AUTONOMOUS DIAL-A-RIDE TRANSIT

Benefit-Cost Evaluation

by

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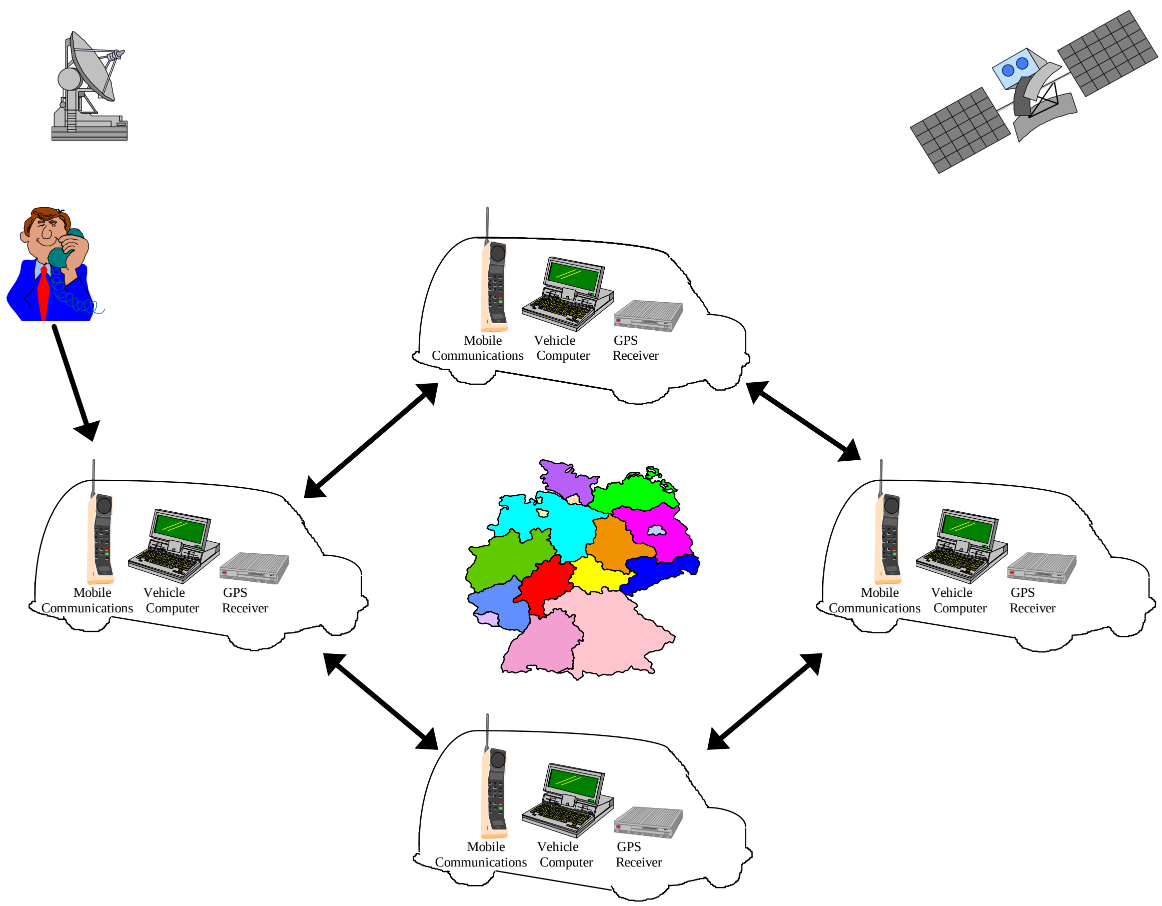

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1. Introduction

Among public transit and for-hire modes, fixed-route bus and rail are most effective in maintaining high ridership in high density areas such as urban centers. The cost effectiveness of fixed-route transit, however, depends on close proximity to the passenger's trip origin and destination, and diminishes rapidly as density decreases. Taxis, on the other hand, provide door-to-door service but at a premium price. Most taxi service, however, is congregated in high density urban areas where there is a higher pool of potential customers. Thus, taxis are expensive to use and hard to hail in low-density suburban areas. Conventional dial-a-ride provides a level of service and cost between fixed-route transit and taxi, but service is only available to a small segment of the traveling population, namely the elderly and handicapped. A*utonomous dial-a-ride transit* (ADART) is a modernized version of dial-a-ride transit that provides service for the general population and offer a level of service, quality and cost somewhere between fixed-route bus and taxi. Compared to conventional dial-a-ride, however, ADART costs less to operate.

1.1 Purpose of Paper

This paper intends to evaluate the benefit-cost (BC) of implementing ADART. It intends to address the "efficiency" question, namely, does implementing ADART increase the total net benefits to society as a whole? Due to the lack of "complete" data for evaluation, this paper stresses the qualitative evaluation rather than the quantitative. Without extensive data collection effort, the quantitative part of the evaluation merely seeks to illustrate the potential benefits and cost savings using "reasonable" figures gathered from various sources.

1.2 Expectations for ADART

At the onset, it must be recognized that ADART cannot serve all areas and trips. In order for ADART to operate effectively, it assumes that there is demand for such a service. If there is inadequate demand, ADART will simply move to a different service area with higher demand to provide service. Second, many of ADART's clientele will likely come from existing dial-a-ride services. ADART has a cost advantage that will prove (later in this paper) to be a tremendous cost savings to public transit agencies that provide costly dial-a-ride services. Furthermore, ADART has the potential to provide effective feeder service to and from line-haul transit. This helps to improve access to transit, especially in suburban, low density areas, making the transit alternative to driving more attractive. Compared to transit, ADART also has a better ability to adapt to peak demand. Since most transit agencies plan for the peak, excess vehicles and manpower are often under utilized and left idle during the off-peak. ADART has the ability to scale services based on demand, regardless of the time-of-day. Thus, it is ideal for supplimenting peak service, presenting a tremendous cost savings to public transit agencies.

ADART also has the potential to attract new trips, especially at major activity centers such as shopping malls or recreational activity centers. It can provide reliable service for shopping and leisure trips at a reasonable cost. Lastly, since ADART has many characteristics that are similar to the private automobile, such as door-to-door service, personal comfort, travel speeds and time, etc., it has the potential to attract some private auto trips. ADART eliminates the stress of driving or the inconvenience and cost of parking. Its door-to-door service eliminates concerns over personal security when walking to access a parked automobile.

2. Project Description

ADART is a fully automated dial-a-ride transit system that provides service to anyone that subscribes to the service. It uses off-the-shelf navigational, scheduling and routing, billing, communications and computer technology.

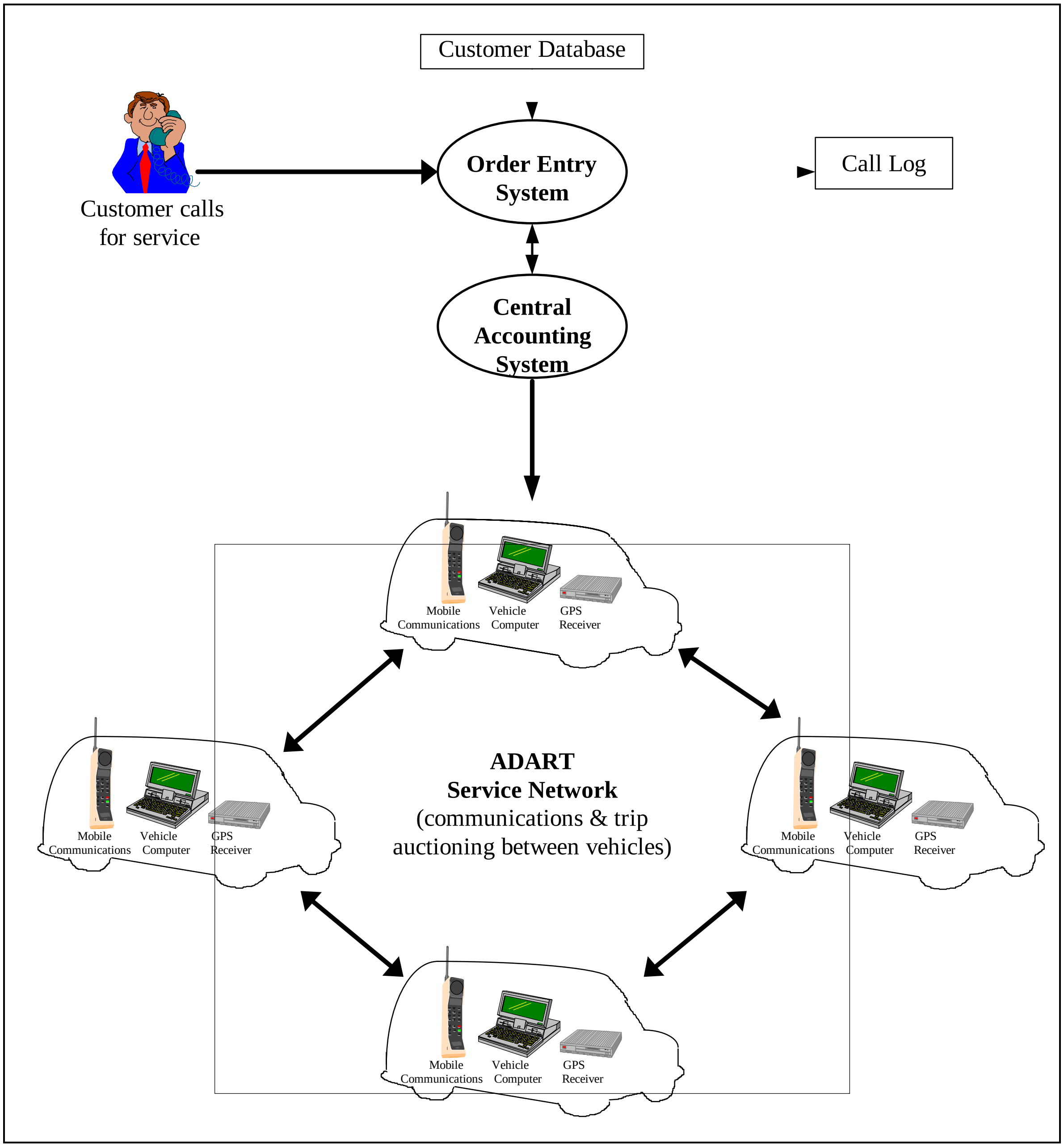
2.1 Operational Features

The *order entry system* (OES) is the "heart" of the service request process. It resides at the Base Station, and all links are wireline connections. A schematic diagram of the ADART system component is presented in Exhibit 2.1. The OES receives all calls from customers requesting ADART service. Service requests almost always come from the customer, but occasionally, the driver of a disabled vehicle can call to request service for customers still onboard. The OES utilizes an audio-prompt, menu-driven IVR system to solicit trip request information and retrieves stored information from the *customer database*. ADART service request information is then forwarded by the OES to the *central accoutning system* (CAS). OES also forwards a copy of the service request information to the *call log* which creates a file of the transaction.

Upon request of the vehicle computer, CAS prompts OES to call the customer minutes before the scheduled pickup of the imminent arrival of an ADART vehicle. Under special circumstances in which ADART cannot serve a scheduled trip, the OES also has the capability to call a taxi, giving information on the origin and destination of the trip as well as the time window for pick-up. In the entire service request process, order-entry is fully automated. The customer is the only human involved.

Other operational features of ADART include a scheduling and routing system that is fully automated, without the need for human dispatchers. With the increasing high cost of hiring dispatchers, a fully automated system like ADART can help reduce labor cost. Other operational features include state-of-the-art vehicle navigation that guides the driver to the correct pick-up or drop-off location.

Exhibit 2.1: Components of ADART Operation



Vehicle Assignment and Trip Auctioning

ADART has a unique vehicle assignment process. The vehicle computer answers the call directly and obtains trip information from the customer. The vehicle computer then initiates a *trip auction* by first calculating the marginal cost of inserting that trip into its itinerary. It then "broadcasts" this cost and trip information to every vehicle in the same area. Each remaining vehicle computer, in turn, makes its own estimate of the cost of inserting the trip into its schedule. Any vehicle computer who has a lower cost estimate responds by posting its cost and informs other vehicles of its responsibility for serving the trip.

Vehicle Navigation

ADART utilizes two state-of-the-art technologies for vehicle navigation - global positioning systems (GPS) and dead reckoning. The GPS signal provides a vectorized digital data of a vehicle's location based on its *latitude* and *longitude*. In case of GPS breakdown or inaccuracy, *dead reckoning* is used as a back-up (or supplemental) system. On-board sensors such as wheel sensors, a magnetic flux reader which acts as a compass, as well as a clock are used to provide information on the vehicle's speed and direction.

Advanced Call-Ahead

To assure minimum passenger wait time and vehicle dwell time, the ADART vehicle computer schedules itself to call the customer before a pre-specified number of minutes. The vehicle computer will initiate the call and trigger the voice unit to confirm the pick-up and inform the customer of the precise time of arrival.

2.2 Accounting Features

The accounting features of ADART include automated fare calculation, billing, and accounting capabilities through the use of electronic payment. This eliminates traditional fare collection by using credit cards or debit cards and security concerns over on-board fareboxes. ADART also features automated data collection capability through the use of ID cards. The vehicle computer notes the passenger's arrival from his/her ID card, swiped upon boarding. The lower cost of automated data collection is a positive feature of ADART's accounting system.

