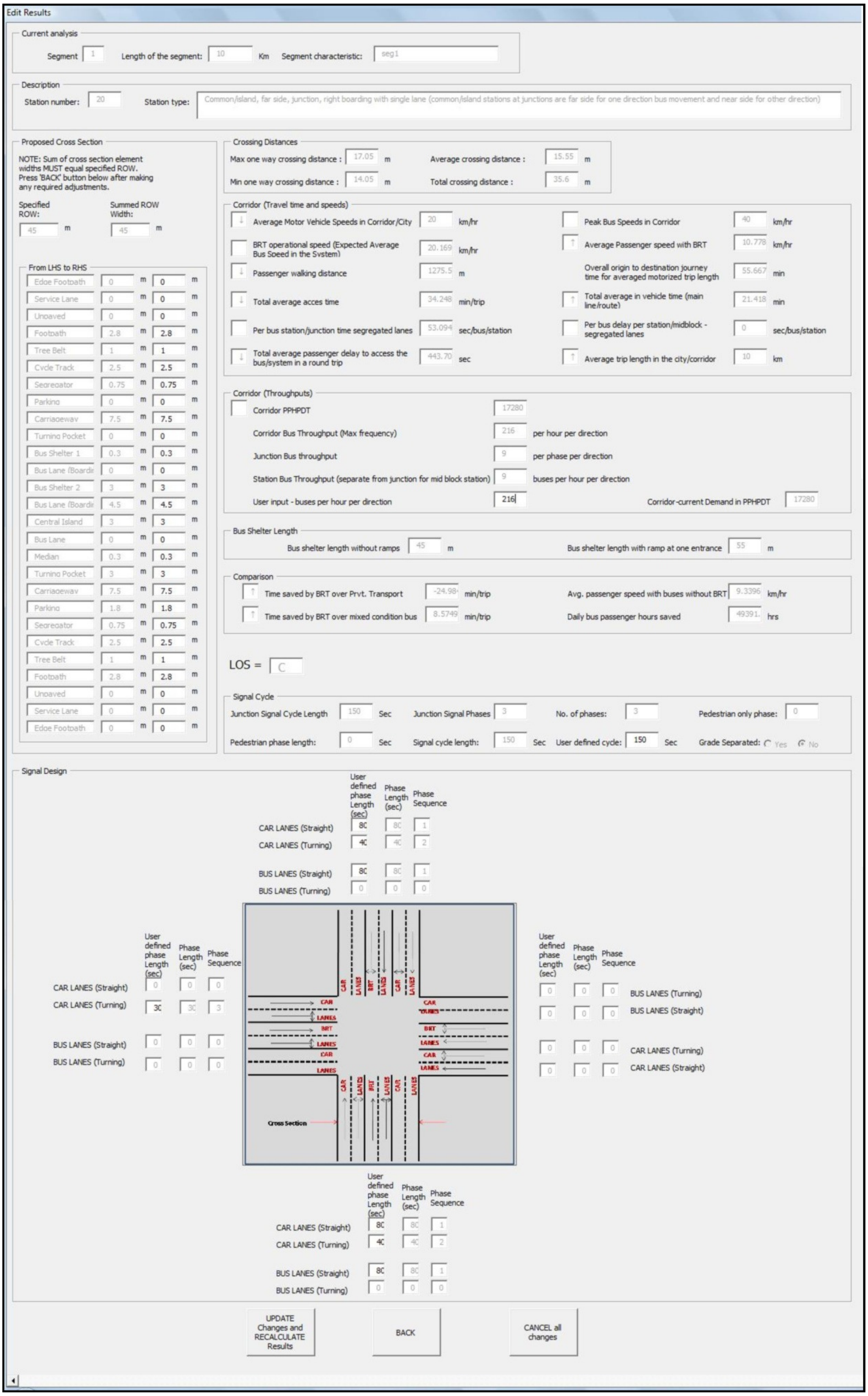
	User defined phase Length (sec)	Phase Length (sec)	Phase Sequence
CAR LANES (Straight)	80	80	1
CAR LANES (Turning)	40	40	2
BUS LANES (Straight)	80	80	1
BIBUS LANES (Turning)	0	0	0

	User defined phase Length (sec)	Phase Length (sec)	Phase Sequence
CAR LANES (Straight)	0	0	0
CAR LANES (Turning)	30	30	3
BUS LANES (Straight)	0	0	0
BUS LANES (Turning)	0	0	0

User defined phase Length (sec)	Phase Length (sec)	Phase Sequence	
0	0	0	BUS LANES (Turning)
0	0	0	BUS LANES (Straight)
0	0	0	CAR LANES (Turning)
0	0	0	CAR LANES (Straight)

	User defined phase Length (sec)	Phase Length (sec)	Phase Sequence
CAR LANES (Straight)	80	80	1
CAR LANES (Turning)	40	40	2
BUS LANES (Straight)	80	80	1
BUS LANES (Turning)	0	0	0

Figure 12: BEAD Tool – Results/Output sheet



Current analysis

Segment: 1 Length of the segment: 10 Km Segment characteristic: seg1

Description

Station number: 20 Station type: Common/island, far side, junction, right boarding with single lane (common/island stations at junctions are far side for one direction bus movement and near side for other direction)

Proposed Cross Section

NOTE: Sum of cross section element widths MUST equal specified ROW. Press 'BACK' button below after making any required adjustments.

Specified ROW: 45 m Summed ROW Width: 45 m

From LHS to RHS

Edge Footpath	0	m	0	m
Service Lane	0	m	0	m
Unpaved	0	m	0	m
Footpath	2.8	m	2.8	m
Tree Belt	1	m	1	m
Cycle Track	2.5	m	2.5	m
Segregator	0.75	m	0.75	m
Parking	0	m	0	m
Carriageway	7.5	m	7.5	m
Turning Pocket	0	m	0	m
Bus Shelter 1	0.3	m	0.3	m
Bus Lane (Boardir	0	m	0	m
Bus Shelter 2	3	m	3	m
Bus Lane (Boardir	4.5	m	4.5	m
Central Island	3	m	3	m
Bus Lane	0	m	0	m
Median	0.3	m	0.3	m
Turning Pocket	3	m	3	m
Carriageway	7.5	m	7.5	m
Parking	1.8	m	1.8	m
Segregator	0.75	m	0.75	m
Cycle Track	2.5	m	2.5	m
Tree Belt	1	m	1	m
Footpath	2.8	m	2.8	m
Unpaved	0	m	0	m
Service Lane	0	m	0	m
Edge Footpath	0	m	0	m

Crossing Distances

Max one way crossing distance : 17.05 m
Average crossing distance : 15.55 m
Min one way crossing distance : 14.05 m
Total crossing distance : 35.6 m

Corridor (Travel time and speeds)

↓ Average Motor Vehicle Speeds in Corridor/City: 20 km/hr
Peak Bus Speeds in Corridor: 40 km/hr
BRT operational speed (Expected Average Bus Speed in the System): 20.169 km/hr
↑ Average Passenger speed with BRT: 10.778 km/hr
↓ Passenger walking distance: 1275.5 m
Overall origin to destination journey time for averaged motorized trip length: 55.667 min
↓ Total average acces time: 34.248 min/trip
↑ Total average in vehicle time (main line/route): 21.418 min
Per bus station/junction time segregated lanes: 53.094 sec/bus/station
Per bus delay per station/midblock - segregated lanes: 0 sec/bus/station
↓ Total average passenger delay to access the bus/system in a round trip: 443.70 sec
↑ Average trip length in the city/corridor: 10 km

Corridor (Throughputs)

Corridor PPHPDT: 17280
Corridor Bus Throughput (Max frequency): 216 per hour per direction
Junction Bus throughput: 9 per phase per direction
Station Bus Throughput (separate from junction for mid block station): 9 buses per hour per direction
User input - buses per hour per direction: 216
Corridor-current Demand in PPHPDT: 17280

Bus Shelter Length

Bus shelter length without ramps: 45 m
Bus shelter length with ramp at one entrance: 55 m

Comparison

↑ Time saved by BRT over Prvt. Transport: -24.98 min/trip
Avg. passenger speed with buses without BRT: 9.3396 km/hr
↑ Time saved by BRT over mixed condition bus: 8.5749 min/trip
Daily bus passenger hours saved: 49391. hrs

LOS = C

Signal Cycle

Junction Signal Cycle Length: 150 Sec
Junction Signal Phases: 3
No. of phases: 3
Pedestrian only phase: 0
Pedestrian phase length: 0 Sec
Signal cycle length: 150 Sec
User defined cycle: 150 Sec
Grade Separated: ○ Yes ● No

Signal Design

	User defined phase Length (sec)	Phase Length (sec)	Phase Sequence
CAR LANES (Straight)	80	80	1
CAR LANES (Turning)	40	40	2
BUS LANES (Straight)	80	80	1
BUS LANES (Turning)	0	0	0

	User defined phase Length (sec)	Phase Length (sec)	Phase Sequence
CAR LANES (Straight)	0	0	0
CAR LANES (Turning)	30	30	3
BUS LANES (Straight)	0	0	0
BUS LANES (Turning)	0	0	0

User defined phase Length (sec)	Phase Length (sec)	Phase Sequence	
0	0	0	BUS LANES (Turning)
0	0	0	BUS LANES (Straight)
0	0	0	CAR LANES (Turning)
0	0	0	CAR LANES (Straight)

	User defined phase Length (sec)	Phase Length (sec)	Phase Sequence
CAR LANES (Straight)	80	80	1
CAR LANES (Turning)	40	40	2
BUS LANES (Straight)	80	80	1
BUS LANES (Turning)	0	0	0

Figure 13: 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 (minutes)	$H = 60/f$
Minimum Headway (reaction time modified in seconds)	$H_{min} = t_s + (t_r*n_s) + n*l'/v + v(k + 1)/2b + \sqrt{(2*n_s*l'/a)}$
Operation Time for buses (sec)	$T_o = n_s(t_a + t_b + t_s) + \sum t_{vi}$
Operation Speed (km/h)	$V_o = 3600* L/T_o$
Minimum Gap between buses	$S_{min} = V^2*(a+b)/(5*a*b)$
Poisson Distribution	$P(x) = e^{-\lambda}*\lambda^x/x!$
Waiting time for bus	$T_w = (H^2 + \sigma^2)/2H$

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_w	Waiting Time for Bus
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
σ	Standard deviation of headway
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** & **Modelling Transport by Juan de Dios Ortuzar, Luis G. Williamson**. 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 are 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 Chirag Delhi Bus Stop on November 04, 2011. The survey was conducted by counting the number 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 number 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 began the stop watch after opening of bus doors and stopped when the last passenger boarded or un-boarded. Data were analyzed for low floor or entry plus zero step and high floor, i.e., entry plus two steps. The results are 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, these data represent 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 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 that had single channel of passenger movement on each door due to reduced width. Further, since the data are 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 is 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 have primarily been collected from standard and urban buses. These have two channels for boarding and alighting. The average capacity of these buses is assumed to be 60passengers 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 the number of channels increase proportionately with the size of the transit vehicle, it is assumed that vehicle type has no impact on dwell time, and it is only dependent on the number 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 as flowcharts in Annexure 5. Some of the critical logic or processes used in the tool have been explained 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 that are separate for each segment. Thus, for a closed system, the user is prompted to not select the bus-turning allowed option at intersections. For an open system, some segments can be chosen with bus-turning allowed at intersection, while others can be without bus-turning allowed option, allowing one to generate a hybrid system design.

After inputting 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, presents 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 are explained in detail in Section 3.4.

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 56) 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 midblock) (Figure 58)** – In case of junction stations the common pedestrian cum vehicular crossing signal design is used for assessment, while in case of midblock 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. For delay estimates, an 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, if the bus is ready to leave within the green phase of the signal, i.e., signal delays are zero, the minimum delay is the dwell time plus reaction time plus 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. In the worst case scenario, the delay shall be dwell time plus reaction time plus acceleration and deceleration time lost plus time lost in waiting for a boarding slot at the station, i.e., buses queuing to enter station, plus delay at the signal during the red phase. Since all buses must pass through the intersection during one signal cycle, the maximum red phase delay must be longer than or account for the time lost in waiting for a boarding slot at the station, i.e., 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. The maximum delay can be calculated by dwell time plus reaction time plus acceleration and deceleration time lost plus maximum delay at the signal during the red phase. Average per bus delay at the signal can be estimated by dwell time plus reaction time plus acceleration and deceleration time lost plus 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 as shown in Figure 59. 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 62 –straight moving bus delay at far side stations with overtaking lane, Figure 63 – turning bus delay at far side stations with overtaking lane, Figure 66 – straight moving bus delay at far side station without overtaking lane, Figure 67 – 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 70) and without overtaking lane(Figure 71) as well turning buses at common station with (Figure 72) and without overtaking lanes (Figure 73).

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 60) or turning (Figure 61) 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 bus 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 64) and turning (Figure 65) 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 that is taken as 1/4th 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. The delay in interchanging from feeder bus to a trunk route bus on corridor is estimated for the passengers who have origin and destination more than 500m from the corridor. In a close system, this delay is accounted for 100% of such passengers, whereas in an open system, it is accounted 30% of such passengers.

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 Comprehensive Traffic and Transport (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 dwell 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 buses 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. This delay is 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 midblock pedestrian crossing effect both the vehicle (bus) and 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 of 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 midblock 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 midblock stations.

    For junction stations only the first or the station access signal design component is activated, whereas for the midblock 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/leg junction is 150 sec and 180 sec respectively.

        iv. Minimum and maximum desirable cycle length for 3 arm/leg junction is 120 sec and 150 sec respectively.

        v. Minimum and maximum desirable cycle length for 2 arm/leg location or midblock 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 results sheet for each segment, and generate revised values; however the same is not permitted in the aggregate output (xls file) of the corridor. The users can though use the output 'xls' file to load data in BEAD and edit to derive a revised output file. A description of each of the results category present both, on the results page and the output xls file has been given below.

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 Current Analysis

Under this head, the user will get to know the segment information for which following result is calculated by the BEAD tool.

3.4.1.2 Description

This result shows the station description designed by the tool to a particular station design type as specified by the user through inputs in different BEAD user forms.

3.4.1.3 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, Intermediate Public Transport (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 that over-ride the system defined design.

3.4.1.4 Crossing Distances

This head displays the crossing distances in meter, experiencing by the users or passengers for accessing the bus stations from either side of the road for every trip. These results are presented under the following sub heads:

Max one way crossing distance: This is the maximum crossing distance passengers accessing the station from one of the two sides of road. This value is derived from the cross-section (proposed by the tool) which includes widths of Cycle track, Segregator, Carriageway, Turning pocket, Median and Bus lanes, etc. This value estimated by tool, is in meter. This value gets edited if the user overrides the widths allocated by the tool, using the edit results button.

Min one way crossing distance: This is the minimum crossing distance for passengers accessing the station, from one of the two sides of road. This value is derived from the cross-section (proposed by the tool) which includes widths of Cycle track, Segregator, Carriageway, Turning pocket, Median and Bus lanes, etc. This value estimated by tool, is in meter. This value gets edited if the user overrides the widths allocated by the tool, using the edit results button.

Average crossing distance: This is the average crossing distance for passengers accessing the station from either side of road. This value is derived from the cross-section proposed by the tool, which includes average widths of Cycle track, Segregator, Carriageway, Turning pocket, Median and Bus lanes, etc. This value estimated by tool, is in meter. This value gets edited if the user overrides the widths allocated by the tool, using the edit results button.

Total crossing distance: This is the total crossing width or full carriageway (cum cycle track) crossing distance for pedestrians, across the designed corridor including widths of Cycle tracks, Segregators, Carriageways, Turning pockets, Median, Bus station and Bus lanes of the both sides of road from proposed cross-section. This value estimated by tool is in meter. This value gets edited if the user overrides the widths allocated by the tool, using the edit results button.

3.4.1.5 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.

3.4.1.6 Corridor Travel Time and Speed

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

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

Average Motor Vehicle Speed in Corridor/City: This is the average motor speed in the base or horizon year (depending on the period of assessment) on the corridor. Where estimates of corridor average speeds are not known the average speed of motor vehicles in the city may be used.

Peak Bus Speed in Corridor: The vale estimated by the tool is the desirable speed limit in bus lanes during peak hours in corridor.

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 such as 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 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 midblock 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 midblock 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.

Average trip length in City/Corridor: The estimated value by the tool is the average trip length of the passenger experienced with bus in corridor.

3.4.1.7 Corridor Throughput

This category presents results under the following sub heads:

1. Corridor PPHPDT
2. Corridor Bus Throughput (Maximum frequency)
3. Junction/Intersection Bus throughput
4. Station Bus Throughput that is separate from junction for midblock 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 midblock throughput (at pedestrian signal cycles) and at junction throughput (for junctions between midblock 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 midblock 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.

3.4.1.8 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 square meter area, which is useful in determining a rough estimate of costs involves.

3.4.1.9 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. Average 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. The default value is set as 20km/h but is editable by the user. This comparison estimates the passenger speed on the basis of walking distance to access parked vehicle. This distance is 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.

3.4.1.10 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 that is the 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 rather 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. 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. Higher delays lead to lower attractiveness of public transport.
8. **Total Bus Delay (Station plus 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. 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. 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 (<=30)	41 – 45 (31-35)	46 – 50 (36-40)	51 – 55 (41-45)	56 – 60 (46-50)	> 60 (>50)	Peak Bus Speed in Km/h in segregated lanes (un-segregated lanes)
Walking Distance	0.1399425	< = 900	901 - 1050	1051 - 1200	1201 - 1350	1351 - 1500	> 1500	Total walk distance in a trip in 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:

1.000 - 0.800	0.799 - 0.650	0.649 - 0.540	0.539 - 0.460	0.459 - 0.400	0.399– 0.000
A	B	C	D	E	F

3.4.1.11 Signal Cycle

Under this head, BEAD will give a result which includes different type of signal cycles and phases at intersections or mid-blocks, designed for buses and pedestrians. These results are presented under the following sub heads:

Junction Signal Cycle Length: This is the Signal cycle length at intersection between two adjacent junction stations for whole traffic including BRT buses, motorized and non-motorized vehicles, pedestrian crossing, etc. The cycle length is in seconds and can be between 120 sec to 300 sec. Example '150 sec'.

Junction Signal Phases: This is the number of signal phases at intersection between two adjacent junction stations. It is depending on intersection type. Example if it is 4-arm intersection Junction Signal Phases can be '4'.

No. of Phases: This is the number of signal phases at intersection between two adjacent Mid-blocks. It is depending on intersection type. Example if it is 4-arm intersection Junction Signal Phases can be '4'.

Pedestrian only phase: This is the number of pedestrian Signal phases at intersection if it is Signalized Crossing at intersection.

Pedestrian phase length: If the intersection is with Signalized Pedestrian Crossing then this is the Pedestrian phase length at that intersection. The phase length is in second. Example: '20 sec'.

Signal Cycle Length: This is the Signal cycle length at intersection between two adjacent Mid-blocks for whole traffic including BRT buses, motorized and non-motorized vehicles, pedestrian crossing, etc. The cycle length is in seconds. Example: '60 sec'.

User defined cycle: Enter the user defined Signal cycle length at intersection. This can be affects the result values.

Grade Separated: Choose whether pedestrian crossing at intersection is Grade separated or not. Pedestrian crossing can be signalized as well as grade separated at one time.

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 is provided with a comprehensive user manual along with standard trend charts using results, derived for different design combinations, from the BEAD tool (Annexure 7 and Figure 14 to Figure 18). The charts are 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 4have 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 midblock

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 as shown in Table 4. The data derived from this exercise were plotted as trends. 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 14throughFigure 18, 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. 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. In case of open systems, the passenger journey time savings are significant for station spacing around 750m, than those at 500 or 1000m. For closed system designs750m spacing allows the maximum travel time saving though this saving is lesser in terms of absolute numbers, and 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. This operational speed advantage does not translate in to journey time savings. Open systems provided faster journey time than closed system for up to 10-12km trip length while closed systems prove advantageous for longer trips.

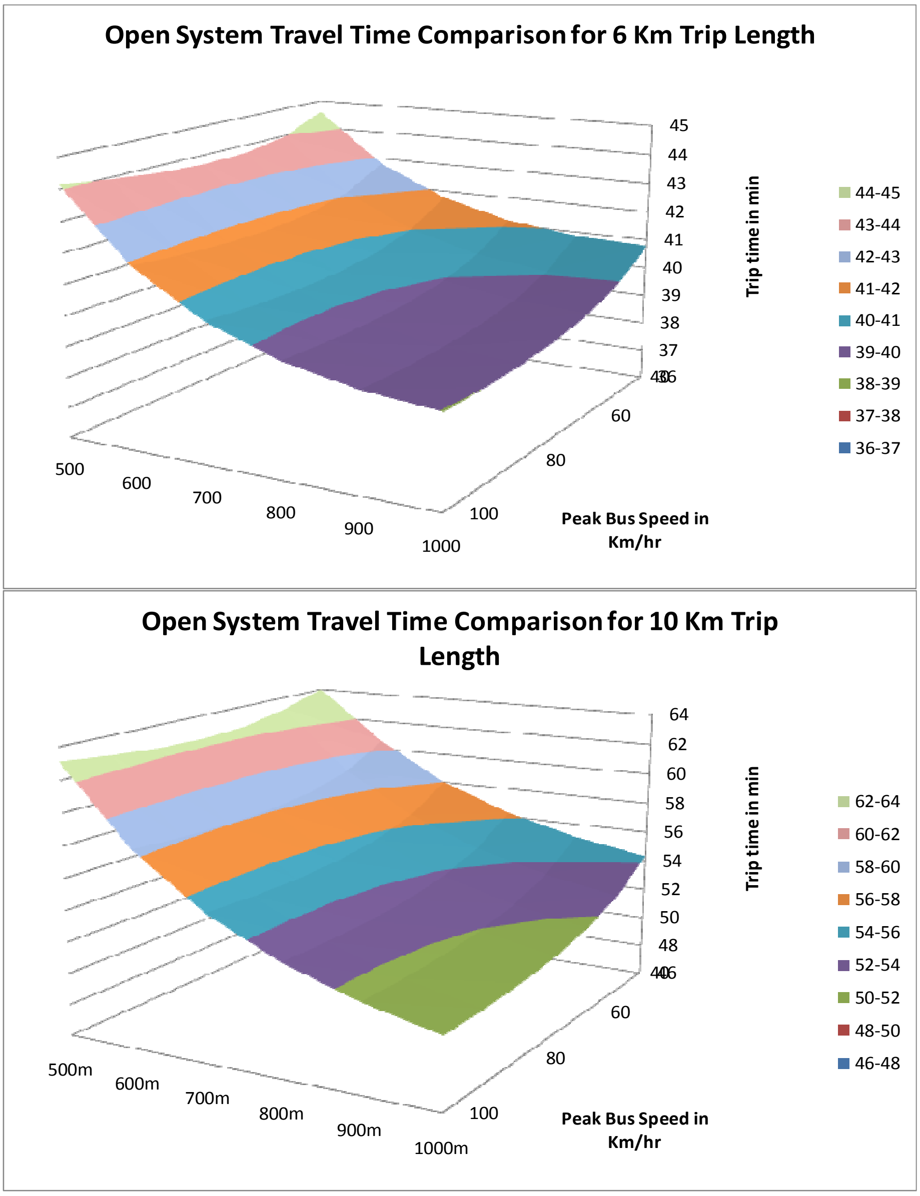
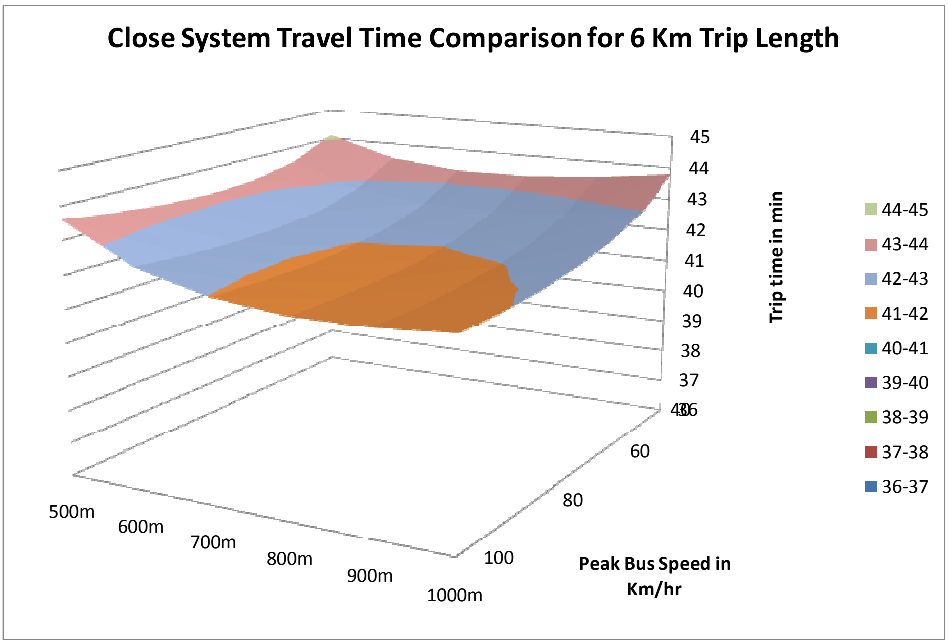


Figure 14: Comparison of trends for journey time changes (for 6 and 10km trip lengths using BRTS system) in an open system with staggered junction stations (based on results derived from BEAD Tool).



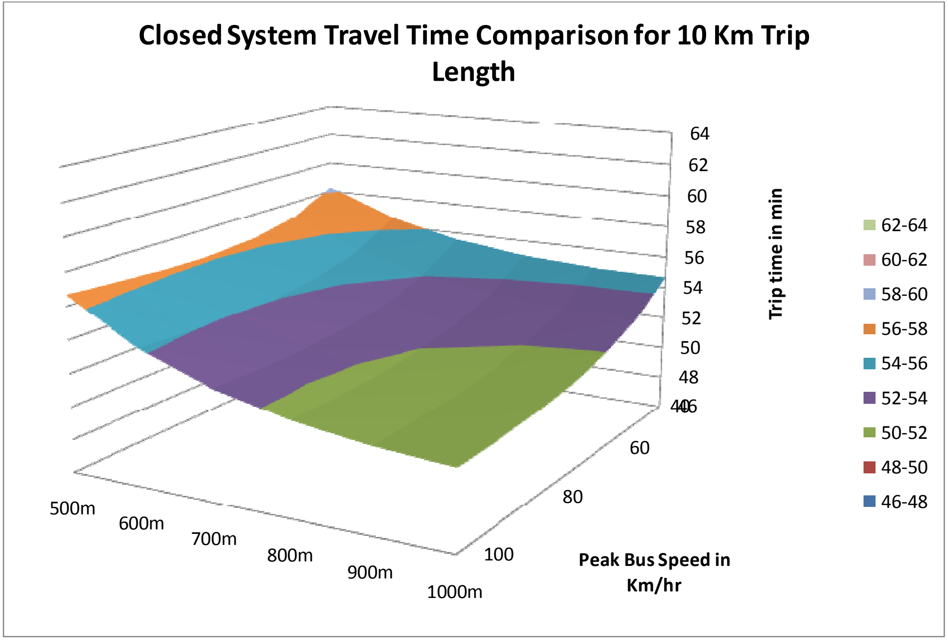


Figure 15: Comparison of trends for journey time changes (for 6 and 10km trip lengths using BRTS system) in a closed system with island junction stations (Based on results derived from BEAD Tool).

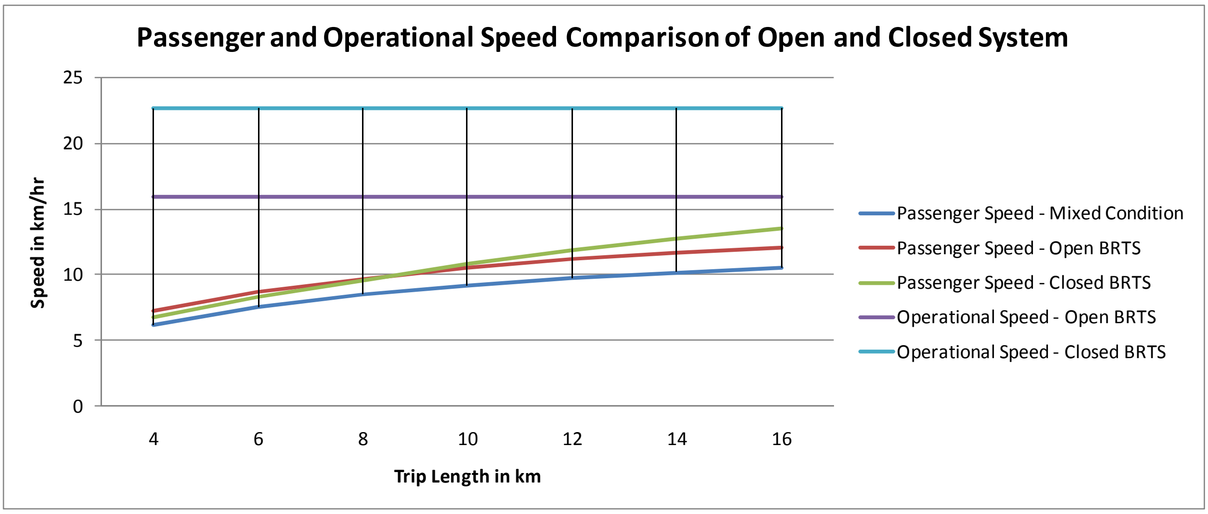


Figure 16: Passenger and operational speed comparison between open and closed system for different trip lengths

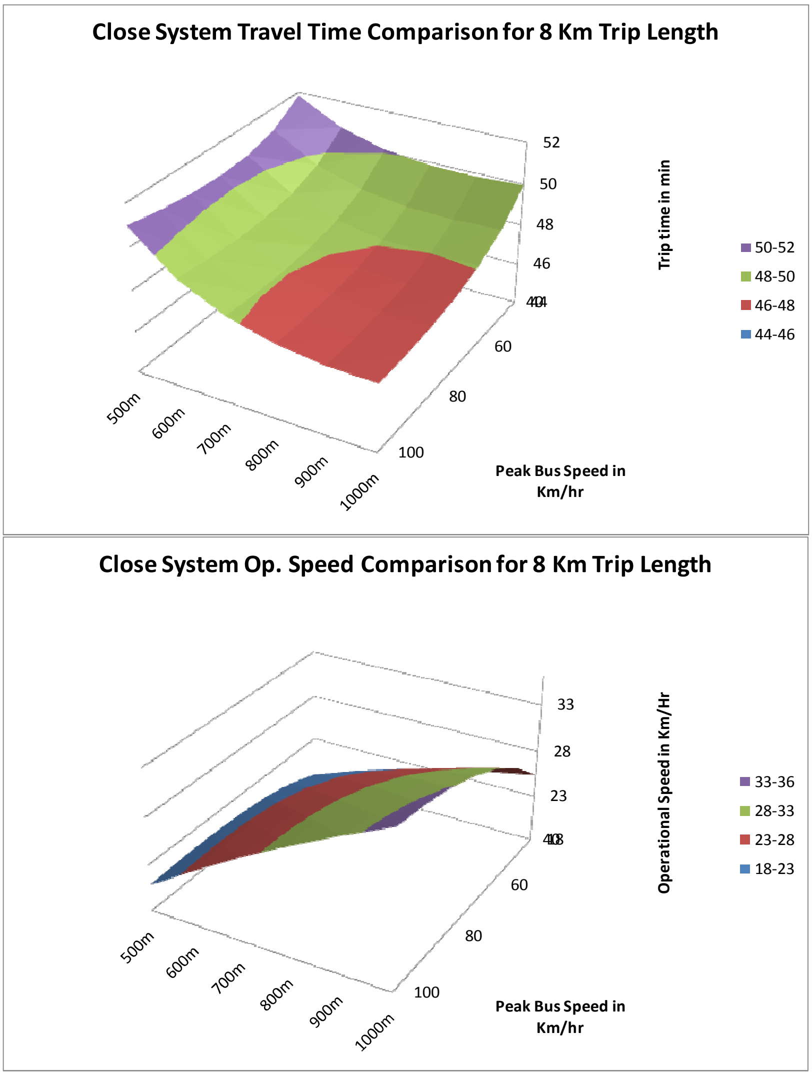


Figure 17: Operational and passenger speed comparison for closed system (with island stations) for a trip length of 8 km and varying stations spacing as well peak bus speeds in the corridor.

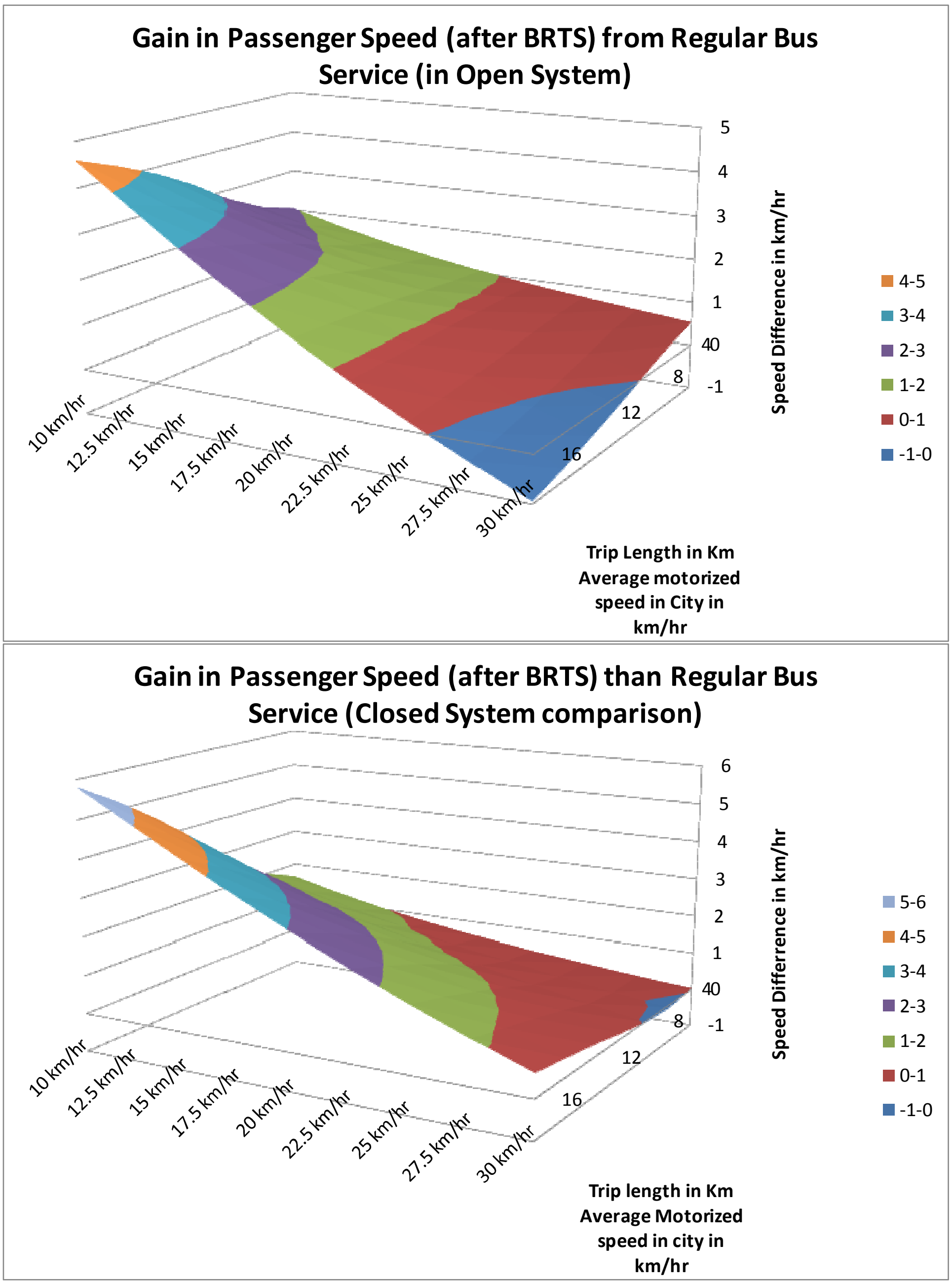


Figure 18: Time gain for passengers in BRTS over regular bus service (in mixed condition) compared for open and closed system against varying trip lengths and average speed of motorized vehicles in mixed traffic (on the corridor or in the city).

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 as shown in Figure 19. It has a total of nine stations including end stations along a length of approximately5.6km. The average distance between stations is approximately730m. Although the corridor has two midblock stations and seven 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 19: 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 byDelhi Integrated Multi-modal Transit Ltd. (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 Ahmadabad BRTS corridor from RTO to Shivrajani shown in Figure 20uses closed bus operations with island stations. It has an average station spacing of approximately800m 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 20: Aerial view of Ahmadabad 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 720mas 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 21: Aerial view of (Google Earth) Bogota BRTS – Caracas Corridor

The comparative results, between the tool output and the actual site studies generated by ITDPhave 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

5 Conclusions

The final BEAD tool is a result of a well researched approach, including consensus building with stakeholders and prospective users. BEAD has been calibrated using data and formulas mainly from **Urban Transit, Operations, Planning and Economics by Vukan R. Vuchic.** It uses standards for lane widths and other dimensions for cross section design from '**Recommendations for Traffic Provisions in built-up areas (ASVV) CROW', Record 15.**In addition existing literature review, primary data was collected to arrive at a variety of default values[1]used by the tool. This data included passenger boarding/alighting time survey (for buses with different floor height), conducted on Delhi BRTS corridor, as well per passenger processing time at entry and exit turnstiles at the two different Metro Stations in Delhi. The tool has been extensively tested and debugged to arrive at its current stage.

BEAD has been validated using three different case studies. These are Delhi BRTS, Ahmadabad BRTS and Bogota BRTS. These BRTS systems were selected for validation as they are well documented operational systems and ample data is available for comparison against BEAD generated results. BEAD has been able replicate the designs and current performance of these systems with 94 to 99% accuracy, indicating that it is a robust and comprehensive tool which is sensitive to a variety of different BRTS specific design scenarios.

The utility of BEAD lies in its ability to generate transit passenger specific data, in addition to transit vehicle oriented results. These numbers are useful in comparing alternate designs both at planning stage as well for analysis and improvement/extension of existing corridors. For example almost all existing BRTS corridors have been documented against their capacity and operational speeds of vehicles while little or no data exists regarding passenger walking distances involved, access and egress time, door to door travel time for commuters, commuter delays in accessing the bus/system, etc. In other words current data is useful in estimating operational performance of the systems but may not be a good indicator on its utility to passengers as an effective 'alternate mobility' choice. BEAD proves useful here; it estimates these commuter specific values allowing planners and decision makers to make effective choices to balance commuter demands with operational requirements.

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[1] All default values used in BEAD are editable using the 'Default Values' tab on the 'Main Page' in the tool

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 120mmay 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.

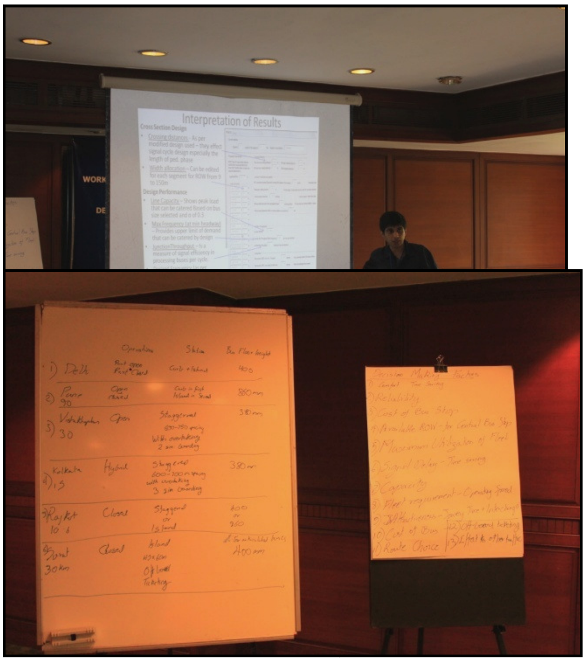
Annexure 2: Second BEAD Workshop – Finalization of Output Variables and Discussions on the Working of the Tool

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 Corporation (PMC)
8. Greater Vishakapatnam Municipal Corporation (GVMC)
9. Rajkot Municipal Corporation (RMC)
10. Surat Municipal Corporation (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

Feedback 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 (Vishakhapatnam, Rajkot)
- Glossary required so that BEAD can be used on their own (Pune)
- Useful, but only after more practice (Pune, Vishakhapatnam, 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

5.1.1.1 S No.	**5.1.1.2 Category**
1	Mid block, Signalized or roundabout junction station
2	System Operation Type
3	Bus Lane Location and Type
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
57	Segment 1 length
58	Segment 1 characteristic
59	Number of bus stations in the segment
60	Segment 2 length
61	Segment 2 characteristic
62	Number of bus stations in the segment
63	Segment 3 length
64	Segment 3 characteristic
65	Number of bus stations in the segment
66	Segment 4 length
67	Segment 4 characteristic
68	Number of bus stations in the segment
69	Segment 5 length
70	Segment 5 characteristic
71	Number of bus stations in the segment
72	Segment 6 length

73	Segment 6 characteristic
74	Number of bus stations in the segment
75	Segment 7 length
76	Segment 7 characteristic
77	Number of bus stations in the segment
78	Segment 8 length
79	Segment 8 characteristic
80	Number of bus stations in the segment
81	Segment 9 length
82	Segment 9 characteristic
83	Number of bus stations in the segment
84	Segment 10 length
85	Segment 10 characteristic
86	Number of bus stations in the segment
87	Segment 11 length
88	Segment 11 characteristic
89	Number of bus stations in the segment
90	Segment 12 length
91	Segment 12 characteristic
92	Number of bus stations in the segment
93	Segment 13 length
94	Segment 13 characteristic
95	Number of bus stations in the segment
96	Segment 14 length
97	Segment 14 characteristic
98	Number of bus stations in the segment

99	Segment 15 length
100	Segment 15 characteristic
101	Number of bus stations in the segment
102	Segment 16 length
103	Segment 16 characteristic
104	Number of bus stations in the segment
105	Segment 17 length
106	Segment 17 characteristic
107	Number of bus stations in the segment
108	Segment 18 length
109	Segment 18 characteristic
110	Number of bus stations in the segment
111	Segment 19 length
112	Segment 19 characteristic
113	Number of bus stations in the segment
114	Segment 20 length
115	Segment 20 characteristic
116	Number of bus stations in the segment
117	Ratio of transfer stations to the total station no.'s on the corridor
118	Edge Footpath
119	Service Lane
120	Unpaved
121	Footpath
122	Tree Belt
123	Cycle Track
124	Segregator

125	Parking
126	Carriageway
127	Turning Pocket
128	Bus Shelter 1
129	Bus Lane (Boarding 1)
130	Bus Shelter 2
131	Bus Lane (Boarding 2)
132	Central Island
133	Bus Lane
134	Median
135	Turning Pocket
136	Carriageway
137	Parking
138	Segregator
139	Cycle Track
140	Tree Belt
141	Footpath
142	Unpaved
143	Service Lane
144	Edge Footpath
145	Cross road/crossing Car lane - straight traffic eastbound
146	Cross road/crossing Car lane - turning traffic eastbound
147	Cross road/crossing BRT lane - straight traffic eastbound
148	Cross road/crossing BRT lane - turning traffic eastbound
149	Main corridor BRT lane - turning traffic southbound
150	Main corridor BRT lane - straight traffic southbound

151	Main corridor Car lane - turning traffic southbound
152	Main corridor Car lane - straight traffic southbound
153	Main corridor Car lane - straight traffic northbound
154	Main corridor Car lane - turning traffic northbound
155	Main corridor BRT lane - straight traffic northbound
156	Main corridor BRT lane - turning traffic northbound
157	Cross road/crossing BRT lane - turning traffic westbound
158	Cross road/crossing BRT lane - straight traffic westbound
159	Cross road/crossing Car lane - turning traffic westbound
160	Cross road/crossing Car lane - straight traffic westbound
161	User bus throughput in buses per hour per direction
162	User cycle length
163	Bus Speed limit
164	Average speed of motor vehicles in the city
165	Total No. of Distinct routes using a segment in an open system

S. No.	**Default Variables**
1	Green phase for buses per direction without turning
2	Green phase for buses per direction turning phase (separate turning phase)
3	Green phase for buses common lane, turning buses
4	BRTS - current design (dwell time)
5	Minimum bus delay
6	Average bus acceleration
7	Average Bus Deceleration
8	Junction width
9	Minibus length
10	Urban Bus length
11	Articulated bus length
12	Bi articulated bus length
13	Gap between buses without overtaking
14	Gap between buses with overtaking
15	Reaction delay at junction per bus

16	Ratio of turning buses as a proportion of total buses
17	Overtaking lane rule
18	Bus Speed limit
19	Pedestrian Ramp gradient
20	Walking speed
21	Half Subway level difference
22	Full subway level difference
23	FOB level difference
24	Climb rate for Escalator
25	Climb rate for Ramps
26	Climb rate for steps
27	Minimum Pedestrian green phase
28	Desirable Pedestrian Green Phase
29	Gap between waiting buses
30	Minibus Capacity
31	Urban Bus Capacity
32	Articulated bus Capacity
33	Bi articulated bus Capacity
34	Lost Crossing time due to yellow pedestrian Phase
35	Distance of stop line from cross road edge
36	Average Motorized vehicle trip length in city
37	Trip1 - 0.5km from corridor - walk access
38	Trip1 - 9km on corridor - walk access
39	Trip1 - length in BRTS corridor
40	Trip2 - 1km from the corridor
41	Trip2 - on corridor - walk access
42	Trip 2 - Length in BRTS corridor
43	Trip3 - 2km from corridor - walk access
44	Trip3 - 6km on corridor - walk access
45	Trip3 - length in BRTS corridor
46	Trip4 - 3km from corridor - walk access
47	Trip4 - 4km on corridor - walk access
48	Trip4 - length in BRTS corridor
49	Average Distance of side feeder station from corridor
50	Average Crossing delay of cross road
51	Average Crossing distance
52	Average Bus speed outside corridor
53	Average bus wait time in open system
54	Average Bus Wait time in closed system
55	Expected % of passengers opting for interchange at corridor in an open system
56	Avg. crossing width of cross road, feeder road or spine hosting bus routes in open system, mixed condition
57	Average delay to find gap in vehicles for crossing side road
58	Minimum gap between buses (including bus length)

59	% inefficiency in bus signal priority
60	Average speed of motor vehicles in the city
61	Desired signal cycle length for 2 phase signal
62	Maximum desirable signal cycle length
63	Min desirable signal cycle length for 4 arm BRT corridor
64	Maximum desirable signal cycle length for 3 artm junction
65	Minimum desirable signal cycle length for 3 arm junction
66	Maximum desirable signal cycle length for 2 arm or mid block junction
67	Minimum desirable signal cycle length for 2 arm or mid block junction
68	Indicative cycle length for no signal (or single green phase)
69	Avg. per passenger time lost due to off board fare collection
70	Avg. Per passenger time lost due to delay between platform and bus doors
71	Sum of average Distance of Pvt. Vehicle parking from Origin and destination
72	Total No. of Distinct routes using a segment in an open system
73	Default distance of Feeder Station on Side road from Corridor (not for transfer stations)
74	Distance of transfer station from main corridor
75	Additional Station Time at transfer station on account of additional manoeuvring, longer bays, additional passengers, etc.
76	Time Lost Per step for Boarding
77	Average Dwell Time for Level boarding

Result Categories

A. Current Analysis:

1. Segment
2. Length of the segment
3. Segment Characteristic

B. Description

4. Station Number
5. Station Type

C. Proposed Cross Section (From LHS to RHS)

6. Edge Footpath
7. Service Lane
8. Unpaved

9. Footpath
10. Tree Belt
11. Cycle Track
12. Segregator
13. Parking
14. Carriageway
15. Turning Pocket
16. Bus Shelter 1
17. Bus Lane (Boarding 1)
18. Bus Shelter 2
19. Bus Lane (Boarding 2)
20. Central Island
21. Bus Lane
22. Median
23. Turning Pocket
24. Carriageway
25. Parking Segregator
26. Cycle Track
27. Tree Belt
28. Footpath
29. Unpaved
30. Service Lane
31. Edge Footpath

D. Crossing Distances:

32. Max. one way crossing distance
33. Min. one way crossing distance
34. Average crossing distance
35. Total crossing distance

E. Corridor Travel Time and Speeds:

36. Average Motor Vehicle Speed in Corridor/City
37. Peak Bus Speed in Corridor
38. BRT operational speed (Expected Average Bus Speed in the System)
39. Passenger speed with BRT
40. Passenger walking distance
41. Overall origin to destination journey time for average motorized trip lengthTotal average access time
42. Total average access time
43. Total average in vehicle time (main line/route)
44. Per bus delay per station/junction - segregated lanes
45. Per bus delay per station/mid-block – segregated lanes
46. Total average passenger delay to access station in a round trip
47. Average trip length in City/Corridor

F. Corridor Throughputs:

48. Corridor PPHPDT
49. Corridor Bus Throughput (Max frequency)
50. Junction Bus throughput
51. Station Bus Throughput (separate from junction for mid block station)
52. User input - buses per hour per direction
53. Corridor -current demand in PPHPDT

G. Bus Shelter Length:

54. Bus shelter length without ramp
55. Bus shelter length with ramp at one entrance

H. Comparison:

56. Time saved by BRT over Private Transport
57. Avg. passenger speed with buses without BRT
58. Time saved by BRT over mixed condition bus

59. Daily bus passenger hours saved

I. Signal Cycle:

60. Junction signal cycle length
61. Junction signal phases
62. No. Of phases
63. Pedestrian only phase
64. Pedestrian phase length
65. Signal cycle length
66. User defined signal cycle
67. Junction is grade separated or not

J. Signal Design:

68. User defined Phase length (For Turning and Straight Bus lanes and Cars lanes)
69. Phase length (For Turning and Straight Bus lanes and Cars lanes)
70. Phase sequence (For Turning and Straight Bus lanes and Cars lanes)

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	1.285714
DTC L	Closed			2	1	down	2

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			
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:

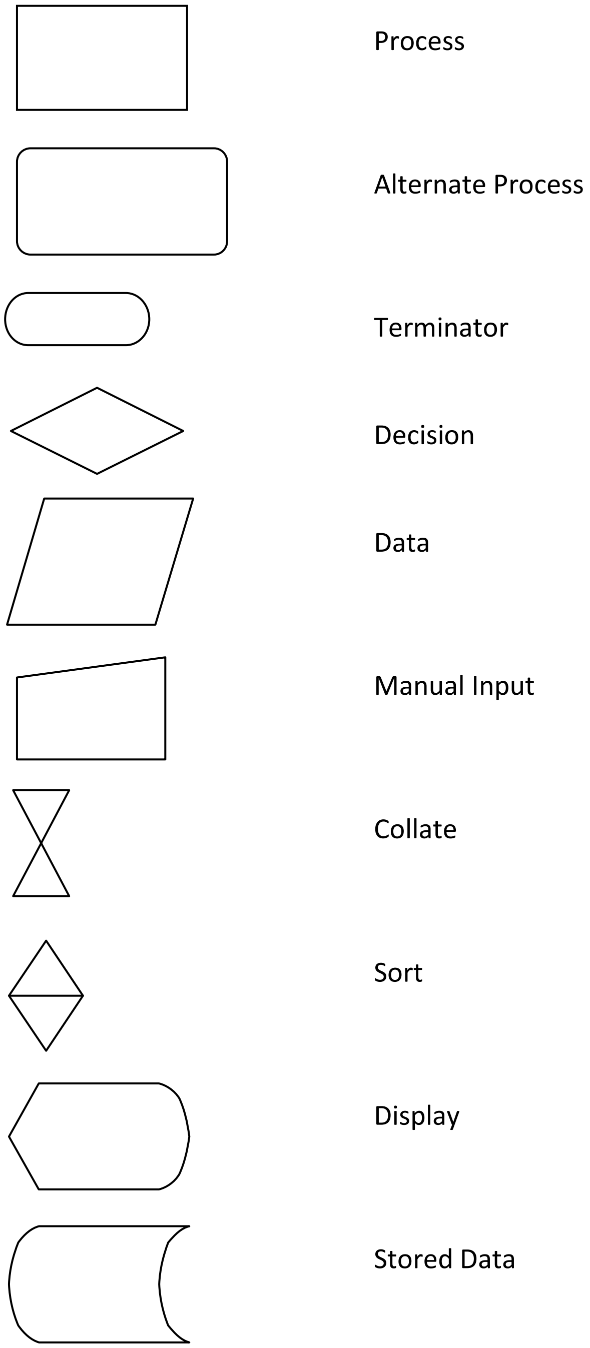


Figure 22 – Flow chart for Process 1: Journey time for average trip in the city, in mins

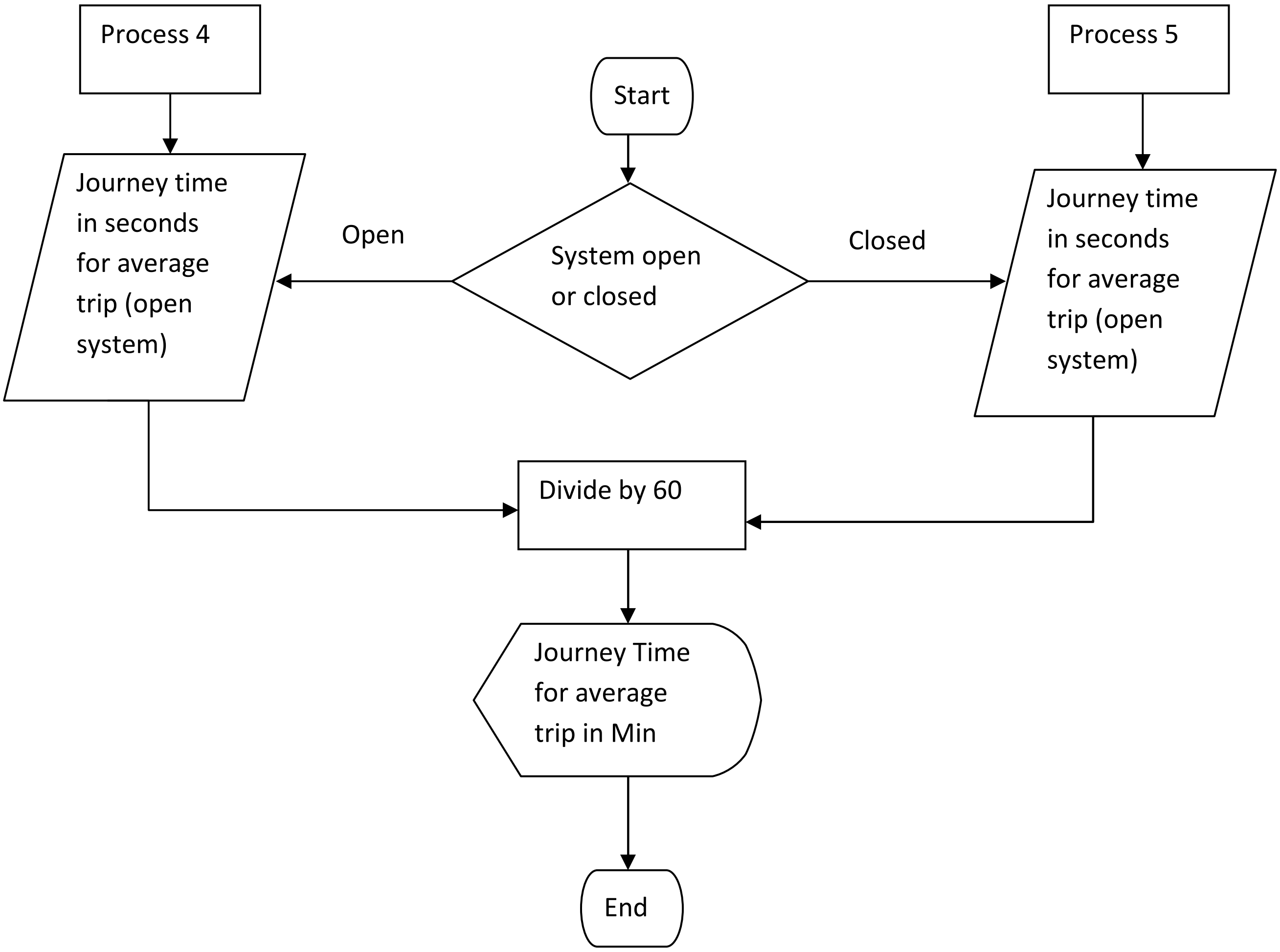


Figure 23 – Flow chart for Process 2: Determining average bus speed in the BRTS corridor

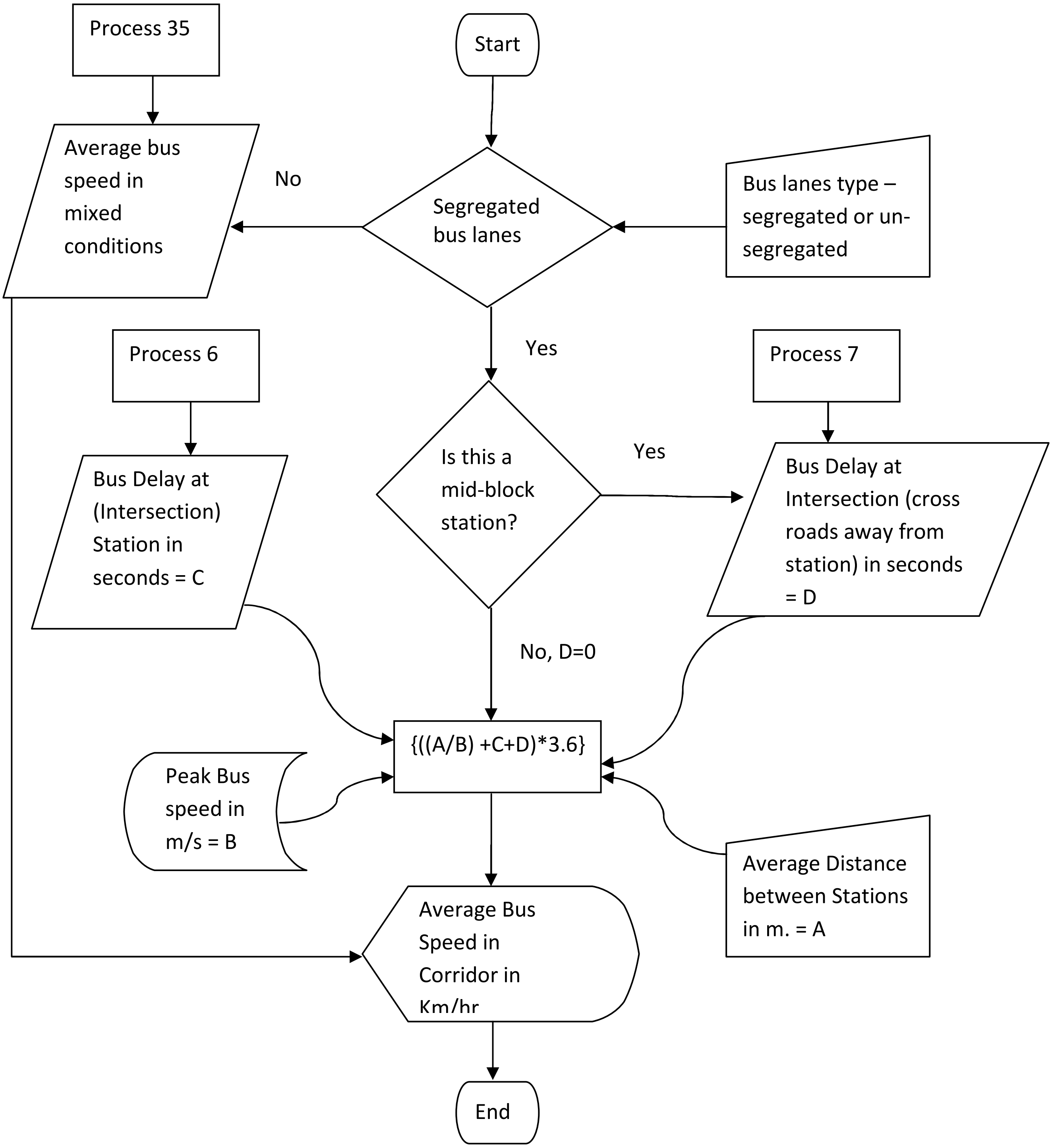


Figure 24 – Flow chart for Process 3: Determining Capacity of the BRTS Corridor/Segment

