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PRINCETON UNIVERSITY

POPULATION, LAND USE AND TRANSPORTATION STUDY OF PHILLYDELPHIA

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Abstract

The city of Phillydelphia is the hidden gem of the state of Pemmsylvania and is known for its history, culture, and beauty. With a busy population of students, workers,and elderly, the vibrant community is always bustling. Due to the plethora of resources, Phillydelphia is fully self sustained. All the food, space, jobs, and other needs can be met right in the city itself.

Recently, the city council commissioned a transportation study in order to assess the types of improvements to the transportation infrastructure that it could consider. Particularly, the city requested that the transportation demand be determined in order that the transportation systems could be adapted to the needs of the population.

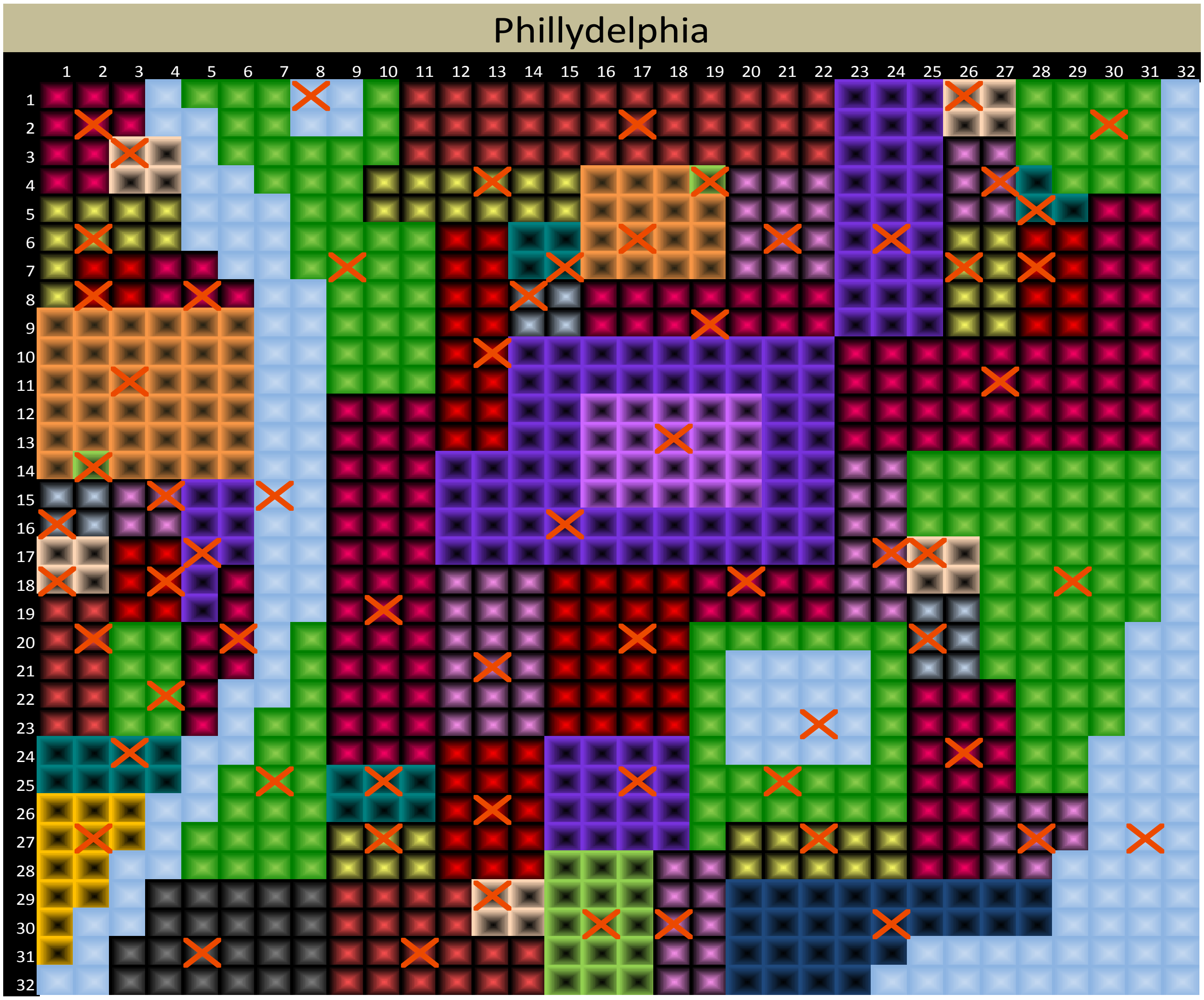
This project reports our finding about the population, the land use, and the transportation needs of Phillydelphia

Contents

Map

This is the Map of Phillydelphia. Below is a brief summary on interpreting it.

Map



(Figure 1 – WorkBook: Phillydelphia.xlsm, Worksheet: Map)

1	Recreational	10	Industrial
2	Restaurant	11	Hotel / Entertainment
3	Medical	12	Education: K - 12
4	Retail / Commercial	13	Education: University
5	Government Buildings	14	Sports Complex
6	Professional Buildings	15	Water
7	Residential - Low Income / Subsidized	16	Open space
8	Residential - Upper / Middle Class	17	Naval Base
9	Airport		

Map Overview

Phillydelphia is a perfectly square city whose boundary is 10.119 miles long and covers 102.4 square miles of space. Each square unit has boundary length of about 0.316 miles.