2.3 Technical Features

The technical component replaces the centralized dispatching function with a fully automated distributive system. It includes dispatching hardware and software on-board the vehicle, as well as a GPS receiver and other vehicle locationing hardware. An on-board mobile communication system allows the vehicle computer to communicate with other vehicle computers, as well as retrieve information from customer files.

2.4 ADART Target Trips

ADART does not attempt to serve all trips. Instead, it will target the following five types of trips:

1. ***Many-to-Few Trips****:* ADART provides *many-to-few* service by consolidating all trips from *many* different origins and transporting customers to a *few* common destinations. Service includes trips to attraction centers such as work (office park, office complex), shopping (shopping center, shopping mall), and personal purposes (medical complex, recreational parks), etc. ADART serves "anyone" who has subscribed to the service, but ignores street hails.
2. ***Routine, Recurring Trips***: ADART also seeks to target routine, recurring trips, which is said to account for over 50 percent of urban travel (Dial, 1995). ADART provides incentives and cost savings for advanced trip scheduling such as for work or school trips.
3. ***Off-Peak Transit-Dependent Trips***: Since lower demand and the high cost of operating fixed-route transit during off-peak periods necessitates service to be scaled-down, ADART can supplement sparse services and provide a reliable alternative and satisfy the travel needs of the transit-dependent population.
4. ***Reverse Commute Trips***: Peak period public transit service is typically good for passengers inbound into city centers. However, service heading outbound to the suburbs are often sacrificed for the more profitable inbound direction. Furthermore, low density and suburban sprawl often make it difficult for transit to compete with the ubiquitous automobile which provides the convenience and reliability of a door-to-door service. ADART, on the other hand, can provide reliable door-step service for commuters traveling from urban centers to the suburb where access from the transit stop to one's final destination is often a concern. Moreover, it can provide feeder

service to traditional line-haul transit service, eliminating the need to drive in order to access transit.

5. ***Return Trips***: Even if trips to a destination on transit may be convenient, not all return trips are so. For travelers who work late, for example, or when transit service is not available, the lack of a safe and viable option for the return trip may force many to drive instead. ADART provides service for transit users who wish to take transit on at least one leg of the trip but desire a safe and reliable service for the return trip. For auto drivers or passengers who need to walk a distance to access their automobile, ADART provides a safe and reliable door-to-door service that increases security, especially during evening hours.

2.5 ADART Service Levels and Price Structure

ADART fares vary, depending on the type of service the customer selects. Exhibit 2.2 present a framework for the different level of service ADART provides. Fares are determined based on the following three conditions:

1. Reservation Time to Actual Pick-up
2. Trip Frequency
3. Time Constraint

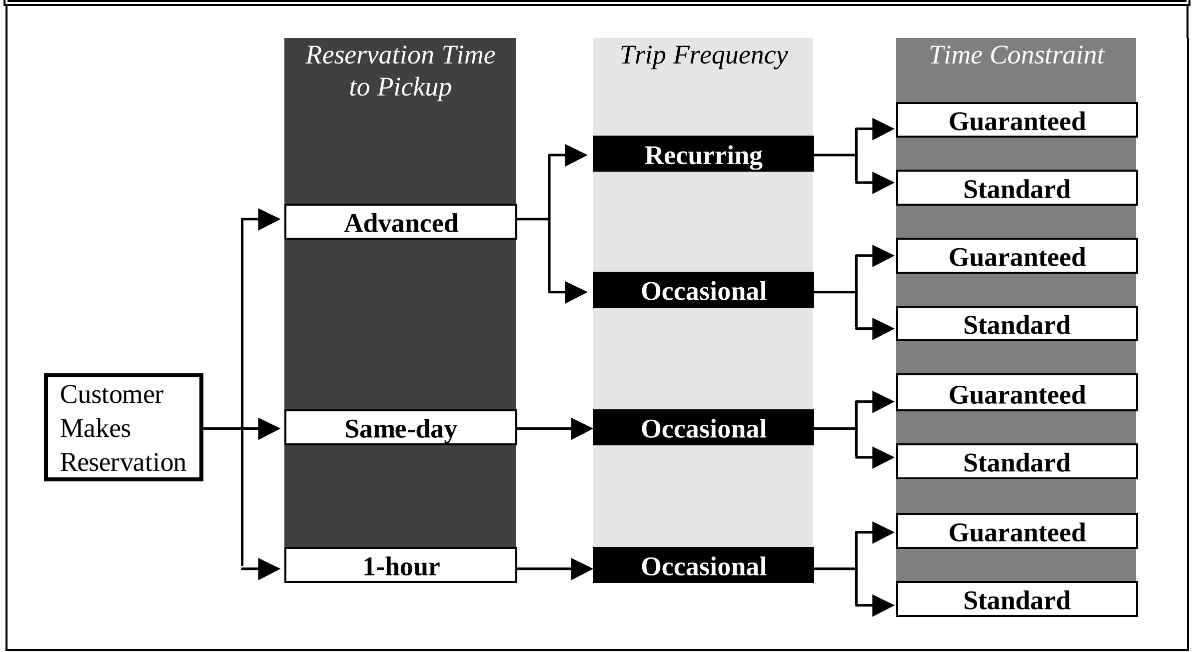
Reservation Time to Actual Pick-up

There are three types of reservations possible, from the least to the most expensive:

1. ***Advanced Reservation***: all reservations that are made before 12 a.m. midnight the day of the actual trip; a discount is applied to this type of reservation.
2. ***Same-day Reservation***: reservations made on the day of the trip after 12 a.m. midnight; a high fare is charged on this type of reservation.

3. ***1-hour in Advance Reservation***: reservations made 1-hour before the actual pick-up; a premium fare is charged on this type of reservation.[1]

Exhibit 2.2: ADART Service Level Framework



Trip Frequency

Fares also vary by trip frequency. Recurring trips originating from the same origin and destined to the same destination for three or more times in a week are eligible for a discount. Work/commute and school trips, for example, fall into this category. The purpose is to encourage ADART users to make advanced reservations for "repeated" trips which provide ADART with a steady stream of trip demand. Reservations for non-recurring or occasional trips are charged a regular fare, without any discounts.

Time Constraint

[1] A premium fare is charged for 1-hour in advance reservations as opposed to a "high" fare for same day reservations for two reasons: 1) 1-hour in advance reservations may "tax" the limits of the scheduling and routing algorithm to service the trip request. In some cases, if all vehicles are busy serving other trips or no ADART vehicle is close enough in proximity or available to pick-up the passenger in-time, a new vehicle (previously out-of-service) may have to be called in to service the trip. This will add to the operating cost for ADART. 2) Same-day reservations as opposed to 1-hour in advance reservations allow more time for the system to react and respond to the service request and provide the scheduling and routing algorithm more time to feasibly insert the new trip request into an existing vehicle tour.

Since different trips have different time constraints, the service is segmented into two fare categories that price the trip based on the user's time constraint. The *guaranteed time* service charges a premium fare for time constrained users and guarantees on-time pick-up and drop-off. If the user is picked-up or dropped-off later than the latest user-specified time, the trip is free, and ADART bears the cost. The *standard* service promises a drop-off time of ± 15 minutes and charges the standard fare.[2] For the purpose of pricing the service, we do not use general trip purpose categories to determine a user's time constraint. Instead of obtaining trip purpose information to assign a generic time constraint for the trip (for example, assuming all work trips have a greater time constraint), the user is asked to specify what time constraint category best describes the specific trip in question. Not all work trips necessarily have the same time constraint. Only the ADART customer will be able to determine it as such. Thus, when a user calls ADART to make a reservation, he/she is asked whether a *guaranteed time* service is preferred or the *standard* service.

[2] As the scheduling algorithm is refined and more data and experience can be learned from a microsimulation of the operation or through field tests, it is conceivable that this "time window" may be further reduced. But for the meantime, we will assume that the feasible time window as such.

3. Evaluation Framework

The introduction of ADART, a new form of dial-a-ride/transit service, is expected to have impacts on existing users and service providers of fixed-route transit, conventional dial-a-ride, taxi and the private automobile. The impacts can be classified into three categories:

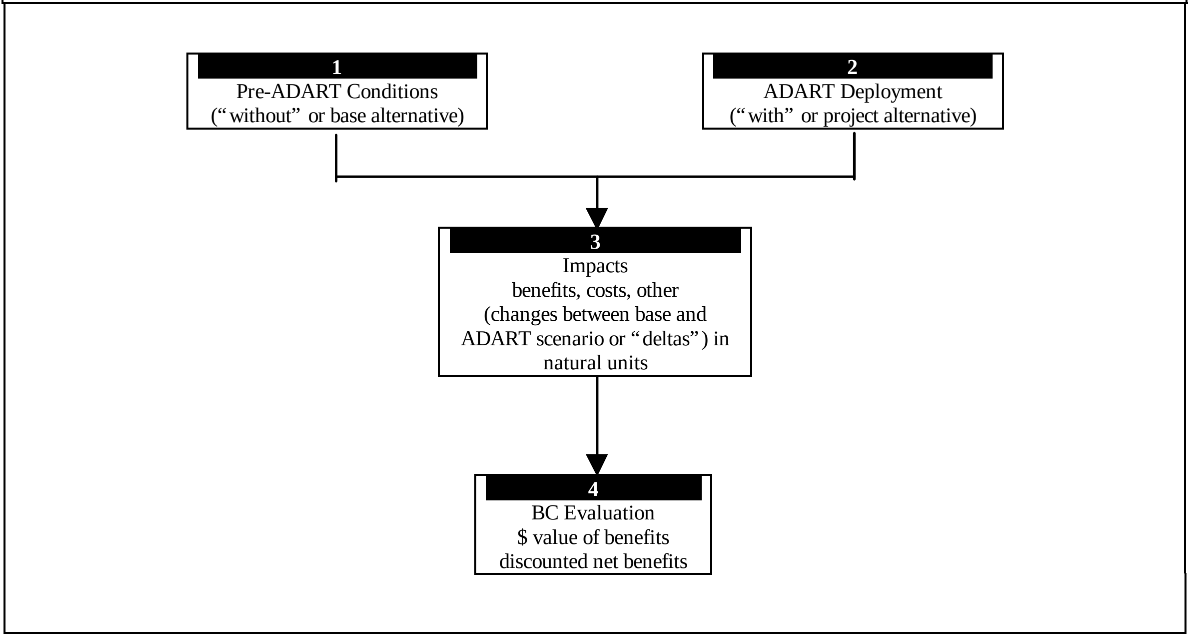
- ***Costs***: include initial capital costs[3] and operating and maintenance costs.
- ***Benefits (or disbenefits)***: other impacts that are not part of initial capital costs, or operating and maintenance costs.
- ***Transfers***: impacts that create gains or losses for individuals or groups but net to zero when considered from a societal standpoint. (Also assumes that there are no resources expended during the transfer.)

Exhibit 3.1 presents the ADART BC evaluation structure. In the BC evaluation, two sets of alternatives are compared, a "without ADART" or base alternative (box 1), and a "with ADART" or project alternative (box 2).

3.1 The Base Case ("without" ADART)

In the base case, it assumes that the current level of investment in transit and highway will continue in the future, along with other demographics and external changes. In other words, the base case assumes a "natural" development of the current state, without significant investments or changes such as introducing a new service or technological solution such as ADART.

Exhibit 3.1: ADART Benefit-Cost Evaluation Framework



3.2 Project Alternative (“with” ADART)

In the “with ADART” scenario, the project alternative is to introduce ADART, a new form of dial-a-ride/transit system with a completely new concept and operating procedures. The ADART alternative also assumes an incremental deployment of ADART as demand for service increases.

After the base and project alternatives are specified, the next step is to measure or estimate the impacts (“box 3” in Exhibit 3.1). The “impacts” are categorized as *benefits* or *costs*. Benefits consist of all impact that make society better or worse off when ADART is introduced. Costs include initial capital costs to implement ADART, as well as ongoing operating and maintenance costs to keep the service running. The changes in the impacts or “deltas” (Δs) between the base case and the ADART alternative yields the net benefit in box 4. For ADART, changes in total travel time, operating costs, capital costs, service reliability or a sense of security for the user, etc., between the base case and the ADART alternative can be measured to obtain the total net benefit of all relevant impacts.

[3] If the implimentation of ADART makes an operator of another mode reduce the number of vehicles operated.

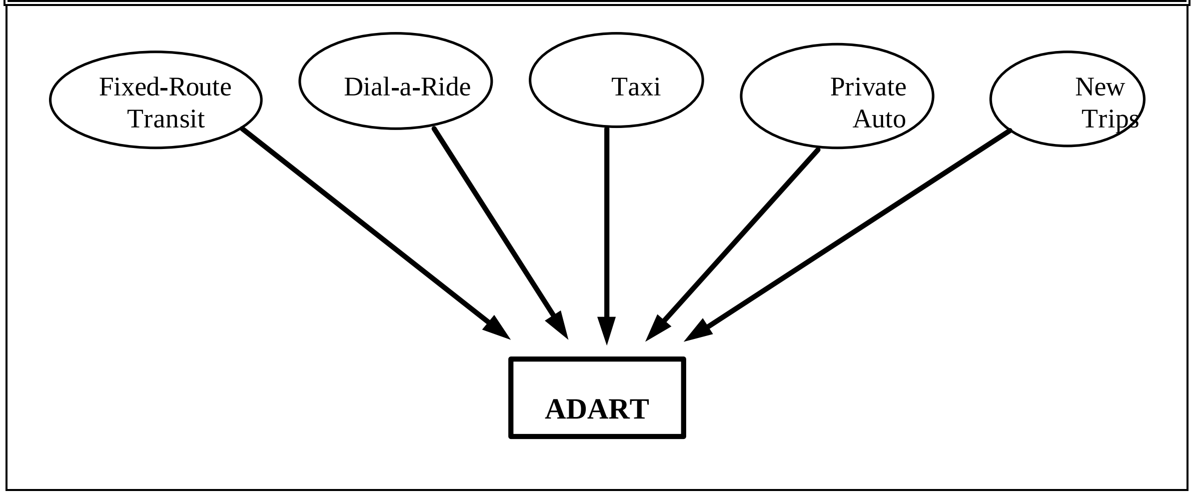
The natural units for each impact category can be converted into base year dollar units in order to obtain the annual net benefits.