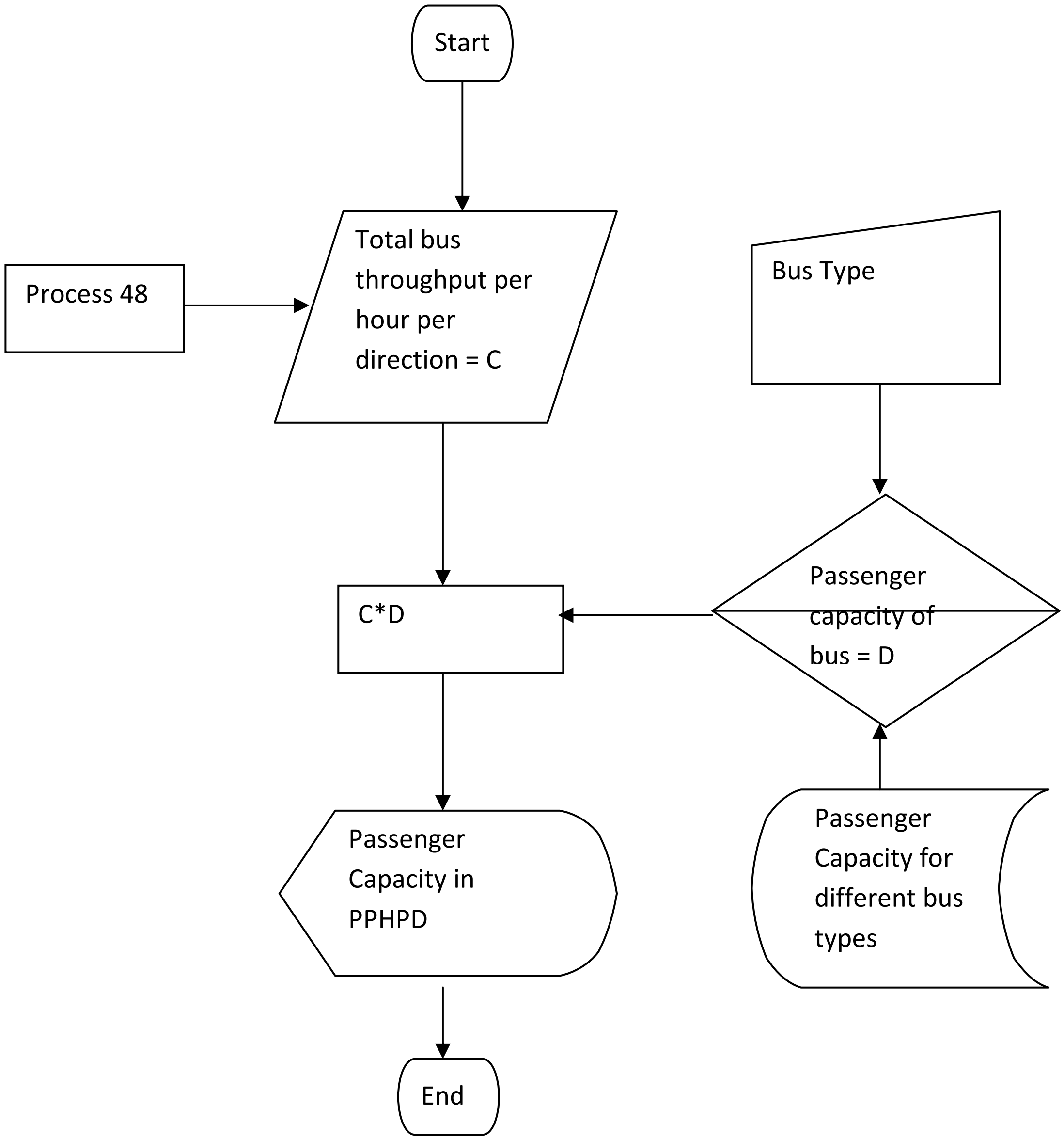


Figure 25: Flow chart for Process 4 – Journey time in seconds for average trip in open system

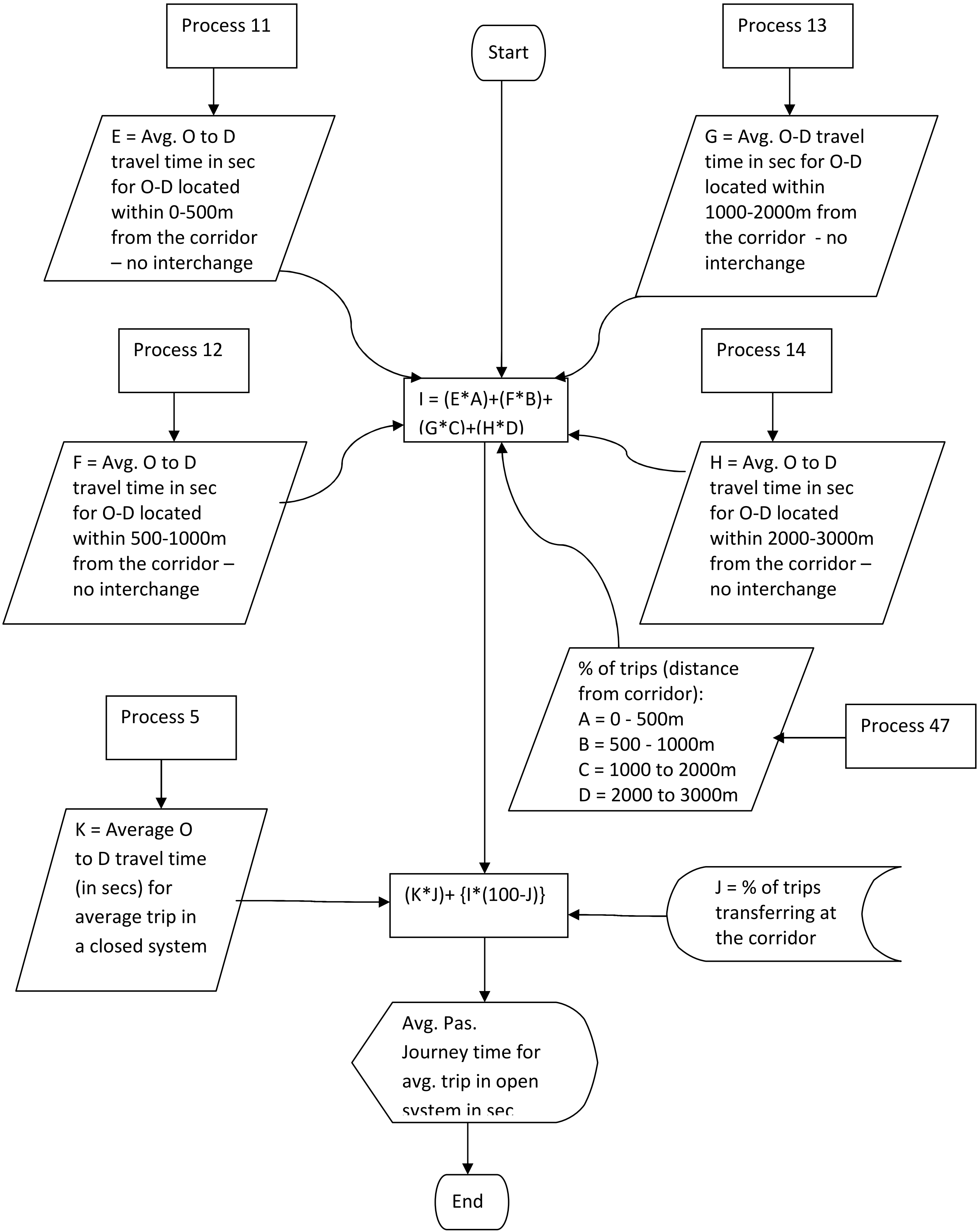


Figure 26 – Flow chart for Process 5 – Average journey time in seconds for average trip length in a closed system

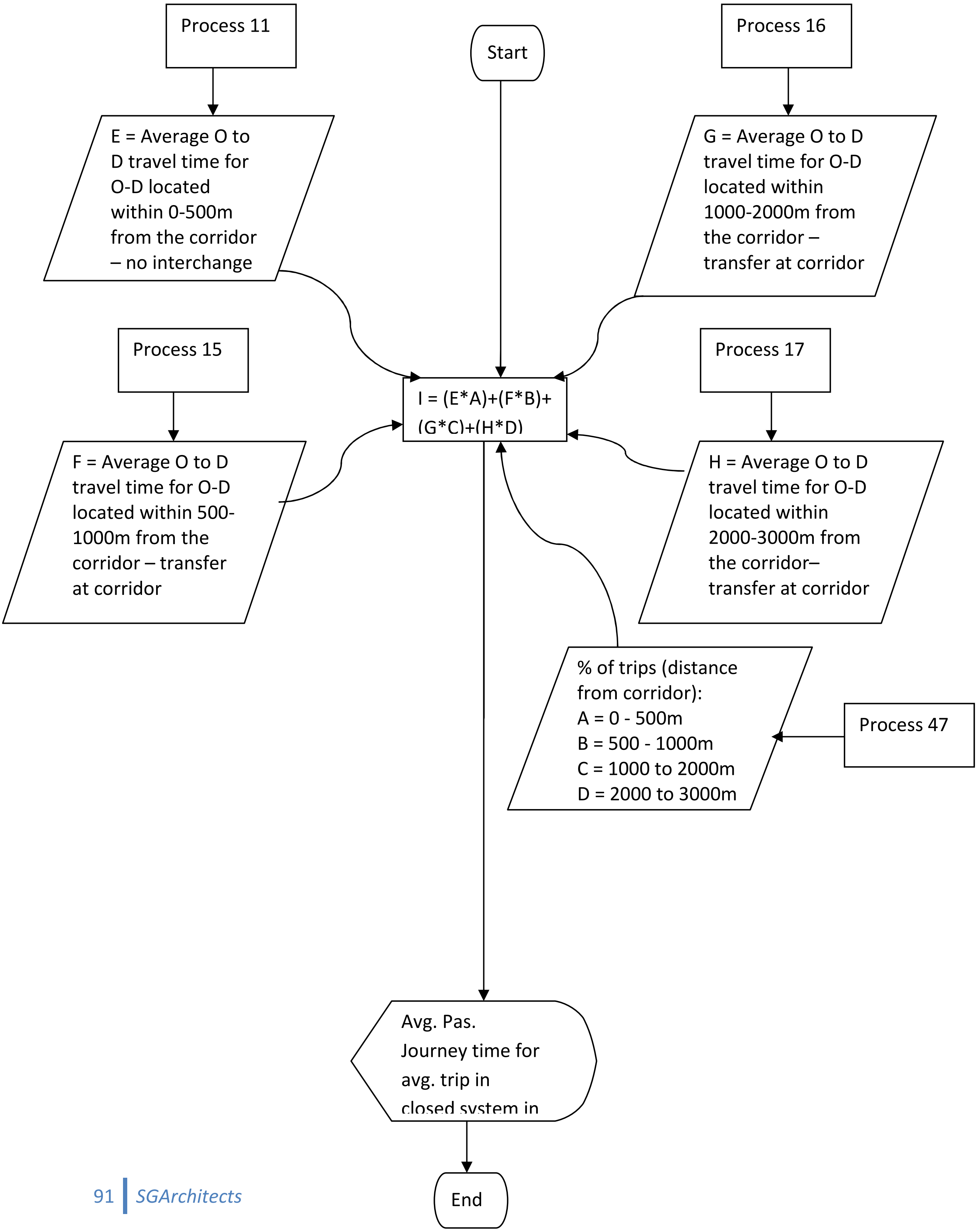


Figure 27 – Flow chart for Process 6: Bus delay at stations including signal delay (pedestrian signal delay at mid block stations)

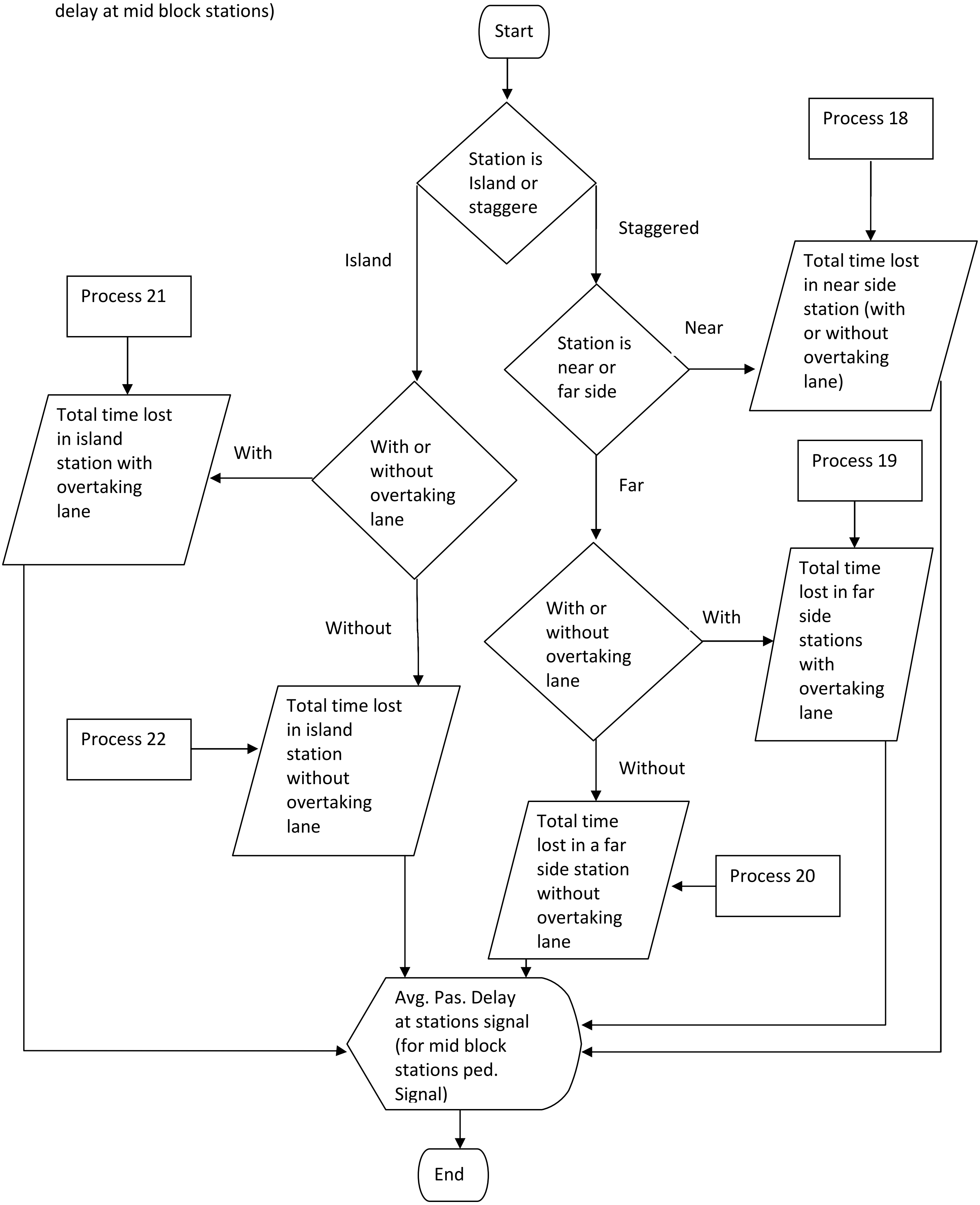


Figure 28 – Flow chart for Process 7: Bus delay at intersection (cross roads) on corridors with mid block stations

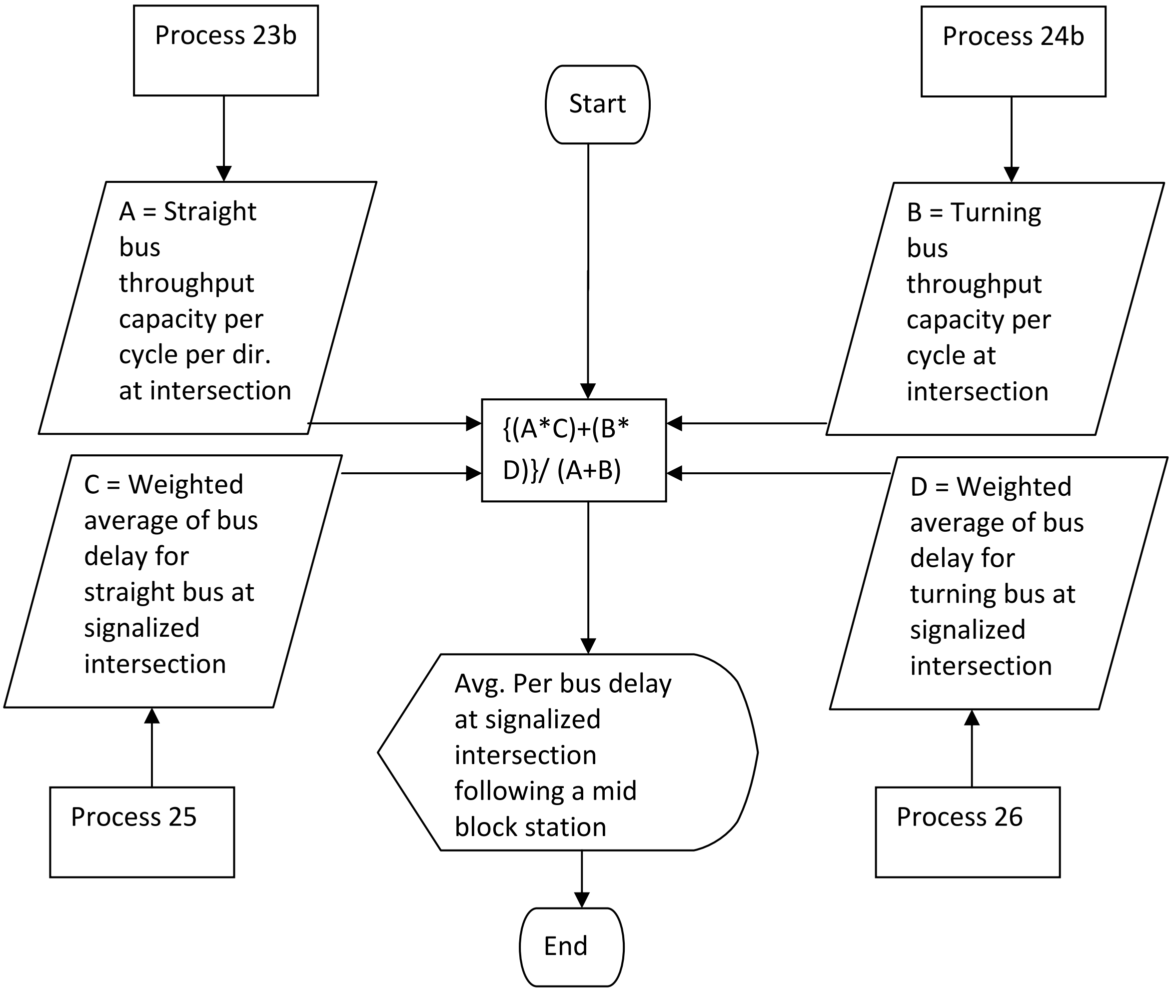


Figure 29: Flow chart for Process 8 - Bus throughput per signal cycle per direction from station including intersections throughput for junction stations (roundabout or signalized).

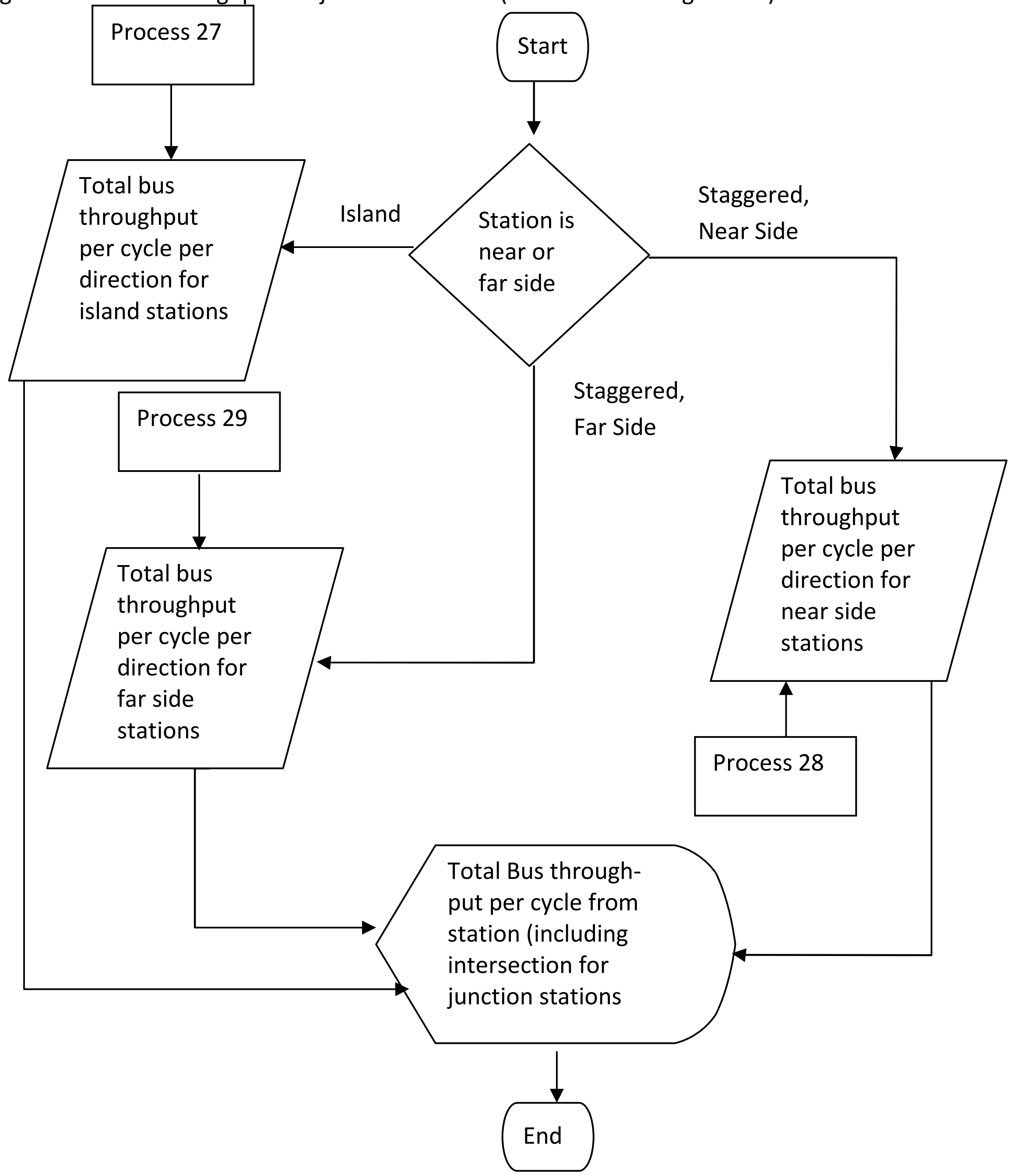


Figure 30: Flow chart for Process 9 - Total Buses Throughput per signal cycle per direction from intersection (for mid block station)

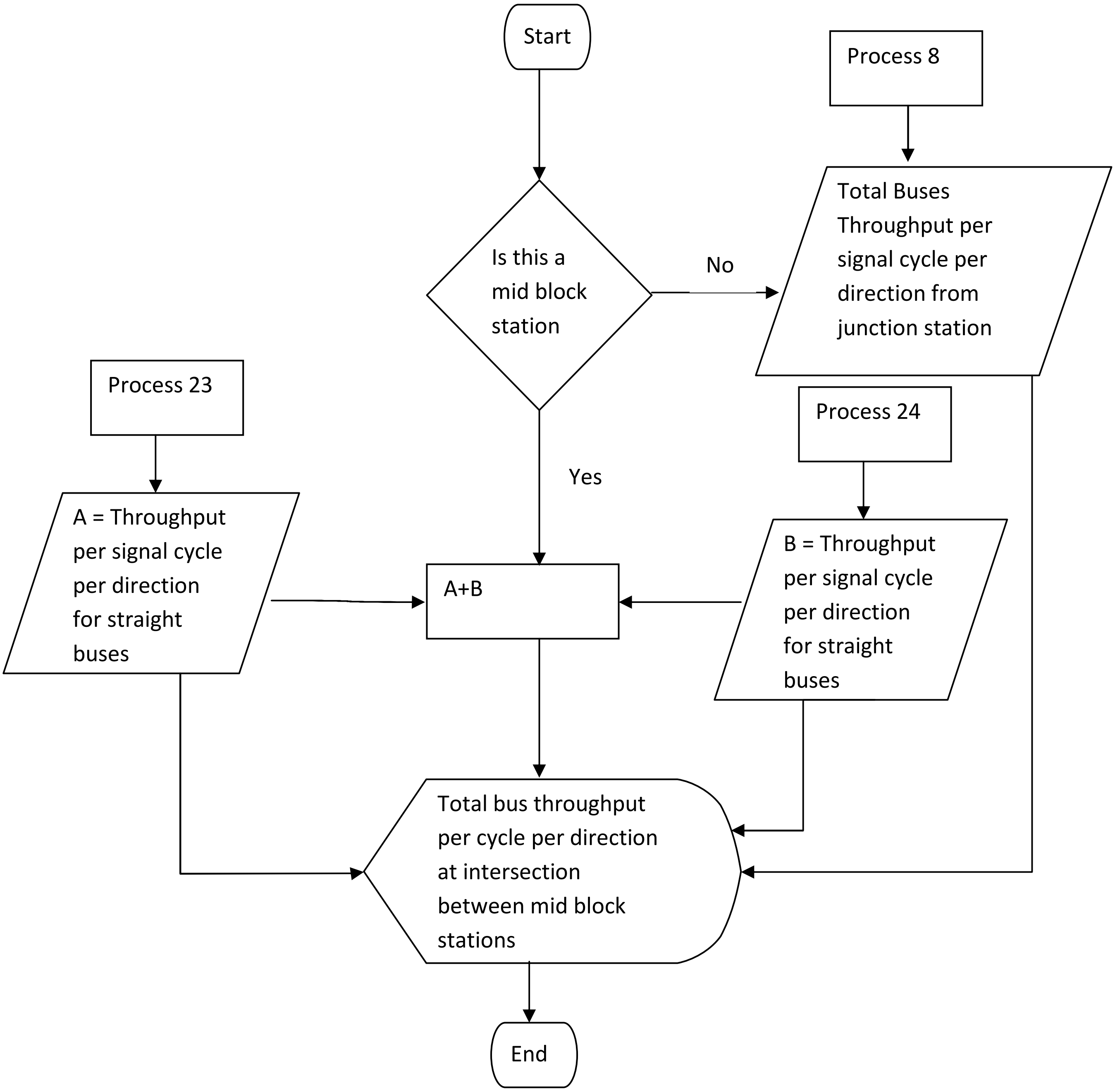


Figure 31: Flow chart for Process 10 – Signal cycle length in secs at intersection.

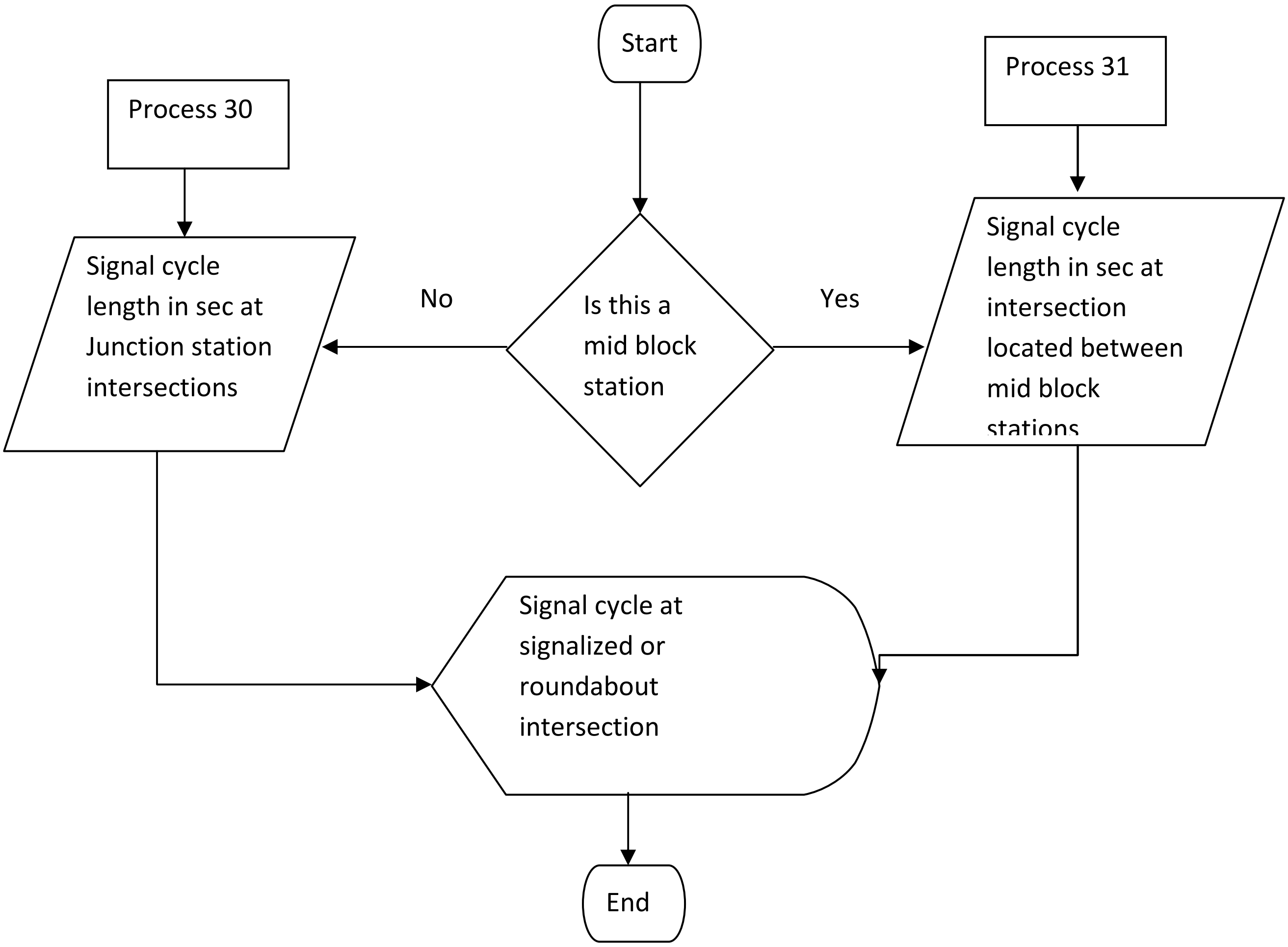


Figure 32: Flowchart for Process 11 - Average O to D travel time for O-D located within 0-500m from the corridor – no interchange (in an open or closed system)

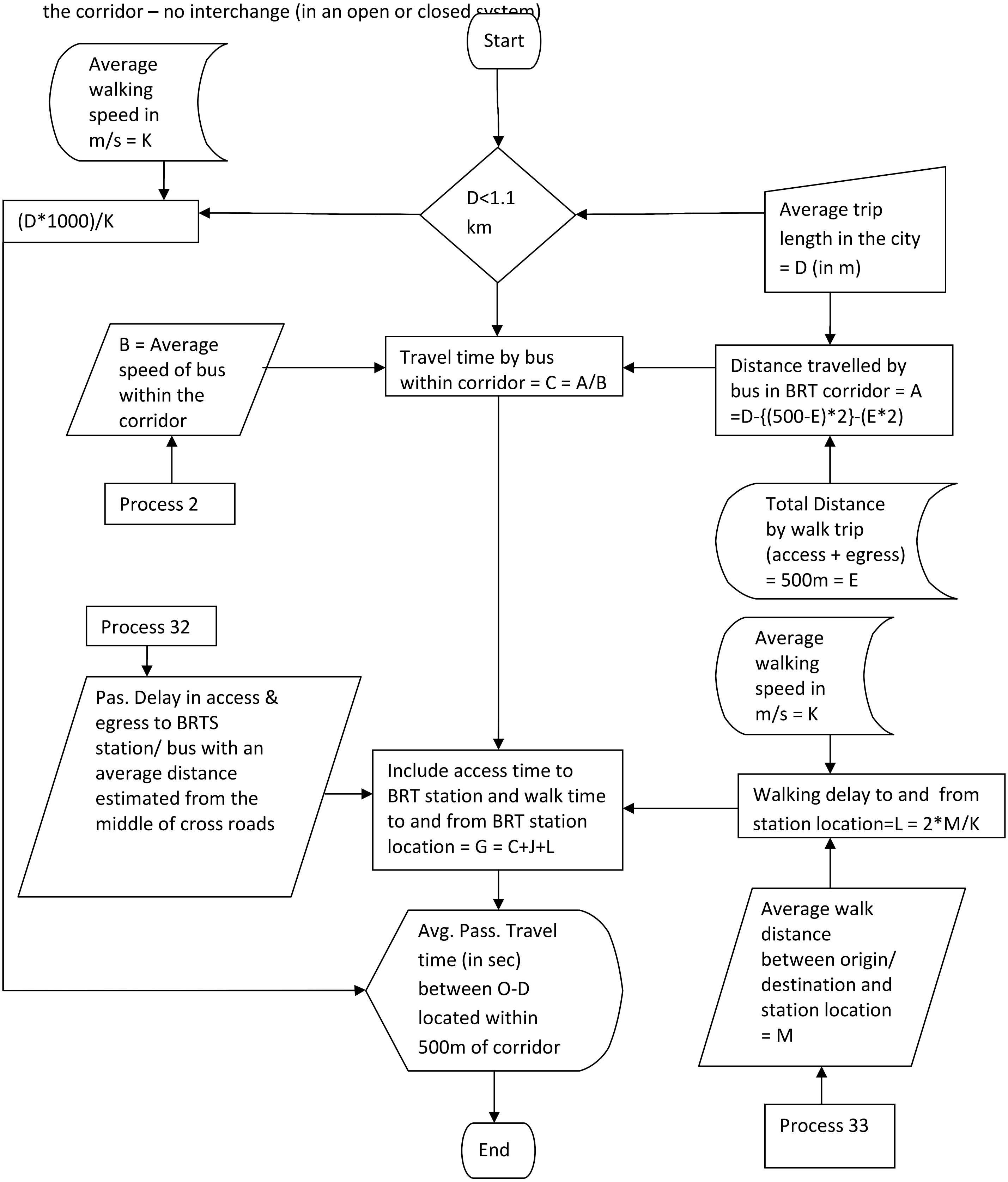


Figure 33: Flowchart for process 12 – Average O to D travel time for O-D located within 500-1000m from the corridor – no interchange (in an open system)

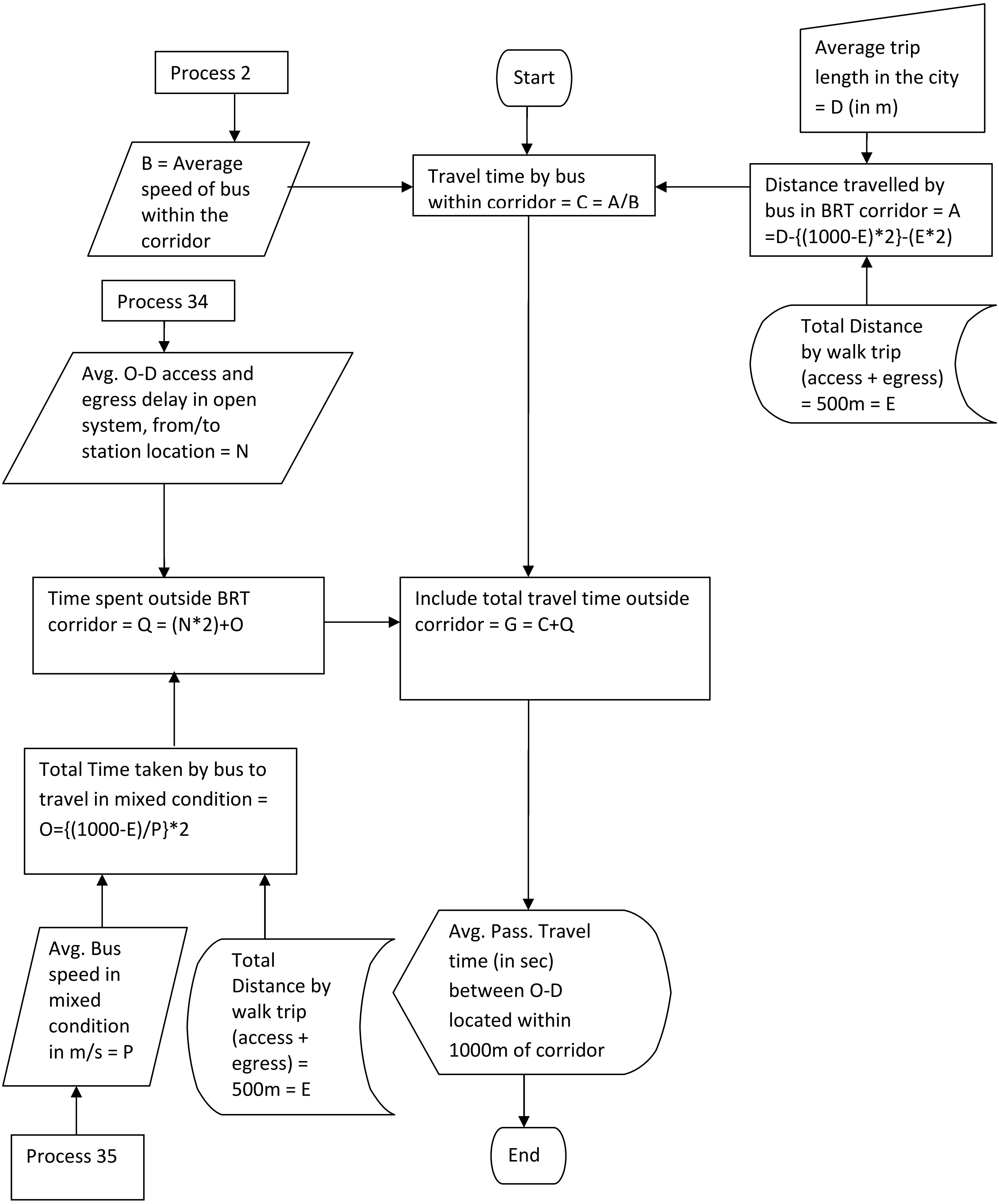


Figure 34: Flowchart for process 13 – Average O to D travel time for O-D located within 1000-2000m from the corridor – no interchange (in an open system)

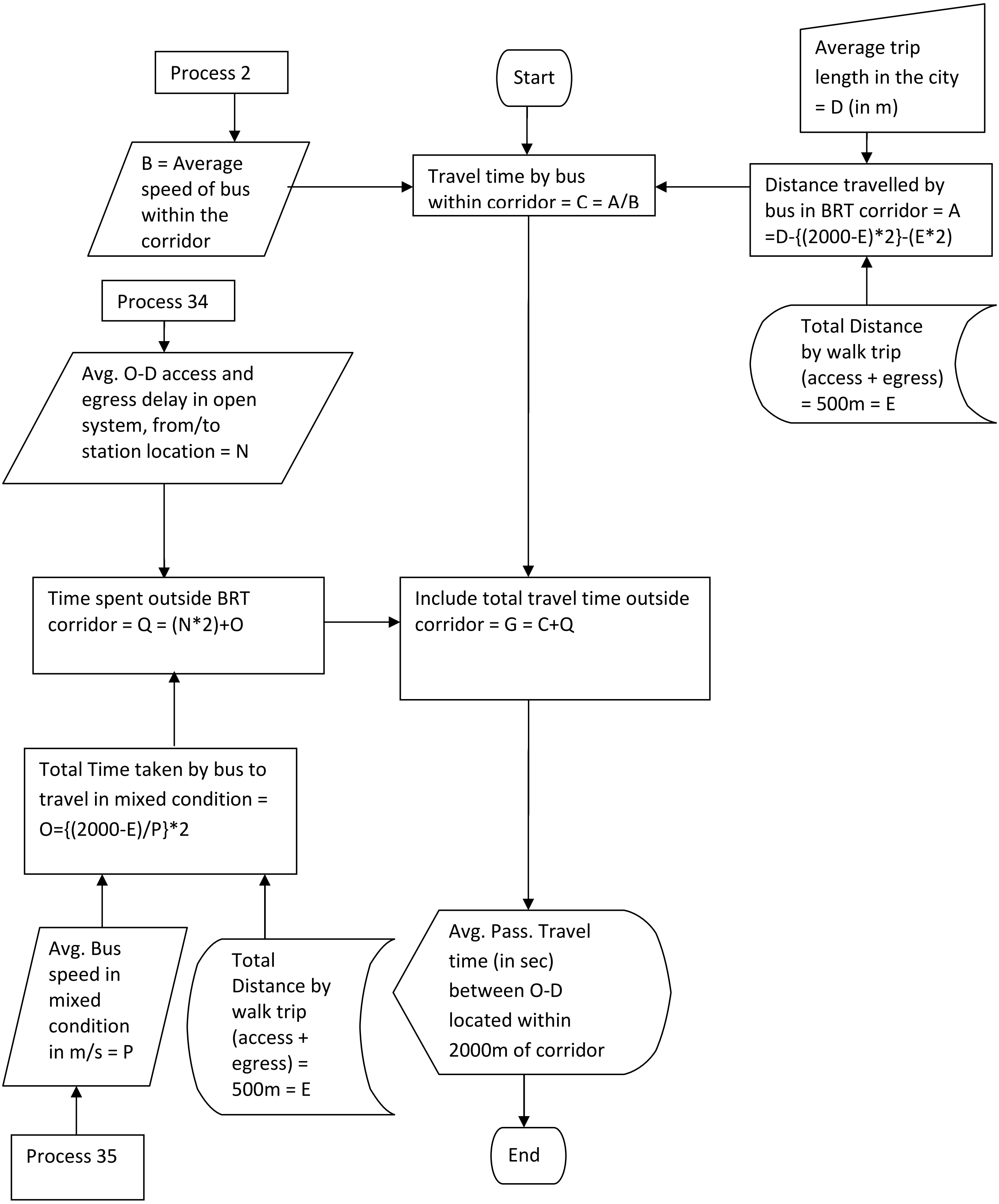


Figure 35: Flowchart for process 14 – Average O to D travel time for O-D located within 2000-3000m from the corridor – no interchange (in an open system)

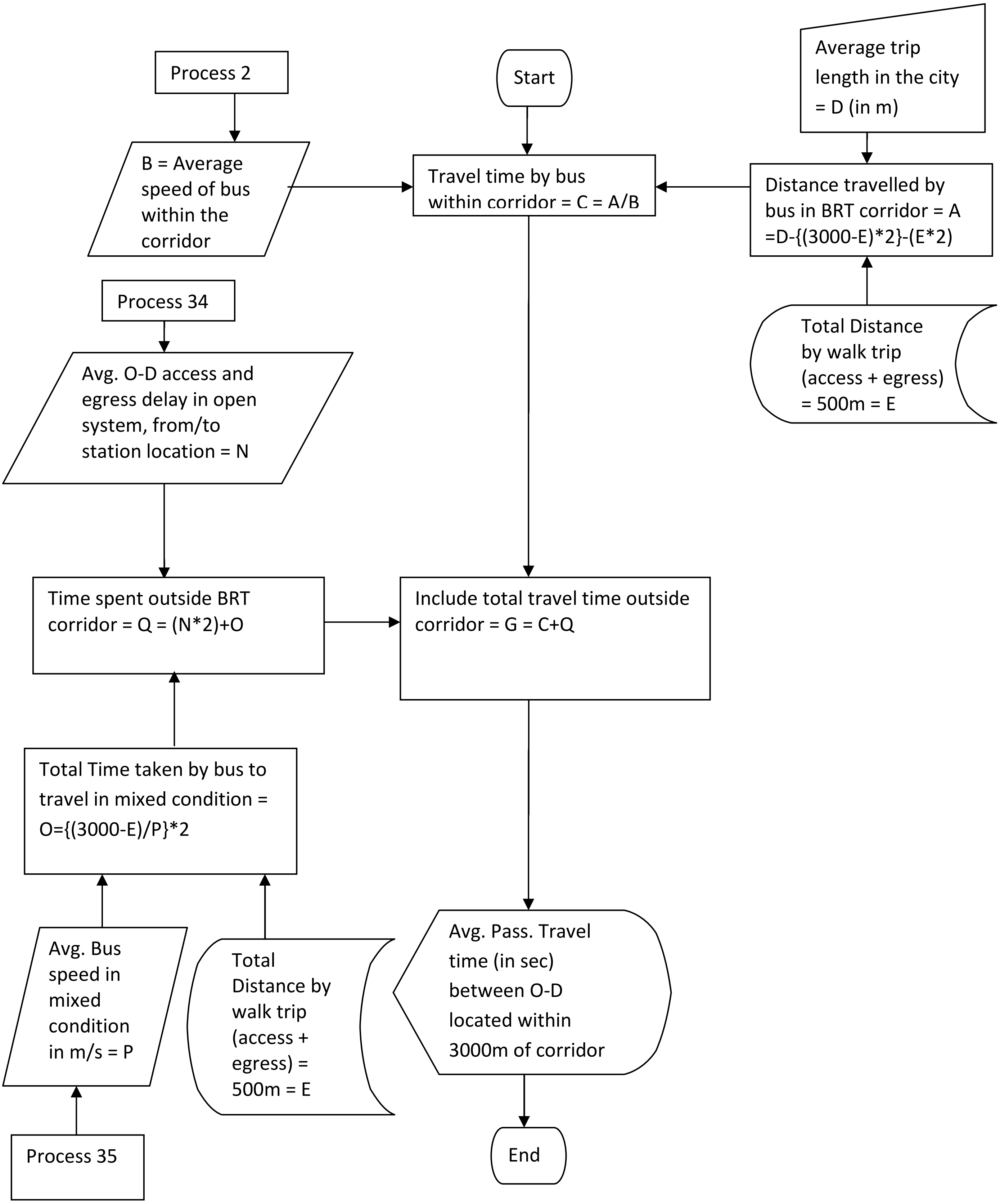


Figure 36: Flowchart for Process 15 - Average O to D travel time for O-D located within 500-1000m from the corridor in a closed system

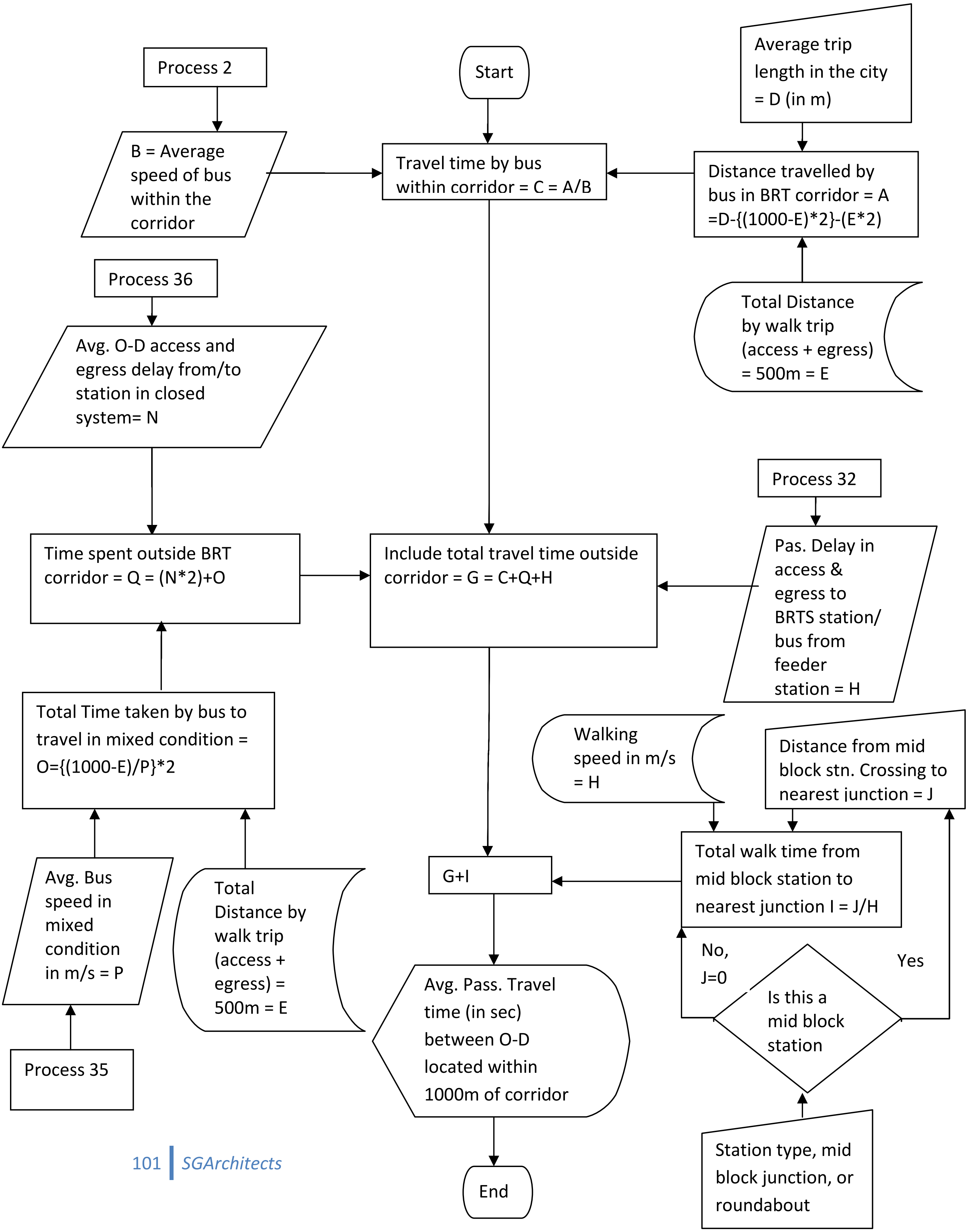


Figure 37: Flowchart for Process 16 - Average O to D travel time for O-D located within 1000-2000m from the corridor in a closed system

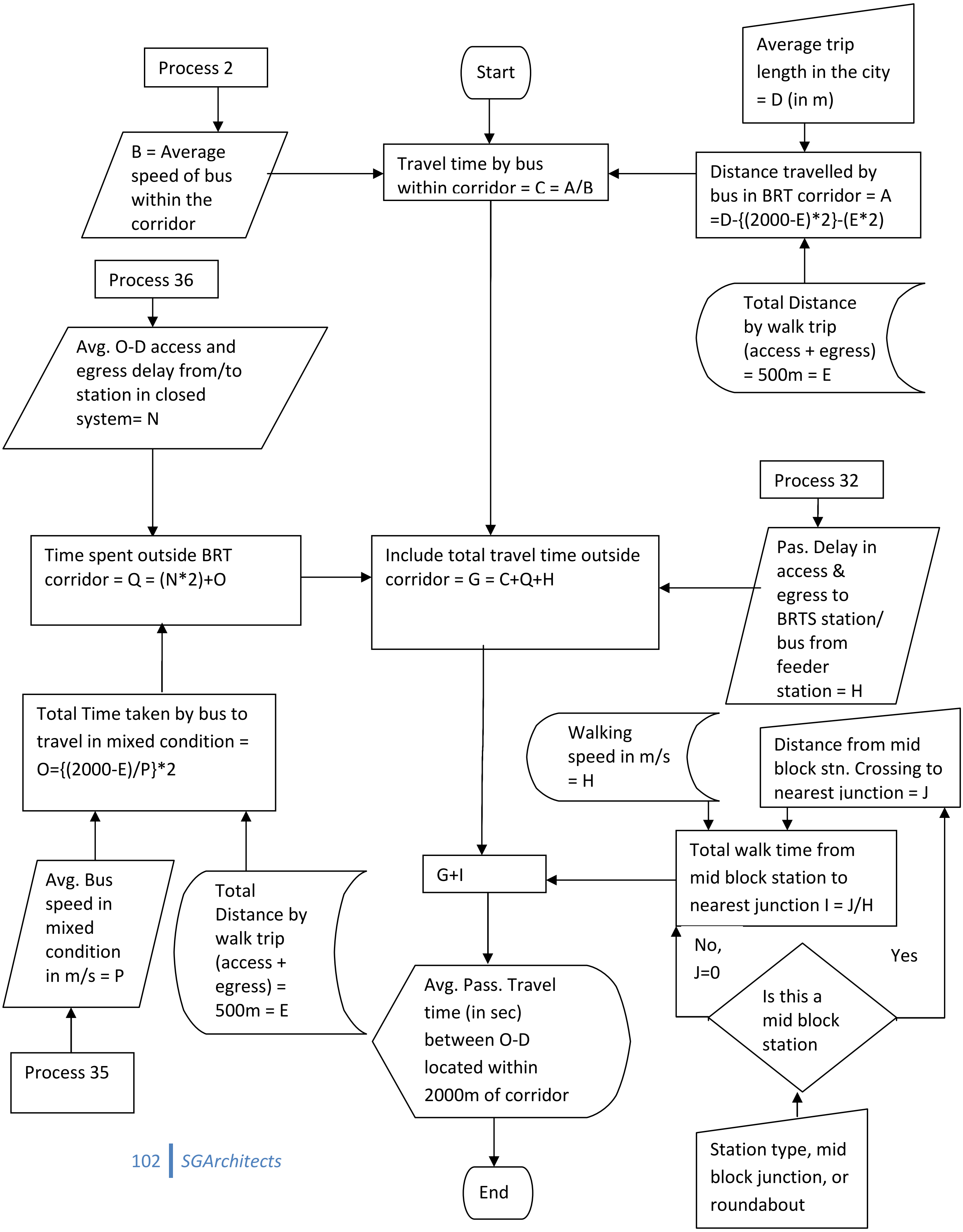


Figure 38: Flowchart for Process 17 - Average O to D travel time for O-D located within 2000-3000m from the corridor in a closed system

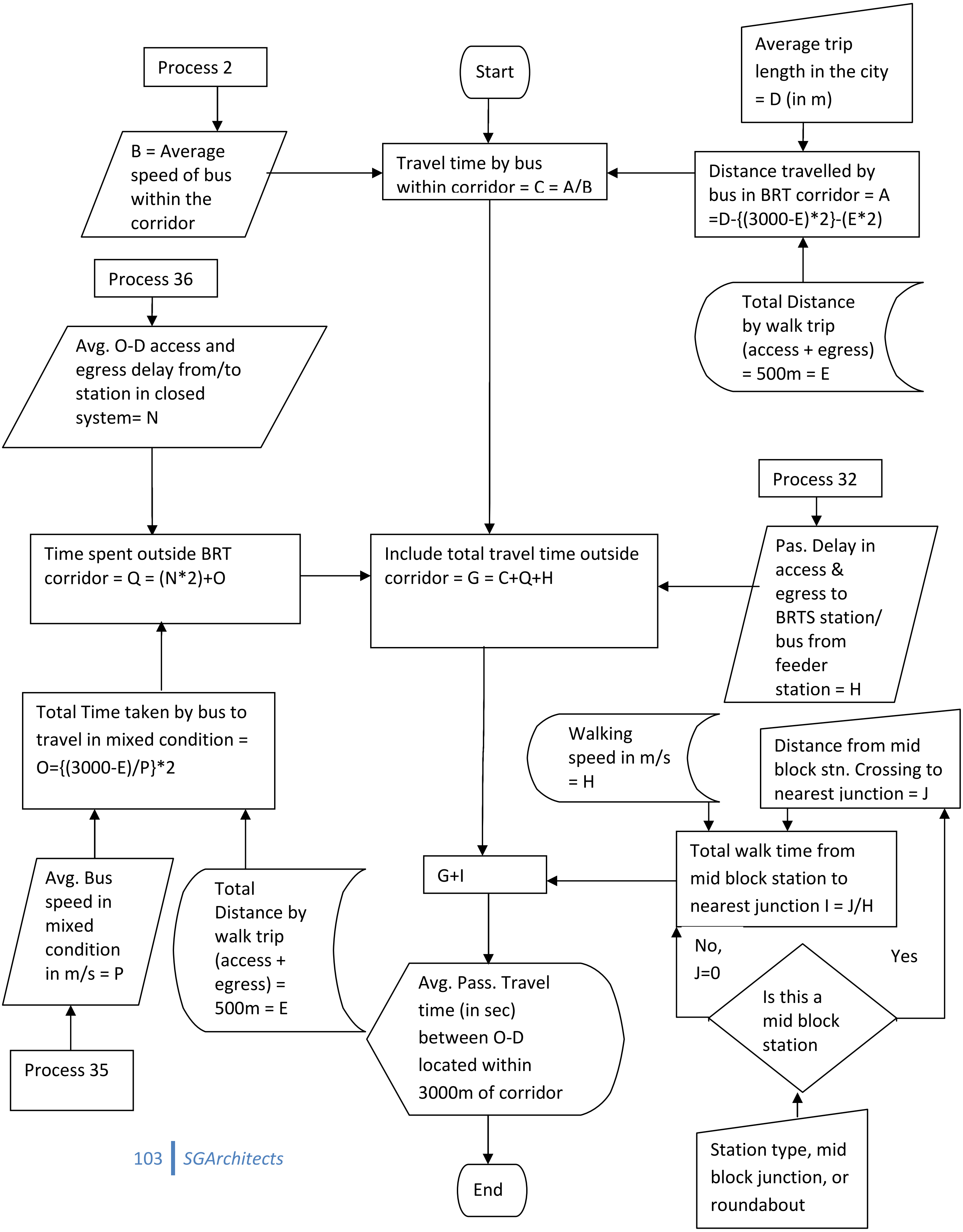


Figure 39: Flow chart for Process 18 - Average per bus delay at near side (staggered) junction stations (including junction delay) in secs (with or without overtaking lane)

