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Integrated Smart Feeder/ Shuttle Bus Service

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Integrated Smart Feeder/Shuttle Bus Service

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ABSTRACT

This paper presents the design of an integrated smart feeder/shuttle system. The design of such a system was motivated by the need to provide easy access to main haul transit services. Park and ride lots in many train stations can no longer accommodate automobiles brought to the stations. Some train riders have switched their mode of transportation from public transit to solo driving. Shortage of parking spaces at rail stations encourages passengers to drive alone, hence more cars on freeways and worsening traffic congestion. The purpose of this study is to design an innovative feeder/shuttle system that will 1) meet the needs and desires of end users, 2) utilize intelligent transportation technologies, and 3) increase the operational efficiency.

Ideally, this smart feeder/shuttle system should be attractive to consumers because the service should be reliable and routing/scheduling should be flexible enough to meet the needs of riders. Among the attributes are the provision of door-to-door services and smooth and synchronized transfers between main haul and collector transit systems. To design an innovative feeder/shuttle system, new integrated and routing concepts have been developed. Ten different routing strategies are examined, including combinations of fixed/flexible routes, fixed/flexible schedules, one or bi-directional approaches, and short-cut (shortest path) and/or short-turn (turn around) concepts. The evaluation of these strategies is performed using a simulation model which is developed and constructed for this project. This simulation tool allows for the examination of: (a) various operating strategies from the user and the operator perspectives, (b) different routing models and scenarios, and (c) different real-time communication possibilities between the user, operator and a control center. This simulation model is used in a case study of Castro Valley in Alameda County, California. In this case study the feeder/shuttle service is coordinated with the Bay Area Rapid Transit (BART) service and the ten routing strategies are compared while using four fleet sized scenarios.

KEYWORDS : Feeder/Shuttle Transit Service, Advanced Public Transit Systems, Demand Responsive Transit, Simulation, Case Study, California

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EXECUTIVE SUMMARY

Increased demand for automobile use to and from train or express bus stations is identified as a major problem in the support of main haul public transit systems in growing urban and suburban communities in the US. A need for innovative solutions to the transit feeder service problem is apparent. The known transportation objectives for any residential community are to: 1) find a reasonable-cost approach in order to ease traffic congestion, 2) eliminate parking problems, 3) reduce road accidents and 4) improve the pollution level. Such a reasonable-cost approach must rely on an attractive, well distributed, and comfortable public transit system. However, many communities are not able to achieve these objectives. Among the reasons are: a user-unfriendly transit system, insufficient funding, inadequate level of service, ineffective marketing strategies, and the high cost of transit operation.

To improve the feeder system, a personalized demand responsive transit (DRT) service is investigated. Our innovation is an integrated smart feeder/shuttle system. The integrated smart feeder/shuttle system is a public transit system that offers flexible schedule, easy access, door-to-door service, and smooth and synchronized transfers between the feeder and main haul transit services.

The purpose of the present study is to design an innovative feeder/shuttle system that will 1) meet the needs and desires of end users, 2) utilize intelligent transportation technologies, and 3) increase the operational efficiency. Ideally, this smart feeder/shuttle system should be attractive to consumers because the service should be reliable and routing/scheduling should be flexible enough to meet the needs of riders. To design an innovative feeder/shuttle system, new integrated and routing concepts have been developed.

Ten different routing strategies are examined, including combinations of fixed/flexible routes, fixed/flexible schedules, one or bi-directional approaches, and short-cut (shortest path) and/or short-turn (turn around) concepts. The evaluation of these strategies is performed using a simulation model which is developed and constructed for this project. This simulation tool allows for the examination of: (a) various operating strategies from the user and the operator perspectives, (b) different routing models and scenarios, and (c) different real-time communication possibilities between the user, operator and a control center. This simulation model is used in a case study in Castro Valley in Alameda County, California. In this case study the feeder/shuttle service is coordinated with the Bay Area Rapid Transit (BART) service and the ten routing strategies are compared while using four fleet sized scenarios.

By creating pilot projects on certain segments with ideal transit service, shifts from cars to transit can gradually be made. The pilot projects (if successfully implemented) can then become elements of a community plan along with some complementary measures (higher parking prices, road pricing, fuel taxes, etc). It is known that the basics for attracting more transit patronage is to allow for: (a) comfort ,(b) low perceived out of pocket cost, and (c) flexibility (always there when it is needed, allows its user to enjoy door to door services, low level of information required for its use). One essential item for increasing the system attractiveness is to have good integration which can be interpreted as: (i) good information on the available options, (ii) stability of perception of service (iii) network integration (iv) ticketing integration using smart cards, and (v) maximal synchronization.

European Union studies have indicated that successful integration requires a road network hierarchy design that integrates surface transit, private cars, bicycles and pedestrians. Physical integration is pursued by means of the optimal arrangement of individual motorized transportation and transit and transfers from individual motorized transportation to transit. These include

Park+Ride (P+R), Kiss+Ride (K+R), Bike+Ride (B+R) and taxis. Interconnections between different types of transit systems (rail, bus, taxi, ferry) take place in many architectural forms. The number of cities considering these schemes continues to grow; there is also a growth in developed interchanges for different transit systems.

One emerged benefit of P+R systems is that they can enable economic and environmental enhancement. A successful P+R scheme can help pedestrianisation, which might otherwise be resisted. A successful transit practice at interchanges is the combination of activities of different transit systems, such as, feeder buses and local train services using the same platform. In interchanges studies, emphasis is given to short-distance transport facilities. These include continuous systems (pedestrian corridors, constant-speed and accelerated conveyors, and escalators), semi-continuous systems (vehicles slowing down in stations) and discontinuous systems (shuttles). A recently developed innovative system is an accelerated conveyor called a 'walkway.'

Transfers - Transit passengers usually perceive a transfer (vehicle to vehicle either using same transit mode or from mode to mode) as one of the most inconvenient attributes. Such a transfer involves walking and waiting (often in a queue), the two elements that usually are not part of using a car. In existing transit systems, the recommendation is to minimize this type of transfer or at least to minimize one (or both) of the elements of walking and waiting.

Smart Feeder/Shuttle – This is an advanced and attractive feeder/shuttle transit system that operates reliably and relatively rapidly, part of the passenger door-to door chain with smooth and synchronized transfers.

Routing Strategies

Smart routing strategies represent the flexibility and, to some extent, part of the attractiveness of the transit system. Ten routing strategies investigated in this work are:

(1) Fixed route with a fixed schedule (timetable) and fixed direction,
(2) Fixed route with a flexible (demand driven) schedule, and fixed direction,
(3) Fixed route with a flexible schedule and bi-directional,
(4) Fixed route, flexible schedule, fixed direction and with a possible short-turn,
(5) Fixed route, flexible schedule, bi-directional and with a possible short-turn,
(6) Fixed route, flexible schedule, fixed direction and with a possible short-cut,
(7) Fixed route, flexible schedule, bi-directional and with a possible short-cut,
(8) Fixed route, flexible schedule, fixed direction and with possible short-turn and short-cut,
(9) Fixed route, flexible schedule, bi-directional and with possible short-turn and short-cut,
(10) Flexible (demand-responsive) route with a flexible schedule.

Simulation

The simulation is in C++ language and can be operated on PC consol application under Windows. The demand can be inserted as part of the input or can be generated randomly on the network. Together, ten different routing strategies were examined. The simulation model is based on events. The simulation starts with reading the input data, and proceeds by arranging the train arrival events and the passenger arrival events.

Eight main events were simulated. Event 1 represents passengers walking to the shuttle stop to wait for the next shuttle in order to arrive at the train station. Event 2 represents passengers arriving on the train, waiting for the next shuttle. Event 3 is the situation when a vehicle becomes available for the next trip. Event 4 is when the shuttle arrives at a node (intersection) on the considered road network. Event 5 represents the arrival of passengers who want to ride the shuttle from its stop to the train station. Event 6 represents passengers who are about to arrive at the train station (but not yet) and will seek to ride the shuttle. Event 7 is the arrival of the train at the station including the time for the passengers to arrive at Event 2. The last, Event 8, is the arrival of the time in which the shuttle departs according to a timetable.

Implementation Stages

In order to secure the potential success of creating a new feeder/shuttle service, steps should be undertaken gradually and carefully. There are five major components: 1) constructing a base street network, 2) creating groups of fixed routes, 3) constructing short-turn, short-cut and bi-directional strategies, 4) creating a DRT type of service, and 5) comparing the strategies with the given demand.

Castro Valley Site

To test a real-life situation the area of Castro Valley in California was selected for data collection and simulation runs. The BART station in Castro Valley is on the “blue” line, Dublin/Pleasanton-Daly City. Currently there is one bus line (AC Transit, line 87) within the Castro Valley neighborhood that provides a transit service to the BART station. However this 87 line is not effective and has a low level of passenger use.

A site observation was made in the area of Castro Valley from which the base network and stops were created. On this base network one route is considered as beginning at the BART station. Single and double route systems were constructed based on the site visit, but a systematic algorithm was not used.

Many simulation runs were executed across the ten described routing strategies and for the availability of four different numbers of shuttle buses: 1, 2, 3 and 4 buses (See Appendix C). In these runs only one level of demand was considered. That is, an estimated current demand of 400 daily passengers in Castro Valley was considered where the demand is generated randomly. The criterion of 20 minutes was used; if the announced wait time for the bus shuttle/feeder is more than 20 minutes then the caller will not actually wait but will cancel the requested trip or will do something else.

Concluding Remark

The report described the smart feeder/shuttle system which can be implemented in any community in the US. It is recommended that a pilot study be implemented. The pilot study can follow a twelve step procedure. These twelve steps can serve as a framework for the master plan of a pilot study where each outcome of a previous step becomes an additional input to the next step, except for step 6. Step 1 is a demand analysis by time of day and day of week to find the origin-destination pattern and the consumer oriented features. Step 2 is to design the fixed routing and stop system. Step 3 is to determine the base frequencies and timetables for each route. Step 4 is to determine the number and size of the feeder/shuttle vehicles and to create the chains of trips (vehicle schedules) which will serve Step 5 of constructing the crew schedules.

The pilot plan continues in Step 6 with the establishment of effective information channels and instruments (e.g. Tel center, internet, newspapers, radio, TV, mail leaflets) which will lead to the development of user-friendly communication procedures between the users and the operator in Step 7. Step 8 is to construct the DRT operational strategies without the use of the fixed routing/stop/schedule system. Step 9 determines the testing scenarios of the pilot while step 10 presents the process of how to select an adequate operator. Step 11 uses proper advertisement tools to approach an operable pilot, and the last, Step 12, of the plan aimed at improving the instruments, procedures and strategies with the use of innovative ITS (Intelligent Transportation Systems) elements.

Finally and overall, this work attempts to construct a new idea for designing an integrated smart feeder/shuttle bus service. Ideally, this smart bus system will provide advanced and attractive feeder and distributor services that operate reliably, and relatively rapidly, part of the passenger door-to-door chain with smooth and synchronized transfers. In order to approach the design of this innovative bus system a simulation model was constructed and tested. This simulation tool allows for the examination of: (a) various operating strategies from both the user and operator perspectives (b) different routing models and scenarios, and (c) different real-time communication possibilities between the user, operator and a control center.

INTRODUCTION

The need for feeder transit

The evolution of lifestyles in the US (more leisure time, more disposable income) and of land use patterns (greater dispersion of activities, low density peripheral developments) favors the adoption of the car as the universal mode of transport, making full use of its flexibility and availability.

It is an axiom that a problem adequately stated is a problem well on its way to being solved. The known transportation objectives for any residential community are to: 1) find a reasonable-cost approach in order to ease traffic congestion, 2) eliminate parking problems, 3) reduce road accidents and 4) improve the pollution level. Such a reasonable-cost approach must rely on an attractive, well distributed, and comfortable public transit system.

Mark Twain said:" You cannot depend on your eyes when your imagination is out of focus". Our eyes see what transit services are currently providing for high- and low-density communities. Our eyes can read reports covering urban transport characteristics, the influence of transport investments, ground transport strategy, and passenger transport action plan. However, we cannot depend on our eyes alone to trigger our imagination. It was Alfred Einstein who said: "Imagination is more important than knowledge". One such focused imagination is the hope for a personalized demand responsive sy including *a door-to-door with smooth and synchronized transfers transit service* to achieve the study objectives. It will require changes in travel behavior, and hence must be done carefully, and gradually.

Equally, service improvements will require spatial changes in public transit that may lead to unfeasible solutions due to the high cost involved. However, by creating pilot projects on certain segments with ideal transit service, shifts from cars to transit can gradually be made. The pilot projects (if successfully implemented) can then become elements of a community plan along with some complementary measures (higher parking prices, road pricing, fuel taxes, etc). We cannot change the direction of the wind (evolution of lifestyles, and land use patterns), but we can adjust the sails (create 4-and 5-star transit services which eventually will pay off their expenses).

The European Commission perspective expressed in the 1999 paper (1) indicates that the mission of transit has changed: "whereas until the 70's its main function was to satisfy the individual needs of the less affluent members of society, progressively the policy discourse has been changing, pointing instead to the necessary contribution of public transport for congestion relief and environmental preservation. This represents a fundamental change of emphasis, in the sense that public transport now would be a role geared more to the satisfaction of *collective wellbeing* than to the direct *individual needs* of those who use it".

The choice between public and private transport is an individual decision that is influenced by government/community decisions. These decisions are often sending mixed signals to the transit and potential transit passengers while failing to recognize more system-wide and integrated implications. Generally speaking, the majority of large cities have encouraged the use of the private car through planning (dispersed land-use in the suburbs), infrastructural (available parking and circulation traffic flow), pricing and financial decisions. Consequently, in many of those cities there is a growing confusion about what to do. One way to handle the decline in transit use is to retain the high level of satisfaction among transit users while fully retaining the protection of access to the less affluent travelers. Some research in Europe ISOTOPE (2), QUATTRO(3) and (4) attempt to show the way to overcome this decline in transit patronage.

Project objectives

This work attempts to construct a new idea for designing an integrated smart feeder/shuttle bus service. The feeder service idea stems from the need to overcome the problem of people driving their cars to train or express bus stations (e.g. BART). This problem results in high parking demand around the train or bus stations. Moreover, some potential train riders are, instead, driving their cars to their workplace and hence increasing the traffic congestion. The purpose of this study is to design an innovative feeder/shuttle system that will 1) meet the needs and desires of end users, 2) utilize intelligent transportation technologies, and 3) increase the operational efficiency.

Ideally, this smart shuttle/bus system will provide advanced and attractive feeder and distributor services that operate reliably, and relatively rapidly, part of the passenger door-to-door chain with smooth and synchronized transfers. In order to approach the design of this innovative bus system a simulation model was constructed and tested. (See appendices) This simulation tool allows for the examination of: (a) various operating strategies from both the user and operator perspectives, (b) different routing models and scenarios, and (c) different real-time communication possibilities between the user, operator and a control center.

This work is comprised of six parts. First, an overview of the literature is presented. Second, the concepts of transit integration and routing strategies for a feeder/shuttle bus system are described. Third, a simulation model is developed for a smart feeder/shuttle service. Fourth, the necessary and recommended implementation stages are outlined and explained. Fifth, a case study is presented in Castro Valley. That is, how and on what basis should a smart shuttle service in Castro Valley be designed to coordinate with the BART service. Finally, the last part provides the conclusions of the study.

BACKGROUND

The key issue in providing a smart transit service is how to provide a good match between the users' needs/desires and the offered service. The term "good match" doesn't mean to rely on known concepts; instead, it means that the transit service is provided with a full understanding of the needs and desires of existing and potential transit riders. This section presents an overview of various known operational transit concepts and related research.

In order to alleviate the problems encountered in traditional transit service several flexible services were studied and offered. Dial-a–ride and door-to-door paratransit have played a vital role in North America in providing equitable transportation service to elderly and handicapped persons who have difficulty in accessing regular public transit systems(5). Such a Demand Responsive Transit (DRT) can be investigated with different perspectives (6,7) but it doesn't fulfill the need of the entire transit population. An interesting recent study (8) distinguishes between two classes of users, so called *passive users* and *active users*. The *passive users* make use of the traditional transit, i.e., boarding and alighting at compulsory stops. No reservation is necessary since vehicles are guaranteed to serve each compulsory stop within a given time window. The *active users* ask for a ride while boarding or alighting at an optional stop. Active users must issue a *service request* and specify pick up and drop off stops, as well as earliest departure and latest arrival times. In this study (8), transit vehicles have to be rerouted and scheduled in order to satisfy as many requests as possible, complying with passage-time constraints at compulsory stops, while, between two compulsory stops, optional stops can be activated on demand. The method used in this study integrates mathematical programming tools into a tabu search framework, taking advantage of the particular structure of the problem formulation. .

