WEST SIDE TRANSIT ENHANCEMENT STUDY

PHYSICAL INFRASTRUCTURE NEEDS

JANUARY 2014

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Executive Summary

Background

The West Side Transit Enhancement Study (WSTES), an activity of the Denver Livability Partnership, focuses on the feasibility of improved transit service that enhances physical connections between Denver's West Side and existing light rail service. WSTES works to leverage the opening of the Regional Transportation District's (RTD) West Corridor by harnessing the attention on that line and expanding it to include an assessment of existing route services and existing infrastructure at local bus stops. Phase One of the study accessed current RTD routes and services to identify ways to improve or adjust those services to better connect West Side neighborhoods to the expanding rail transit network. The Phase One effort was conducted through a strong partnership with RTD and informed by numerous public input opportunities. The full WSTES Phase One Service Plan Assessment report with resulting recommendations is available at www.denvergov.org/DLP.

This document summarizes Phase Two of the WSTES effort, which focuses on identifying and prioritizing improvements to the physical infrastructure at and around bus stops in order to better serve and support transit use by both transit-dependent and choice riders.

Study Area

For the purposes of the WSTES study, use of the term "West Side" refers to a study area that includes neighborhoods roughly bounded by 17th Avenue south to Mississippi Avenue and Sheridan Boulevard east to Broadway and Speer Boulevard. While the Phase Two effort narrows the study area slightly by moving the eastern boundary edge to I-25, the study still considers an influence area that includes existing connections to the Central Corridor light rail line and future access to the West Corridor light rail line. Particular attention for the study is given to the following neighborhoods: Westwood, Athmar Park, Barnum West, Barnum, Valverde, Villa Park, Sun Valley, and West Colfax.

Purpose

While the WSTES Phase One study identified how existing bus transit service could better connect West Side neighborhoods to the rail transit network, the Phase Two effort focuses on localized infrastructure improvements needed to facilitate the physical connections required for pedestrians and cyclists to access the system. The study assumes that bus stops with poor connecting infrastructure (i.e. missing sidewalks, curb ramps, poor ADA compatibility, etc.) could actually be barriers to transit use for both transit-dependent and choice riders. Recognizing that every stop has a unique set of characteristics informed by user profiles, adjacent land uses, and routes served; Phase Two seeks to identify a categorical set of stop "typologies" that can be used to organize and better understand the stops in the study area. The goal is to identify a discrete package of improvements for each stop within the study area and create a way to rank each improvement for its ability to support and/or improve ridership for that specific typology. Identifying the infrastructure improvements that are most needed for each stop's context is the first step towards allocating limited funding towards the creation of accessible, safe and welcoming portals to transit service on the West Side.

To facilitate and mechanize these goals, the project team determined that a dynamic database tool could be created to house inventory information summarizing the existing infrastructure elements at each stop in the study area as well as be used to help guide investment decisions. This dynamic tool could be built to help prioritize funding investment through identifying a benefit/cost ratio that compares the relative cost of improving existing infrastructure elements to the impact of those investments on attracting new ridership. This tool could also be expanded to include stop assessments for additional areas of the City and County of Denver thus positioning the Phase Two effort and the dynamic database as a beta test for the concept.

The initial field inventory was conducted for stops in the study area in the fall of 2012 by numerous volunteers including City and County of Denver staff and student teams from the University of Colorado at Denver. The teams were trained by the WSTES Project Team to use a consistent data collection method that would support consistent bus stop evaluations across the numerous field teams. The resulting field information was combined with RTD-provided stop inventory information to provide raw base data for the dynamic database.

With oversight provided by the Denver Livability Partnership's Grant Management Team along with input from the WSTES Stakeholder Steering Committee, the project team identified nine (9) discrete stop typologies broad enough to uniquely describe every stop within Denver jurisdiction limits. The typologies focus on three stop characteristics:

1) Surrounding land use
2) Primary service
3) Ridership level

Table 1 shows all nine (9) stop typologies.

Table 1: Typologies for Bus Stops

Land Use	Transit Function	Ridership
Commercial	Origin/destination	High
Commercial	Origin/destination	Low
Commercial	Transfer	High
Commercial	Transfer	Low
Residential	Origin/destination	High
Residential	Origin/destination	Low
Residential	Transfer	High
Residential	Transfer	Low
Industrial	Origin/destination	Low

The project team also refined the list of possible improvements to 11 general infrastructure categories that the City could typically include as part of ongoing improvements or as part of transit-specific infrastructure projects. The 11 possible improvements were grouped into three levels based on their importance to a stop's identified typology. The classes identified were:

1) **A: *Critical*** – Infrastructure that is critical to the base expectations and function of a stop.

2) **B: *Should Have*** – Infrastructure that should be included to support transit ridership.

3) **C: *Nice to Have*** – Infrastructure that is not necessarily expected by a user, but that would improve rider experience.

Table 2 shows the typologies along with the amenity classifications used as default assumptions in making benefit/cost calculations.

Table 2: Bus Stop Typologies and Amenity Levels

			Concrete pad	Stop Controlled	Curb Ramp	Sidewalk	Crosswalks	Access Walk	Bench	Lighting	Shelter	Trash can	Bike Rack
Commercial	Origin/destination	Low	A	C	A	A	A	A	B	C	C	C	A
Commercial	Transfer	High	A	C	A	A	A	A	B	B	B	B	A
Commercial	Transfer	Low	A	C	A	C	A	A	C	B	C	C	C
Residential	Origin/destination	High	A	C	A	A	B	A	B	B	C	C	C
Residential	Origin/destination	Low	A	C	A	A	B	A	C	C	C	C	C
Residential	Transfer	High	A	C	A	A	A	A	B	A	B	B	C
Residential	Transfer	Low	A	C	A	A	A	A	B	A	C	C	C
Industrial	Origin/destination	Low	A	C	A	A	A	A	B	A	C	C	C
Commercial	Origin/destination	High	A	C	A	A	A	A	B	B	B	B	B

A key goal of the overall WSTES effort is to attract new riders to transit. Therefore, significant attention was given to the creation of a formula that could begin to estimate the potential positive impacts on ridership resulting from an infrastructure investment. Estimating the potential for new users is an important part of the overall benefit calculation but requires an understanding of both the current and potential ridership at a given stop. To generate estimates that could reflect an ideal level of transit trips for a specific stop, the project team created a formulaic method that considered both surrounding land use and the Institute of Transportation Engineers (ITE) Trip generation rates. A detailed explanation of the predicted transit trip methodology and the new user estimate is included in the body of this report.