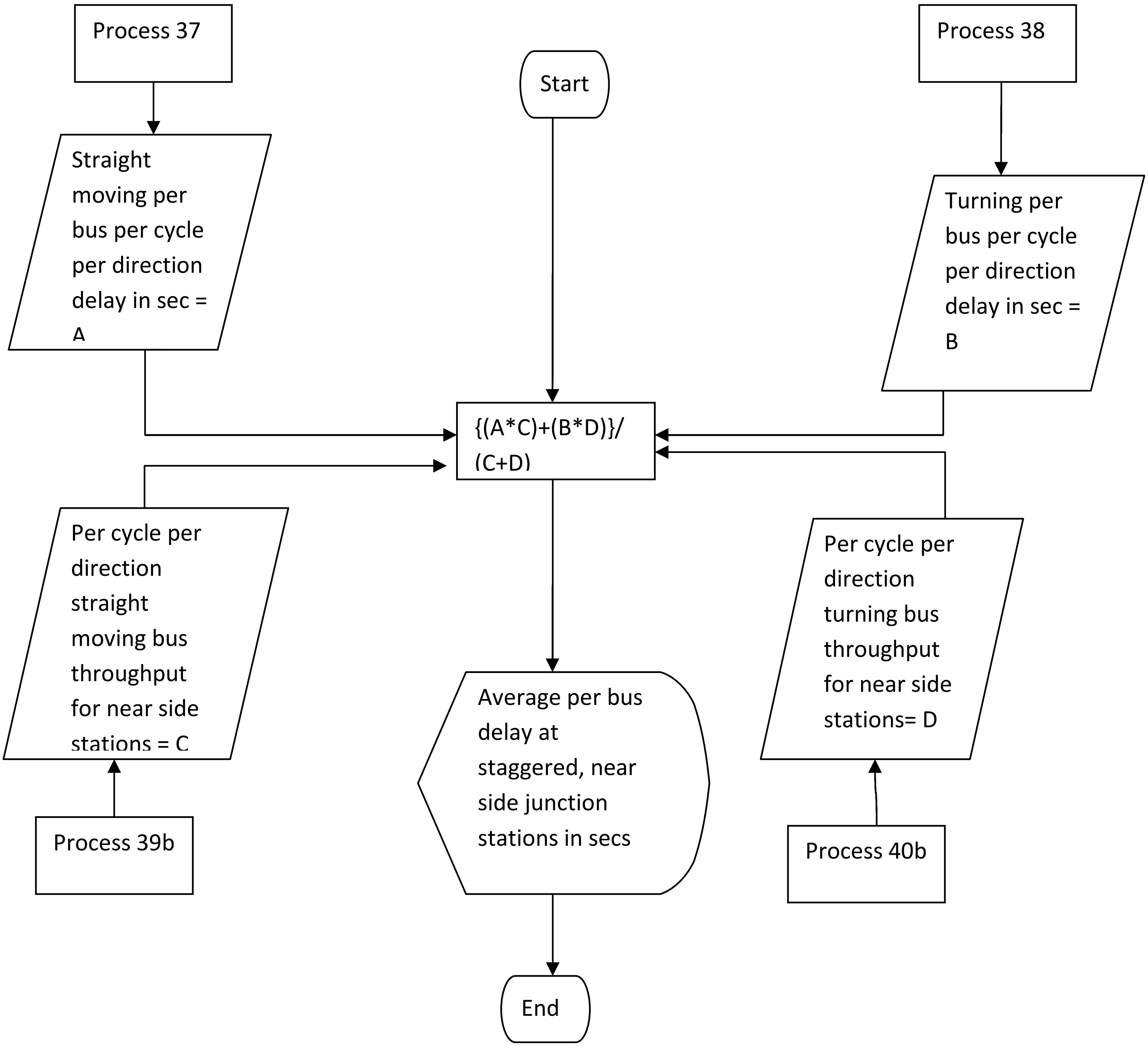


Figure 40: Flow chart for Process 19 - Average per bus delay at far side (staggered) junction stations (including junction delay) in secs (with overtaking lane)

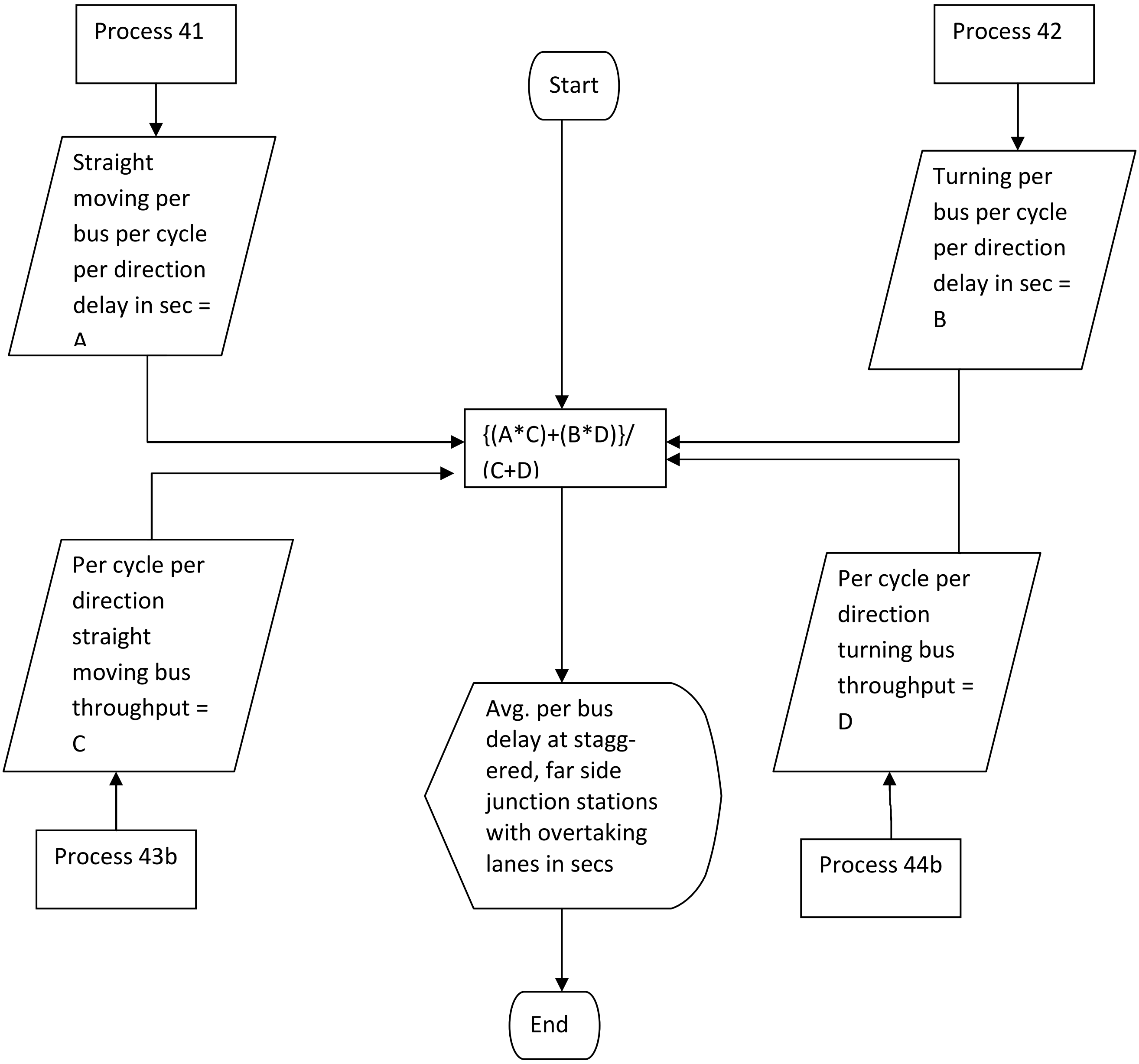


Figure 41: Flow chart for Process 20 - Average per bus delay at far side (staggered) junction stations (including junction delay) in secs (without overtaking lane)

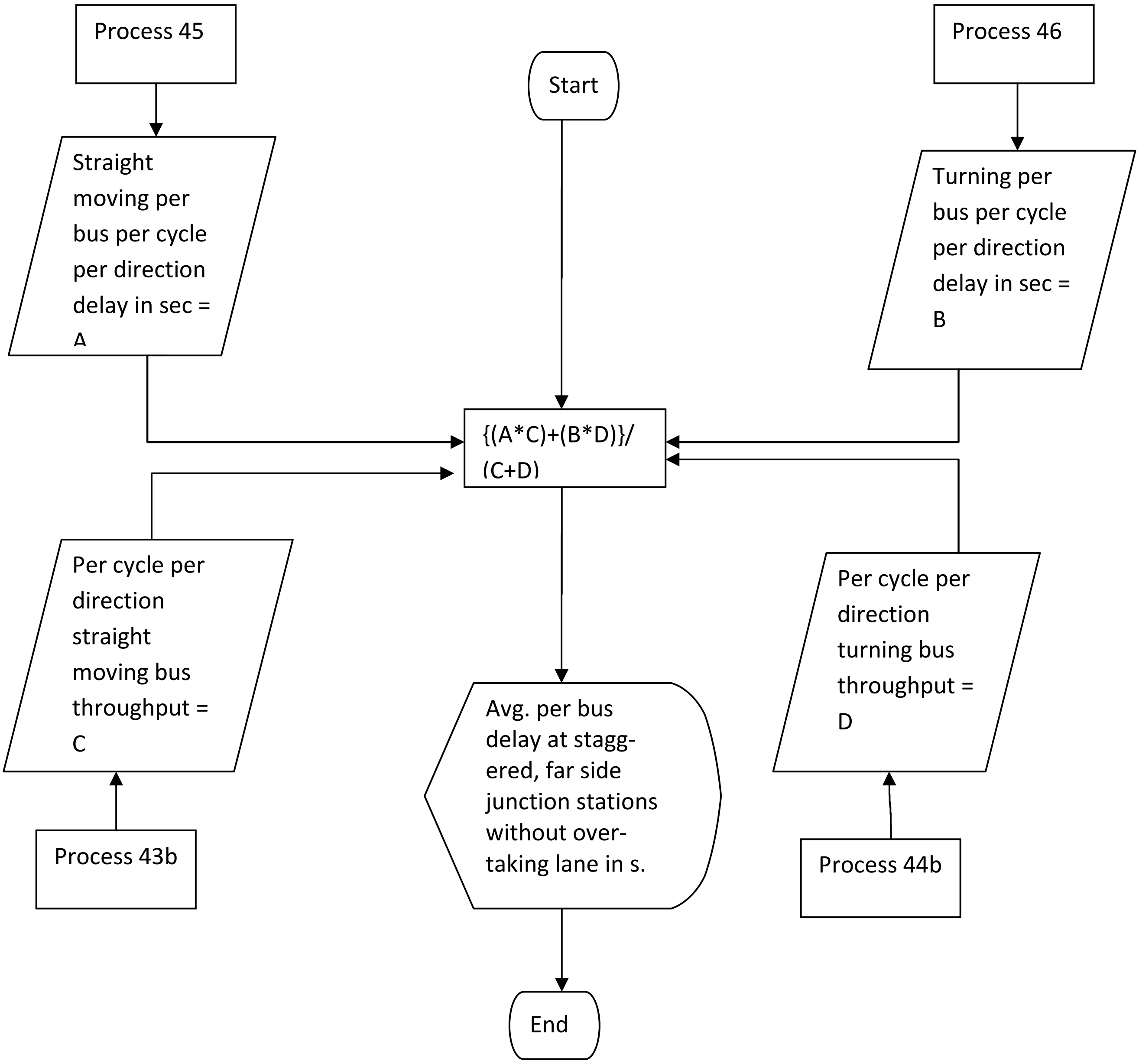


Figure 42: Flow chart for Process 21 - Average per bus delay at Junction Island stations with overtaking lane

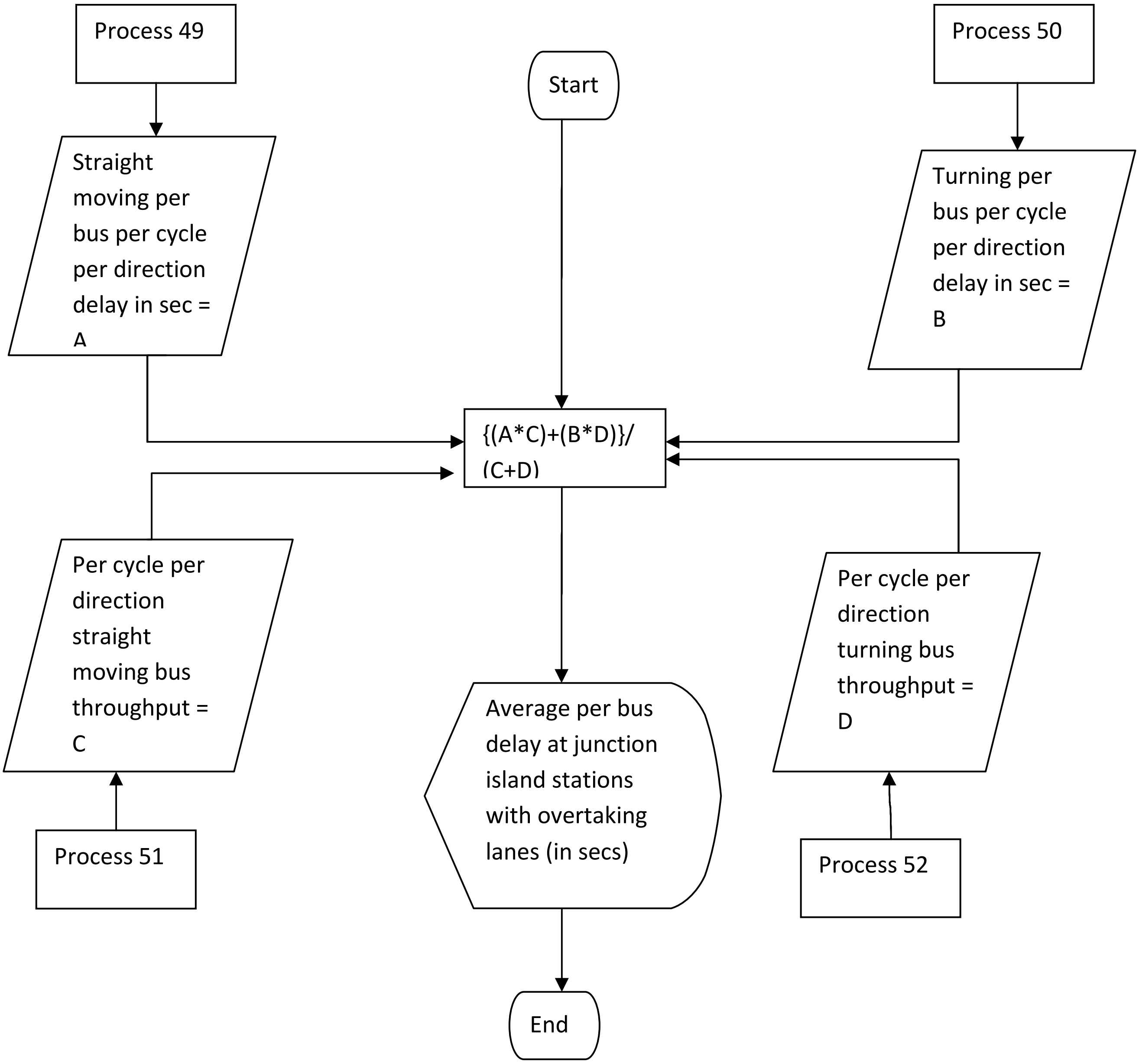


Figure 43: Flow chart for Process 22 - Average per bus delay at Junction Island stations without overtaking lane

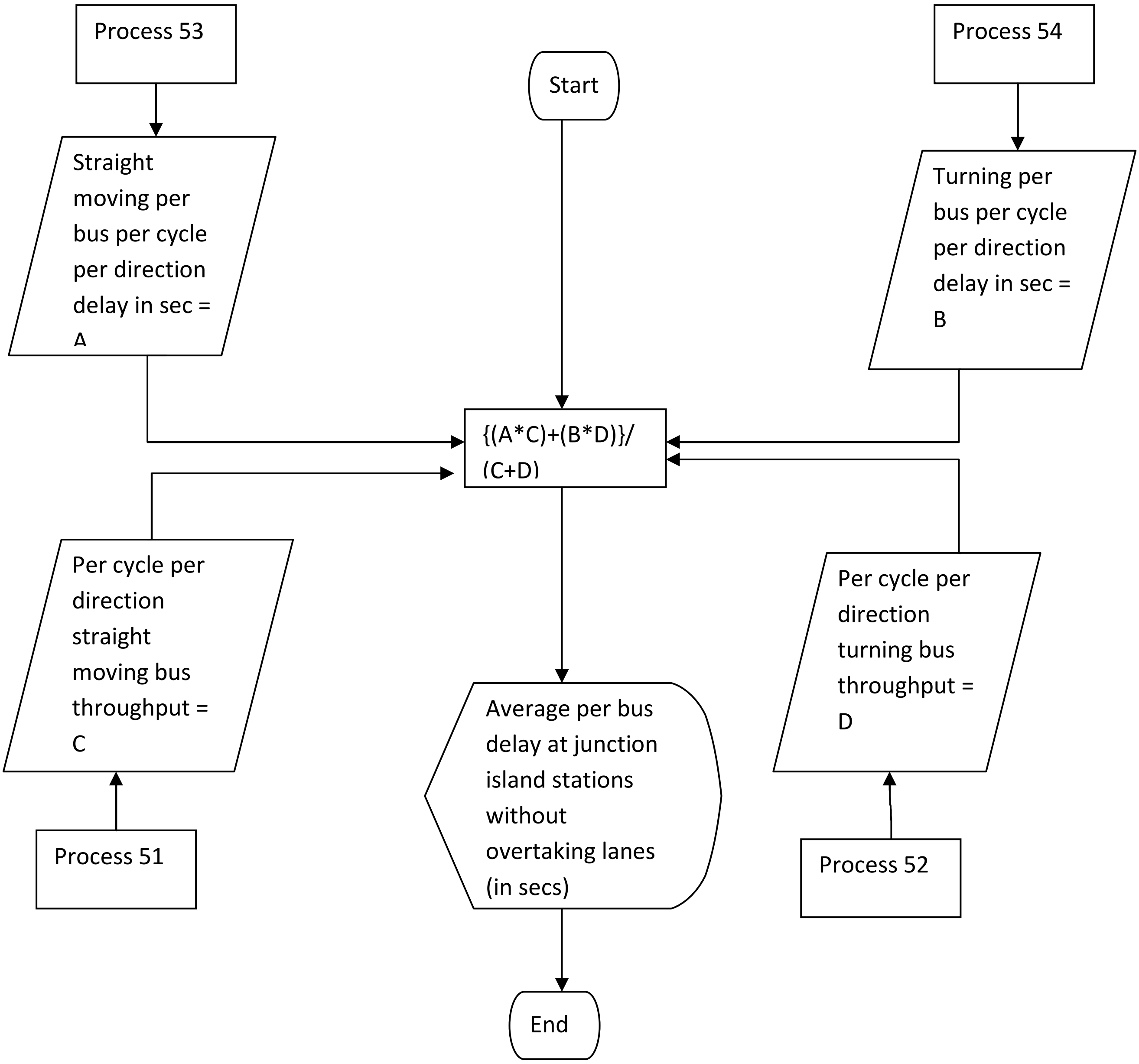


Figure 44: Flowchart for process 23 – Straight bus throughput per cycle per direction at intersections (between mid block stations).

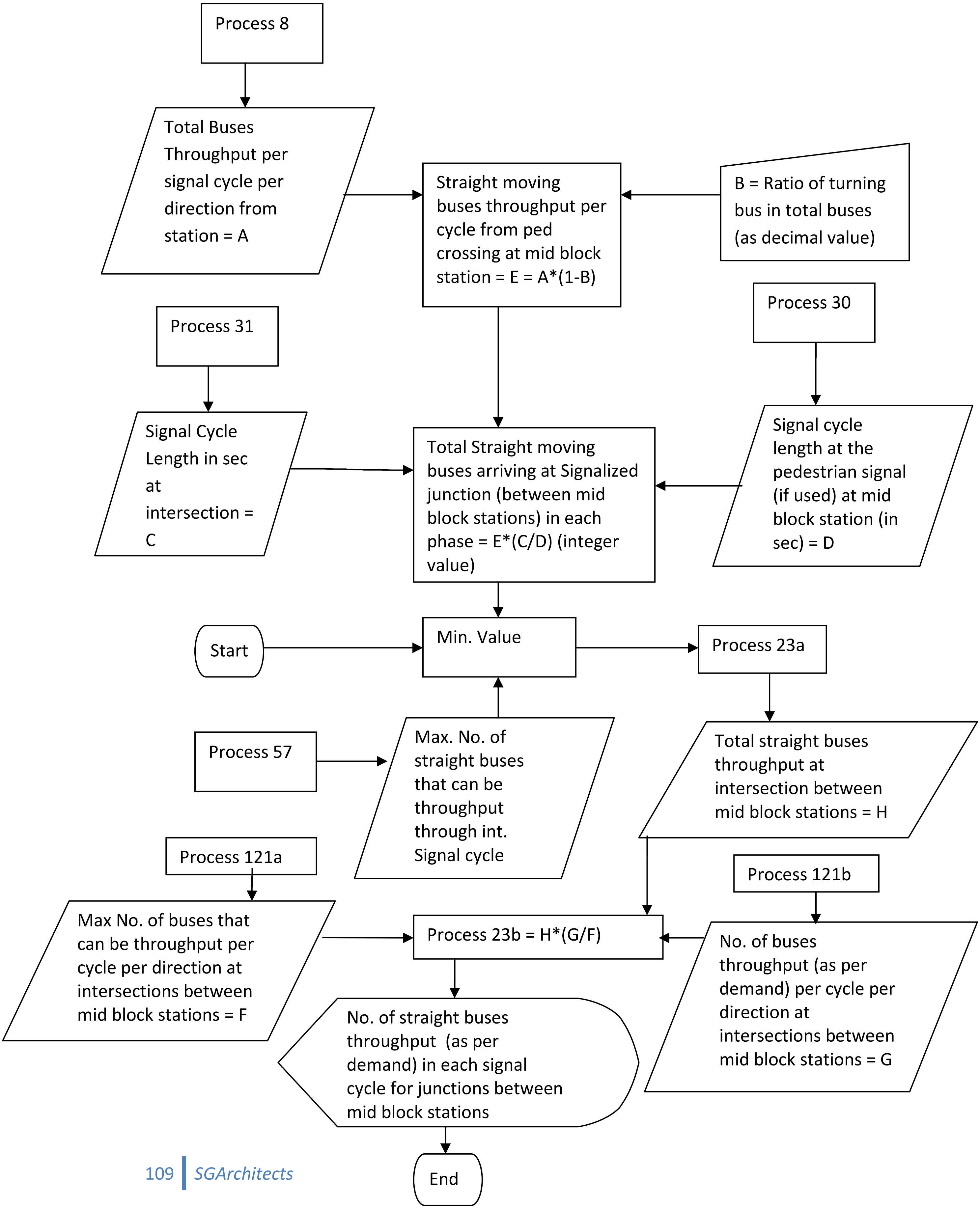


Figure 45: Flowchart for process 24 – Turning bus throughput per cycle per direction at intersections (between mid block stations).

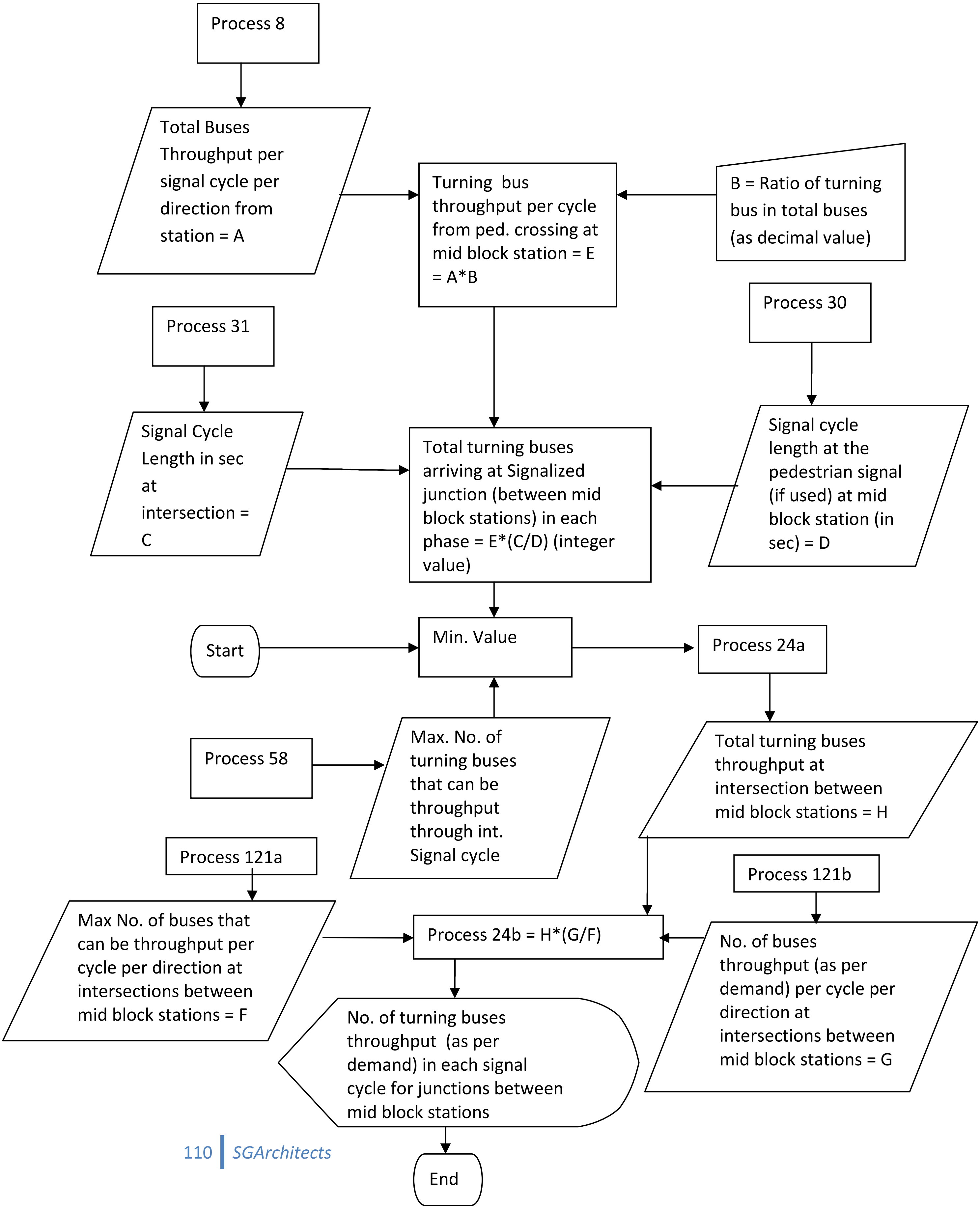


Figure 46: Flowchart for process no. 25 –Weighted average of bus delay for straight moving bus at a signalized intersection between bid block stations.

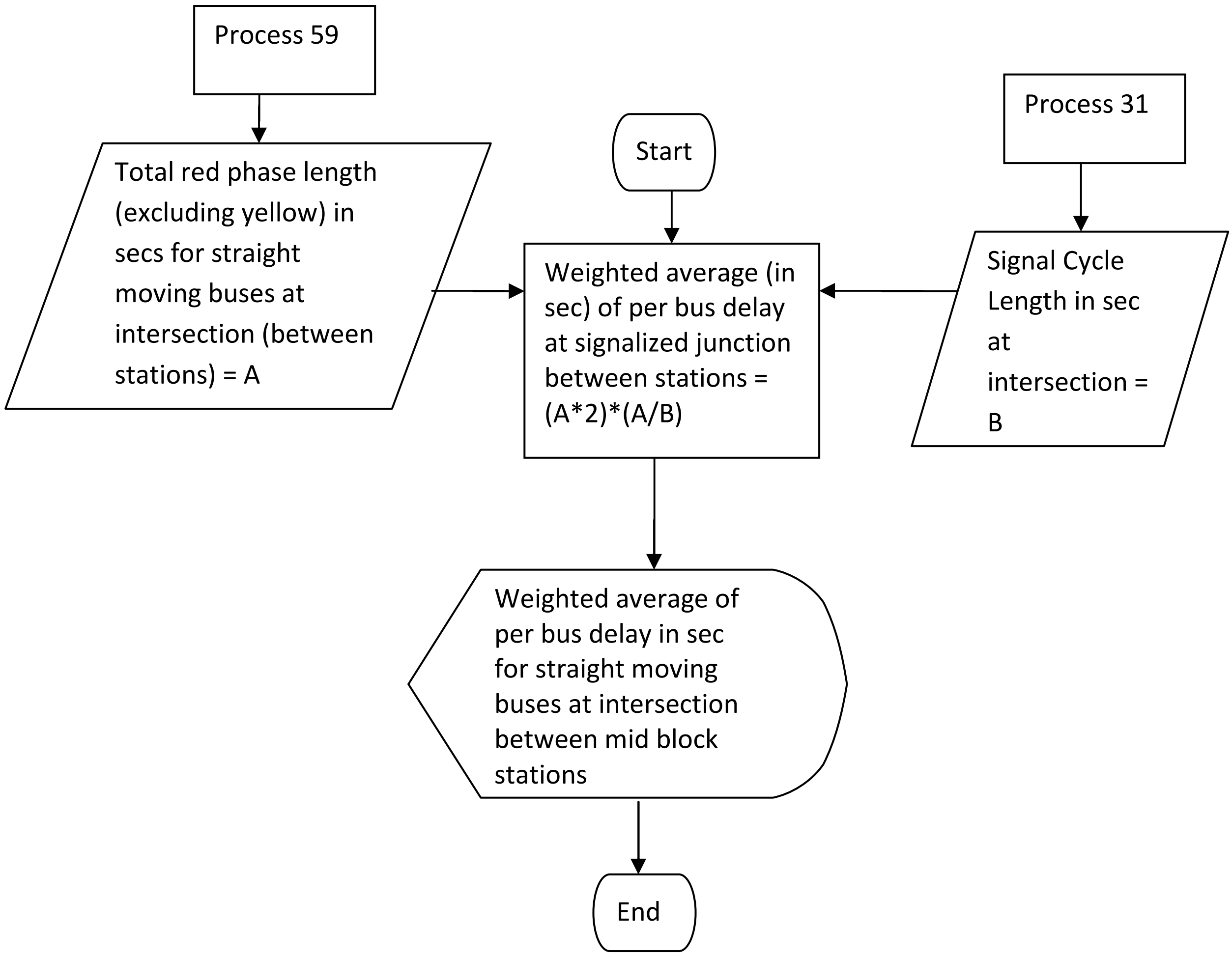


Figure 47: Flowchart for process no. 26 – Weighted average of bus delay for turning bus at a signalized intersection between bid block stations.

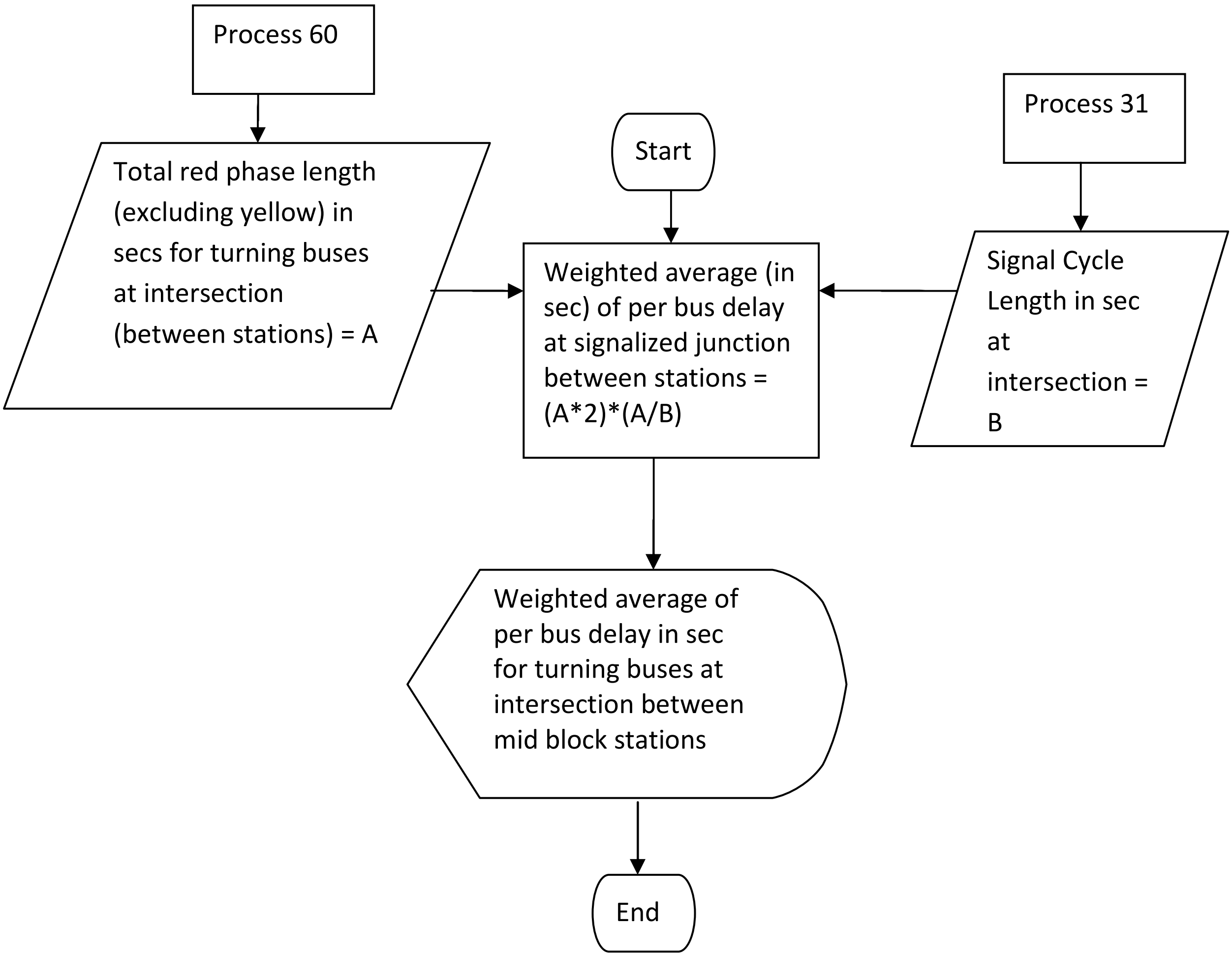


Figure 48: Flowchart for Process 27 – Total bus throughput per signal cycle per direction at (junction or mid block) island stations

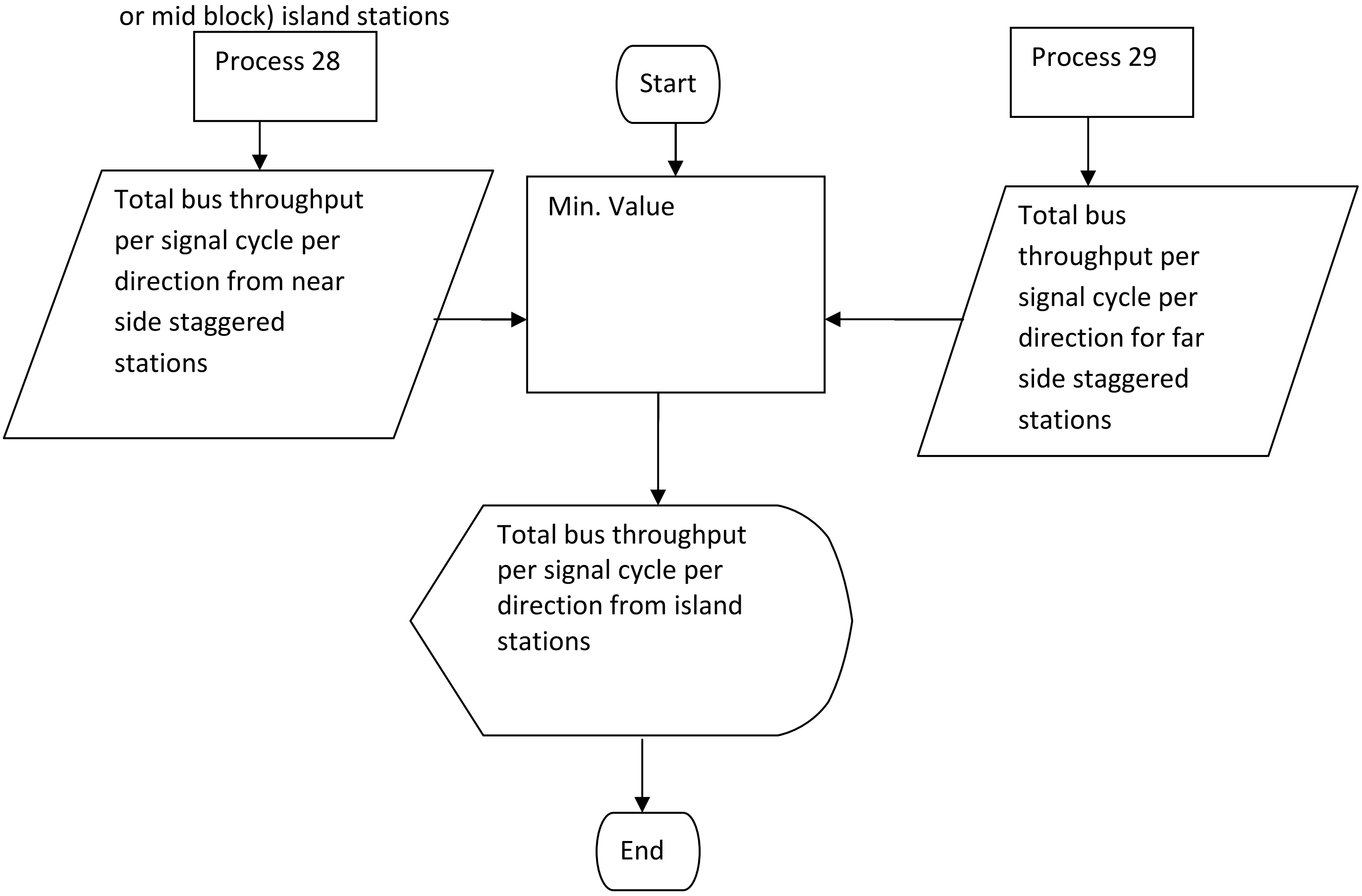


Figure 49: Flowchart for Process 28 – Total bus throughput per signal cycle per direction at (junction or mid block) staggered, near side stations

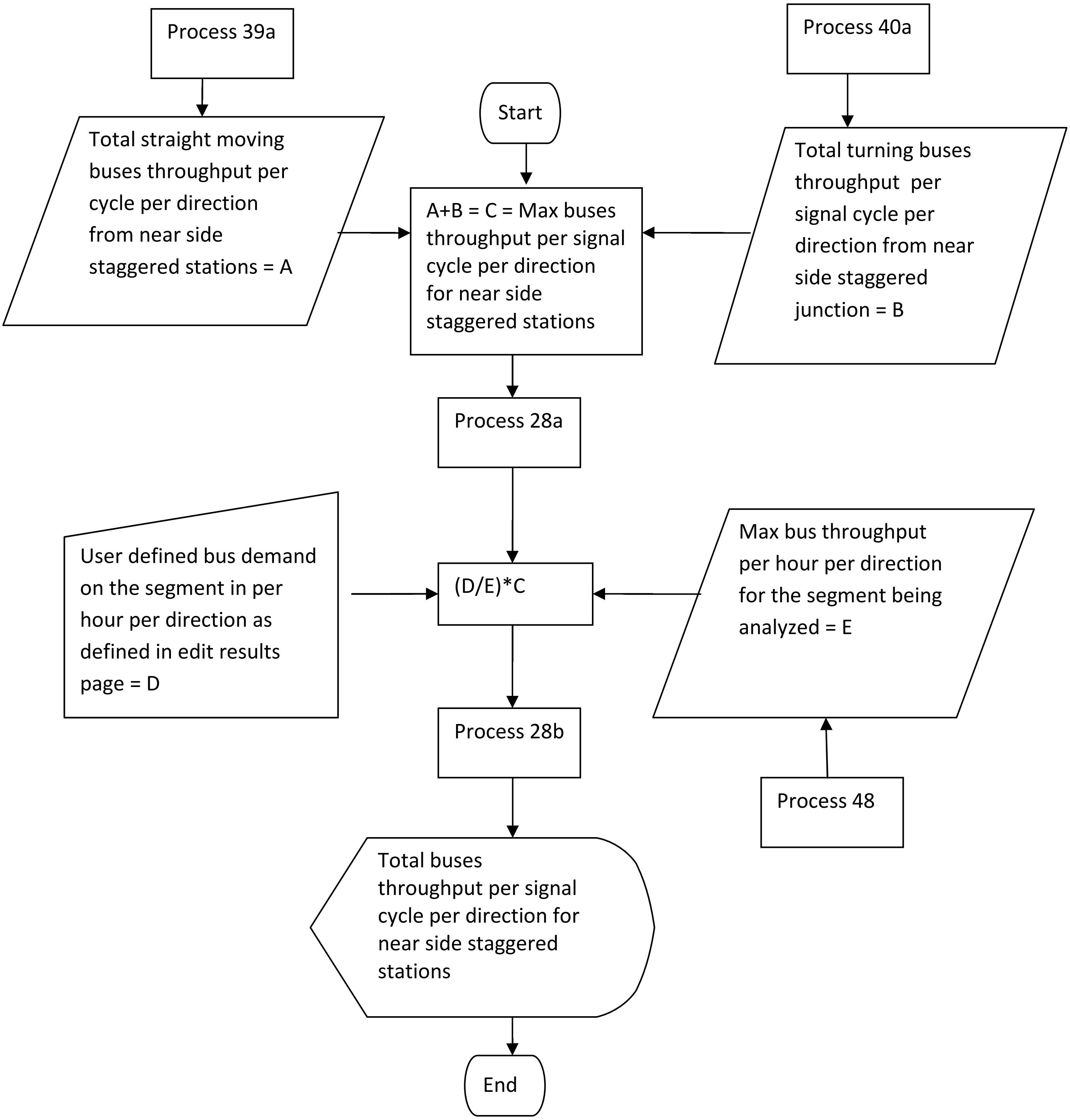


Figure 50: Flowchart for Process 29 – Total bus throughput per signal cycle per direction at (junction or mid block) staggered, far side stations

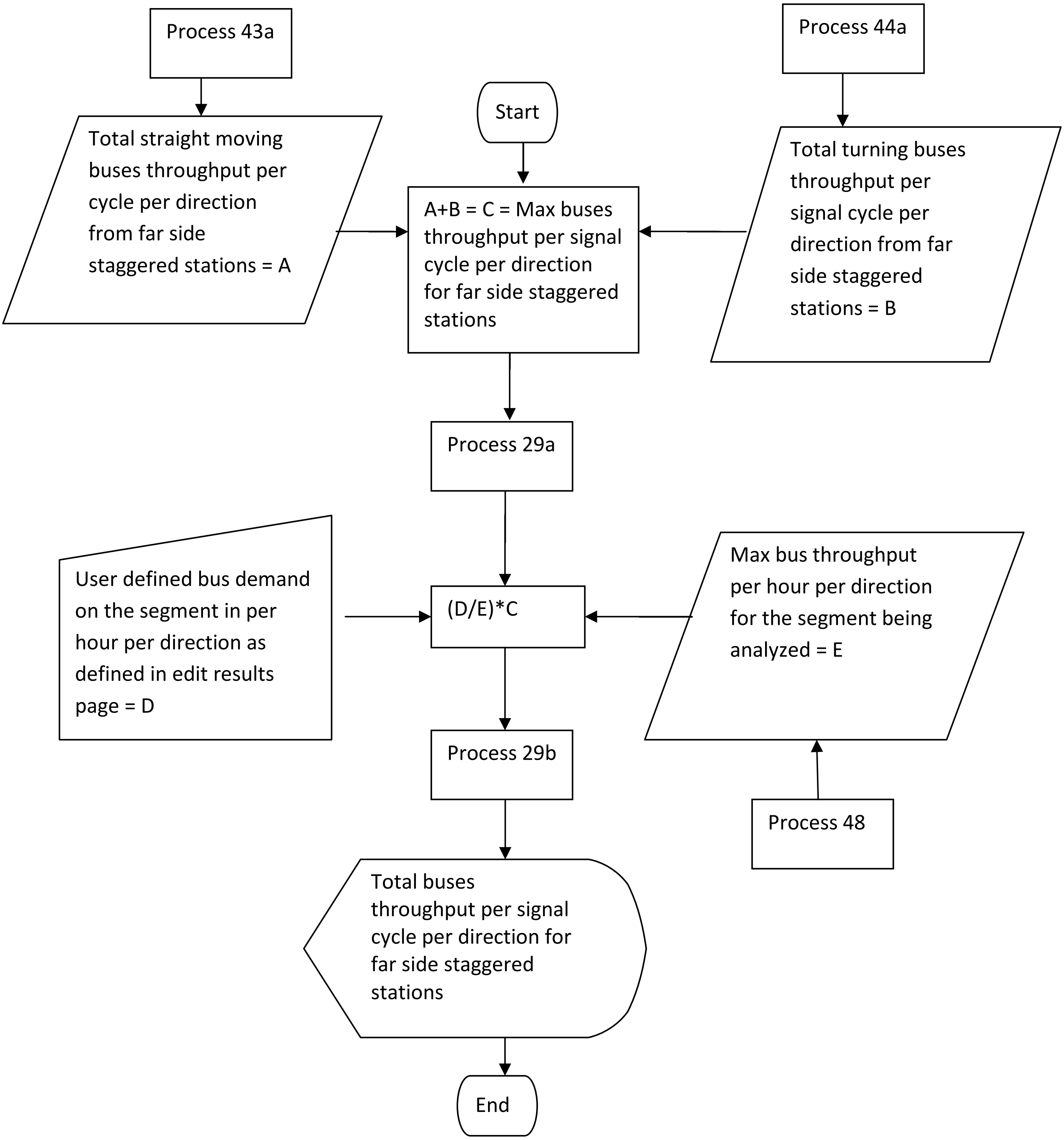


Figure 51: Flow chart for process 30 – Signal cycle length in sec for junction station intersections

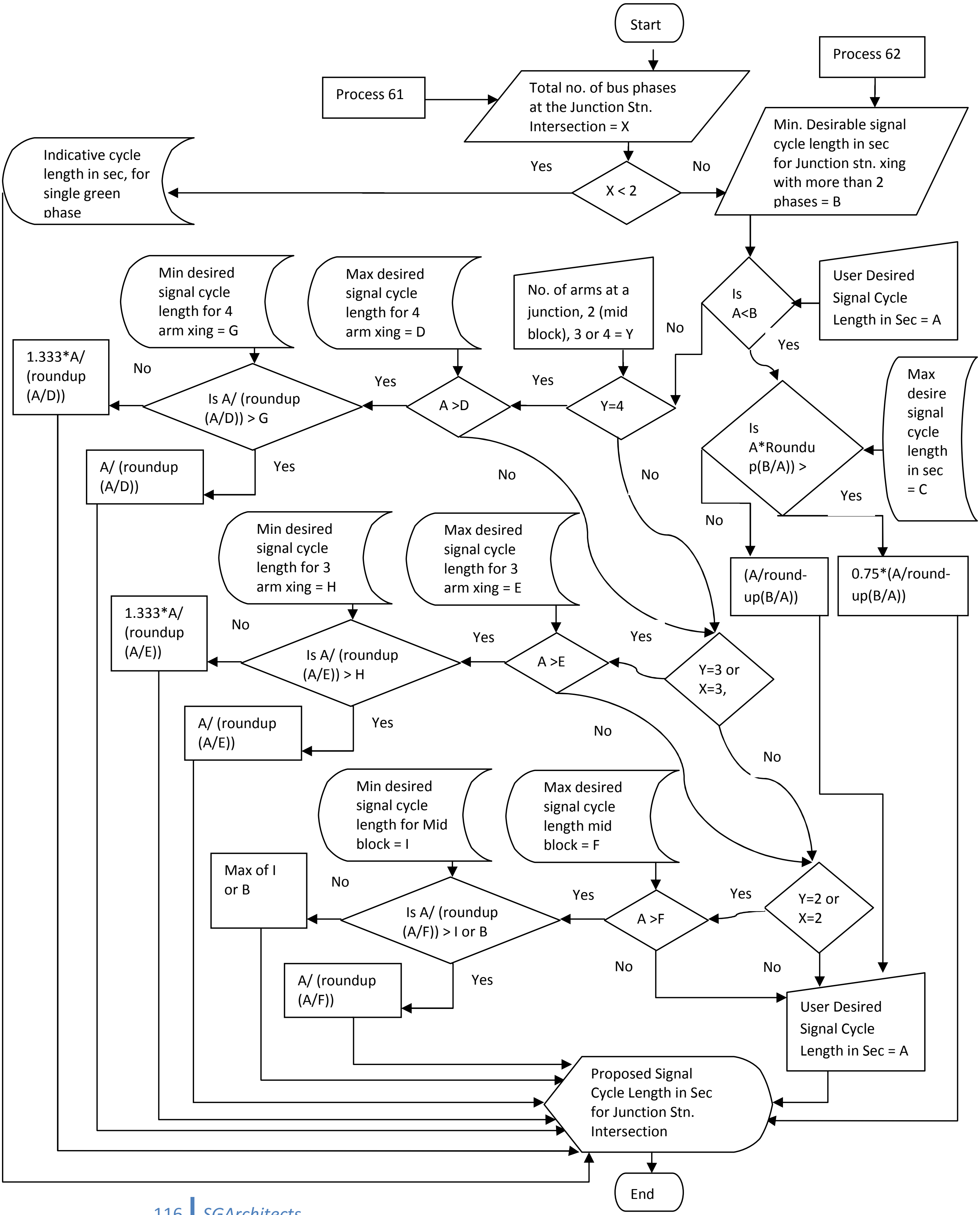


Figure 52: Flow chart for process 31 – Signal cycle length in sec for Mid Block station intersections

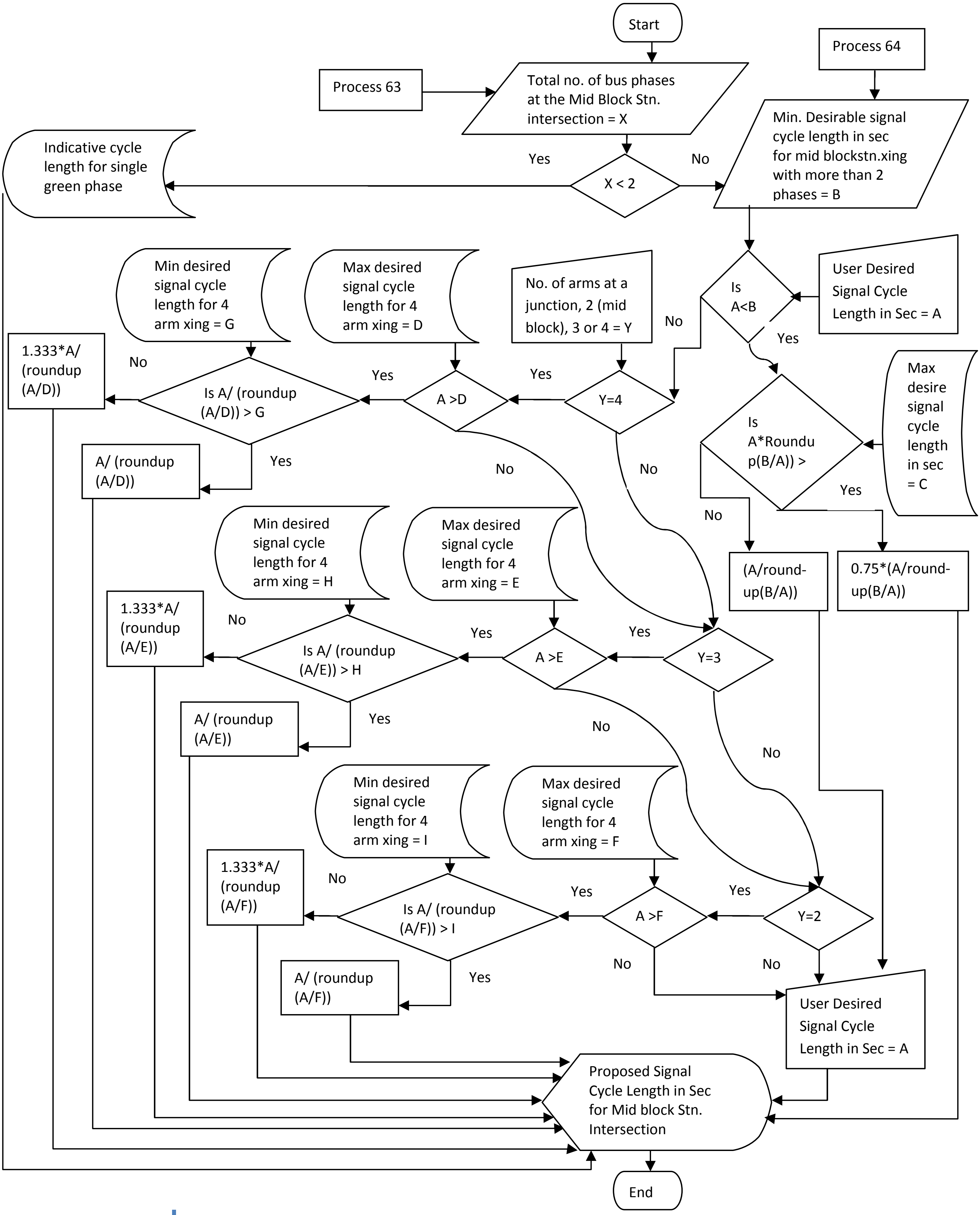


Figure 53: Flowchart for Process No. 32 – Passenger access delay for a BRTS bus based on average walking distance from median on the cross roads.

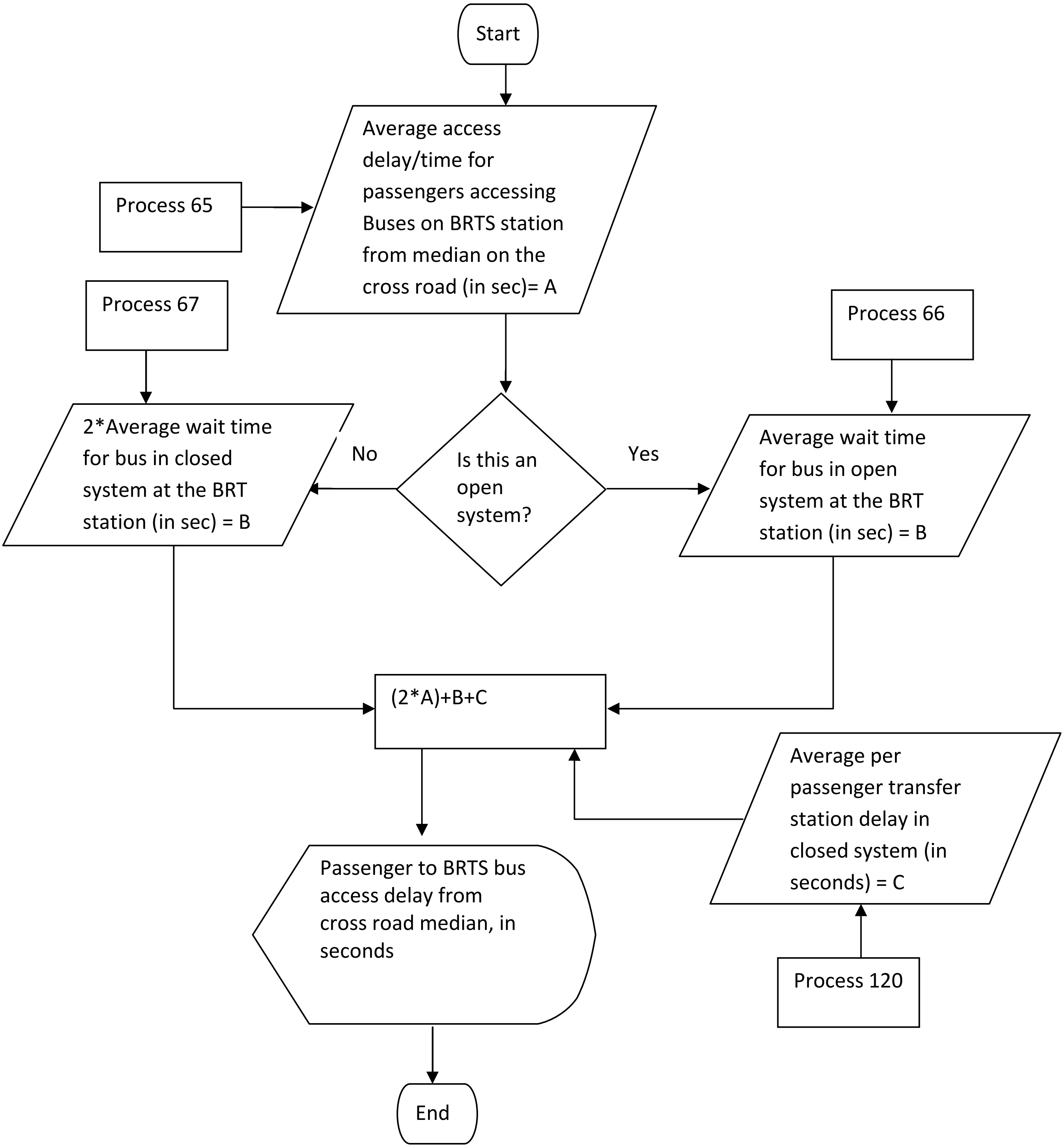


Figure 54: Flow chart for Process no. 33 – Average walking distance in m. from origin/destination point to the BRTS or feeder station location.

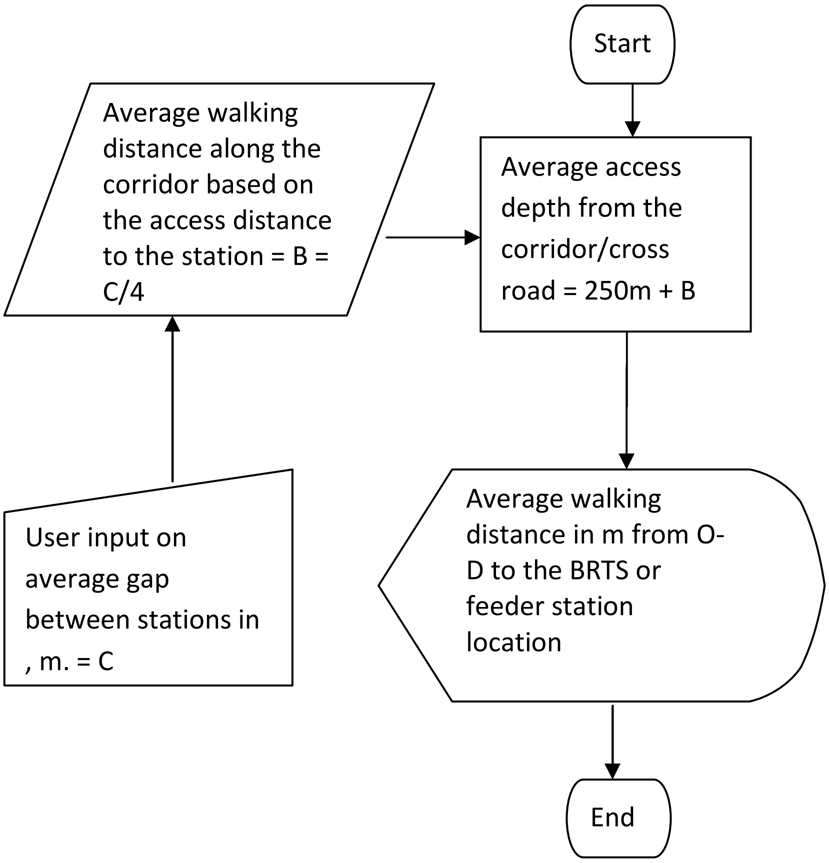


Figure 55: Flowchart for process no. 34 –Average total access delay to bus outside the corridor in an open system

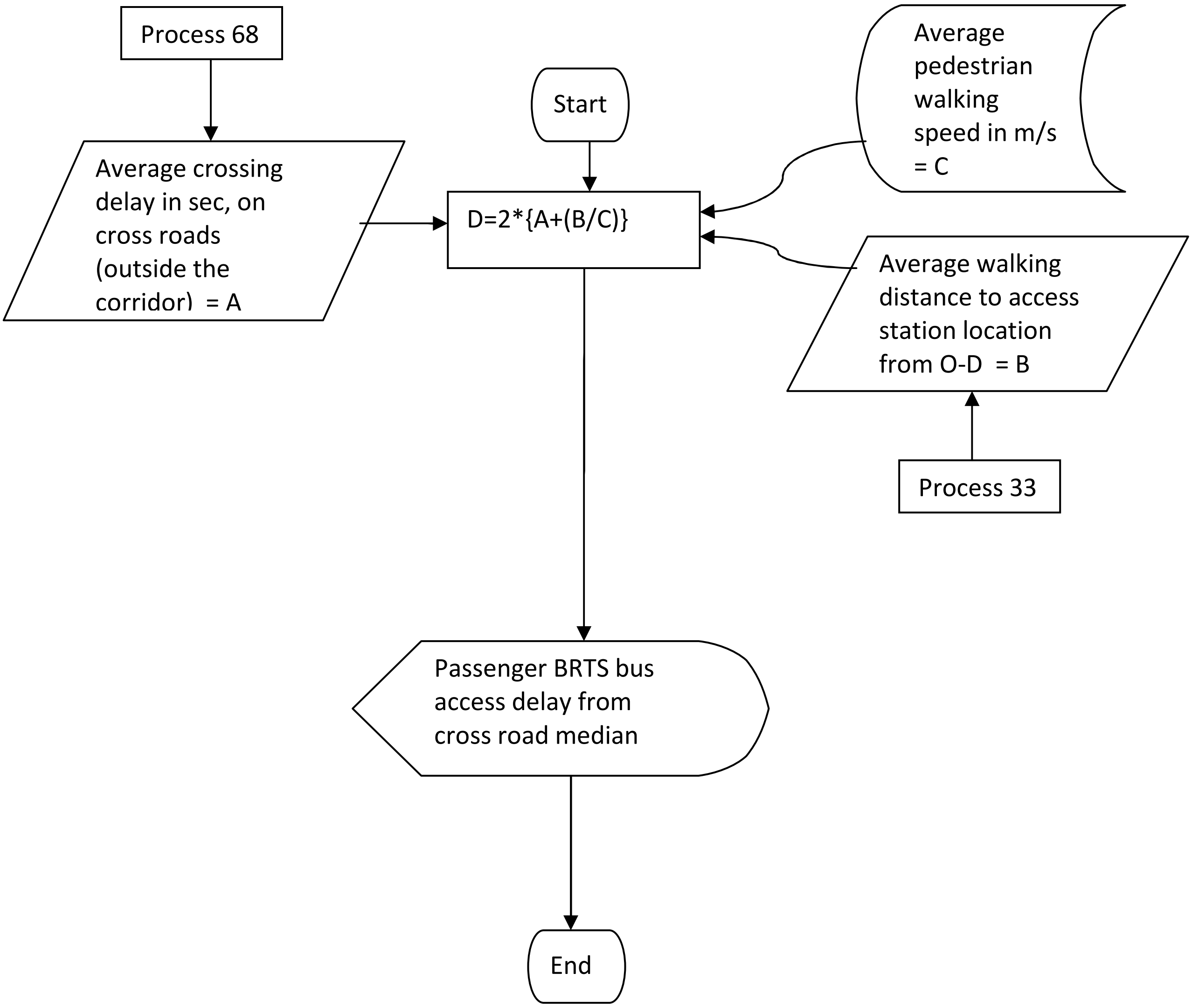


Figure 56: Flowchart for Process no. 35 – Average bus speed in mixed conditions in m/s.