3.3 ADART Customer Source and Factors that Affect Mode Shift to ADART

ADART is expected to draw its core customers from four main sources (Exhibit 3.2). These four sources include users of existing modes - from fixed-route transit, conventional dial-a-ride, taxi, and the private automobile. Although the benefits considered only include the four main modes, it is conceivable that ADART will attract some walk and bike trips as well as new induced trips. Since walk and bike trips account for only 6 percent of total person trips (NPTS, 1997), for the purpose of this paper, such trips are considered negligible and are absorbed in the "new/induced trips" category. There are seven potential factors for existing users of a particular mode to switch to ADART:

1. *Time Savings*: travelers seeking a faster mode that reduces total travel time
2. *Service Reliability*: travelers seeking a mode that provides more reliable service in terms of on-time performance
3. *Service Quality*: travelers seeking a mode with better comfort and amenities such as air-conditioning, guaranteed seating, etc.
4. *Flexibility*: travelers seeking a mode that provides increased flexibility such as customer-specified pick-up and drop-off times, as well as the ability to change or cancel trips
5. *Convenience*: travelers seeking a mode that is easy and convenient to use such as door-to-door service, the ability to cancel or make trip reservations through different mediums (i.e., telephone, in-person, kiosk, internet, etc.)
6. *Safety and Security*: travelers seeking a mode that provides a safer and more reliable service, without the worry of personal security, especially during evening and off-peak periods
7. *Cost Savings*: travelers seeking a less expensive mode

Exhibit 3.2: ADART Market Sources



3.4 Expected Impacts

This section will first identify all potential impacts of implementing ADART for each existing "source" from which ADART is expected to draw its customers. The "cause-and-effect" linkages of potential impacts can be illustrated, when appropriately, by using a series of "tree" diagrams. Second, relevant data that will measure the magnitude of each impact category will be identified. It is important to point out that the majority of impacts are either time-based or cost-based.

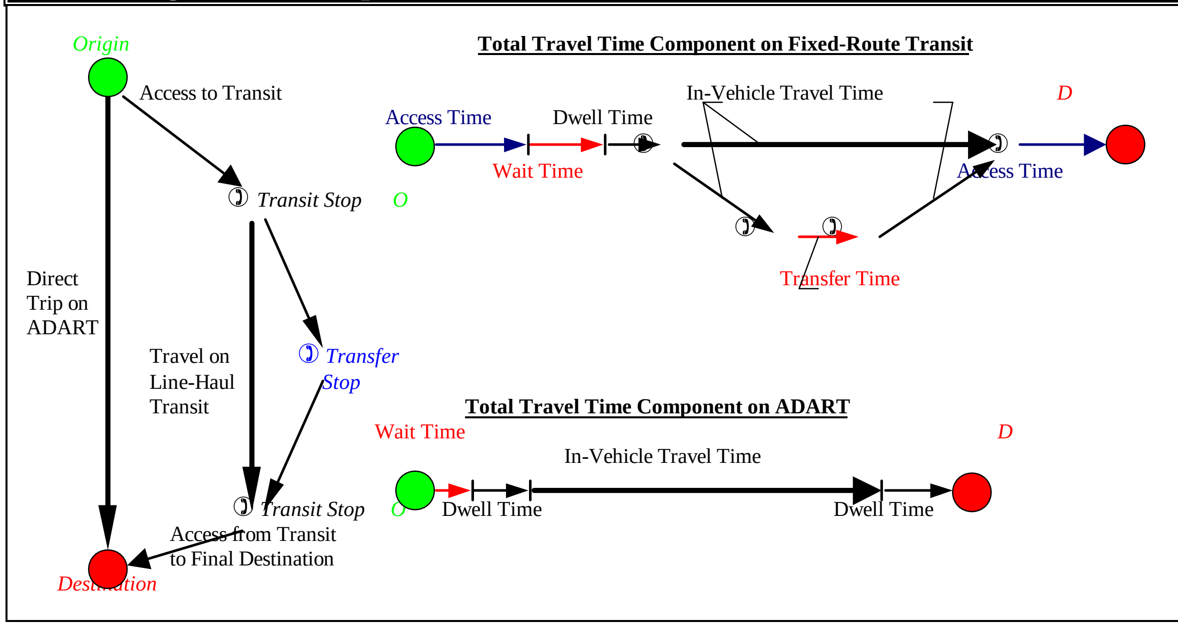
3.4.1 Expected Impacts to Fixed-Route Transit

Figure 3.1 provides a schematic comparison between fixed-route transit and ADART. It compares the total travel time components of both modes. These include:

1. Access to transit (with associated access time)
2. Waiting for vehicle arrival (with associated wait time)
3. Waiting to board vehicle (with associated dwell time)
4. In-vehicle travel on transit (with associated in-vehicle travel time)
5. Transfer onto another vehicle or mode (with associated transfer time, if applicable)

6. Access from transit to final destination (with associated access time)

Figure 3.1: Comparison betweem Fixed-Route Transit and ADART

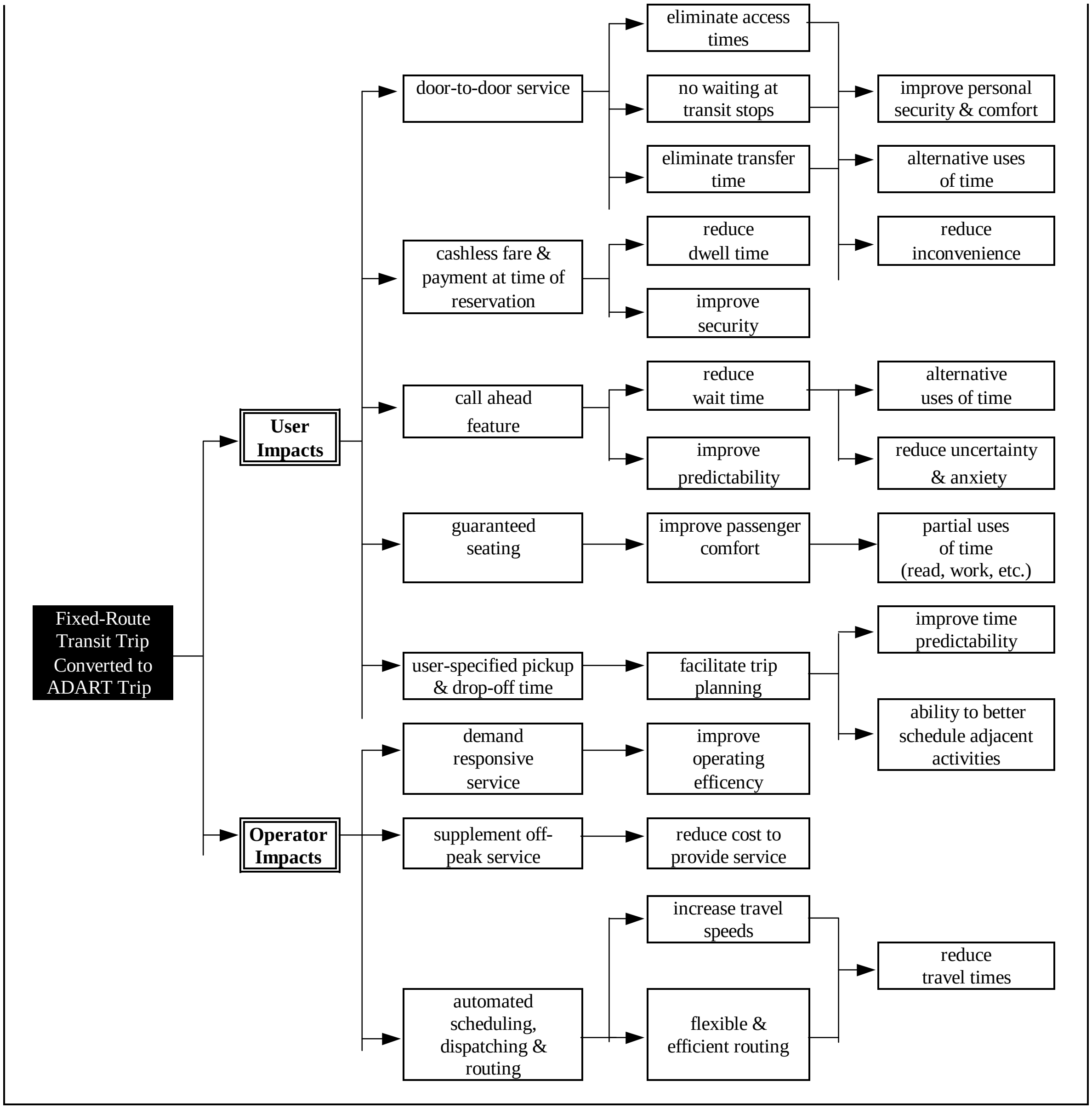


Compared to fixed-route transit, an ADART trip is more direct and has only four (compared to at least six for fixed-route transit) travel time components:

1. Wait time for vehicle arrival
2. Dwell time for vehicle boarding
3. In-vehicle travel time
4. Dwell time for alighting at destination

The expected impacts of ADART on fixed-route transit is divided into two parts - one on the users and the other on the service provider. The potential impact linkages are illustrated in Figure 3.2. A summary of the impacts and associated data requirements are presented in Table 3.1. For travelers who switch from fixed-route transit to ADART, ADART is expected to generate the following impacts:

Figure 3.2: Impact Linkages from ADART Compared to Fixed-Route Transit



1. *Time Savings*: elimination of access time to and from fixed-route transit; reduction in out-of-vehicle wait time as a result of ADART's *call ahead* feature which informs the passenger via the phone of the estimated time of arrival minutes before the actual pick-up (more "meaningful" or productive use of wait time); reduction in in-vehicle travel time as a result of flexible and efficient routing and no need to adhere to a fixed route and "stop at every stop"; the ability to circumvent congestion by taking alternative routes; elimination of possible transfer penalties (transfer time, inconvenience, etc.)

2. *Service Reliability*: demand responsive providing reliable service throughout the day without hurting off-peak service
3. *Service Quality*: improved comfort and amentities such as air conditioning and guaranteed seating
4. *Flexibility*: flexible operation not confined by timetables and fixed routes; allows the customer to specify the desired pick-up and drop-off time
5. *Convenience*: door-to-door service, easy to use service order entry system
6. *Safety and Security*: improved security and comfort as a result of door-to-door service (no need to wait at transit stop for an undetermined amount of time)
7. *Cost Savings*: reduce capital and operating costs of peak transit service (compared to full-size buses, for example)

Table 3.1: Data Requirements for Estimating ADART Impacts on Fixed-Route Transit

Impact Category	**Data Requirements**	
	Fixed-Route Transit	**ADART**
Total Out-of-Vehicle Travel Time	• average access time to/from transit • average wait time • average dwell time • average transfer time	• average wait time • average dwell time
In-Vehicle Travel Time	• average in-vehicle travel time	• average in-vehicle travel time
Reliability of Travel Time	• % of trips w/ wait certainty • % of trips w/ wait uncertainty	
Number of Trips	• expected total annual number of fixed-route transit trips by mode (bus, rail, etc.) • % fixed-route transit trips (by mode) attracted to ADART	• expected total annual number of ADART trips
Cost to Provide Service	• annual operating and maintenance costs • annual capital costs • annual cost to retrofit service to be ADA compliant	• annual operating and maintenance costs • annual capital costs
Other	• % of trips congested • % of trips uncongested • % of trips w/ passenger standing • % of trips w/ passenger seated	

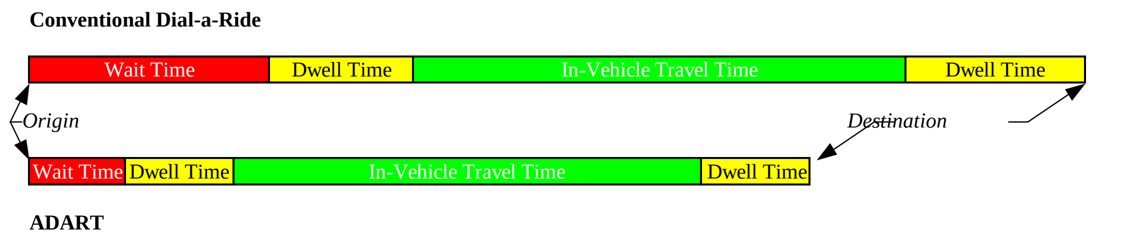
3.4.2 Expected Impacts to Conventional Dial-a-Ride