The Project team assumed that some stop locations within the study area possess a greater potential to serve their surrounding land uses than is currently being demonstrated through actual ridership figures. The project team created a formula in order to quantify the potential each stop possessed to attract and serve additional riders. This value or "benefit" can inform the prioritization methodology and help allocate limited funding to the stop locations that could benefit the most. The "benefit" of providing a specific improvement or a package of improvements was defined as:

$B = (E + 2N) * \text{sum}(I)$

Where:

B = Benefit

E = Number of existing riders using a stop

N = Estimated new users who could potentially be attracted by infrastructure improvements

I = The value associated with the stop typology need itself

Cost information for each potential infrastructure improvement was derived from data obtained from the City and County of Denver, RTD, and the CDOT cost data book (2012).

All data and calculations referenced above work together to provide a dynamic database tool that can be used to rank improvements based on a number of different query factors and then ranks stops based on the calculated benefit/cost ratio of improvements along with a list of specific improvements with the highest benefit ratio. While additional development is needed to make this tool more comprehensive and functional, the WSTES Phase Two effort confirmed how this methodology can be utilized to help maximize high benefit investments at bus stops on the West Side.

Background/Project Purpose

As part of the Denver Livability Partnership, the City and County of Denver, along with the Regional Transportation District, applied for and received an FTA grant to address changing transit needs due to the opening of RTD's West Rail Line. The West Side Transit Enhancement Study's (WSTES) Phase One Service Plan Assessment reviewed current RTD bus transit facilities and services to identify ways those services could be adjusted to better connect the West Side to light rail transit. After recommending enhancements to existing bus service, the Phase Two portion of the study was designed to then determine the physical infrastructure improvements needed at stops to better support and attract transit ridership in the study area. The objectives of Phase Two of study are to identify infrastructure barriers to riding bus transit and prioritizing future investments by ranking the improvements for their overall ability to contribute to the goal of increasing ridership. The Phase Two study assumes that identifying these barriers and limitations and by prioritizing infrastructure improvements to address them, transit users will more easily be able to access and utilize RTD's full suite of transit services. A successful outcome of this Phase Two study will enable the City and County of Denver to more thoughtfully and systematically invest in areas that have both the greatest need and can yield the greatest benefit to enhancing the City's diverse multi-modal transportation network on the West Side.

For the purposes of the WSTES study, use of the term "West Side" generally refers to a study area that includes neighborhoods roughly bounded by 17th Avenue south to Mississippi Avenue and Sheridan Boulevard east to Broadway and Speer Boulevard. The Phase Two study area varies slightly from the Phase One effort by moving the eastern boundary edge from Broadway to I-25. However, the study still recognizes an influence area that considers the existing connections to both the Central Corridor and West Rail Lines. Particular attention is given to the following neighborhoods: Westwood, Athmar Park, Barnum West, Barnum, Valverde, Villa Park, Sun Valley, and West Colfax.

As defined in the original scope of services for Phase Two, this study recognizes the numerous needs for improved bus stop transit infrastructure around the West Side. In order to prioritize the allocation of limited funding resources towards these needs in the most impactful way possible, the Phase Two scope of work identified the opportunity to create a dynamic decision making tool to support the City and County of Denver in directing investment.

The study approach was broken into four main parts:

- Field data collection and inventorying of physical amenities and needs for each stop within the defined study area
- Development and assignment of bus stop typologies
- Public outreach/engagement to inform prioritization methodology
- Decision tool development and testing

Methodology

Field Data

The first step in identifying needed improvements was to inventory the existing conditions at each bus stop in the study area. Denver worked with student teams from the University of Colorado at Denver as well as City and County of Denver staff volunteers. The project team provided a training session for teams prior to the fieldwork in order to ensure a consistent data collection and recording methodology. To assist in this process, the project team developed a comprehensive inventory sheet to capture information describing current conditions at each stop. The data collection sheet is shown in Figure 1. Information for each stop was recorded on a single row on the collection sheet, which allowed for easy documentation and the ability to compare the existing conditions results from numerous stops. The data collection sheet also provided qualitative descriptions to help each volunteer team consistently identify the quality of a particular infrastructure element (i.e. the condition of existing sidewalk). This guidance also helped improve consistent interpretation across teams.

Figure 1: Bus Stop Data Collection Sheet

West Side Transit Enhancement Study — Bus Stop Data Collection — Name of Volunteer(s):

MyStop Number	Date of observation	Time of observation	What is the PRIMARY function of the stop?	Does the stop have route schedule information posted?	What is the material of the landing area?	Are there obstacles that would limit the mobility of a wheelchair?	If so, describe the nature of those obstacles.	What is the approximate adjacent sidewalk width?	What is the adjacent sidewalk condition?	Are there curb ramps that facilitate access to the stop?	Are there adjacent crosswalks that facilitate access to the stop at the nearest corner?	Are there stop controlled intersections that facilitate access to the stop at nearest corner?	Is there a bike rack within 15 ft of the stop?	What is the condition of the bench/ seating?	What is the condition of the concrete landing pad?	What is the condition of the shelter?	What is the condition of the trash can/receptacle?	What is the condition of the lighting?
			For each question, choose the number that best describes the conditions at each stop															
			1 = Serves local residential uses 2 = Serves local commercial uses 3 = Acts as a transfer stop	0 = none present 1 = schedule information posted	1 = concrete 2 = asphalt 3 = gravel 4 = dirt 5 = other (fill in)	1= stop is accessible 2= stop has limited accessibility 3= stop has significant obstacles that would be impossible for wheeled access	Describe the nature/ location of obstacle(s)	Measure usable sidewalk in feet	0 = none present 1 = Poor, very rough 2 = Fair, minor cracks 3 = Good, no repairs needed	0 = No curb ramp at nearest corner 1 = Curb ramp at nearest corner	0 = No adjacent painted crosswalk exists 1 = One or more adjacent painted crosswalks	0 = None 1 = One or more stoplights / stop signs for crossing	0 = none present 1 = one or more present (indicate number of racks)	0 = none/ unusable 1 = One or more usable benches	0 = none/ hazardous 1 = Poor, very rough 2 = Fair, minor cracks, usable 3 = Good condition	0 = none 1 = No sides 2 = up to 3 sides 3 = enclosed on 4 sides	0 = none 1 = present/not fixed to ground 2= present/fixed to ground	0 = none 1= a nearby light provides ambient illumination 2= there is a light dedicated to the stop or directly above the stop

Reverse side for more data collection locations

After each team completed their assigned observations, the project team reviewed the collected data and revisited selected stops to make sure there was sufficient consistency between field teams. Minor differences in reporting were discovered, although deemed fairly insignificant for the overall purpose of the data. One minor example of inconsistency was evident in the "Lighting" data field. All observations took place during the day and, as a result, each team made assumptions related to ambient light and its benefits to an adjacent stop. Figure 2 shows a completed data collection sheet after field inventory.