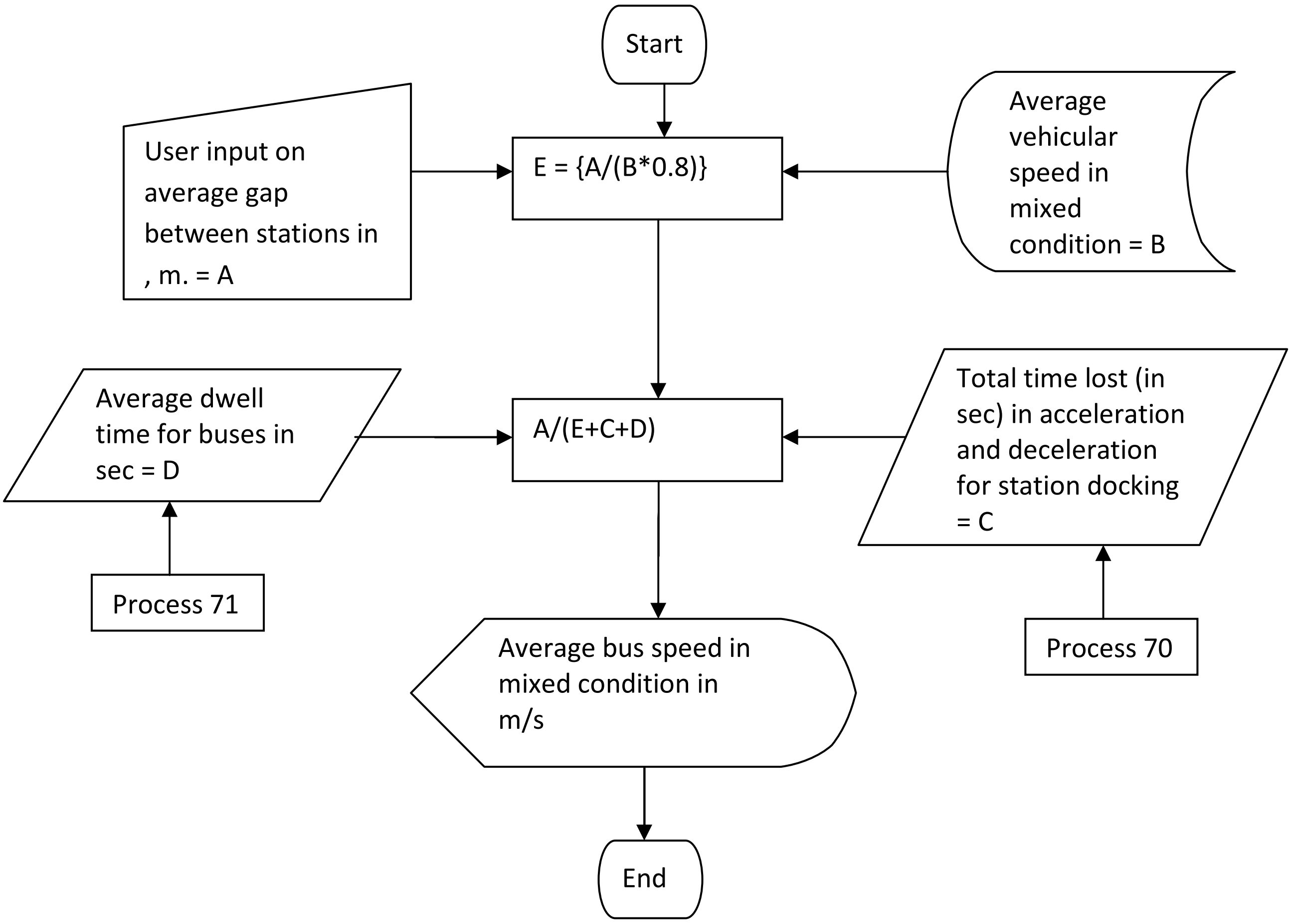


Figure 57: Flowchart for Process no. 36 - Average total access delay to bus outside the corridor in closed system

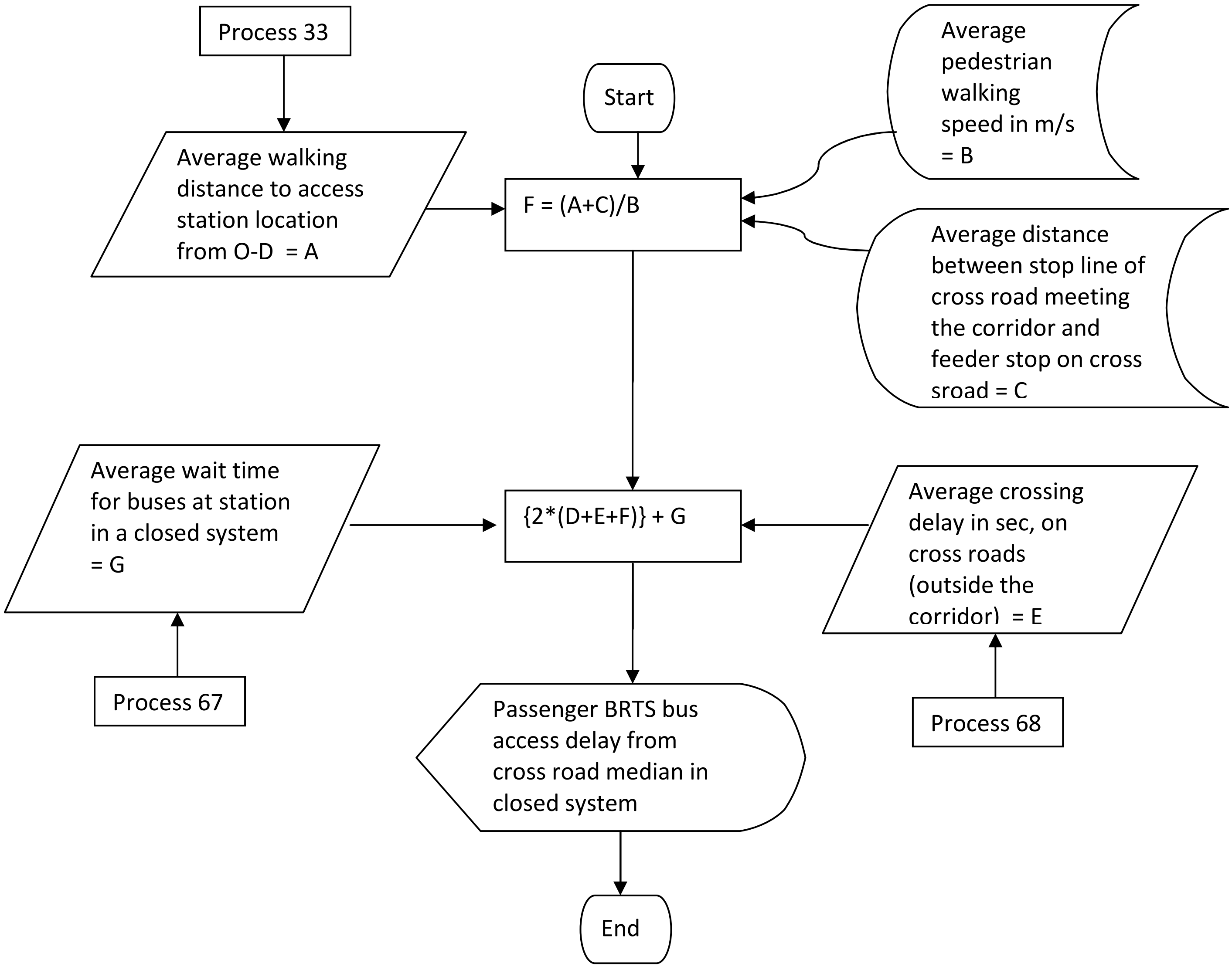


Figure 58: Flow chart for process 37 – Straight moving per bus per cycle per direction delay for buses at near side (staggered stations) in secs.

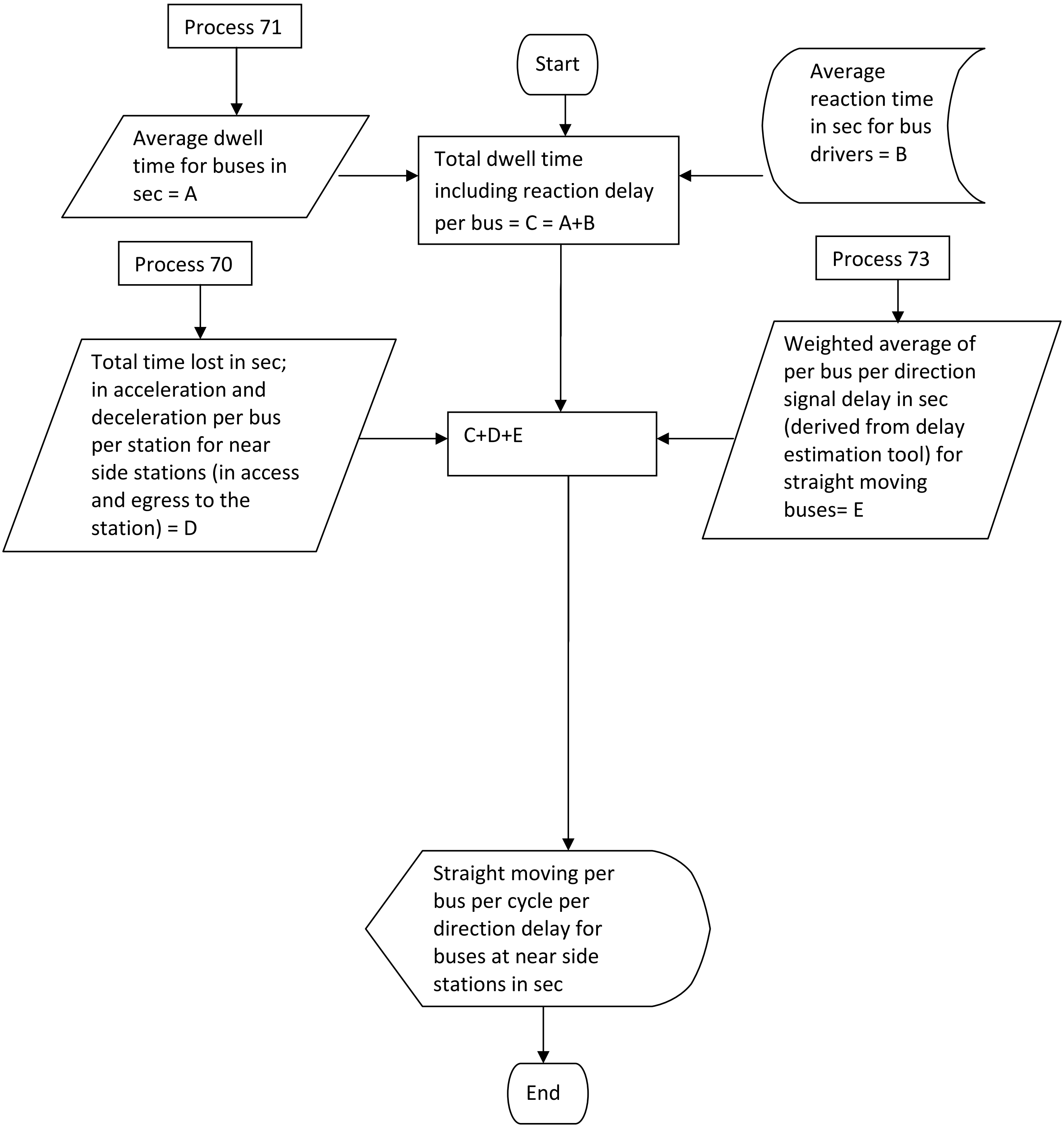


Figure 59: Flowchart for process 38 - Turning per bus per cycle per direction delay for buses at near side (staggered stations) in secs.

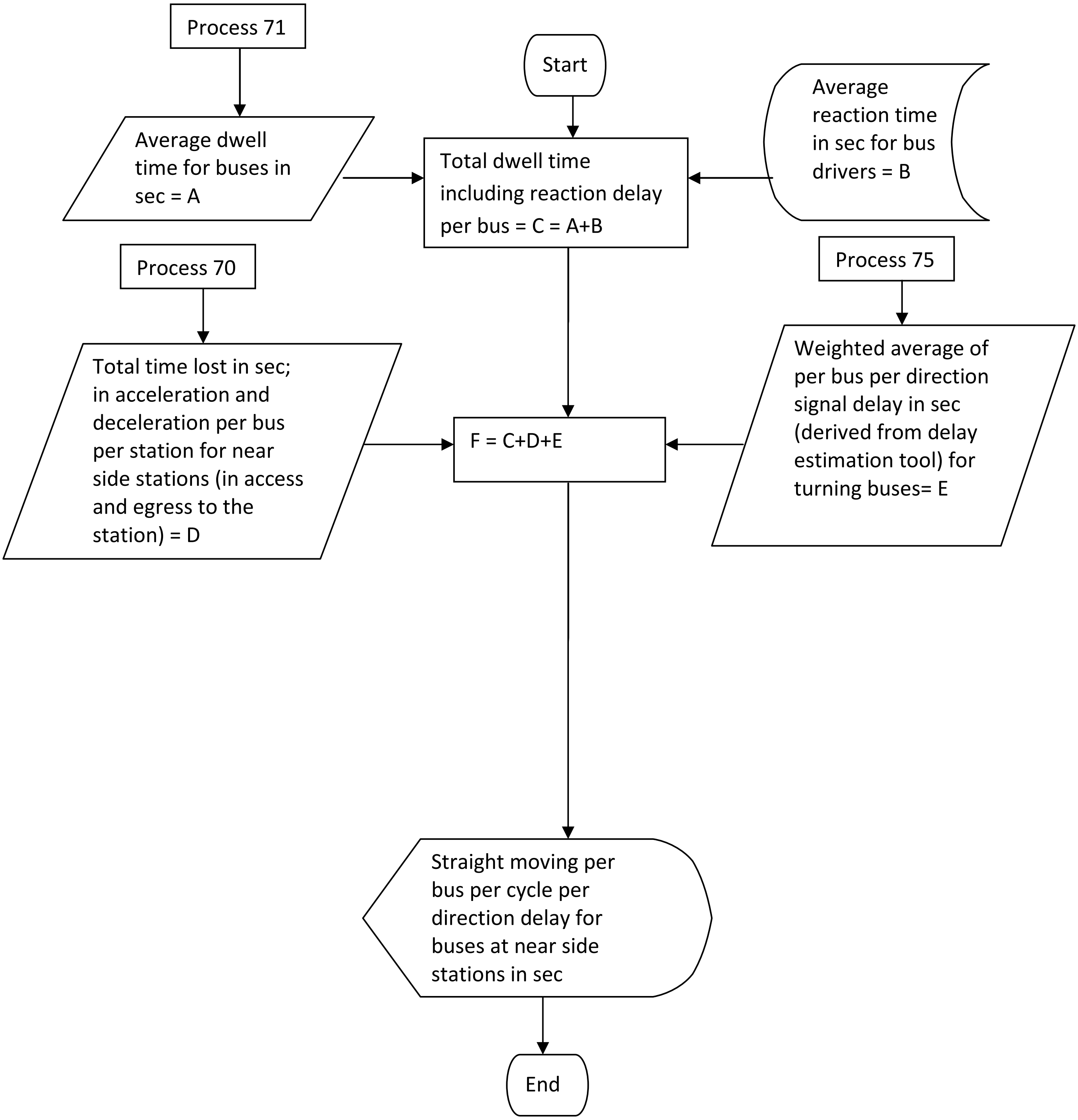


Figure 60: Flow chart for process 39 –Straight moving bus throughput per direction per signal cycle for near side stations

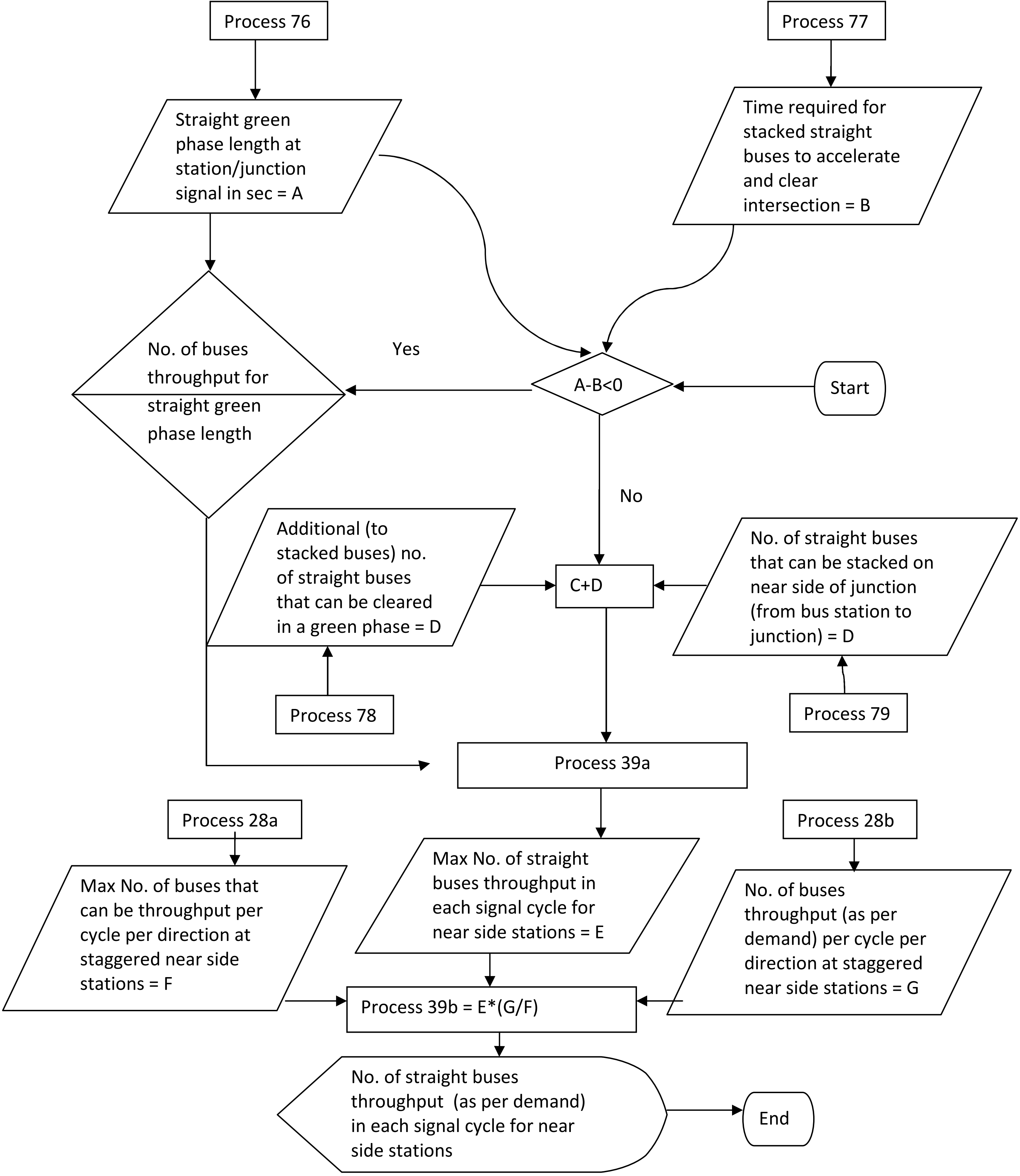


Figure 61: Flowchart for process 40 - Turning bus throughput per direction per signal cycle for near side stations

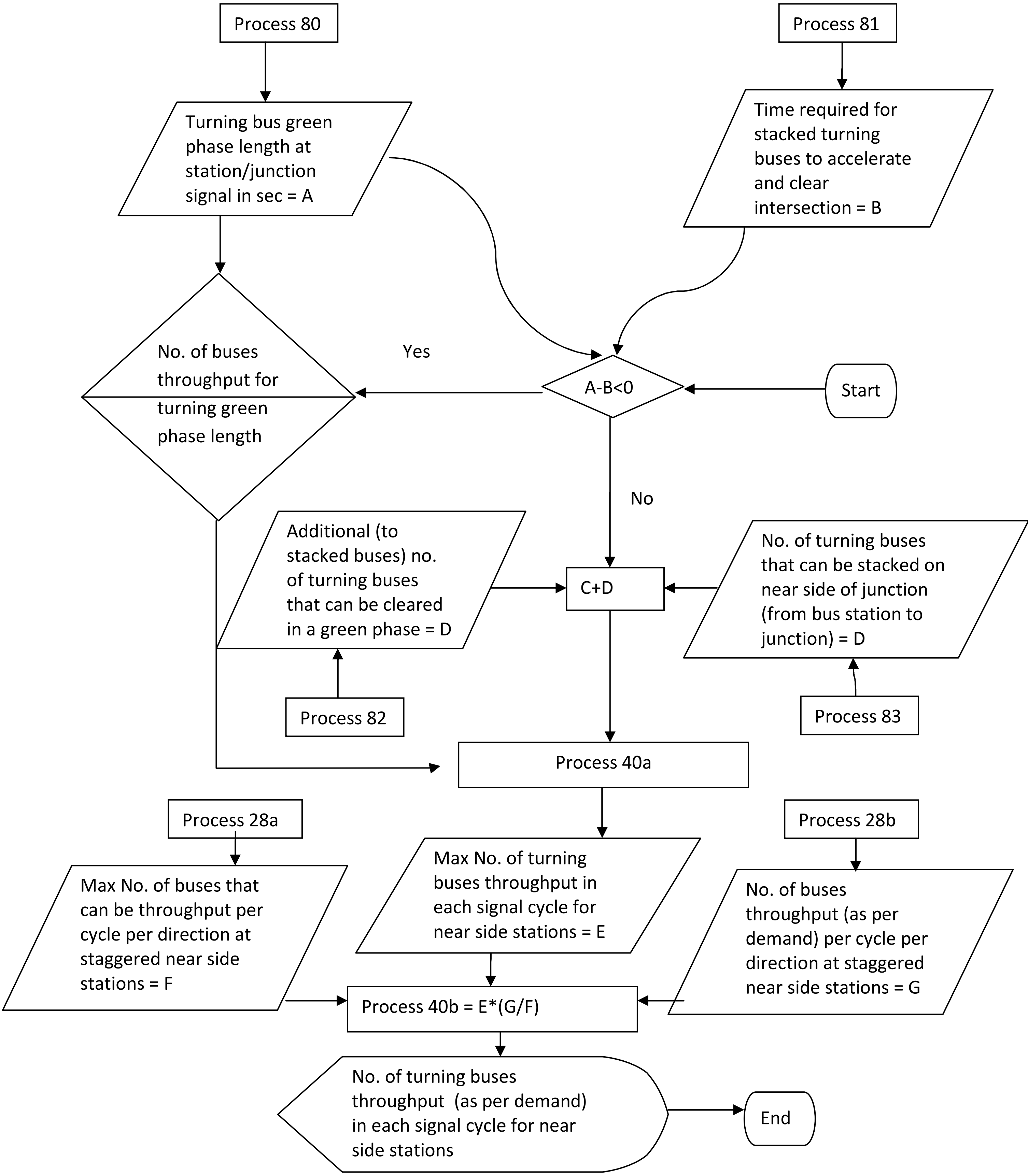


Figure 62: Flow chart for process 41 - Straight moving per bus per cycle per direction delay for buses at far side (staggered stations) with overtaking lanes in secs.

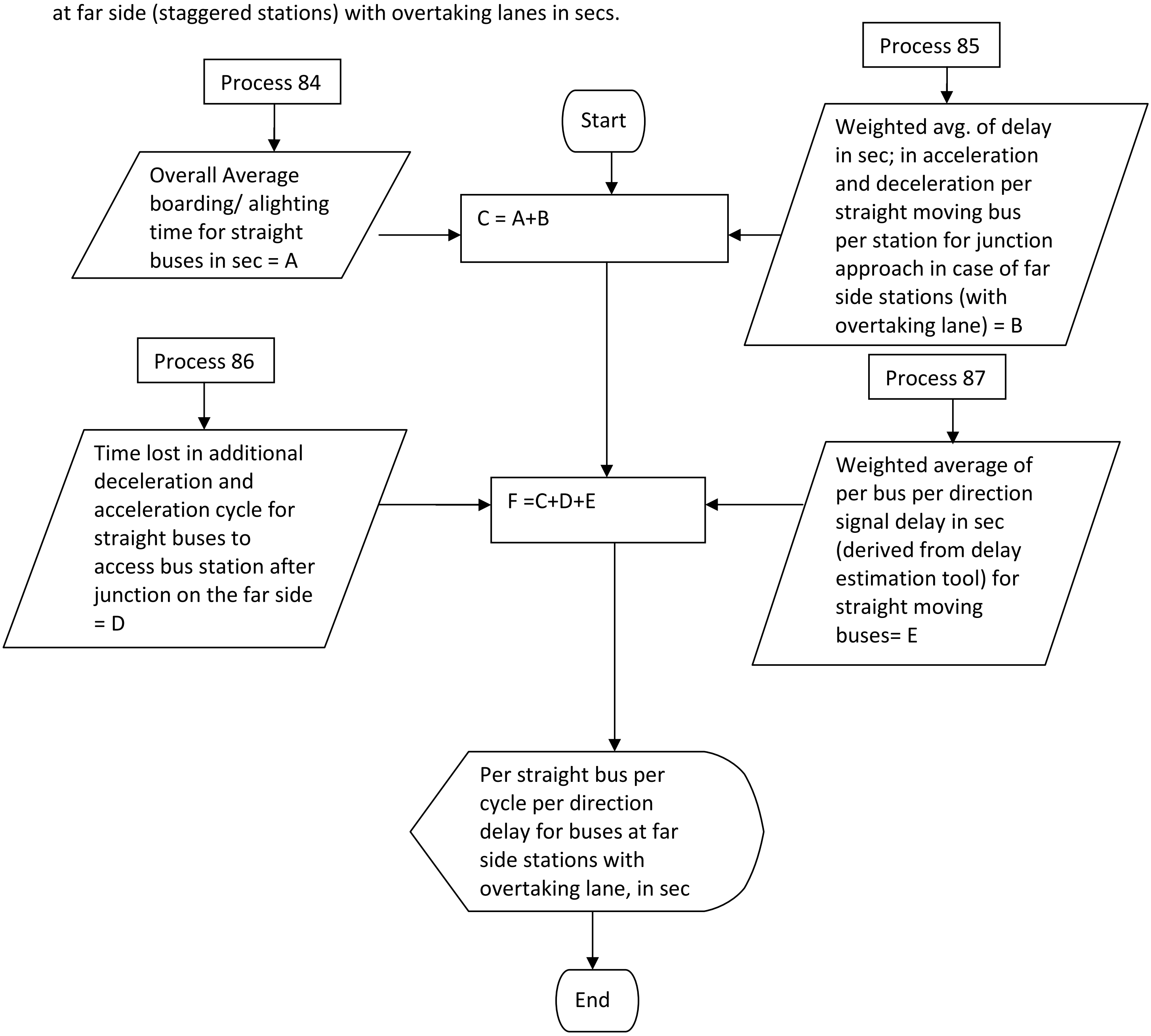


Figure 63: Flow chart for process 42 –Per bus per cycle per direction delay for turning buses at far side (staggered stations) with overtaking lanes in secs.

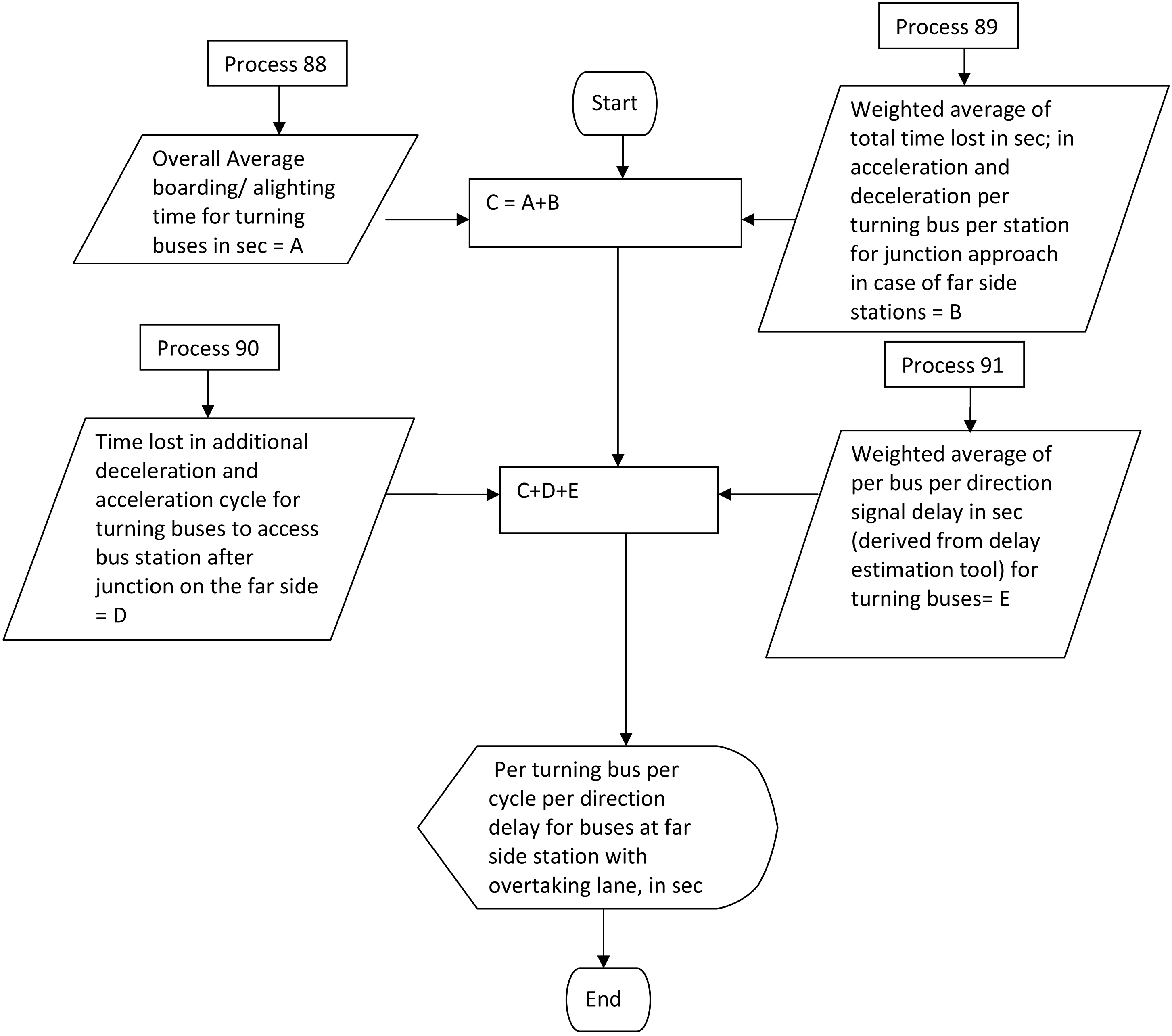


Figure 64: Flow chart for process 43 – Per cycle per direction straight moving bus throughput for far side stations with or withoutovertaking lanes

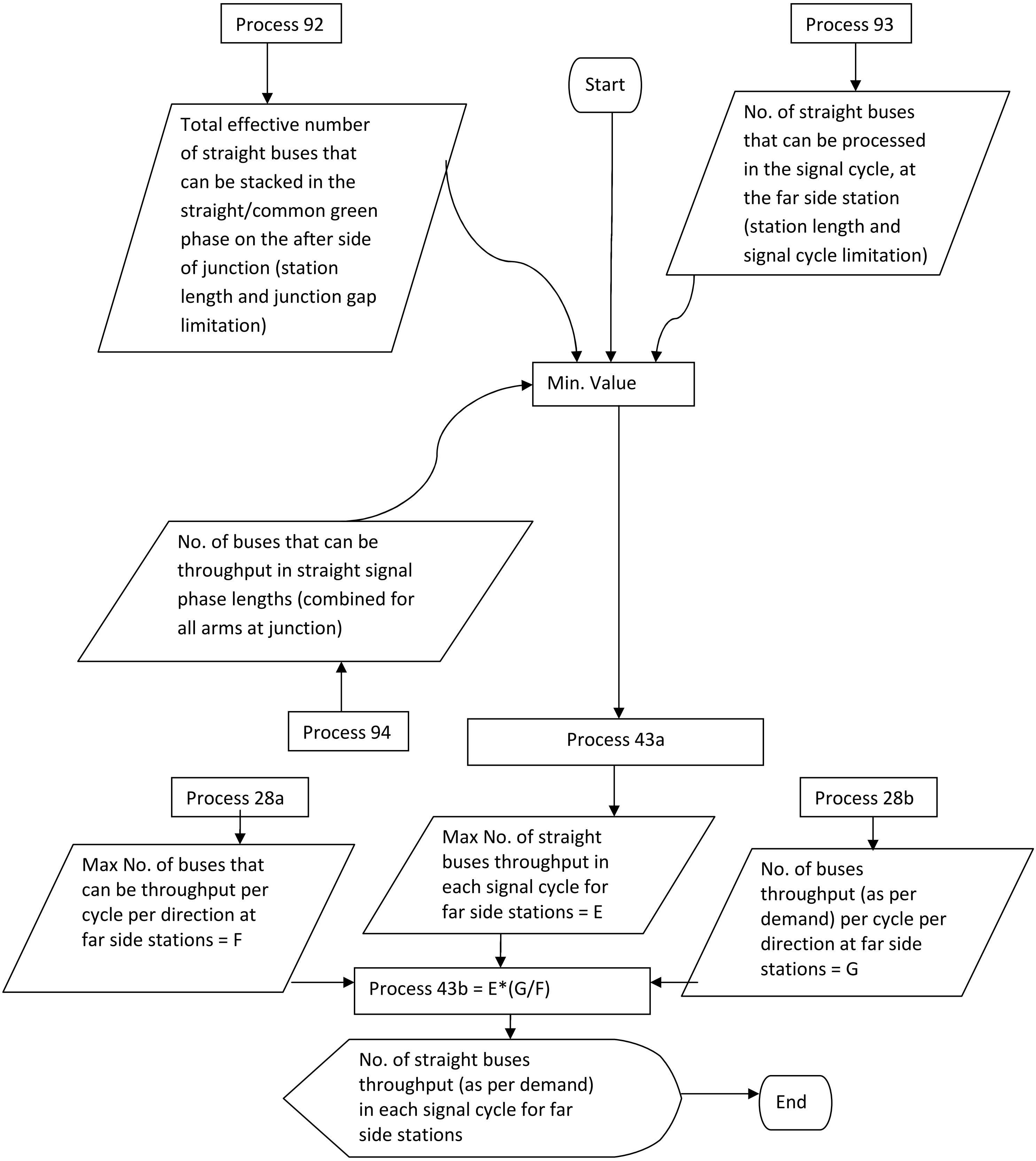


Figure 65: Flow chart for process 44 – Per cycle per direction turning bus throughput for far side stations with overtaking lanes

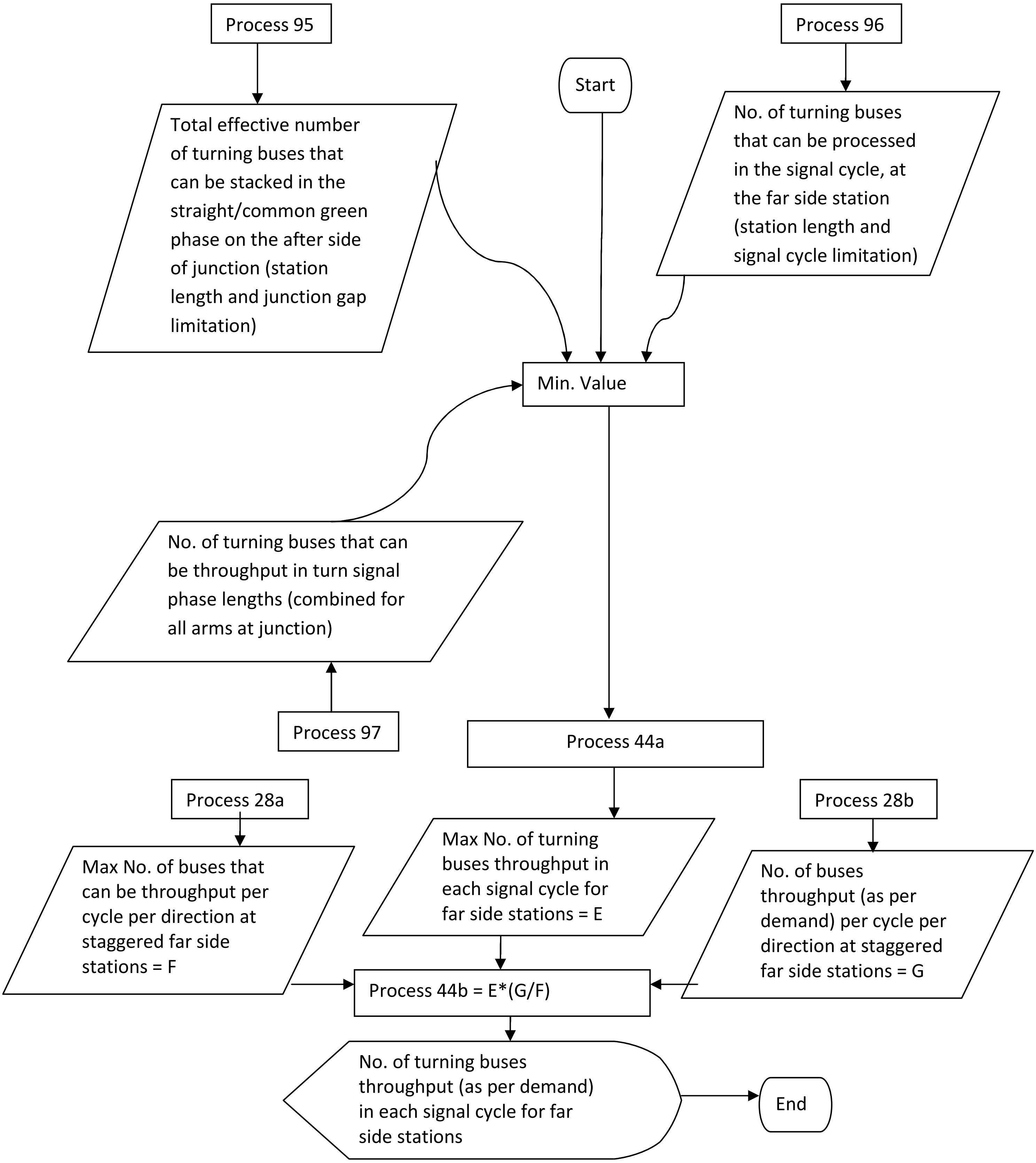


Figure 66: Flow chart for process 45 - Straight moving per bus per cycle per direction delay for buses at far side (staggered stations) without overtaking lanes, in secs.

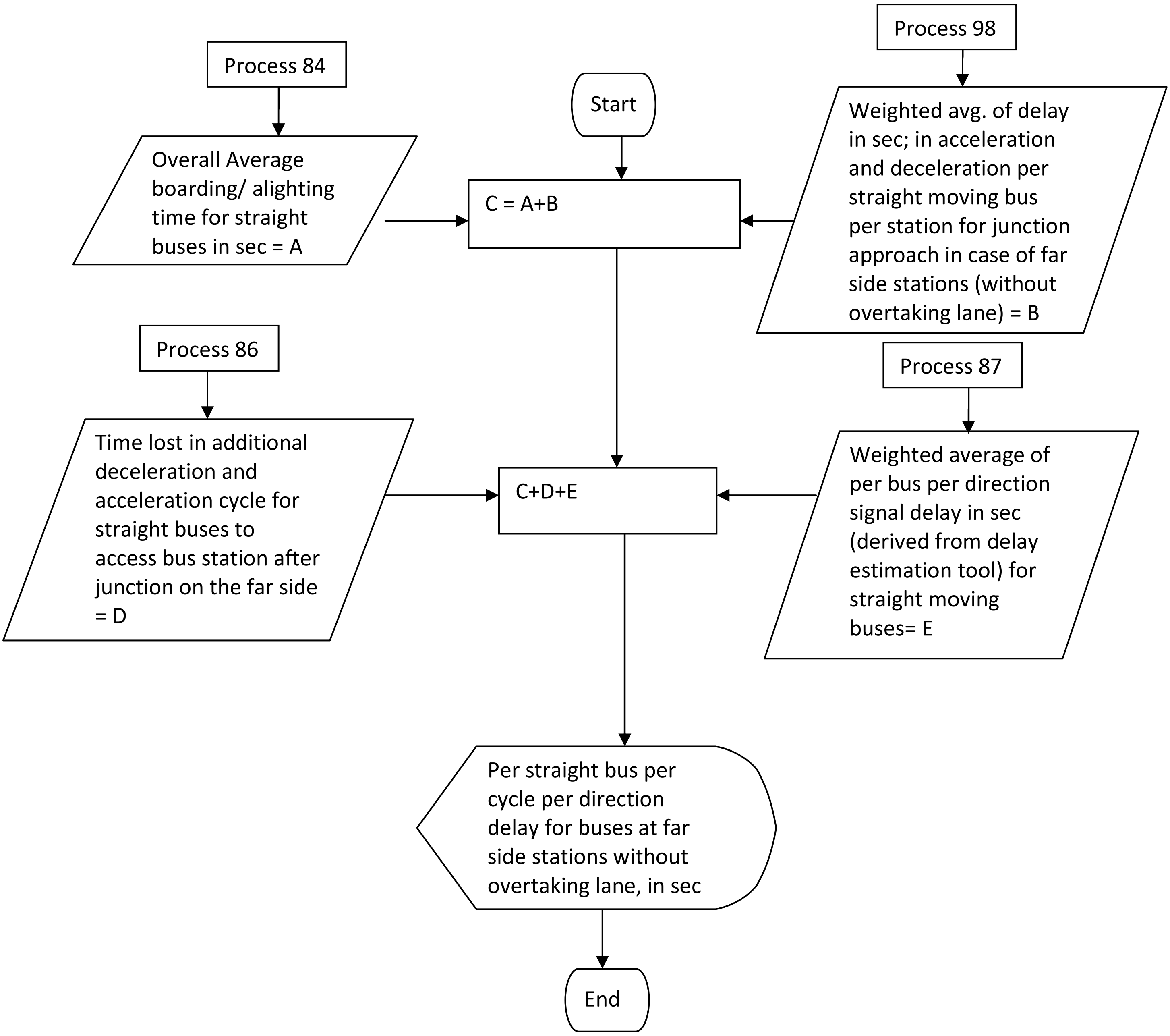


Figure 67: Flow chart for process 46 –Per bus per cycle per direction delay for turning buses at far side (staggered stations) without overtaking, lanes in secs.

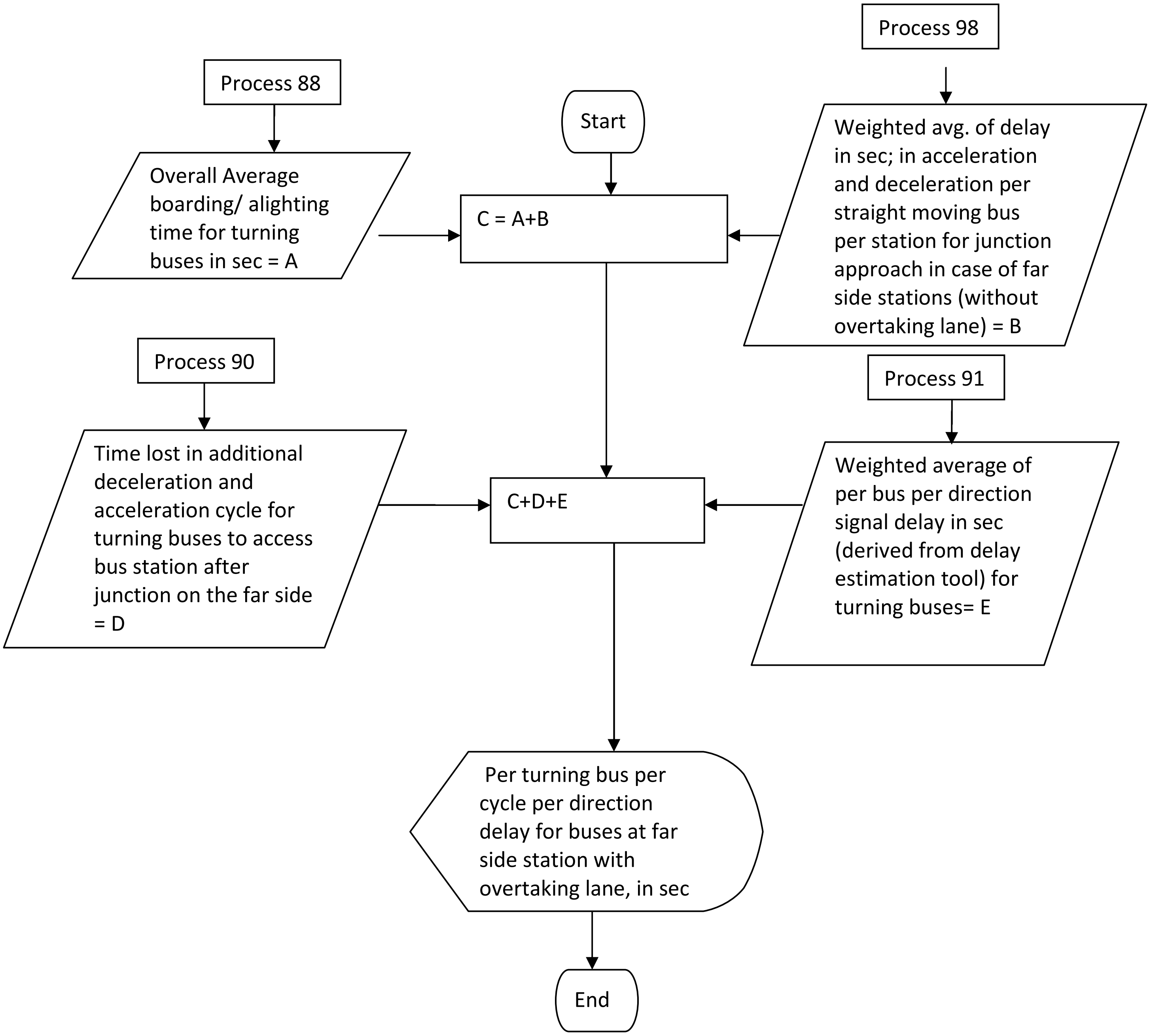


Figure 68: Flow chart for process 47 –Percentage of trips with varying distance of O-D situated of the corridor on the basis of average motorized trip length in the city

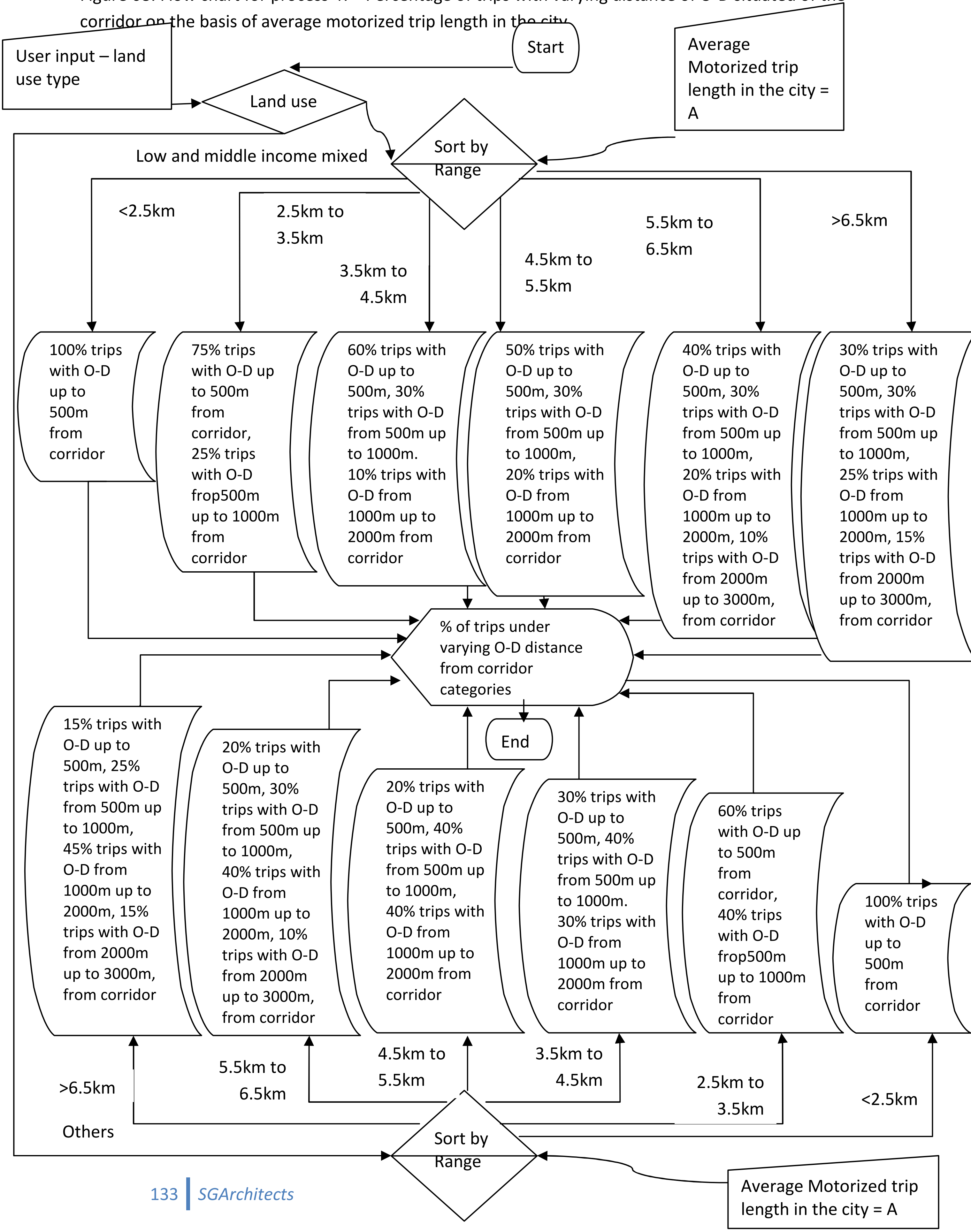


Figure 69: Flowchart for process 48 – Total bus throughput per hour per direction capacity of the corridor.

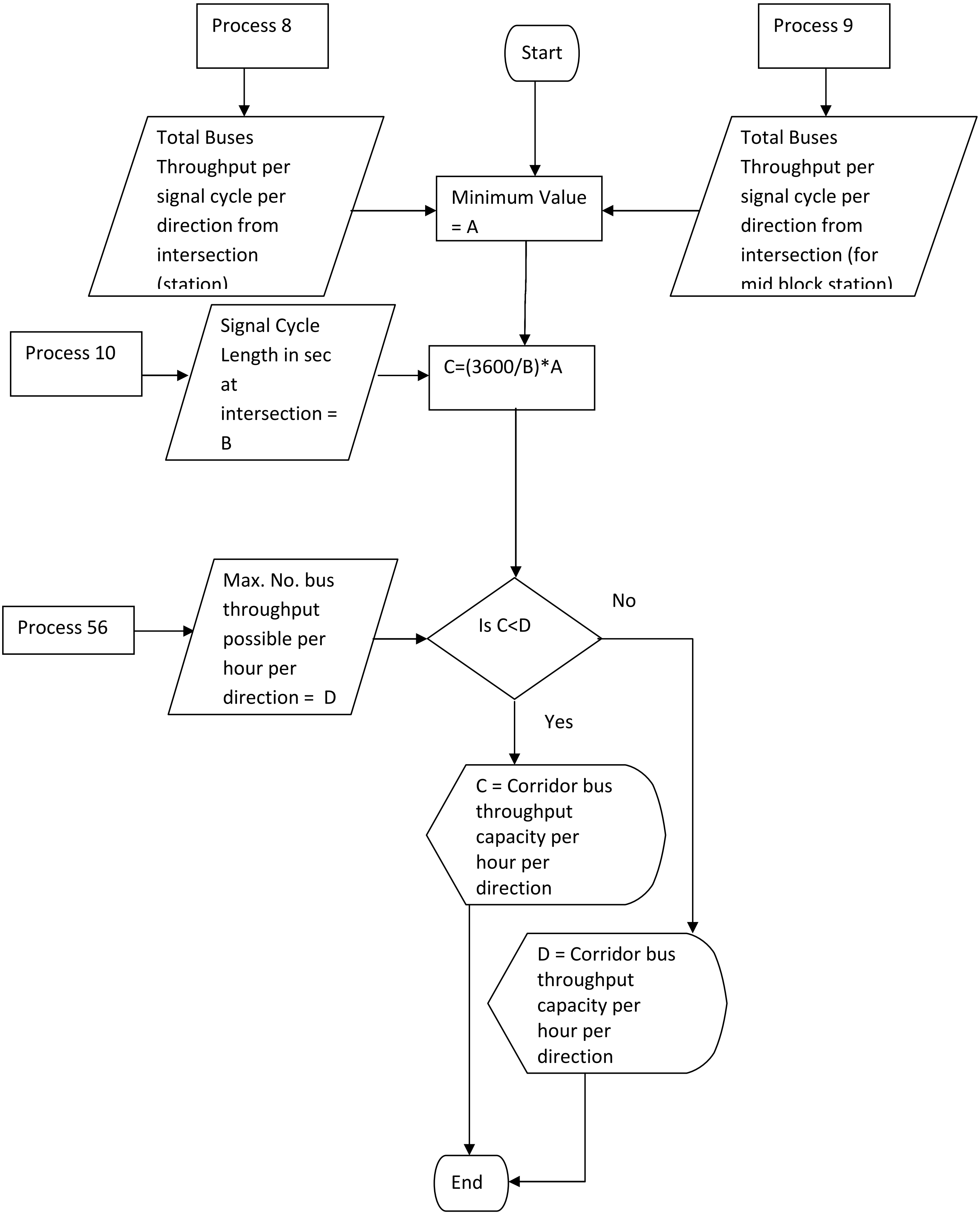


Figure 70: Flow chart for process 49–Average per bus delay for straight moving buses at common or island stations with overtaking lanes.

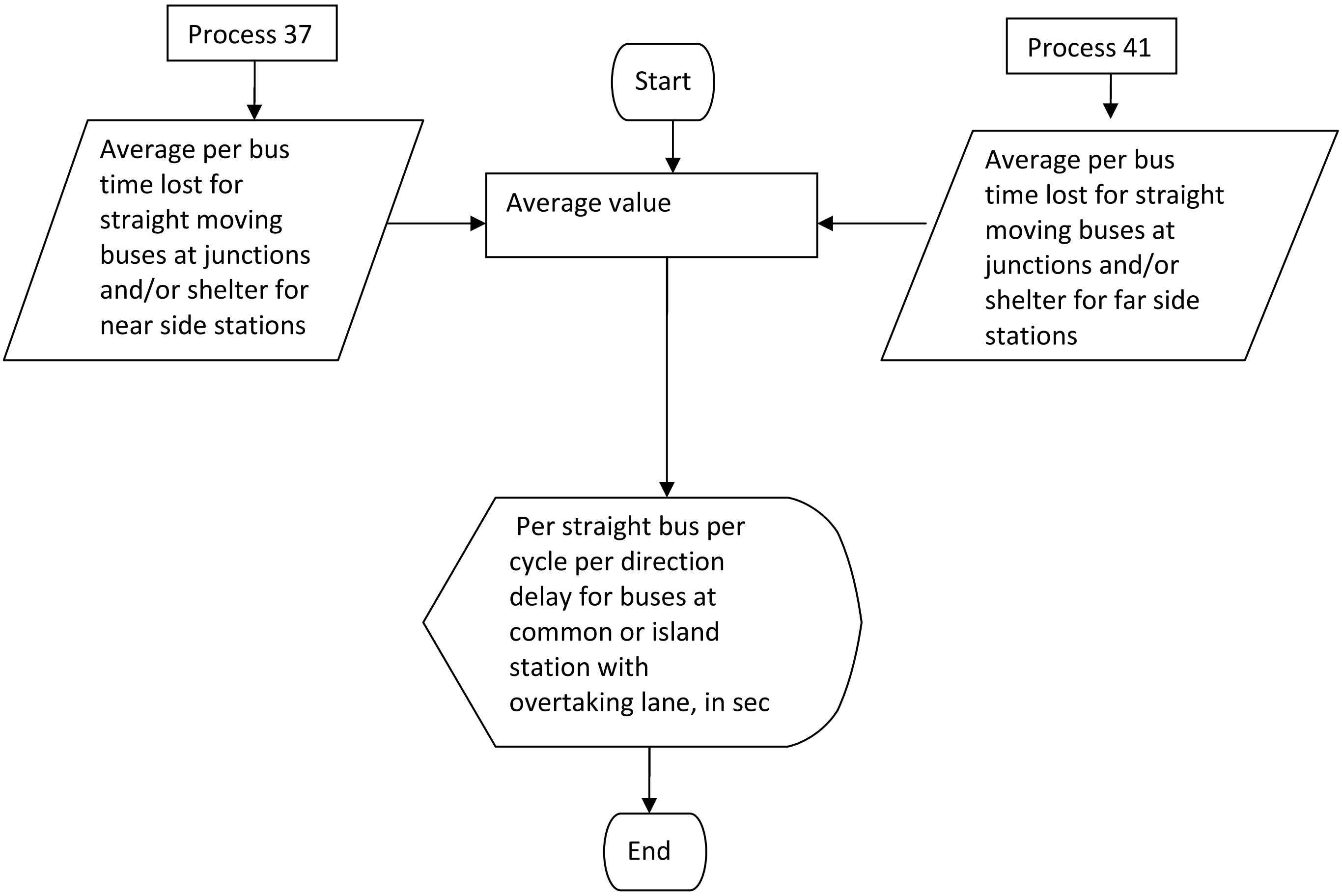


Figure 71: Flow chart for process 50 – Average per bus delay for turning buses at common or island stations with overtaking lanes.

