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Estimating Accessibility to Destinations Offered By Transit

Technical Memo Regarding DelDOT sponsored research September 15, 2022

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Thanks go out to Delaware Transit Corporation (DART First State) for providing current GTFS data for Delaware

Introduction, Examining Transit Service To Communities Using Network Models

There is an increasing need to examine transportation needs and services at the community level. General estimates of transit service such as, "within a quarter mile of a bus stop" do not capture trip characteristics with respect to where people want to go. Using the General Transit Feed Specification (GTFS), which captures the current transit schedules, stop to stop travel times were examined and mapped to describe service to local communities.

This technical memo discusses research into methods for transit route analysis to describe and develop tools for determining transit access. In this context, access and accessibility is in terms of the availability of paths and the length of time to reach destinations. Routing tools developed and analysis conducted in this research are around support of planning and the ability to examine service to communities in relation to a wide range of demographic, land use, and travel demand variations. Supported applications include examination of transit options for transportation challenged areas (impoverished areas, food deserts), and as input for multimodal travel demand estimation. Products developed include tabulation of transit stop to stop travel time estimates by time of day.

General Transit Feed Specification (GTFS)

The General Transit Feed Specification (GTFS), captures the current arrival and departure times of all stops for all routes for all times of day and days of week, just as listed on bus schedules. It is produced and updated by transit agencies or their consultants, and with an understanding of the formats of the bus schedule information, could be created from transit schedules by others. The GTFS defines possible routes from one place to another and is necessary for a wide range of internet-based transit routing applications. For a detailed description of the file formats and examples, and downloads, the GTFS website is available (https://gtfs.org). The data itself can be downloaded in various places, often by transit agencies and particularly by TransitFeeds (https://transitfeeds.com) . In this research a current GTFS (September 2021) was made available courtesy of Delaware Transit Corporation. GTFS is a format where transit schedules can be imported into routing and transportation network models and applications.

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Routing Network

The transit routing network in this research is incorporated with the CADSR Multimodal Network that includes streets and paths of various kinds. Network development, processing of the GTFS, and routing operations were all conducted using ESRI (www.esri.com) tools (ArcPro, ArcMap, Transit Utilities). The results of routing analysis between origins and destinations include estimates of total travel time and distance, and the wait and walk times, for to and from bus stops. Access to residences and destinations is integrated into the travel network model.

Specifying Transit Level of Service

For policies and serving customers a certain level of service could be specified, for instance:

- Any transit route(s) possible for however long it takes
- Trips that don't involve transfers
- Trips that involve no more than 10 minutes walking
- Trips where paths to transit stops are safe and where sidewalks are available.

These and other specifications can be included in routing when examining transit service.

The level of service can define planning targets. Quality or level of service can also focus the computation of transit travel times. For instance, one might be interested in service that meets a threshold like; "door to door trip time less than 45 minutes, where no trip involves more than 10 minutes walking", which would result in significantly less cases to consider than having no threshold and involving unlimited walking.

This memo deals with technical aspects of making the transit trip time estimate and does not discuss level of service and components of that, like frequency.

HIgh Resolution Transit Service Analysis and Computational Considerations

Increasingly travel demand and strategies of serving that demand is at a high resolution, like at the housing unit or tax parcel level. Transit network routing tools work fairly well in examining large numbers of origins and destinations in an accessibility matrix. Calculations on origins and destinations as below are fairly managable.

100 house subdivision	20 destinations	20 x 100 = 2000 pairs/routes/records
150,000 housing units	20 destinations	3 million pairs/routes
150,000 housing units	200 destinations	30 million pairs/routes

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But if one were to also like to consider time of day, day of week or other factors that would inflate the number of origin/destination pairs to consider, things could get cumbersome particularly when not working in isolated areas or with methods to limit the question. That said, very large computing power is available if a particularly large calculation was determined to be worth the set up time and costs. In the research stage, the focus of time is more appropriately on what the data means and investigation and application of preliminary results. There may be a point once things are better understood where it turns out a small amount of information is enough to serve planning needs.

Determining Optimum Transit Travel Times,

As computer routing is done with respect to the schedule, various departure times will yield different travel times. If you didn't leave enough walking time to get to the bus stop, you may have to wait for the next bus , or maybe you arrived at the stop just as the bus was approaching. In judging transit service we would assume a situation where the rider would know the schedule and would leave at an optimum time. Use of a GTFS routing network requires a departure time to be specified but "What is that optimal trip departure time?". It varies depending on location and where one is going and by what time of day.