Dial-a-Ride problems usually arise from using the classical vehicle routing heuristics, constructive or improving (9-12). These methods are based on arc and node manipulation which generally is based on insertion, deletion, and exchange of stops in and out of a current tour. The computation of an upper bound in finding the optimal dial-a-ride solution is not a trivial issue. The linear relaxation of any arc-based integer linear programming model provides to some extent a loose bound. Therefore heuristics are necessary to cope with practical routing problems.

A few studies make use of simulation as a tool to approach satisfactory routing and scheduling DRT solutions. Two waves of simulation studies can be traced in the literature. The first wave is the research conducted by Wilson et al (13,14) for evaluating various heuristic routing rules and algorithms used in a computer-aided routing system. These studies were developed for mainframe computers and have limitations in handling large size road networks with different routing strategies. The second wave of research was recently conducted by Fu and his team (15-17) while considering the use of advanced technologies. Their studies present a simulation model Sim-Paratransit, which has been developed for evaluating advanced paratransit systems such as AVL (Automatic Vehicle Location) and CAD (Computer-Aided Dispatch) systems. The simulation model is described in (15,16) and the evaluation of AVL and CAD systems in (17). The ability to track continuously the location of the transit vehicle allows for the introduction of intelligent paratransit systems which will naturally lead to operating the paratransit systems at a significantly improved level of productivity and reliability (15-19).

According to the American Public Transit Association, the total operating expenses of paratransit service in the US in 2000 exceeded \$1.2 billion while only \$173 million were collected in fares. Introduction to the advanced technologies opens a window of opportunity to reduce the operating costs and increase ridership of these types of transit services. At the same time, there is also a need to investigate the users' willingness to use and pay for an advanced transit system. Using the computer-assisted telephone interview method, a consumer response study of demand responsive transit systems in the San Francisco Bay Area was carried out by the PATH program in 1999 (20) to address the user's perspective. This study examined the factors that are likely to influence the decision to take "on-demand" versus "fixed-schedule" DRT systems, where, for a fixed-schedule DRT, the pick-ups and drop-offs are made at fixed but convenient locations. Their survey indicates that the DRT idea appeals to commuters as well as to non-commuters. About 15% of those surveyed were considered "very likely" to use the DRT service while about 48% were willing to consider it as an option. A majority of these DRT pre-disposed were willing to pay between \$5-\$10 for a 30 minute trip using fixed schedule service (62%) and on-demand service (73%). Overall, the results of this study (20) show that a reasonably priced DRT service that is reliable and meets costumer expectations (of cost, travel time and wait time) can be successful.

All in all, there exists a recognition that demand for public transit will grow in the future given the provision of attractive and advanced transit systems. Galileo said: "Science proceeds more by what it has learned to ignore than by what it takes into account". In order to proceed toward a better transit system more attention should be given to reducing the gap between the users' needs and desires and the offered transit service and to ignore subordinate issues. The previous studies mentioned above do not contain the strategic-operational side of potential smart systems. This side cannot be ignored. It is the intention of this work to map, explore and analyze all possible operational strategies that may appeal to potential transit users. Certainly these strategies assume the use of advanced technologies and will be investigated using a simulation tool.

SMART FEEDER/SHUTTLE: INTEGRATION AND ROUTING CONCEPTS

System Integration

It is known that the basics for attracting more transit patronage is to allow for: (a) Comfort ,(b) Low perceived out of pocket cost, and (c) Flexibility (always there when it is needed, allows its user to enjoy door to door services, low level of information required for its use). One essential item for increasing the system attractiveness is to have good integration which can be interpreted by: (i) Good information on the available options, (ii) Stability of perception of service (iii) Network integration (iv) Ticketing integration using smart cards, and (v) Maximal synchronization.

Good information on the user's options should cover all transit modes and needs to be tailored to the user's needs. The information should be based on simplicity and accuracy while taking into account the exact way to reach B from A for any A,B points on the transit network. The information should comprise all transit modes and all operators in a single system. The *stability of perception of service* implies infrequent changes since frequent changes may introduce confusion among the users. In other words, "stability" refers to long validity periods for transit timetables. *Network Integration* implies smooth transfers and comfortable interchanges. That is, easy change on routes in a single trip no matter if routes are operated by one or more modes and/or operators, and available interchanges to allow for smooth transfers. *Ticketing integration* is based on a combined tariff using the same payment method such as the same smart card (e.g. the Octopus card in Hong Kong used across heavy rail, metro, bus, and ferry). Finally to *maximal synchronization* for better co-ordination among the routes and transit modes and minimization of the transfer and wait times. This synchronization of the user timetables should be carried out both off-line (planning stage) and on-line (considering actual situations of the transit vehicle being behind or ahead of schedule).

Based on the European Union Papers and Studies (1-4), successful integration requires a road network hierarchy design that integrates surface transit, private cars, bicycles and pedestrians. Physical integration is pursued by means of the optimal arrangement of individual motorized transportation and transit and transfers from individual motorized transportation to transit. These include Park+Ride (P+R), Kiss+Ride (K+R), Bike+Ride (B+R) and taxis. Interconnections between different types of transit systems (rail, bus, taxi, ferry) take place in many architectural forms. The number of cities considering these schemes continues to grow; there is also a growth in developed interchanges for different transit systems.

One emerged benefit of P+R systems is that they can enable economic and environmental enhancement. A successful P+R scheme can help pedestrianisation, which might otherwise be resisted. A successful transit practice at interchanges is the combined activities of different transit systems, e.g. feeder buses and local train services using the same platform. In interchanges studies (2,4) emphasis is given to short-distance transport facilities. These include continuous systems (pedestrian corridors, constant-speed and accelerated conveyors, and escalators), semi-continuous systems (vehicles slowing down in stations) and discontinuous systems (shuttles). A recently developed innovative system is an accelerated conveyor called 'Walkway' produced by Mitsubishi, Japan.

Transfers

Transit passengers usually perceive a transfer (vehicle to vehicle either using same transit mode or from mode to mode) as one of the most inconvenient attributes. Such a transfer involves walking and waiting (often in a queue), the two elements that usually are not part of using a car. In existing transit systems, the recommendation is to minimize this type of transfer or at least to minimize one (or both) of the elements of walking and waiting.

Whenever a transit development alternative is under consideration there is a need to evaluate the adverse effects of inherent transfers in the alternative plan. However, instead, one should think how to avoid an inconvenient transfer by introducing the idea of smooth and synchronized transfers. These smooth and synchronized transfers rely on new technologies; (e.g. moving walkways, escalators, elevators, using carts, electrical slow-speed vehicles). The synchronization is based on an exact arrival/departure timing that can be handled by a certain real-time intelligent control system, and by using certain algorithms to create the transfer meetings in the timetables. Therefore, any transit development alternative that contains large walking + waiting transfers should be eliminated or revised.

Smart Feeder/Shuttle

One definition of a smart feeder and/or shuttle transit service: *Advanced and attractive feeder/shuttle transit system that operates reliably and relatively rapidly, part of the passenger door-to door chain with smooth and synchronized transfers.* The interpretation of each component in this definition is as follows:
Attractiveness: available information (telephone center, Internet, newspaper, radio, TV, mail leaflets), simple communication (short telelephone number., automatic storage of users' telephone number and address), clear user / service intersect (smart vehicle color and logo, user waving smart vehicle card) boarding/alighting/riding comfort (low-floor, extra space next to driver, comfortable seats, possible features for physically challenged people, low noise), on-board service (newspapers, magazines, free coffee/tea, TV/video display of timetable, weather, etc), simple payment (electronic ticketing and pre-paid, transfer and smart card ticketing);
Reliability: small variability of concern to users (total travel time, waiting time, in-vehicle time, seat availability), small variability of concern to smart vehicles (schedule adherence, headways, on-time pullouts, missed trips, breakdowns, load counts, late reports), small variability of pre-trip information using telephone communication (on-line timetable, travel time to caller, suggested time interval for 2nd call from or to the user);
Rapidness**:** local authority permission for smart vehicles to stop along the route (fixed stops with shelters and information, bus bays at timepoints with extra approach lane at signalized intersection, flexible stops along the route where the smart vehicle is with flashing lights), smart vehicle preference at unsignalized intersections ("yield" or "stop" not according to traffic procedures, special bypass arrangements at strategic points), smart vehicle preference at signalized intersections (passive priority by extending or preceding green, active priority using AVL / actuated smart vehicle signals, e.g. radio, inductive loop), purchase and validate tickets (electronically, ordinary) on smart vehicles (one-way, round trip, transfer, daily, weekly, monthly);
Smoothness: comfortable routing (minimax criterion on walking distance, round-trip deviation from designated route in bad weather, evolution of flexible routing and scheduling), special train

station entrance (smart vehicle special gate, smart vehicle entrance door with comfortable stairs/escalator to the train platform), special train exit (exit door next to the train platform for smart vehicle ticket holders, smart vehicle wait at exit, or under shelter wait with vehicle arrival announcement on variable message signs (VMS));
Synchronizes*:* on-line communication between the train service and the smart vehicle (vehicle equipped with (i) arrival information of the train service to relevant station(s), (ii) time difference, positive or negative, for synchronization), smart vehicle subscription with serial numbers (adding variable scheduling element to meet subscribers, planning the fixed scheduling component with subscribers' information), short-turn and short-cut routing strategies (computerized suggestion for the smart vehicle driver on short-turn and short-cut, VMS on-board information on meeting time).

Routing Strategies

Having once defined the major elements of the smart feeder/shuttle transit service, attention should be given to smart routing strategies. These strategies represent the flexibility and, to some extent, part of the attractiveness of the transit system. Ten routing strategies are investigated in this work:

(10) Fixed route with a fixed schedule (timetable) and fixed direction,
(11) Fixed route with a flexible (demand driven) schedule, and fixed direction,
(12) Fixed route with a flexible schedule and bi-directional,
(13) Fixed route, flexible schedule, fixed direction and with a possible short-turn,
(14) Fixed route, flexible schedule, bi-directional and with a possible short-turn,
(15) Fixed route, flexible schedule, fixed direction and with a possible short-cut,
(16) Fixed route, flexible schedule, bi-directional and with a possible short-cut,
(17) Fixed route, flexible schedule, fixed direction and with possible short-turn and short-cut,
(18) Fixed route, flexible schedule, bi-directional and with possible short-turn and short-cut,
(19) Flexible (demand-responsive) route with a flexible schedule.

Fixed direction means that the shuttle always maintains the same direction of travel (same sequence of stops) whereas bi-directional allows for having the flexibility to select the direction based on real-time demand information. The term short-cut means that, based on certain loading threshold and synchronization criteria, the shuttle will not continue its fixed route and instead will use the shortest path (minimum travel time) to arrive at the train station. The loading threshold is a given (input) number of passengers on board the shuttle. The synchronization criterion is to be complied with the possibility that the shuttle will match its new (short-cut) arrival time with an earlier train than its planned arrival time. The term short-turn means that, based on certain loading threshold and synchronization criteria, the shuttle will not continue its fixed route and instead will turn around and arrive at the train station in the opposite direction from the fixed route with the possibility of picking up more passengers who were too late to be picked up when the shuttle passed through. The loading threshold and synchronization criteria for the short-turn strategy (including the consideration of more pick-ups) are the same as for the short-cut strategy. The strategy of either short-cut or short-turn allows the flexibility of either of the two strategies. That is, the loading threshold of the short-cut strategy is higher than the loading threshold of the short-turn strategy. If the latter is reached with the possibility of picking up x passengers (after turning around), where x is equal or greater than the difference between the two loading thresholds, then the short-turn strategy is recommended.

Figure 1 represents the 10 strategies on a small network with 2 shuttle routes, one with a dashed line and one with a dotted line. The clock on the upper right hand side exhibits the fixed schedule (only in one strategy) and when crossed it means a flexible schedule situation. Arrows on both directions of the route means a bi-directional situation. It can be seen in Figure 1 that in the short-cut strategy the lines with the arrows deviate from the fixed route. In the short-turn strategy the arrows turn around at a certain point of the network, and in the strategy with a possible combination of short-cut and short-turn, both representations appear. The last strategy is for a DRT type of service allowing for the creation of a new route every time, based on the trip bookings.

The idea to cover almost all possible practical routing strategies stemmed from the need to approach user desires and understandings. Certainly, it is not intended that all strategies be used at the same time but rather to examine which strategy is best for a given demand pattern and magnitude while considering the real time traffic situation in the area of the shuttle's trips. For that purpose a simulation model is devised. This simulation tool explained in the next session enables to compare the various strategies based on the following comparison measures:

(a) sum of total time (in passenger-hours) from passengers' pick-up to train departure times
(b) sum of total time (in passenger-hours) riding the shuttle vehicle
(c) sum of total wait time (in passenger-hours) for the train
(d) sum of total wait time (in passenger-hours) for the shuttle vehicle
(e) total number of transit vehicles (by number of seats) required to comply with the demand.

These measures of travel and wait times and number of vehicles provide for the effectiveness and efficiency of each strategy. Certainly, for a given demand, the selected strategy is the one with the minimum weighted travel and wait times (user perspective) and minimum number of vehicles (operator perspective).

SIMULATION MODEL

The simulation is in C++ language and can be operated on PC consol application under Windows. The demand can be inserted as part of the input or can be generated randomly on the network. Together, there are 10 different routing strategies, expressed in the previous section, that can be examined.

Simulation input variables

Following are the input variables in the simulation model. Each variable is presented by its simulation name and explanation and interpretation of its substance. What is referred to here as "bus" can be applied to any feeder/shuttle vehicle.

Bus2Train	-Time in seconds that bus must be there before train arrives to ensure meeting
Train2Bus	-Time in seconds that bus must wait after train arrival to ensure pick-up
SizeType	-Number of seats in this bus type
Quantity	-Number of vehicles from this SizeType
FixPick	-Fixed time in seconds for one passenger pick-up, including bus slow down
FixDrop	-Fixed time in seconds for one passenger drop-off, including bus slow down
FixBoard	-Fixed (additional) boarding time per passenger
FixAlight	-Fixed (additional) alighting time per passenger
NodeNo	-Node index at section end points

SectionNo	-Section number between two nodes
StopNo	-Stop number starts with SectionNo and represents an intersection, not a node
MeanDemand	-Mean number of potential travel requests per given hour and SectionNo to train
MeanDestin	-Mean number of potential travel requests per given hour and SectionNo from train
MeanTime	-Mean section travel time in seconds
StDevTime	-Standard deviation of section travel time in seconds
Min4Turn	-Minimal number of on-board passengers to allow a short-turn
Min4Cut	-Minimal number of on-board passengers to allow a short-cut
Min4Trip	-Minimal number of travel requests by calls to allow a non-scheduled trip
Min4Dep	-Minimal number of waiting passengers to allow a non-scheduled trip
RouteNo	-Unique index of route
RouteDir	-Direction of RouteNo (start westbound or eastbound)
TTimeTable	-Fixed Train timetable in hhmmss form, hh is from 00 to 24
BTimeTable	-Fixed Bus timetable in hhmmss form, hh is from 00 to 24
Layover	-Fixed time for driver rest at the end of each trip

All the above variables are interacting in each simulation iteration while using the various strategies and other simulation internal features.