In comparison to conventional dial-a-ride, ADART's expected impacts are mainly time and cost-based. Figure 3.3 provides a comparison of the total travel time components between ADART and conventional dial-a-ride. Both modes have four travel time components consisted of:

1. Wait Time

2. Pre-Departure Dwell Time
3. In-Vehicle Travel Time
4. Arrival Dwell Time

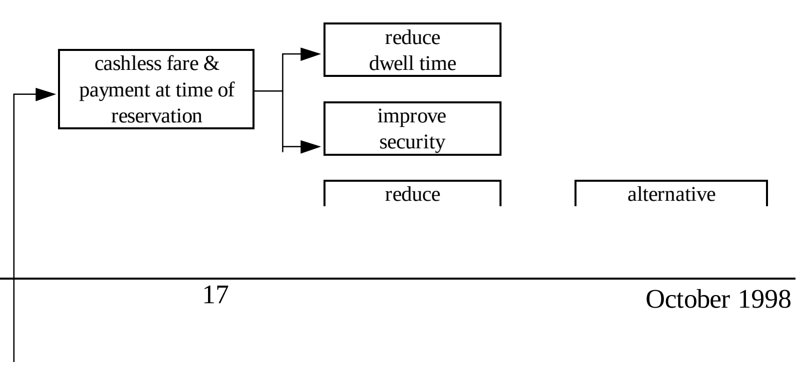
Figure 3.3: Total Travel Time Component Comparison between Conventional Dial-a-Ride and ADART

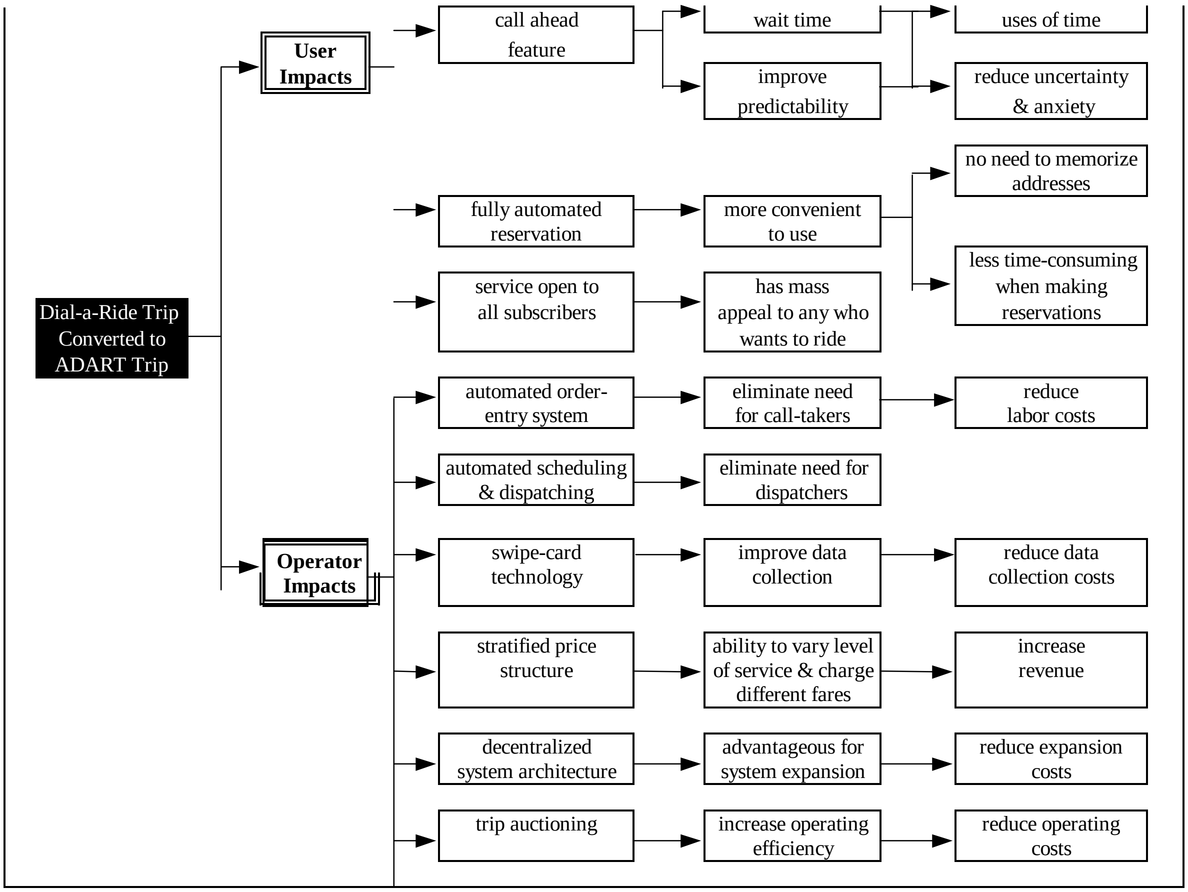


The impact linkages are presented in Figure 3.4. The expect impacts can be summarized as follows:

1. *Time Savings*: ADART's *call ahead* feature helps to alleviate uncertainty for the customer in waiting for service, as well as minimize wait time and vehicle dwell time, a feature that conventional dial-a-ride does not provide; ADART's automated identification and data collection capability through the use of magnetic-swipe ID cards reduces dwell time and helps to lower the cost of automated data collection.
2. *Convenience*: ADART's fully automated reservation system is more convenient to use and less time-consuming when making trip reservations. Customer information such as common trip origin and destination addresses, phone numbers, credit and billing information, as well as special needs are all stored in a personal data file. As a result, there is no information to remember. A customer can use his/her ID# and just select from a menu of trip origin and destinations to complete a reservation

Figure 3.4: Impact Linkages from ADART on Conventional Dial-a-Ride





3. *Safety and Security*: ADART's automated fare collection, billing, and accounting capabilities eliminate traditional cash fare collection by using credit cards or debit cards to pay for service at time of reservation. This reduces security concerns over on-board fareboxes and increases accounting accuracy.
4. *Cost Savings*: ADART's automated order entry system (OES) with interactive voice response (IVR) capability can reduce labor cost by eliminating the need for human call-takers (Lau and Dial, 1997). The reduced operating cost can be passed on to the customer as lower fares, saving the operator and users (of conventional dial-a-ride) of an otherwise costly and highly subsidized service. Moreover, unlike conventional dial-a-ride systems that have a uniform pricing structure and are forced to serve all types of trips, ADART targets recurring trips and has the potential to provide a "stable base" of business. This is achieved by structuring its fare system to encourage advanced and recurring trip reservations through discount fares. This strategy allows ADART to maximize *consumer surplus*.

5. *Productivity and Operating Efficiency*: through its scheduling and routing algorithm, ADART targets many-to-few trips by consolidating all trips from many different origins and transporting customers to a few common destinations. This consolidation of trips allows it to achieve higher productivity and increase operating efficiency. ADART utilizes a decentralized system architecture (i.e., each vehicle solves its own optimal or feasible solution as opposed to a system optimal or feasible solution for centralized systems) for dispatching and routing purposes which significantly reduces computational time and improves the chance of satisfying real-time constraints.
6. *System Expansion*: A decentralized operating structure is also advantageous for system expansion. With conventional dial-a-ride systems, an increase in demand and fleet size results in the need for larger and faster computers to solve a larger algorithm. For ADART, adding an additional vehicle to the fleet only results in adding another mini-computer to the vehicle. ADART only considers trips in the scheduling and routing of a single vehicle, not the entire system. Although the fleet size has increased, the size of the algorithm for each vehicle has not.
7. *Other Benefits*: ADART service is opened to the general public, providing a travel alternative for elderly travelers that previously took conventional dial-a-ride. It offers a similar level of service but without the "negative" stigma that is often associated with dial-a-ride systems.

Some of the data requirements for estimating the relative impacts of ADART on conventional dial-a-ride is summarized in Table 3.2 below.

Table 3.2: Data Requirements for Estimating ADART Impacts Compared to Dial-a-Ride

Impact Category	Data Requirements	
	Dial-a-Ride	ADART
Total Out-of-Vehicle Travel Time	▫ average wait time ▫ average dwell time	▫ average wait time ▫ average dwell time
In-Vehicle Travel Time	▫ average in-vehicle travel time	▫ average in-vehicle travel time
Reliability of Travel Time	▫ % of trips w/ wait certainty ▫ % of trips w/ wait uncertainty	
Number of Trips	▫ expected total annual number of dial-a-ride trips ▫ % dial-a-ride trips attracted to ADART	▫ expected total annual number of ADART trips
Cost to Provide Service	▫ annual operating and maintenance costs ▫ annual capital costs	▫ annual operating and maintenance costs ▫ annual capital costs
Other	▫ % of trips congested	

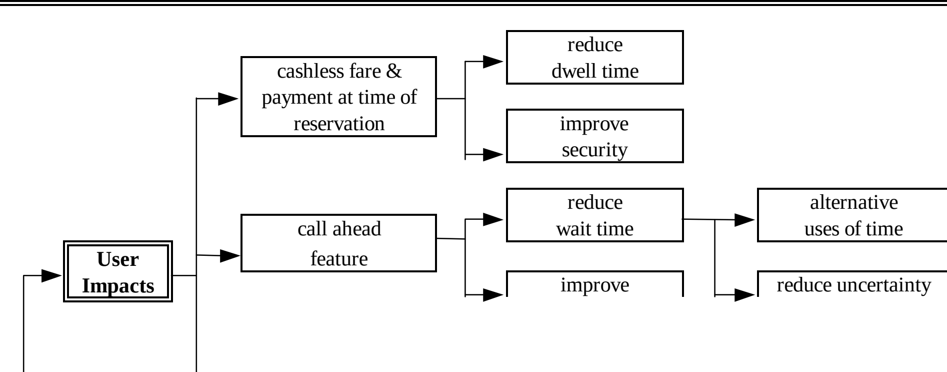
	% of trips uncongested	

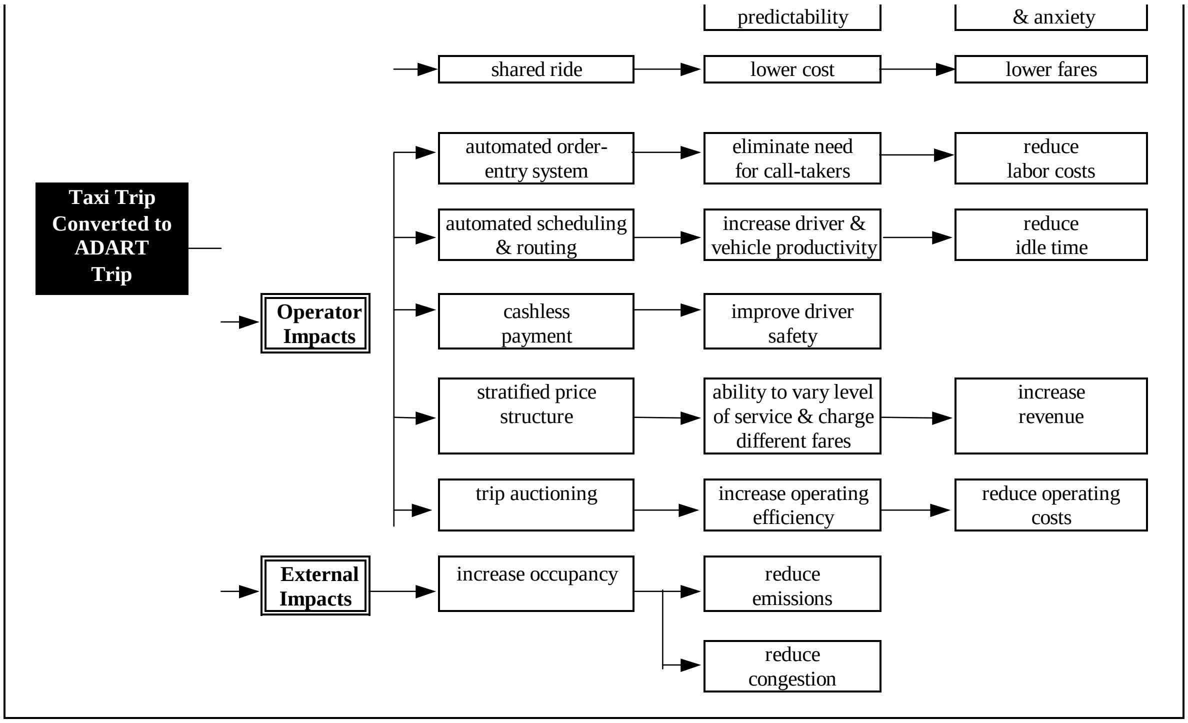
3.4.3 Expected Impacts to Taxi

Figure 3.5 presents the impact linkages for taxi. ADART is expected to impact taxi service in the following ways:

1. *Service Reliability*: In low density suburban areas, where there are less taxis in service (most taxis like to congregate in high density activity areas where there is higher demand for service and customers are easier to find), ADART can fill a void by providing a reliable alternative but at a lower cost. During off-peak periods or when taxi availability is scarce, ADART allows a customer to specify the pick-up and drop-off time, improving reliability of service.
2. *Safety and Security*: With occasional reports of taxi-robbery in urban areas, ADART's automated credit and billing system provides a cashless system that increases safety and accounting accuracy for both the driver and passenger.
3. *Cost Savings*: Compared to taxi, ADART allows passengers to share rides. This has the potential to lower the cost per passenger and hence, lower fares.
4. *Increased Productivity*: Compared to taxi, ADART's automated scheduling and routing algorithm has the potential to increase driver and vehicle productivity and reduce idle time which is common among "roaming" taxis.
5. *Other Benefits*: ADART also increases the occupancy per vehicle which has emissions and systemwide congestion reduction "effects."