The different colored block units correspond to a particular land use. For instance, the red block designates a square area of restaurants. These similar block units in aggregate form our Traffic Assignment Zones. In our example, the red block units in aggregate form one TAZ of restaurants. In this city, we have 17 land uses ad 64 TAZ. Note that these land uses are not exclusive. That is, one block unit might actually contain another use (e.g. some areas marked as "Education: University" have both University attributes and Residential attributes). We simply assign one TAZ to these areas in the map for ease convenience of use and analysis.

The "X" marks on the map represent the centers of each of TAZ. These were calculated by averaging out the coordinates of the blocks that form each TAZ and placing it on the block unit closest to this average. These represent the "hub" of the TAZ where it is most dense with people and activity. Hence, this will be used as the coordinates in future distance calculations that will be made.

A neat feature of this map is that it can take into account the potential development of land (i.e. a particular block unit undergoing a change in its land use type.) On the accompanying Excel Spreadsheet, one simply has to change the key number in the block unit that is undergoing the development and the entire analysis will repopulate. It's a feature that allows us to update the map in real-time to reflect the state of Phillydelphia's land and have the most recent information.

We will delve deeper into the land use analysis in the Land Use Analysis section.

Population Analysis

The city of Phillydelphia is a perfect mix of a college town, a professional capital of the world, an industrial powerhouse, and a naval hub. It holds 250,000 residents and boasts much diversity as there are a variety of ethnicities represented in the city.

Primary Ethnic Identification	Percentage
Caucasian	35%
African American / Black	20%
Hispanic	12%
Asian	22%
Indian	8%
Native American	3%
Total	100%

(Figure 2 – WorkBook: Phillydelphia.xlsm, Worksheet: Writeup)

With its variety of land use and skills of the population, all the resources that any city would ever need can be found in Phillydelphia. Thus, Phillydelphia is entirely self-sustained. From computer manufacturers to farmers to professors to shoemakers, everything can be found in Philadelphia.

Excluding open space, Phillydelphia has 3,662 persons per square mile. This is comparable to the person per square mile measure of Washington, DC[1]. Including the open space, the average person per square mile measure is 2,441 which is comparable to Boise, Idaho.

Below is the breakdown of the population

Demographics and Population Needs

The most recent census data for Phillydelphia bucketed the residents into five categories:

Age Group Breakdown		
Type	**Residents**	**% of Type**
Children (0 to 5)	9,564	3.8%
Students (5 to 20)	78,934	31.6%
Employed Adults (21 - 66)	134,521	53.8%
Unemployed Adults (21 - 66)	10,746	4.3%
Seniors (66+)	16,235	6.5%
Totals	250,000	100.0%

(Figure 3 – WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

The population of Phillydelphia leans toward a younger more energetic demographic. With over a quarter of the population under 20 and over 90% under than 66, this city has a colorful and vibrant atmosphere. Only 4.3% of the population is unemployed which translates to about 7.4% of the actual pool of able workers. Both are below the national means.

The children aged 0 to 5 generally stay at home or go to daycare. They are irrelevant in our transportation analysis. Students attend either one of the 5 area elementary / middles / high school or one of the 2 universities. There are many productive workers in the city and most them have some sort of employment due to the city's vibrant economy that flourishes due to the amount of retail and professional firms in the city. Unemployed adults are generally jobless by choice (either not energized to seek work or resting on riches). There are enough posts in this economy to employ all able workers. There is also a minimal presence of seniors in this city. Seniors tend to leave due to the lack of services and

[1] http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_73a.pdf

accommodation available. In addition, this city has a reputation for being a young town so they tend stay away from what they perceive as "riff-raff."

A key characteristic of the city is that there is no homelessness; there is shelter for all residents. There are 5 main types of housing TAZ where residents can live:

Residential Breakdown			
Type	**Density (People / sq mile)**	**Residents**	**% of Type**
Residential - Low Income / Subsidized	9,500	62,700	25.1%
Residential - Upper / Middle Class	7,750	114,700	45.9%
Hotel / Entertainment	2,500	5,250	2.1%
Education: University	12,000	60,000	24.0%
Naval Base	2,722	7,350	2.9%
Totals		250,000	100.0%

(Figure 4 – WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

A quarter of the city lives in low income / subsidized housing. These include some students in University, recent graduates, the unemployed, and generally those in a lower pay class than others in the city. Although these areas are marked off as low income area, they are not dirty, rundown environments. These are well constructed, well-kept homes in neat areas that are equipped with all the necessities that a regular house should provide. The average size of a home in this area is about 965 square feet and the median cost is of ownership is about $85,000. Part of the reason that property values are a little lower is that the location of these homes are closer to less desired areas (farther inland, near industrial / heavily trafficked sites, etc.)

Most residents of Phillydelphia are affluent. About half of the population lives in areas determined to be Upper / Middle class. These are generally on the waterfront and nearby green space. These are also generally closer to the professional and governmental areas where they are employed so getting to work is quite easy and convenient. The average home size is about 2,600 square feet. The median home value in these areas is $450,000 and property taxes are on par with national averages.

Most of the university students in the city live in on-campus housing or areas immediately surrounding the university (which are stilled zoned as "Education: University"). Only about 5% of the students are commuters as these prestigious universities have enough money in the coffers to provide substantial aid and cheap housing to these students. The students in this town are smart and fun. They wisely realize that living on campus is conducive to a superior social experience.

There is also a number of individual living in hotels, motels, lodges, and other areas. This is a very small part of the population. Indications have been that these were residents of the nearby town, Paradise City. The rumor has been that these individuals have fled due to the iron rule of its totalitarian leader of state, Brett Leibowitz.