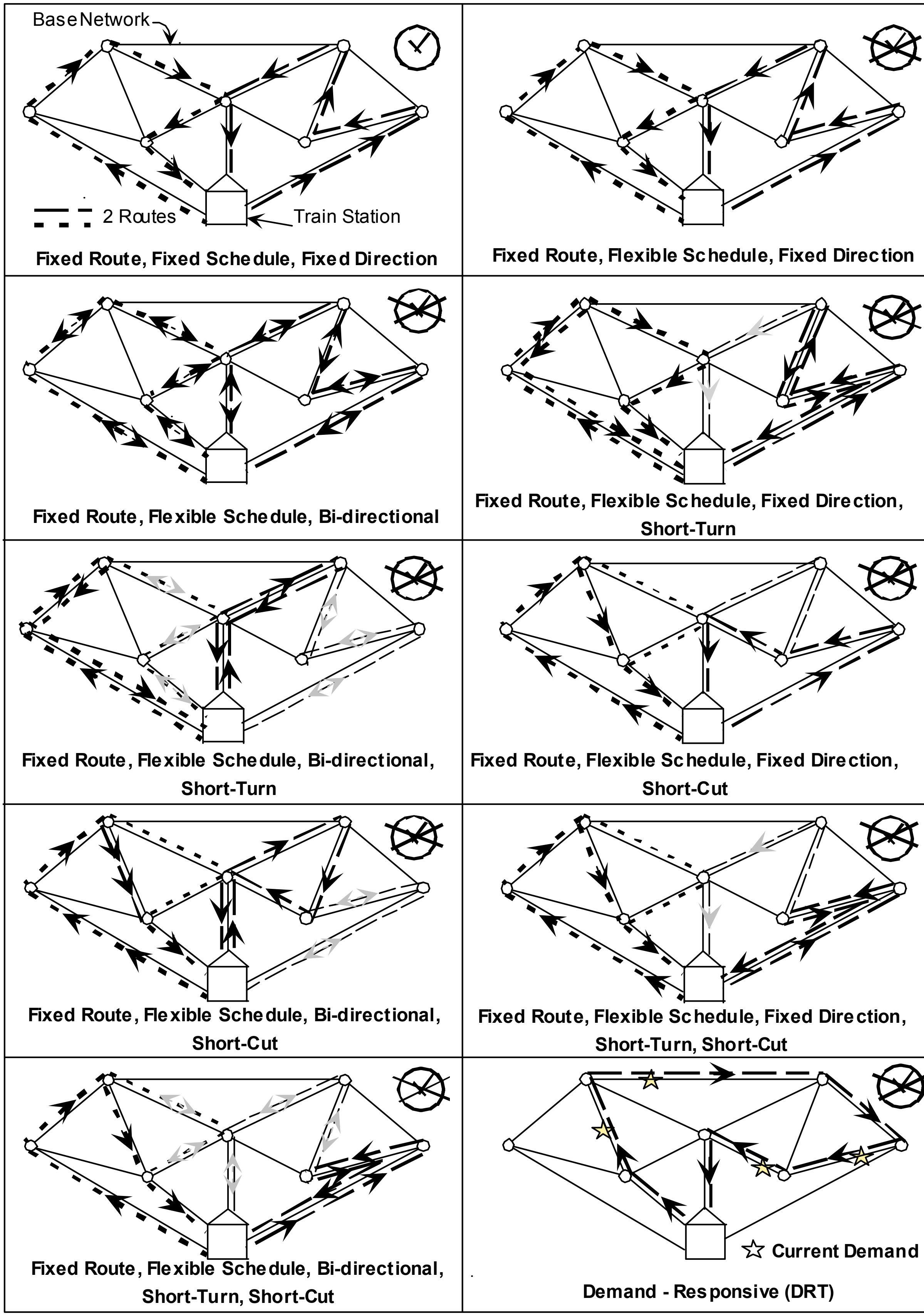


Figure 1. Routing strategies considered on a small network example

Simulation Procedures

The simulation model is based on events. The simulation starts with reading the input data, and proceeds by arranging the train arrival events and the passenger arrival events. Figure 2 presents the basic event-oriented simulation logic.

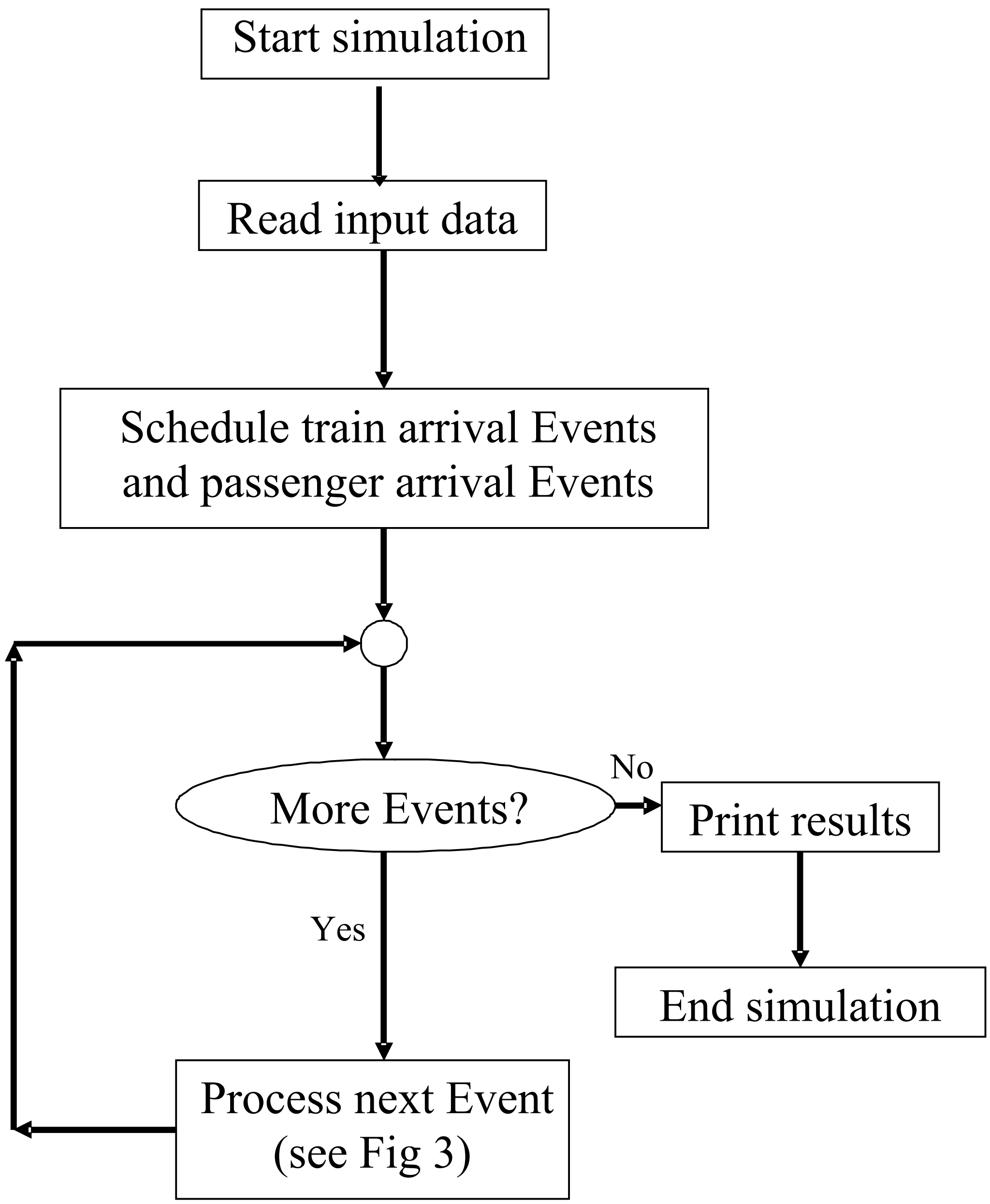


Figure 2. Basic simulation logic

There are 8 main events classified in Figure 3. Event 1 represents passengers walking to the shuttle stop to wait for the next shuttle in order to arrive at the train station. Event 2 represents passengers arriving on the train, waiting for the next shuttle. Event 3 is the situation when a vehicle becomes available for the next trip. Event 4 is when the shuttle arrives at a node (intersection) on the considered road network. Event 5 represents the arrival of passengers who want to ride the shuttle from its stop to the train station. Event 6 represents passengers who are about to arrive at the train station (but not yet) and will seek to ride the shuttle. Event 7 is the arrival of the train at the station including the time for the passengers to arrive at Event 2. The last Event 8 is the arrival of the time in which the shuttle departs according to a timetable.

The actions, taken for Events 1, 2 and 3, appear in Figure 4. It starts with enquiring if the number of passengers who want the service reaches the minimum required for dispatching a vehicle. Then for the DRT strategy (no fixed route), the procedure in Figure 4 identifies the section with a current (booked) demand and a simple shortest–path algorithm is applied. This algorithm simply finds the shortest path using a known dynamic-programming process called Bellman-Ford (21). The dynamic routing procedure is to move with the shuttle from the train station to the first demand point which is within the shortest path from the station across all the demand points. Then from the last point, to use again the shortest path algorithm for all the other points of demand that were not visited until all the demand points are included in the dynamic route. This DRT routing procedure has been found to be effective and convenient to use in the simulation.

In Figure 4 once a vehicle is available the next Event is of type 4 described in Figure 5. Event 4, in Figure 5, starts either with a station node (train station) at the end or at the beginning of the shuttle ride, or at an intermediate node. For any intermediate node the procedure checks if the minimum number of passengers on-board the shuttle reaches the threshold for either a short-turn or short-cut. Then the procedure checks to see if by creating a short-turn or short-cut it will be possible to arrive at an earlier train than the train to meet if completing the entire route.

Finally, Figure 6 describes the actions taken in the simulation for Event 5. This is the process on how to inform the user of the on-line available service. There are two alternatives: (a) that the user will be able to reach on time his/her adjacent stop, or (b) that the user will be notified via a call-back on the reliable arrival time. It is assumed that the users will either call or look at the shuttle web site to find out about the arrival time. Then the user will be asked to click, for instance, “1” for want to use the service and “2” for not wanting to use it (following the announcement of the expected arrival time, which might be inappropriate for his/her use). Only those who click “1”(OK) are taken into account in the simulation process. The simulation model can either consider a given demand figure or be used to generate a random demand based on the residential density of each section of the network. In the fixed route case the users reach their closest stop in the network. The travel time is random variable with a normal distribution and the simulation model calculates the probability to be on-time. If this probability is below 90% the user is notified to wait for a call-back. In this way the system uses the philosophy of advanced technologies and maintains highly reliable service.

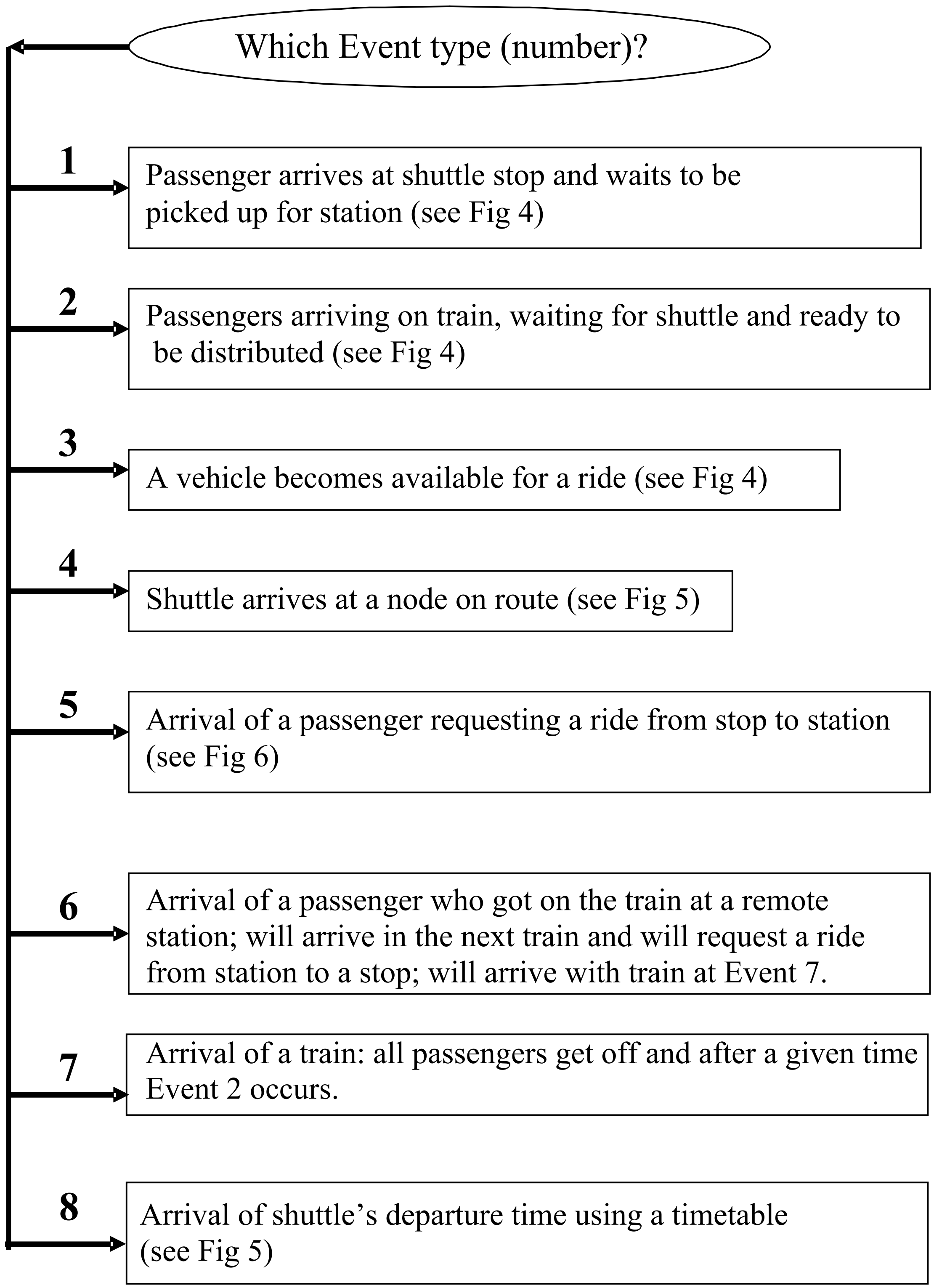


Figure 3. Event classification.

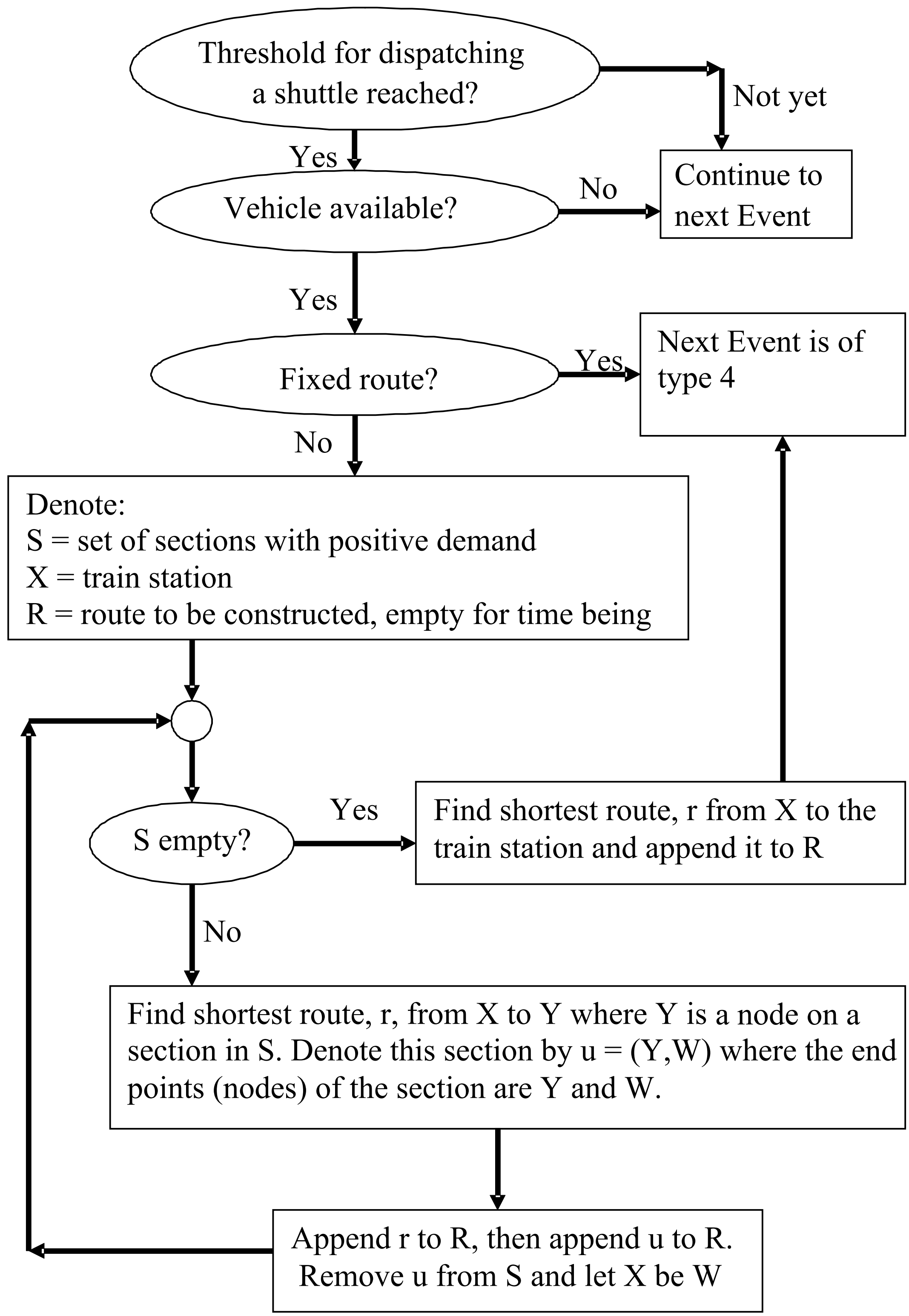


Figure 4. Actions taken for Events 1, 2 & 3.