An example of the varying trip times by departure time is a sample output from ESRI Transit Summary Analysis below. In that figure transit travel time between two locations is estimated for every departure minute. In this example, as expected, departure time makes a clear difference. The shortest travel time would be 19.3 minutes at a start time at 8:15am, with about a 3.6 minute walk. That is considerably different from the total trip time of 38 minutes for a trip starting at 8:16am.

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Sample of ESRI Transit Summary Analysis
Total Public Transit Trip Time for Departure at Each Minute of the 8AM Hour
{Total_WalkTime is a combination of walking and wait times.}

StartTimeUTC	Total_PublicTransitTime	Total_WalkTime	Total_Length	TimeOfDay
1/10/1990 8:05:00 AM	29.3214	16.158663	8346.321918	1/3/1900 8:05:00 AM
1/10/1990 8:06:00 AM	28.3214	11.146377	8343.471615	1/3/1900 8:06:00 AM
1/10/1990 8:07:00 AM	27.3214	11.146377	8343.471615	1/3/1900 8:07:00 AM
1/10/1990 8:08:00 AM	26.3214	11.146377	8343.471615	1/3/1900 8:08:00 AM
1/10/1990 8:09:00 AM	25.3214	11.146377	8343.471615	1/3/1900 8:09:00 AM
1/10/1990 8:10:00 AM	24.3214	6.464937	8347.277171	1/3/1900 8:10:00 AM
1/10/1990 8:11:00 AM	23.3214	6.464937	8347.277171	1/3/1900 8:11:00 AM
1/10/1990 8:12:00 AM	22.3214	6.464937	8347.277171	1/3/1900 8:12:00 AM
1/10/1990 8:13:00 AM	21.3214	3.658703	8347.881709	1/3/1900 8:13:00 AM
1/10/1990 8:14:00 AM	20.3214	3.658703	8347.881709	1/3/1900 8:14:00 AM
1/10/1990 8:15:00 AM	19.3214	3.658703	8347.881709	1/3/1900 8:15:00 AM
1/10/1990 8:16:00 AM	38.3214	24.235907	8342.033143	1/3/1900 8:16:00 AM
1/10/1990 8:17:00 AM	37.3214	24.235907	8342.033143	1/3/1900 8:17:00 AM
1/10/1990 8:18:00 AM	36.3214	24.235907	8342.033143	1/3/1900 8:18:00 AM
1/10/1990 8:19:00 AM	35.3214	20.882615	8346.887855	1/3/1900 8:19:00 AM
1/10/1990 8:20:00 AM	34.3214	20.882615	8346.887855	1/3/1900 8:20:00 AM
1/10/1990 8:21:00 AM	33.3214	20.882615	8346.887855	1/3/1900 8:21:00 AM
1/10/1990 8:22:00 AM	32.3214	16.158663	8346.321918	1/3/1900 8:22:00 AM
1/10/1990 8:23:00 AM	31.3214	16.158663	8346.321918	1/3/1900 8:23:00 AM

Stop to Stop Travel Times, A Planning Level View Of Service

One method of simplifying the problem is to separate access to transit facilities from the In-Transit travel. These are very different parts of the trip and are dealt with in very different ways. To get a comprehensive picture for In-Transit we could examine the travel time from any point (a stop) in the system to every other point in the system. With around 2300 origin transit stops to 2300 destination stops we would be looking at roughly 5 million pairs/routes for

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any given time of day. To minimize the computation and to address a higher level of service only trips that were 35 minutes or less, and that involved 10 minutes or less walking, were considered.

To address what would be an optimum departure time and to judge the service without extra wait times, the routing was done for every 5 minutes of the day. A sample for a random pair of stops is shown below. Some of the 5 minute departure time points are not listed as they were filtered out either because the trip was over 35 minutes or involved greater than a 10 minute walk. The stop to stop routing was processed for all stops and 5 minute increments creating a 46 million record set.