The naval officers and other seamen are also considered residents of Phillydelphia and mostly reside in the base and the surrounding areas. They have become an integral part of the community and many resident go into the Navy after school.

The average household size hovers around the national mean[2] at 2.6 individuals per household. That means that there is about 96,000 households in this city. Taking the residential space into account, this is about 3,500 household per square mile.

[2] The 2010 Census counted 2.57 per household. http://www.census.gov/population/socdemo/hh-fam/cps2003/tabAVG1.pdf

There are numerous educational options for this city's stellar academic community:

Student Breakdown			
Type	**Density**	**Students**	**% of Type**
Education: K - 12	8,102	16,204	20.5%
TAZ 2: St. Sebastian's Private School		3,241	
TAZ 10: Churchill High School		3,241	
TAZ 22: La Jolla Middle School		3,241	
TAZ 48: Edison Elementary School		3,241	
TAZ 59: Penn Prep		3,241	
Education: University	12,546	62,730	79.5%
TAZ 29: Teemple University		18,819	
TAZ 6: Dreexel University		43,911	
Totals		78,934	100.0%

(Figure 5 – WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

Students in kindergarten through high school can attend the area elementary, middle, and high schools. The city offers a public education but private educational tracks are available as well. The private elementary / middle school is St. Sebastian's and the private high school is Penn Prep. The public schools include Edison Elementary School, La Jolla Middle School, and Churchill High School.

Typically, 83% of high school graduates continue to university education which exceeds national averages. They either attend the public Teemple University (home of the Owls) known for its liberal arts and sciences or the private Dreexel University (home of the Dragons) known for its engineering and business schools. The student to faculty ratio at Dreexel is 15:1 while Teemple boasts an 11:1 ratio.

Most residents working in Phillydelphia are employed. There is only a 7.4% unemployment rate (which is below the national mean). The breakdown of where these individuals are working are below.

Employment Breakdown			
Type	**Density (Per Floor Space)**	**Employees**	**% of Type**
Recreational	245	3,381	2.5%
Restaurant	325	6,825	5.1%
Medical	275	3,850	2.9%
Retail / Commercial	215	9,417	7.0%
Government Buildings	750	18,000	13.4%
Professional Buildings	275	51,893	38.6%
Airport	200	1,200	0.9%
Industrial	550	14,520	10.8%
Hotel / Entertainment	250	5,250	3.9%
TAZ 32: Parx Casino			
Education: K - 12	263	1,575	1.2%
Education: University	150	4,500	3.3%
TAZ 29: Teemple University			
TAZ 6: Dreexel University			
Sports Complex	354	3,611	2.7%
TAZ 28: Teemple University Complex			
TAZ 27: Dreexel University Complex			
TAZ 51: Lincoln Financial, Citizens Bank Park, Wells Fargo Centers			
Naval Base	778	10,500	7.8%
Totals		134,521	100.0%

(Figure 6 -– WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

Since Phillydelphia is self-sustained, it has the capacity to provide sufficient employment across all job types. Recreational employment includes work at fitness centers, bowling alleys, golf courses, and other recreational sites. The hungry Phillydelphians create a booming restaurant industry. With about 5% of employees in the restaurant industry, it is a thriving business. Physicians, nurses, PTs and others in the medical field are quite strong in number as well. This is partly due to having two of the top medical schools in the nation at the Phillydelphia universities.

Government and professional employment (particularly in finance) make up the bulk of the employees in this city. These jobs are located generally in heart of the city. The aggregation of these two types of employment gives the feeling of a meshed D.C. and NYC.

There is a fairly strong industrial presence as well so that the city is supplied with its textiles, autos, and other manufactured items. Typically, high school graduates who do not attend university are employed here.

The city also has one casino in the northeast corner of the city. This generates a lot of revenue for the community and the funds are used to maintain low property taxes and bolster the educational system.