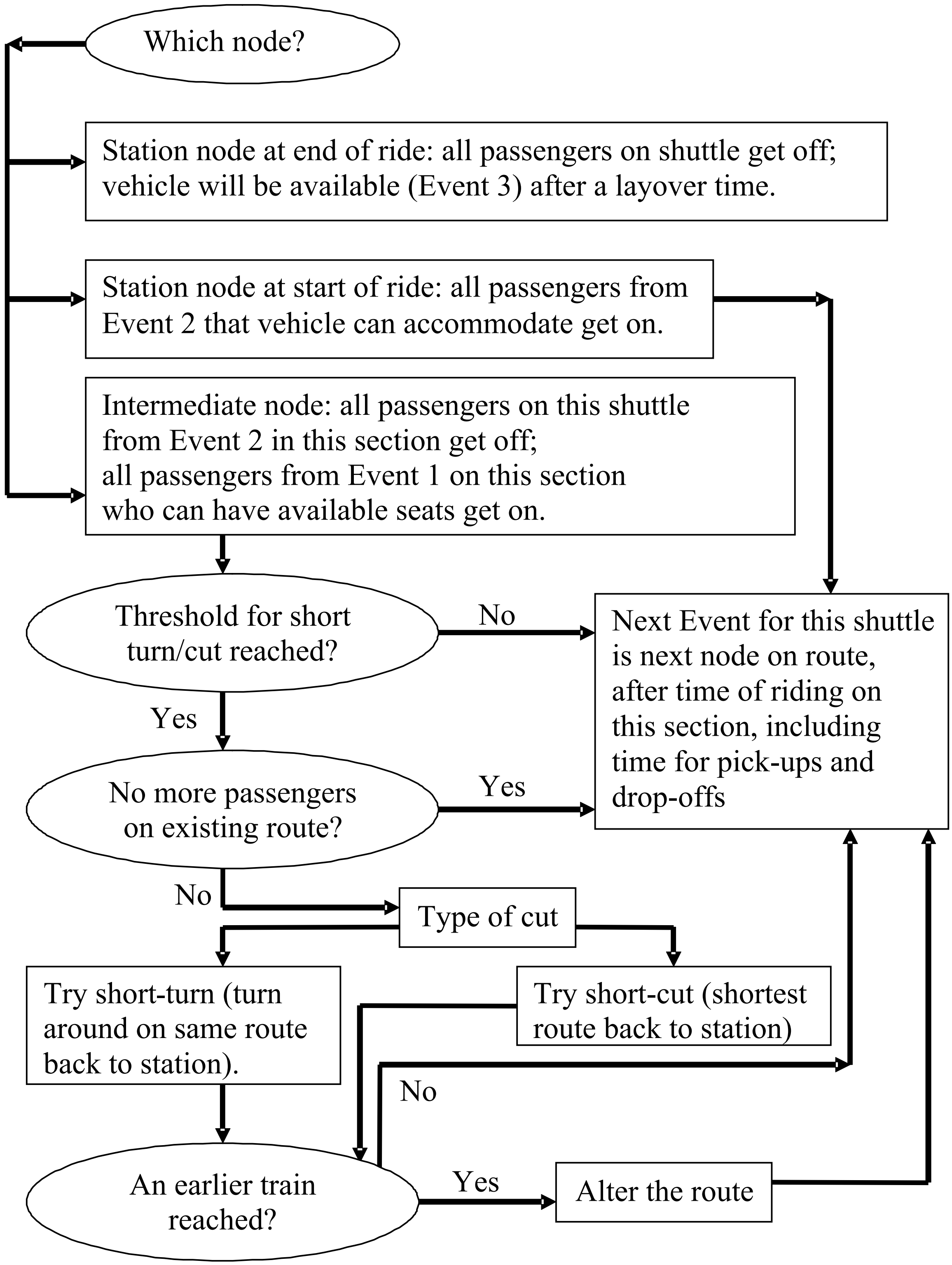


Figure 5. Actions for Events 4 and 8.

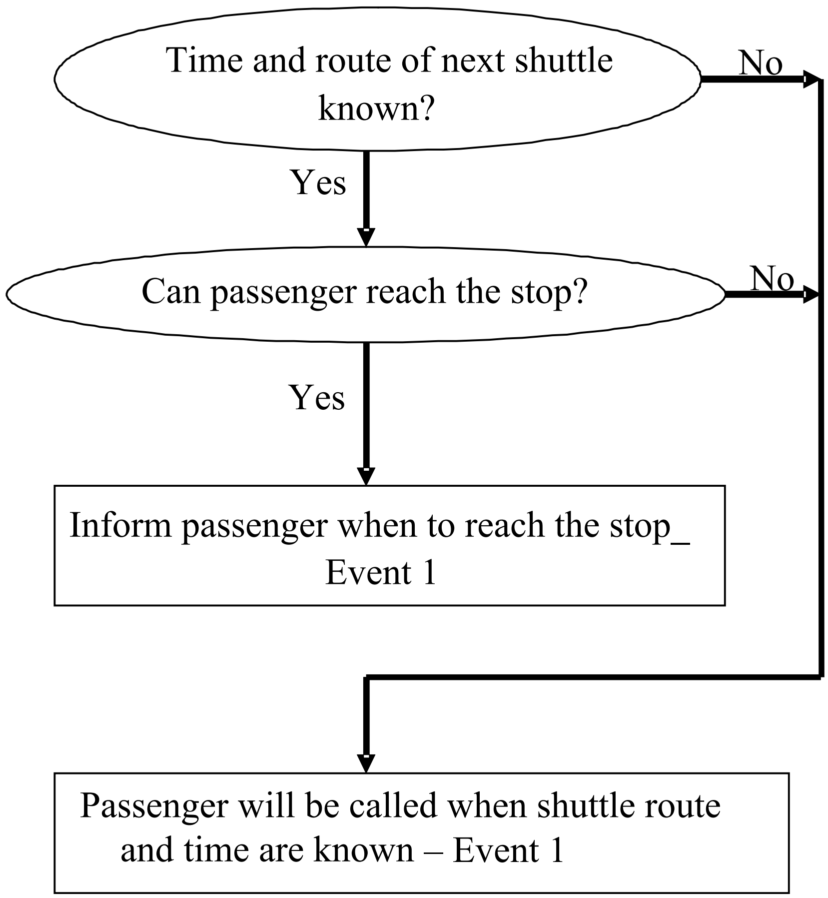


Figure 6. Actions taken for Event 5.

Detailed Example

A small example is depicted in Figure 7. In this example there are 6 sections, 5 of which are two-way and one a one-way section. There are also 4 stops where, in this example, in none of the nodes is there a stop. That is, the shuttle can make pick-ups only in the 4 stops.

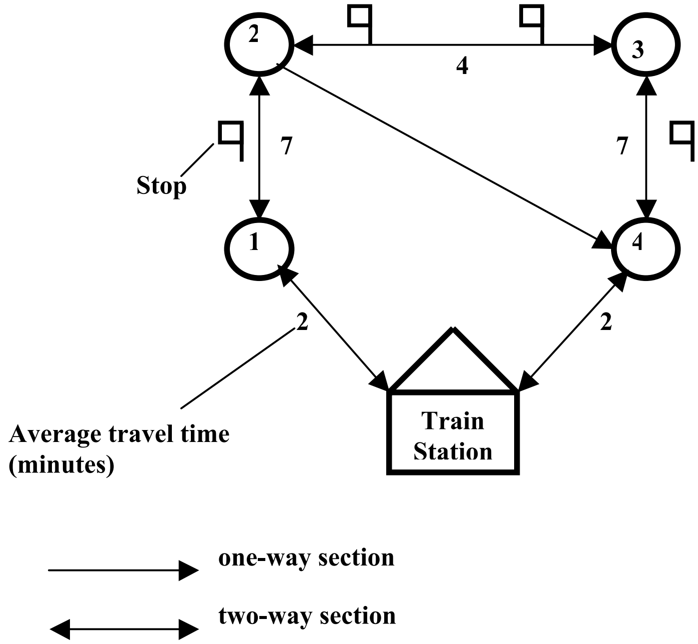


Figure 7. Small network example

Following is the input parameters and data of the example for the simulation. First, the information on sections (called SECTION GEOMETRY in the simulation model)is represented by 6 numbers separated by commas in the following order: starting node, ending node, mean travel time in seconds w/o stopping, standard deviation of travel time w/o stopping, number of stops, and directions (1=one-way, 2=two-way). The train station is node 0. In this example the travel time is deterministic (standard deviation=0).
In the example:
SECTION GEOMETRY: 0, 1, 120, 0, 0, 2;
SECTION GEOMETRY: 0, 4, 120, 0, 0, 2;
SECTION GEOMETRY: 1, 2, 420, 0, 1, 2;
SECTION GEOMETRY: 2, 3, 240, 0, 2, 2;
SECTION GEOMETRY: 2, 4, 120, 0, 0, 1;
SECTION GEOMETRY: 3, 4, 420, 0, 1, 2;
In Table 1 the parameters of the simulation model are shown.

Table 1. Simulation parameters and their values for the detailed example

Name	*Explanation*	*Value*	*Remark*
Quantity	Number of vehicles	2	Only one type of shuttle
Size	No. of seats in each vehicle	27	
Bus2Train	Time that a vehicle must be there before train arrival to ensure meeting	240	Time in seconds
Train2Bus	Time that a vehicle must wait after train arrival to ensure pick-up	180	Time in seconds
FixAlight	Alighting time per passenger	3	Time in seconds, starting with 2nd passenger
FixBoard	Boarding time per passenger	5	Time in seconds, starting with 2nd passenger
FixDrop	Time for first passenger drop-off	20	Time in seconds
FixPick	Time in seconds for first passenger pick-up	25	Time in seconds
Layover	Time for driver rest at the end of each trip	10	Time in minutes
Min4Dep	Minimal number of waiting passengers to allow a non-scheduled trip	20	Infinity for all trips in a timetable
Min4Trip	Minimal number of travel requests by calls to allow a non-scheduled trip	19	Infinity for all trips in a timetable
Min4Cut	Minimal number of on-board passengers to allow a short-cut	18	Infinity for no short cut
Min4Turn	Minimal number of on-board passengers to allow a short-turn	17	Infinity for no short turn

In the simulation the input in Table 1 is expressed as follows:
BUS: 1, 2, 27;
T DELAYS: 240, 180;
B DELAYS: 3, 5, 20, 25;
LAYOVER: 10;
START ROUTE: 20, 19;
STOP ROUTE: 18, 17;

Passenger demand is assumed to be 50 for both train station pick-up and drop-off per hour. This demand is distributed among the sections according to:

Section	*Demand, percent of total*
1-2	10
2-3	65
3-4	25

In the simulation model the demand is expressed as:
T2B DEMAND LIMITS: 630, 50, 1000;
That is, between 06:30 and 10:00 the average number of passengers to be distributed by the shuttle service following arrival by train is 50.
B2T DEMAND LIMITS: 630, 50, 1000;
That is, between 06:30 and 10:00 the average number of passengers to be picked up by the shuttle service for the train station is 50..
Times are in hhmm (without colons) and start just after midnight. Thus 6 pm is 1800 and quarter past midnight next day is 2415.
Next, the demand's distribution is inserted (for each direction) as:
SECTION DEMAND: 10, 10;
SECTION DEMAND: 65, 65;
SECTION DEMAND: 25, 25;
In the simulation input each demand proportion appears after its corresponding SECTION GEOMETRY.
Fixed routes such as 0 to 1 to 2 to 3 to 4 to 0 is inserted simply as
ROUTE: 1, 0, 1, 2, 3, 4, 0;
Note that each route must start and end with node 0. However the first number in this input is the route's index starting with 1. This index is for reference for shuttle timetables (if they exist).
Train timetable (arrival times at the station) is given as
TRAIN TIMES: 700, 800, 900, 1000;
That is, trains arrive at each round hour from 7:00 to 10:00 inclusive.
Finally, shuttle timetable is defined for the example as:
FIXED BUS TIMES: 1, 630, 720, 735, 820, 825, 920, 925;
The first number is the index of the route and then the times are in hhmm format.

The simulation output files appear best on Excel while reading them as tab-delimited text files (the default for text files within Excel). Appendix A provides more information on the simulation process using the example of this section. For instance, one file summarizes what occurred to each passenger. Part of it is reproduced below:

Index	*Phoned to order a ride*	*Stop number*	*Got on the bus at*	*Bus No.*	*Got off the bus at stop*	*Arrival time at Destination*	*Wait time in Minutes*	*Time between phone and pick-up (Min)*
15	6:39	3	6:46	0	-1	6:52		7
13	6:38	2	6:41	0	-1	6:52		4
…	…	…	…	…	…	…	…	…
6	7:03	-1	7:20	1	0	7:22	17	
35	7:03	-1	7:20	1	1	7:29	17	

The first 4 columns are interpreted as follows
- *Index:* ID for each passenger
- *Phoned*: the time the demand for a pick-up arises (via Tel or arrival at the station)
- *Stop:* stops are numbered, -1 is the train station, 0,1,… are the shuttle stops
- *Bus No*: ID for each vehicle

The simulation format and explanation appear in Appendix B. Statistics on the results can be easily obtained using Excel. For example, the histogram for Phone-RideStart for passengers seeking a ride to the train station can be depicted as is shown below in Figure 8. The Y-axis represents the number of passengers who experienced wait time from call to pick-up between 5*(I-1) to 5*I minutes where I is the number on the X-axis.

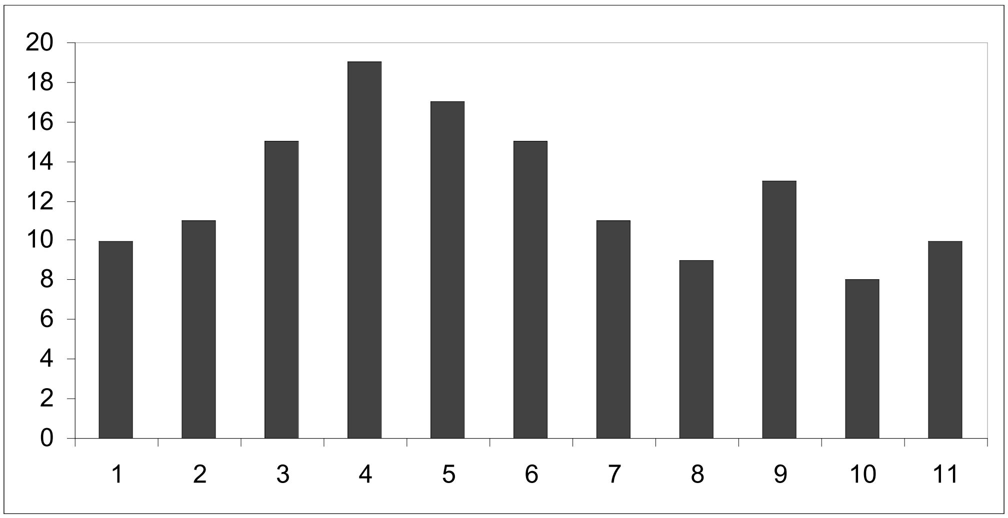


Figure 8 . Frequency (No. of Passengers in Y-axis) experiencing wait for the shuttle (in units of 5 minutes) in the example problem..