Sample of routing result between stops 938 and 91 by time of day

orig	dest	timeint	hour	Total_Transit	TotalWalk Wait
938	91	0700	7	20.97	6.21
938	91	0705	7	25.60	8.60
938	91	0730	7	25.60	8.60
938	91	0745	7	25.60	8.60
938	91	0825	8	24.84	6.21
938	91	0835	8	22.52	9.70
938	91	0845	8	25.60	8.60
938	91	0905	9	20.47	6.21
938	91	0930	9	21.38	3.74
938	91	1005	10	21.47	7.11
938	91	1010	10	21.38	6.61
938	91	1030	10	26.61	9.35
938	91	1035	10	21.61	5.61
938	91	1100	11	26.61	9.35
938	91	1105	11	21.61	5.61
938	91	1130	11	22.97	6.21
938	91	1135	11	17.97	2.47
938	91	1200	12	26.61	9.35
938	91	1205	12	21.61	5.61
938	91	1210	12	22.07	6.61
938	91	1235	12	24.01	8.08
938	91	1305	13	24.61	8.08
938	91	1310	13	22.07	6.61
938	91	1335	13	24.61	8.08
938	91	1400	14	22.47	6.21

From this step , one could examine minimums and distributions and establish travel times that could be used at the planning scale. The table below is an example that tabulates the minimum time by hour of the day for weekday service.

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Minimum Transit Travel Time By Hour of the Day Between Stops 938 and 91

(generated from routing every 5 minutes)

orig	dest	hour	Total_Publ_min	Total_Walk_min
938	91	7	20.97	6.21
938	91	8	22.52	6.21
938	91	9	20.47	3.74
938	91	10	21.38	5.61
938	91	11	17.97	2.47
938	91	12	21.61	5.61
938	91	13	22.07	6.61
938	91	14	22.07	4.33
938	91	15	24.61	9.23
938	91	16	22.75	3.74
938	91	17	21.38	3.74
938	91	18	23.19	7.33
938	91	19	23.60	7.33
938	91	21	17.19	2.47
938	91	23	22.45	4.86

The transit stop to stop table provides a view of the travel time to any other transit stop, from the location of interest. A few screen shots are shown as examples below

Transit Trip Times to Stops, Northeast City of Wilmington

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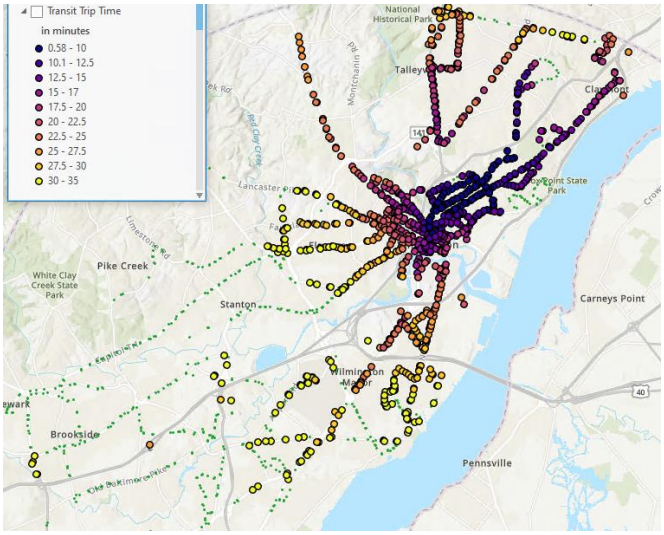
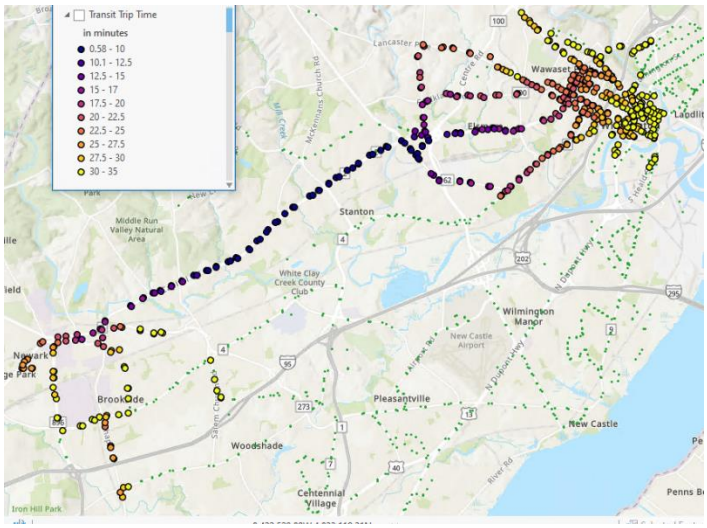