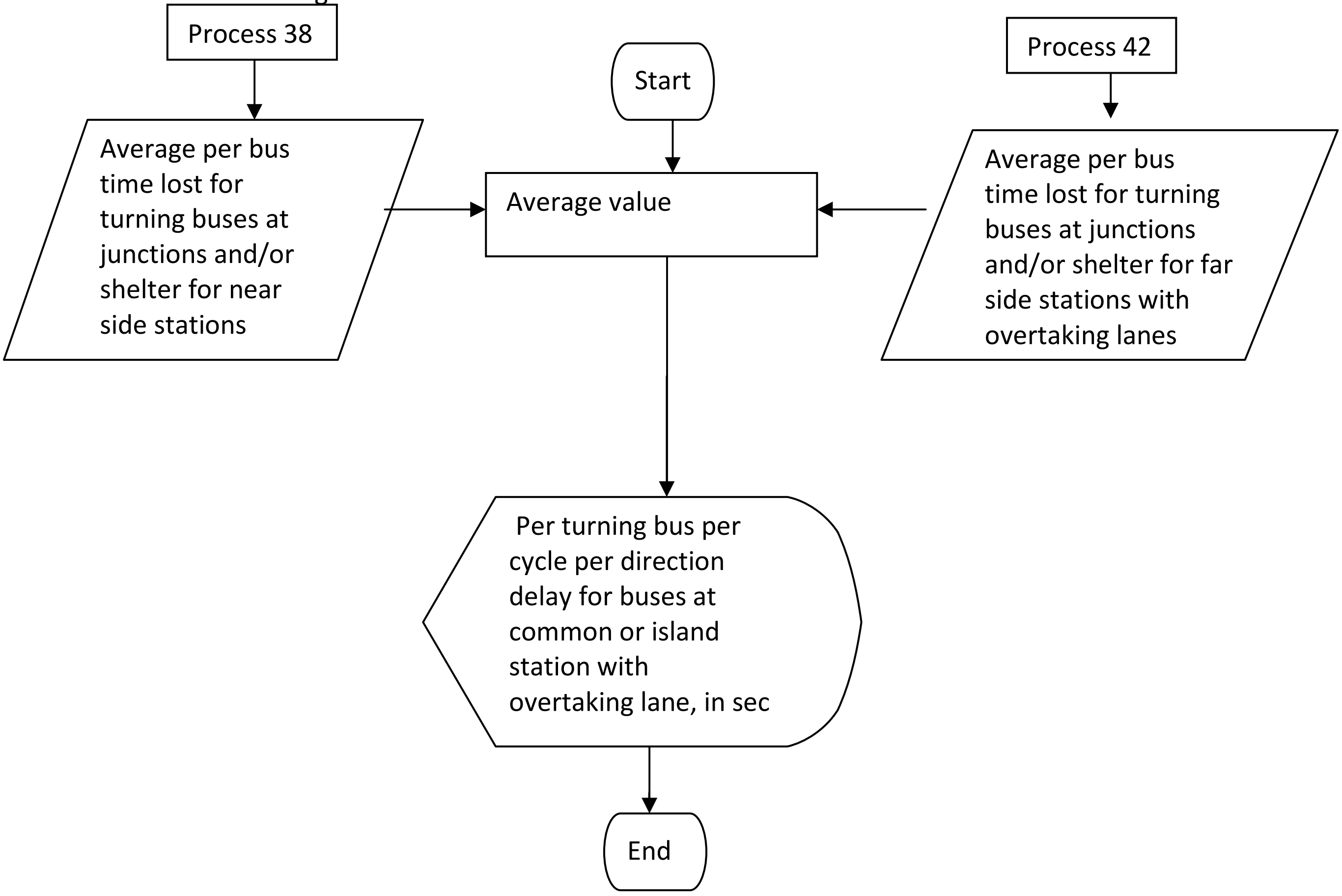


Figure 72: Flow chart for process 51 - Per cycle per direction straight moving bus throughput for common/island stations with or without overtaking lanes

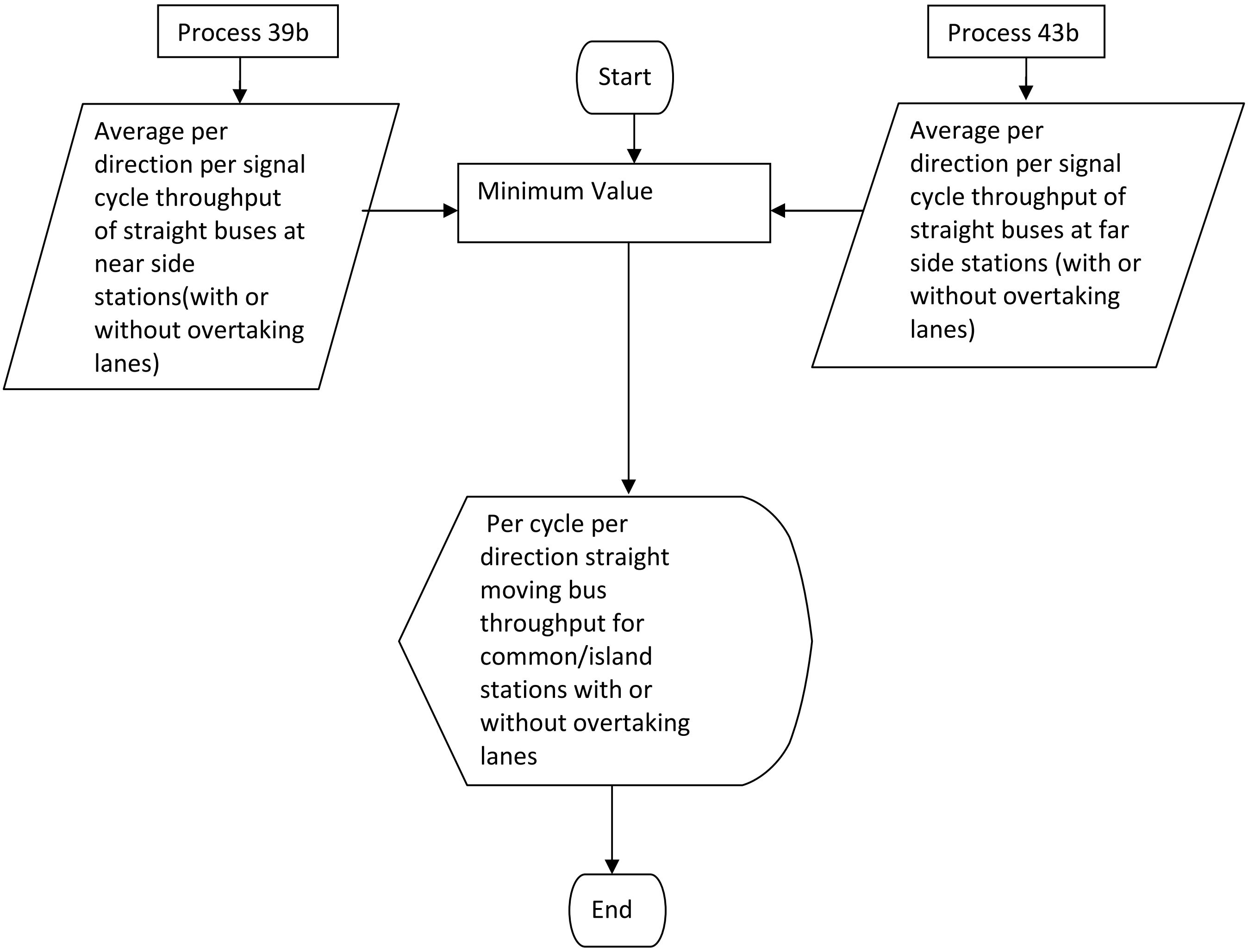


Figure 73: Flow chart for process no. 52 - Per cycle per direction turning bus throughput for common/island stations with or without overtaking lanes

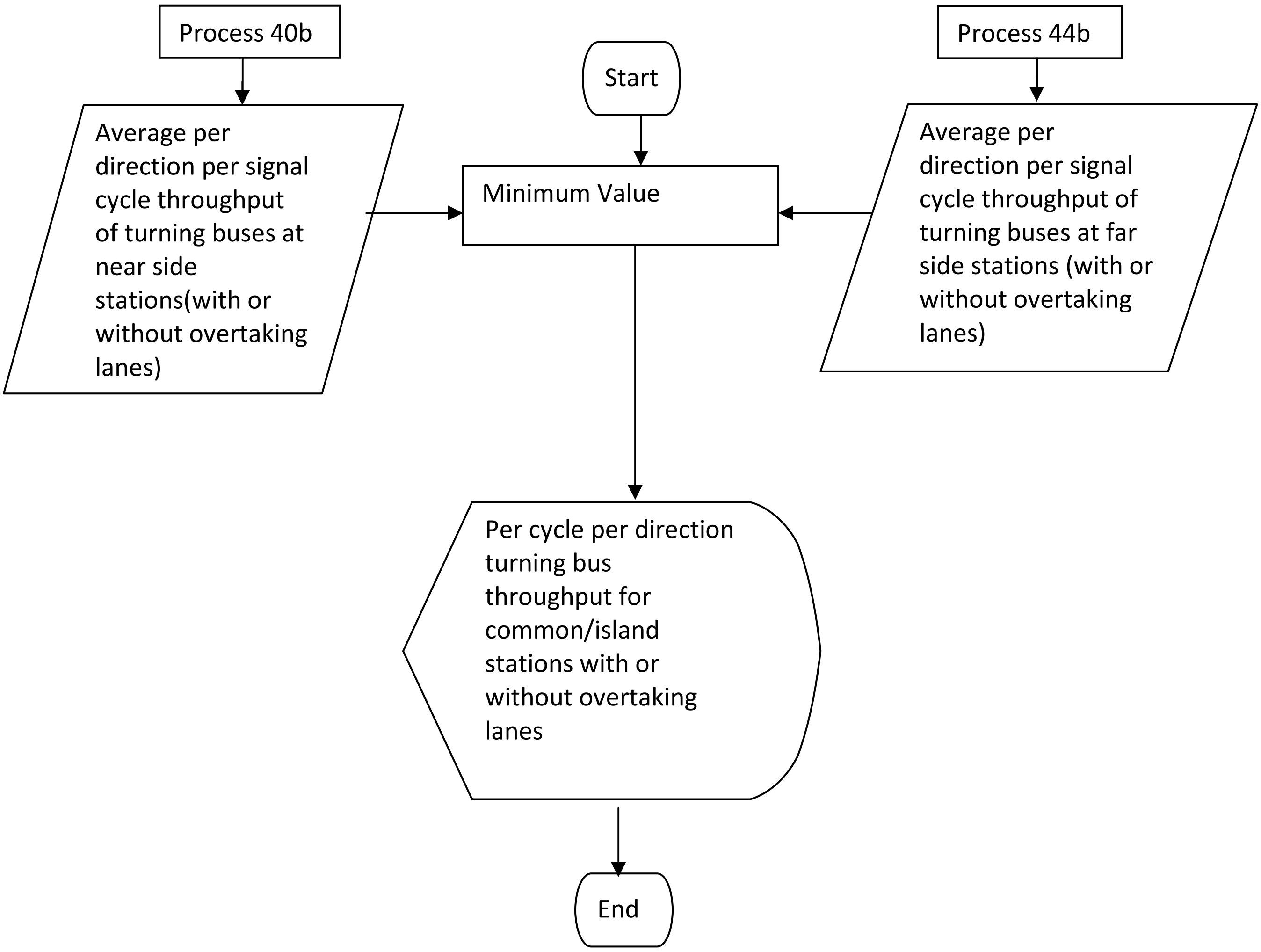


Figure 74: Flowchart for Process no. 53 - Straight moving average per bus per cycle per direction delay in sec for island stations without overtaking lanes.

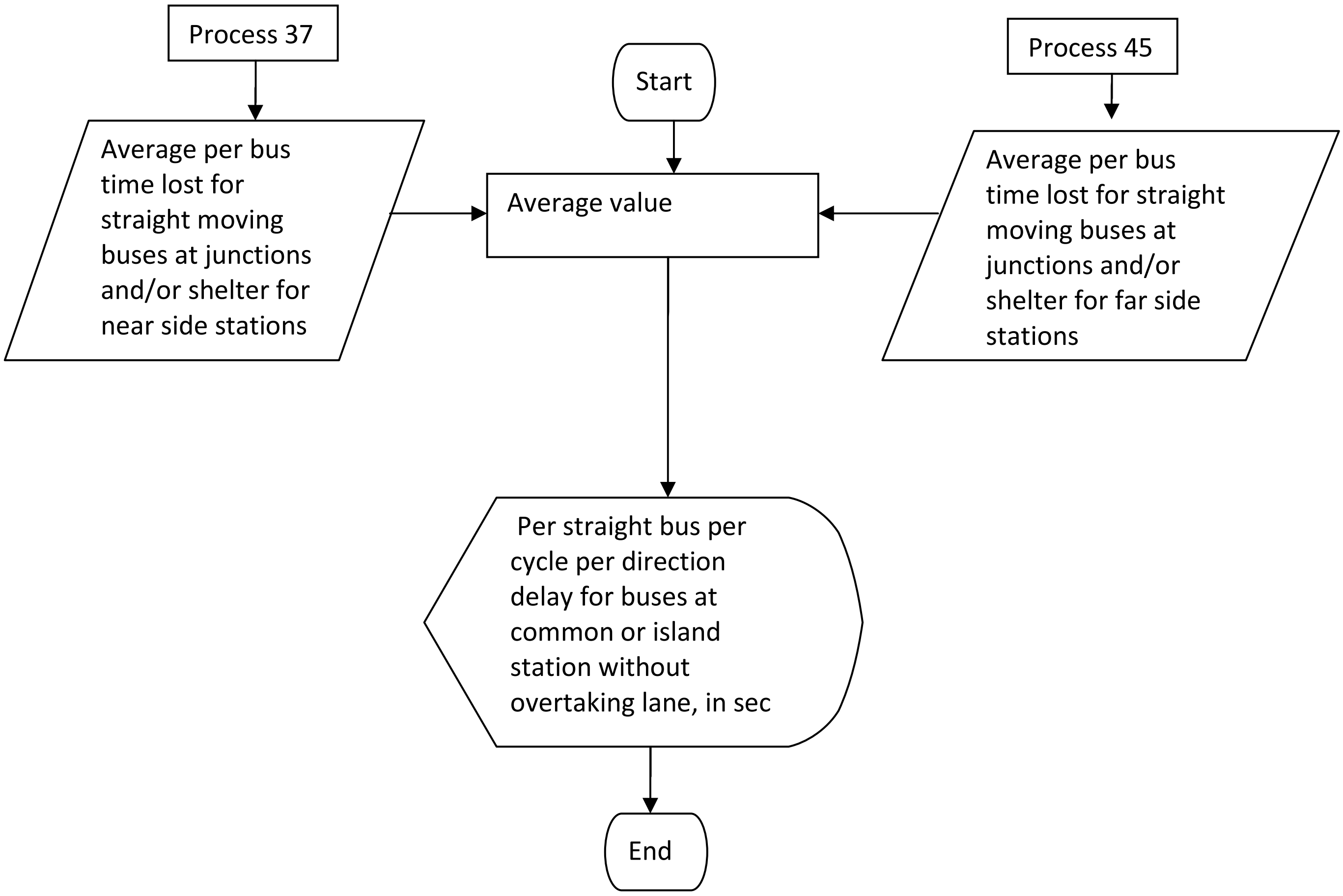


Figure 75: Flowchart for process no. 54 - Average per bus per cycle per direction delay in sec for island stations without overtaking lanes for turning buses.

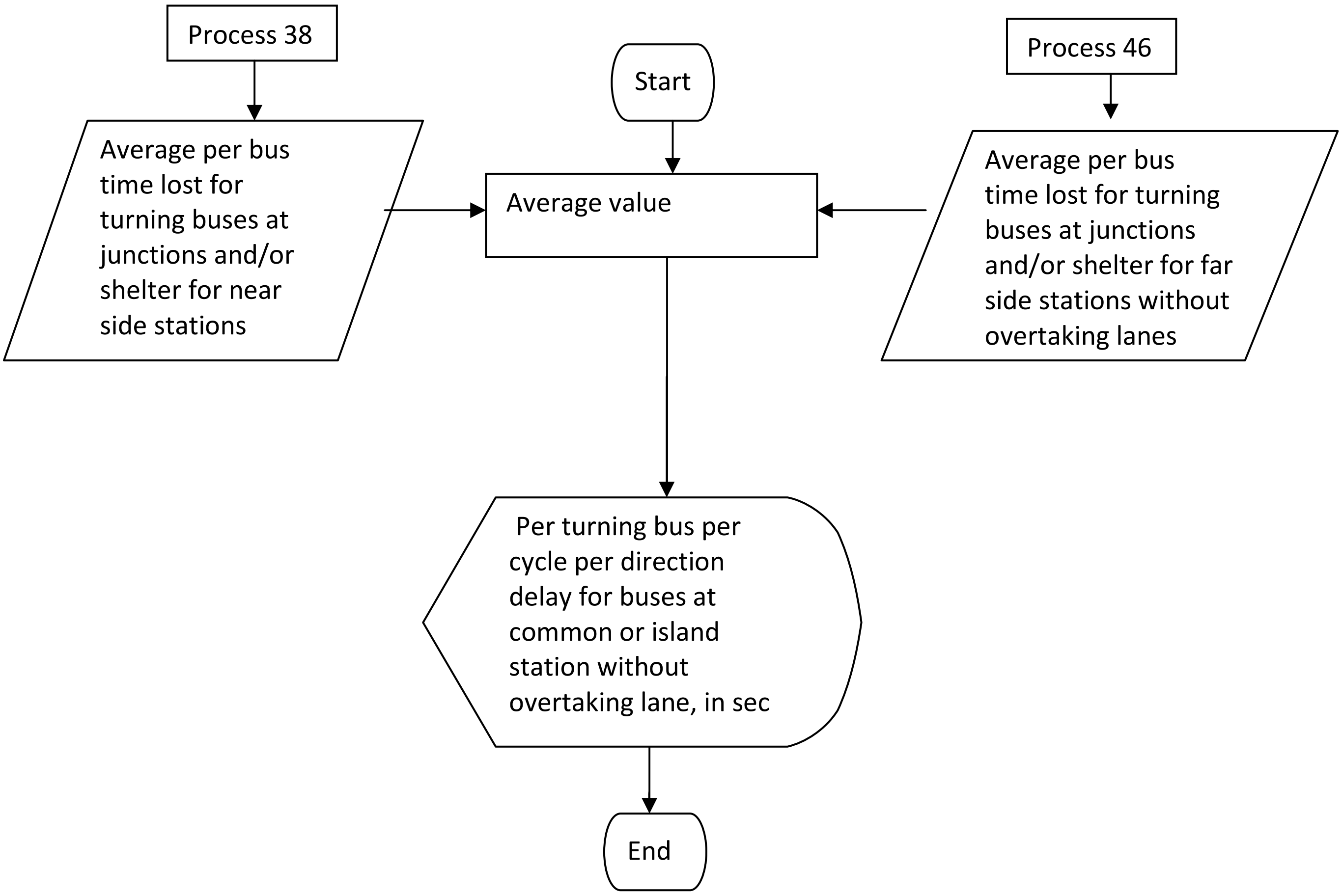


Figure 76: Flowchart for process 55 –Safe gap between buses on the corridor

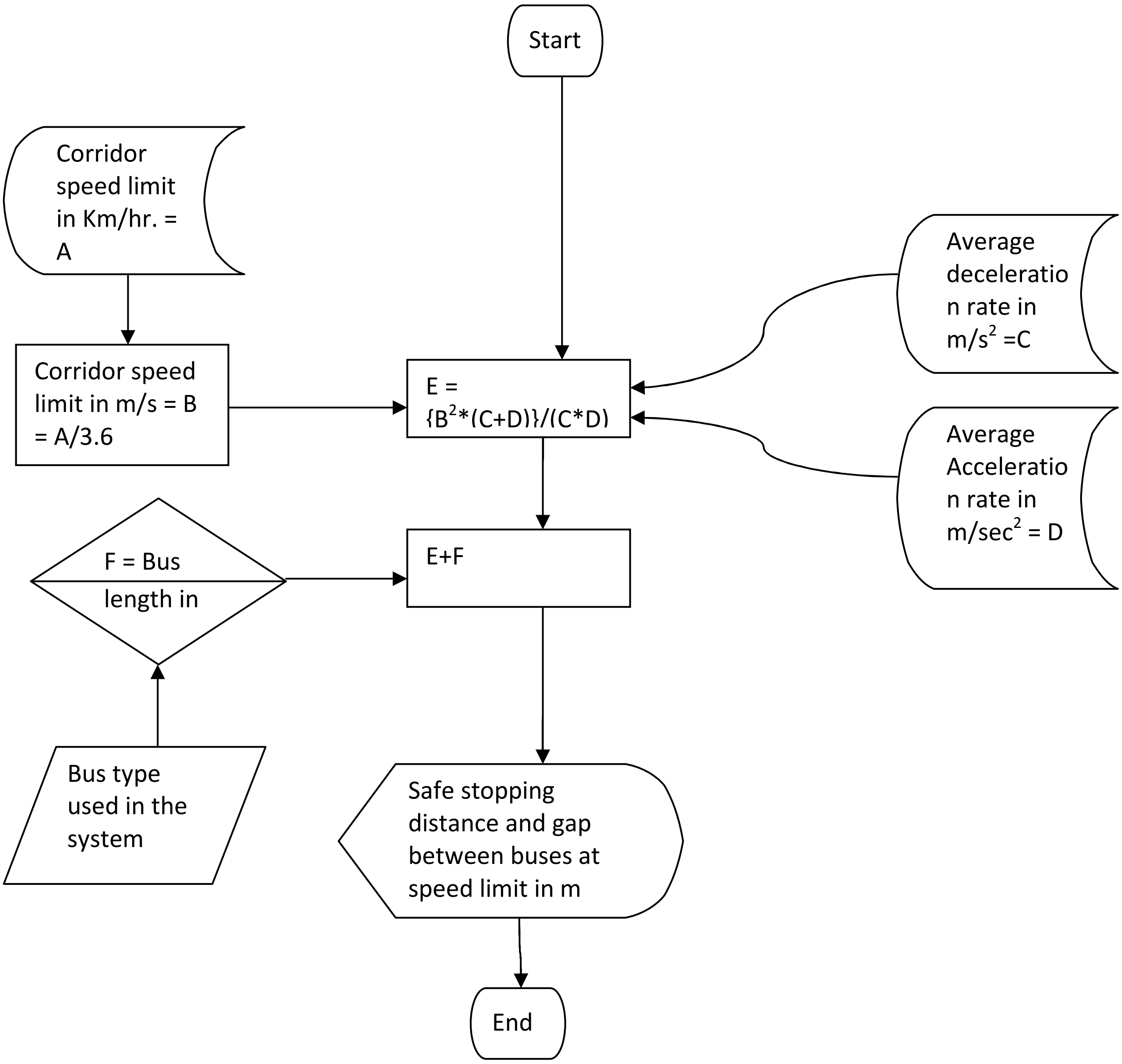


Figure 77: Flow chart for process 56 – Maximum no. of buses (per hour per direction) that can cruise in the corridor safely (maintaining safe gap between buses)

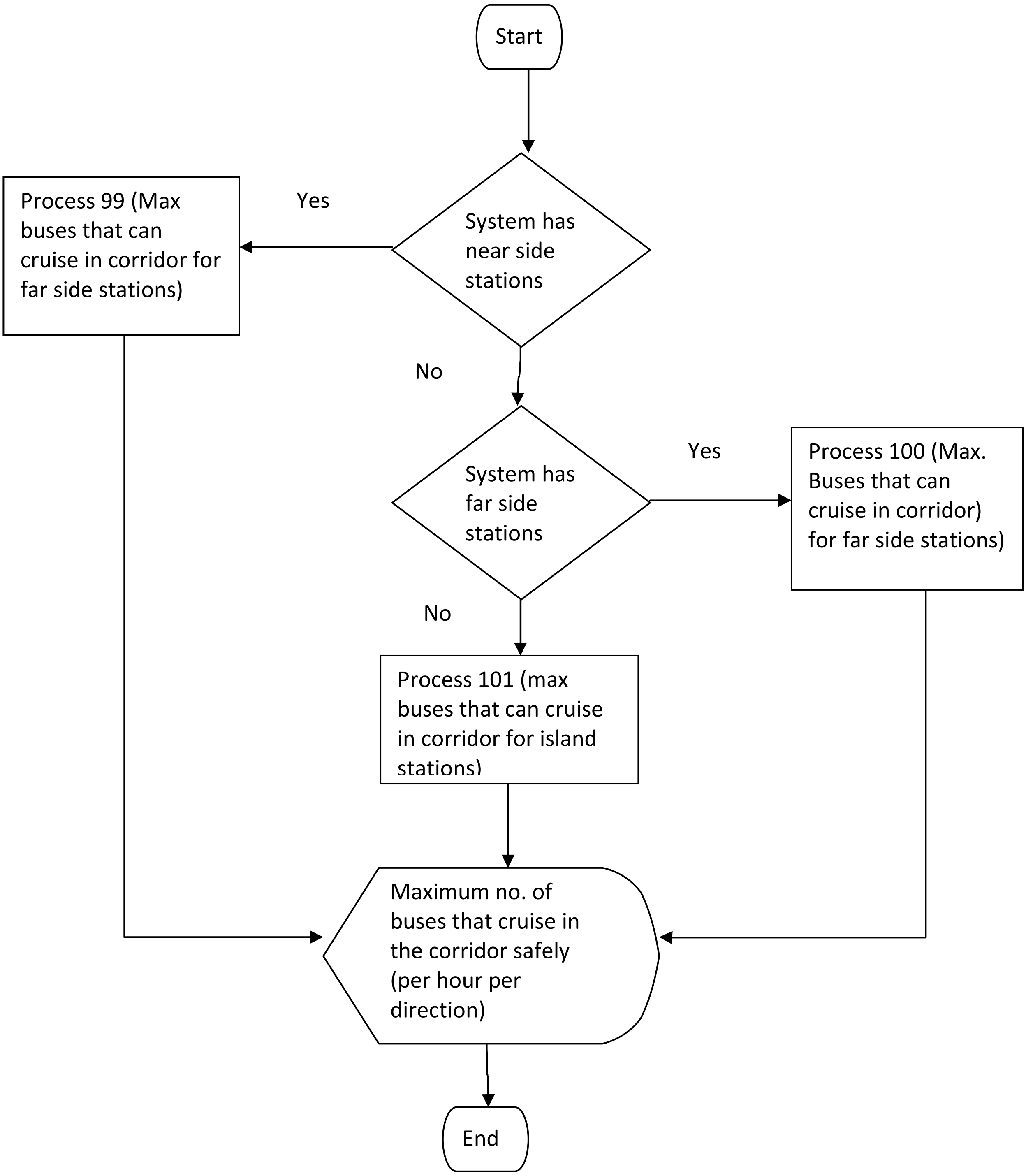


Figure 78: Flowchart for Process 57 – Maximum number of straight buses that can be throughput at an intersection signal cycle between two mid block stations.

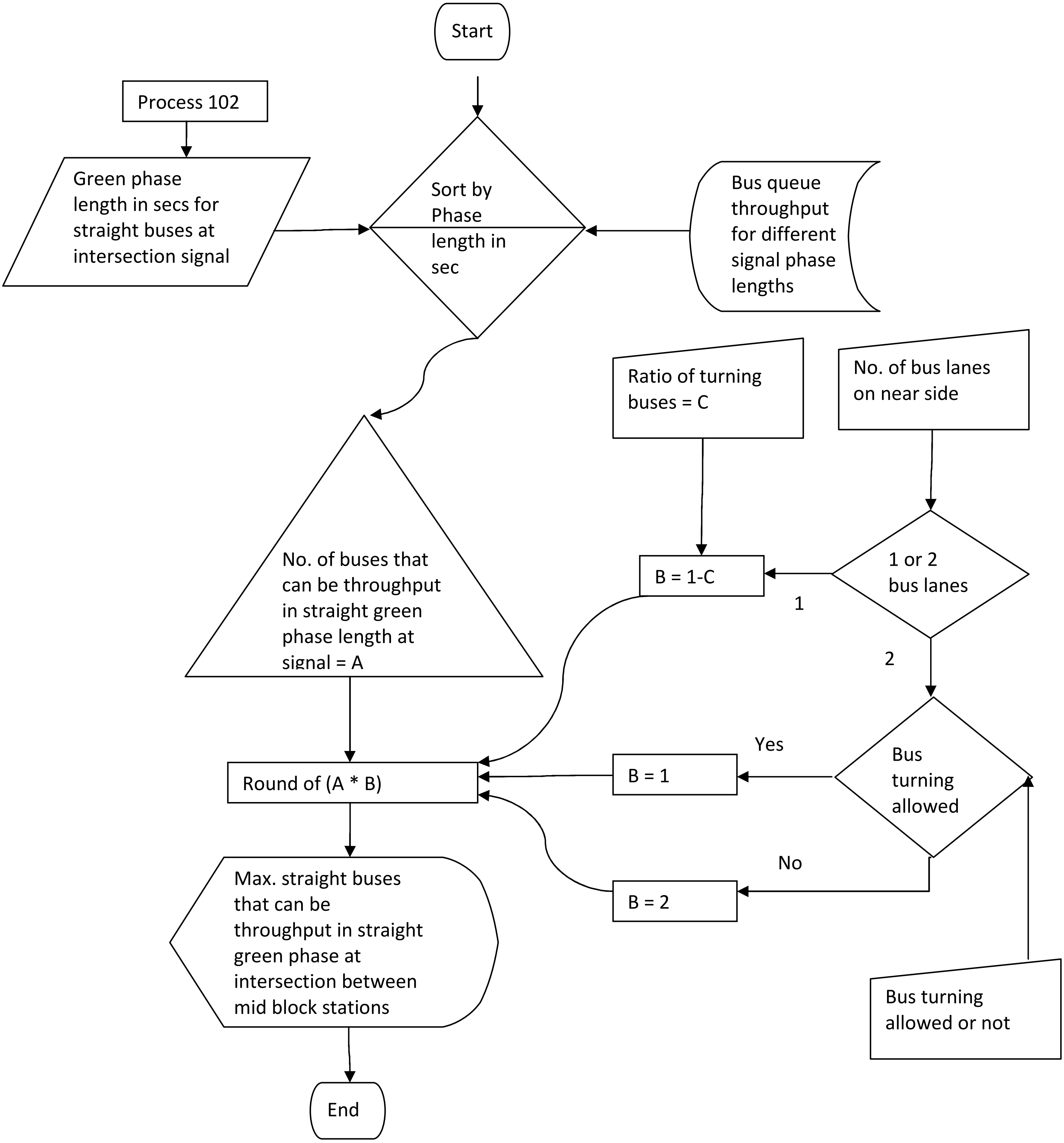


Figure 79: Flowchart for process no. 58 - Maximum number of turning buses that can be throughput at an intersection signal cycle between two mid block stations.

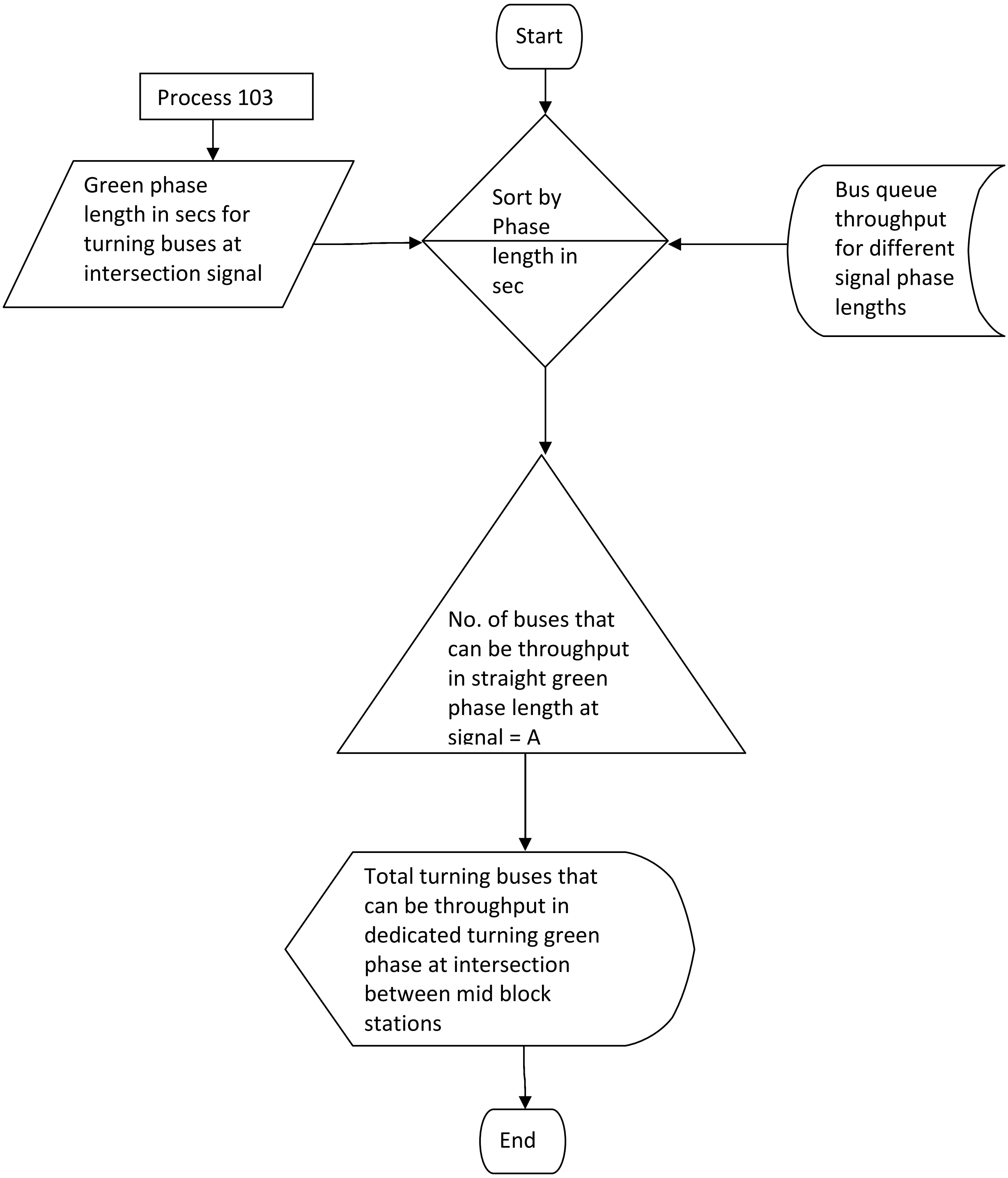


Figure 80: Flow chart for process no. 59–Total red phase length for buses (excluding yellow) in seconds, for straight buses at vehicular intersection between two mid block stations.

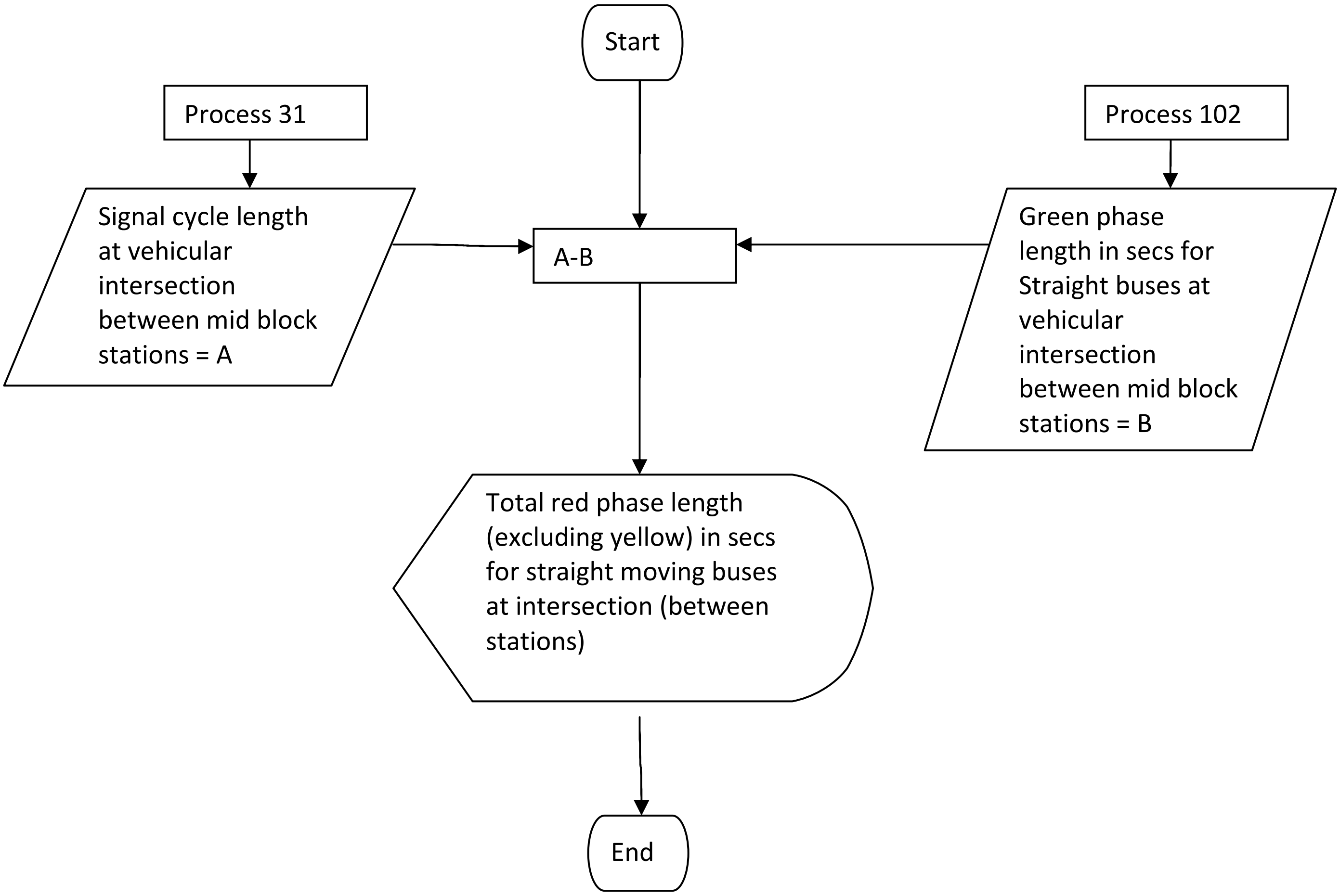


Figure 81: Flow chart for process 60 - Total red phase length for buses (excluding yellow) in seconds, for turning buses at vehicular intersection between two mid block stations.

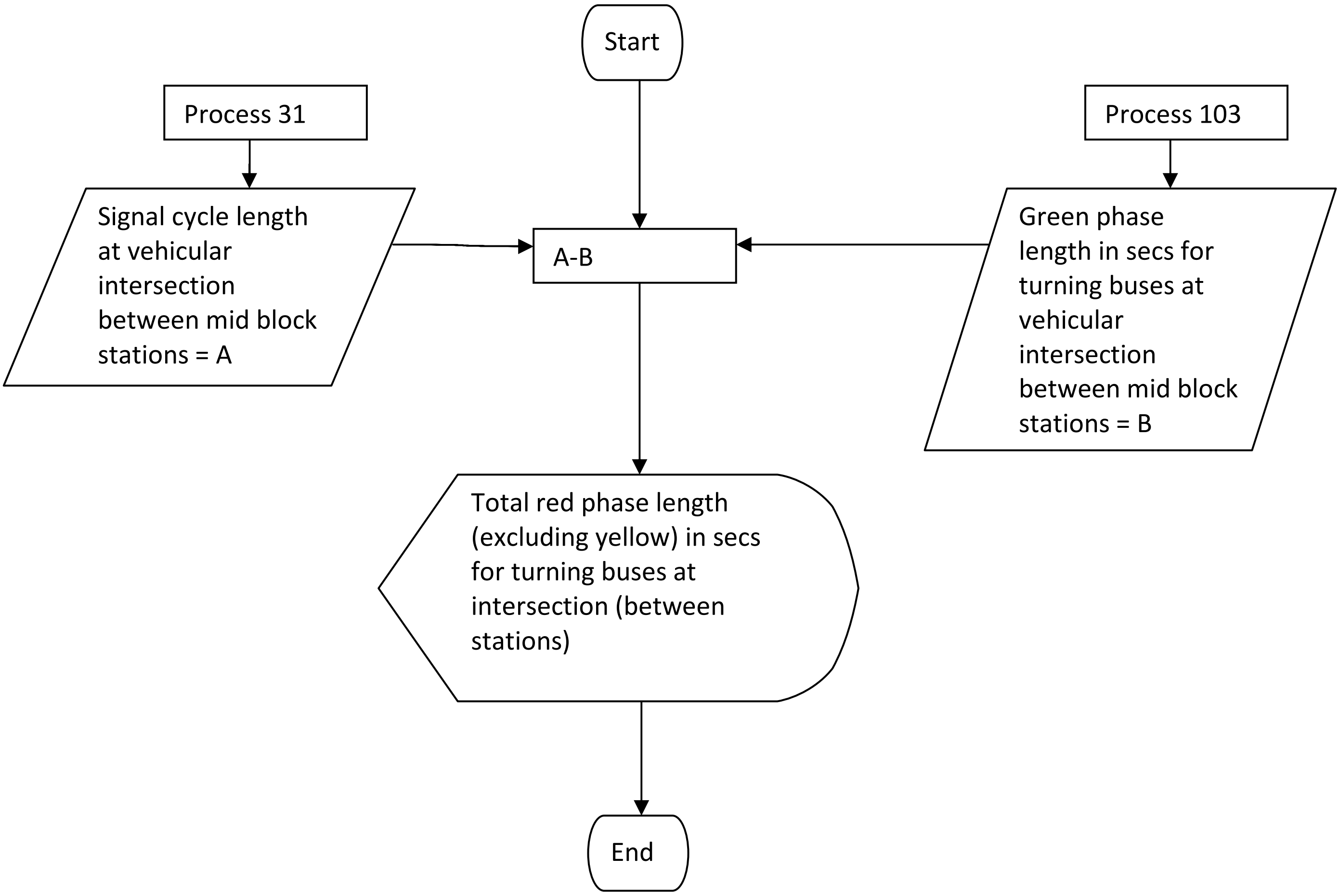


Figure 82: Flow chart for process 61 – Total no. of phases at Station Crossing Signal/ intersection signal

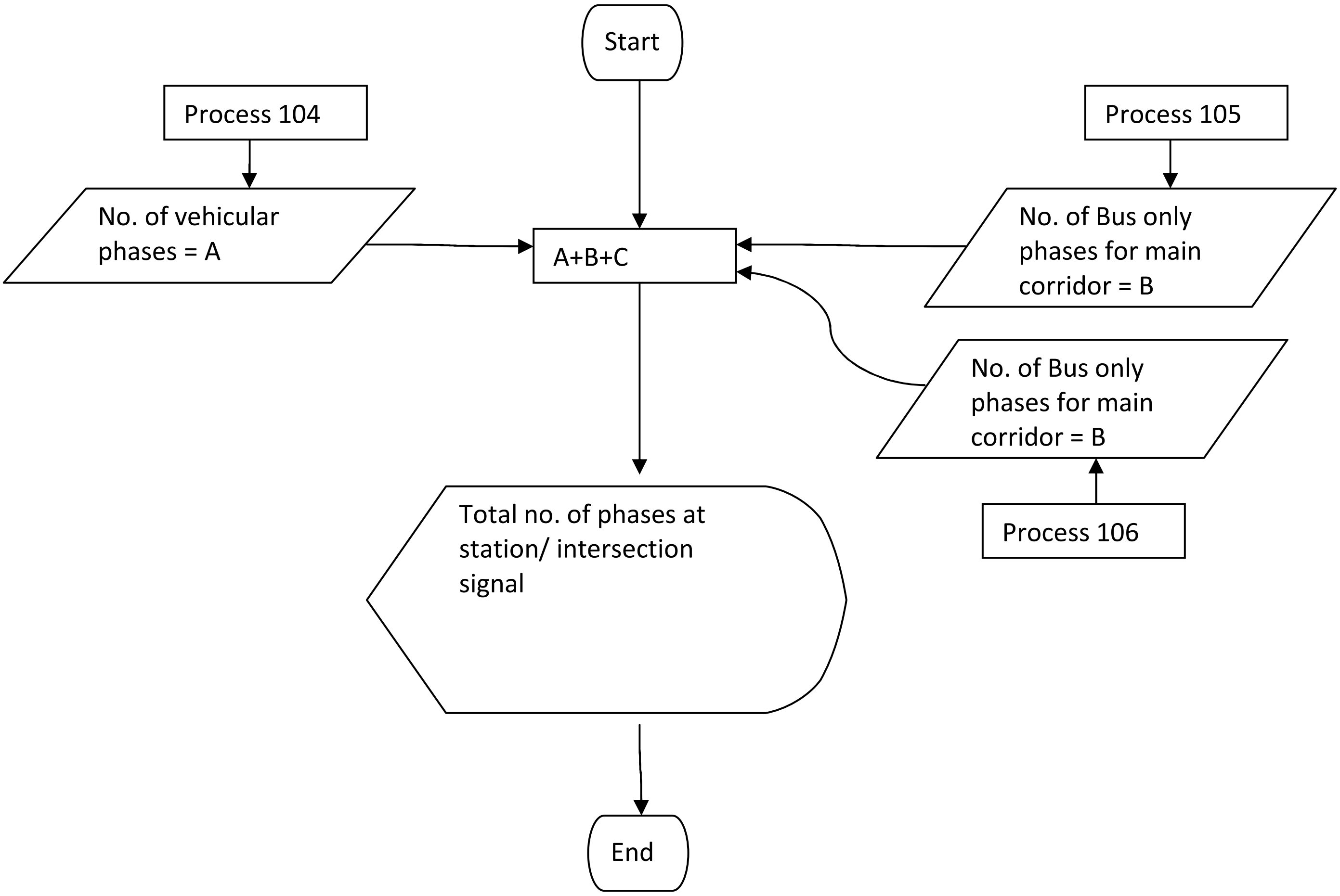


Figure 83: Flow chart for process 62 - Minimum Desirable signal cycle length in sec for station/junction signal with more than 2 phase signal cycle

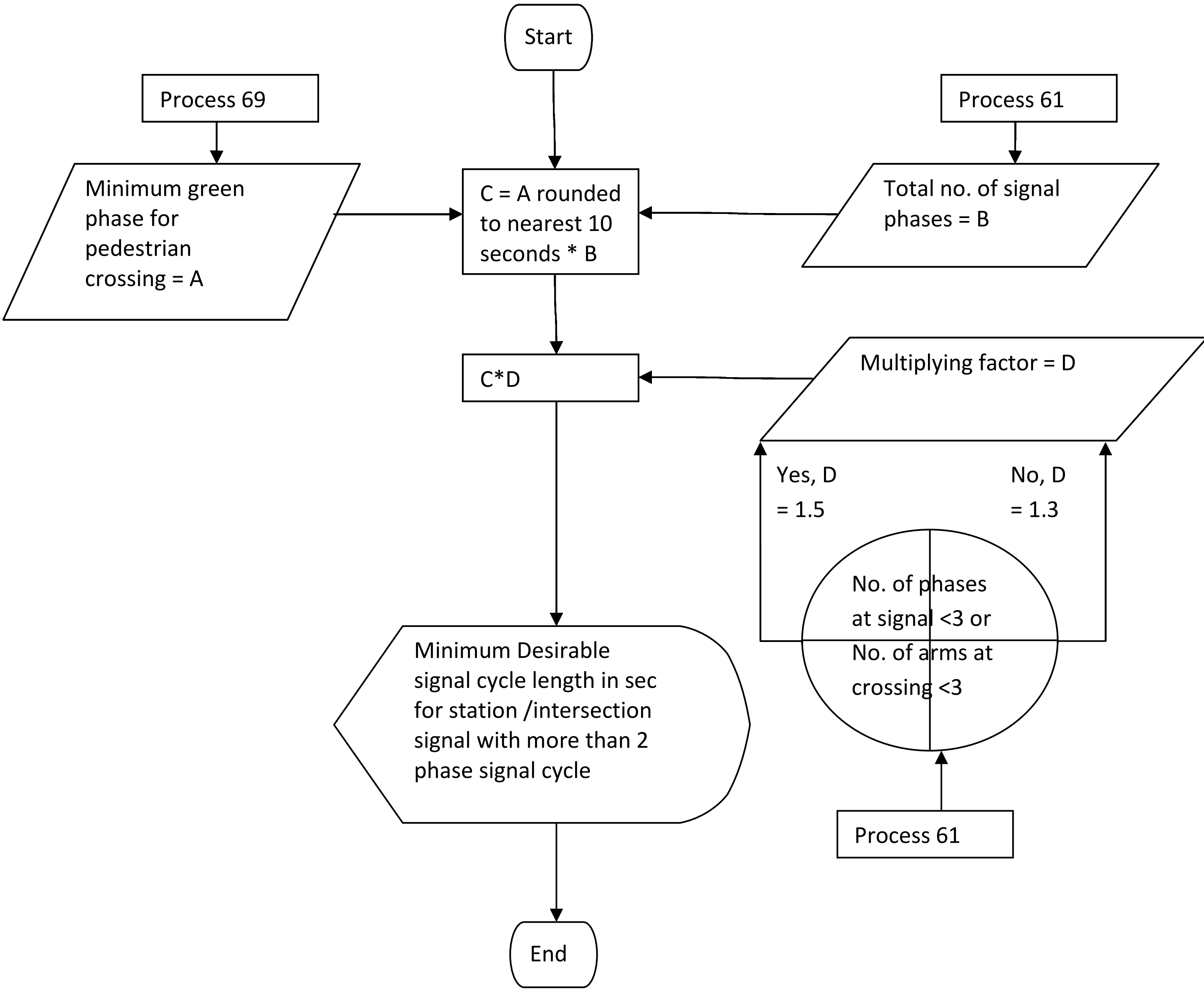


Figure 84: Flow chart for process 63 – Total no. of phases at Junction Signal between two mid block stations

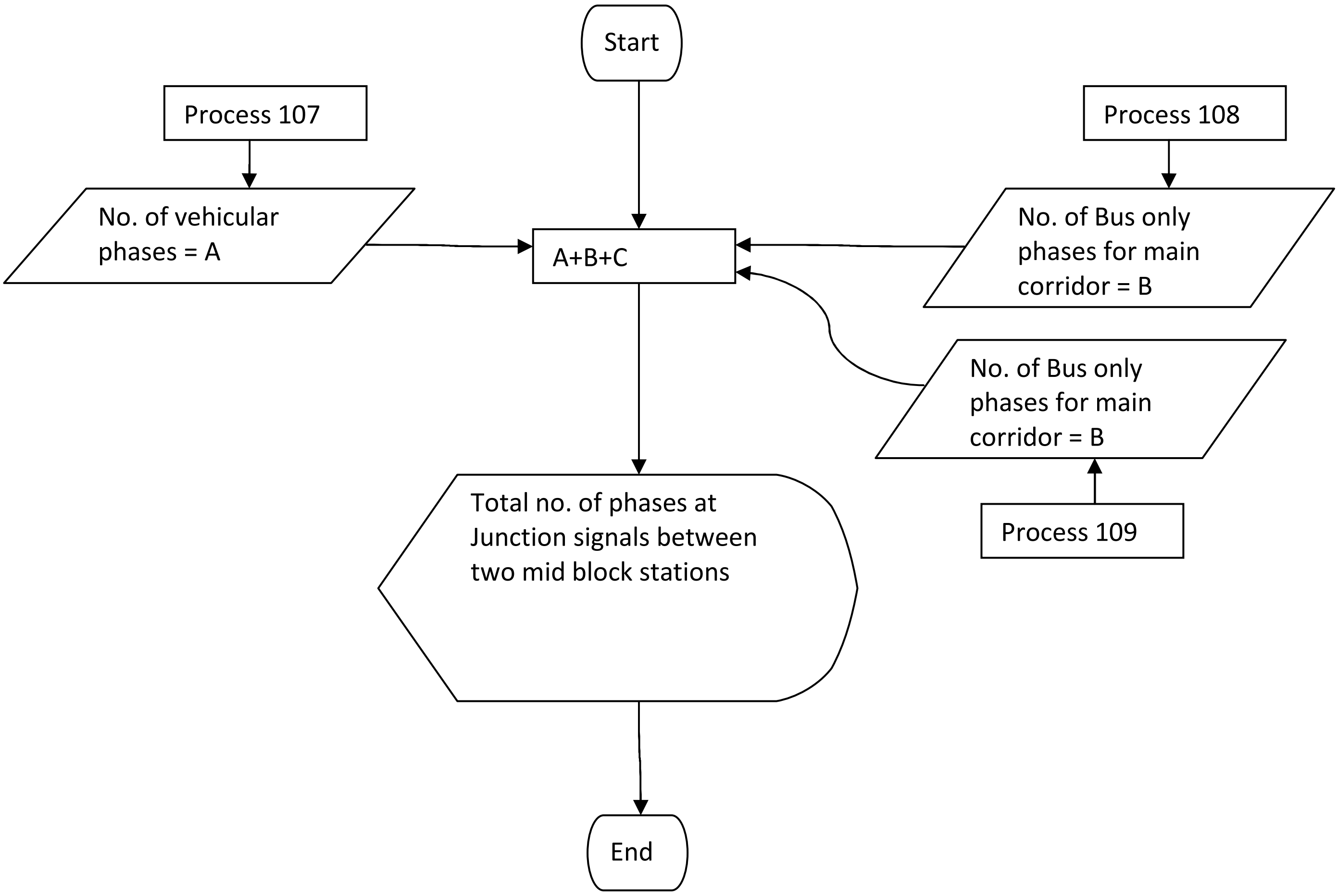


Figure 85: Flow chart for process 64 - Minimum Desirable signal cycle length in sec for station/junction signal with more than two phase signal cycle

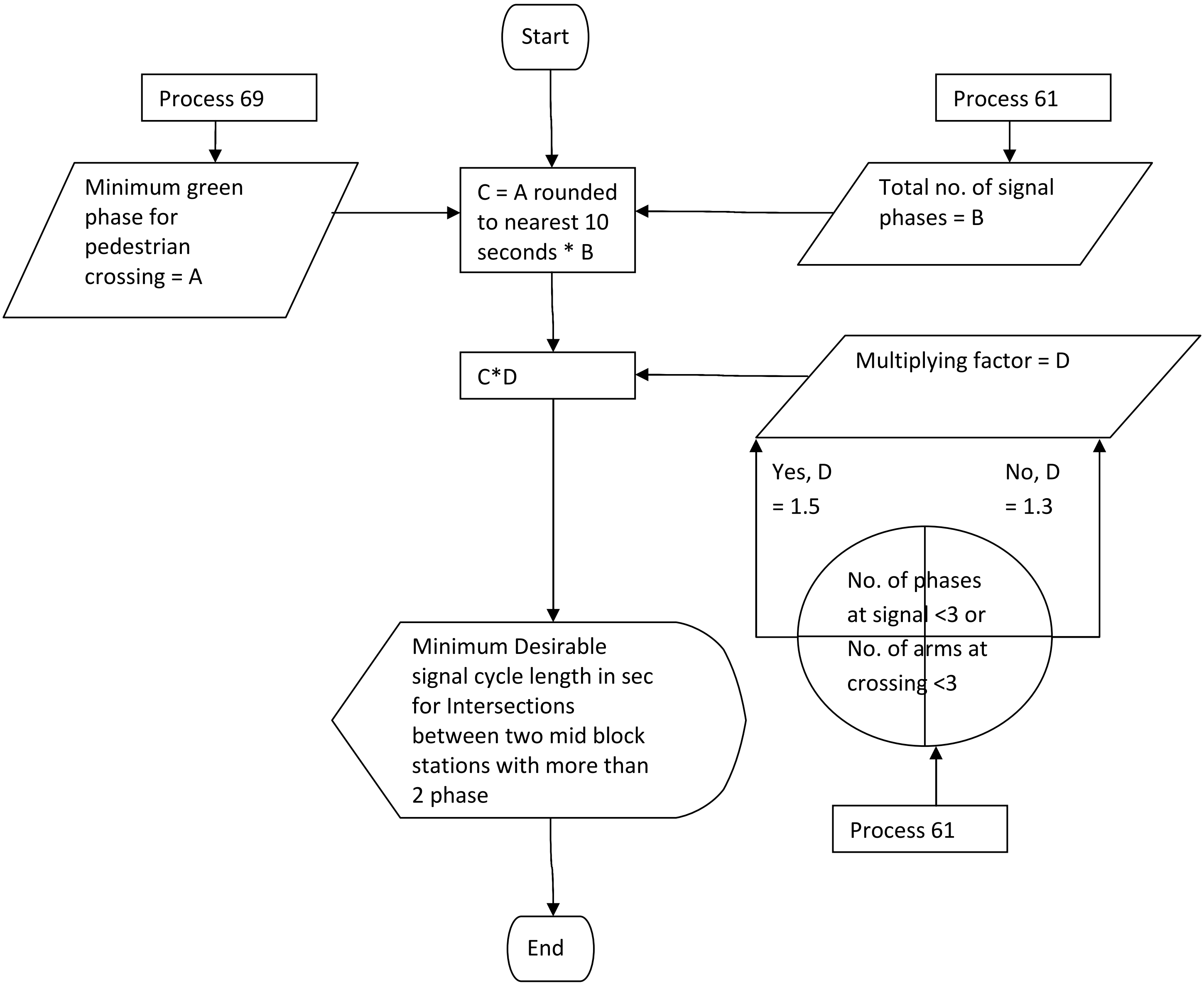


Figure 86: Flow chart for process 65 - Average one way access delay/time for passengers accessing Buses on BRTS station from median on the cross road (in sec)