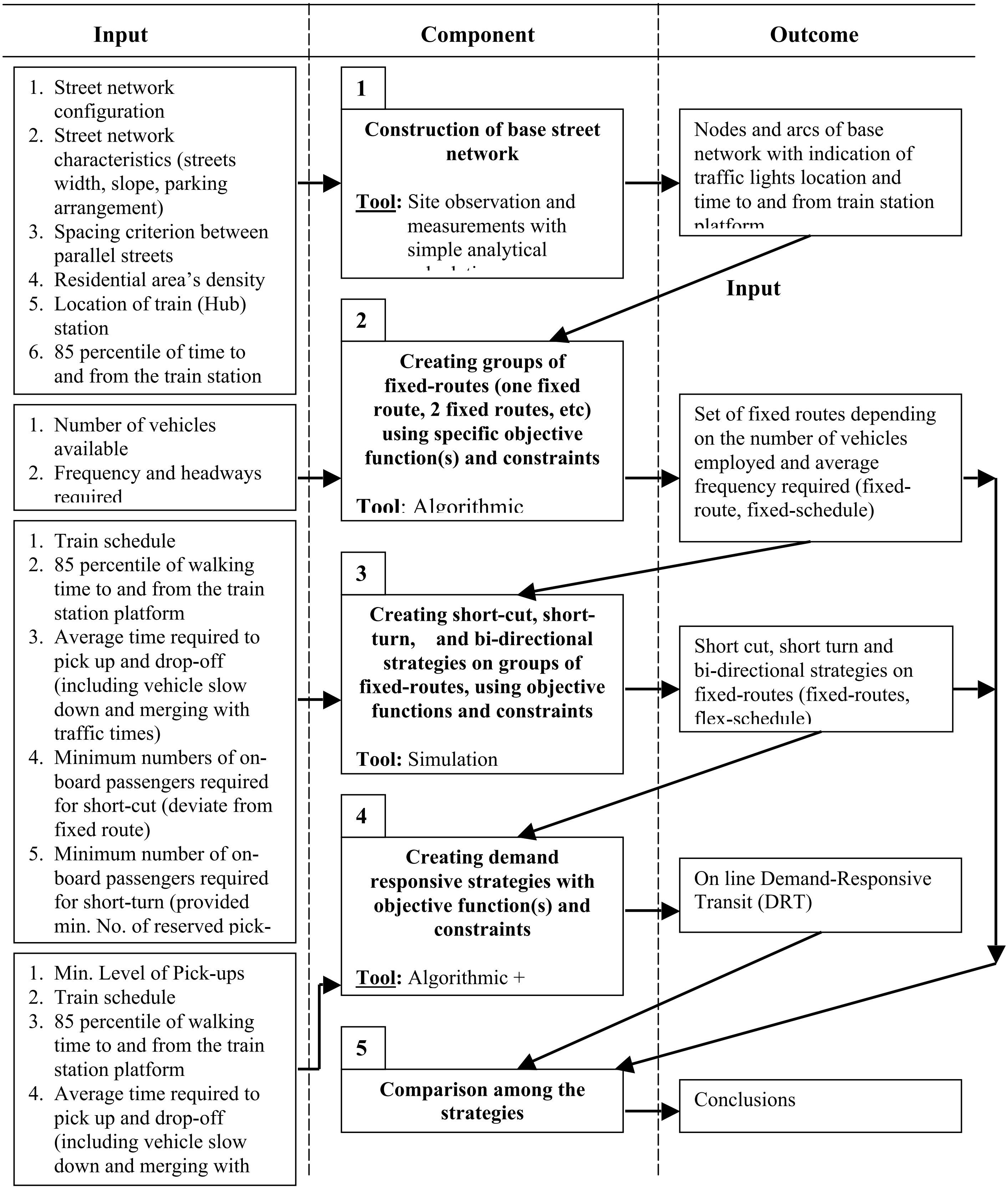
IMPLEMENTATION STAGES

In order to secure the potential success of creating a new feeder/shuttle service, steps should be undertaken gradually and carefully. Figure 9 attempts to schematically outline the steps required to complete the initial analysis. There are 5 major components: 1-constructing a base street network, 2-creating groups of fixed routes, 3-constructing short-turn, short-cut and bi-directional strategies, 4-creating a DRT type of service, and 5-comparing the strategies with the given demand.

In component 1 of Figure 9 there is a need to use site observations and measurements in order to arrive at a base road network configuration including traffic light locations and 85 percentile of time to and from the train station platform. The 85 percentile of the different times observed is to ensure adequate walking time for the majority of the people, and at the same time, not to allow excessive time from an efficiency perspective. The determination of the base road network considers the following elements: approximate (low, average, high) residential area's density, street characteristics (width, slope, parking arrangements), spacing between parallel streets, and the road network shape of each zone in the area .

Component 2 of the initial analysis creates the fixed routes to be considered. These routes are then subjected to further investigation. The length of the routes to be selected is affected by the number of shuttle vehicles available and, if given, also the minimum frequency required. The selection procedure can be based on an optimal routing algorithm (not yet available in the literature) that minimizes the sum of all walking distances to and from the selected routes.

Component 3 constructs the operational strategies that can continuously ensure a good level of service. These strategies are outlined and explained in the section on routing strategies above. It basically covers the possibilities of short-turn, short-cut, and bi directional. These strategies can be analyzed by the simulation tool as is done in this work.



Component 4 in Figure 9 creates the DRT strategies given certain input elements. That is, the input is based on the minimum number of passengers to allow for sending a vehicle for a pick-up, the train schedule for matching between the expected arrival time of the DRT vehicle and the train, 85 percentile of walking time to and from the train station platform, and average times required to pick-up and drop-off passengers. The tool to create the dynamic on-line routing can be based on an algorithm (e.g. shortest path from point-to-point) and simulation has been done in this work.

Finally, component 5 comprises the outcome of components 2, 3, and 4 and performs a comparison among the different strategies. This comparison can cover different demand levels, different numbesr of vehicles available, and different input parameters (travel times, threshold values for dispatching a trip, short-turn, short-cut, etc). This comparison will lead to which strategy can better fit a given situation (time-of-day, demand level).

Once the analysis of the feeder/shuttle service is completed, the application of a pilot study is recommended. This pilot study can be implemented in the area of to explore the possibility of a feeder/shuttle service and can follow, for example, the 12 steps shown in Figure 10. These 12 steps of Figure 10 can serve as a framework for the master plan of a pilot where each outcome of a previous step becomes an additional input to the next step, except for step 6.

The pilot master plan starts with a demand analysis by time of day and day of week in order to find the origin-destination pattern and consumer oriented features. The second step is to design the fixed routing and stop system. The third step is to determine the base frequencies and timetables for each route. The fourth step is to determine the number and size of the feeder/shuttle vehicles and to create the chains of trips (vehicle schedules) which will serve the fifth step of constructing the crew schedules.

The pilot plan continues in step 6 with the establishment of effective information channels and instruments (e.g. Tel center, internet, newspapers, radio, TV, mail leaflets) which will lead to the development of user-friendly communication procedures between the users and the operator in the next step. Step 8 constructs the DRT operational strategies without the use of the fixed routing/stop/schedule system. Step 9 determines the testing scenarios of the pilot while step 10 presents the process to select an adequate operator. The 11th step uses proper advertisement tools to approach an operable pilot, and finally, the last step of the plan is aimed at improving the instruments, procedures and strategies with the use of innovative ITS (Intelligent Transportation Systems) elements.

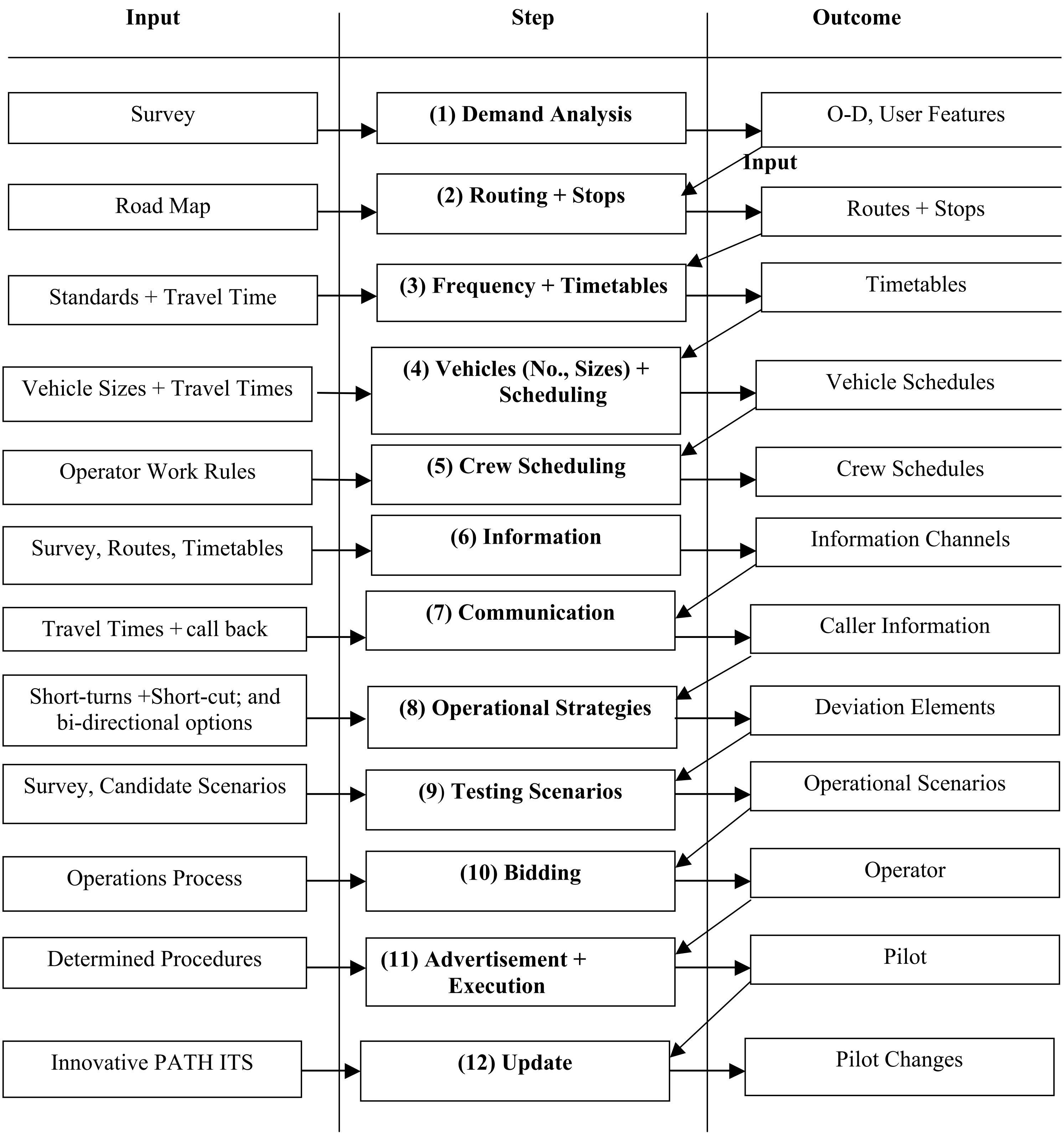


Figure 10. Overview of feeder/shuttle pilot master plan

CASE STUDY: CASTRO VALLEY

In order to test a real-life situation the area of Castro Valley in California was selected for data collection and simulation runs. The BART station in Castro Valley is on the "blue" line, Dublin/Pleasanton-Daly City. Currently there is one bus line (AC Transit, line 87) within the Castro Valley neighborhood that provides a transit service to the BART station. However this 87 line is not effective and has a low level of passenger use.

Following the implementation procedures outlined in Figure 9, a site observation was conducted in the area of Castro Valley from which the base network and stops were created; they appear in Figure 11. On this base network one route is considered as beginning at the BART station. The determined single route which appears in Figure 12, and the 2-route system which appears in Figure 13, were constructed using a site visit and without any systematic algorithm.

Many simulation runs were executed across the ten described routing strategies and for the availability of four different numbers of shuttle buses: 1, 2, 3 and 4 buses. The input for these runs appears in Appendix C. In these runs only one level of demand was considered. That is, an estimated current demand of 400 daily passengers in Castro Valley was considered where the demand is generated randomly (see explanation above of the simulation components). Table 2 summarizes the results obtained for the wait time per passenger for forty cases related to the determined single route depicted in Figure 12. The minimum (best) passenger wait time results in Table 2 are indicated by an asterisk for each number-of-buses scenario, as well as the second best results which are marked by a "✓" symbol. The wait time, in Table 2, is the average time per passenger, in minutes, from the time he/she called the feeder/shuttle bus information center until he/she boards the bus. It includes the walking time from the place of call (e.g. home) to the bus route (assuming shortest walk time) and the waiting time until the bus arrived.

From Table 2 one can see that the fixed route, fixed schedule strategy (#1) results in the highest waiting times. It is also observed that the flexible route, flexible schedule (demand-responsive) strategy (#10) does not always provide the best results and hence, cannot be an a priori superior to the other strategies. In fact, the best routing strategies observed in this simple real life test are those with two asterisks and two "✓" symbols: fixed route, flexible schedule, bi-directional with possible short-turn (#5), fixed route, flexible schedule, bi-directional with possible short-cut (#7), and fixed route, flexible schedule, bi-directional with possible short-turn and short-cut (#9). The short-turn, short-cut and bi-directional based routing strategies indeed proved worthwhile to consider. These three uncommon strategies reflect the current availability of on-line information and communication systems that allow for detecting when and how to adopt each of these strategies.

In addition six more simulation runs were performed for the 2-route system depicted in Figure 13, using strategies #1,8,and 10, with 4 buses, and for both picking up passengers and taking them to the train station and distributing them from the station. In these six runs an additional criterion was established about the maximum wait time that can be perceived while being at the phone location (e.g. home, work). That is, the criterion of 20 minutes was used (can be changed in the simulation runs) to reflect the fact that if the announced wait time for the bus shuttle/feeder is more than 20 minutes then the caller will not actually wait but will cancel his/her request or will do something else rather than "really" wait. Table 3 summarizes the average wait time per passenger for these two pick-up and drop-off cases including the determined standard deviation of each simulation run.

Figure 11. The basic network configuration on the Castro Valley map.