Trips less than 35 minutes, walking <= 10 minutes

Transit Trip Times to Stops, Kirkwood Highway Near Limestone (Rt 7) Road



Trips less than 35 minutes, walking <= 10 minutes

Transit Trip Times to Stops, from Newark Hub

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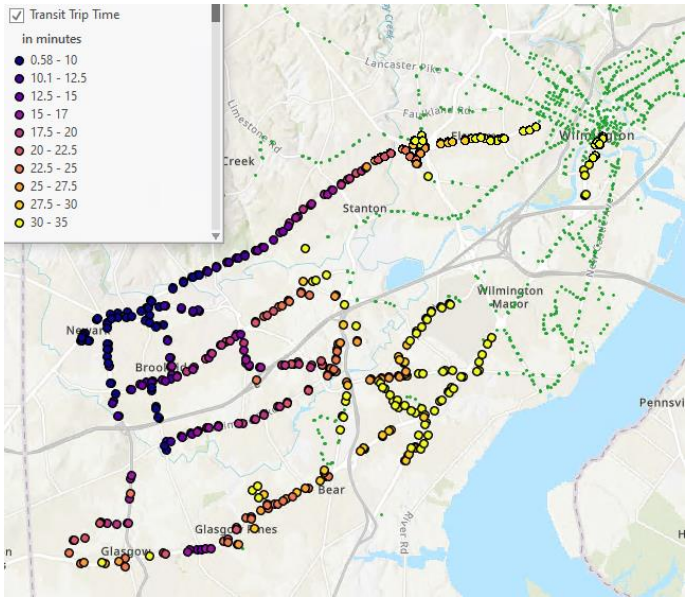
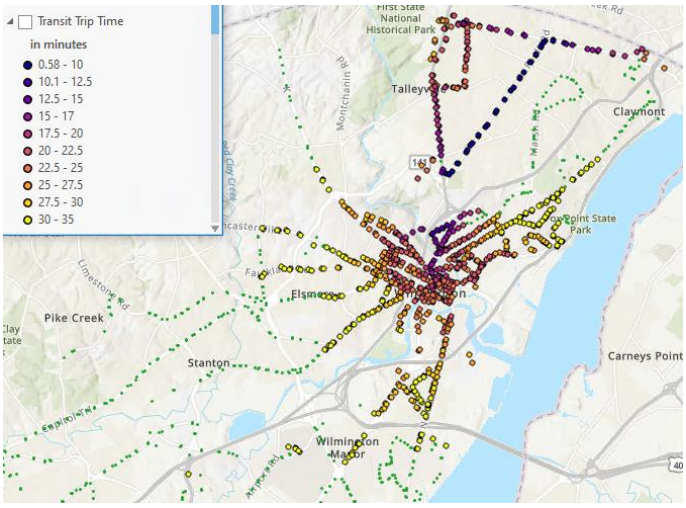


Trips less than 35 minutes, walking <= 10 minutes

Transit Trip Times to Stops, from Foulk Road



Trips less than 35 minutes, walking <= 10 minutes

Transit Trip Times to Stops, from Center of Dover

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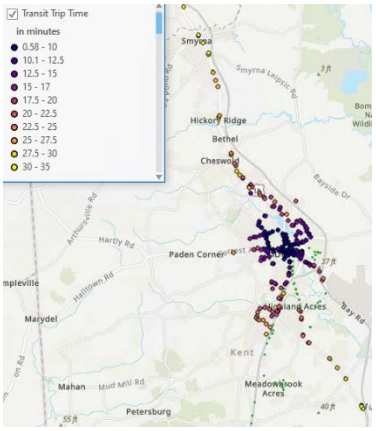

Trips less than 35 minutes, walking <= 10 minutes

Stop to Stop Routing Based on Arrival Times in the Schedule

In the approaches above, all stop to stop trips were checked every 5 minutes. Another approach is to use arrival/departure times from the transit schedule as in the GTFS file. The thought being that most of the time the departure would then involve minimum wait times since most trips would start immediately when the bus is scheduled to be at the origin stop. All stops are selected from the GTFS data that leave at a particular time, and the routing to all other stops is started at the scheduled times. A few hours of the day were examined in this way. For instance, to continue with the example stops above, in the table below the buses were scheduled to arrive at the times shown (7:02,7:08,7:33, 7:48)

Transit Trip Time Where Trip Starts At Scheduled Arrival

orig	dest	timeint	Total_Publ	Total_Walk
938	91	7:02:00	18.97	2.47
938	91	7:08:00	22.60	4.86
938	91	7:33:00	22.60	4.86
938	91	7:48:00	22.60	4.86

orig	dest	timeint	Total_Publ
938	91	7:02:00	18.97
938	91	7:08:00	22.60
938	91	7:33:00	22.60
938	91	7:48:00	22.60

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When compared to the 5 minute interval departure times approach below, leaving at 7:02 and the other scheduled times produce lower trip times as expected.