Figure 2: Completed Data Collection Sheet

West Side Transit Enhancement Study — Bus Stop Data Collection — Name of Volunteer(s): Olga Mikhailova + Tim Watkins

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For each question, choose the number that best describes the conditions at each stop

MyStop Number	Date of observation	Time of observation	What is the PRIMARY function of the stop? (1 = Serves local residential uses; 2 = Serves local commercial uses; 3 = Acts as a transfer stop)	Does the stop have route schedule information posted? (0 = none present; 1 = schedule information posted)	What is the material of the landing area? (1 = concrete; 2 = asphalt; 3 = gravel; 4 = dirt; 5 = other (fill in))	Are there obstacles that would limit the mobility of a wheelchair? (1= stop is accessible; 2= stop has limited accessibility; 3= stop has significant obstacles that would be impossible for wheeled access)	If so, describe the nature of those obstacles. (Describe the nature/ location of obstacle(s))	What is the approximate adjacent sidewalk width? (Measure usable sidewalk in feet)	What is the adjacent sidewalk condition? (0 = none present; 1 = Poor, very rough; 2 = Fair, minor cracks; 3 = Good, no repairs needed)	Are there curb ramps that facilitate access to the stop? (0 = No curb ramp at nearest corner; 1 = Curb ramp at nearest corner)	Are there adjacent crosswalks that facilitate access to the stop at the nearest corner? (0 = No adjacent painted crosswalk exists; 1 = One or more adjacent painted crosswalks)	Are there stop controlled intersections that facilitate access to the stop at nearest corner? (0 = None; 1 = One or more stoplights / stop signs for crossing)	Is there a bike rack within 15 ft of the stop? (0 = none present; 1 = one or more present (indicate number of racks))	What is the condition of the bench/ seating? (0 = none/ unusable; 1 = One or more usable benches)	What is the condition of the concrete landing pad? (0 = none/ hazardous; 1 = Poor, very rough; 2 = Fair, minor cracks, usable; 3 = Good condition)	What is the condition of the shelter? (0 = none; 1 = No sides; 2 = up to 3 sides; 3 = enclosed on 4 sides)	What is the condition of the trash can/receptacle? (0 = none; 1 = present/not fixed to ground; 2= present/fixed to ground)	What is the condition of the lighting? (0 = none; 1= a nearby light provides ambient illumination; 2= there is a light dedicated to the stop or directly above the stop)	Additional Notes (Please include any additional observations you think the WSTES team should know about any particular stops)
24392	12/28	12:55	1,2	0	1	1		3	2,3	1	0	0	0	0	2,3	0	0	0	
15359	12/28	1:01	2	0	3	2	no landing	5	3	1	1	0	0	0	0	0	0	1 across street	
15360	12/28	10:30	2	0	1, 2	2	Broken surface (asph)	5	3	1	0	0	0	1	1	0	0	0	
15377	12/28	12:55	2	0	1	1		5	3	1	1	1	0	0	3	0	0	1	
15378	12/28	10:30	2, 3	0	1	1		5	3	1	1	1	0	1	3	0	2	0	
24393	12/28	11:48	2	0	2	2	no adj sidewalk	–	0	0	0	0	0	0	1	0	0	1	sign
24394	12/28	11:45	2	0	2	3	steep slope	–	0	0	0	0	0	0	0	0	0	0	
24396	12/28	11:50	2	0	2	3	grades, surface	–	0	0	0	0	0	0	1,0	0	0	1	

Reverse side for additional stop locations

Each field team was also instructed to document existing conditions at each stop with photographs carefully labeling each with the RTD Bus Stop ID number. The photos below are two examples of the photographs that each volunteer team turned in along with their filled out data collection sheet (Figure 3, Bus Stop ID Number 24392 and Figure 4, Bus Stop ID Number 15359).

Figure 3: Stop ID Number 24392

Figure 4: Stop ID Number 15359

RTD Inventory Data

In partnership with RTD, the study team also utilized inventory information that is part of the data set collected and maintained by RTD staff. While not always complete, this data set provided additional opportunity to test and validate volunteer team findings. In addition to basic stop amenity information, RTD's stop data includes the longitude and latitude of each stop as well as boarding and alighting data. The project team found several discrepancies between the RTD-supplied data and the field-collected data and, in most cases, the field-collected data tended to be more accurate and up to date. For the purposes of the development of the decision making tool, the field-collected data was used as the main data set.

Data Organization

Once each field team had returned their data collection sheets and photographs for each stop within the study area, the existing conditions results for each stop were organized into a single excel spreadsheet using the RTD Bus Stop ID (BSID) as the unique identifier for each stop. The columns in the spreadsheet hold all collected information about each stop. As the study progressed, this base spreadsheet expanded to include calculated formula fields that could quickly determine the "gaps" between existing infrastructure elements and those missing, the benefit/cost ratios of each, and the applied ranking methodology of improvements to be installed. Since the prioritization of needed improvements would be ultimately based on a combination of factors including current ridership, predicted ridership, and the type of route/service provided by each stop; it was important to include these data points in the excel spreadsheet as well. Finally, stop typologies were developed and assigned to each stop to inform the level of infrastructure needed and desired at each location.

Public Outreach

Consistent with the goals and outreach plan for the Denver Livability Partnership, the WSTES Phase Two effort has a strong commitment to providing information and engagement opportunities to interested stakeholders. These opportunities provided the project team with valuable feedback to inform the development of project methodologies and outcomes. The WSTES activity website page (www.denvergov.org/westsidetransit) provided a basic description of the Phase One and Phase Two efforts while also listing meeting and update announcements as necessary. The website also served to provide links to affiliated projects as applicable and an opportunity to add contact information to the project's distribution list. The project team also held several briefings with impacted City Council districts to detail the scope and process of each phase of the project. While the Phase One effort relied on general public engagement to inform its recommendations and outcomes, the Phase Two effort created a Technical Advisory Committee (TAC) to help provide technical guidance at key policy decision points in the study. The TAC included representatives from neighborhood non-profit organizations, business improvement districts, pedestrian advocacy organizations, and City and County of Denver staff. The TAC held two meetings where the project team summarized findings to date and solicited feedback on approach and methodology. The project team relied on the group to represent a broader set of area stakeholders and distribute information as needed to those groups.

Typology

The project team developed and refined a set of stop typology definitions based on discussions both internally and with the TAC. The TAC and the project team agreed that, for the purposes of this study, three main characteristics could be utilized to identify the types of amenities needed at a specific stop: **land use, transit function,** and **ridership levels.** Although each stop is unique and fitting each of the stops into three classification categories can be extremely difficult, the team decided that a smaller set of classifications could help provide a more a consistent approach to the investment decision process. Allowing for too much detail in the typology definitions could quickly become cumbersome and ultimately less effective in the database and decision-making process.