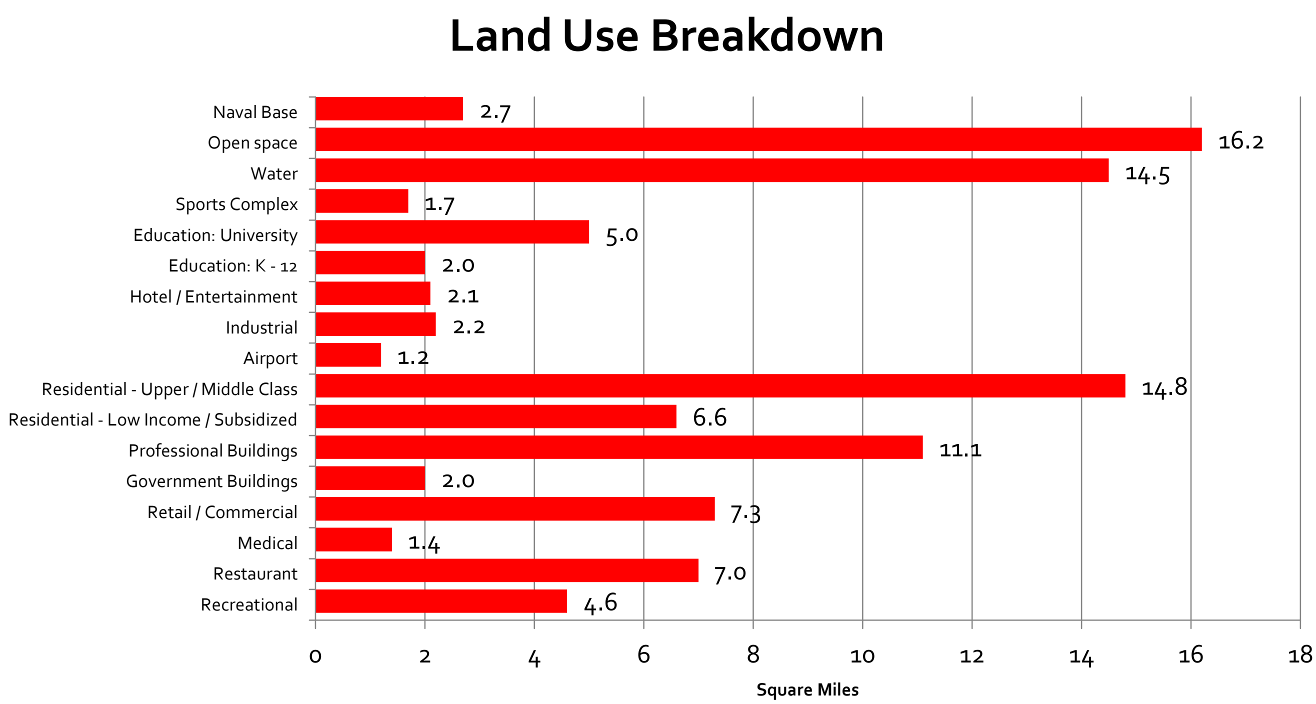
Naval Station Phillydelphia is found along the Delayware River on the southeast region of the city. This is an important shipyard where some of the Navy's most expensive and important assets are housed. In addition naval seaman are trained here.

Land Use Analysis

There are 17 fundamental uses for land including include residential, recreational, occupational, and educational types. As stated earlier, some of these areas have multiple uses (e.g. within areas designated as "Education: University", there are actual educational attributes as well as residential attributes). There are a total of 64 TAZ distributed within the city.

Land Use Distribution

The land has been extensively surveyed and since the units of each TAZ are in square blocks, it is quite simple to ascertain precisely how much land is being used for a particular purpose.



(Figure 7 – WorkBook: Phillydelphia.xlsm, WorkSheet: Breakdown)

We can see that undeveloped areas (water and open space) contribute to a significant amount of the total land use. These areas include parks, lakes, rivers, and trails that occupy the open space/ nature reserves. Such sites are attractions that help to more evenly (though not uniformly) spread the population throughout the city. With a more evenly distributed population, congestion is less sever and urban centers are more efficient.

Land Development Breakdown		
Type	**Area (sq. miles)**	**% of Land**
Developed	71.7	70.0%
Undeveloped	30.7	30.0%
Totals	102.4	100.0%

(Figure8 – WorkBook: Phillydelphia.xlsm, WorkSheet: Breakdown)

The Delayware River borders the city on the right and the Schoolkill River runs through the western part of the city. Both these rivers flow southward as they progress to the Atlantic Ocean. They have served as crucial waterways for transportation and commerce since the founding of Phillydelphia. In addition, there are green spaces and water in the city itself. Unfairmount Park in the northwest provides a scenic area of rest and relaxation. The Kelsy drive runs down the east of the Schoolkill. It is frequented by runners and mothers with strollers alike as it provides the perfect outdoor getaway.

There are other parks and water ways sprinkled all over the city that serve as a channel of transportation and an area of serenity and beauty when the city becomes too much to handle.

Land Area by Use				
Key	**Land Use**	**Area**	**% of Land**	**Use Count**
1	Recreational	4.6	4.49%	5
2	Restaurant	7.0	6.84%	7
3	Medical	1.4	1.37%	3
4	Retail / Commercial	7.3	7.13%	6
5	Government Buildings	2.0	1.95%	1
6	Professional Buildings	11.1	10.84%	4
7	Residential - Low Income / Subsidized	6.6	6.45%	3
8	Residential - Upper / Middle Class	14.8	14.45%	8
9	Airport	1.2	1.17%	1
10	Industrial	2.2	2.15%	1
11	Hotel / Entertainment	2.1	2.05%	4
12	Education: K - 12	2.0	1.95%	5
13	Education: University	5.0	4.88%	2
14	Sports Complex	1.7	1.66%	3
15	Water	14.5	14.16%	4
16	Open space	16.2	15.82%	6
17	Naval Base	2.7	2.64%	1
	Total	**102.4**	**100.00%**	**64**

(Figure 9 – WorkBook: Phillydelphia.xlsm, WorkSheet: TAZ)

Figure 9 shows that higher end housing complexes occupy much of the developed land in the city. In addition, there are 8 of them distributed throughout the city. These are typically found around the waterfront and close to professional centers. Conversely, there is less low income housing space since the need for them is low due to the affluence of the city as a whole.

It is interesting to note that 14% of all the land is marked as restaurant and retail zones. Once again, the wealthy denizens of this fair city have a penchant for spending their earnings and these restaurants and retailers are enjoying the patronage.

The Parx racetrack and casino is the main attraction for those seeking entertainment. Although it is quite removed from the other TAZ, it still attracts numerous residents. In addition, there are 3 sports stadiums which attract many people in the city. Both universities have a stadium to house it sports. In addition, the sports area in southern part of the city houses the complexes of all the major teams including the Phillydelphia Seagulls (football), Phillys (baseball), and the Seventy Seveners (basketball). There are numerous other recreational activities available in the city including movies, bowling paintballing, physical fitness activities, and much more.