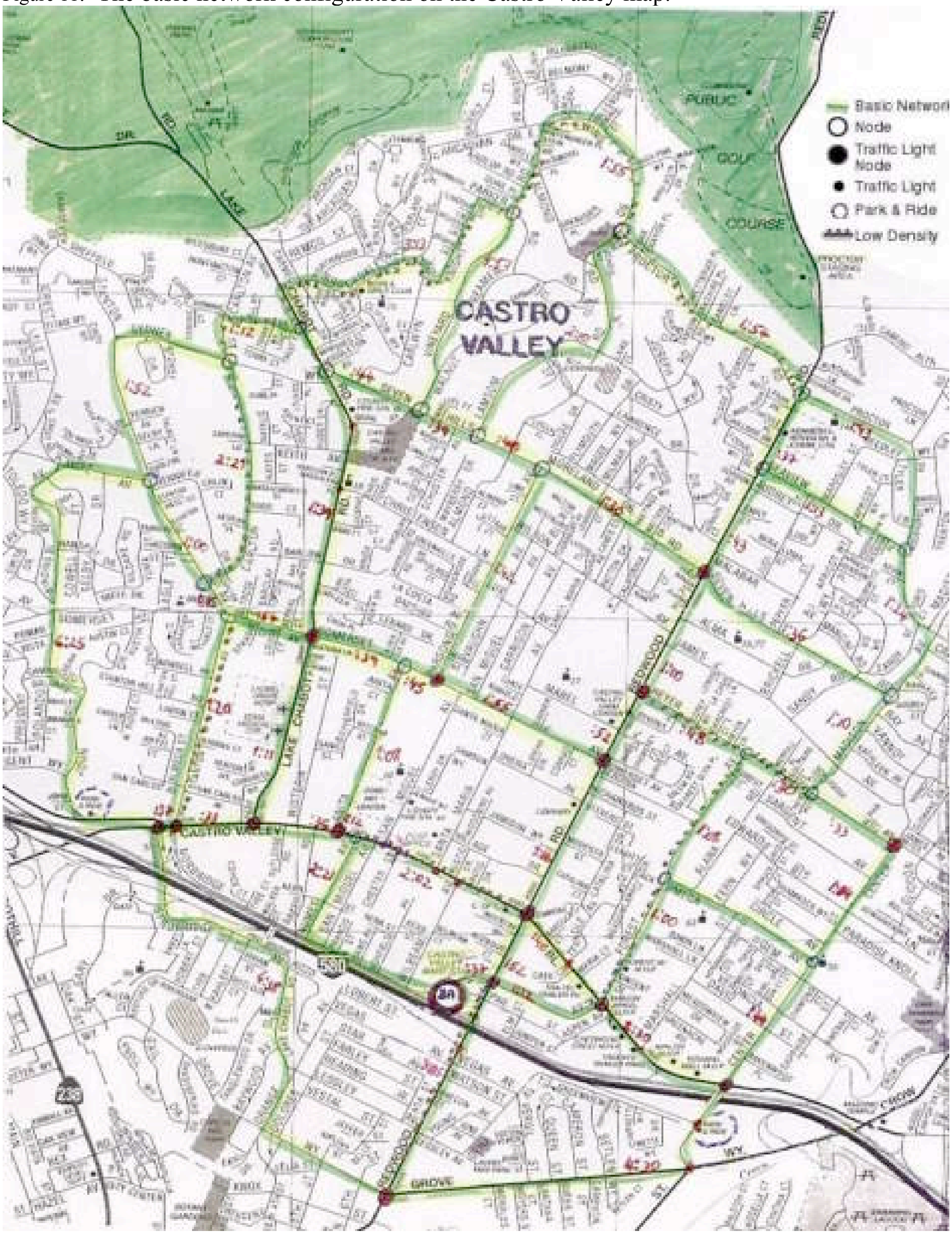


Figure 12. The determined single route on the basic network

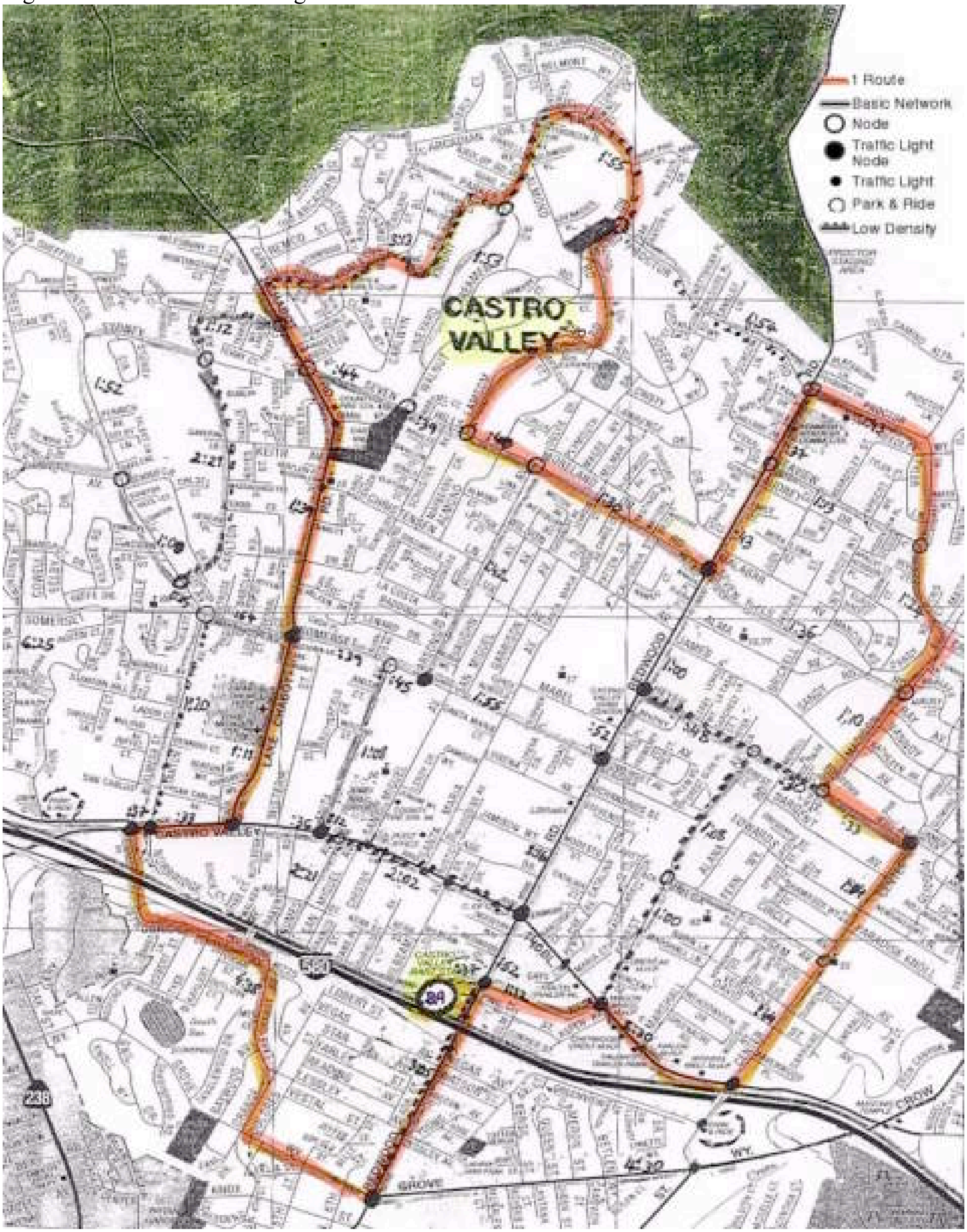


Figure 13. The 2 determined routes on the basic network

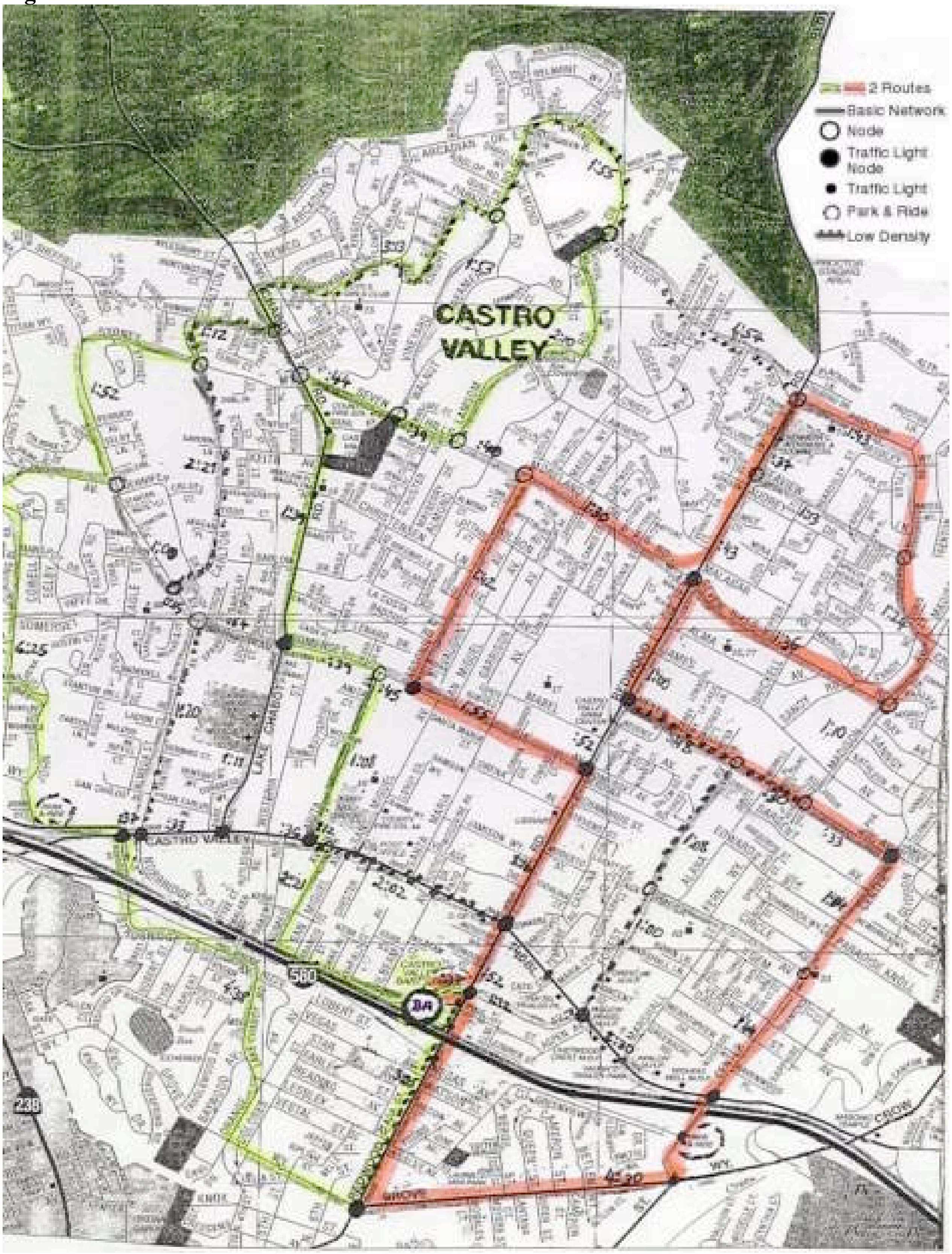


Table 2. Simulation results of wait time per passenger (in minutes) using different combinations of strategies and numbers of buses for the Castro Valley case study (given demand: 400 daily passengers).

# of buses / strategy	1 bus	2 buses	3 buses	4 buses
1	51	22	20	20
2	25	22	17	15
3	24 ✓	23	15 ∗	14 ✓
4	25	17 ∗	16 ✓	15
5	24 ✓	18 ✓	15 ∗	12 ∗
6	24 ✓	17 ∗	16 ✓	15
7	24 ✓	18 ✓	15 ∗	12 ∗
8	24 ✓	23	16 ✓	15
9	24 ✓	18 ✓	15 ∗	12 ∗
10	22 ∗	18 ✓	15 ∗	15

Key; ∗ = best results
✓ = 2nd best result

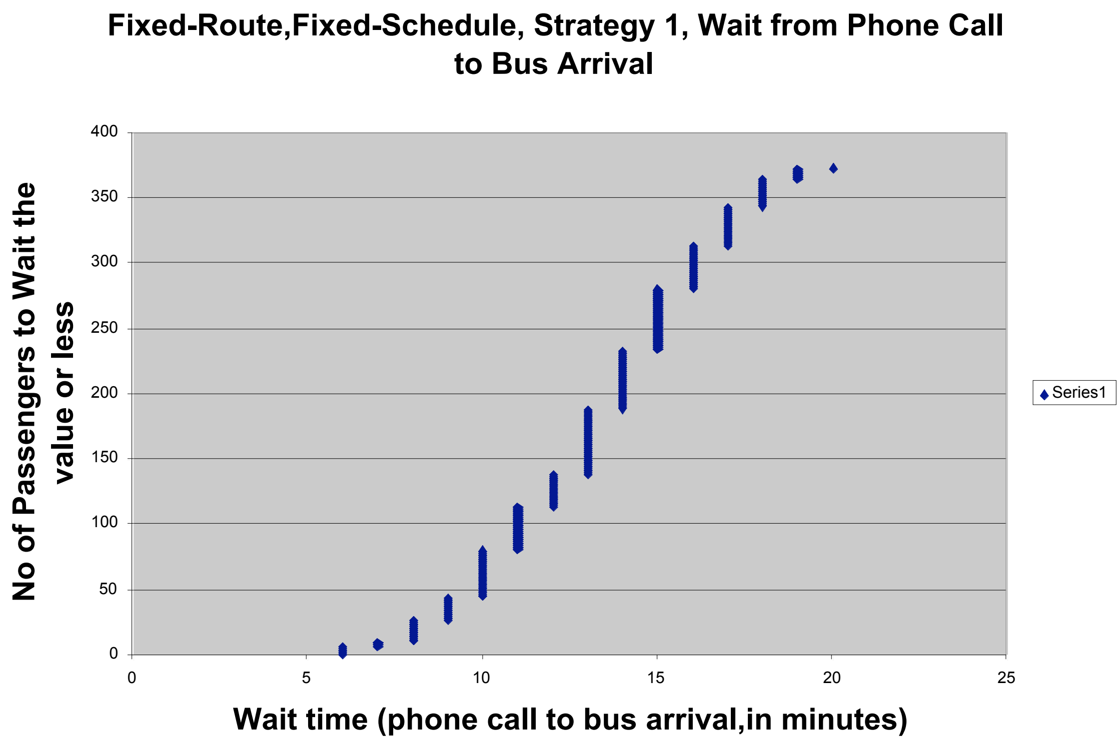
Table 3. Simulation Analysis for 2-route, 4-bus case with 20 minutes criterion (max wait after call)

Strategy	**Fixed-Route Fixed-Sched (#1)**	**Fixed-Route Flex-Sched (#8)**	**Flex-Route Flex-Sched (#10)**
Average Wait from phone call to bus arrival (min.)	**13.3**	**8.9**	**6.8**
Stand. Dev. (min)	**3.0**	**3.7**	**2.5**
Average Wait at Train Station (min.)	**13.6**	**1.6**	**1.4**
Stand. Dev.(min)	**15.3**	**8.5**	**5.0**

The cumulative curves for the wait times in these six situations appear in Figures 14, 15, and 16. Table 3 shows that the average wait time for distributing passengers in the fixed schedule case is much higher than for those in the other flexible schedule cases. Also the standard deviations are lower in the pick-up cases than in the drop-off cases. More precise configurations of these results are shown in Figures 14-16.

In these figures the upper cumulative curve refers to the pick-up case and the lower curve to the drop-off case. It is certain that in the drop-off case the wait time depends on the bus departure time from the train station. This is why the cumulative curves of the waits at the train station have the shape of large step functions. Also it worth mentioning that the X-axis scale is not the same in all cases and simply reflects the resultant waiting time range. In strategy 1 (fixed 2-route, fixed schedule) the wait time at the train station is heavily distributed between low values (short waits) and at the next bus departure after 20 minutes. In strategies 8 and 10 (with flexible schedules) the wait time is sharply reduced, indicating that once a train arrives and there are passengers, the bus will depart immediately. The comparison between strategies 1 and 2 (Figures 14,15) for the pick-up case reveals that while in the fixed schedule the wait ranges between 5-20 minutes, in the flexible schedule this wait ranges between 3-18 minutes. In the demand-responsive case (strategy 10, Figure 16) the wait time for the pick-up case ranges between 3-13 minutes.

These simulation runs are only preliminary steps toward the examination of a smart feeder/shuttle operation. More simulation runs are required for different numbers of fixed routes and various demand levels (especially the existing current demand) along with further sensitivity analysis of the input parameters.