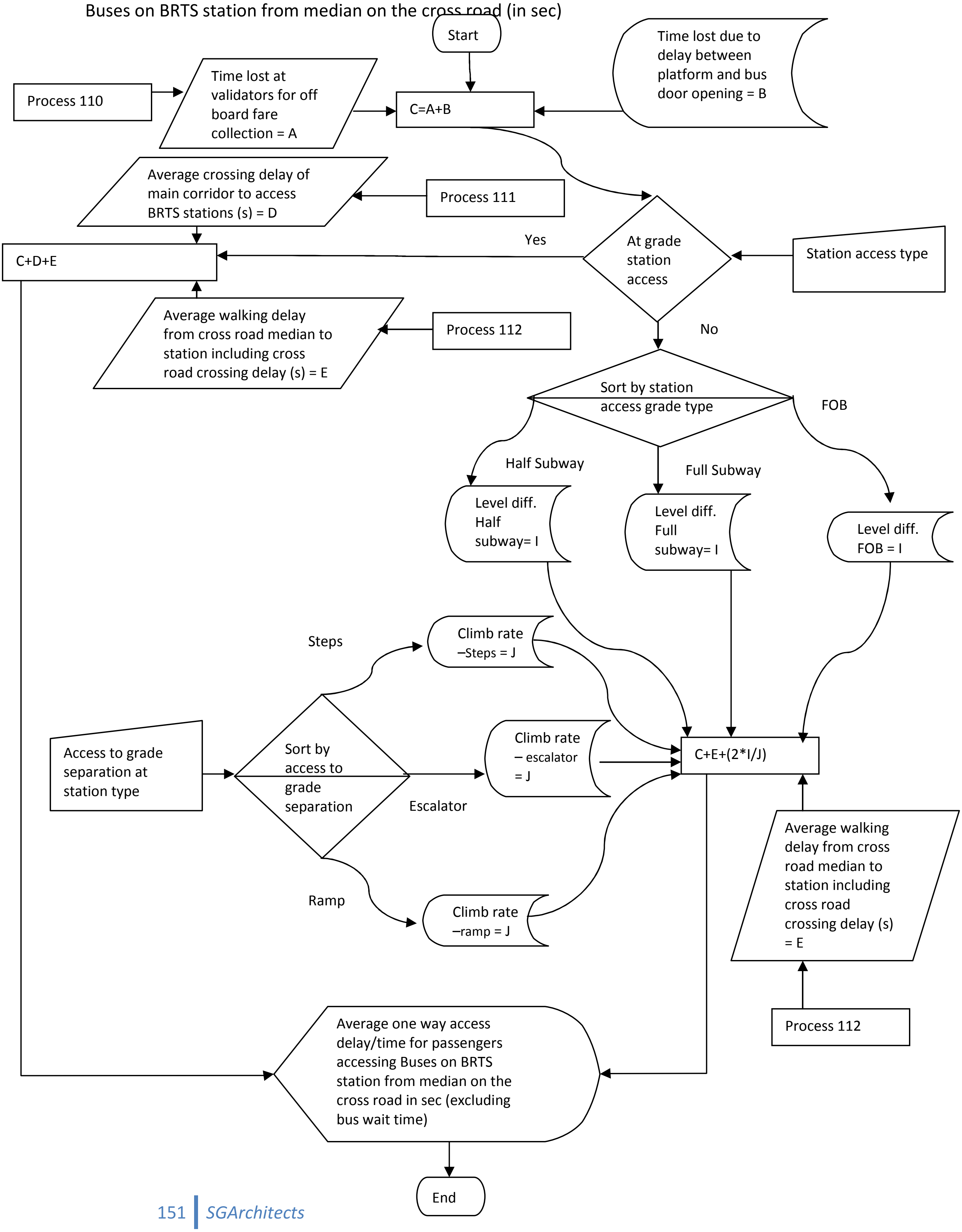


Figure 87: Flowchart for process 66 – Average wait time for buses (in sec) in open system

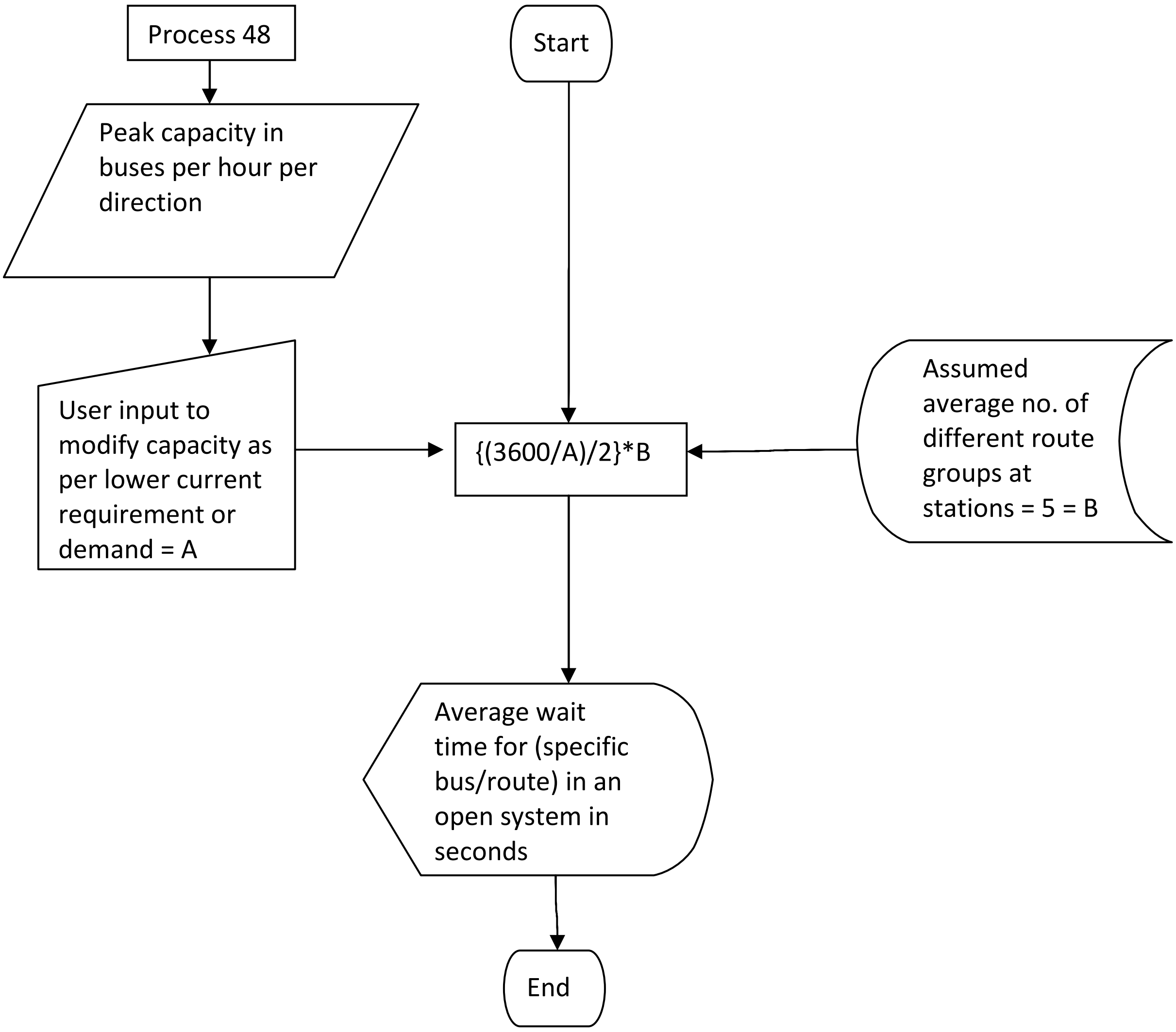


Figure 88: Flowchart for process 67 – Average wait time for buses (in sec) in closed system

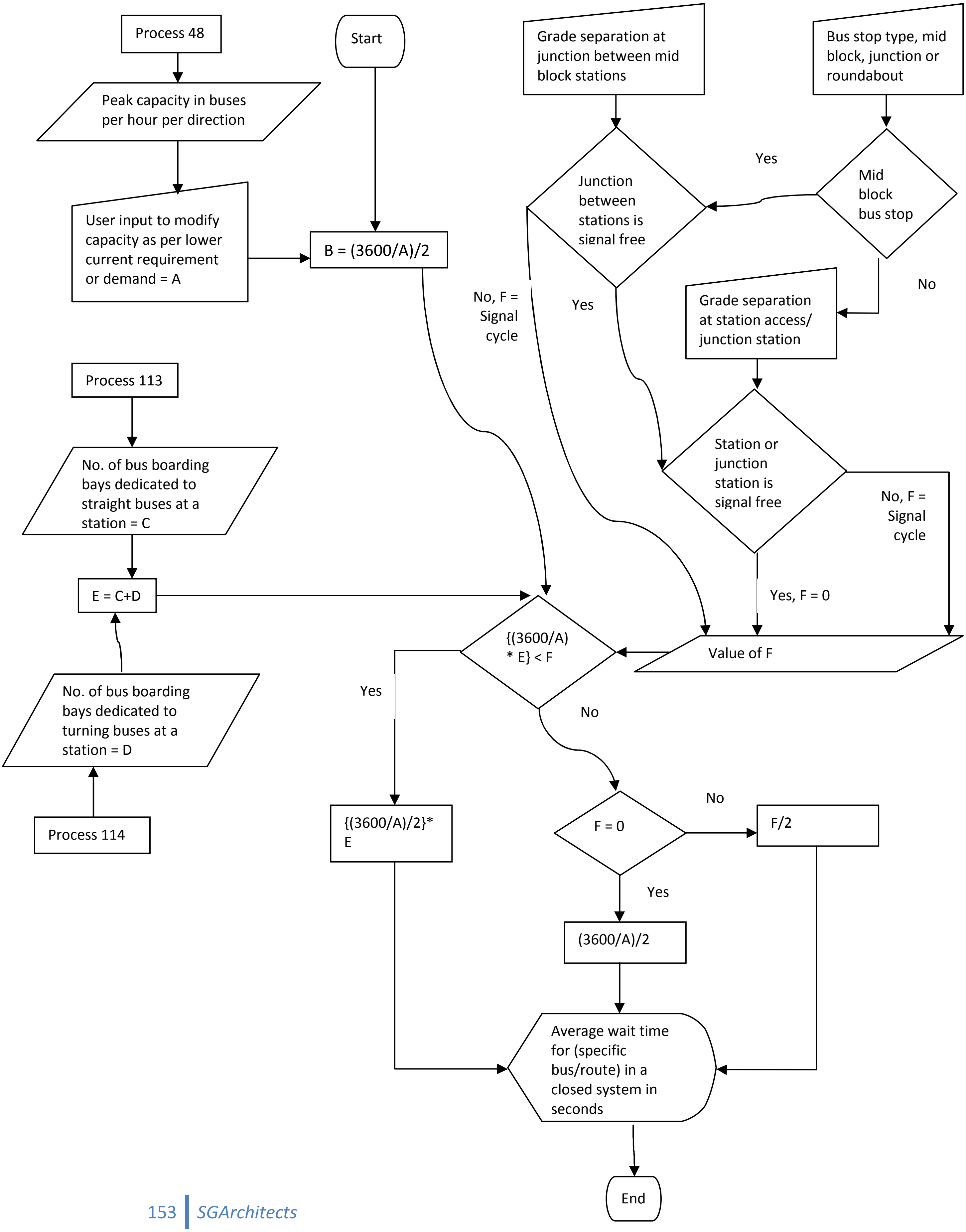


Figure 89: Flowchart for process 68 – Average crossing delay in sec, on cross roads (outside the corridor)

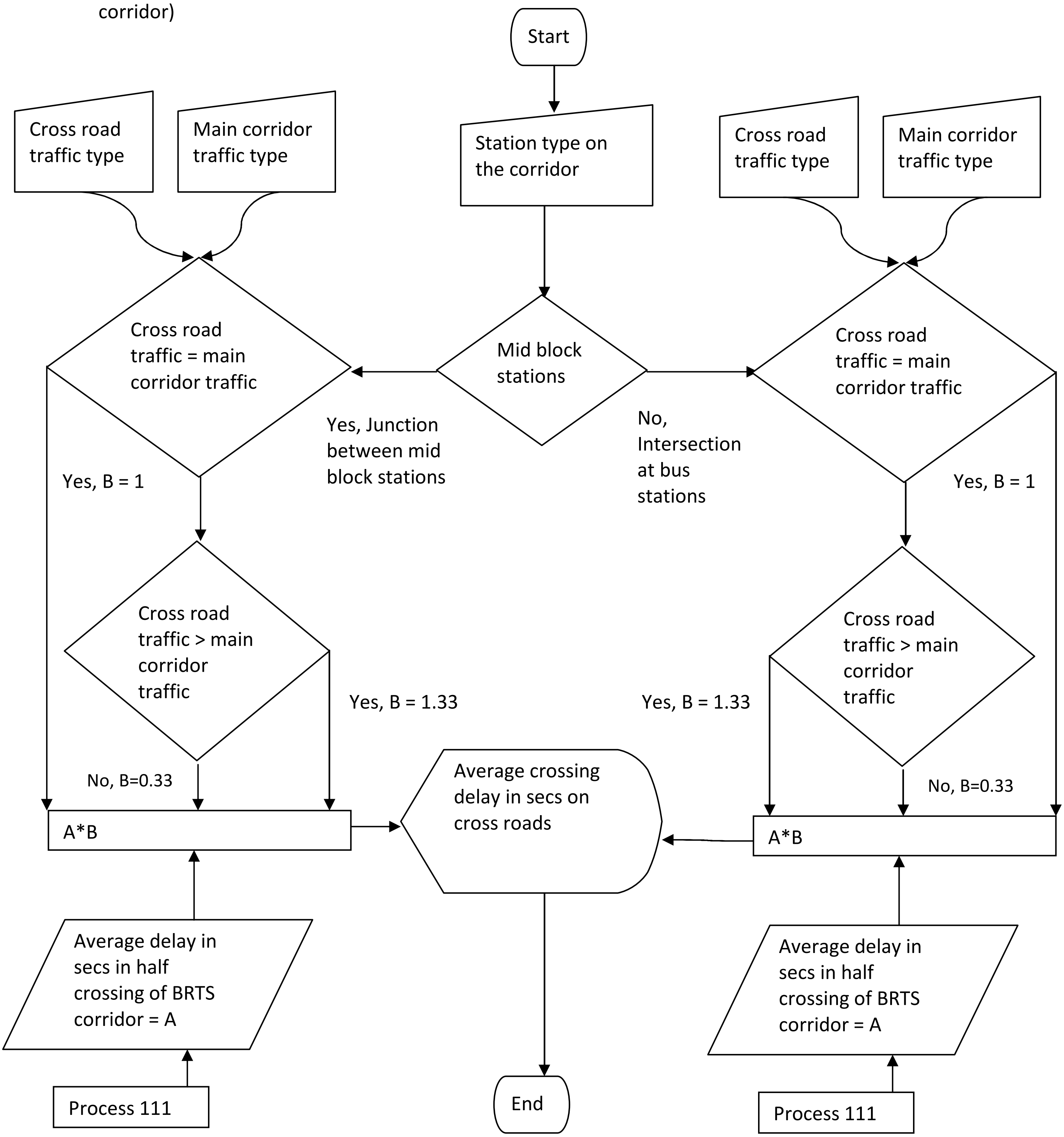


Figure 90: Flowchart for process 69 – Minimum green phase length for pedestrian crossing requirements in seconds.

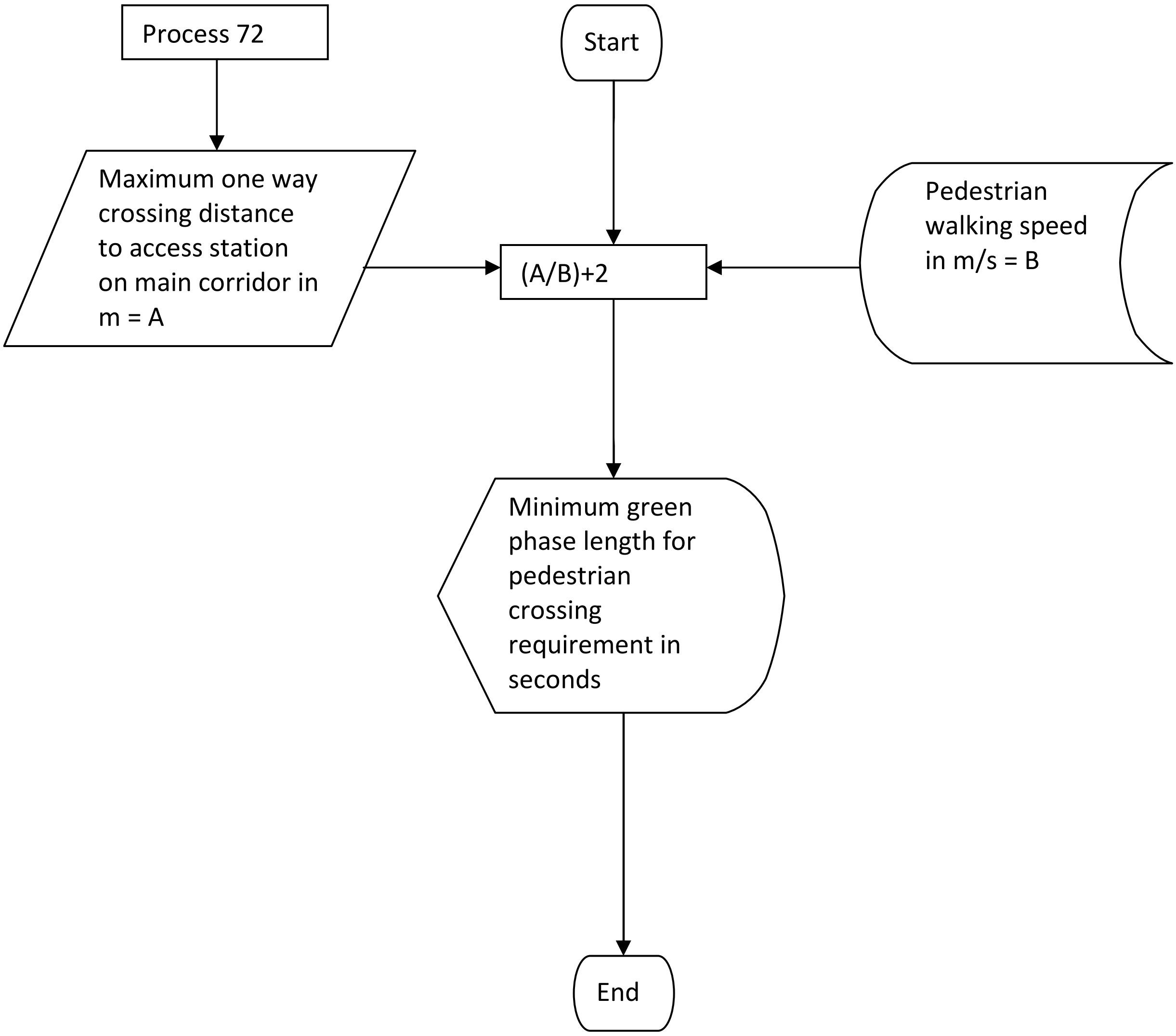


Figure 91: Flowchart for process 70 – Total time lost (in seconds) in acceleration and deceleration of bus to and from peak speed

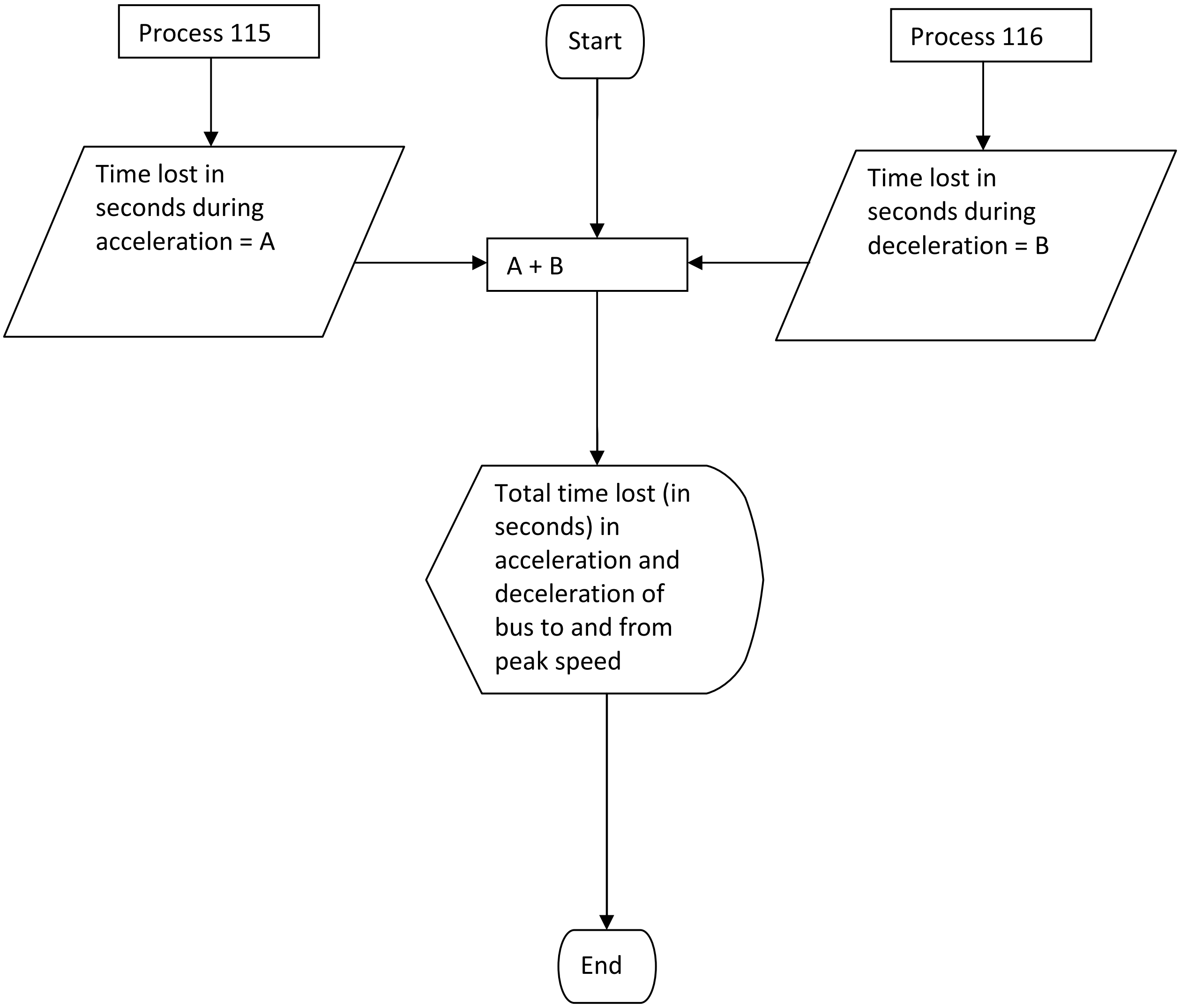


Figure 92: Flowchart for process 71 – Average dwell time for buses in seconds

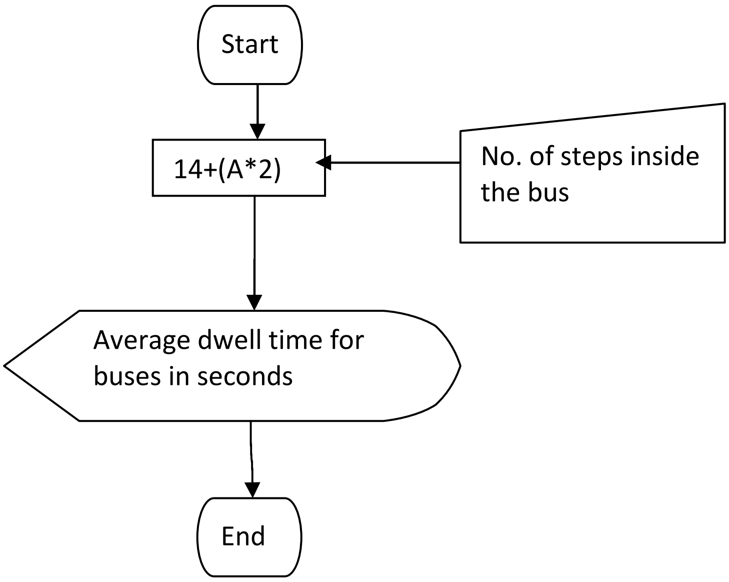


Figure 93: Flowchart for process 72 – Maximum crossing or access distance (in m) for passengers, in

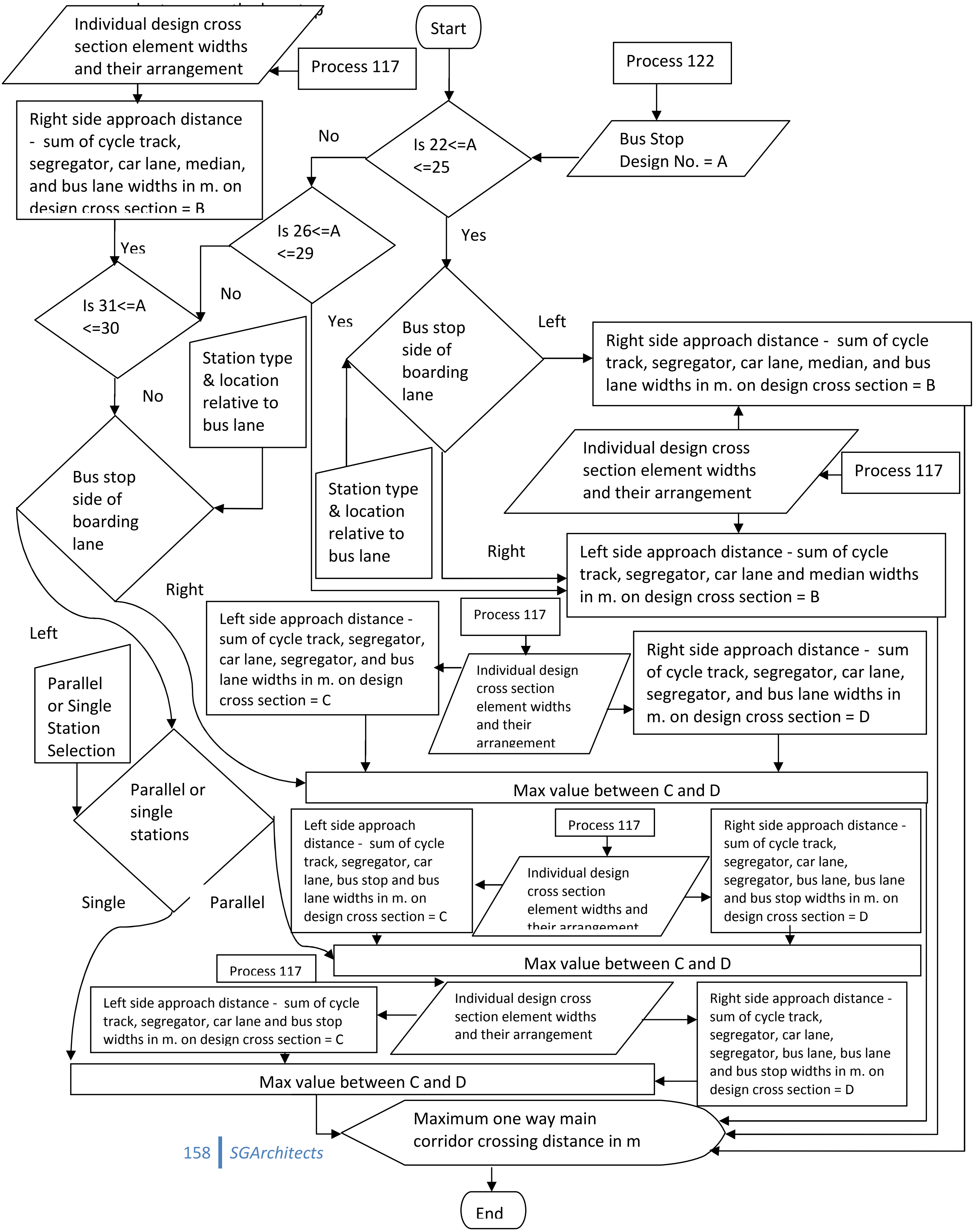


Figure 94: Flow chart for process 73 – Weighted average of straight moving bus delay at bus stop or junction bus stop signal.

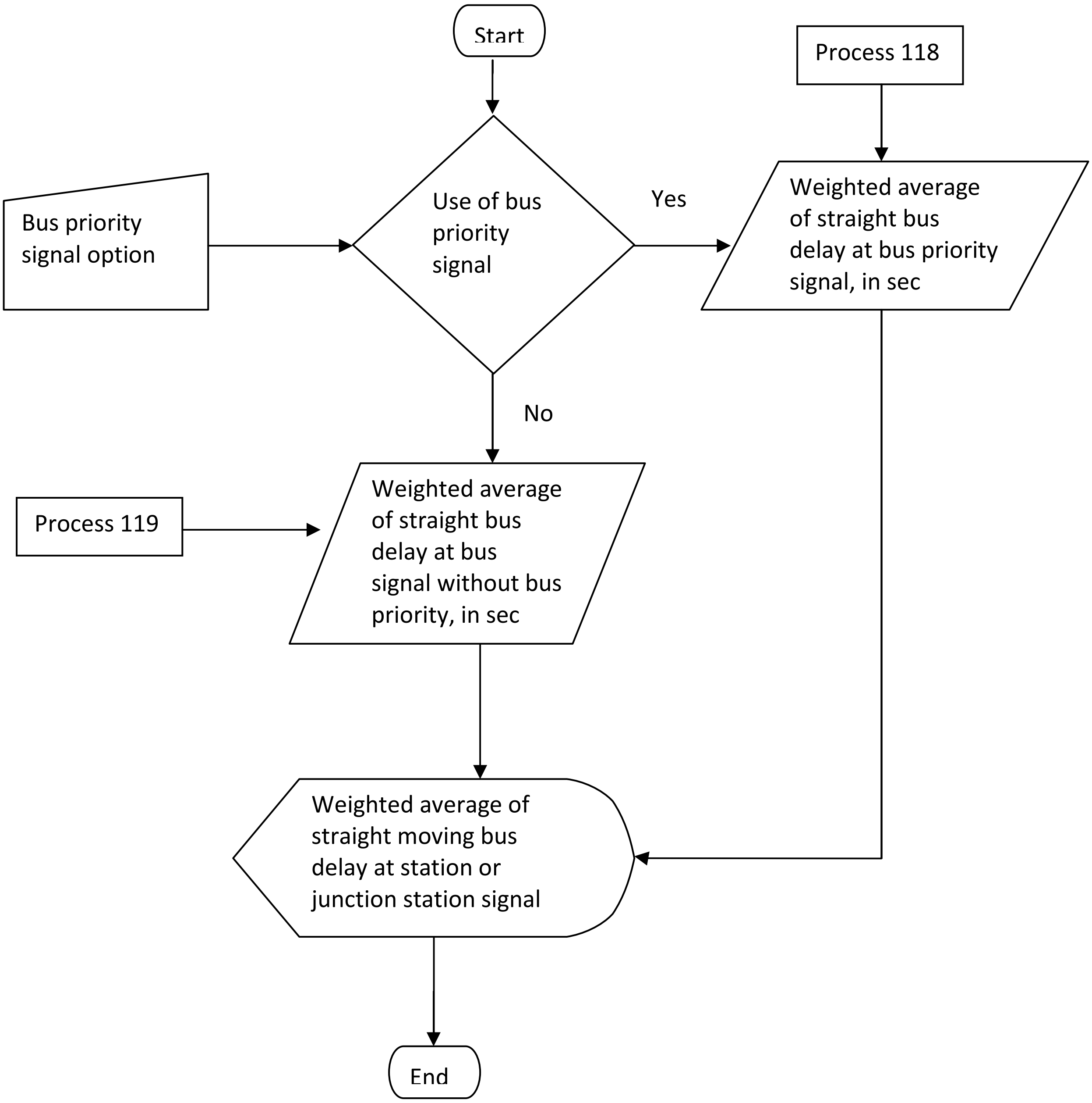
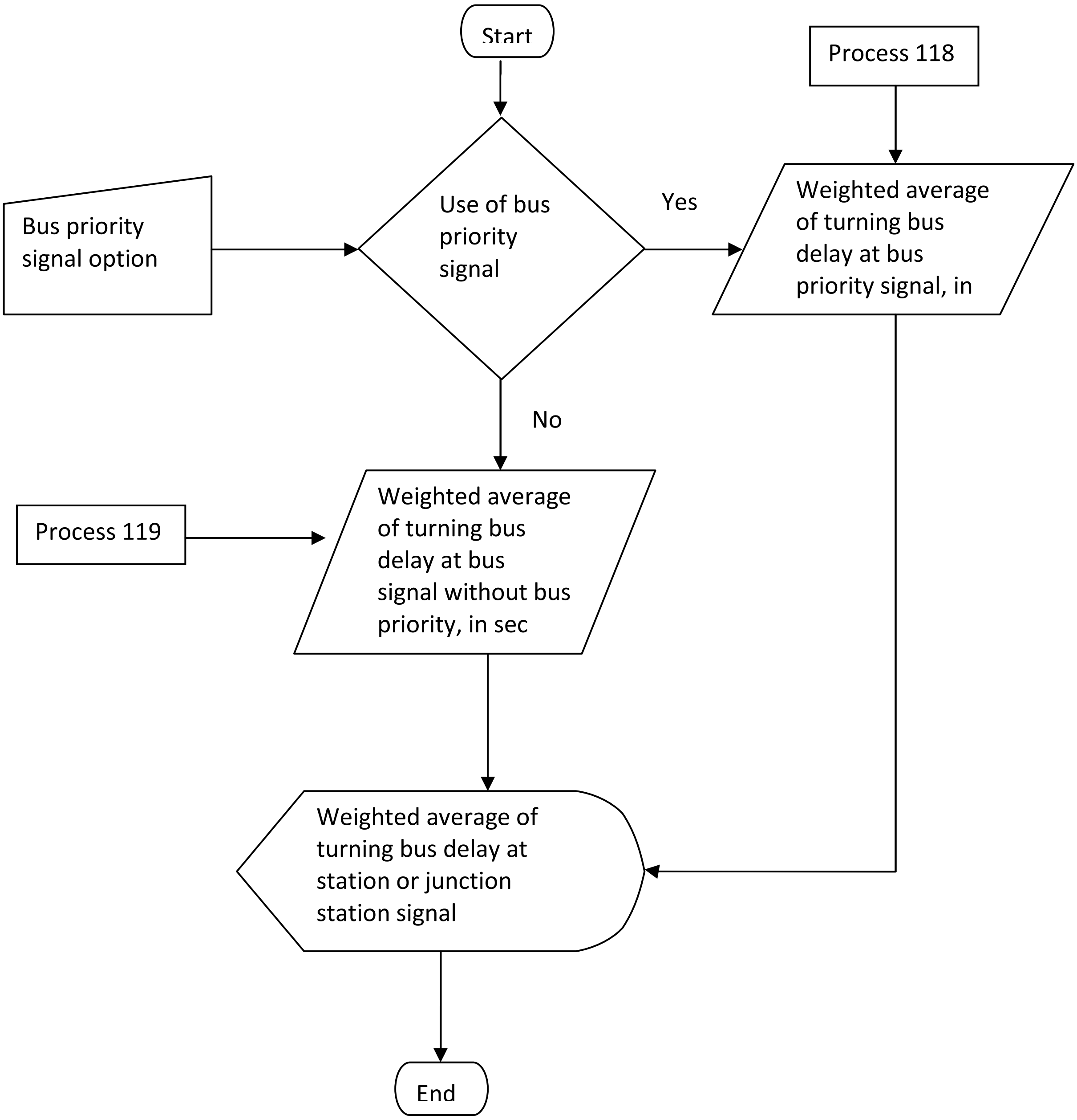


Figure 95: Flow chart for process 75 – Weighted average of turning bus delay at bus stop or junction bus stop signal.



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 lead 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
User	0.294118	0.3	0.333333
Operator	0.117647	0.1	0.111111

0.581264
0.30915
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
Shift from Pvt. 2 Wheelers	0.333333	0.333333333

0.666667
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
Operational Speed	0.4	0.333333333	0.25
Bus Delay	0.2	0.333333333	0.25

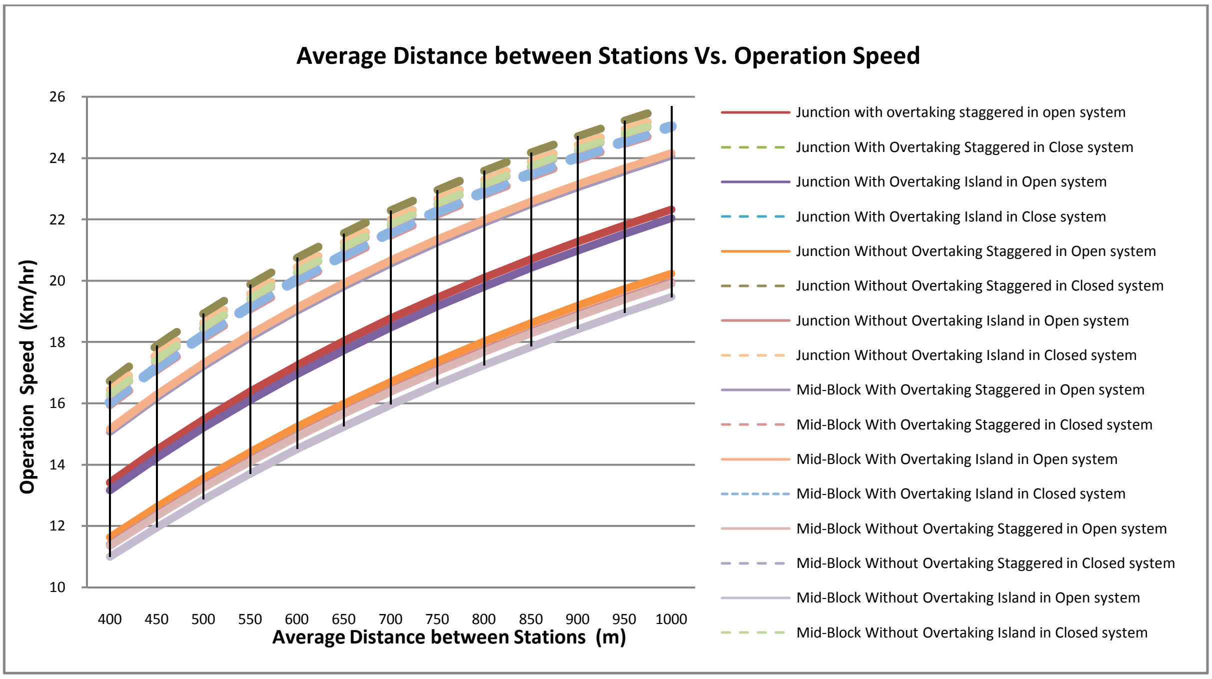
0.4111111
0.3277778
0.2611111

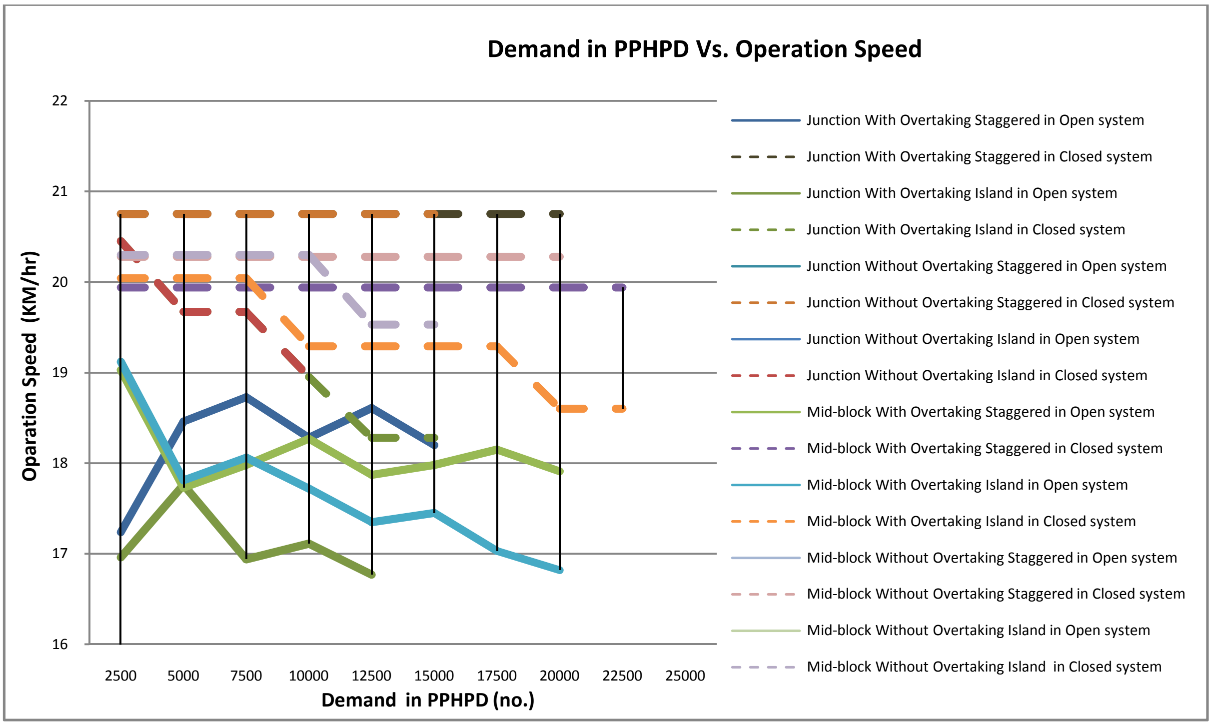
Determination of Overall Weightage of all Indicators

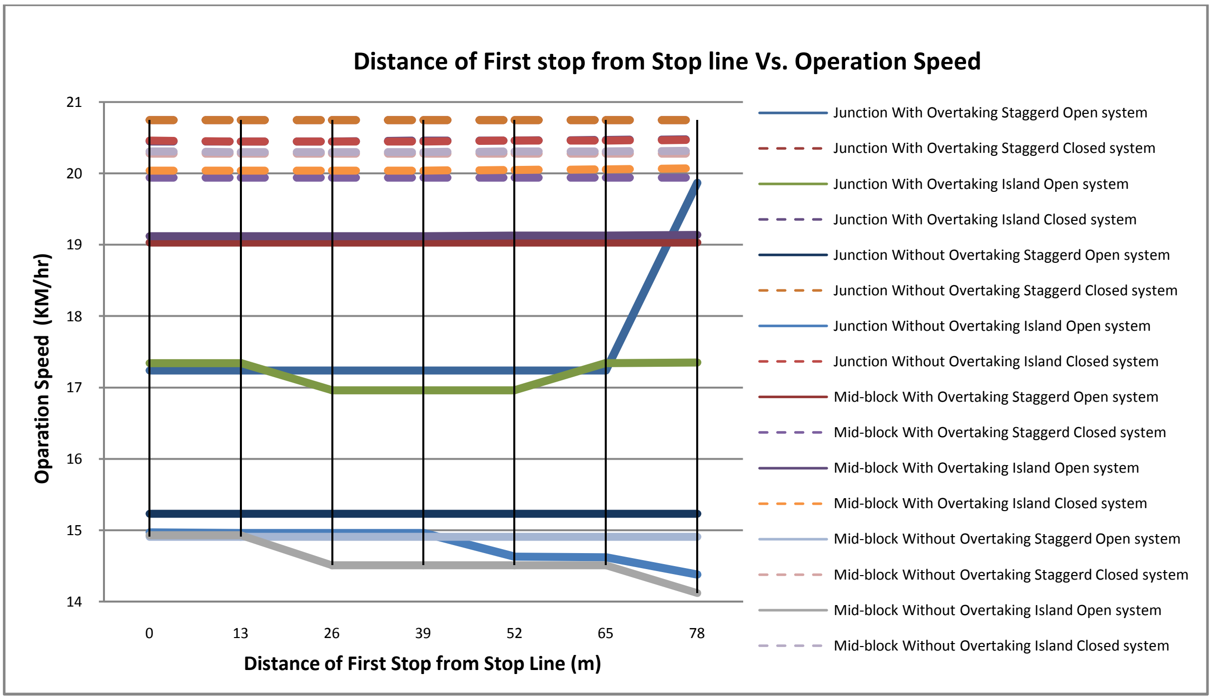
The weight of each indicator in every category is weighted by the weight of the category to determine the overall weights of indicators to be used in the BEAD Tool LOS estimator tool. These weights are listed in the table below.

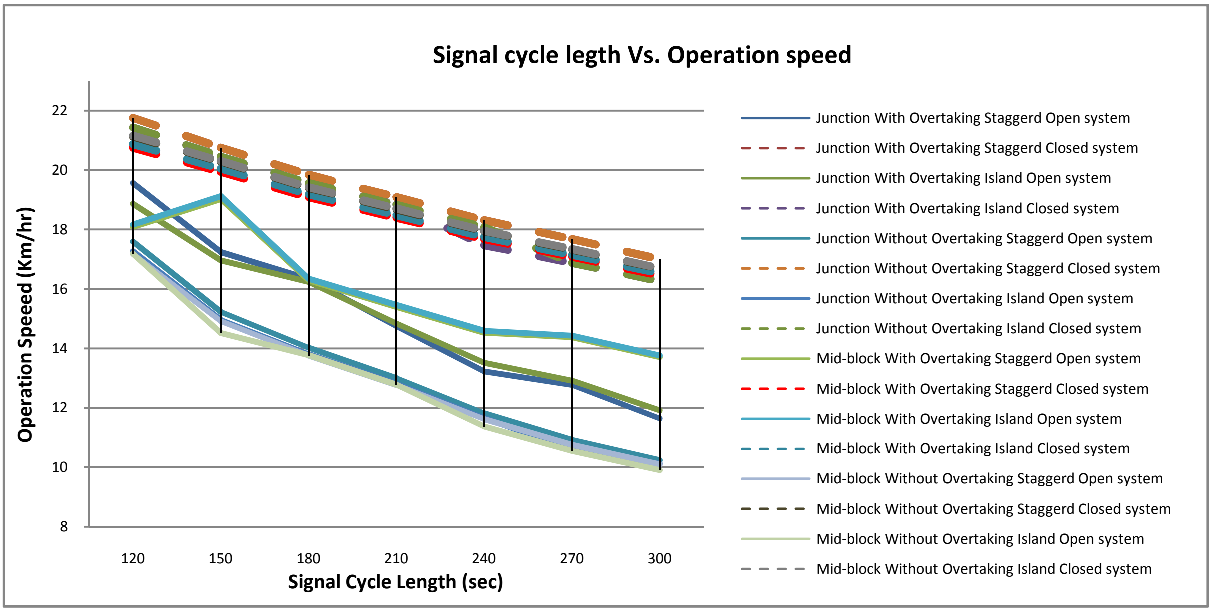
Safety	0.38750908
Shift from Pvt. 2 Wheelers	0.19375454
Attractiveness to PT Users	0.08322117
Pass. Speed	0.03895355
Walk Dist.	0.13994251
Pass. Delay	0.02419451
Ratio of Access to in-vehicle Time	0.02283858
Capacity	0.04505205
Operational Speed	0.03591987
Bus Delay	0.02861414
Total	1

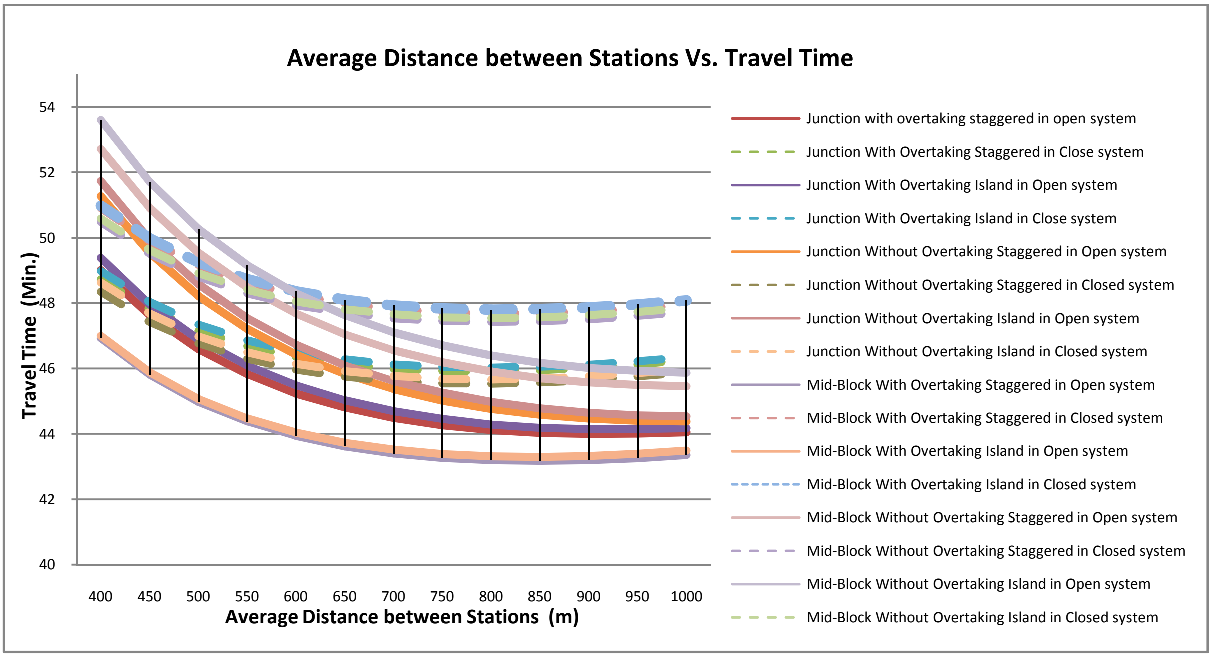
Annexure 7: Comparative graphs using BEAD Tool Generated Results

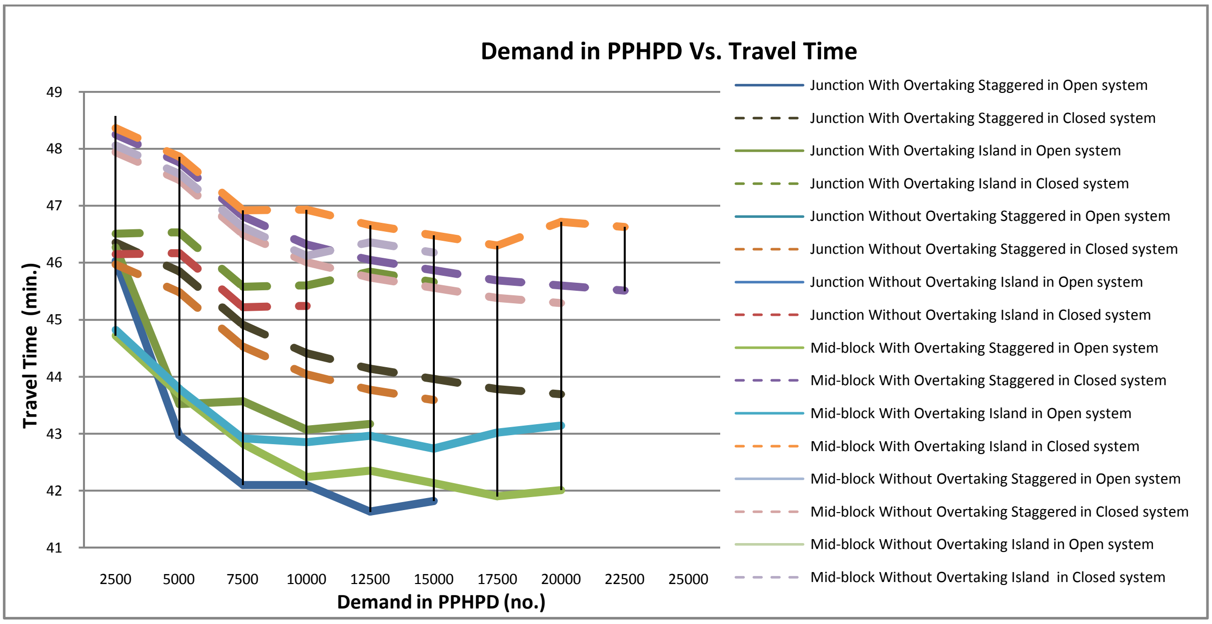


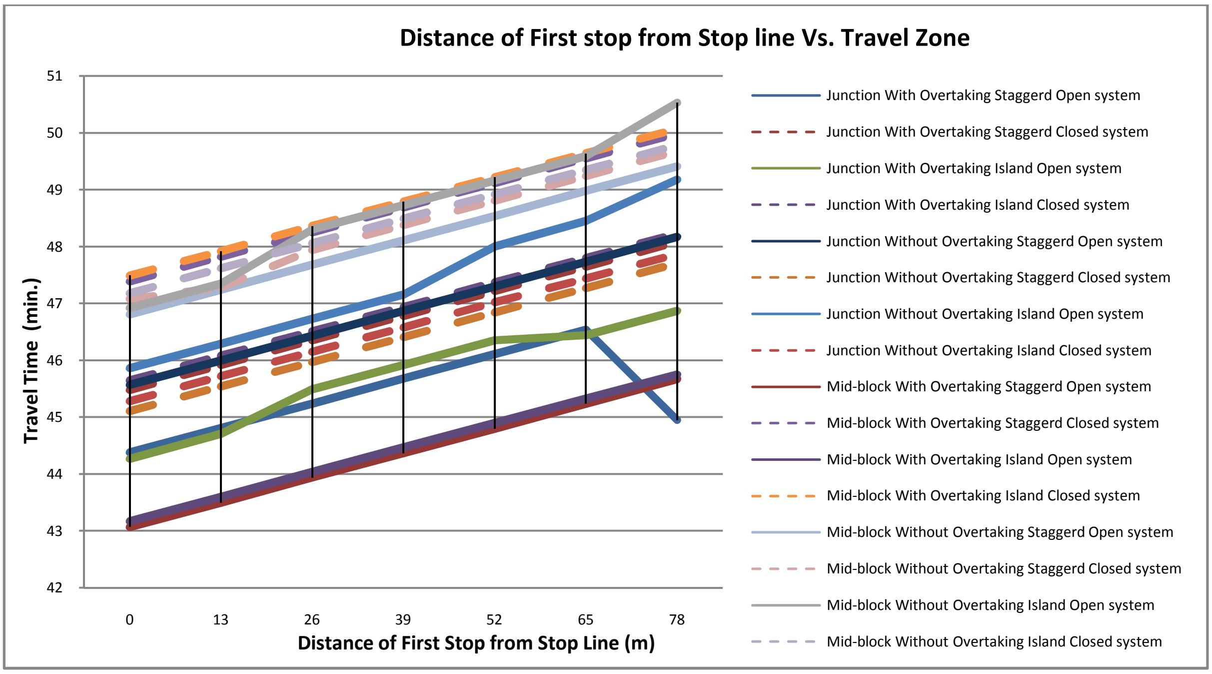


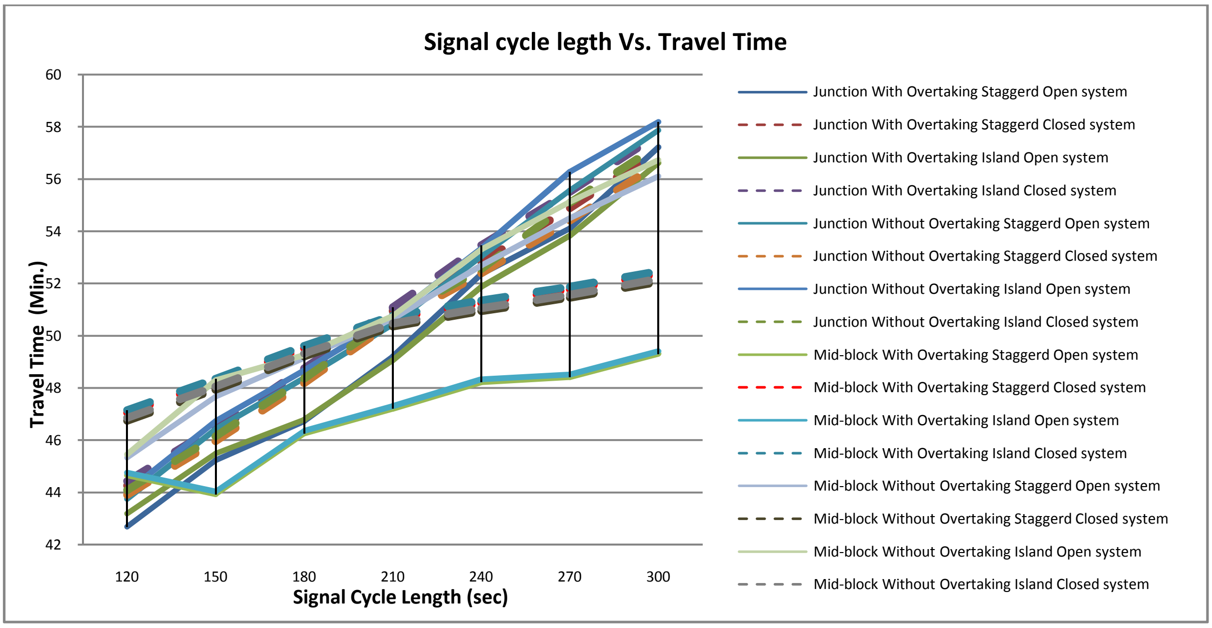

Distance of First stop from Stop line Vs. Operation Speed
Operation Speed (KM/hr)
14
15
16
17
18
19
20
21
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
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

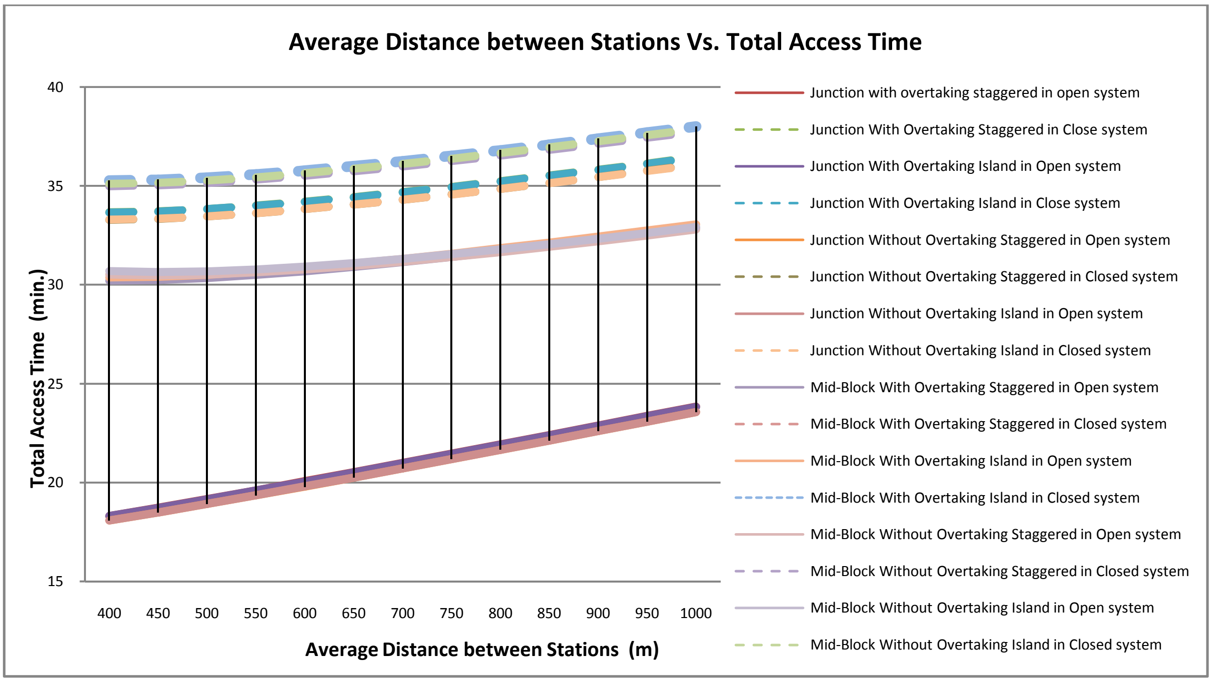

Signal cycle legth Vs. Operation speed
Operation Speed (Km/hr)
8
10
12
14
16
18
20
22
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking 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