Figure 3.5: Impact Linkages from ADART Compared to Taxi





The data requirements for estimating ADART impacts on taxi is summarized in Table 3.3 below.

Table 3.3: Data Requirements for Estimating ADART Impacts Compared to Taxi

Impact Category	Data Requirements: Taxi	Data Requirements: ADART
Total Out-of-Vehicle Travel Time	average wait time for taxi	average wait time average dwell times
In-Vehicle Travel Time	average in-vehicle travel time in taxi	average in-vehicle travel time on ADART
Number of Trips	expected total annual number of taxi trips % taxi trips attracted to ADART % and # of trips congested and uncongested	expected total annual number of ADART trips
Costs	annual operating and maintenance costs annual capital costs	annual operating and maintenance costs annual capital costs

3.4.4 Expect Impacts to Private Auto

Figure 3.6 provides a total travel time component comparison between private auto and ADART. The left-half of the diagram presents a one-way trip from origin to destination, while the right-half represents the return trip. The bottom bars represent the total travel time components between private auto and ADART. For a typical auto trip, the trip time components include:

1. In-vehicle travel time in auto
2. Time to search for parking, and
3. Walk access time from parked auto to final destination

The time spent searching for parking and access time to final destination may vary from trip to trip, depending on availability of parking, congestion levels on the road and walking distance from parking to final destination. For a typical return trip on a private auto, the total travel time components consist of:

1. Walk access to parked auto, and
2. In-vehicle travel time in auto

The total travel time components on ADART remain the same for the round trip.

Figure 3.6: Total Travel Time Component Comparison between Private Auto and ADART

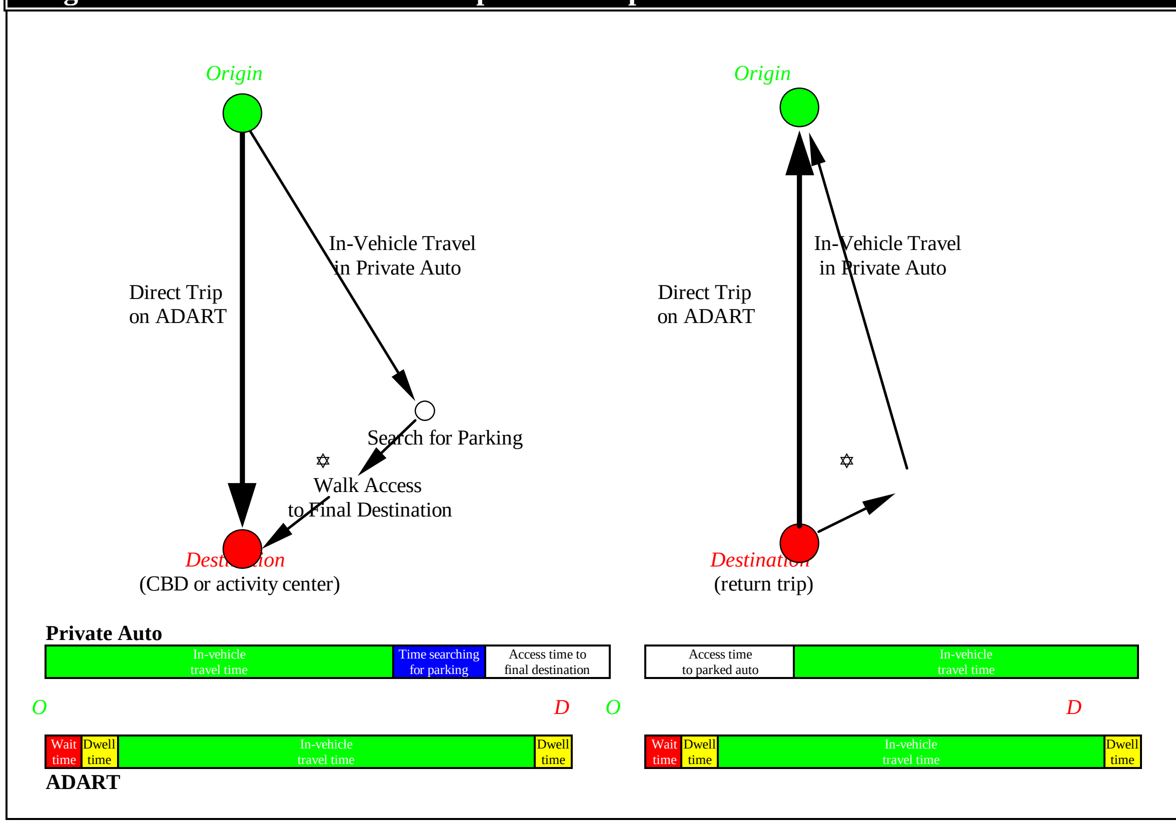
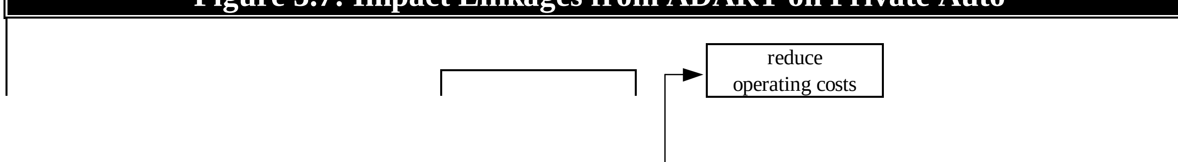
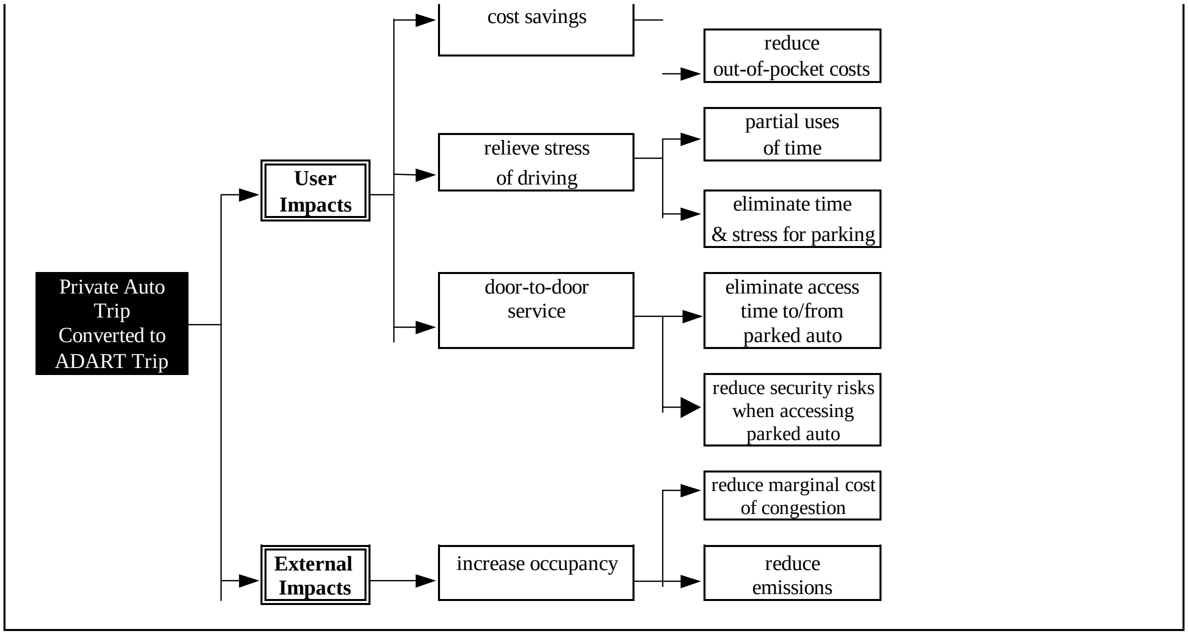


Figure 3.7 illustrates the impact linkages for private auto. For private auto drivers and passengers, ADART has the following potential impacts:

1. *Time Savings*: Onboard each ADART vehicle is an array of real-time routing software and traffic information gathered from regional traffic management centers, news reports, traveler reports, messages from other ADART vehicles, etc., which can help an ADART vehicle avoid certain congested areas and seek alternate routes. This "information" advantage allows ADART to seek less congested routes and improve its travel time and average operating speed.
2. *Service Quality*: For private auto drivers, taking ADART alleviates the stress of driving in traffic and allows one to engage in other activities, such as reading, resting, etc., that were previously not possible.
3. *Convenience*: ADART eliminates the inconvenience of search for parking or walking to or from a parked car.
4. *Cost Savings*: Compared to owning and operating a private automobile, riding ADART costs less. The total out-of-pocket operating and maintenance costs of operating a private automobile, not to mention the insurance cost (often considered a sunk cost by motorists), can be several time more expensive than taking ADART. I n congested urban city centers, ADART eliminates the stress and time of searching for a parking space as well as the high cost of parking.
5. *Safety and Security*: ADART's door-to-door service eliminates personal security concerns associated with walk access to and from a parked private automobile.
6. *Other Benefits*: From a societal point of view, taking ADART instead of driving a private automobile also has the potential to reduce emissions and decrease the marginal cost of congestion whenever a private auto trip is converted into a trip on ADART.

Figure 3.7: Impact Linkages from ADART on Private Auto





Some of the data requirements for estimating the relative impacts of ADART on private auto is summarized in Table 3.4 below.

Table 3.4: Data Requirements for Estimating ADART Impacts on Private Auto

Impact Category	Data Requirements	
	Private Auto	ADART
Total Out-of-Vehicle Travel Time	average time spent searching for parking average walk access time from auto to final destination average walk access time to/from parked auto (before beginning trip in auto)	average wait time average dwell times
In-Vehicle Travel Time	average in-vehicle travel time	average in-vehicle travel time
Number of Trips	expected total annual number of private auto trips % private auto trips attracted to ADART	expected total annual number of ADART trips
Costs	annual vehicle operating and maintenance costs annual capital costs average out-of-pocket costs (for insurance, parking, etc.)	annual operating and maintenance costs annual capital costs

3.5 Distribution of Benefits

Benefits of ADART are captured by users who previously used other modes of travel as well as those who, because of ADART's convenience, are making new trips. A summary of the distribution of benefits is summarized in Table 3.5.

Table 3.5: Potential Recipients of Benefits

BENEFIT	RECIPIENT(S)
Service Quality and Reliability	
Door-to-door service eliminates waiting at transit stops/street curb & increase personal security	FRU, DRU*, TXP
Eliminate access time and trip to/from mode	FRU, PAD, PAP
Eliminate transfer time onto another mode/vehicle to complete trip	FRU
ADART's customer-specified pick-up and drop-off time and *advanced call ahead* feature help to increase service reliability, predictability, as well as uncertainty and anxiety for the traveler	FRU, DRU, TXP, PAP[#]
Guaranteed time service increases on-time performance	FRU, DRU, TXP
Amenities such as air-conditioning, guaranteed seat, etc., increase passenger comfort	FRU
On-board magnetic swipe-card reader and pre-paid fare via credit card (upon reservation) reduces dwell times, improves accounting accuracy, data collection quality and security	DRU, FRU, TXP, DRO, FRO, TXO
No need to serve fixed-stops and automated routing and navigational systems reduce in-vehicle travel times	FRU
Improve service information, exposure and ease of reservation by using different mediums (telephone, in-person, kiosks, internet, etc.)	ALL
Increase service availability regardless of peak/off-peak periods, evening, etc.	FRU, PAD, PAP, TXP
Elimination of the stress of driving, looking for parking, personal security issues related to accessing vehicle	PAD, PAP
Operating Efficiency	
Trip auctioning feature ensures that the trip's marginal cost is minimized to increase operating efficiency	FRO, DRO
Fully automated scheduling and routing reduces "idle" time and increases driver productivity	FRO, DRO[@], TXO
Use of smaller vehicles and shared-ride policy increase the chance of increasing vehicle occupancy and vehicle productivity	FRO, TXO
Costs	
Reduce insurance and out-of-pocket costs	PAD^
Reduce capital cost of expanding system	DRO, FRO
Reduce operating and maintenance costs (especially during off-peak periods)	FRO, DRO, PAD
Reduce the cost of retrofitting fixed-route transit to be ADA compliant	FRU, FRO, EXT[$]
Reduce the cost and resources devoted to providing "specialized" transit service	DRU, DRO, EXT[$]
Lower cost to provide service translated to potential lower fares for passengers	TXP, DRU, FRU
Other	
Reduce emissions by converting SOV to HOV trips	EXT
Reduce marginal cost of congestion by converting SOV to HOV trips	EXT

Legend

FRU	Fixed-Route Transit Users
FRO	Fixed-Route Transit Operator
DRU	Dial-a-Ride Users
DRO	Dial-a-Ride Operator
TXP	Taxi passengers
TXO	Taxi Operator
PAD	Private Auto Driver
PAP	Private Auto Passenger
ALL	All of the Above
EXT	Benefits External to the Above

* Some dial-a-ride services only provide curb-to-curb service and require users to wait at the curb. This exposes the user to weather and personal security risks.