Through the consideration of these three characteristics, nine separate typologies were developed to allow the team to begin associating an ideal level of amenity at each. This number provided for a level of meaningful differentiation between classes of stops while still allowing for a reasonable and manageable set of class groupings for the stops.

Surrounding Land Use – The types of land uses surrounding a stop has a substantial impact on the expectation and needs of that particular stop's infrastructure or amenity level. As part of the field data collection effort, each volunteer team was asked to document their interpretation of the dominant land uses surrounding each stop. As the project team reviewed the volunteer teams' interpretations, it was apparent that this determination could be made based on a number of different subjective queues. There were substantial differences, even within the same field team, as to whether a single stop should be classified as a "residential" or a "commercial" stop. For example, a stop near a convenience store or small retail area could be classified as "commercial" even though immediately behind the retail was a large residential community. For consistency in application of this definition, the project team determined that the predominant zoning within a ¼-mile walk radius would determine a stop's land use classification. The City's zoning information contained in Denver's geographic information systems (GIS) database was the basis for defining this stop characteristic. If residentially zoned land area was greater than the commercial land area within the ¼-mile radius, then the stop was defined as "residential." If the area of commercially zoned property was greater than residential area, the stop was classified as "commercial."

Transit Function –Transit function was defined as the primary way riders used the stop. The two categories used to define this function were: "Origin/Destination" and "Transfer." While RTD defines a transfer stop as one that serves more than one bus route, for the purposes of this study the field teams were instructed to note how riders actually used the stop. Each field team was asked whether riders observed mainly used the stop as an origin/destination or if they waited at the stop to transfer to another bus? All stops were assigned one of these two categories.

Ridership – The amount of riders served by a stop was determined to be a key characteristic. The project team decided to consider the median combined boardings and alightings recorded at a stop as the line between "high" and "low" usage stops in order to keep the number of typologies manageable while still providing a useful demarcation between stops. The median, by definition, makes half of the stops in the inventory database low usage stops and half the stops high usage stops.

The above definitions create eight (8) separate typologies:

Land Use	Transit Function	Ridership
Commercial	Origin/destination	High
Commercial	Origin/destination	Low
Commercial	Transfer	High
Commercial	Transfer	Low
Residential	Origin/destination	High
Residential	Origin/destination	Low
Residential	Transfer	High
Residential	Transfer	Low

As this study continued, it became necessary to include one additional typology for special cases in industrial areas served in the study area. To accommodate this special case, the following typology was added to bring the total number of typologies to nine (9):

Land Use	Transit Function	Ridership
Industrial	Origin/destination	Low

Clearly each of the three categories (land use, transit function, and ridership) used to determine a stop's typology are, in reality, less of a discrete value than a continuum. This makes the drawing of any line between definitions subject to disagreement. For example, near the arbitrary dividing line between "high" and "low" ridership there will be stops with very similar ridership values. However, the stop groupings provide a mechanism to make useful comparisons between the nine (9) typologies. These typologies are considered default values but the database allows the individual user to challenge each definition as he or she sees fit in order to address individual priorities.

Infrastructure Needs

The project team developed the data collection sheet for field volunteer teams to capture as much data on existing amenities as possible. The team then met to determine whether additional items could potentially be added and reflected to the database columns. In addition to the items collected in the field, the team determined that sidewalk access to the neighborhood was important infrastructure that had a strong potential to influence transit usage. For the purposes of this pilot project, a distinction was made between an "access walk" and "sidewalk". An "access walk" was defined as a paved walk from the nearest corner to the bus stop itself. This could be and often was provided by a sidewalk parallel to the street on which the stop was located. A "sidewalk" was defined as paved access to the land uses surrounding the stop. While sidewalk that connects to residential and commercial land uses is important to complete a comprehensive transportation network serving each stop, the resource limitations of this study did not allow for a comprehensive look at the limits and associated costs of such improvements. Placeholders for sidewalk information at each stop have been included in the database, but no attempt at a general cost or benefit of a default sidewalk project has been included. The other improvements defined are more easily associated with a specific stop and quantified.

The infrastructure elements considered in this study are:

- **Concrete Pad –** The above-curb, paved surface at a stop location meant for rider waiting, boarding, and alighting.
- **Stop-Controlled Intersection –** The presence of stop-control (traffic signals or stop signs) at the nearest intersection to the stop.
  Note: There was some disagreement within the project team as to whether this item should be included, as the control of an intersection is determined as part of the overall traffic network considering the safety and mobility of all users. Not all stop locations need a stop-controlled intersection for safe access of the stop. Information is included in the database for cost and benefit calculations. If a stop-controlled intersection improvement ranks high, it should be seen as a recommendation to study the intersection control.
- **Curb Ramp –** An accessible curb ramp at the street corner nearest the stop.
- **Sidewalk –** A continuous paved connection to the surrounding land use. Typically a paved walk perpendicular to the street served by the stop.
- **Crosswalks –** Painted crosswalks at the nearest intersection to the stop.
  Note: Denver's policy, at the time of this study, is to mark crosswalks only at stop-controlled intersections.
- **Access Walk –** Paved connection from the stop to the nearest street corner and ramp.
- **Bench –** Bench provided specifically to serve riders waiting at the stop.
- **Lighting –** Lighting specifically provided for the stop. There are cases where

stops are adequately lit by nearby street lighting or adjacent properties.

- **Shelter –** Presence of a bus stop shelter specifically provided for riders waiting at the stop.
- **Trash can –** Presence of a trash can specifically provided for riders waiting at the stop.
- **Bicycle Rack –** Presence of a bicycle rack specifically provided for riders using the stop.

Once the infrastructure improvements were identified and listed, the project team met to determine which elements were needed at each stop based on the stop's typology. The team worked together with the TAC to discuss and determine the priority of each item for each stop typology. The initial exercise was to rank the level of importance of each item from 1-10 with 1 being the most important item and 10 being the least important item. (*Note: Due to the operational considerations associated with a stop-controlled intersection, this improvement was not included in this exercise*). In the discussions involved in the exercise, it became clear that for each bus stop typology there were three classes of improvements:

- Items critical to the basic functioning of a stop
- Items that should be included at a stop
- Items that would be "nice to have"

This classification proved more useful than a strict rank ordering of items. Table 3 illustrates the initial rank ordering the team developed along with the classification settled on for each typology. Yellow indicates critical items, green are the items that should be provided, and blue indicates the "nice to have" items.