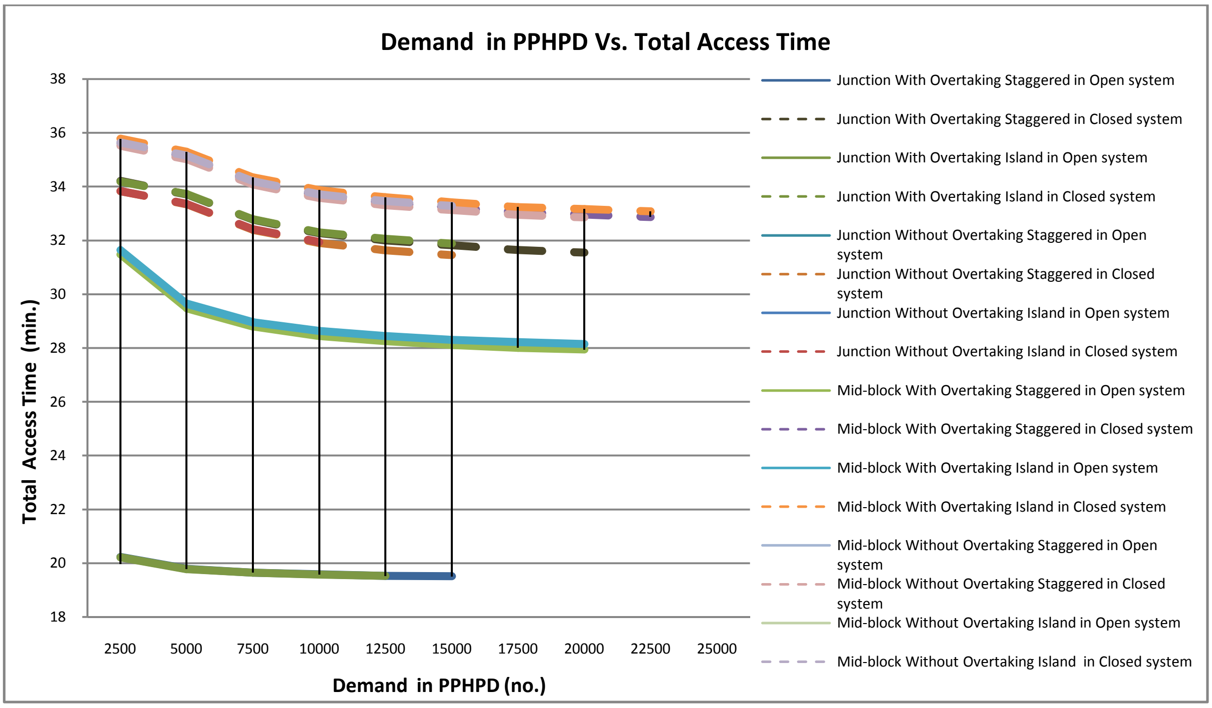

Average Distance between Stations Vs. Travel Time
Travel Time (Min.)
54
52
50
48
46
44
42
40
400
450
500
550
600
650
700
750
800
850
900
950
1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With Overtaking 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

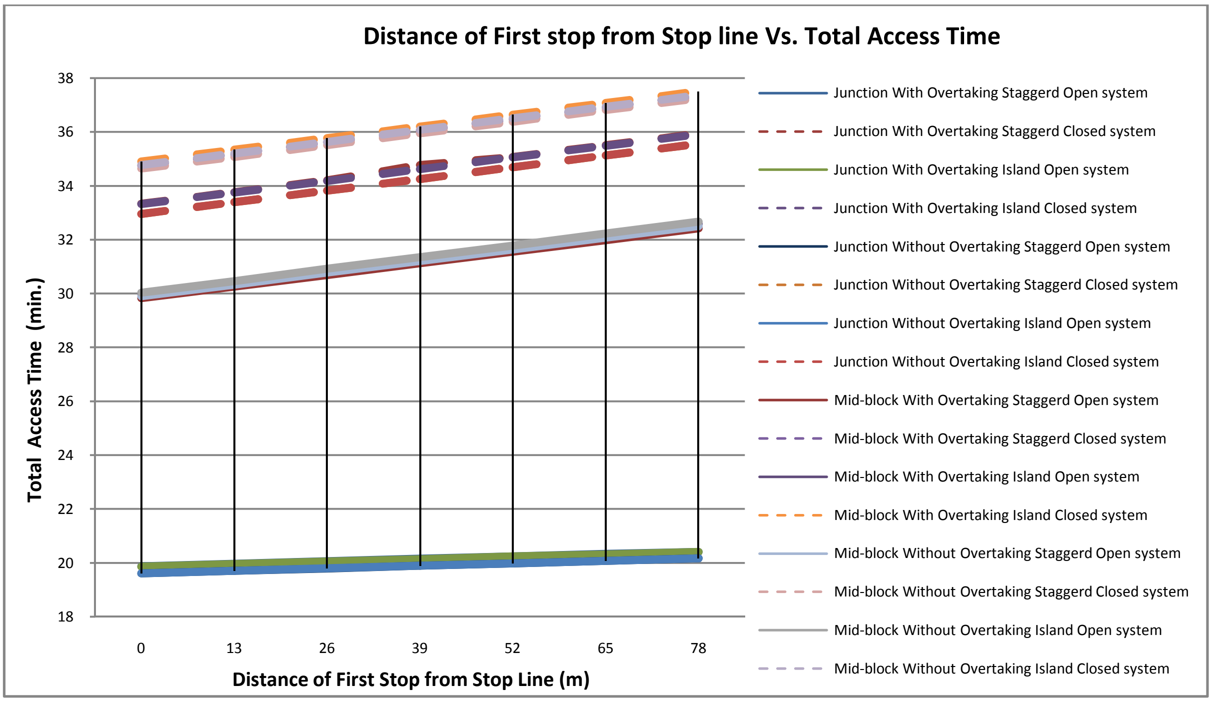

Demand in PPHPD Vs. Travel Time
Travel Time (min.)
49
48
47
46
45
44
43
42
41
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
Demand in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking Island in Open system
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

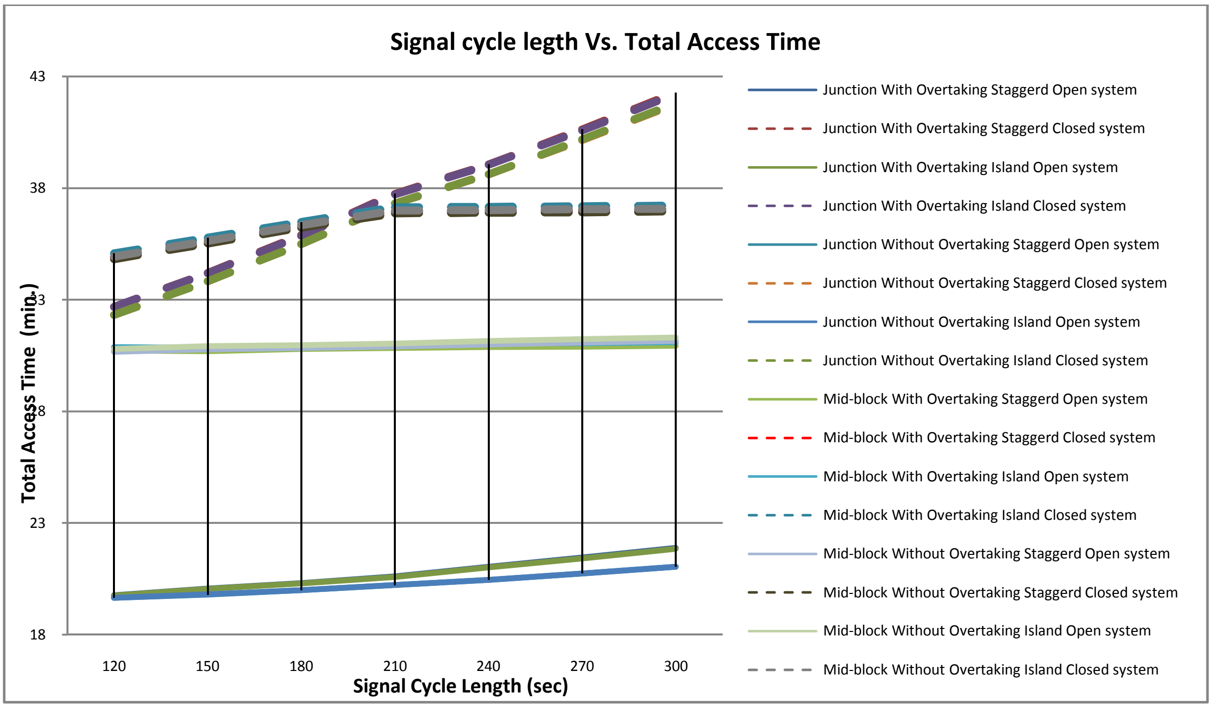

Distance of First stop from Stop line Vs. Travel Zone
Travel Time (min.)
51
50
49
48
47
46
45
44
43
42
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
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

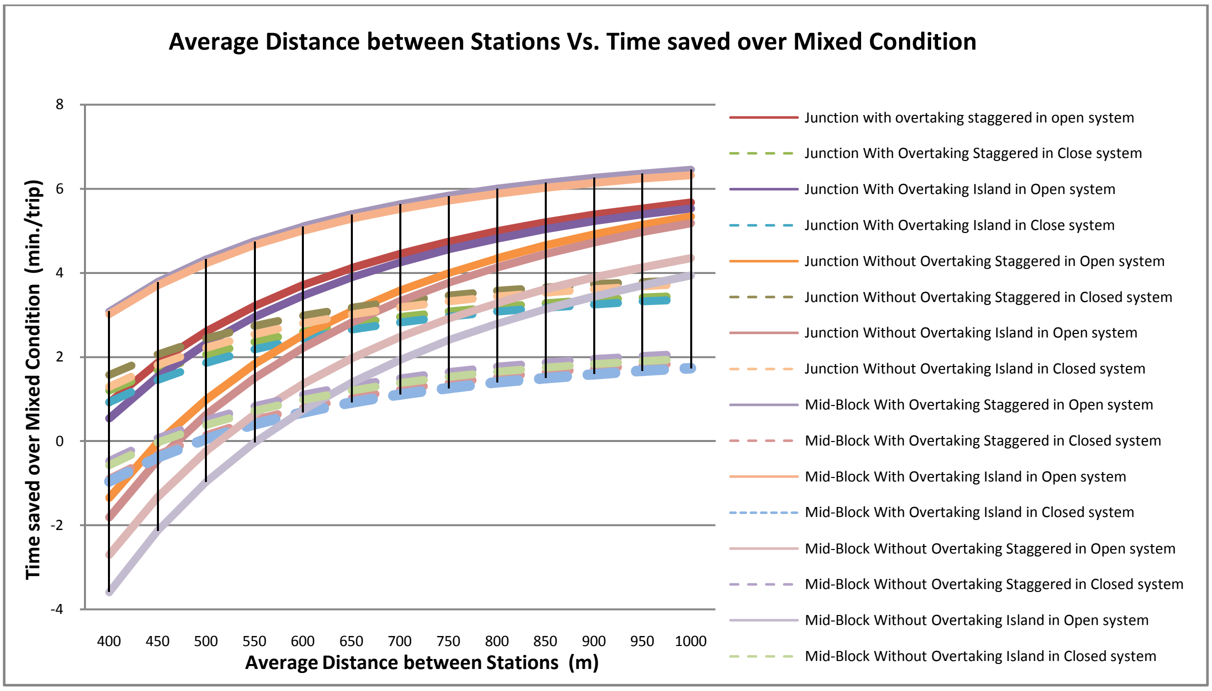

Signal cycle legth Vs. Travel Time
Travel Time (Min.)
60
58
56
54
52
50
48
46
44
42
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking 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

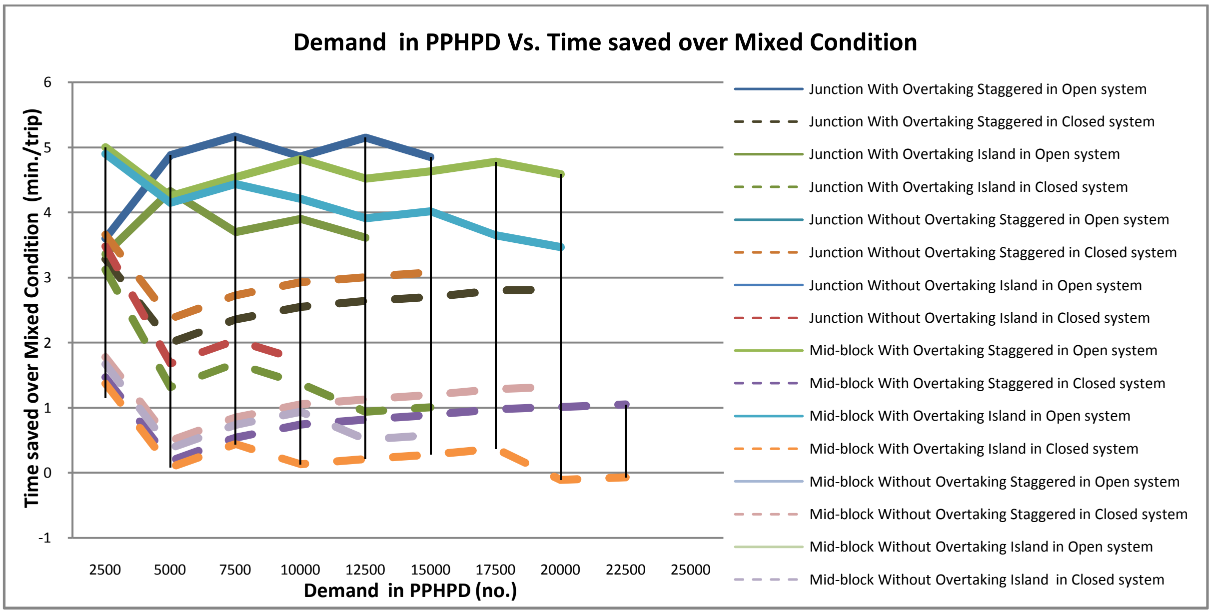

Average Distance between Stations Vs. Total Access Time
Total Access Time (min.)
40
35
30
25
20
15
400
450
500
550
600
650
700
750
800
850
900
950
1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered in Close system
Junction With 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

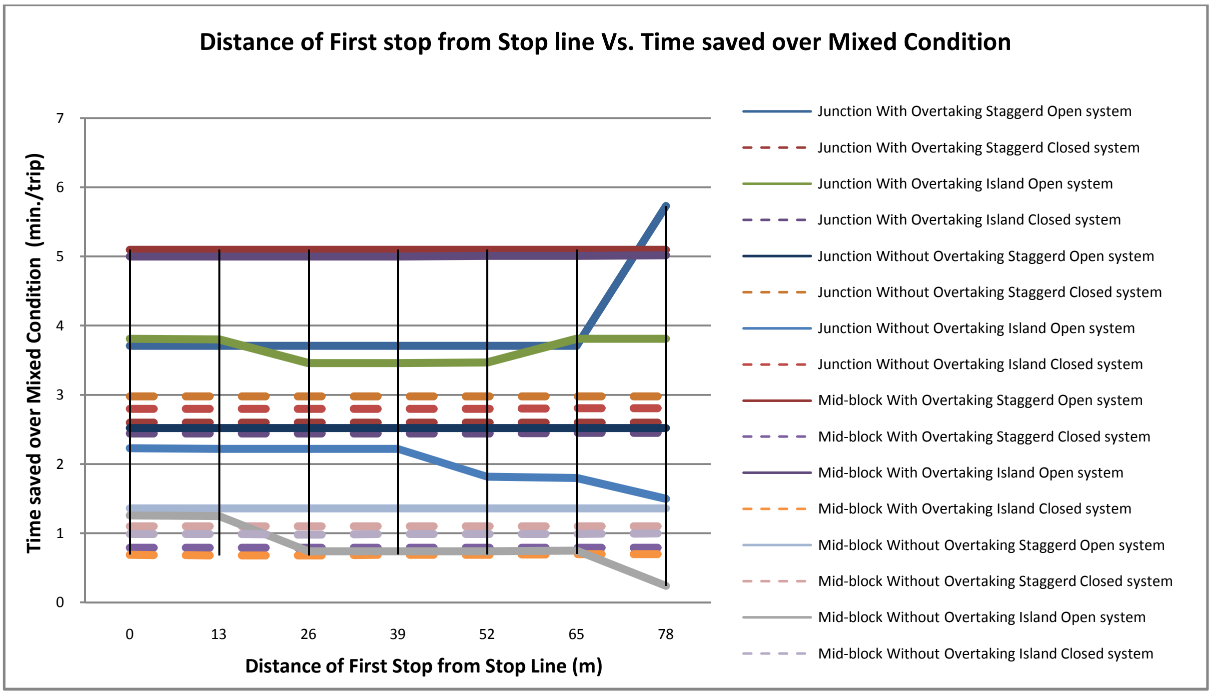

Demand in PPHPD Vs. Total Access Time
Total Access Time (min.)
38
36
34
32
30
28
26
24
22
20
18
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
Demand in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction With Overtaking 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

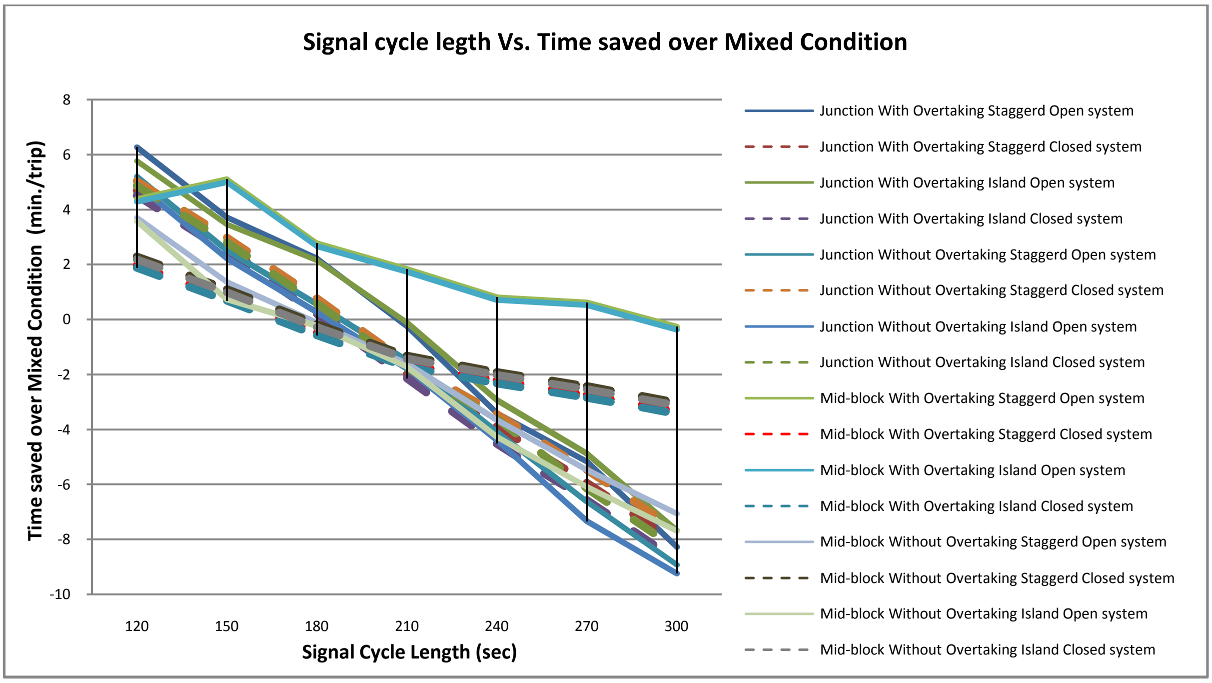

Distance of First stop from Stop line Vs. Total Access Time
Total Access Time (min.)
38
36
34
32
30
28
26
24
22
20
18
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island 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

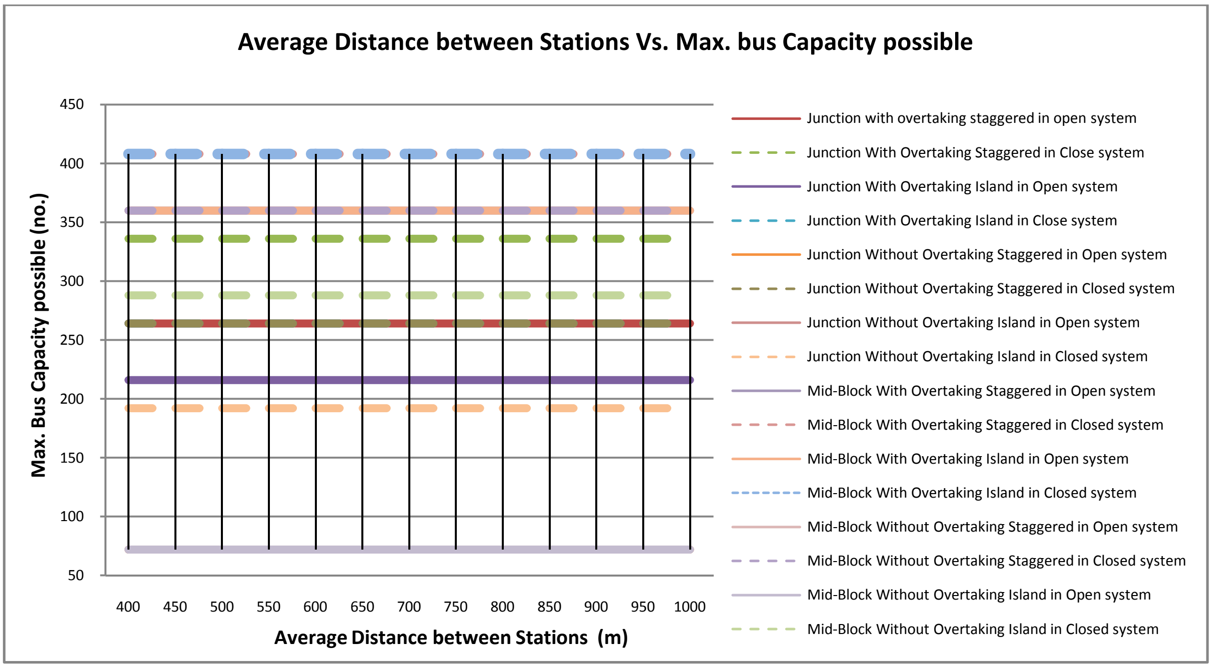

Signal cycle legth Vs. Total Access Time
Total Access Time (min.)
43
38
33
28
23
18
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island Open system
Junction With Overtaking 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

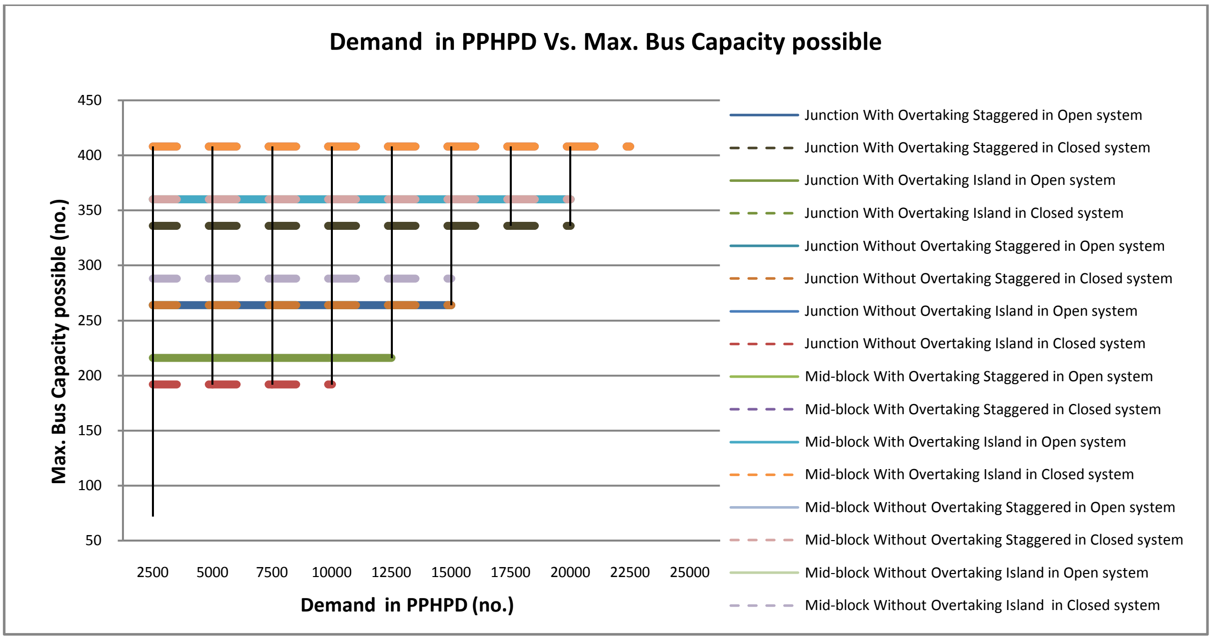

Average Distance between Stations Vs. Time saved over Mixed Condition

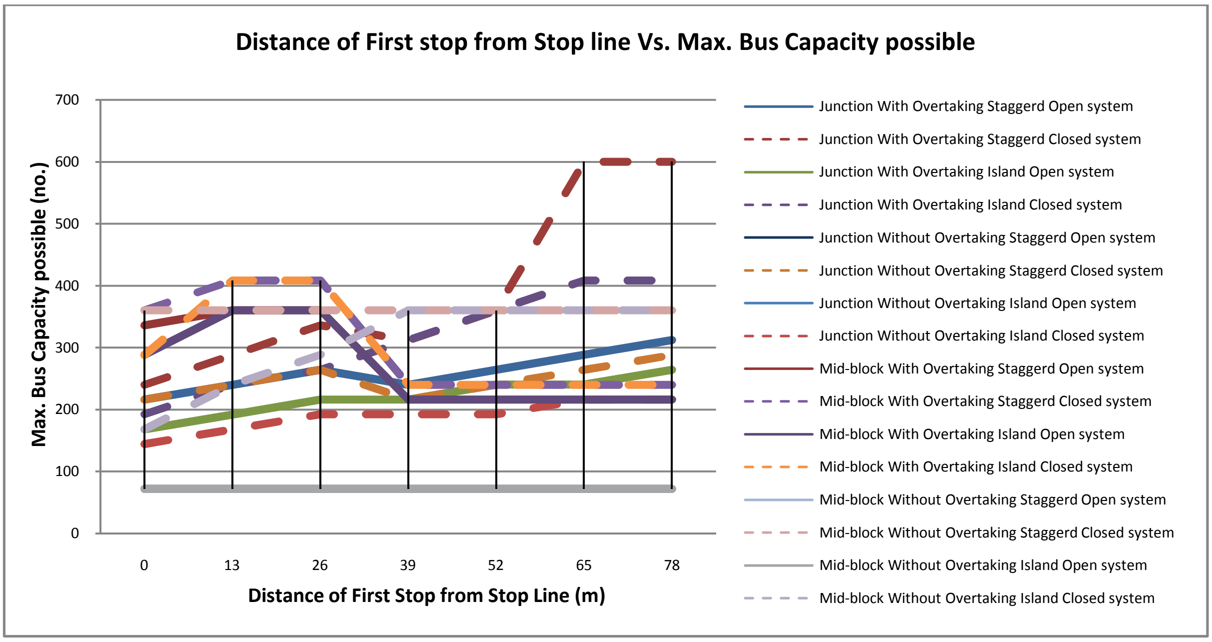

Demand in PPHPD Vs. Time saved over Mixed Condition

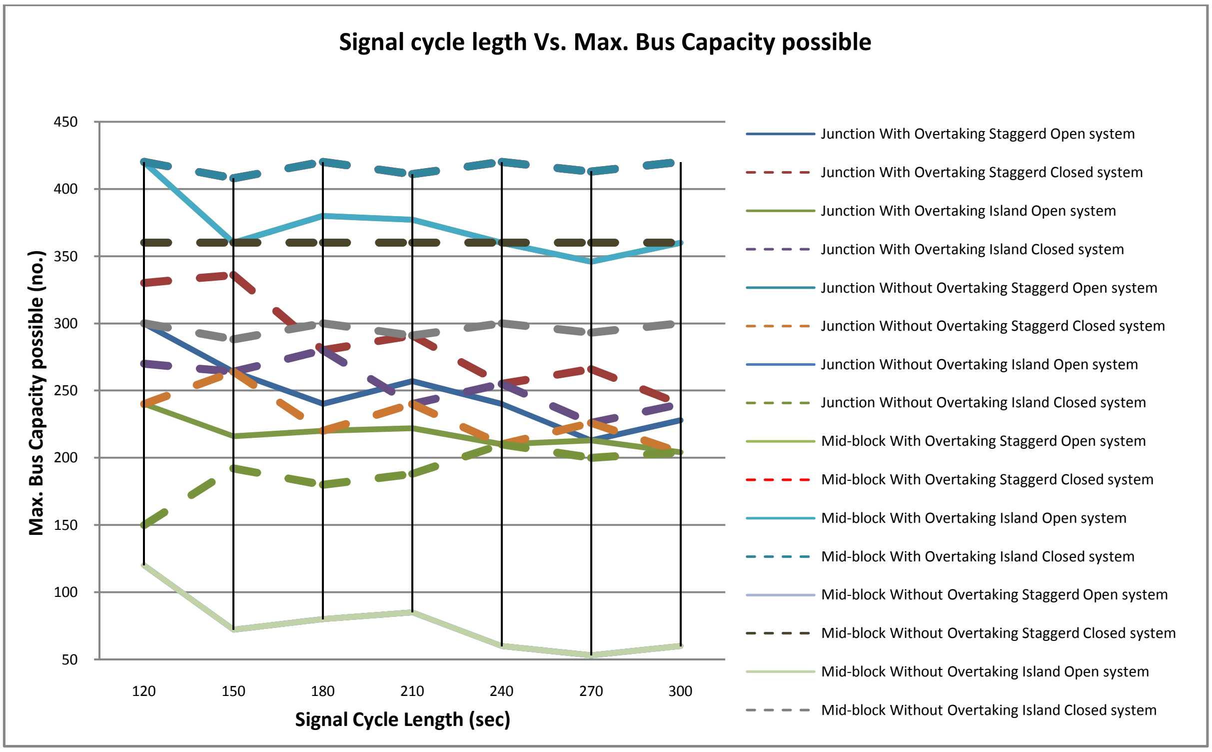

Distance of First stop from Stop line Vs. Time saved over Mixed Condition
Time saved over Mixed Condition (min./trip)
0
1
2
3
4
5
6
7
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With 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

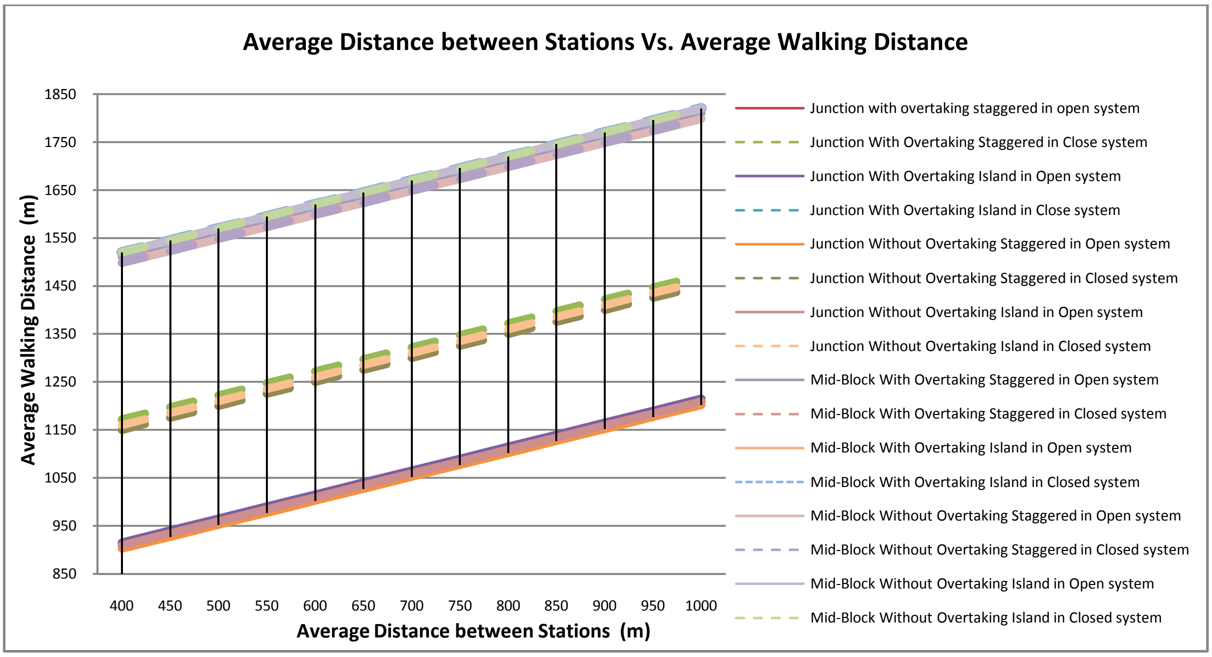

Signal cycle legth Vs. Time saved over Mixed Condition
Time saved over Mixed Condition (min./trip)
-10
-8
-6
-4
-2
0
2
4
6
8
120
150
180
210
240
270
300
Signal Cycle Length (sec)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With Overtaking Island 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

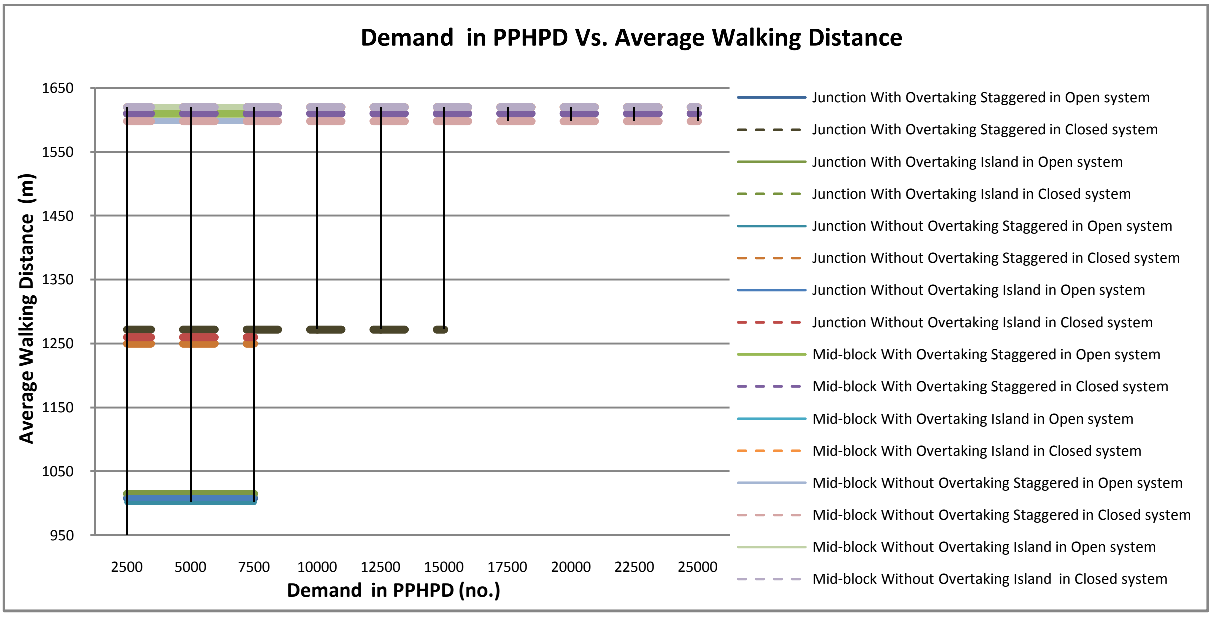

Average Distance between Stations Vs. Max. bus Capacity possible
Max. Bus Capacity possible (no.)
450
400
350
300
250
200
150
100
50
400
450
500
550
600
650
700
750
800
850
900
950
1000
Average Distance between Stations (m)
Junction with overtaking staggered in open system
Junction With Overtaking Staggered 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

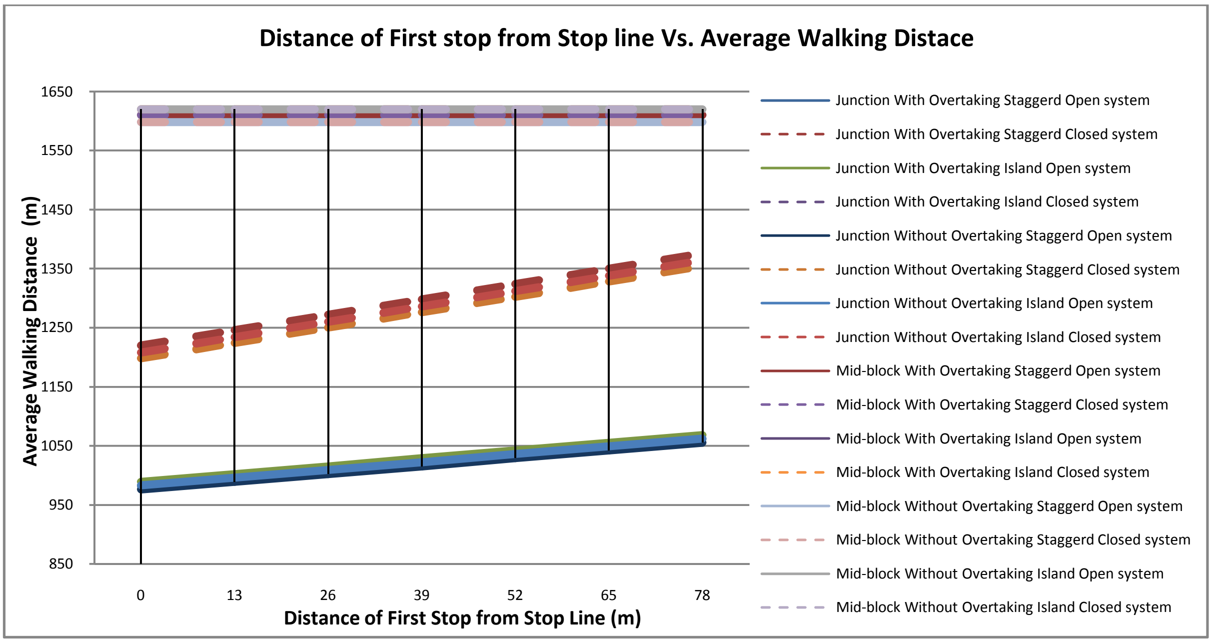

Demand in PPHPD Vs. Max. Bus Capacity possible
Max. Bus Capacity possible (no.)
450
400
350
300
250
200
150
100
50
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
Demand in PPHPD (no.)
Junction With Overtaking Staggered in Open system
Junction With Overtaking Staggered in Closed system
Junction 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

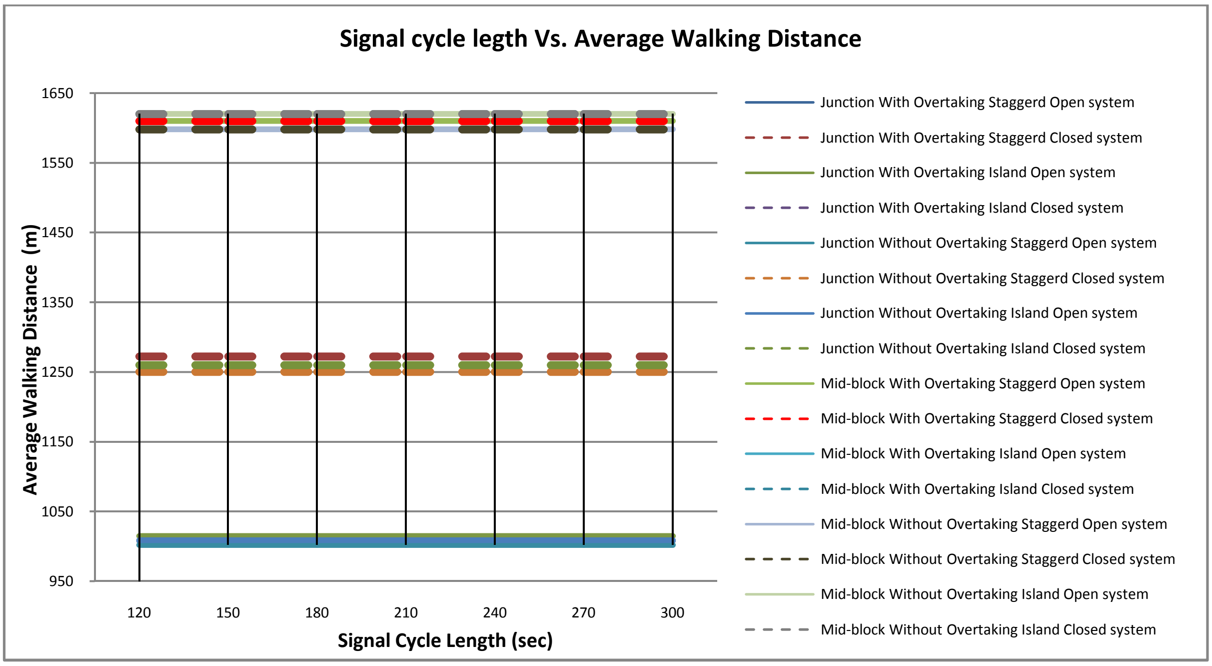

Distance of First stop from Stop line Vs. Max. Bus Capacity possible
Max. Bus Capacity possible (no.)
0
100
200
300
400
500
600
700
0
13
26
39
52
65
78
Distance of First Stop from Stop Line (m)
Junction With Overtaking Staggerd Open system
Junction With Overtaking Staggerd Closed system
Junction With 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.)
50
100
150
200
250
300
350
400
450
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)
1850
1750
1650
1550
1450
1350
1250
1150
1050
950
850
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


Demand in PPHPD Vs. Average Walking Distance
Average Walking Distance (m)
1650
1550
1450
1350
1250
1150
1050
950
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
Demand 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)
1650
1550
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)
1650
1550
1450
1350
1250
1150
1050
950
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

Annexure 8 – List of Reviewers

The draft final version of the tool and user manual was sent to various agencies and experts for review and comments in the last week of January'2012. These have been listed below.

Formal Reviewers:

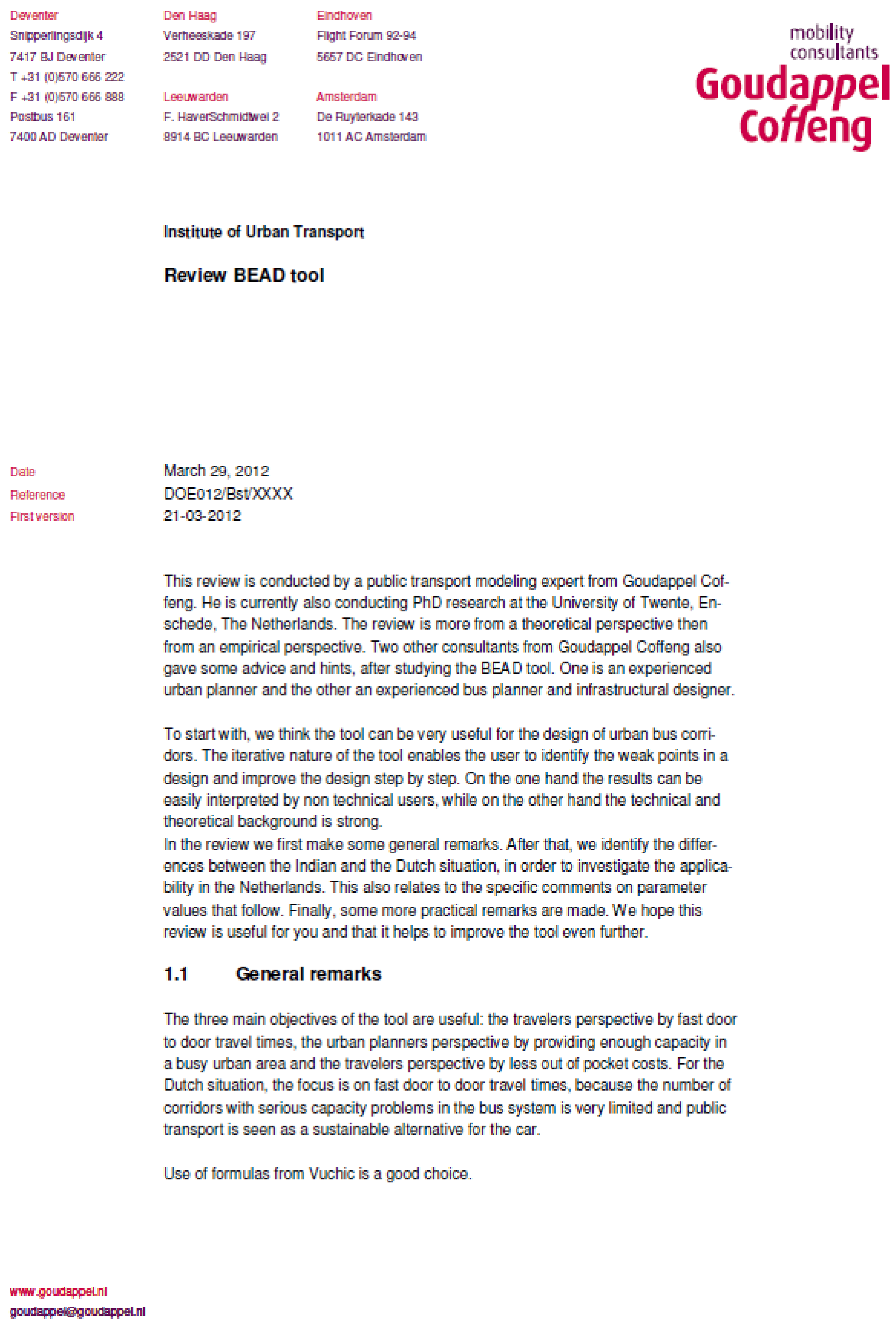
1. Delhi Integrated Multi Modal Transport Systems Ltd (DIMMTS)
2. Pune Municipal Corporation (PMC)
3. Greater Vishakapatnam Municipal Corporation (GVMC)
4. Rajkot Municipal Corporation (RMC)
5. Surat Municipal Corproration (SMC)
6. Institute for Transportation & Development Policy (ITDP)
7. UTTIPEC, DDA (Delhi Development Authority)
8. Kolkata Metropolitan Development Authority (KMDA)
9. IL&FS Infrastructure Development Corporation Ltd.
10. Voyants Solutions Pvt. Ltd.
11. PWD, Govt. Of NCT, Delhi
12. Urban Mass Transit Company (UMTC) Ltd.
13. Capita Symonds

Expert Reviewers:

1. Prof. Jason Chang, National Taiwan University, Taiwan
2. Prof. Shivanavd Swamy, CEPT University, India
3. Dr. O P Agarwal, World Bank
4. Prof. Hermann Knochflaker
5. Sujit Patwardhan and Ranjit Gadgil, Parisar

Annexure 9 – Review Comments by Goudappel Coffeng, Amsterdam

Goudappel Coffeng, a transport Engineering and Planning Consulting firm based out of Amsterdam provided and exhaustive list of comments on the BEAD tool on March 29, 2012. These have been presented below:



Deventer
Snipperlingsdijk 4
7417 BJ Deventer
T +31 (0)570 666 222
F +31 (0)570 666 888
Postbus 161
7400 AD Deventer

Den Haag
Verheeskade 197
2521 DD Den Haag

Leeuwarden
F. HaverSchmidtwei 2
8914 BC Leeuwarden

Eindhoven
Flight Forum 92-94
5657 DC Eindhoven

Amsterdam
De Ruyterkade 143
1011 AC Amsterdam

mobility
consultants
Goudappel
Coffeng

Institute of Urban Transport

Review BEAD tool

Date March 29, 2012
Reference DOE012/Bst/XXXX
First version 21-03-2012

This review is conducted by a public transport modeling expert from Goudappel Coffeng. He is currently also conducting PhD research at the University of Twente, Enschede, The Netherlands. The review is more from a theoretical perspective then from an empirical perspective. Two other consultants from Goudappel Coffeng also gave some advice and hints, after studying the BEAD tool. One is an experienced urban planner and the other an experienced bus planner and infrastructural designer.

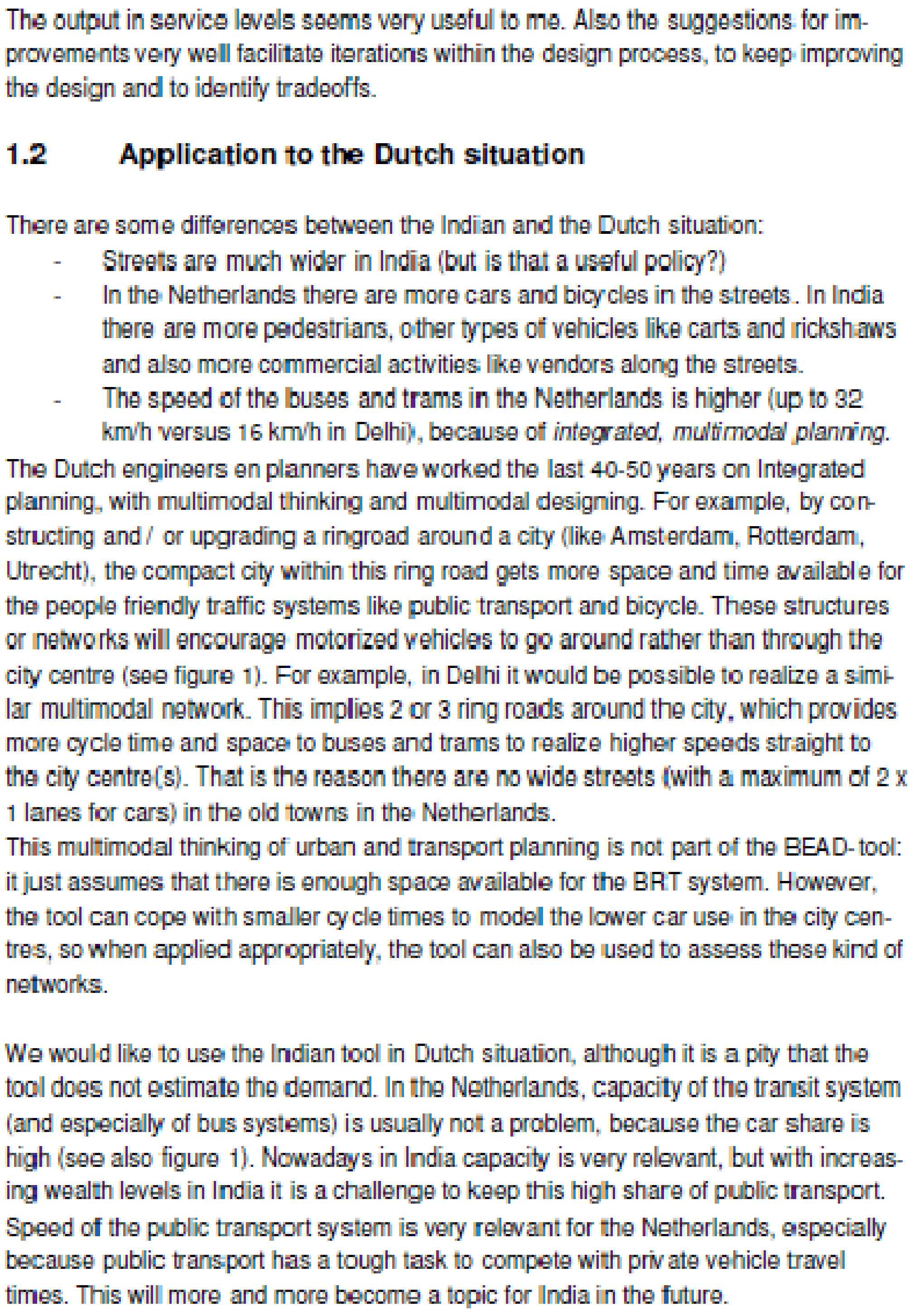
To start with, we think the tool can be very useful for the design of urban bus corridors. The iterative nature of the tool enables the user to identify the weak points in a design and improve the design step by step. On the one hand the results can be easily interpreted by non technical users, while on the other hand the technical and theoretical background is strong.
In the review we first make some general remarks. After that, we identify the differences between the Indian and the Dutch situation, in order to investigate the applicability in the Netherlands. This also relates to the specific comments on parameter values that follow. Finally, some more practical remarks are made. We hope this review is useful for you and that it helps to improve the tool even further.

1.1 General remarks

The three main objectives of the tool are useful: the travelers perspective by fast door to door travel times, the urban planners perspective by providing enough capacity in a busy urban area and the travelers perspective by less out of pocket costs. For the Dutch situation, the focus is on fast door to door travel times, because the number of corridors with serious capacity problems in the bus system is very limited and public transport is seen as a sustainable alternative for the car.

Use of formulas from Vuchic is a good choice.

Comments by GoudappelCoffeng, page no. 1



The output in service levels seems very useful to me. Also the suggestions for improvements very well facilitate iterations within the design process, to keep improving the design and to identify tradeoffs.

1.2 Application to the Dutch situation

There are some differences between the Indian and the Dutch situation:

- Streets are much wider in India (but is that a useful policy?)
- In the Netherlands there are more cars and bicycles in the streets. In India there are more pedestrians, other types of vehicles like carts and rickshaws and also more commercial activities like vendors along the streets.
- The speed of the buses and trams in the Netherlands is higher (up to 32 km/h versus 16 km/h in Delhi), because of *integrated, multimodal planning*.

The Dutch engineers en planners have worked the last 40-50 years on Integrated planning, with multimodal thinking and multimodal designing. For example, by constructing and / or upgrading a ringroad around a city (like Amsterdam, Rotterdam, Utrecht), the compact city within this ring road gets more space and time available for the people friendly traffic systems like public transport and bicycle. These structures or networks will encourage motorized vehicles to go around rather than through the city centre (see figure 1). For example, in Delhi it would be possible to realize a similar multimodal network. This implies 2 or 3 ring roads around the city, which provides more cycle time and space to buses and trams to realize higher speeds straight to the city centre(s). That is the reason there are no wide streets (with a maximum of 2 x 1 lanes for cars) in the old towns in the Netherlands.
This multimodal thinking of urban and transport planning is not part of the BEAD-tool: it just assumes that there is enough space available for the BRT system. However, the tool can cope with smaller cycle times to modell the lower car use in the city centres, so when applied appropriately, the tool can also be used to assess these kind of networks.

We would like to use the Indian tool in Dutch situation, although it is a pity that the tool does not estimate the demand. In the Netherlands, capacity of the transit system (and especially of bus systems) is usually not a problem, because the car share is high (see also figure 1). Nowadays in India capacity is very relevant, but with increasing wealth levels in India it is a challenge to keep this high share of public transport. Speed of the public transport system is very relevant for the Netherlands, especially because public transport has a tough task to compete with private vehicle travel times. This will more and more become a topic for India in the future.

Comments by Goudappel Coffeng, page no. 2

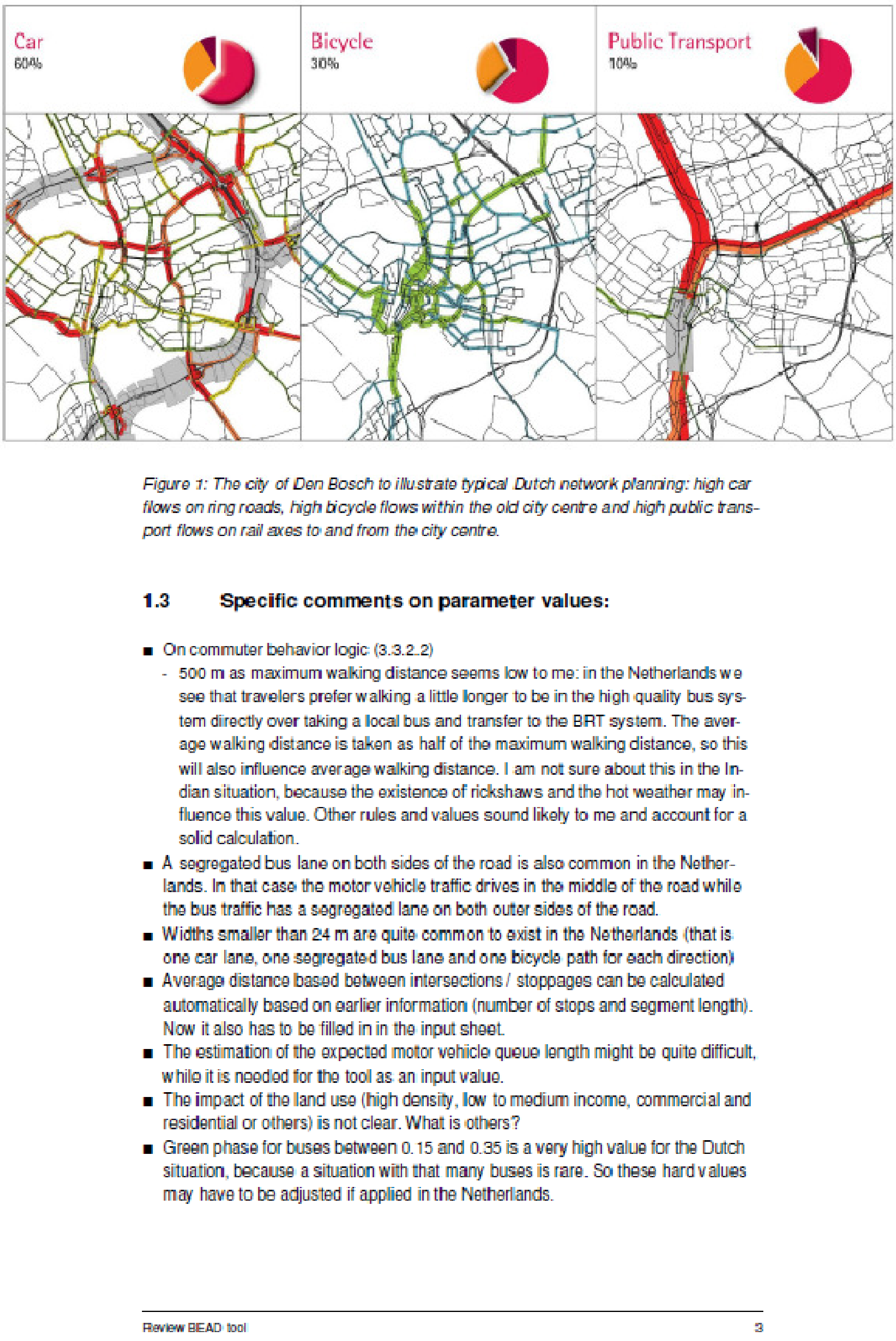


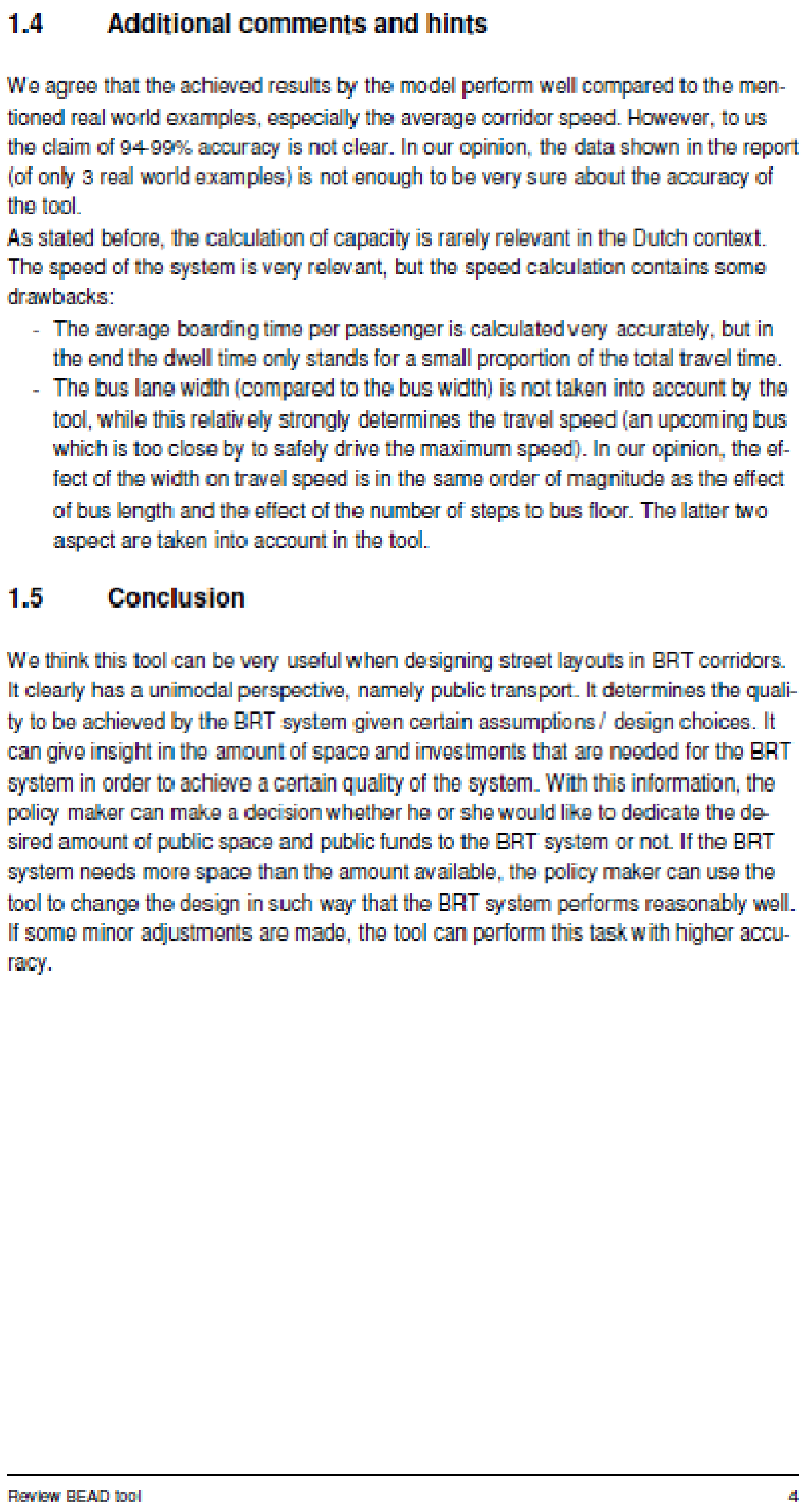
Figure 1: The city of Den Bosch to illustrate typical Dutch network planning: high car flows on ring roads, high bicycle flows within the old city centre and high public transport flows on rail axes to and from the city centre.