In addition to looking at the square mileage of each type of land use, it is instructive to inspect the amount of floor space in each of these land use areas since that is the key driver of the number of people that are attracted to it.

Floor Space Breakdown			
Type	**Land Area**	**Avg Flr Space/Area**	**Avg Floor Space**
Recreational	4.6	3	13.8
Restaurant	7	3	21.0
Medical	1.4	10	14.0
Retail / Commercial	7.3	6	43.8
Government Buildings	2	12	24.0
Professional Buildings	11.1	17	188.7
Residential - Low Income / Subsidized	6.6	1	6.6
Residential - Upper / Middle Class	14.8	1	14.8
Airport	1.2	5	6.0
Industrial	2.2	12	26.4
Hotel / Entertainment	2.1	10	21.0
Education: K - 12	2	3	6.0
Education: University	5	6	30.0
Sports Complex	1.7	6	10.2
Water	14.5	1	14.5
Open space	16.2	1	16.2
Naval Base	2.7	5	13.5
Totals	102.4		470.5
Averages		6.0	

(Figure 10 – WorkBook: Phillydelphia.xlsm, WorkSheet: Breakdown)

The professional buildings have a significant amount of floor space. This industry is the driver of the economy in the city so this space is needed to carry out business. The retail / commercial land use also has a lot of floor space. Many multi-story retailers and stores abound in the city to satiate the purchasing needs of the town.

Land Use Design and Characteristics

The city was strategically planned so that the open space would serve as a protective barrier to rivers vulnerable to runoff of urban pollutants. All open space borders one of the 4 bodies of water, more than a third of the boundary of the river is protected by green space, and both of the lakes are surrounded by open space. In addition, zoning laws restrict industrial zones to the southwest corner of the city so that pollution does not affect city water.

The natural landscape also contributes to the economy of the city. In addition the many homes on the riverfront, many of the retail and commercial areas are located along the river. Riverfront hotels and riverfront recreational facilities serve as getaways that satiate the desire of the citizens to vacation.

Phillydelphia also provides all of its citizens with high accessibility to various destinations. The plethora of restaurants and the sports complexes provide accessible, low-cost getaways no more than 15 miles away from home. In fact, there are retail / commercial areas within 0.2 square miles of all but 1 residential area.

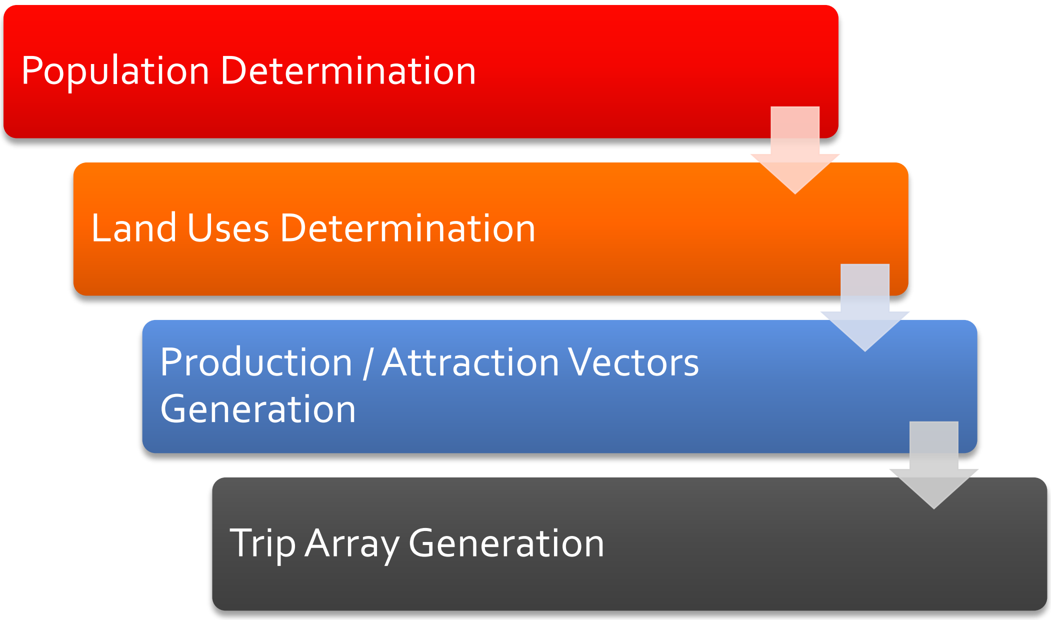
The heart of the city houses the bustling government seat and professional sector including many financial institution and big banks. This is a bustling center where decisions both impacting Phillydelphia and the world are made on a daily basis. The central location makes it accessible by the residents and it allows residents to reach any location fairly easily after work.

The universities are also a major factor in the personality of the city. With a university located on both sides of the Schoolkill River, there is a college type feel in over half of the city. The TAZ surrounding these universities were placed there to serve the needs of these students and to drive the economy.

The naval base is located on the southeast corner of the city which is known as Pemm's Landing. It houses a shipyard that has some of the navy's most important equipment and ships. The location is a crucial since it has easy access to Atlantic and there are numerous channels of transportation in and out of Phillydelphia..