Table 3: Initial Rank Ordering and Classification of Bus Stop Items

			Concrete pad	Access Walk	Ramp	Crosswalks	Sidewalk	Bench	Lighting	Shelter	Trash can	Bike Rack
Commercial	Origin/ destination	High	1	3	4	5	2	6	8	7	9	10
Commercial	Origin/ destination	Low	1	3	4	5	2	6	8	7	9	10
Commercial	Transfer	High	1	4	3	2	5	7	6	8	9	10
Commercial	Transfer	Low	1	2	3	4	9	6	5	7	8	10
Residential	Origin/ destination	High	5	2	3	4	1	7	6	8	10	9
Residential	Origin/ destination	Low	5	2	3	4	1	6	9	8	10	7
Residential	Transfer	High	1	3	4	2	5	7	6	8	9	10
Residential	Transfer	Low	1	4	3	2	6	7	5	9	8	10
Industrial	Origin/ destination	Low	1	4	3	2	6	7	5	9	8	10

The color coding of the above table became the basis for the default values used in the database tool, as shown in Table 4. As is the case with most of the subjective portions of the decision input, flexibility of these rankings is preserved in the final database.

Table 4: Rankings of Bus Stop Items Used in Database

			Concrete pad	Stop Controlled	Curb Ramp	Sidewalk	Crosswalks	Access Walk	Bench	Lighting	Shelter	Trash can	Bike Rack
Commercial	Origin/destination	Low	A	C	A	A	A	A	B	C	C	C	A
Commercial	Transfer	High	A	C	A	A	A	A	B	B	B	B	A
Commercial	Transfer	Low	A	C	A	C	A	A	C	B	C	C	C
Residential	Origin/destination	High	A	C	A	A	B	A	B	B	C	C	C
Residential	Origin/destination	Low	A	C	A	A	B	A	C	C	C	C	C
Residential	Transfer	High	A	C	A	A	A	A	B	A	B	B	C
Residential	Transfer	Low	A	C	A	A	A	A	B	A	C	C	C
Industrial	Origin/destination	Low	A	C	A	A	A	A	B	A	C	C	C
Commercial	Origin/destination	High	A	C	A	A	A	A	B	B	B	B	B

Data Analysis

A key goal of this project was to provide a tool to assist in making improvement decisions based on a benefit-to-cost ratio. The project team wanted to include in the benefit calculation an estimate of new riders that could be attracted to a stop.

New User Estimate

Transit studies historically look at ridership by transit line and on the system as a whole. In a literature review conducted for this project, no documentation of estimating usage by individual stop could be found. Analysis of development and land use changes for vehicle trips has a long history of using the Institute of Transportation Engineers (ITE) Trip Generation Handbook. The ITE trip generation handbook uses counts surrounding specific development types to provide estimates of changes to vehicle trips should a new development of a specific type be constructed and operated. Estimates of transit, bicycle, and pedestrian trips are generally seen as a fixed percentage of the vehicle trips. When conducting a traffic impact analysis of a new development, ITE includes methodologies to account for redirected trips (pass-by), trips between different uses on the same site (internal capture) and the like. In essence, a direct usage of the estimate based on land use alone will tend to overestimate the impact of a specific use without accounting for interdependency of the adjacent land use and travel patterns.

A traffic impact analysis of each individual stop in the WSTES study area is impractical, and the stop itself does not generate trips; it is only a focus for trips generated by the surrounding land uses. Nevertheless, the ITE trip generation rates are the best information available to estimate transit trips. Denver provided land use information maintained in its GIS system. The data most easily used for this exercise was number of buildings and building footprint in square feet (sf). Using this information, rough estimates of total trips generated by each land use was calculated directly from the best fit curve for each land use from the ITE trip generation handbook (8th edition). Table 5 below shows the ITE codes used to estimate the generated trips.

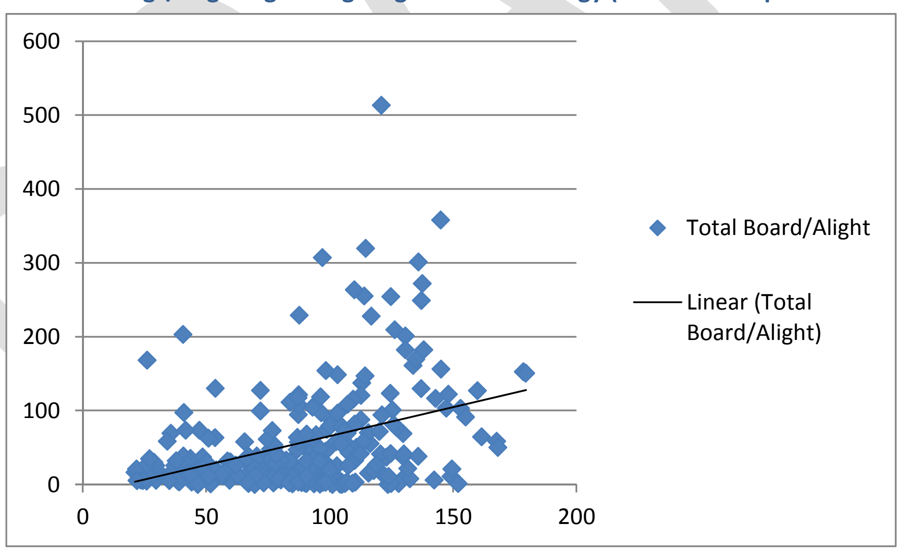
Table 5: ITE Codes Used to Estimate Generated Trips

ITE Code	210	230	240	820	110	270	710	495
Description	Single Family Detached	Residential Condominium/ Townhouse	Mobile Home Park	Shopping Center	General Light Industrial	Residential Planned Unit Development	General Office Building	Recreational Community Center

Total transit trips were assumed to be 1% of the total vehicle trips. In the Denver metro region, the actual mode split is much higher; but, as stated earlier, the ITE trip generation rates tend to overestimate trips if directly using the trip generation rates. Comparing the total estimated trips to the actual boardings and alightings, the 1% assumed transit riders results in 22,987 estimated transit trips compared to 17,295 reported boardings/alightings.

While the total trips reported is important to be certain that the estimated trips are within an acceptable range, the distribution of those trips to individual stops is more important. To evaluate the distribution, the correlation between estimated trips and actual trips was calculated. Correlation is a measure of how related two sets of numbers are. A perfect correlation of 1 means that as one set of numbers changes, the other set changes in exact proportion to the other. In other words, the graph of two sets of data plotted against each other would result in a straight line. The correlation of the estimated trips and the reported boardings and alightings is 0.39. While this is a very weak correlation, there are a number of other factors that drive which stop a transit user will use. A large variable clearly not explained by land use is transfers between routes. These behaviors will be captured in boarding/alighting data but not in the estimate generated by land use. In the absence of better methodology, the estimated transit trips based on land use was used for this study. Figure 5 below shows the plot of estimated trips (x-axis) to reported boardings/alightings (y-axis) along with the best fit linear approximation.