Transit Trip Times Every Five Minutes

orig	dest	timeint	hour	Total_Transit	TotalWalk Wait
938	91	0700	7	20.97	6.21
938	91	0705	7	25.60	8.60
938	91	0730	7	25.60	8.60
938	91	0745	7	25.60	8.60
938	91	0825	8	24.84	6.21
938	91	0835	8	22.52	9.70
938	91	0845	8	25.60	8.60
938	91	0905	9	20.47	6.21
938	91	0930	9	21.38	3.74

The trip times calculated from the schedule show more consistency as would be expected, as in the example below.

Transit Trip Time Where Trip Starts At Scheduled Arrival

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orig	dest	timeint	Total_Publ	Total_Walk
1022	2208	7:19:00	25.87	7.66
1022	2208	7:39:00	25.87	4.87
1022	2208	7:57:00	27.87	6.24
1022	2208	7:59:00	25.87	6.24
1022	2209	7:19:00	26.15	7.66
1022	2209	7:39:00	26.15	4.87
1022	2209	7:57:00	28.15	6.24
1022	2209	7:59:00	26.15	6.24
1022	2210	7:19:00	26.43	7.66
1022	2210	7:39:00	26.43	4.87
1022	2210	7:57:00	28.43	6.24
1022	2210	7:59:00	26.43	6.24
1022	2211	7:19:00	31.63	7.66
1022	2211	7:39:00	31.63	4.87
1022	2211	7:57:00	33.63	6.24
1022	2211	7:59:00	31.63	6.24
1022	2212	7:19:00	32.97	7.66
1022	2212	7:39:00	32.97	4.87

Routing using the scheduled times would not always produce the least time between stops. In the cases where the closest stop is not the best stop and a rider would need to walk to another stop, then optimum leave time would depend on the other stop departure times. Transfers could also complicate the situation. But in general, routing using the scheduled times would provide a better minimum time and that calculation has been partially completed. Checking routing for every minute of the day for every stop to stop pair would be the optimum approach though it is more compute intensive.

Evaluating Transit Accessibility Using the Stop to Stop Transit Trip Time Table

Having the stop to stop transit trip time table would allow estimates of accessibility by transit to be produced without repeating the routing operation. For instance, if one wanted to calculate the access to employment from any area, one could associate destinations with closest stops and then use the table to develop an overall measure. Access to any destination could be quickly determined and visualized. The examples above show trip time less than 35 minutes and up to 10 minute walk, but if a broader span or level of service is of interest, for instance, transit trips that involve access to stops by sidewalks and pedestrian facilities, the network routing could be done once and then used again and again. Users would not need to have the routing capabilities for analysis.

Example of Examining Transit Access

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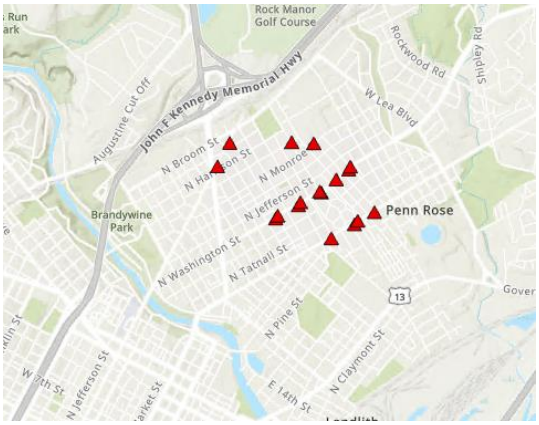
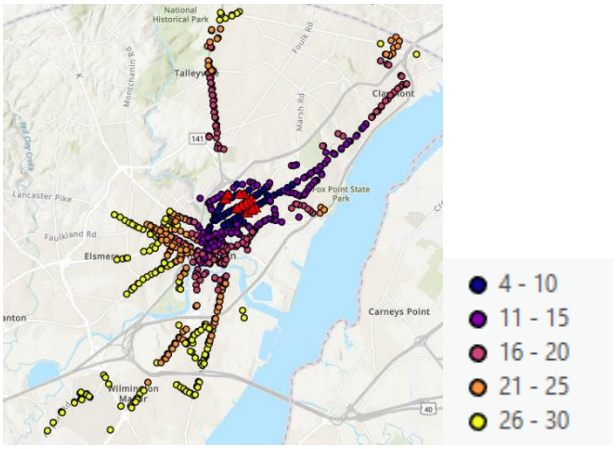