Transportation Analysis

This goal of this project is to determine the transportation needs of the city. The logical approach to this is to figure out the trip distribution within the city. This starts with determining the population, which shapes the land use, which can then be used to determine trips. The general process to determine the transportation needs of a city includes:



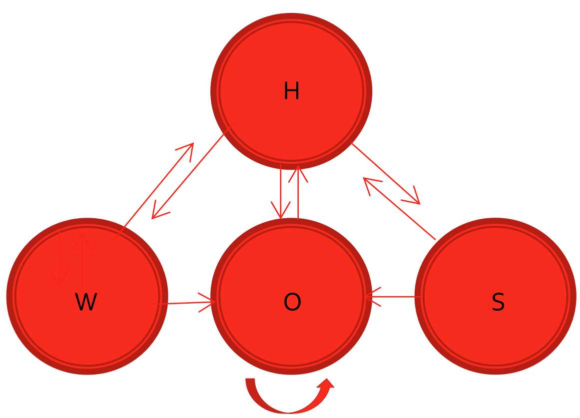
Thus far, we have assessed the population and determined (and rationalized) the land uses. The next step is to determine the trips. We can do this by figuring out the how many trips each TAZ produces and how many trips each TAZ attracts. We can then use this information along with the locations of each of these TAZ to determine which trips are made in the city and those trips' frequency.

Production - Attraction Generation

Trip - Type Purposes

Every trip has a source and a destination. In other words, each TAZ produces trips and attracts trips. In order to determine this production and attraction, we need to classify the types of trips in order that the movement of the residents is well defined. There are 9 main trip types:

- Home – Work
- Home – School
- Home – Other
- Work – Home
- Work – Other
- School – Home
- School – Other
- Other – Home
- Other – Other



Home to work includes all trips from residential areas (Figure 4) to a place of employment (Figure 6). Home to school includes all trips from residential areas to schools (Figure 5). Home to other includes all trips from Home to shops, recreational areas, restaurants, etc. The rest of the trips use these locations as a source or destination.

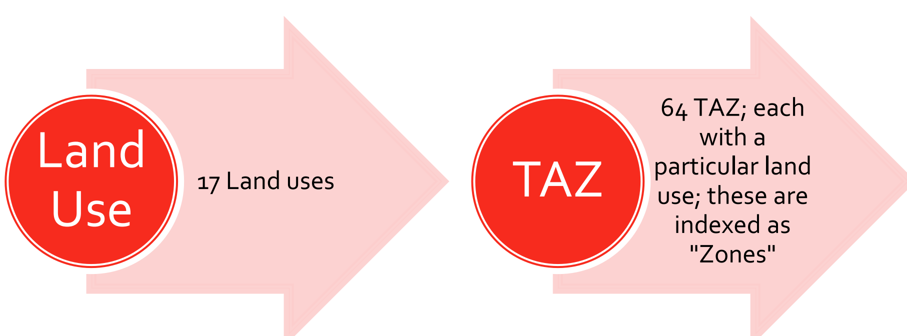
Further there are other assumptions that we can make about these trip types that help in the generation of the trips. Use the above graphic for visual reference:

- All the trips to work and to school are from home. We assume only one trip is made to work (for work purposes) or school (for education purposes; other trips might be made for social purposes) on a given day.
- Exactly 80% of the trips to school and to work that came from home, return home. Since all to work and to school trips are from home, 80% of those at work will return home and 80% of those at school will return home.
- The only other destination from work and from school is to other. Hence, 20% of those at work go to other and 20% of those at school go to other.
- There is no stipulation on how many people go from home to other. Individuals that returned to home from work or from school can make any number of these trips, individuals can initially start from home and make at trip of this type, and individuals that returned to home from other can make a trip of this type. Since there can be an infinite number of trips of this type we must be reasonable in our selection. (In my analysis, I just made the assumption that an individual going to home from somewhere would stop at on average one different other location. Hence, the number of Other – Other trips produced equals Other – Home)
- The number of individuals going from other to other is theoretically infinite as well. We must be reasonable in our assumption.
- The number of individuals going from other to home must be all the people that flowed into other. This is 20% of workers (home based workers that came to other), 20% of students (home based students that came to other), and the number of people that came to other from home.

Production Vector Generation

Using these guidelines, it is rather simple to generate the production and attraction values. We will represent these in a production vector (in which each element i refers to the number of trips produced from zone i) and attraction vector (in which each element j refers to the number of trips attracted to zone j). An easy check to make sure we are on right path will be to ensure that the sum of the production vector equals the sum of the attraction vector. This is sensible since each trip produced must have a destination (no one is just going for a cruise.)

First, let us clarify the levels of our map:



Hence, each TAZ has a type of land use as an attribute. This clarification is essential in understanding the analysis.

For the **Home – Work Production Vector**, we simply spread out the number of employed individuals among the various residential sources. There are exactly 5 residential land uses and 18 TAZ that can be a home source. For each of these TAZ, we have a Land Use. First, we figure out what how many people come from a certain land use as a proportion of total population, then figure out how many people come from the particular TAZ as a proportion of the total number of people that live in that land use, and multiply that by the number of employed people. We then apply this across the vector. Essentially we are weighting the number of employees in a structured way to determine where they came from. Generally:

$$\frac{Residents\ from\ Land\ Use\ of\ Interest}{\sum Residents\ from\ all\ Land\ Uses} \times \frac{TAZ\ Area}{Area\ of\ All\ TAZ\ with\ Same\ Land\ Use\ of\ Interest} \times \#\ of\ Employees = \#\ of\ Trips\ Produced$$

For instance, the first element of the production vector refers to the upper / middle class residential area in the northwest corner of the city. Since there are residential characteristics in this TAZ, trips will be produced from here. In order to compute the trips generated from here, we first determine the proportion of residents that lives in this land use type:

Residential Breakdown			
Type	**Density (People / sq mile)**	**Residents**	**% of Type**
Residential - Low Income / Subsidized	9,500	62,700	25.1%
Residential - Upper / Middle Class	7,750	114,700	45.9%
Hotel / Entertainment	2,500	5,250	2.1%
Education: University	12,000	60,000	24.0%
Naval Base	2,722	7,350	2.9%
Totals		250,000	100.0%

(Figure 11 – WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

$$\frac{Residents\ from\ Land\ Use\ of\ Interest\ (Residential\text{: }Upper/Middle\ Class)}{\sum Residents\ from\ all\ Land\ Uses} = \frac{114700}{250000}$$

Next we go to TAZ level and determine the proportion of people that live in this TAZ area as a percentage of the total number of people that live in that particular land use. In other words, how many people come from Zone 1 out of how many people across our city would come from a "Residential – Upper / Middle Class" TAZ. We believed that these values would be directly proportional to the area of the TAZ, so we conducted the calculations using "areas" instead of "residents":

TAZ Breakdown by Zone								
Zone #	**Key**	**Land Use**	**Pixels**	**Area**	**% of Land**	**x-coord**	**y-coord**	**% of Type**
1	8	Residential - Upper / Middle Class	10	1.0	0.98%	2	2	6.8%
2	12	Education: K - 12	4	0.4	0.39%	3	3	20.0%
3	1	Recreational	10	1.0	0.98%	2	6	21.7%
4	4	Retail / Commercial	4	0.4	0.39%	2	8	5.5%
5	8	Residential - Upper / Middle Class	5	0.5	0.49%	5	8	3.4%

(Figure 12 – WorkBook: Phillydelphia.xlsm, Worksheet: TAZ)

Land Area by Use				
Key	**Land Use**	**Area**	**% of Land**	**Use Count**
1	Recreational	4.6	4.49%	5
2	Restaurant	7.0	6.84%	7
3	Medical	1.4	1.37%	3
4	Retail / Commercial	7.3	7.13%	6
5	Government Buildings	2.0	1.95%	1
6	Professional Buildings	11.1	10.84%	4
7	Residential - Low Income / Subsidized	6.6	6.45%	3
8	Residential - Upper / Middle Class	14.8	14.45%	8
9	Airport	1.2	1.17%	1
10	Industrial	2.2	2.15%	1
11	Hotel / Entertainment	2.1	2.05%	4
12	Education: K - 12	2.0	1.95%	5
13	Education: University	5.0	4.88%	2
14	Sports Complex	1.7	1.66%	3
15	Water	14.5	14.16%	4
16	Open space	16.2	15.82%	6
17	Naval Base	2.7	2.64%	1
	Total	**102.4**	**100.00%**	**64**

(Figure 13 – WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

$$\frac{Residents\ from\ Zone\ of\ Interest}{Residents\ from\ All\ Zones\ with\ Same\ Land\ Use\ As\ Zone\ of\ Interest} = \frac{TAZ\ Area}{Area\ of\ All\ TAZ\ with\ Same\ Land\ Use\ of\ Interest} = \frac{1}{14.8}$$

We can then figure out the production numbers by using these weight on the total number of employees (134,521):

$$\frac{114700\ residents\ in\ Residential\ -\ Upper/Middle\ Class}{250000\ total\ residents} \times \frac{1\ sq.miles}{14.8\ sq.miles} \times 134521\ employees = 4170\ trips$$

We can apply this formula to the entire Production vector to figure out the number of trips from this source.

For the **Home – School Production Vector**, we take a similar approach. Now, instead of taking 134,512 employees and weighting them differently, we will take the total population of students.

$$\frac{Residents\ from\ Land\ Use\ of\ Interest}{\sum Residents\ from\ all\ Land\ Uses} \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} \times \#\ of\ Students = \#\ of\ Trips\ Produced$$

For the **Home – Other Production Vector**, we apply the same process. Now, we have more leeway in choosing instead of being restricted to using the population of employed people or students. A reasonable choice is $\frac{population}{1.5}$. In our city, about 167,000 trips will be made from home to other. This is viable because it reasonable accounts for the people that start their trip from home and go to other and that comes to home from another destination and then makes a trip to other.

$$\frac{Residents\ from\ Land\ Use\ of\ Interest}{\sum Residents\ from\ all\ Land\ Uses} \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} \times \frac{Population}{1.5} = \#\ of\ Trips\ Produced$$

The **Work – Home Production Vector** and **School – Home Production Vector** are simple because they are just 80% of the people who arrived at school or work via Home – Work and Home –School trips respectively.

$$\#\ of\ Trips\ Attracted\ Home - Work(or\ School) \times 0.8 = \#\ of\ Trips\ Produced$$

In the same vein, the **Work – Other Production Vector** and the **School – Other Production Vector** are just 20% of the attraction of Home – Work and Home – School trips respectively.

$$\#\ of\ TripsAttracted\ Home - Work(or\ School) \times\ 0.2 = \#\ of\ Trips\ Produced$$

The **Other – Home Production Vector** must be the sum of the people that flowed into other from home, from work, and from school. Hence,

$$(\#\ Trips\ Home - Work \times\ 0.2)\ + (\#\ Trips\ Home - Work \times\ 0.2) + (\#\ Trips\ Home - Other) = \#\ \ Trips\ Produced$$