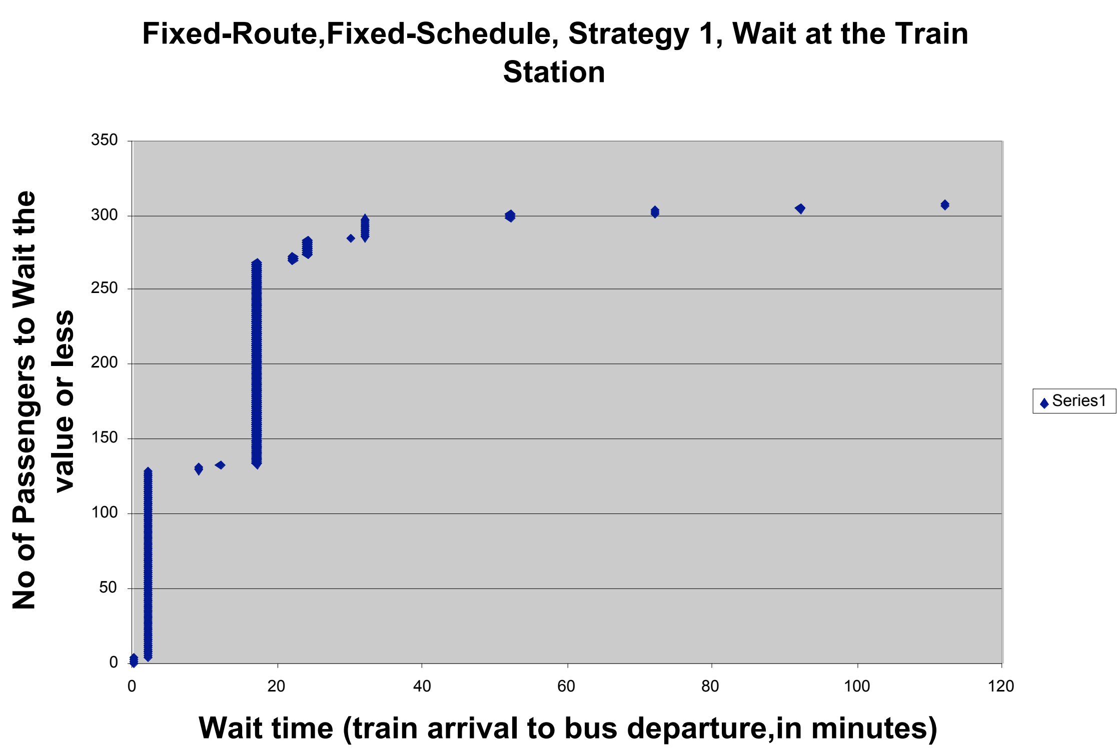
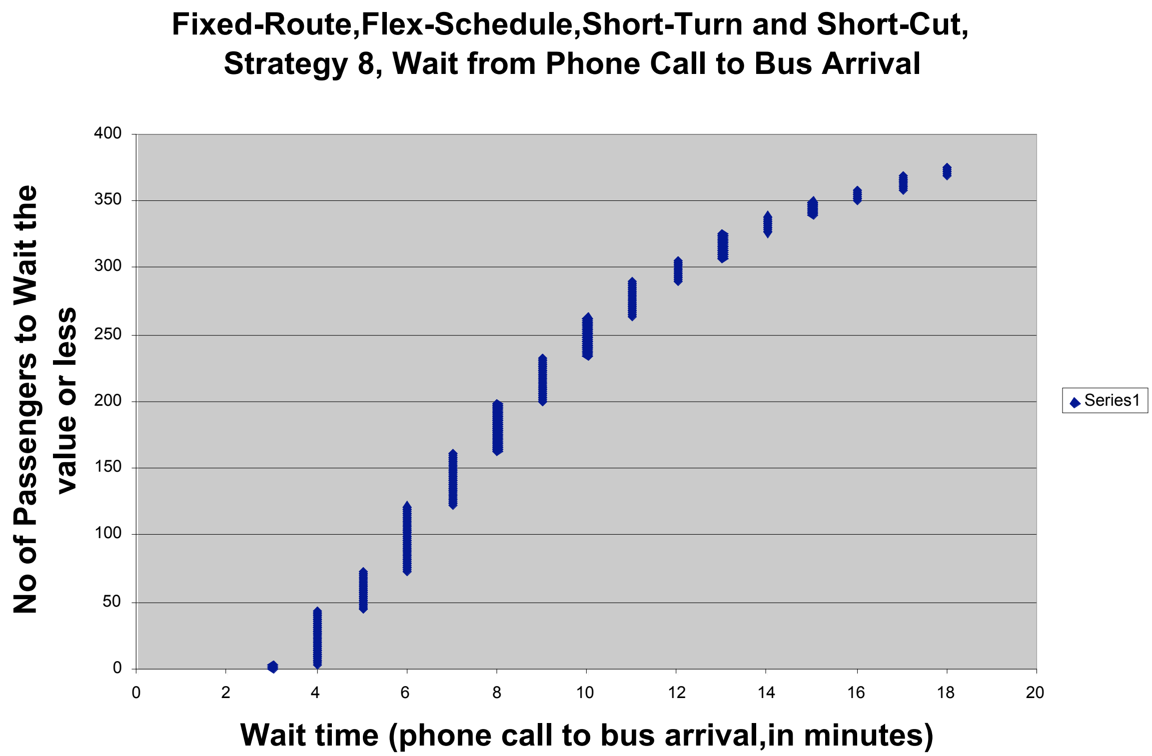


Figure 14. Wait time (phone call to bus arrival in upper curve, and at the train station in lower curve, in minutes) for strategy 1 (fixed 2-route and schedule)



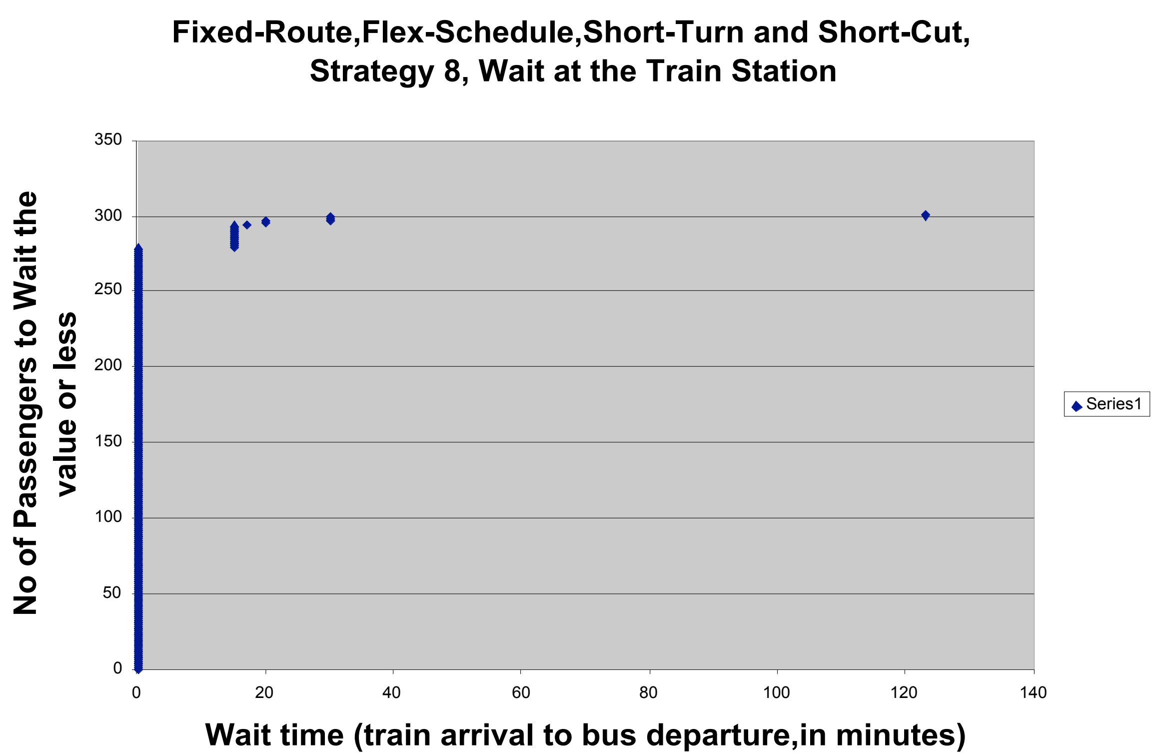
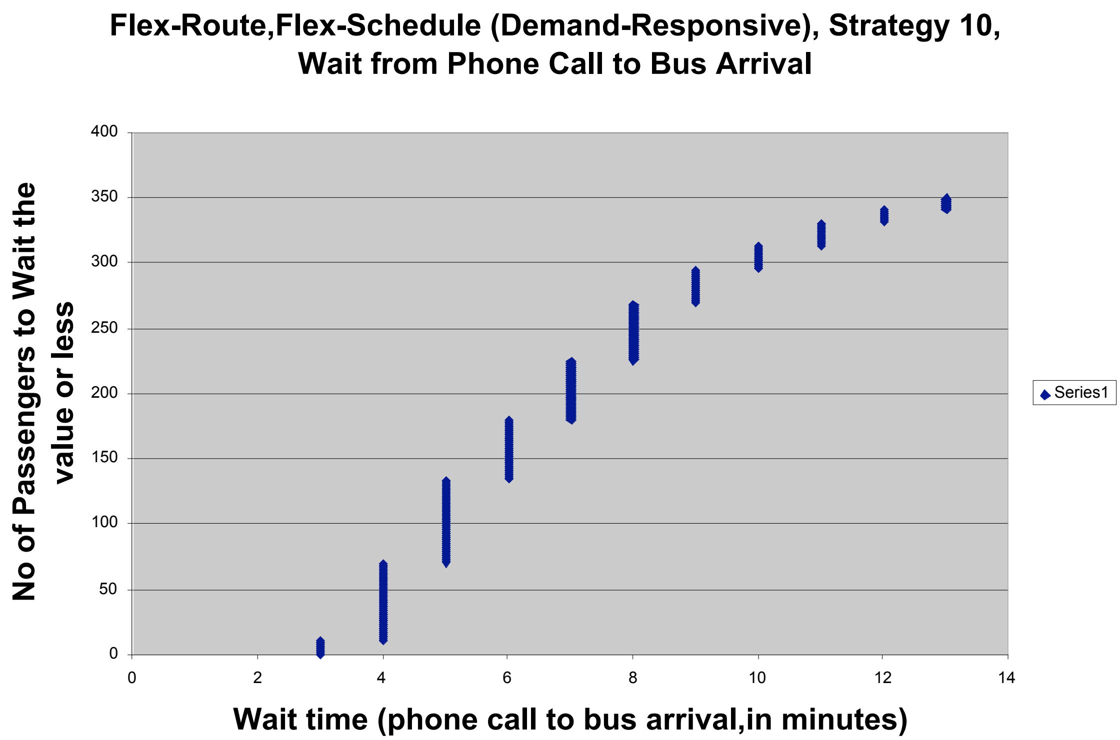


Figure 15. Wait time (phone call to bus arrival in upper curve, and at the train station in lower curve, in minutes) for strategy 8 (fixed 2-route, flex schedule with short-turn and short-cut)



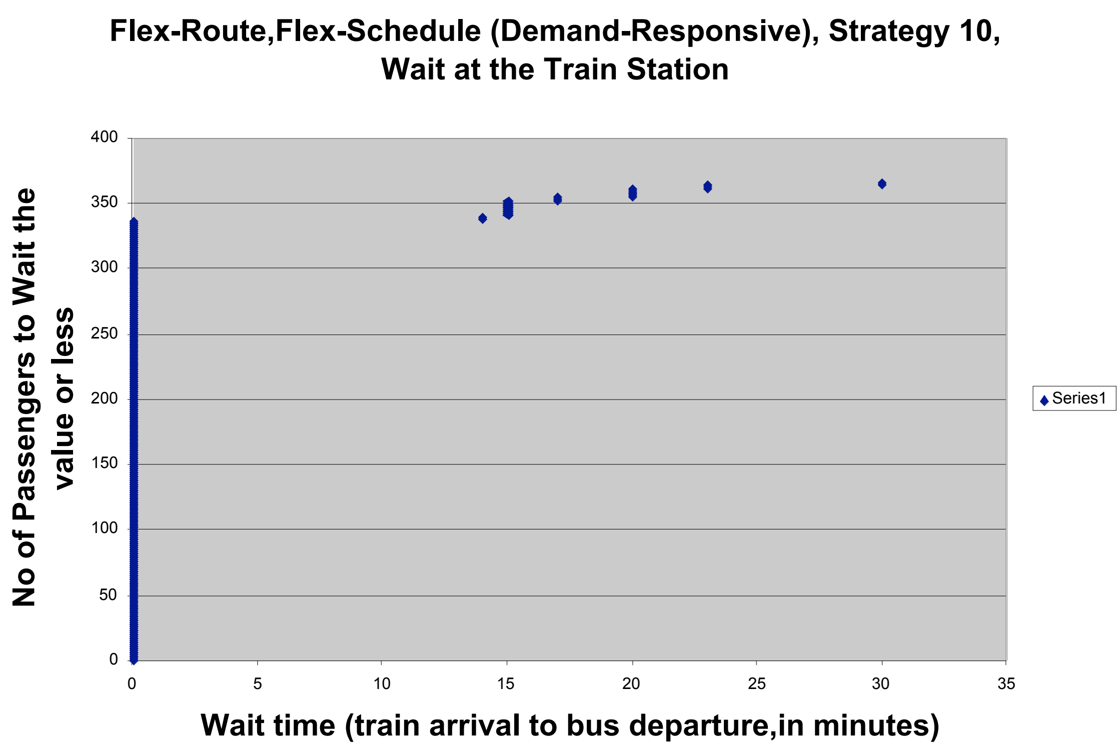


Figure 16. Wait time (phone call to bus arrival in upper curve, and at the train station in lower curve, in minutes) for strategy 10 (demand-responsive)

CONCLUDING REMARK

Once the analysis of the feeder/shuttle service is completed it is recommended that a pilot study be implemented. The pilot can adopt the following twelve steps in order to explore the possibility of a feeder/shuttle service in the study site. These twelve steps can serve as a framework for the master plan of a pilot where each outcome of a previous step becomes an additional input to the next step, except for step 6.

The pilot master plan starts, in Step 1, with a demand analysis by time of day and day of week in order to find the origin-destination pattern and the consumer oriented features. The second step is to design the fixed routing and stop system. The third is to determine the base frequencies and timetables for each route. The fourth step is to determine the number and size of the feeder/shuttle vehicles and to create the chains of trips (vehicle schedules) which will serve the fifth step of constructing the crew schedules.

The pilot plan continues in step 6 with the establishment of effective information channels and instruments (e.g. Tel center, internet, newspapers, radio, TV, mail leaflets) which will lead to the development of user-friendly communication procedures between the users and the operator in the next step. Step 8 constructs the DRT operational strategies without the use of the fixed routing/stop/schedule system. Step 9 determines the testing scenarios of the pilot while step 10 presents the process of how to select an adequate operator. The 11th step uses proper advertisement tools to approach an operable pilot, and finally, the last step of the plan aimed at improving the instruments, procedures and strategies with the use of innovative ITS (Intelligent Transportation Systems) elements.

Finally and overall, this work attempts to construct a new idea for designing an integrated smart feeder/shuttle bus service. Ideally, this smart bus system will provide advanced and attractive feeder and distributor services that operate reliably, and relatively rapidly, part of the passenger door-to-door chain with smooth and synchronized transfers. In order to approach the design of this innovative bus system a simulation model was constructed and tested. This simulation tool allows for the examination of: (a) various operating strategies from both the user and operator perspectives (b) different routing models and scenarios, and (c) different real-time communication possibilities between the user, operator and a control center.