Transit access could be examined for one location but for this example we will look at local area as shown in the adjacent figure with the bus stops as red triangles. This is the northeast portion of the City of Wilmington. To estimate access for this area we can select all records in the stop to stop transit trip table where there are trip records for these northeast stops for all destinations within a 30 minute transit trip. We can then average the transit trip time by destination stop which can provide a view of destination stops that are reachable in 30 minutes as shown below and similar to pictures above for point locations.

Stops within 30 minutes of Northeast City of Wilmington



The stops shown above can then be compared to employment in proximity to estimate what is accessible. In this example employment locations 200 meters from stops. The table below shows accessible estimates of employment by category. The GIS functions for this analysis are simple to apply once the stop to stop trip table is available. The same type of approach could be used to examine accessibility to any critical destination of interest. The stop to stop table makes this much easier at a planning level to examine accessibility.

Selection of Employment Locations 200 Meters From Stops That Can Be Reached in 30 Minutes

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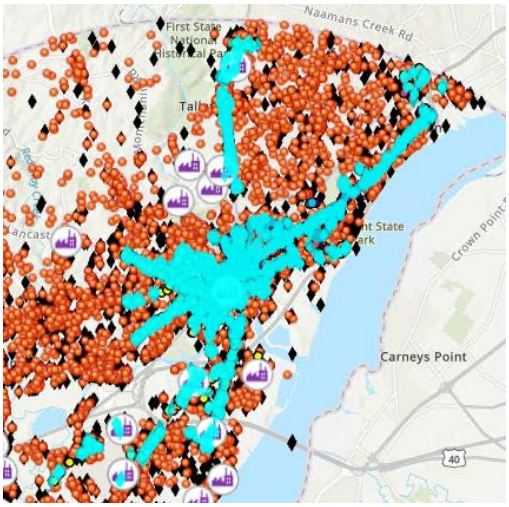

Employment Estimates By Type

Accessible to NW Wilmington within 30 Minutes Transit Ride

Agricultural	2
Agriculture	20
Beauty	319
Child Care	103
Community	7257
Construction	2
Contractor	729
Corporate	25
Eat Out	4412
Education	3076
Finance	3321
Financial	31
Government	768
Manufacturing	151
Media	445
Medical	2668
Place of Worship	36
Real Estate	130
Recreation	420
Rental	240
Retail	3425
Services	8892
Short Stop	7744
Store Basics	1687
Transportation	984
Utilities	165
Wholesale	331

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Door to door Housing Unit Level Transit Routing

Examining transit travel time at the housing unit level can involve significant computing. We probably aren't going to calculate the 12 billion routes for the over 400,000 housing units and around 30,000 non residential destinations in Delaware (but maybe). Performing the routing for transit trip time to destinations at the housing unit level was previously done in research where the computation was less due to there being only 200 destinations of interest, and the routing was only sampled for 2 times of the day. For small communities, or less destinations, housing unit level routing is preferable and accounts for local paths.

Door to door transit trip times between housing units and destinations could be done by adding estimates of top to stop travel times, as produced above, with estimated housing unit access times to bus stops. Assigning a housing unit to a particular transit stop for a particular destination would require a scan of nearby stops, as the best stop to go to a particular place wouldn't necessarily be the closest.

GTFS as a Format to Examine Network Changes

The GTFS format may be a convenient simple format for working with proposed changes to the network, as the production of the files needed seems straightforward and the incorporation into routing networks is fairly simple, and a standard so readily transferable. Mostly GTFS could provide a sufficient organization to build around.

GTFS Files

- agency
- calendar
- stops
- trips
- calendar_dates
- feed_info
- routes
- shapes
- stop_times

Summary

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- Facility with mapping transit accessibility encourages a better understanding of where the transit system serves relative to spatial data about where people want to go.
- Transit stop to transit stop routing simplifies computation of trip times while serving at a very good scale for general planning and visualization of services. Results of routing are incorporated into the table, and users can quickly look up estimates. Stop to Stop trip time tables provide accessibility measures for any transit stop location.
- The GTFS standard and data are useful in development of transit routing network and show promise as a target standard format for studying service changes or scenarios.
- Finding trip time estimates as measure for transit accessibility in some cases requires specification of departure time. Departure time very significantly affects an estimate of a reasonable trip time to use for estimating transit service. A solution is to route only where departure times coincide with the scheduled boarding thru the day, or to route for every 5 to 1 minute of each hour thru the day.
- Where destinations under consideration are small and/or the number of housing units are small, transit routing based on housing units provides an easily computed door to door estimate, and a useful small area evaluation of service. Determining optimum departure time can be a challenge with housing unit based routing.