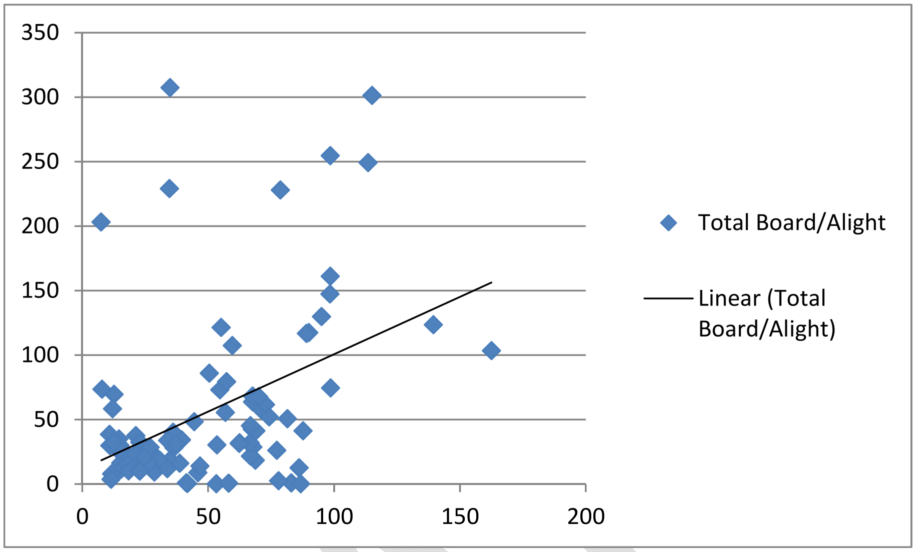
Figure 5: Total Boardings/Alightings Using Original Methodology (Estimated Trips Based on Land Use)



One potential improvement to the land use methodology explored by the project team included eliminating potential double counting of land use area. The land use assignment to each stop described above results in land use trips being assigned to two different stops, essentially “double counting,” when ¼-mile walk sheds overlap. To address this potential issue, Denver’s GIS personnel used walk path assignments to assign land use to only one stop based on the shortest walk distance to a stop. Because the calculation of walk paths is resource-intensive, a sample of stops based on bus routes was used to test the more detailed analysis.

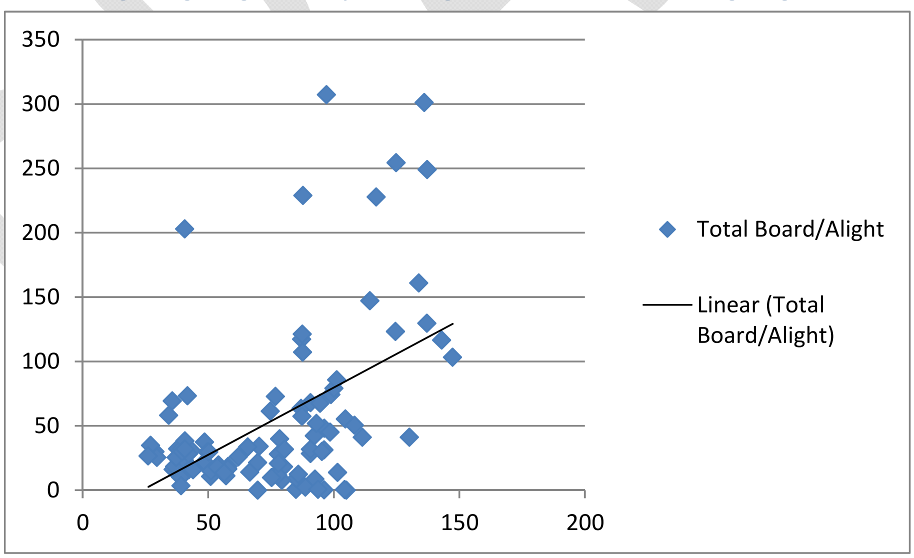
Stops serving Routes 1, 9, and 31 were assigned estimated transit trips based on shortest walk path. These 96 stops had a correlation of 0.44 (Figure 6), slightly higher than the correlation for the whole dataset under the first methodology.

Figure 6: Boardings/Alightings for Stops Serving Routes 1, 9, and 31 Using Revised Methodology (Shortest Walk Path)



However, when looking at just these stops under the original methodology, their correlation was very similar at 0.48 (Figure 7).

Figure 7: Boardings/Alightings for Stops Serving Routes 1, 9, and 31 Using Original Methodology



Given that there wasn't a significant difference in the correlation between the two methodologies, the original methodology was used to estimate transit trips at each stop.

Benefit of Infrastructure Improvements

To provide a value or benefit of each infrastructure improvement identified (the list of 11 items) the value of the item as it relates to the stop typology must be addressed. The total benefit of a package of infrastructure amenities installed must be some combination of taking care of existing riders, attracting new riders, and meeting the needs of the specific stop typology. In other words, the benefit is some function of:

E = the number of existing riders,

N = the potential to attract new riders, and

I = how well the package of improvements meets the typology needs.

In the discussion above regarding amenities, the idea of three categories of improvements was presented, including items that are critical to the basic function of the stop (Class A), items that should be included at a stop (Class B), and items that would be nice to have included (Class C). To assign a value to these three classes of improvements, the project team used a logarithmic increase between the different classes. For the purposes of calculating a benefit value, if Class C items are assumed to have a benefit value of 1, Class B items have a value of 10 and Class A items have a value of 100. Another way to say this is that Class B items are 10 times as important to provide as Class C items, and class A items are 10 times more important than Class B items.

Secondly, a stated goal of the WSTES study is to attract new riders to transit. Therefore, while taking care of existing riders is important, if an infrastructure improvement can attract new riders, it should take some precedence over providing infrastructure that has little opportunity to attract new riders. For a default value in ranking possible infrastructure investments, attracting a new user was seen as double the value of providing infrastructure for an existing user.

Stated in a formula, the Benefit (B) of a package of improvements was defined as:

$$B = (E + 2N) * \text{sum}(I)$$

For example; the benefit of providing one class A improvement and one Class C improvement to a stop that currently has 20 existing riders and the potential to attract 4 new riders would be determined to be:

$$B = (20 + 2(4)) * (100 + 1) = 2,828$$

With this benefit calculation every amenity and combination of amenities can be assigned a benefit value. The amenity package that provides the best benefit-to-cost ratio provides a starting point for making investment decisions. For the database tool developed as part of this study, all of the values discussed above are set as defaults. The user can modify each of these values, providing flexibility and the ability for each user to adjust the benefit calculation based on their individual values and goals.