1.3 Specific comments on parameter values:

- On commuter behavior logic (3.3.2.2)
  - 500 m as maximum walking distance seems low to me: in the Netherlands we see that travelers prefer walking a little longer to be in the high quality bus system directly over taking a local bus and transfer to the BRT system. The average walking distance is taken as half of the maximum walking distance, so this will also influence average walking distance. I am not sure about this in the Indian situation, because the existence of rickshaws and the hot weather may influence this value. Other rules and values sound likely to me and account for a solid calculation.
- A segregated bus lane on both sides of the road is also common in the Netherlands. In that case the motor vehicle traffic drives in the middle of the road while the bus traffic has a segregated lane on both outer sides of the road.
- Widths smaller than 24 m are quite common to exist in the Netherlands (that is one car lane, one segregated bus lane and one bicycle path for each direction)
- Average distance based between intersections / stoppages can be calculated automatically based on earlier information (number of stops and segment length). Now it also has to be filled in in the input sheet.
- The estimation of the expected motor vehicle queue length might be quite difficult, while it is needed for the tool as an input value.
- The impact of the land use (high density, low to medium income, commercial and residential or others) is not clear. What is others?
- Green phase for buses between 0.15 and 0.35 is a very high value for the Dutch situation, because a situation with that many buses is rare. So these hard values may have to be adjusted if applied in the Netherlands.

Review BEAD tool 3

Comments by Goudappel Coffeng, page no. 3



1.4 Additional comments and hints

We agree that the achieved results by the model perform well compared to the mentioned real world examples, especially the average corridor speed. However, to us the claim of 94-99% accuracy is not clear. In our opinion, the data shown in the report (of only 3 real world examples) is not enough to be very sure about the accuracy of the tool.
As stated before, the calculation of capacity is rarely relevant in the Dutch context. The speed of the system is very relevant, but the speed calculation contains some drawbacks:

- The average boarding time per passenger is calculated very accurately, but in the end the dwell time only stands for a small proportion of the total travel time.
- The bus lane width (compared to the bus width) is not taken into account by the tool, while this relatively strongly determines the travel speed (an upcoming bus which is too close by to safely drive the maximum speed). In our opinion, the effect of the width on travel speed is in the same order of magnitude as the effect of bus length and the effect of the number of steps to bus floor. The latter two aspect are taken into account in the tool.

1.5 Conclusion

We think this tool can be very useful when designing street layouts in BRT corridors. It clearly has a unimodal perspective, namely public transport. It determines the quality to be achieved by the BRT system given certain assumptions / design choices. It can give insight in the amount of space and investments that are needed for the BRT system in order to achieve a certain quality of the system. With this information, the policy maker can make a decision whether he or she would like to dedicate the desired amount of public space and public funds to the BRT system or not. If the BRT system needs more space than the amount available, the policy maker can use the tool to change the design in such way that the BRT system performs reasonably well. If some minor adjustments are made, the tool can perform this task with higher accuracy.

Review BEAD tool 4

Comments by Goudappel Coffeng, page no. 4

Annexure 10: Response to Comments by Goudappel Coffeng

The BEAD development team used most of the comments provide by Goudappel Coffeng in either improving the explanation in this report or in making further improvements in the BEAD tool version 1.69. The development team responded to comments provided by the Public Transport Modelling Expert in Goudappel Coffeng on March 30, 2012. These have been listed below:

"Streets are much wider in India (but is that a useful policy?)"
We fully agree, wide roads are a bad policy and not a good option for Indian cities as well.

"We would like to use the Indian tool in Dutch situation, although it is a pity that the tool does not estimate the demand."
The tool does lack any assessment of Demand and relies on that as an input. However it is understood that the output/estimates from the tool can be used to make a demand assessment, however one does need to generate a separate model for the same. I do hope we take this up subsequently and come with an updated version of the tool with Demand estimation capabilities.

"Speed of the public transport system is very relevant for the Netherlands, especially because public transport has a tough task to compete with private vehicle travel times."
We agree Public Transport has tough time competing with Private Vehicles as far as door to door travel time is concerned. And this evident from the BEAD results as well. Since Public Transport even in best conditions will not be able to exceed passenger's speeds of 12-13km/h; till the time Private Vehicle speeds in the city drop to comparable levels, it is tough to attract demand for Public Transport. Hence what is emerging is to generate demand for Public Transport, congestion for Private Vehicles need to be generated, and this ties up with your point on very wide roads in India.

"500 m as maximum walking distance seems low to me: in the Netherlands we see that travelers prefer walking a little longer to be in the high quality bus system directly over taking a local bus and transfer to the BRT system."
What was intended was that catchment of walk feeder trips to a Transit line of 500m in each direction (total catchment zone width of 1km). However average walk distances are effected by gap between stations and gap between trunk and feeder stations, and all of this leads to increased walking distances which the model totals and presents as walking distances in the result. So average walk distance per direction per trip is falling between 500 to 800m, while total comes to 1000 to 1600m. So the tool does not assume 500m walk distances but 500m walk feeder catchment as an assumption. We will re-word this section to explain better.

"Average distance based between intersections / stoppages can be calculated automatically based on earlier information (number of stops and segment length). Now it also has to be filled in the input sheet. "
We agree that one should use the average distance between stops based on the data input in the segment description form, so I will change/update that in the final version of the tool.

"The estimation of the expected motor vehicle queue length might be quite difficult, while it is needed for the tool as an input value."

Yes estimation of the queue length is not really being used in the analysis, except to provide a warning when a mid block station falls within this length. So we agree, may be we can look at removing this variable from the tool. On the other hand, we had retained some variables (though they are not used now) so as up gradation by just inserting more calculations and formulas is easy and forms do not require to be changed. However we will certainly review the inclusion of this variable.

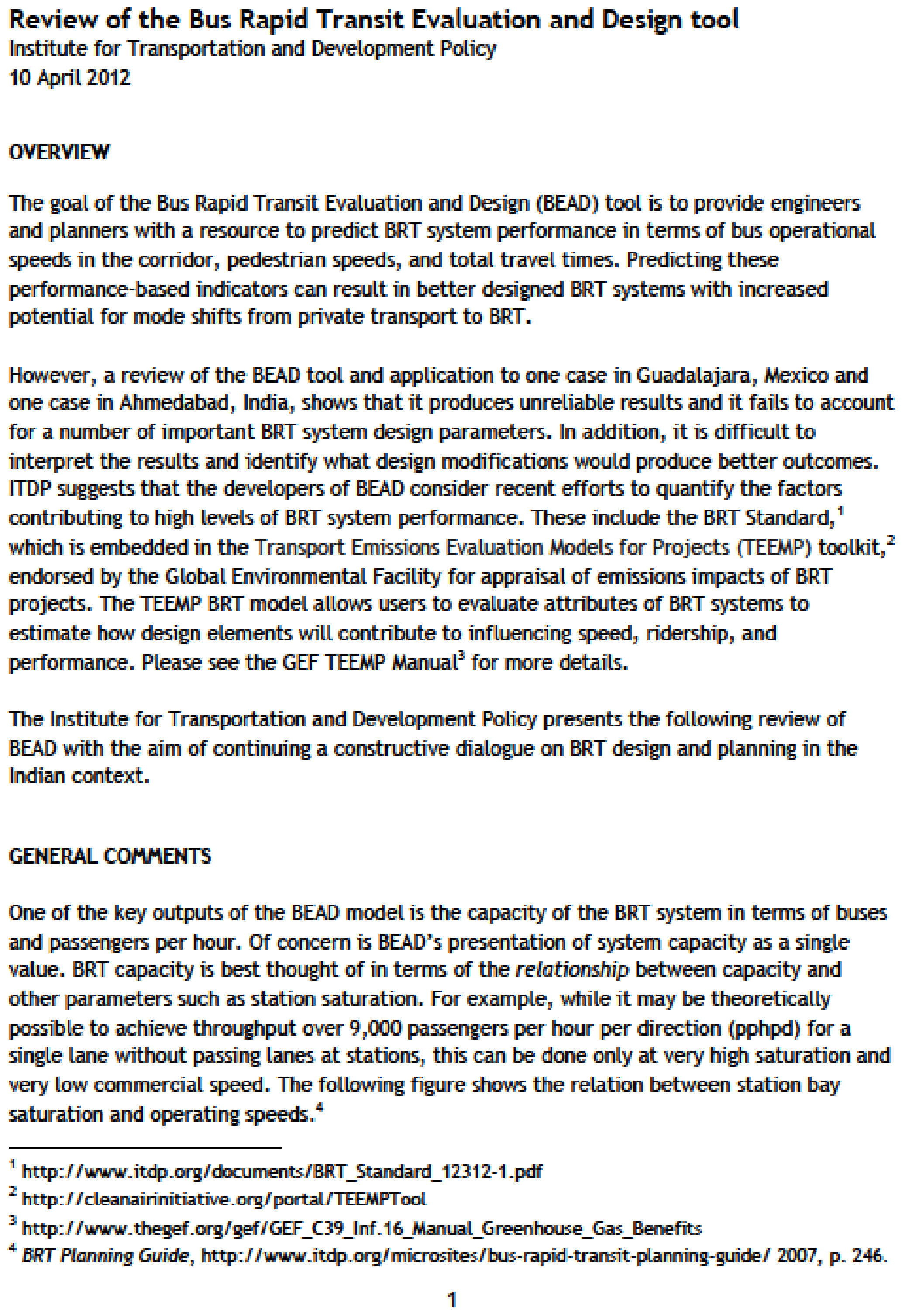
"The impact of the land use (high density, low to medium income, commercial and residential or others) is not clear. What is others?"
This is another example of leaving a variable for up gradation of the tool. For now we have only included 2 land use categories. One is for high catchment on the periphery of the corridor. In Indian context bus mode catchment is low or medium income communities. These are generally dense neighbourhoods with smaller dwelling units, and mixed land use. All other indicators of land use point to a high catchment of private motor vehicle traffic along the corridor, and this is what refers to 'others'. These two broad categories were used to divide the percentage of expected commuter catchment from the corridor in to two groups. The breakup is further illustrated on page 129 using flow chart of process no. 47.

"The average boarding time per passenger is calculated very accurately, but in the end the dwell time only stands for a small proportion of the total travel time."
Average boarding time was estimated in detail mainly to capture the effect of no. of steps (between station and bus floor) on the dwell time. This has been a focus of lots of debates in India, and thus it was important for us to include it in the study. I do agree the impact of the dwell time would remain low on the overall passenger speed, which is mainly effected by access/egress time and gap between stations (and both counter each other). The tool does capture the impact of all these factors.

"The bus lane width (compared to the bus width) is not taken into account by the tool, while this relatively strongly determines the travel speed (an upcoming bus which is too close by to safely drive the maximum speed)."
We agree the relationship between bus speed and bus lane width does not come out clearly from the tool. I think this is not yet built in and is certainly a good point for us to include it in the final version of the tool. In Indian condition the starting point is speed as that is generally a legal requirement, and once the peak speed is fixed the tool should be able to generate a cross section which responds to this peak speed value.

Annexure 11: Review Comments by ITDP

ITDP provided a list of exhaustive comments on BEAD on April 13, 2012. These are presented below.



Review of the Bus Rapid Transit Evaluation and Design tool

Institute for Transportation and Development Policy
10 April 2012

OVERVIEW

The goal of the Bus Rapid Transit Evaluation and Design (BEAD) tool is to provide engineers and planners with a resource to predict BRT system performance in terms of bus operational speeds in the corridor, pedestrian speeds, and total travel times. Predicting these performance-based indicators can result in better designed BRT systems with increased potential for mode shifts from private transport to BRT.

However, a review of the BEAD tool and application to one case in Guadalajara, Mexico and one case in Ahmedabad, India, shows that it produces unreliable results and it fails to account for a number of important BRT system design parameters. In addition, it is difficult to interpret the results and identify what design modifications would produce better outcomes. ITDP suggests that the developers of BEAD consider recent efforts to quantify the factors contributing to high levels of BRT system performance. These include the BRT Standard,[1] which is embedded in the Transport Emissions Evaluation Models for Projects (TEEMP) toolkit,[2] endorsed by the Global Environmental Facility for appraisal of emissions impacts of BRT projects. The TEEMP BRT model allows users to evaluate attributes of BRT systems to estimate how design elements will contribute to influencing speed, ridership, and performance. Please see the GEF TEEMP Manual[3] for more details.

The Institute for Transportation and Development Policy presents the following review of BEAD with the aim of continuing a constructive dialogue on BRT design and planning in the Indian context.

GENERAL COMMENTS

One of the key outputs of the BEAD model is the capacity of the BRT system in terms of buses and passengers per hour. Of concern is BEAD's presentation of system capacity as a single value. BRT capacity is best thought of in terms of the *relationship* between capacity and other parameters such as station saturation. For example, while it may be theoretically possible to achieve throughput over 9,000 passengers per hour per direction (pphpd) for a single lane without passing lanes at stations, this can be done only at very high saturation and very low commercial speed. The following figure shows the relation between station bay saturation and operating speeds.[4]

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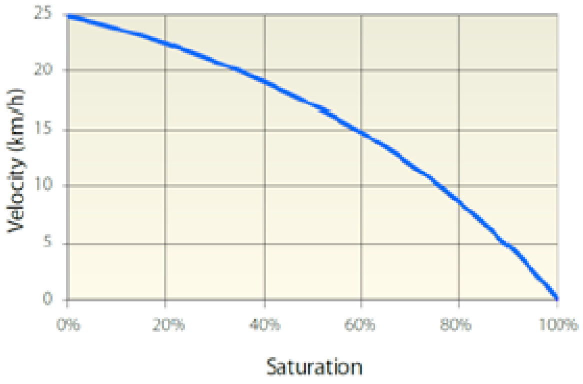
[1] http://www.itdp.org/documents/BRT_Standard_12312-1.pdf
[2] http://cleanairinitiative.org/portal/TEEMPTool
[3] http://www.thegef.org/gef/GEF_C39_Inf.16_Manual_Greenhouse_Gas_Benefits
[4] *BRT Planning Guide*, http://www.itdp.org/microsites/bus-rapid-transit-planning-guide/ 2007, p. 246.

Comments by ITDP, page no. 1



The saturation level at a station refers to the percentage of time that a bus station bay is occupied. The risk of congestion increases significantly if saturation level crosses 40 percent, and with it a gradual deterioration of the service quality. A high saturation level indicates long queues at stopping bays and low commercial speeds. For the model to serve as a more effective instructional tool, it should highlight these relationships rather than presenting capacity as a discrete value.

Comments on specific model components are presented below.

MODEL ASSUMPTIONS

Boarding-alighting time

The model assumes 1.67 seconds per boarding or alighting (per door) for low-floor buses from a platform of the same height based on observations in the Delhi BRT system.[5] However, the boarding time in Ahmedabad has been observed as 0.83 seconds (per door).[6] While both systems ostensibly offer level boarding, the wide variation in boarding time suggests there are significant differences between the boarding arrangements. Possible explanations are the bus-platform gap and the door width and arrangement. The model should take these differences into account rather than assuming that all "level boardng" systems function alike.

The dwell time[7] is assumed to be a standard input value of 14 sec irrespective of the total number of passengers boarding/alighting at any station by considering only 10% of the bus capacity as passenger interchanges. In an ideal case scenario it should vary for each station location depending upon the number of boardings/alightings at each station, which will vary depending upon the surrounding land use. Apart from passenger volumes, dwell time is also

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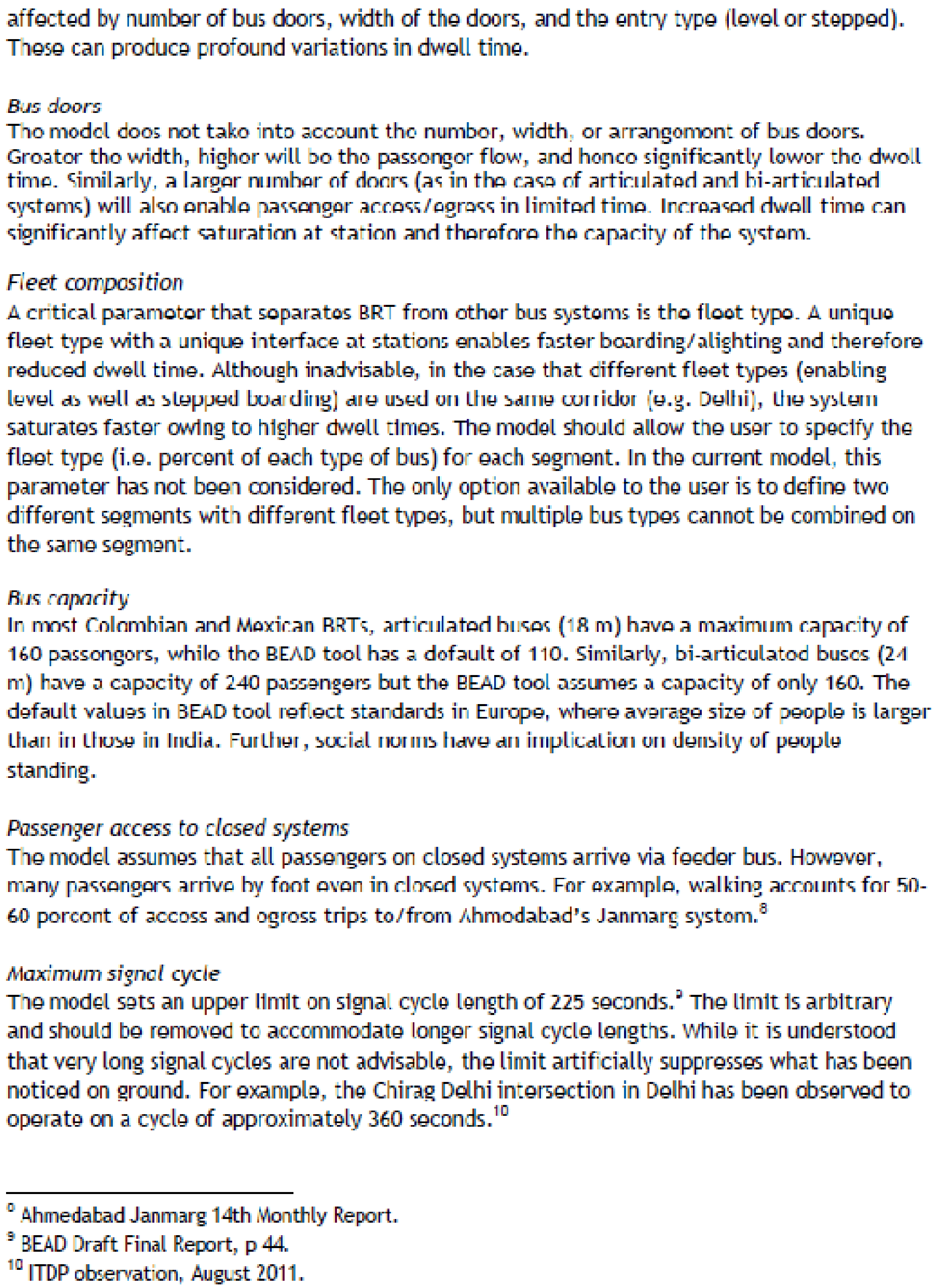
[5] BEAD Draft Final Report, p 32.

[6] ITDP survey.

[7] BEAD Draft Final Report, p 23.

Comments by ITDP page no. 2



affected by number of bus doors, width of the doors, and the entry type (level or stepped). These can produce profound variations in dwell time.

Bus doors
The model does not take into account the number, width, or arrangement of bus doors. Greater the width, higher will be the passenger flow, and hence significantly lower the dwell time. Similarly, a larger number of doors (as in the case of articulated and bi-articulated systems) will also enable passenger access/egress in limited time. Increased dwell time can significantly affect saturation at station and therefore the capacity of the system.

Fleet composition
A critical parameter that separates BRT from other bus systems is the fleet type. A unique fleet type with a unique interface at stations enables faster boarding/alighting and therefore reduced dwell time. Although inadvisable, in the case that different fleet types (enabling level as well as stepped boarding) are used on the same corridor (e.g. Delhi), the system saturates faster owing to higher dwell times. The model should allow the user to specify the fleet type (i.e. percent of each type of bus) for each segment. In the current model, this parameter has not been considered. The only option available to the user is to define two different segments with different fleet types, but multiple bus types cannot be combined on the same segment.

Bus capacity
In most Colombian and Mexican BRTs, articulated buses (18 m) have a maximum capacity of 160 passengers, while the BEAD tool has a default of 110. Similarly, bi-articulated buses (24 m) have a capacity of 240 passengers but the BEAD tool assumes a capacity of only 160. The default values in BEAD tool reflect standards in Europe, where average size of people is larger than in those in India. Further, social norms have an implication on density of people standing.

Passenger access to closed systems
The model assumes that all passengers on closed systems arrive via feeder bus. However, many passengers arrive by foot even in closed systems. For example, walking accounts for 50-60 percent of access and egress trips to/from Ahmedabad's Janmarg system.[8]

Maximum signal cycle
The model sets an upper limit on signal cycle length of 225 seconds.[9] The limit is arbitrary and should be removed to accommodate longer signal cycle lengths. While it is understood that very long signal cycles are not advisable, the limit artificially suppresses what has been noticed on ground. For example, the Chirag Delhi intersection in Delhi has been observed to operate on a cycle of approximately 360 seconds.[10]

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[8] Ahmedabad Janmarg 14th Monthly Report.

[9] BEAD Draft Final Report, p 44.

[10] ITDP observation, August 2011.

Comments by ITDP, page no. 3

Intersection design

The model documentation does not explain the methodology for accounting for a two-phase squareabout intersections, as found in the Janmarg BRT system in Ahmedabad.[11]

Bus delay

For staggered stations, model assumes that "bus delay is in no condition longer than the signal cycle."[12] However, if the platform is not long enough to accommodate boarding and alighting from all of the buses that accumulate during a signal cycle, buses that have not docked at the station while the light is red may not be able to proceed through the junction during the same cycle because they may need to spend all of the green phase docked at the station to allow passengers to board/alight. It has been observed on ground in Delhi that buses allow passengers to board and alight even before they get a chance to dock at a platform to avoid waiting for an additional cycle or more. In effect, they treat the area before platforms as an extension of the platform.

Land use

There is no definition of "high density, low to medium income, and mix of commercial and residential" land use, a parameter included in the model. More details on income and population density/growth could help improve the model.

MODEL OUTPUT

Inconsistencies in mixed traffic speeds

There is a bit of confusion when observing the benefits of BRTs as shown in the output. For example, configuring the model for the Guadalajara BRT system (see Case Studies, below) indicates that BRT saves time in comparison with using private transport (-22.8 min) as well as conventional buses (6.3 min). The first value makes sense, as the BRT will save passengers 23 minutes compared to using cars. However, compared to conventional buses, BRT seems to add additional minutes to the commute. At least this is the way that this could be interpreted. There are two issues with this information: first, the data are not in same format (negative versus positive), which is misleading; and second, if conventional buses are in mixed traffic there should be a delay of at least 23 minutes.

"Current demand" and capacity

The model presents two passenger throughput figures: "Capacity in PPHPD" and "Current Demand in PPHPD." It is not clear how "Current Demand" is calculated, given that the user at no point enters any demand data.

Improvement arrows

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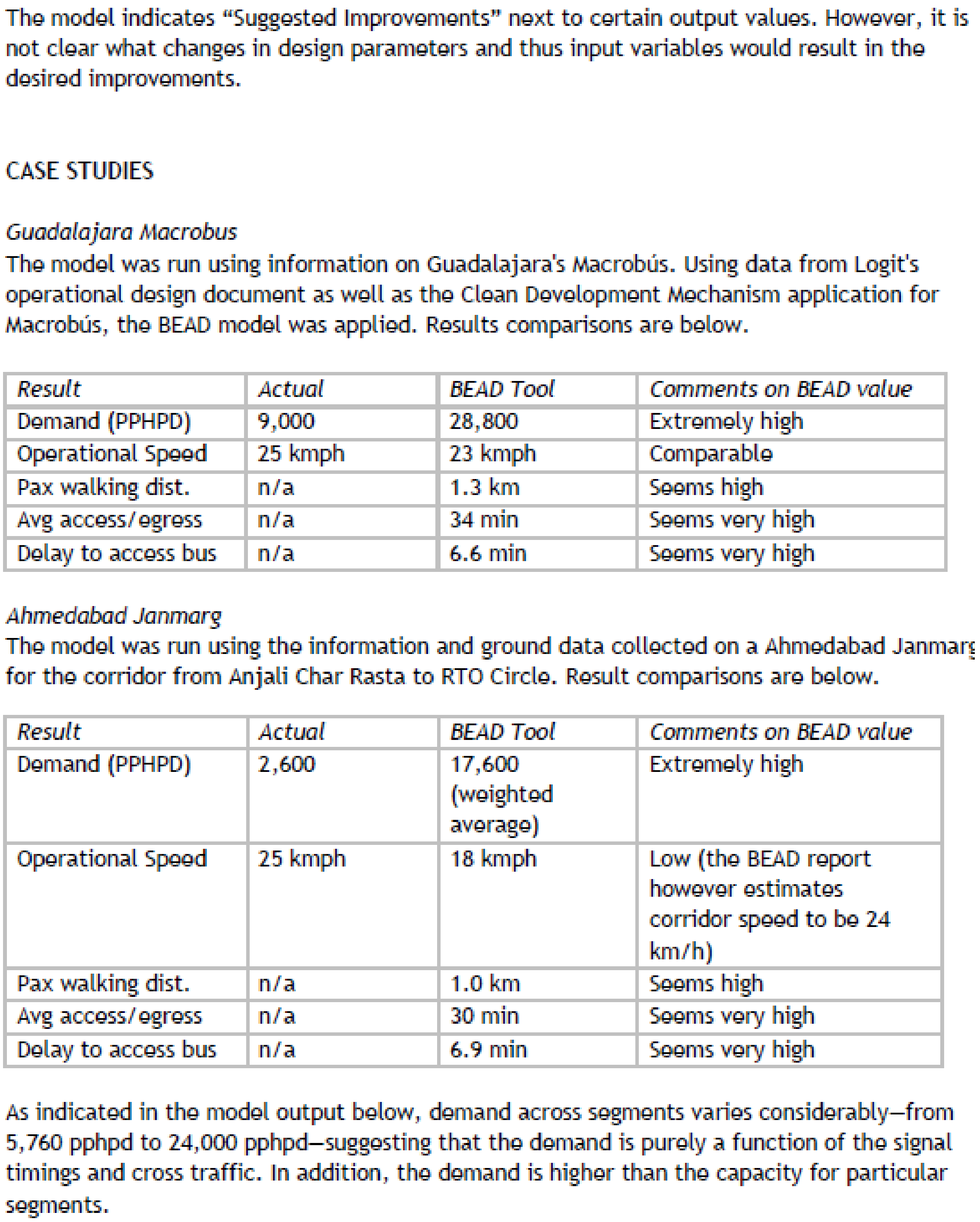
[11] Akhbar Nagar, Nehrunagar, Anjali, and Narol junctions in Ahmedabad have this type of design. This type of design has also been employed in Delhi (on non-BRT sections) and in other cities worldwide.

[12] BEAD Draft Final Report, p 36.



The model indicates “Suggested Improvements” next to certain output values. However, it is not clear what changes in design parameters and thus input variables would result in the desired improvements.

CASE STUDIES

Guadalajara Macrobus

The model was run using information on Guadalajara's Macrobús. Using data from Logit's operational design document as well as the Clean Development Mechanism application for Macrobús, the BEAD model was applied. Results comparisons are below.

Result	*Actual*	*BEAD Tool*	*Comments on BEAD value*
Demand (PPHPD)	9,000	28,800	Extremely high
Operational Speed	25 kmph	23 kmph	Comparable
Pax walking dist.	n/a	1.3 km	Seems high
Avg access/egress	n/a	34 min	Seems very high
Delay to access bus	n/a	6.6 min	Seems very high

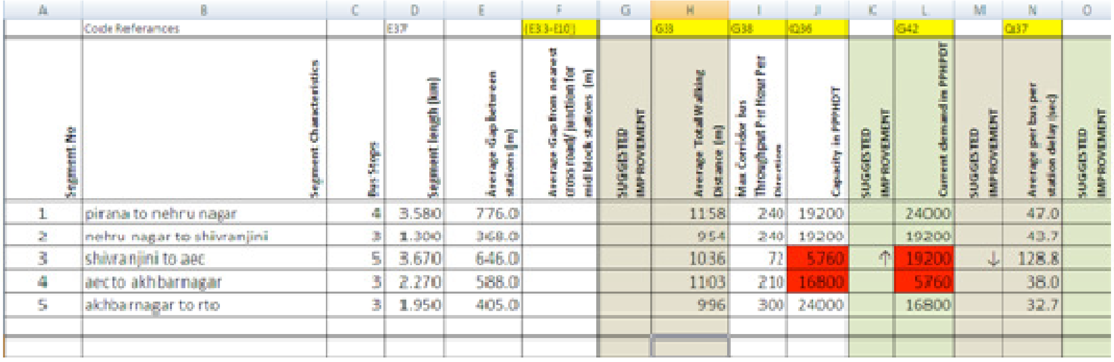
Ahmedabad Janmarg

The model was run using the information and ground data collected on a Ahmedabad Janmarg for the corridor from Anjali Char Rasta to RTO Circle. Result comparisons are below.

Result	*Actual*	*BEAD Tool*	*Comments on BEAD value*
Demand (PPHPD)	2,600	17,600 (weighted average)	Extremely high
Operational Speed	25 kmph	18 kmph	Low (the BEAD report however estimates corridor speed to be 24 km/h)
Pax walking dist.	n/a	1.0 km	Seems high
Avg access/egress	n/a	30 min	Seems very high
Delay to access bus	n/a	6.9 min	Seems very high

As indicated in the model output below, demand across segments varies considerably—from 5,760 pphpd to 24,000 pphpd—suggesting that the demand is purely a function of the signal timings and cross traffic. In addition, the demand is higher than the capacity for particular segments.

Comments by ITDP, page no. 5



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Code Referances		E37		(E33-E10)		G33	G38	Q36		G42		Q37	
Segment No	Segment Characteristics	Bus Stops	Segment length (km)	Average Gap between stations (m)	Average Gap from nearest cross road/ junction for mid block stations (m)	SUGGESTED IMPROVEMENT	Average Total Walking Distance (m)	Max Corridor bus Throughput Per Hour Per Direction	Capacity in PPHPDT	SUGGESTED IMPROVEMENT	Current demand in PPHPDT	SUGGESTED IMPROVEMENT	Average per bus per station delay (sec)	SUGGESTED IMPROVEMENT
1	pirana to nehru nagar	4	3.580	776.0			1158	240	19200		24000		47.0	
2	nehru nagar to shivranjini	3	1.300	368.0			954	240	19200		19200		43.7	
3	shivranjini to aec	5	3.670	646.0			1036	72	5760	↑	19200	↓	128.8	
4	aec to akhbarnagar	3	2.270	588.0			1103	210	16800		5760		38.0	
5	akhbarnagar to rto	3	1.950	405.0			996	300	24000		16800		32.7	

According to Janmarg's monthly report, up to 60 percent of passengers access the system by foot, while 20 percent use a feeder bus. This implies that the majority of the passengers live within walking distance of the system, in contrast to the assumption made on the trips by mode of access to BRT.[13]

CONCLUSION

The BEAD tool has potential for estimating time savings and other operational impacts of well designed BRTs. However, much more work is needed to ensure that the model produces robust, consistent results.

More transparency in terms of the model assumptions is required, and the tool developer should reach out to other professionals to reach consensus over:

- Standard design parameters
- Default values used
- Assumptions used

Interrelationships between the performance parameters and system design are not clear and therefore do not help an user understand and interpret the results from the model. The lack of clarity in the processes can also lead to different results when evaluated by different persons. Given the complexity of the tool, city officials with limited experience and capacity in BRT and transport planning in general will face considerable difficulty in understanding it as well as using the model.

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[13] BEAD Draft Final Report, p 129.

Annexure 12 – Response to Comments by ITDP

Most of the comments provided by ITDP could be addressed by better explanation and/or clarification, however some of them were used in the improved of draft BEAD tool version 1.68 to Final BEAD tool version 1.69. The explanations these comments were submitted by IUT to ITDP on April 23, 2012 and the same are presented below.

Response/Clarifications to Comments by ITDP on BEAD Tool

ITDP has provided detailed feedback on BEAD tool on April 13, 2012. The comments are detailed and clear. ITDP comments were categorized into three categories: (1) clarification, (2) user manual - draft final report, and (3) tool specific. Comments in the clarification category have resulted in better explanation and rephrasing of BEAD model processes and definitions. User manual - draft final report category comments lead to specific improvements and corrections in the BEAD user manual and the Draft final report (Now Final Report). The third category of comments resulted in improvements in the tool and is being incorporated in the final version of BEAD. Table 1 below provides a brief summary of these comments and is followed by detailed response/clarifications.

Table 1: List of comments provided by ITDP as well response and action taken by BEAD development team.

Comment	**Response**	**Action Taken**
Refer Indicators from other tools such as TEEMP	Explanation provided	No action required
BEAD limitations in capacity estimates	Explanation provided	No action required
BEAD model assumptions questioned	Explanation provided	No action required
Per passenger boarding alighting time used in default values	Explanation provided	No action required
Dwell time used in BEAD default values	Explanation provided	BEAD final/revised tool will allow disaggregation of dwell time by no. of passengers and rate of passenger entry/exit
Model does not allow using different fleet types	Explanation provided (methods explained)	No action required
Model does not take in to account no. and width of bus doors	Modification required to BEAD tool	Will be included in the revised/final version of the tool
Default values of bus capacity	Explanation provided – Edition required in BEAD final report and user manual	Max capacity limit for bi articulated bus will be revised in the BEAD revised/final tool
Walk feeder trips to BRT not accounted for	Explanation provided – typographical error needs to be removed from BEAD final report	BEAD final report will included an improved/corrected explanation of this point
Upper limit of signal time set to 225 seconds	Modification required to BEAD tool	The BEAD final/revised tool will now include an upper limit of 600 seconds for signal cycles
Model documentation does not provide methodology for modelling 2 phase square bouts	Explanation provided – Edition required in BEAD final report and user manual	The BEAD final report will now carry an explanation on the same

Comment	Response	Action Taken
Model assumption of bus delays not exceeding 1 signal cycle length are unrealistic	Explanation provided	No action required
There is no definition of high density, low to medium income groups.	Explanation provided – Edition required in BEAD final report and user manual	The BEAD final report and user manual will carry additional explanation
Confusion regarding interpretation of BEAD output results	Explanation provided	Explanation in User Manual will be improved
Estimation of current demand by Tool	Explanation provided	No action required
Changes required to carry out design improvements not explained	Explanation on where this is listed provided	No action required
Unreliable results by the model in validation on existing case studies	Explanation on each result output provided	No action required
BEAD is showing higher demand than capacity for some segments in Janmarg validation	This needs attention in the tool, as may be caused by a bug in the tool.	Request for sharing the BEAD output file of the validation, so as corrective action can be undertaken
Motorized feeder trip length distribution along Janmarg corridor does not match the assumptions in the tool	Explanation Provided – Although some corrective action can be taken on the tool	BEAD development team is considering making non-walk feeder trip length distribution editable

General Comments

"In addition, it is difficult to interpret the results and identify what design modifications would produce better outcomes. ITDP suggests that the developers of BEAD consider recent efforts to quantify the factors contributing to high levels of BRT system performance. These include the BRT Standard, which is embedded in the Transport Emissions Evaluation Models for Projects (TEEMP) toolkit, endorsed by the Global Environmental Facility for appraisal of emissions impacts of BRT projects."

The BEAD user manual includes a dedicated chapter on interpreting the results against each indicator in (Chapter 3). The arrow display besides each parameter on BEAD results page allows users to undertake design improvements targeted to improve system performance. Chapter 3 of the BEAD user manual includes detailed tables listing a variety of strategies that can be adopted by each city to address specific design shortcomings as indicated by arrows besides each parameter result. BEAD tool indicators have evolved after discussion with different stakeholders including city officials, consultants, operators, regulators, research institutes, and CSOs in two different workshops totalingthree days. These indicators have been specifically selected to cover three major stakeholders in a BRTS project, i.e. user of the system, system operator and the society at large. The main difference between BEAD approach and the TEEMP toolkit is that BEAD is based on quantitative evaluation of performance indicators. The quantitative evaluation is based on standard motion equations such as those listed by Vukan R. Vuchic. TEEMP examines qualitative indicators. Thus, both the toolkits use fairly different indicators. BEAD looks as passenger speed, commercial speed, walking distances, bus delays, passenger delays, access time, etc. as indicators while TEEMP looks at bus maintenance, off vehicle fare collection, presence of system control centre, if other vehicles use the corridor, etc. BEAD and TEEMP though can complement each other. For example the impact of many of indicators such as use of off board ticketing, use of routes other than BRT in the corridor, etc., on passenger speeds and thus the mathematical utility to use the system can be quantified as associated delays in BEAD.

"One of the key outputs of the BEAD model is the capacity of the BRT system in terms of buses and passengers per hour. Of concern is BEAD's presentation of system capacity as a single value. BRT capacity is best thought of in terms of the relationship between capacity and other parameters such as station saturation. For example, while it may be theoretically possible to achieve throughput over 9,000 passengers per hour per direction (pphpd) for a single lane without passing lanes at stations, this can be done only at very high saturation and very low commercial speed."

BEAD tool defines a number of factors that affect capacity. Amongst them are station design i.e. number of simultaneous boarding bays at station, signal cycle design i.e. the no. of buses that can be throughput in each cycle, station locations i.e. near or far side of junction, presence or absence of overtaking lane, bus capacity, etc. Similarly station saturation is a function of station design and associated signal cycle design. For example if a signal cycle is three minutes long and allows a maximum of four buses to be throughput during the green phase (based on the length of green phase), the maximum capacity possible is 4*(60/3) = 120 buses per hour per direction. The **tool defines capacity as the number of buses that can be throughput by the system without experiencing delays which are more than one signal cycle length** and thus in that way it addresses the question of saturation. This point has been explained in detail as an explanation to related specific comment below. The impact of high saturation on commercial speeds is also well accepted. However because of the definition of capacity mentioned above, these conditions do not arise in the model output as the capacity is limited by the saturation condition as mentioned above.

The tool does not provide a theoretical capacity of 9000pphpd in an open system without an overtaking lane (it is limited to 4500 to 5400). However it does provide this capacity for a closed system without overtaking lanes. The methodology used by the tool is estimating these have been explained in detail in part 2j(i) of section 3.3.2.1 of the draft final report, and has been articulated below by using the example of 9000 pphpd (mentioned in the comment).

It can be shown that system capacity has different relation to the presence of absence of overtaking lane for buses, for open and closed systems. If a bus is assumed to carry 6 to 80 passengers on an average, 112 to 150 buses per hour per direction are required to provide the said capacity of 9000pphpd. If bus stations with three simultaneous boarding bays are assumed in a **closed system** with 60 second signal cycle (all turns restricted), it is possible to throughput 3 to 5 buses without a problem in a single lane per cycle (**no overtaking lane required**). This allows a total throughput of 180 to 300 buses per hour per direction. However if the buses are allowed to turn at the junction in an **open system**, 60 second signal cycle is not possible, and the tool shows that under such conditions even with 120 to 150 second signal cycle it may not be possible to throughput more **than 4500 to 5400pphpd**. This is because a dedicated bus phase is required which is typically not more than 10 to 20% of the cycle length, and can throughput a maximum of 3 buses per cycle, making a total in 25 to 30 cycles to 75 to 90 buses. However in an open system it can be enhanced to 9000pphpd by providing an overtaking lane which allows a much longer green phase for the majority straight moving buses.

The above example has been used to demonstrate that the tool does not use capacity estimation as a linear function of any one variable and is a result of complex multivariable estimates. These estimates are also sensitive to station saturation, design factors such as presence or absence of overtaking lane, operation type, station location, number of boarding bays per station and safety factors such as safe stopping distance at defined bus peak speed (between cruising buses) etc.

General Comments on Model Assumptions

As explained in the meeting with ITDP on March 02, 2012 the model assumptions mentioned in the default values form is to provide base calibrated default values where adequate detailed data are unavailable. All values are editable and allow users to calibrate their own results.

Specific Comments

"The model assumes 1.67 seconds per boarding or alighting (per door) for low-floor buses from a platform of the same height based on observations in the Delhi BRT system. However, the boarding time in Ahmadabad has been observed as 0.83 seconds (per door)."

As explained in the report on page 32, the 1.67 second per passenger value accounts for **boarding/alighting per door** since data are collected separately for boarding and alighting and is separate for each door**. Data collected in Ahmadabad is from 1 of 1 door in the bus, whereas that in Delhi is from 1 of 2 doors in the bus**. The two results cannot be compared directly. In order to compare the two, it is appropriate to half the average time value from data collected in the Delhi study in order to include the simultaneous boarding alighting from the second door. Thus for Delhi data, per passenger boarding and alighting is approximately 0.835 sec. This corresponds exactly with the 0.83 sec survey conducted by ITDP in Ahmadabad.

"The dwell time is assumed to be a standard input value of 14 sec irrespective of the total number of passengers boarding/alighting at any station by considering only 10% of the bus capacity as passenger interchanges."

The 14 second dwell time is a default value estimation based on an average 10% interchange on a bus carrying 60 passengers. Since model results are averaged across all stations, this is considered a reasonable assumption. However the model allows editing of these default values. And as agreed during a discussion with ITDP team in Delhi, the tool will further include detailed breakup of the dwell time estimation, by allowing users to change average number of passengers interchanging at each station and average boarding/alighting time per passenger.

"A critical parameter that separates BRT from other bus systems is the fleet type. A unique fleet type with a unique interface at stations enables faster boarding/alighting and therefore reduced dwell time. Although inadvisable, in the case that different fleet types (enabling level as well as stepped boarding) are used on the same corridor (e.g. Delhi), the system saturates faster owing to higher dwell times. The model should allow the user to specify the fleet type (i.e. percent of each type of bus) for each segment."

The interface between bus and station that enables faster boarding and alighting is level boarding and close docking of buses. The tool builds in this function and allows the user to define number of steps that a passenger encounters while accessing a bus from the station and vice versa. Time penalty for each step added in this transition can be defined in the default values tab, and the default value on the basis of primary survey conducted in Delhi is one second. The current architecture of the tool allows segmentation of the corridor based on infrastructure design differences only and not on the basis of fleet variations. This is because a constant and uniform fleet composition is expected on the corridor. However it is possible to generate results for different types of fleets used in the corridor and generate aggregate results based on the composition of each fleet type. For example, if a corridor uses 40% low floor buses, 40% buses with one step entry to bus and 20% buses with 2 step entries to the bus. The BEAD model could be run thrice, each time defining different fleet type as 100% of the bus fleet, and then the results, A, B and C for each parameter, aggregated as (0.4*A) + (0.4*B) + (0.2*C). An easier method is to define the time penalty for step entry in a bus in the default value form, as a weighted average of the fleet composition and penalty involved for each fleet type.

"The model does not take into account the number, width, or arrangement of bus doors. Greater the width, higher will be the passenger flow, and hence significantly lower the dwell time. Similarly, a larger number of doors (as in the case of articulated and bi-articulated systems) will also enable passenger access/egress in limited time."

Wide agreement exists on this point, and the same was conveyed to the visiting ITDP team during the March 02 meeting. The revised model now accounts for the impact of number of doors and the door width on the dwell time.

"In most Colombian and Mexican BRTs, articulated buses (18 m) have a maximum capacity of 160 passengers, while the BEAD tool has a default of 110. Similarly, bi-articulated buses (24 m) have a capacity of 240 passengers but the BEAD tool assumes a capacity of only 160. The default values in BEAD tool reflect standards in Europe, where average size of people is larger than in those in India."

BEAD tool estimates on capacity are based on averages. It is reasonable to assume that a bus would not be packed to capacity throughout the length of its route. Bus capacity values used in the default values form are based on σ value of 0.8 instead of 1 for maximum capacity. The tool allows user to define a higher value with a maximum of 160 for articulated bus and 200 for bi-articulated bus as referred on page 38 of BEAD user manual. However, in line with the observation of maximum capacity of bi-articulated buses, we have revised the maximum editable default value for bi-articulated bus capacity in the default value form to 240 from existing 200 while retaining the default values in the tool as explained above.

"The model assumes that all passengers on closed systems arrive via feeder bus. However, many passengers arrive by foot even in closed systems. For example, walking accounts for 50-60 percent of access and egress trips to/from Ahmedabad's Janmarg system."

The model divided passenger origin and destination into four zones:

- Zone 1 - 0-500m,
- Zone 2- 500m to 1000m
- Zone 3 - 1000m to 2000m
- Zone 4 - 2000m to 3000m

The model assumes bus based feeder trips only for Zones 2through 4 and not for Zone 1. All O-D within Zone 1 is taken as walk based feeder trips. The number of trips from Zone 1 varies with the average trip length in the corridor and the land use surrounding the corridor. This is presented on figure 67, page 129 in Annexure 5 of the BEAD draft final report and also mentioned in point 8, page 23 of the same report. The variation in the trips originating from Zone 1, walk based feeder to BRT, varies between 15 to 100% depending on the conditions mentioned. This covers the current condition in Ahmadabad. The final report now includes this explanation of the point raised.

"The model sets an upper limit on signal cycle length of 225 seconds. The limit is arbitrary and should be removed to accommodate longer signal cycle lengths. While it is understood that very long signal cycles are not advisable, the limit artificially suppresses what has been noticed on ground. For example, the Chirag Delhi intersection in Delhi has been observed to operate on a cycle of approximately 360 seconds."

The signal cycle length mentioned on page 44 of BEAD draft final report is a typographical error. is the length has a maximum of 300 seconds as mentioned on page 41 of the BEAD user manual. However based on this point the BEAD development team is currently revising this limit to 600seconds, and so the final version of the tool will address this comment.

"The model documentation does not explain the methodology for accounting for a two-phase Square about intersections, as found in the Janmarg BRT system in Ahmedabad"
The model allows evaluation of 2 phase roundabout junctions, which are similar in characteristics square about junctions.

"For staggered stations, model assumes that "bus delay is in no condition longer than the signal cycle."12 However, if the platform is not long enough to accommodate boarding and alighting from all of the buses that accumulate during a signal cycle, buses that have not docked at the station while the light is red may not be able to proceed through the junction during the same cycle because they may need to spend all of the green phase docked at the station to allow passengers to board/alight. It has been observed on ground in Delhi that buses allow passengers to board and alight even before they get a chance to dock at a platform to avoid waiting for an additional cycle or more. In effect, they treat the area before platforms as an extension of the platform."
As explained on page 36 of the BEAD draft final report **the delay and capacity of the system are interlinked**. The capacity estimation in the tool takes the **maximum delay equivalent to one signal cycle for a bus as a limiting factor**. For the given capacity of the system, as generated as a part of the output of the tool, the maximum bus delay is never longer than the signal cycle length. This typically results in lower capacity for near side stations than for far side stations (explained in point 2j(ii) of section 3.32.1), however the trade off means that far side station per bus delay is higher at enhanced capacity (than at near side of staggered stations).
As for the case in Delhi, when this condition is replicated in the tool, it shows that for a 360 second signal cycle the peak capacity of the system shall be close to 100 buses per hour per direction, which is less than current demand of 120 to 140 buses per hour per direction. This explains the queuing of buses resulting in delays longer than a signal cycle length.

"There is no definition of "high density, low to medium income, and mix of commercial and residential" land use, a parameter included in the model. More details on income and population density/growth could help improve the model."
The final report and the BEAD final user manual now carries a description on this parameter. This parameter is used to allow the tool to pick between two sets of assumptions for percentage breakup of trips from different catchment distances from the corridor as presented on Figure 67 on page 129 of the draft final report.

"There is a bit of confusion when observing the benefits of BRTs as shown in the output. For example, configuring the model for the Guadalajara BRT system (see Case Studies, below) indicates that BRT saves time in comparison with using private transport (-22.8 min) as well as conventional buses (6.3 min). The first value makes sense, as the BRT will save passengers 23 minutes compared to using cars. However, compared to conventional buses, BRT seems to add additional minutes to the commute."
Since the output is in time saving, positive value means positive time saving., Hence BRT will save 6.3 minutes in a passenger point to point journey over regular buses in mixed condition. Similarly a negative value for time saving means the inverse, i.e. time lost. The output shows that if a passenger in the car took the same journey by BRT bus, the passenger will lose 22.8 minutes. As this travel time accounts for door to door journey, it is consistent with global findings. This is because any public transport is dependent on access, which is mostly walk i.e. first and last mile connectivity. This access and egress is the slowest component of the journey which results in lower passenger speeds for any transit system. As compared to BRT buses, cars have none or negligible access time, and thus are much faster than buses. One can look for pointers to this inference from the results as the results also present total walk distance and access + egress time for the system. It is also interesting to note that since the tool allows defining parking distance at origin and destination and average

speed of vehicles in the city/corridor one can try lowering the average speed of motor vehicles in the city and increasing the parking distance at O-D to arrive at a combination of effects targeted at private motor vehicle use to make public transport more attractive against private transport.

"The model presents two passenger throughput figures: "Capacity in PPHPD" and "Current Demand in PPHPD." It is not clear how "Current Demand" is calculated, given that the user at no point enters any demand data."

The tool takes the input of demand in terms of buses per hour per direction in the 'edit results form' as mentioned on page 86 of the user manual. This allows the user to model the current or expected demand and is useful for validating the tool or for performance evaluation at some given demand levels. If no value is provided by the user for 'user input on buses per hour per direction' the tool assumes the capacity of the system as the default value for demand. To better explain this point the user manual now includes additional explanation on interpreting this part of the output.

"The model indicates "Suggested Improvements" next to certain output values. However, it is not clear what changes in design parameters and thus input variables would result in the desired improvements."

Section 3.1 of the user manual is dedicated to interpreting the results, and lists all possible interventions that can be applied to improve the results. This has been presented in detail for each arrow for each associated output parameter in the results page in Table 3-2, page 18 to 24.

"However, a review of the BEAD tool and application to one case in Guadalajara, Mexico and one case in Ahmedabad, India, shows that it produces unreliable results and it fails to account for a number of important BRT system design parameters.

Guadalajara Macrobus

The model was run using information on Guadalajara's Macrobús. Using data from Logit's Operational design document as well as the Clean Development Mechanism application for Macrobús, the BEAD model was applied. Results comparisons are below."

Result	*Actual*	*BEAD Tool*	*Comments on BEAD value*
Demand (PPHPD)	9,000	28,800	Extremely high
Operational Speed	25 kmph	23 kmph	Comparable
Pax walking dist.	n/a	1.3 km	Seems high
Avg access/egress	n/a	34 min	Seems very high
Delay to access bus	n/a	6.6 min	Seems very high

The results can be explained as following:

Demand – As mentioned above, if the current observed bus demand and associated average bus occupancy in the default form is not defined, the BEAD tool takes the capacity as the default value for demand. Thus, here 28,800 PPHPD is defining the peak capacity of the system and not the demand. The demand is not estimated by the tool but taken as an input in the edit results form in the form of buses per hour per direction.

Operational speed – 23km/h is the speed estimated by the tool at peak capacity because no demand current bus demand was defined. It is observed that operational speeds of systems with far side stations, operating at peak capacity are approximately 10 - 20% lower than at lower demands. As Guadalaraja Macrobus uses an island station with at least one direction station on the far side of the junction, it is likely that the operational speeds generated by the tool would be closer to 25 km/h once the current bus demand is input in the tool.

Pax walking distance – 1.3km is the sum total of average walking involved in the first and last mile of the journey. So the breakup of say access should total to about 650m. If the catchment for walk trips to the corridor is taken as 500m, and the average gap between station is 800m, then the average walking distance is 250m (average depth of the zone) + 200m (average walking distance to any station along the corridor). In addition, the tool estimates crossing distance totaling to 100m estimated by tool, based on station length, gap of station from junction, crossing distance/ROW, etc.. If the trip is made by a feeder mode, the default distance of feeder station from corridor is 150m. Thus for each direction, access and egress, 150m is added. While average walking distance for walk feeder can be expected to be 550*2 = 1100m, those for trips based on feeder bus can be estimated as 700*2 = 1400m. Thus, depending on the land use and average trip length defined, the tool would have assigned a breakup of trips from different O-D distances from the corridor, applying those weights between say low and high values of 1.1 and 1.4km, the tool would have estimated 1.3km. The value appears logical and in the expected range of about 0.9 to 1.8km.

Avg. Access/Egress Time 34min - This is estimated by the tool based on the average trip length in the city and the kind of land-use affecting the distribution of trips from different catchment distances off the corridor. Since 1.3km walking as explained above would entail 1300 seconds of walking time at default walking speeds of 1m/s. Bus based feeder would entail waiting time for feeder buses at both ends in addition to waiting time for BRTS bus on the trunk route Assuming four-minute frequencies, average wait time would be 2*3 = 6 minutes. In addition, the tool estimates waiting time at signal, waiting time for crossing side feeder roads. Assume this total to an average of 30 seconds each, thus total waiting time in crossings = 30*6 including average crossing for feeder buses = 180 seconds or 3 minute. In addition, depending on the speeds on the mixed roads, and assume average distance of 1.5km by feeder bus on each end of the trunk line journey would consume about 9 to 12 minutes, roughly 10 minutes. This shows that while access + egress time for walk trips would be about 24 minutes, those by bus feeder would be about 40 minutes. Depending upon different factors specified and the trip O-D distribution off the corridor assigned by the tool, the average is expected to be in the range of 30 to 35 minutes. The result fits that expectation.

Delay to access bus – 6.6minutes – This delay estimation is based on crossing time lost, average walking time from the middle of cross road to the middle of the BRTS station, and waiting time for the bus. The calculation example shown above, presents the reason why 6.6minutes is in line with experienced time on the ground.

Ahmedabad Janmarg

"The model was run using the information and ground data collected on a Ahmedabad Janmarg for the corridor from Anjali Char Rasta to RTO Circle. Result comparisons are below."

Result	*Actual*	*BEAD Tool*	*Comments on BEAD value*
Demand (PPHPD)	2,600	17,600 (weighted average)	Extremely high
Operational Speed	25 kmph	18 kmph	Low (the BEAD report however estimates corridor speed to be 24 km/h)
Pax walking dist.	n/a	1.0 km	Seems high
Avg access/egress	n/a	30 min	Seems very high
Delay to access bus	n/a	6.9 min	Seems very high

The results can be explained as following:

Demand – As mentioned above, if the current observed bus demand and associated average bus occupancy in the default form is not defined, the BEAD tool takes the capacity as the default value for demand. Thus here 17,600 PPHPD is defining the peak capacity of the system and not the demand. The demand is not estimated by the tool but taken as an input in the edit results form in the form of buses per hour per direction.

Operational speed – Validation using JanmargBRT conducted by the development team showed results of 23.5km/h and 25km/h when data with different levels of details was used. Both match with the observed commercial speeds of 25km/h. Most likely reason for the reduced commercial speed is that the user may have failed to notice that the model modifies input signal cycle based on the input junction details. This sometimes leads to signal cycle being increased by up to 50% on the results page. Besides lowering commercial speed, this can also lower the capacity of the system as explained in Chapter 3 of the user manual. The signal cycle can be corrected by going to the edit results page, and manually changing the signal cycle back by using the 'Edit Results Button' on the result pages. Additional reason for lower than observed speeds being presented by the tool could be that it is estimating performance at peak capacity as explained above and not as per current demand. To accurately pinpoint the reason for this discrepancy, the comparison between the two BEAD output files can be helpful. BEAD development team has shared the output file for this validation with Shakti foundation to be shared with ITDP team.
Pax walking distance – 1.0 km - This can be explained by the dummy example used to explain *Guadalajara Macrobus*results above. Based on that, it can be said that it is in line with the expected results.
Avg. Access/Egress Time 30 min - This can be explained by the dummy example used to explain *Guadalajara Macrobus* results above. Based on that, it can be said that it is in line with the expected results.
Delay to access bus – 6.9 minutes – This can be explained by the dummy example used to explain *Guadalajara Macrobus* results above. Based on that, it can be said that it is in line with the expected results.

"As indicated in the model output below, demand across segments varies considerably—from 5,760 pphpd to 24,000 pphpd—suggesting that the demand is purely a function of the signal timings and cross traffic. In addition, the demand is higher than the capacity for particular segments."
The demand cannot exceed capacity as per the algorithms defined in the tool. It needs to be investigated if a bug in the tool is leading to this error. If the BEAD output file for Jnamarg is shared, it would be helpful. The variation can be due to signal timings.

"According to Janmarg's monthly report, up to 60 percent of passengers access the system by foot, while 20 percent use a feeder bus. This implies that the majority of the passengers live within walking distance of the system, in contrast to the assumption made on the trips by mode of access to BRT."
Janmarg currently sees very low ridership of less than 3000 pphpd. Lack of feeder access to the system may be one reason behind it and that is what is reflecting from the current data, i.e., 60% walk and 40% non walk feeder. However if the ridership on the corridor has to increase, matching its unutilized capacity, it will need to expand its catchment and evidently non-walk feeder will see an increase in proportion. BEAD tool assumes feeder trip distance distribution **at (or closer to) capacity** based on average trip length specified for the corridor and the land use selected. As mentioned earlier, walk trips can vary between 15 to 100% based on these factors. For mixed land use, the percentage of walk feeder trips is 60% for 3.5 to 4.5km average trip length, 50% for 4.5 to 5.5 km average trip length, 40% for 5.5 to 6.5km average trip length and 30% for average trip lengths greater than 6.5km. The Janmarg study is pointing at a possible need to include a user defined non-walk feeder trip length distribution based on **current demand** for situations where the current demand is substantially lower than say expected 8000 to 10000 pphpd figures. The BEAD development team will look in to the feasibility of including this in the tool.

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Janmarg: BRTS Ahmedabad (8th Month MIS).2010. Janmarg.

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