[#] Some private auto passengers may have to wait for his/her "ride" which may add to uncertainty and anxiety as to the pick-up time or arrival time.

^ Assuming that the driver pays for insurance and all out-of-pocket costs such as parking fees and other non-vehicle maintenance-related costs.

[@] Reduction of "idle" time and increase in driver productivity varies and depends on the scheduling and routing software used.

[$] Includes all taxpayers.

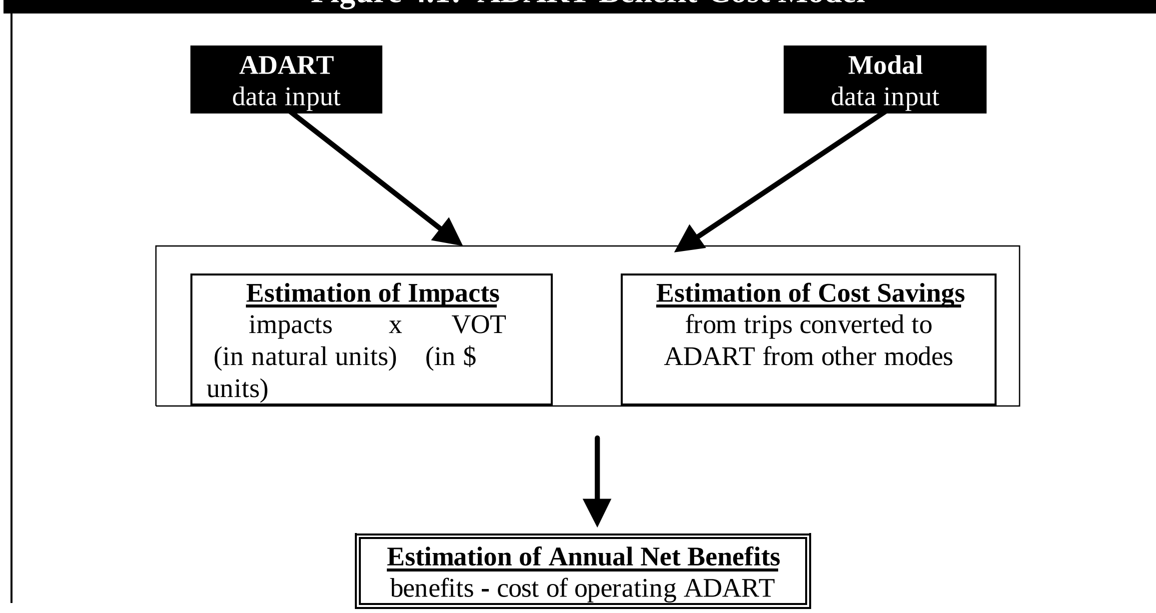
4. Estimation of Annual Net Benefits

4.1 Components of the Model

The simple benefit-cost (B-C) model developed for ADART is presented in Figure 4.1. It includes the following components:

- *ADART Input Data*: ADART performance data used to estimate benefit impacts
- *Modal Input Data*: performance measures and data of modes from which ADART is expected to attract trips
- *Valuation of Time*: value-of-time parameters as well as adjustment factors used to convert the impacts in natural units to dollar units
- *Calculation of Time-Related Benefits*: estimating impacts by summing the benefits from all time-related performance measures
- *Operating, Maintenance and Capital Cost Calculations*: estimating the annual cost savings of trips converted from other modes to ADART
- *Annual Benefit-Cost Calculation*: totaling the annual benefits and cost savings minus the cost of operating ADART to arrive at the annual net benefit-cost of implimenting ADART

Figure 4.1: ADART Benefit-Cost Model



4.2 Short-comings of the model

This model has several short-comings and does not assume to be able to capture the full benefits of implementing ADART. It only attempts to directly quantify time-related impacts, which is of importance in travel. However, other qualitative impacts such as convenience, personal security, comfort, etc., are either indirectly incorporated or ignored. One reason being that they are often more difficult to quantify or estimate from data collection efforts.

The model only assumes that ADART trips will come from the modes listed and ignores previous bike or walk trips. The cost calculations employs an average per unit cost figure (cost per trip) and does not use a full-blown cost model for each mode. This might over-simplify the cost calculations and ignore the affects of service changes and competition from other modes on cost. This model does not show the effects of cost subsidy on ADART and its competing modes.

4.3 Data Sources

Data sources for transit modes include the National Transit Database (NTD) and the National Transit Analysis Tool (NTAT). The 1996 versions of the data were used to obtain cost (average operating cost per trip) and annual unlinked passenger trip figures for Corpus Christi's transit system, which includes motor bus transit and dial-a-ride. The Bureau of Transportation Statistics *National Transportation Statistics* (1995, 1998) was used to obtain data on private auto and transit costs, travel time statistics, etc. The Federal Transit Administration *Characteristics of Urban Transportation Systems* (1992) was referenced to obtain transit and taxi cost as well as performance statistics.

Since ADART is a new type of transit service with no prior history of its performance and costs, many of the data (particularly demand and costs) in the model are guesses or based on reasonable orders-of-magnitude estimates. Whenever possible, real data will be used and mentioned. The hope is that as ADART becomes operational, or when new data is available, one can input the real-life data into the model or add to the existing data "modules" to enhance the accuracy of the estimates.

4.4 Description of the Data

4.4.1 ADART Input Data

ADART input data for the model include peak and off-peak average wait time, vehicle dwell time and in-vehicle travel time. *Wait time* is the time a passenger waits for ADART to arrive for a pick-up. *Dwell time* is the time the vehicle door(s) open for boarding and alighting, and *in-vehicle travel time* is the time it takes for the vehicle to travel enroute to its trip destination. The input data parameters and figures are presented in Table 4.1. for all data tables hereafter, the shaded cells are input data. None-shaded cells are calculated figures.

Table 4.1: ADART Input Data

Time (min.)	Peak	Off-Peak
Wait Time	2.5	1.8
In-Vehicle Travel Time	22.0	16.0

4.4.2 Modal Input Data

The first set of modal input data is time-related and categorized by mode. The data is used to estimate time-related impacts of implementing ADART. A description is as follows:

Transit Bus includes all motorized buses as categorized in the National Transit Database.

Transit Rail includes both heavy and light rail systems.

Dial-A-Ride includes all demand responsive services for the elderly and handicap.

Taxi Street Hail are curb-side taxi services where a passenger hails the taxi down to board.

Taxi Call Service is when a passenger telephones the taxi dispatcher to schedule for service.

Auto refers to a privately-operated automobiles.

A description of the time-related variables are as follows:

Access Time for bus and rail transit include in-vehicle and out-of-vehicle time to access a transit mode. Access time for auto includes walk access to parked vehicle.

Wait Time includes the total out-of-vehicle wait time before the vehicle arrives for pick-up, regardless of where the "waiting" is done (i.e., at home, bus stop, etc.). It begins with the scheduled pick-up time to when the vehicle arrives. It does not include dwell time, in which the vehicle has already arrived.

In-Vehicle Travel Time is the total time when a passenger is spent inside the vehicle, traveling to a destination.

Table 4.2 presents the time-related input data.

Table 4.2: Modal Input Data

	AT(min)		WT(min)		IVTT(min)	
Mode	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
TransitBus	**9.0**	**6.0**	**8.0**	**15.0**	**32.0**	**24.0**
TransitRail	**10.0**	**8.0**	**4.0**	**10.0**	**18.0**	**14.0**
DRT			**4.0**	**3.0**	**24.0**	**18.0**
TaxiStreetHail			**3.5**	**3.0**	**23.0**	**15.0**
TaxiCallService			**0.5**	**0.5**	**23.0**	**15.0**
Auto	**1.0**	**0.8**			**23.5**	**15.5**

4.4.2.1 Annual Unlinked Passenger Trips

The annual unlinked passenger trips by mode by peak and off-peak time periods are direct inputs into the model. They are used to calculate the potential number of trips converted to ADART from different modes. The input data set is presented in Table 4.3.

Table 4.3: Annual Unlinked Passenger Trips

	Peak		Off-Peak	
Mode	#Trips	%	#Trips	%
TransitBus	**2,429,000**	7.7%	**2,429,000**	10.7%
TransitRail	**0**	0.0%	**0**	0.0%
DRT	**95,200**	0.3%	**190,400**	0.8%
TaxiStreetHail	**120,000**	0.4%	**100,000**	0.4%
TaxiCallService	**40,000**	0.1%	**30,000**	0.1%
Auto	**29,000,000**	91.5%	**20,000,000**	87.9%
Total	31,684,200	100.0%	22,749,400	100.0%

The figures for bus transit and dial-a-ride for Corpus Christi are obtained from the National Transit Database (1996). The other figures are estimated based on a "reasonable" proportion of shares between the different modes (by looking at the "%" column) by using mode share figures from data available for the nearest metropolitan area (San Antonio, TX). The information was obtained from the Bureau of Transportation Statistics' *National Transportation Statistics* (1998).

4.4.2.2 Annual Modal Trips Converted to ADART

The next step in data input involves keying in the rate (as percentages) at which trips on other modes are converted to ADART. New or "induced" trips are entered separately in exact trips. Again, trips are classified by time periods. The input percentages can potentially be obtained from the output of a demand model. Short of a "full-blown" demand estimation, some "reasonable" rates were used. The reasoning behind the rates are as follows:

- Since ADART is expected to be more efficient in providing reliable off-peak transit services, it is expected to attract more off-peak trips from traditional transit bus users (thus, 30% trips converted for off-peak versus 10% for peak).
- Since taxi call service is very similar to ADART (a customer calls to reserve service), it is expected that ADART's lower cost and comparable level-of-service will attract some taxi call service users.
- Some auto drivers and passengers may be attracted to ADART's convenience, ease of use, door-to-door service at a reasonable price, similar amenities to the

private automobile, etc. However, in the current scenario, we expect ADART to have a modest impact on private auto trips (only 1%). Nevertheless, the total number of trips attracted is still significant.

The annual number of trips converted to ADART from each mode is calculated by:

$$ct_{ij} = yt_{ij} \times cr_{ij}$$

such that,

ct_{ij} = # of converted trips from mode *i* and time period *j*

yt_{ij} = # of annual trips for mode *i* and time period *j*

cr_{ij} = rate at which trips were being attracted from mode *i* and time period *j* to ADART

The inputs are presented in Table 5.4.

Table 5.4: Annual Trips Converted to ADART

	Peak		**Off-Peak**	
Mode	Rate	#Trips	Rate	#Trips
TransitBus	**10.0%**	242,900	**20.0%**	485,800
TransitRail	**3.0%**	0	**5.0%**	0
DRT	**10.0%**	9,520	**20.0%**	38,080
TaxiStreetHail	**1.0%**	1,200	**2.0%**	2,000
TaxiCallService	**10.0%**	4,000	**15.0%**	4,500
Auto	**0.5%**	145,000	**0.5%**	100,000
New Trips*		**5,000**		**8,000**
Total		402,620		630,380

* "New trips" are new and induced trips that do not come from existing trips on the other modes listed

4.4.2.3 Number of Congested/Uncongested Trips

The number of congested versus uncongested trips by mode by time period is used as inputs to calculate travel time impacts. The model takes the input, as a percentage of congested trips in the associated time period, and converts the percentage rate to actual trips by:

$$tc_{ij} = yt_{ij} \times rc_{ij}$$

such that,

tc_{ij} = # of congested trips for mode *i* during time period *j*

yt_{ij} = # of annual trips for mode *i* and time period *j*

rc_{ij} = percent of trips congested for mode *i* during time period *j*

The percent of uncongested trips (ru_{ij}) is simply:

$$ru_{ij} = 1 - rc_{ij}$$

The figures used for the model are hypothetical and is presented in Table 4.5. This data can probably be obtained at the regional or MPO level.

Table 4.5: % Trips Congested/Uncongested

	Peak				Off-Peak			
Mode	%cong.	#Trips	%uncong.	#Trips	%cong.	#Trips	%uncong.	#Trips
TransitBus	**80.0%**	194,320	20.0%	48,580	**20.0%**	97,160	80.0%	388,640
TransitRail	**70.0%**	0	30.0%	0	**70.0%**	0	30.0%	0
DRT	**80.0%**	7,616	20.0%	1,904	**80.0%**	30,464	20.0%	7,616
TaxiStreetHail	**85.0%**	1,020	15.0%	180	**85.0%**	1,700	15.0%	300
TaxiCallService	**85.0%**	3,400	15.0%	600	**85.0%**	3,825	15.0%	675
Auto	**90.0%**	130,500	10.0%	14,500	**90.0%**	90,000	10.0%	10,000
Total		336,856		65,764		223,149		407,231

4.4.2.4 Number of Trips with Wait Certainty/Uncertainty

Wait certainty is a measure of comfort and security in knowing that a vehicle will arrive within a certain period of time. Uncertain wait time contributes to passenger anxiety and stress, while one's certainty of a vehicle's arrive time relieves stress and anxiety. The model assumes that transit modes can reduce wait uncertainty by running services closer to the posted schedule or implementing passenger information technologies that relay information on arrival and departure times. The number of trips with and without wait certainty is used to estimate the value of wait time for a trip. The model takes the input, as the average percent of trips with wait certainty, and converts the percentage rate into the actual number of trips such that:

$$wc_{ij} = yt_{ij} \times pc_i$$

where,

wc_{ij} = # of trips with wait certainty for mode *i*, time period *j*

yt_{ij} = # of annual trips for mode *i* and time period *j*

pc_{ij} = percent of trips with wait certainty for mode *i*

The percent of trips with wait uncertainty (pu_{ij}) is simply:

$$pu_{ij} = 1 - pc_{ij}$$

The figures used for the model are hypothetical and is presented in Table 4.6.