Going Forward

Next steps in this area include:

- Communications with DTC and other transportation agencies to get suggestions or find other approaches.
- Refining stop to stop travel times either thru sampling based on scheduled times, or every one minute of the day. Also include longer transit trip access (45 minutes to an hour)
- Produce housing unit based accessibilities for some destinations
- Research into an Internet mapping approach to facilitate display of accessibilities.
- Incorporating consideration of frequency and coverage

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Addendum : Notes on GTFS Structure

November 3, 2021

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This memo briefly reviews the structure of the General Transit Feed Specification (GTFS).

Basic Components of the GTFS Transit Model

Shapes, are collections of points that can be built into trips and represent the geometric paths of trips. The 155,154 Shape points can be grouped into various collections and new shape points added if need be. Points with the same shape_id have a sequence assigned.

A selected set of shape points put together as a trip (stops are red triangles)

Shapes Table

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shapes

Field: Selection:

	OBJECTID *	Shape *	SHAPE_ID	SHAPE_PT_L	SHAPE_PT_A	SEQUENCE	LASTDISTANCE
1	1	Point	31873	39.737059	-75.549456	1	0
2	2	Point	31873	39.737479	-75.549233	2	0.0507
3	3	Point	31873	39.737655	-75.549683	3	0.0945
4	4	Point	31873	39.738367	-75.549247	4	0.1831

543 of 155,154 selected Filters:

There are 4,764 Trips in the August GTFS file and each are associated with a Route.

Trips Table

routes trips stop_times

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy Rows: Insert

	OBJECTID *	ROUTE_ID	SERVICE_ID	TRIP_ID	TRIP_HEADS	TRIP_SHORT	DIRECTION	BLOCK_ID	SHAPE_ID	WHEELCHAIR	BIKES_ALLO
1	1	5976	1	444585	Brandywine Town Cent	0	0	158012	31873	0	0
2	2	5976	1	444584	Brandywine Town Cent	0	0	158013	31873	0	0
3	3	5976	1	444583	Brandywine Town Cent	0	0	158020	31873	0	0
4	4	5976	1	444603	Brandywine Town Cent	0	0	158010	31873	0	0

0 of 4,764 selected Filters: 100%

There are 57 Routes and a Route can have many Trips, and so the path insn't necessarily the same for a particular heading of a route from time to time. For instance, route 5976 has 215 trips. And that includes more than one shape for the From and To headings of the route. 31873, 31874

Routes Table

routes trips stop_times

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy Rows: Insert

	OBJECTID *	ROUTE_ID	AGENCY_ID	ROUTE_SHOR	ROUTE_LONG	ROUTE_DESC	ROUTE_TYPE	ROUTE_URL	ROUTE_COLO	ROUTE_TEXT
1	1	5976	DART_DE	2	Concord Pike	0	3	0	FF0000	0
2	2	5977	DART_DE	4	W 4th Street / Govern...	0	3	0	008000	0
3	3	5978	DART_DE	5	Maryland Ave / Chris...	0	3	0	00FFFF	0

The access and routing is based on Stops, that have a graphic and tabular representation.

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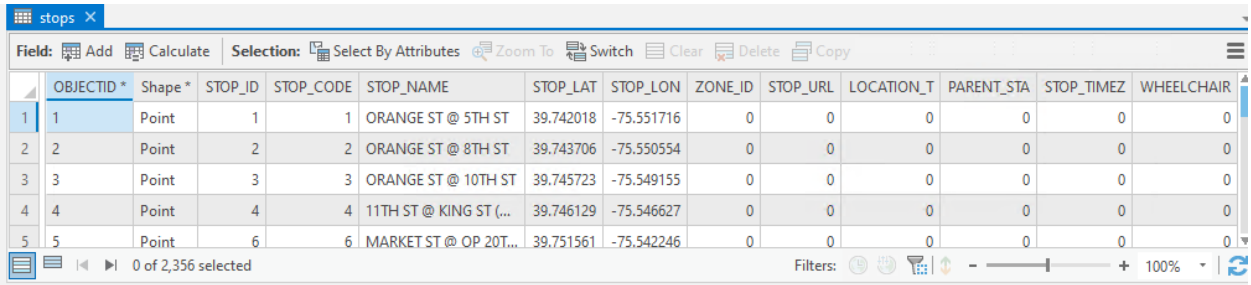
Stops Table