Estimating New Users

The benefit calculation just described is straightforward. The existing ridership number is available through RTD and the value of infrastructure improvements is easily defined by the user. Estimating new users requires some explanation and additional assumptions.

An underlying assumption in providing additional infrastructure at a stop is that the better the stop is, the more comfortable existing riders will feel and the more likely additional riders will use the system. The data we have available is existing ridership, estimated ridership (described under **New User Estimate** above), installed infrastructure, stop typology and the value of each amenity to the typology.

From this available information, we need to estimate the impact of each individual amenity and its ability to attract new riders. To arrive at a relative influence value, the difference between ridership at stops with an amenity and without can be compared. Clearly, decisions to install the infrastructure already deployed were often the result of placing amenities where riders already were. Using existing ridership and infrastructure data to determine an infrastructure influence is reversing the causation. The project team recognizes that this is not necessarily a valid assumption, but in the interest of using the data available, the existing data was used for the estimate of potential new users. While many of the assumptions used in calculating new users are lacking rigorous support, the benefit calculation is most heavily influenced by the typology value and the existing ridership. The less rigorous assumptions have a reduced influence on the final rankings.

Using RTD's ridership data and the installed infrastructure data collected in the field surveys, we can compare the average ridership at stops with and without a specific amenity. The difference in this ridership can be used to estimate the influence each amenity has on attracting new riders. For example, it is not surprising that the largest difference in ridership is seen between stops with a shelter and without. There are, on average, 154 more riders at stops with a shelter than stops without a shelter.

At the other end of the influence scale, stops with a bike rack have approximately 7 more riders than stops without a bike rack.

These relative **influence points** for each of the items are presented in Table 6 below:

Table 6: Relative Influence Points for Bus Stop Amenities

Concrete pad	Stop Controlled	Curb Ramp	Sidewalk	Crosswalks	Access Walk	Bench	Lighting	Shelter	Trash can	Bike Rack
50.857	0	49.328	0	66.171	38.509	70.287	79.972	153.98	91.399	7.1857

*Note – Stop Controlled set to 0 because operational/safety impacts and sidewalk data (as defined under **Infrastructure Needs**) were not collected.

In a perfect world, if all amenities were provided at a stop, then the predicted ridership and existing ridership would be equal. Where items are missing, the existing ridership would be reduced below the predicted ridership by a proportionate amount. Of course, with our imperfect manner of estimating potential ridership at a stop, this is often not the case. The calculation of the benefit of providing additional amenities has to be robust enough to handle various real world situations where ridership exceeds predicted ridership. The base assumption of infrastructure decisions is that the amenity provided has value as one of the typology classes and that value will attract new riders, albeit relatively few when compared to the existing number of riders. To provide a benefit number for each amenity we need to handle real world information.

At each specific stop we have the following data:

- Existing riders
- Existing amenities
- Predicted riders
- Missing amenities

With this data, three different values can be calculated:

1) Existing riders per existing number of influence points
2) Predicted riders per total influence points
3) Missing riders per missing influence points
   (missing riders = predicted – existing)

The second two values are estimates based on the predicted ridership. Where existing ridership exceeds the predicted ridership, the last value will be negative. The predicted ridership per total number of influence points will always be positive. Intuitively, adding amenities should not reduce ridership, so to estimate the potential new ridership based on the predicted ridership, the maximum of the last two values is used. This number is then compared to the first value based on existing information. The minimum of these two numbers is used to predict the new riders associated with providing a new amenity.

An example is useful in clarifying this discussion. Assume a stop has currently installed:

- Concrete pad
- Access walk
- Bench

The current ridership is 25; the predicted ridership based on land use surrounding the stop is 20.

The total influence points installed is 50.857 + 38.509 + 70.287 = 160.

The influence point total of all potential amenities is the sum of all the values in the table above or 608.

The total missing influence points is 608 – 160 = 448.

The results of the three formulas above are:

1) 25 / 160 = 0.156 riders/point
2) 20 / 608 = 0.033 riders/point
3) (20 – 25) / 448 = -0.011 riders/point

Formula 1 is based on existing users. Formulas 2 and 3 are estimates based on predicted users. The formula to represent the predicted users is the maximum of formula 2 and 3, or formula 2 (0.033 riders/point). Compare this to formula 1 (0.156 riders/point). The estimate for this stop is the lower of these two values (0.033). To estimate the number of new users attracted by the installation of new infrastructure, in our case curb ramps, the value of formula number 2 is used. Curb ramps have an influence value of 49. 49.

49.49 * 0.033 = 1.63.

Adding curb ramps would attract between 1 and 2 new riders per day to this example stop.

For all stop typologies, curb ramps are seen as being critical to adequate infrastructure. Therefore the improvement value of the curb ramp is 100. The total benefit of adding the curb ramp using the benefit calculation introduced above is:

B = (E + 2N) * sum(I)

B = (25 + 2(1.6)) * 100 = 2,820

Cost Estimating

Compared to estimating the benefit of installing new infrastructure, estimated the cost of installation is much more straightforward. Cost of infrastructure items was based on historic Denver costs of installing benches, bike racks, and concrete walkways. This data was supplemented by RTD provided costs for shelters and trash cans. Costs associated with traditional roadway improvements (cross walks, curb ramps) were estimated based on the CDOT cost data book (2012). These estimates are used as default “rule of thumb” costs for a general improvement installation.

The default assumptions and costs used in the database are shown in Table 7.

Table 7: Cost to Add Each Amenity to a Bus Stop

Cost Data	Length (ft)	Width (ft)	Cost($)	Unit
Pad Size	20	10	10	Sq.ft
Ramp	10	5	10	Sq.ft
Sidewalk	800	5	10	Sq.ft
Crosswalk	60	6	5	Sq.ft
Access Walk	150	5	10	Sq.ft
Bench			500	ea
Lighting			5,000	LS
Shelter			10,900	LS
Trash Can			250	ea
Bike Rack			250	ea
Stop Controlled			15,000	ea

The database tool includes placeholder fields where stop-specific dimensions and costs can be included. Detailed cost estimates for each stop were beyond the scope of this study, but the database will use the best available data when calculating the benefit/cost ratio of improvements at a specific stop.

BETA Database Tool Description

The database tool was created to both house the bus stop inventory data gathered by the volunteer teams and organize it based on a set parameters dictated by the user in order to help guide investment decisions. The beta tool was built using Microsoft Access as an easy and accessible data management system platform. This platform allows for easy data entry, reporting, and an adjustable query interface. The system allows for the data points to be placed on a network, locked at the record level, and then queried in numerous ways without impacting the raw data. A screen shot of the beta database interface is shown in Table 8.