Table 4.6: % Trips with Wait Certainty/Uncertainty				
Mode	**%Certain**	**#Trips**	**%Uncertain**	**#Trips**
TransitBus	**10.0%**	72,870	90.0%	655,830
TransitRail	**30.0%**	0	70.0%	0
DRT	**50.0%**	23,800	50.0%	23,800
TaxiStreetHail	**0.0%**	0	100.0%	3,200
TaxiCallService	**90.0%**	12,600	10.0%	1,400
Auto	**99.0%**	485,100	1.0%	4,900

4.4.2.6 Number of Transit Trips with Passengers Seated/Standing

Standing versus seated trips on transit affects the utility of the trip. Studies have found that the value-of-time of a standing trip on transit is valued higher compared to the same trip seated. Thus, an important input in the model is to obtain the proportion of seated versus standing trips by time period for transit modes. The number of seated trips, for example, is calculated by:

$$st_{ij} = yt_{ij} \times ps_{ij}$$

where,

st_{ij} = # of transit trips with passengers seated for mode *i*, time period *j*

yt_{ij} = # of annual trips for mode *i* and time period *j*

ps_{ij} = percent of trips with passengers seated for mode *i*, time period *j*

The percentage of standing trips (pd_{ij}) is likewise estimated by:

$$pd_{ij} = 1 - ps_{ij}$$

The number of standing trips are calculated the same was as for seated trips. The data can be obtained from transit agencies throught ride-checks. The input figures are presented in Table 4.7.

Table 4.7: % Transit Trips with Seating/Standing								
	Peak				**Off-Peak**			
Mode	%Seated	#Trips	%Standing	#Trips	%Seated	#Trips	%Standing	#Trips

TransitBus	**60.0%**	145,740	40.0%	97,160	**100.0%**	485,800	0.0%	0
TransitRail	**70.0%**	0	30.0%	0	**100.0%**	0	0.0%	0

4.5 Value-of-Time

Value-of-time (VOT) parameters were used to convert impacts in natural units to dollar units. In the example of travel time savings, for example, an hour saved is multipled by the dollar value of travel time per hour to obtain the impact in dollar units. The VOT figures used for the model are presented in Table 4.8. These value of time units can be obtained from previous studies or empirical estimates from the literature.

Table 4.8: Value-of-Time Parameters ($/hr)

	Access Time		Wait Time		In-Vehicle Travel Time	
Trip on Mode	Congested	Free Flow	Certain	Uncertain	Congested	Free Flow
Transit, DRT Peak	**$ 10.00**	**$ 8.00**	**$ 15.00**	**$ 20.00**	**$ 10.00**	**$ 8.00**
Transit, DRT Off-Peak	**$ 8.00**	**$ 7.00**	**$ 12.00**	**$ 18.00**	**$ 8.00**	**$ 7.00**
Taxi Peak	**$ 10.00**	**$ 8.00**	**$ 14.00**	**$ 18.00**	**$ 9.00**	**$ 7.00**
Taxi Off-Peak	**$ 9.00**	**$ 7.00**	**$ 12.00**	**$ 10.00**	**$ 7.00**	**$ 6.00**
Private Auto Peak	**$ 11.00**	**$ 10.00**			**$ .00**	**$ 8.00**
Private Auto Off-Peak	**$ 9.00**	**$ 8.00**			**$ 7.00**	**$ 6.00**

In the model, we have four major value-of-time parameters - access time, wait time, dwell time and in-vehicle travel time. These VOT figures were based on reasonable value-of-time estimates that were consistent with what has been presented in the literature.[4] In general, we have assumed that wait time is valued at close to twice the value of travel time. We have also given different VOTs for *certainty* and *uncertainty* in wait time estimates. The logic is that passengers who have information on the extent of their wait is more likely to be relaxed and less worried about when a bus, for example, will arrive. Thus, their VOT is decreased as a result of increased information. Uncertainty in waiting for a transit vehicle, on the other hand, can increase VOT by increasing passenger anxiety and stress, a disutility or cost to travel.

For access time and in-vehicle travel time, we distinguish between *congested* and *free flow* time. We hypothesize that travel in congested traffic may increase driver and

[4] The DOT Guidance recommends the use of national averages (Office of the Secretary of Transportation, "Departmental Guidance for the Valuation of Travel Time in Economic Analysis," Washington, D.C., U.S. Department of Transportation, April 9, 1997.).

passenger anxiety and further delay travel, whereby incurring a cost and increasing VOT. Free flow travel, on the other hand, relieves stress for the driver and helps to increase the probability of arriving at one's destination on time. Moreover, we also distinguish between peak and off-peak VOTs for all the modes.

4.5.1 Value-of-Time Adjustment Factors

Adjustment factors for seated and standing trips were used for transit bus and rail when estimating their respective VOT. The purpose is to allow the model to incorporate different VOTs to reflect differences in utility for a seated versus a standing trip on transit. Adjustment factors are used to scale up or scale down the VOT for in-vehicle travel times. The figures used for this model is presented in Table 4.9. A seated trip on transit is valued at the same rate (1.0) as the figures in Table 4.8. A standing trip, on the other hand, is valued at 1.5 times the VOT.

Table 4.9: Transit VOT Adjustment Factors

	Seated	Standing
Adjustment Factor	**1.0**	**1.5**

It is important to mention that VOT can be categorized by trip purpose. Since there was not enough information to categorize the trips as such for this paper, it was omitted in the B-C calculation. If good survey data is later available, it would be easy to incorporate it into the model.

4.6 Calculation of Time-Related Benefits

Time-related impacts for access time, wait time and in-vehicle travel time were estimated to obtain the total time benefit of converted trips from other modes to ADART. A "positive" difference (+*D time*) between the associated time on ADART and on the previous mode is considered a benefit, such that

$$If: timeh_{ij} - timeh_{ADARTj} > 0 \Rightarrow benefit$$
$$If: timeh_{ij} - timeh_{ADARTj} \leq 0 \Rightarrow no`benefit$$

where,

h = access time, wait time, or in-vehicle travel time

i = transit bus, transit rail, DRT, taxi street hail, taxi call service, or auto

j = peak or off-peak time periods

D $timeh_{ij}$'s with a negative number were not considered as a benefit. Thus, "0.0" were substituted for negative results. Table 4.10 presents the time impacts by mode in minutes.

Table 4.10: Time Impacts (ADART compared to mode *i*)

	DAT(min)		DWT(min)		DIVTT(min)		Total	
Mode	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
TransitBus	9.0	6.0	5.5	13.2	10.0	8.0	25.8	27.5
TransitRail	10.0	8.0	1.5	8.2	0.0	0.0	12.2	16.5
DRT			1.5	1.2	2.0	2.0	3.7	3.4
TaxiStreetHail			1.0	1.2	1.0	0.0	2.0	1.2
TaxiCallService			0.0	0.0	1.0	0.0	1.0	0.0
Auto	1.0	0.8			1.5	0.0	2.5	0.8

Based on our earlier inputs and assumptions, ADART is expected to have the most time impact on transit buses. A total of almost 26 minutes per trip can be saved if transit bus trips were converted to ADART in the peak period. The off-peak period produced slightly higher time savings (27.5 minutes). Comparing the individual time components, one can see that the highest time savings for transit is in access time, wait time and in-vehicle travel time. ADART is expected to provide a higher level of service that would reduce wait time, and its door-to-door service would eliminate transit access. Time savings for previous trips on taxi and the private auto is less significant.

The dollar-value benefits are calculated by multiplying the time impacts in natural units to it valuation in dollars. The following formulas are used to calculate the dollar impacts for each time component:

<u>Access Time</u>

$$AB_{ij} = \left\{ \left[\frac{\left(\Delta at_{ij} \times tc_{ij} \right)}{60} \right] \times ACV_{ij} \right\} + \left\{ \left[\frac{\left(\Delta at_{ij} \times tu_{ij} \right)}{60} \right] \times AUV_{ij} \right\}$$

such that,

AB_{ij} = access time benefit for mode i, time period j

Dat_{ij} = delta access time for mode *i*, time period *j*

tc_{ij} = # of trips congested for mode *i*, time period *j*

tu_{ij} = # of trips uncongested for mode *i*, time period *j*

ACV_{ij} = value-of-time for congested access trips for mode *i*, time period *j*

AUV_{ij} = value-of-time for uncongested access trips for mode *i*, time period *j*

Wait Time

$$WB_{ij} = \left\{ \left[\frac{\left(\Delta wt_{ij} \times wc_{ij} \right)}{60} \right] \times WCV_{ij} \right\} + \left\{ \left[\frac{\left(\Delta wt_{ij} \times wu_{ij} \right)}{60} \right] \times WUV_{ij} \right\}$$

where,

WB_{ij} = wait time benefit for mode *i*, time period *j*

Dwt_{ij} = delta wait time for mode *i*, time period *j*

wc_{ij} = # of trips with wait certainty for mode *i*, time period *j*

wu_{ij} = # of trips with wait uncertainty for mode *i*, time period *j*

WCV_{ij} = value-of-time for trips with wait certainty for mode *i*, time period *j*

WUV_{ij} = value-of-time for trips with wait uncertainty for mode *i*, time period *j*

In-Vehicle Travel Time

$$TB_{ij} = \left\{ \left[\frac{\left(\Delta tt_{ij} \times tc_{ij} \right)}{60} \right] \times TCV_{ij} \right\} + \left\{ \left[\frac{\left(\Delta tt_{ij} \times tu_{ij} \right)}{60} \right] \times TUV_{ij} \right\} + \left[sd_{ij\times} \left(AVT \times f \right) \right] + \left[st_{ij} \times \left(AVT \times f \right) \right]$$

where,

TB_{ij} = travel time benefit for mode *i*, time period *j*

Dtt_{ij} = delta travel time for mode *i*, time period *j*

tc_{ij} = # of trips congested for mode *i*, time period *j*

tu_{ij} = # of trips uncongested for mode *i*, time period *j*

TCV_{ij} = value-of-time for congested trips for mode *i*, time period *j*

TUV_{ij} = value-of-time for uncongested trips for mode *i*, time period *j*

sd_{ij} = # of transit trips with passengers standing for mode *i*, time period *j*

st_{ij} = # of transit trips with passengers seated for mode *i*, time period *j*

AVT = average value of time for transit trips (take average of peak and off-peak value-of-time)

f = adjustment factor (seated or standing)

A summary of the above calculations are presented in Table 4.11.

Table 4.11: Total Annual Time Impact by Mode ($)

Mode	TotalAT	TotalWT	TotalVTT	Total
TransitBus	$ 699,552	$ 4,092,015	$ 2,312,408	$ 7,103,975
TransitRail	$ -	$ -	$ -	$ -
DRT		$ 35,105	$ 15,232	$ 50,337
TaxiStreetHail		$ 1,600	$ 174	$ 1,774
TaxiCallService		$ -	$ 580	$ 580
Auto	$ 38,208		$ 32,263	$ 70,471
TOTAL	$ 737,760	$ 4,128,720	$ 2,360,657	**$ 7,227,137**

The time benefit calculations show that ADART has the most potential to benefit bus transit (an estimated $7.1 million annually). In addition, ADART can potentially save private auto drivers and passengers an estimate $70,000 annually in time saved. Lastly, the model shows that taxis are least likely to benefit from ADART (only a mere $2,300 plus in time-savings benefit annually). Dial-a-ride time savings is estimated to be over $50,000 annually.

4.6.1 Induced Travel

ADART is expected to provide a high level-of-service and make travel easier and more convenient, as well as reduce the cost to customers. According to basic economic theory, when the price of a product, in our case travel, decreases, the quantity demanded increases. As a result, a change in the generalized cost for transportation would induce travelers to move up or down their demand curves for travel. Since ADART is expected to reduce the cost of travel for some travelers, *consumer surplus* (a measure of benefits to induced trips) would result. To estimate consumer surplus, we multiply the change in consumer surplus per trip to the total number of estimated induced trips, such that:

$$bi_j = \Delta cs \times it_j$$

where,

bi_j = benefit of induced trips

Dcs = average change in consumer surplus per trip

it_j = induced trips for time period *j*

The *D consumer surplus per trip* figures used for the model is presented in Table 4.13.