stops

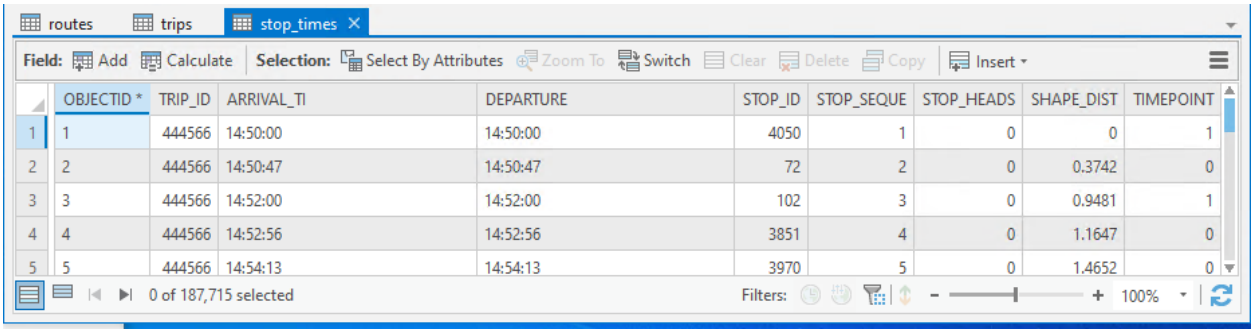
Field: Add Calculate | Selection: Select By Attributes Zoom To Switch Clear Delete Copy

	OBJECTID *	Shape *	STOP_ID	STOP_CODE	STOP_NAME	STOP_LAT	STOP_LON	ZONE_ID	STOP_URL	LOCATION_T	PARENT_STA	STOP_TIMEZ	WHEELCHAIR
1	1	Point	1	1	ORANGE ST @ 5TH ST	39.742018	-75.551716	0	0	0	0	0	0
2	2	Point	2	2	ORANGE ST @ 8TH ST	39.743706	-75.550554	0	0	0	0	0	0
3	3	Point	3	3	ORANGE ST @ 10TH ST	39.745723	-75.549155	0	0	0	0	0	0
4	4	Point	4	4	11TH ST @ KING ST (...	39.746129	-75.546627	0	0	0	0	0	0
5	5	Point	6	6	MARKET ST @ OP 20T...	39.751561	-75.542246	0	0	0	0	0	0

0 of 2,356 selected Filters: 100%

Everything is brought together with the Stop_Times table that includes arrival time at stops for every trip (187,000 records)

Stop_Times Table



routes trips stop_times

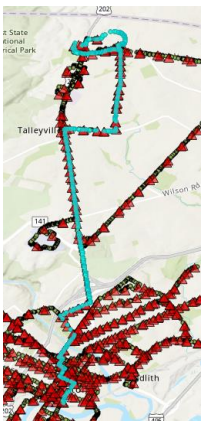
Field: Add Calculate | Selection: Select By Attributes Zoom To Switch Clear Delete Copy Insert

	OBJECTID *	TRIP_ID	ARRIVAL_TI	DEPARTURE	STOP_ID	STOP_SEQUE	STOP_HEADS	SHAPE_DIST	TIMEPOINT
1	1	444566	14:50:00	14:50:00	4050	1	0	0	1
2	2	444566	14:50:47	14:50:47	72	2	0	0.3742	0
3	3	444566	14:52:00	14:52:00	102	3	0	0.9481	1
4	4	444566	14:52:56	14:52:56	3851	4	0	1.1647	0
5	5	444566	14:54:13	14:54:13	3970	5	0	1.4652	0

0 of 187,715 selected Filters: 100%

Steps to Create New Transit Service

A Trip



To add service to the transit network one would first create a trip from a sequential set of shape points, then chart the bus stop arrival times for the trip. The trip would then be added to a route. Additional trips would be added if for various times of the day. The trips, routes, and stop_times tables would need to be appended. The shape and stop tables would need to be appended if there were new stops or new paths. Then the new GTFS file set would need to be built into an updated transit routing network. A similar process of updating the tables would be involved to change existing routes or arrival times.