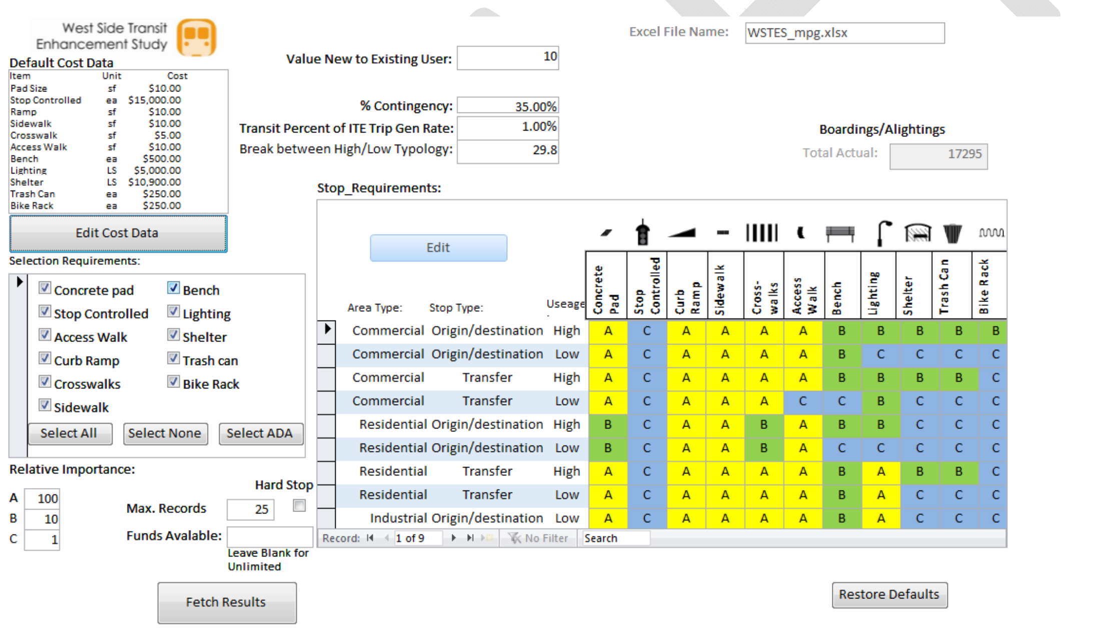
The database pulls from the set of raw bus stop inventory data and the query interface displays a set of base assumptions and variable assumptions (described in detail in the above discussion). The base assumptions are designed to remain consistent throughout a series of queries and include the “stop requirements by stop typology” (i.e. the importance ranking for each stop) and the “default cost data” that is associated with each physical amenity. Another base assumption, the “Value to New Users” section of the interface, attempts to layer in the effect an amenity has on riders as estimated by the “total benefit” formula described in the earlier discussion. Once determined and set in the interface, these base assumptions are designed to provide a foundation from which the other variables available in the database can pivot. Table 8 reflects the base assumptions as determined by the project team, however, each is fully editable.

The database interface also displays a number of variables meant to vary between queries. The user is able to click one or more of the specific physical amenities depending on whether he or she wants to know where general investment is needed (i.e. click all amenities) or where a certain type of amenity is needed. A user can identify the total amount of “Funds Available” for implementation in order to query only the projects that could be done within a limited set of resources. These variables used singly or in combination are incredibly helpful when used to match investment opportunities with the conditions of implementation funding. If funding or resources are tied to a specific amenity type, the database can identify those eligible projects that have the highest estimated impact on new ridership. For example, if a surplus of benches are in need of placement, a user can simply click only on the “bench” selection to find out where the addition of that amenity will have the assumed highest impact on new riders. Alternatively, if a user has $10,000 of implementation funding that can go towards any amenity, that user can simply input the funding available without selecting a specific amenity to identify where that funding can have the greatest impact. Each query result is organized by stop location and includes a hyperlink to a Google Earth image of the existing stop condition and location.

Other features of the interface include adjustments to account for contingencies, number of query outputs, the assumed transit mode share, and various adjustments for the stop requirements based on typology.

While the database tool has succeeded in showing how a dynamic tool may help guide investment at bus stops for maximum impact, there are a number of glitches that prevent it from running smoothly. Challenges include bugs within the system functions that impact the quality of query reports, variations between user CPU systems and versions of Access software package, Adobe updates that neutralize hyperlinks, etc. Additional resources are needed to refine the beta database or research new platform systems that can better mitigate or solve these issues.

Table 8: Screen Shot from Beta Database Tool Interface



Recommendations and Next Steps

Phase 2 of the West Side Transit Enhancement Study broke new ground in many areas in providing a consistent approach to making bus stop improvement decisions. As such, new ideas and methodologies were created that will need to be validated and adjusted as new data is gathered and new studies are conducted. The flexibility included in the benefit calculations will facilitate the calibration of the benefit calculations to help the user make consistent decisions.

The following are untested assumptions, or assumptions that can be improved with more study:

- Predicting transit users based on available land use information
- Predicting users attracted by infrastructure improvements
- Estimating the benefit of each improvement

In addition, the Access database created as part of this study is a new custom application. It will likely require some adjustments to its code and interface as users implement and try out the application. Additional resources are needed to refine the database and its use or identify new platform opportunities that can help mitigate current functionality issues and make the tool available to many users – perhaps even at one time. The benefit of continuing to utilize generally available software (i.e. Microsoft Office applications), is that Denver staff will be able to make adjustments and tweaks without additional costly software required. However, regardless of the platform, it is clear that a single person or entity should be the "keeper" of the most current application in order to avoid different versions being used. Regular updates to the raw inventory data should also be scheduled as the tool develops.

Expanded Use

As Denver expands this pilot study to other areas, additional stop data will be incorporated into the database. As more information is entered, the opportunity to adjust and further test the assumptions discussed above will be presented. Those assumptions should be revisited and at the minimum factors adjusted (for example, amenity influence points) as more data becomes available.

Further, as this study was being conducted, the project team presented the methodology and developing tool to multiple audiences, generating interest from multiple agencies. The City of Lakewood has approached and received permission from Denver to test this tool on stops within their city. Denver and Lakewood should continue to compare application and use of the database decision tool and the assumptions included to help improve the implementation and consistency of application.

Finally, because of the apparent interest in this study and the decision application, Denver may want to consider making this report available to other agencies and academic institutions, inviting criticism and insight to further improvements. The formulas in the spreadsheet are reasonably easily edited, and the more professionals that have access to the code and formulas, the faster the estimating methodologies will improve.