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Appendix A

Simulation input/output and remarks of the example problem

The complete input for the example is therefore:

```
BUS: 1, 2, 27;
T DELAYS: 240, 180;
B DELAYS: 3, 5, 20, 25;
LAYOVER: 10;
START ROUTE: 20, 19;
STOP ROUTE: 18, 17;
T2B DEMAND LIMITS: 630, 50, 1000;
B2T DEMAND LIMITS: 630, 50, 1000;
SECTION GEOMETRY: 0, 1, 120, 0, 0, 2;
SECTION GEOMETRY: 0, 4, 120, 0, 0, 2;
SECTION GEOMETRY: 1, 2, 420, 0, 1, 2;
SECTION DEMAND: 10, 10;
SECTION GEOMETRY: 2, 3, 240, 0, 2, 2;
SECTION DEMAND: 65, 65;
SECTION GEOMETRY: 2, 4, 120, 0, 0, 1;
SECTION GEOMETRY: 3, 4, 420, 0, 1, 2;
SECTION DEMAND: 25, 25;
ROUTE: 1, 0, 1, 2, 3, 4, 0;
TRAIN TIMES: 700, 800, 900, 1000;
FIXED BUS TIMES: 1, 630, 720, 735, 820, 825, 920, 925;
```

This input can be written on file Example.txt in the same directory as program Shuttle.exe. For checking the input one can run the program:
Path\Shuttle Example.txt o1
Where path is the path name of the directory of program Shuttle.exe. Option 1 (o1) means that only input checking is required. This results output on the screen which appears as follows:

```
Upon the prompt '>' press Q to exit or any other key to continue
>Time differences: bus->train:   4.00 [min], train->bus:   3.00 [min]
Time per passenger: pick:  0.42 [min], drop: 0.33 [min]
Time to stop for board:  0.08 [min], for alight: drop: 0.05 [min]
Minimal # passengers to depart: 20, to trip: 19
Minimal # passengers to cut: 18, to turn: 17
Rest for driver:   10[min]
>Routes:
1.  0 1 2 3 4 0
at     390     440     455     500     505     560     565
>Nodes:
0. Arcs to:  1 4
1. Arcs to:  0 2
4. Arcs to:  0 3
2. Arcs to:  1 3 4
3. Arcs to:  2 4
```

```
>
:Bus classes
1. quantity:  2, size: 27
>Train time table:      420     480     540     600
>Demand of passengers getting off train (time1-time2: demand)
390.00-600.00: 50.00
>Demand of passengers get tin on train (time1-time2: demand)
390.00-600.00: 50.00
>>>Sections from node #0 to:
1.: time= 2.00, std(time)= 0.00, demand for T=  0pc, for B=  0pc stops=0
4.: time= 2.00, std(time)= 0.00, demand for T=  0pc, for B=  0pc stops=0

>Sections from node #1 to:
0.: time= 2.00, std(time)= 0.00, demand for T=  0pc, for B=  0pc stops=0
2.: time= 7.00, std(time)= 0.00, demand for T= 10pc, for B= 10pc stops=1

>Sections from node #4 to:
0.: time= 2.00, std(time)= 0.00, demand for T=  0pc, for B=  0pc stops=0
3.: time= 7.00, std(time)= 0.00, demand for T= 25pc, for B= 25pc stops=1

>Sections from node #2 to:
1.: time= 7.00, std(time)= 0.00, demand for T= 10pc, for B= 10pc stops=1
3.: time= 4.00, std(time)= 0.00, demand for T= 65pc, for B= 65pc stops=2
4.: time= 2.00, std(time)= 0.00, demand for T=  0pc, for B=  0pc stops=0

Sections from node #3 to:
2.: time= 4.00, std(time)= 0.00, demand for T= 65pc, for B= 65pc stops=2
4.: time= 7.00, std(time)= 0.00, demand for T= 25pc, for B= 25pc stops=1
```

All the above were for input checking. The run of the simulation is performed by typing:

```
Path\Shuttle Example00.txt
```

Results the following on the screen:

```
Upon the prompt '>' press Q to exit or any other key to continue
Detailed results in files ShuttleBus.txt & ShuttleTrace.txt
End of program
```

The reasons for excessive times can be found by examining the files ShuttleBus.txt and ShuttleTrace.txt themselves. It helps to improve the shuttle service. Note that the file ShuttleBus.txt is much shorter than ShuttleTrace.txt and describes the shuttle trips where each column corresponds to a trip. For the small example:

Bus Index	Starts	Ends	Max Pass.	Route
0	6:30	6:52	7	0 1 2 3 4 0
1	7:20	7:42	27	0 1 2 3 4 0
0	7:35	7:57	18	0 1 2 3 4 0
1	8:19	8:42	27	0 1 2 3 4 0
0	8:25	8:47	26	0 1 2 3 4 0
1	9:20	9:42	27	0 1 2 3 4 0
0	9:25	9:47	27	0 1 2 3 4 0

Appendix B

Simulation format and explanation

Variable	**Explanation**
========	===========
Bus2Train	-Time in seconds that bus must be before train arrival to ensure meeting
Train2Bus	-Time in seconds that bus must wait after train arrival to ensure pick-up
BusType	-Unique index of bus typeSize
	-Number of seats in this BusType
Quantity	-Number of vehicles from this Size
FixPick	-Fixed time in seconds for one passenger pick-up including bus slow down
FixDrop	-Fixed time in seconds for one passenger drop-off including bus slow down
FixBoard	-Fixed (additional) boarding time per passenger
FixAlight	-Fixed (additional) alighting time per passenger
NodeNo	-Node index at section end points
SectionNo	-Section number between two nodes Stop
	-Stop number starts with SectionNo and represents an intersection, not a node
MeanDemand	-Mean percent of potential travel requests per given hour and SectionNo to train, out of Total demand for Bus2Train
MeanDestin	-Mean percent of potential travel requests per given hour and SectionNo from train, out of Total demand for Train2Bus
MeanTime	-Mean section travel time in seconds
StDevTime	-Standard deviation of section travel time in seconds
Min4Turn	-Minimal number of on-board passengers to allow a short-turn
Min4Cut	-Minimal number of on-board passengers to allow a short-cut
Min4Trip	-Minimal number of travel requests by calls to allow a non-scheduled trip
Min4Dep	-Minimal number of waiting passengers to allow a non-scheduled trip
RouteNo	-Unique index of route
RouteDir	-Direction of RouteNo (start westbound or eastbound)
TTimeTable	-Fixed Train timetable in hhmmss form, hh is from 00 to 24
BTimeTable	-Fixed Bus timetable in hhmmss form, hh is from 00 to 24
Layover	-Fixed time for driver rest at the end of each trip
ClassIndex	-Class index of Bustype
	FromNodeNo -Node index where section starts
	IsOneWay -if one way:1 (in order of fromNodeNo toNodeNo);if 2-way: not 1
MeanTime	-Mean section travel time in seconds NodeNo
	-Unique node index at section end points NoStops
	-Number of stops on the section RandomSeed
	-Maximum 4 digit odd number, to obtain different samples on each run ToNodeNo
	-Node index where section ends TotDemand
	-Total demand for/to all sections between specified times in passengers per hour Time
	-Time as hhmm form, hh is from 00 to 24 YesNoAnswer
	-Should be 'yes' or 'no'

About format
============
Generally, keyword in capitals (spelling, case and spaces are important!) followed by a semi-colon and after it integers delimited by commas which may be written in continuation lines. Lines can be up to 90 characters longAfter the integers one puts a semicolon. After the semicolon any remark can be written. It is possible also to start a line with semicolon between two keywords.

Format of lines
===============
TRAIN TIMES: Time1, Time2,...; absolute time as hhmm
BUS: BusType, Quantity, Size;
T DELAYS: bus2Train, train2Bus; time in seconds
B DELAYS: FixAlight, FixBoard, FixDrop, FixPick; time in seconds
LAYOVER: Layover; time in minutes
T2B DEMAND LIMITS: Time1, TotDim1, Time2, ...; absolute time as hhmm
B2T DEMAND LIMITS: Time1, TotDim2, Time2, ...; absolute time as hhmm
T2B DEMANDS: Time1, Stop1 ,Time2, Stop2, ...; single arrivals by times, absolute time as hhmm
B2T DEMANDS: Time1, Stop1 ,Time2, Stop2, ...; single arrivals by times, absolute time as hhmm
START ROUTE: Min4Dep, Min4Trip;
STOP ROUTE: Min4Cut, Min4Turn; they should also take an earlier train
SECTION GEOMETRY: fromNodeNo, toNodeNo, meanTime, stDevTime, NoStops, IsOneWay;
time in seconds
SECTION DEMAND: MeanDemand, MeanDestin;
ROUTE: RouteNo, NodeNo0, NodeNo1,...; must start and finish with 0 (train station)
FIXED BUS TIMES: RouteNo, Time1, Time2,...; if not given for certain routes then
these routes are fixed routes but times are by demand. Absolute time as hhmm
SEED: RandomSeed;
ON SCREEN: YesNoAnswer;

Order of lines:
===============
TRAIN TIMES, BUSes, DELAYs, LAYOVER, DEMANDs and START/STOP ROUTES may be put anywhere
SECTION DEMAND must be put immediately after SECTION GEOMETRY to which it belongs
ROUTE should be after all SECTIONs, besides it can be anywhere
FIXED BUS TIMES, START ROUTE and STOP ROUTE should be after ROUTEs, besides it they can be anywhere.
If DEMANDS is given, LIMITS is not given for the same kind (Train2Bus/Bus2Train), also SECTION DEMAND are not given.

Remarks:
========
The same RouteNo cannot be both in FIXED BUS TIMES and START ROUTE!
Same bus distributes and collects passengers
STOP ROUTE is activated only if an earlier train can be captured
When STOP ROUTE is fired and there are too many unknown customers that can be collected to

an earlier train, the unknowns-are not collected.

Buses in SECTIONs can go both ways. It is enough to input only one direction even for two-way sections.
NodeNo = 0 for the train station

Program Execution
=================

Activate the program from the "Run..." window of the "Start" button by typing:

path/Shuttle data_file [o<option>] [r<RandomSeed>]

where, **path** is the path to the folder in which Shuttle is located (can be easily found by the "Browse..." button)
data_file is name of file holding input data
option is 0 for run, greater than 1 for a debug as follows:
option = DEB_INPUT + DEB_ARRAYS + DEB_ROUTES + DEB_SIMUL + DEB_LOG
RandomSeed is as defined above
while any summand may be missing, their value and meaning are:←-------?????????????????
DEB_INPUT 1 echoes input on DOS screen
DEB_ARRAYS 2 displays additional arrays that are defined on screen
DEB_ROUTES 4 displays details of ad-hoc route calculation on screen
DEB_SIMUL 8 displays simulation stages on screen
DEB_LOG 16 writes simulation stages on file ShuttleLog.txt
Display on DOS screen are **stopped** after a few lines by displaying a **'>'** sign on a new line.
Hitting **'Q'** key **stops the run**, and other key continue the run.

For example:
Shuttle lulu.txt o12 r1239
means that the input file name is lulu.txt, and on DOS screen the route calculation
and simulation stages are displayed and the random seed is 1239.

Assumptions
===========

1) The geographic distribution of demands is independent of time of day
2) Passenger can get to stop at no time if necessary
3) Each route starts and ends at the train station.
4) Bus arrives from parking to train station in no time.
5) All the passengers who want to use the shuttle service are given including their starting stop or destination stop.
6) No passenger balks.
7) Each passenger to be picked up initiates his contact via the telephone and either told when the shuttle will arrive to his/her close stop or asked to wait to a return call.

Simulation psudo-code
====================

The entities in the simulation are:

a) artificial entities that
a1) cause change in total demand of : -
FEEDINTENS bus to train
DISPINTENS train to bus
a2) traces bus timetables
TTOBSERVER or higher.
b) physical entities:
b1) passengers generated randomly in view of demand and geographical distribution:
FEEDERS who needs to arrive to station
DISPERSAND who needs a bus home
b2) passengers generated by specific input:
INDIVB2T who needs to arrive to station
INDIVT2B who needs a bus home
b3) explicit entity:
BUS
TRAIN
PASSENGER a passenger already in the system

Passenger Queues

Passengers in the simulation are held at queues that mirror their states:
PASS2DISPERSE those that should arrive on next train
ATSTATION those arrived already to station and waiting for a bus
WAIT4BUS those arrived already to a stop and waiting for a bus
INRIDE those on the bus
WAITATHOME those that phoned and stay home for a callback
The stages for the passengers are:
PASS2DISPERSE -> ATSTATION -> INRIDE.
WAITATHOME -> WAIT4BUS -> INRIDE.

Event-Oriented Simulation

The simulation is event-oriented where the possible events are:
ARRIVAL an entity arrived to the system.
The explicit action depends on entity type.
BUSATNODE a bus arrived to a node
The explicit action depends whether this is a starting, ending or intermediate stop.
ENDLAYOVER a bus finished the layover period
SENDDISP a bus finished to load all passengers from train station
GO2STOP a passenger arrived to a bus stop.
Upon each event the following is executed:
ARRIVAL of FEEDINTENS: updates overall density of bus to train demand
ARRIVAL of DISPINTENS: updates overall density of train to bus demand
ARRIVAL of FEEDERS: passenger phones requesting to be picked up. If a time can be calculated (in case that a bus is already on way towards the requested stop or if timetable is known) passenger

will appear at that time. Until then can be at home. If this is not possible the passenger will be called back when to be at stop. If known passengers reach a certain threshold, a route is devised, that collect all known passengers and a bus is sent
on that route if a bus is available.
ARRIVAL of INDIVB2T: as for FEEDERS.
ARRIVAL of DISPERSAND: the passenger is considered to arrive in the next train.
ARRIVAL of TRAIN: passengers leave the train. It takes some time (train2Bus) until they embark to bus (if a bus is available).
ARRIVAL of INDIVT2B: as for DISPERSAND
ARRIVAL of TTOBSERVER or higher: a bus is to start its route dictated by the timetable, provided one is available. The bus starts at train station.
BUSATNODE for starting (at station): all the passengers that arrived to station get
on the bus.
BUSATNODE for ending (at station): all passengers on bus get off the bus. The bus itself rests for Layover time.
BUSATNODE in some intermediate node: the bus first tries to shorten the time of its
journey by either short-cut or back turn, that modifies the route. While going towards
the next node, all the passengers wishing to get off and on at stops are let.
ENDLAYOVER: The bus is ready for next trip and starts immediately an ad-hoc route if
known passengers reach a certain threshold along a devised route. (Either for those
to be dispersed or those to be picked up or both.)
SENDDISP: All passengers on the train enter the station. If their number is above a
threshold and there is an available bus, a route is devised to disperse them.
GO2STOP: A passengers goes appears at the station.

Devising an ad-hoc route

Mark all the sections on the graph of possible ways the bus can take that has a known positive demand. Demand is passengers who phones to be picked up or known destination of those getting off. A route is requested starting and finishing at train station that goes over all the marked sections. This is devised only if a bus is available.
Denote the set of all marked sections by S and the starting node as X. At start X = 0 (the node of the train station). Denote by R the route. At start R is empty.
Do the following while S is not empty:
{Find the shortest route r from X to any Y that is an end-node of a section s in S Remove s from S. Add r to R and then add s to R. Let X be the other end-node of s. }
Find the shortest route, r, from X to node 0 (the station) and add it to R.

Appendix C

Castro Valley Input

<u>Input Values for the Castro Valley Runs</u>

Bus2Train	- **3:00** minutes
Train2Bus	- **4:00** minutes
SizeType	- It called 30 feet bus, with **27 seats**
Quantity	- **1,2,3 or 4 buses**
FixPick	- **25 seconds**
FixDrop	- **20 seconds**
FixBoard	- **5 seconds**
FixAlight	- **3 seconds**
NodeNo	- **one route system**
SectionNo	- **network input**
StopNo	**- network input (intersections)**
MeanDemand	- use of a random demand on each segment between 2 nodes (highest demand is between the stops and the Train station) with **a total passengers per day** are between **400 and 2000 (400, 600, 800, 1000, 1500, 2000)**.
MeanDestin	- **same as the demand to the train**, but in opposite direction.
MeanTime	- given in seconds
StDevTime	- **5-10%** of the MeanTime
Min4Turn	- **6,8,10,12,14,or 16, passengers, given that by turning around there are 5 requests waiting, and given of course that the short cut will reach an earlier Train**
Min4Cut	- **8,10,15,18,or 22 passengers given of course that the short cut will reach an earlier Train**
Min4Trip	**- 8 passengers (can be changed from 8 to: 10, 14, 18, and to see the effect of results)**
Min4Dep	- **6, 8, 10, or 14 passengers**
RouteNo	- S1
RouteDir	given for one and bi-directional
TTimeTable	**- See Below**
BTimeTable	- the number of bus departure times is same or similar to the maximum number of departures found in the other runs, where during rush hours (5-8 a.m.) the bus headway (time between 2 departures) is shorter by **25%** than in the other hours of the day (similar to the train-BART schedule)
Layover	- **15,10,or 20 minutes minimum**

Weekdays BART Schedule At Castro Valley toward Oakland and San-Francisco (arrival times)

BART Daily Arrival Times				
4:11	8:24	12:09	3:54	7:54
4:41	8:39	12:24	4:09	8:14
5:09	8:54	12:39	4:24	8:34
5:24	9:09	12:54	4:39	8:54
5:39	9:24	1:09	4:54	9:14
5:54	9:39	1:24	5:09	9:34
6:09	9:54	1:39	5:24	9:54
6:24	10:09	1:54	5:39	10:14
6:39	10:24	2:09	5:54	10:34
6:54	10:39	2:24	6:09	10:54
7:09	10:54	2:39	6:24	11:14
7:24	11:09	2:54	6:39	11:34
7:39	11:24	3:09	7:02	11:54
7:54	11:39	3:24	7:17	12:10
8:09	11:54	3:39	7:34	