Table 4.13: Change in Consumer Surplus		
	Peak	**Off-Peak**
Average D in Consumer Surplus per Trip	**$ 4.00**	**$ 4.00**

4.7 Operating and Maintenance Cost Calculations

As trips are attracted from other modes, ADART is expected to reduce the cost of operation for other modal operators. To estimate cost impacts, we first obtain the average cost per trip as an input parameter into the model for each mode. Next, the total annual cost by mode is determined by:

$$OC_{ij} = ac_{ij} \times ct_{ij}$$

where,

OC_{ij} = operating and maintenance costs for mode *i* in time period *j*

ac_{ij} = average cost per trip for mode *i* in time period *j*

ct_{ij} = number of trips converted from mode *i* in time period *j* to ADART

The difference in total annual operating cost by mode and ADART operating cost[5] for the same number of trips (*D cost*) is the cost savings:

$$\Delta C_{ij} = TC_{ij} - \left(OC_{ADARTj} \times ct_{ij}\right)$$

DC_{ij} = cost savings for mode *i* in time period *j*

TC_{ij} = total annual cost per trip of operating mode *i* in time period *j*

OC_{ADARTj} = operating and maintenance cost per trip of operating ADART in time period *j*

ct_{ij} = number of trips converted from mode *i* in time period *j* to ADART

[5] A formal ADART cost model should be developed when field data is available. The model should be a function of ridership, passenger-miles, vehicle-miles and vehicle-hours, number of peak vehicles, etc. Cost models for the other modes should also be developed if ADART is expected to reduce the number of vehicles operated for other modal operators.

Summing up the savings for all the modes yields the total annual cost savings. The results of the model are presented in Table 4.14.

Table 4.14: Total Costs (Operating Expenses)					
	Average Cost/Trip		Total Annual Cost		Delta
Mode	Peak	Off-Peak	Peak	Off-Peak	**Cost**
TransitBus	**$ 2.25**	**$ 1.80**	$ 546,525	$ 874,440	$ -
TransitRail	**$ 8.00**	**$ 6.00**	$ -	$ -	$ -
DRT	**$ 11.00**	**$ 10.00**	$ 104,720	$ 380,800	$ 152,320
TaxiStreetHail	**$ 12.00**	**$ 12.00**	$ 14,400	$ 24,000	$ 16,000
TaxiCallService	**$ 12.00**	**$ 12.00**	$ 48,000	$ 54,000	$ 42,500
Auto	**$ 2.20**	**$ 2.00**	$ 319,000	$ 200,000	$ -
ADART	**$ 7.00**	**$ 6.00**			
Total Annual Cost Savings					**$ 210,820**

4.8 Annual Net Benefit Calculation

The final calculation of the annual benefit-cost is just a carry-over of the previous calculations already made on time impacts, induced trips and cost savings. The social cost benefit as a result of reduced SOV/lower occupancy trips on private auto and taxi are calculated assuming an average marginal cost of emissions and congestion ($1.50 per trip) multiplied by the number of private auto and taxi trips converted to ADART.

The annual operating and maintenance cost of ADART is subtracted by the sum of all benefits listed above to give the total annual benefit. The results are presented in Table 4.15 and show that ADART is expected to reign in an estimated benefit of $1.26 million annually. The majority of those benefits are time savings from mode changes.

Table 4.15: Total Annual Benefit-Cost			
Mode	**Total Benefit**	**Cost Savings**	**Total Benefit & Cost Savings**
TransitBus	$ 7,103,975	$ -	$ 7,103,975
TransitRail	$ -	$ -	$ -
DRT	$ 50,337	$ 152,320	$ 202,657
TaxiStreetHail	$ 1,774	$ 16,000	$ 17,774
TaxiCallService	$ 580	$ 42,500	$ 43,080
Auto	$ 70,471	$ -	$ 70,471
New Trips	$ 30,500		
Total	$ 7,257,637	$ 210,220	
Internal Benefit (mode change)	$ 7,227,137		
External Benefit (induced trips, social costs)	$ 428,050		

(plus) Total Cost Savings	$ 210,820	[redacted]
	$ 7,866,007	[redacted]
(minus) ADART Op & Maint. Costs	$ 6,600,620	[redacted]
NET BENEFIT	**$ 1,265,387**	[redacted]

5. Cost-Savings Analysis

In order to verify the magnitude of the estimated cost-savings from the B-C model, a simple analysis is conducted using available NTD data and a possible "worst case" scenario. The intention is to demonstrate the *minimum* cost savings attributable to ADART if conventional dial-a-ride services in Corpus Christi were replaced by ADART for the calender year 1996. Second, the results will be compared with the B-C model estimates to determine whether the B-C model has over-estimated or under-estimated the cost savings of ADART to conventional dial-a-ride transit.

5.1 Assumptions

ADART will operate equivalent to the lowest national average figures (from directly operated or purchased transportation figures) for operating cost per revenue-vehicle-mile (OC/RVM), revenue-vehicle-miles per unlinked passenger trip (RVM/UPT), and unlinked passenger trips per revenue-vehicle-hour (UPT/RVH). In other words, we will assume the worst case that ADART will not operate more efficiently or less costly than the national average for all dial-a-ride services. These conservative assumptions will provide a worst case scenario for ADART to compare with conventional DRT.

5.2 The Data

All data used in the analysis are from the 1996 National Transit Database (see Table 5.1). For operating expenses, we assume that ADART will operate at an average of $1.80 per RVM (the higher of the two national averages for OC/RVM), only 5 cents (or 2.7 percent) less than Corpus Christi's 1996 average. For unlinked passenger trips per revenue-vehicle-hour, we assume ADART would serve 2.5 trips (versus almost 3.2 trips for Corpus Christi) per RVH. For RVM/UPT, ADART is assumed to take almost 5.8 RVM per trip (the higher of the two national averages and only 2.4 percent less than Corpus Christi's average).

Table 5.1: Cost Savings Analysis Data

Variables	National Average: Directly Operated	National Average: Purchased	Corpus Christi DRT	ADART
OC/RVM	$ 1.34	$ 1.80	$ 1.85	$ 1.80
RVM/UPT	5.42	5.76	5.90	5.76
UPT/RVH	2.54	2.51	3.17	2.51

Source: 1996 National Transit Database, Federal Transit Administration, USDOT.

5.3 Minimum Cost Savings per Trip Estimation

By doing a simple mathematical manipulation using the variables described above, we can obtain the minimum cost per unlinked passenger trip as follows:

$$\min C_i = \frac{\left(OC / RVM_i \times RVM / UPT_i \times UPT / RVH_i\right)}{\left(T / RVH_i\right)}$$

where,

$\min C_i$ = minimum cost per trip for mode *i*

OC/RVM_i = operating cost per revenue-vehicle-mile for mode *i*

RVM/UPT_i = revenue-vehicle-miles per unlinked passenger trip for mode *i*

UPT/RVH_i = unlinked passenger trips per revenue-vehicle-hour for mode *i*

T/RVH_i = trips per revenue-vehicle-hour for mode *i*

Table 5.2: DRT vs. ADART Cost Savings

Trips/RVH	DRT minCost/trip	ADART minCost/trip	D Cost	1996 ADART Annual Savings
2	$ 17.30	$ 13.01	$ 4.29	$ 1,020,648
3	$ 11.53	$ 8.67	$ 2.86	$ 680,432
4	$ 8.65	$ 6.51	$ 2.14	$ 510,324
5	$ 6.92	$ 5.20	$ 1.72	$ 408,259
6	$ 5.77	$ 4.34	$ 1.43	$ 340,216
7	$ 4.94	$ 3.72	$ 1.23	$ 291,614
8	$ 4.33	$ 3.25	$ 1.07	$ 255,162
9	$ 3.84	$ 2.89	$ 0.95	$ 226,811
10	$ 3.46	$ 2.60	$ 0.86	$ 204,130
11	$ 3.15	$ 2.37	$ 0.78	$ 185,572
12	$ 2.88	$ 2.17	$ 0.71	$ 170,108
13	$ 2.66	$ 2.00	$ 0.66	$ 157,023
14	$ 2.47	$ 1.86	$ 0.61	$ 145,807
15	$ 2.31	$ 1.73	$ 0.57	$ 136,086

The minimum break-even fare per trip for 2 to 15 trips per RVH are presented in Table 5.2. The second and third columns are the DRT and ADART operating costs per trip or minimum break-even fare. The fourth column is the difference between DRT and ADART's minimum cost per trip (Δ Cost) or the ADART savings per trip over DRT. The last column shows ADART's annual cost savings for 1996, based on 238,000 annual trips (1996 NTD). Assuming that there are no subsidies and that ADART will operate at at least the break-even point (revenue covers cost), Figure 5.1 shows the minimum break-even fare between DRT and ADART. It shows that ADART's break-even fares are approximately 25 percent lower than conventional DRT's break-even fares. This is attributed to ADART's cost savings and can be included as ADART's profit.

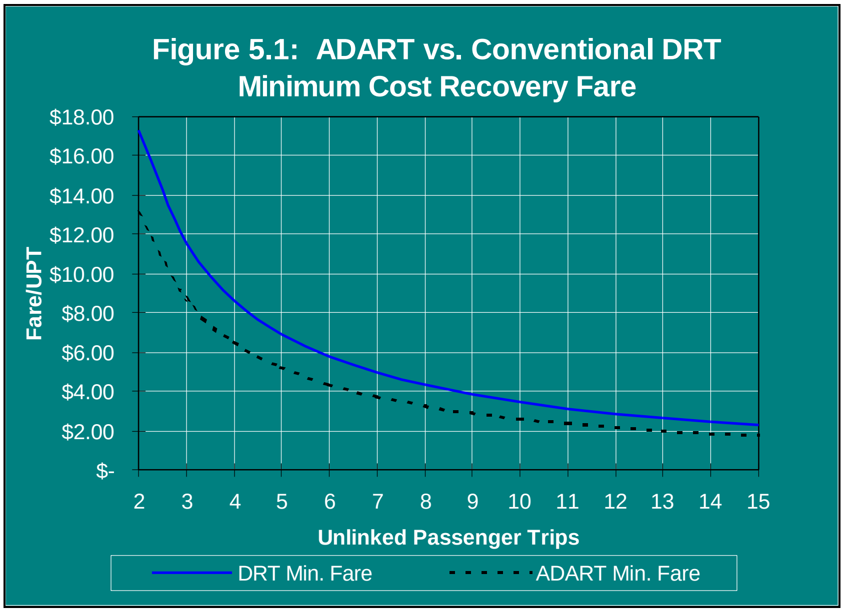


Figure 5.1: ADART vs. Conventional DRT Minimum Cost Recovery Fare

5.4 Cost Savings Comparison

If we assume that ADART replaced DRT in Corpus Christi for the calender year 1996 and operated 3 trips per revenue-vehicle-hour, the average for Corpus Christi for the said year, ADART can expect to save over $680,000 in operating cost alone (see Table 5.2) compared to the estimate cost savings of $152,000 from the B-C model. What this simple scenario shows is that the B-C model estimates are conservative. Since we do not have enough data to complete and validate the B-C model, this simple analysis provides another perspective of the potential cost savings of ADART, even if it is only intended to replace dial-a-ride operation.

6. Summary and Conclusions

6.1 What Can We Learn

Short of accurate data, there are a few lesson we can learn from this analysis of implementing ADART in Corpus Christi, Texas. For previous transit passengers, ADART is expected to have the most impact on transit buses. It's door-to-door service, reduced wait time, higher level of service is superior to bus transit. According to the analysis, the annual time savings to previous bus passengers can accounts for over 97 percent of the total time savings from all modes. However, since ADART costs more to operate than buses, its cost offsets the time savings by more than 65 percent. Since ADART is a new type of service, no cost estimates are available to provide a more accurate estimate of its cost impacts. Nevertheless, what this simple analysis shows is that in order for ADART to maintain a positive annual net benefit, costs must be kept low. On the other hand, since ADART can price discriminate (charge different price for different trips), it has the ability to tailor services to different markets and attract more demand, thus maximizing its *consumer surplus* or revenue.

At the very least, ADART can potentially provide cost and time savings to conventional dial-a-ride transit at an estimated $200,000 annually in Corpus Christi alone. Moreover, the cost savings analysis in the previous section suggests that the B-C model estimates are conservative and underestimated the cost savings alone by over 450 percent. This is a significant savings and benefit as cities and transit authorities across the country spend millions of dollars annually subsidizing elderly and handicap services. Moreover, since ADART is demand responsive, it can supplement peak service and help transit authorities alleviate some of the high expenses of satisfying peak transit service demand. The potential cost and time savings can also increase as passengers from other modes switch to ADART.

Compared to private auto and taxis, ADART has the potential to increase average vehicle occupancy and reduce emissions and congestion by reducing vehicle trips. This reduces the externalities associated with private automobile travel and help to reduce the marginal cost of congestion.

6.2 Issues That Require Further Investigation

In order to accurately estimate ADART's benefit, there are several issues that need further investigation. Understanding the demand for ADART is critical to evaluating its benefit. In this simple analysis, we have assumed a "reasonable" but unsupported estimate of demand. Ultimately, a sophisticated demand model will have to be developed to take into account the affects of service levels and other exogenous factors on demand. It can be stated, however, that ADART's success is dependent on sufficient demand (*many-to-few* origins and destinations). Thus, in markets where there is insufficient demand to sustain a viable return in investment, ADART is not expected nor designed to provide service.

Second, proper understanding of the value-of-time is also critical to the accurate valuation of impacts associated with implementing ADART. In this analysis, average values-of-time were used. However, whenever necessary and possible, value-of-time estimates should be developed for the specific site and type of service for which the evaluation is conducted.

Investigation is needed to determine what the right mix of service levels are in order to maximize *consumer surplus* (revenue). Varying service levels will also affect demand, thus influencing the outcome of any benefit-cost evaluation. It would also be important to understand the effects of subsidy on ADART, both on the cost side as well as on demand.

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