Attraction Vector Generation

We will generate attraction vectors in a very similar fashion. Once again we will use $\frac{\text{TAZ area}}{\text{area of all TAZ with similar land use}}$ as a proxy for $\frac{\text{number of employees in a TAZ}}{\text{number of employees in Land Use of TAZ of Interest}}$. The **Home – Work Attraction Vector** is

$$Total\ Employees\ in\ Land\ Use\ of\ TAZ\ of\ Interest \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} = \#\ of\ Trips\ Attracted$$

Similarly, the **Home – School Attraction Vector** is

$$Total\ Students\ in\ Land\ Use\ of\ TAZ\ of\ Interest \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} = \#\ of\ Trips\ Attracted$$

The **Home – Other Attraction Vector** follows a similar process. Since this was a less constrained process we need to add some additional parameters. First we have the total number of tips (Const) is determined by $\frac{Population}{1.5}$. Also, we create an "Other Schedule" that provides the proportions of people that go form some source to an "Other" location.

Trip Destination Breakdown		
Type	**Propensity to Go From: Home, Work, School to Other**	**Other to Other**
Recreational	20.0%	22.5%
Restaurant	15.0%	22.5%
Medical	4.0%	1.0%
Retail / Commercial	30.0%	0.5%
Government Buildings	0.5%	0.5%
Professional Buildings	0.5%	0.5%
Education: University	1.0%	5.0%
Airport	1.0%	2.0%
Hotel / Entertainment	13.0%	29.5%
Sports Complex	8.0%	13.0%
Water	2.0%	2.0%
Open space	5.0%	1.0%
Totals	100.0%	100.0%

(Figure 14 – WorkBook: Phillydelphia.xlsm, Worksheet: Breakdown)

Now we can apply the formula to determine the attraction vector.

$$Const \times Propensity\ to\ Go\ From\ Source\ Type\ to\ Other \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} = \#\ of\ Trips\ Attracted$$

Since the trips attracted to home from school or work are 80% of the trips initially produced, The **Work to Home Attraction Vector** and the **School to Home Attraction Vector** are

$$\#\ of\ Trips\ Produced\ Home - Work(or\ School) \times\ 0.8 = \#\ of\ Trips\ Attracted$$

The **Other – Home Attraction Vector** is simply all the trips that came to the other from home, from school, and from other.

$$(Number\ of\ Trips\ Produced\ Home - Work + Number\ of\ Trips\ Produced\ Home - School) \times\ 0.2 + Number\ of\ Trips\ Produced\ Home - Other = Number\ of\ Trips\ Attracted\ Home$$

The **Work - Other Attraction Vector** and **School – Other Attraction Vector** uses the “Other Schedule” (figure 14) in order to make attraction assignments.

$$(.2 \times All\ Employees\ (or\ Students)\ ) \times Propensity\ to\ Go\ From\ Source\ Type\ to\ Other \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} = \#\ of\ Trips\ Attracted$$

The **Other - Other Attraction Vector** also uses the “Other Schedule” (figure 14) in order to make attraction assignments.

$$(Sum\ of\ All\ trips\ Produced\ in\ Other - Home\ ) \times Propensity\ to\ Go\ From\ Source\ Type\ to\ Other \times \frac{TAZ\ Area}{Land\ Use\ of\ Interest\ Area} = \#\ of\ Trips\ Attracted$$

This takes into the assumption that the number of trips produced in Other – Home is the same as Other – Other (which is reasonable.)

Now we can apply these formulas to all of the vectors to produce our P & A Arrays. Here are outputs for the first 5 zones.

	Home - Work		Home - School		Home - Other		Work - Home		School - Home	
Zone	P	A	P	A	P	A	P	A	P	A
1	4,170	0	2,447	0	5,167	0	0	3,336	0	1,958
2	0	315	0	3,241	0	0	252	0	2,593	0
3	0	735	0	0	0	7,246	588	0	0	0
4	0	516	0	0	0	2,740	413	0	0	0
5	2,085	0	1,223	0	2,583	0	0	1,668	0	979

	Other - Home		Other - Other		Work - Other		School - Other	
Zone	P	A	P	A	P	A	P	A
1	0	6,490	0	0	0	0	0	0
2	0	0	0	0	63	0	648	0
3	9,103	0	9,103	10,240	147	1,170	0	686
4	3,441	0	3,441	57	103	442	0	260
5	0	3,245	0	0	0	0	0	0

(Figure 15 – WorkBook: Phillydelphia.xlsm, Worksheet: P & A Vectors)

Information for all 64 zones can be found in **the P & A Vectors Tab** of the associated model workbook.

Here is a summary of our trips:

MyCity Comparisons																	
		Trips															
		Home-> Work	*Home-> School*	*Home-> Other*	*Work-> Home*		*School-> Home*		*Work-> Other*		*School-> Other*		*Other-> Home*	*Net Not Home*	*Other-> Other*	Total	
City Name	Population	#	#	#	#	% H->W	#	% H->S	#	% H->W	#	% H->S	#	#	#	#	#/Pop
Phillydelph	250,000	134,521	78,934	166,667	107,617	80%	63,147	80%	26,904	20%	15,787	20%	209,358	-	209,358	1,012,293	4.05

(Figure 16 – WorkBook: Phillydelphia.xlsm, Worksheet: Summary)

From this summary we can see that there are about 1 million trips made in this city which is about 4 trips per person in the population. The largest trip type is the Other – Home and the Other – Other which is expected. The lowest totals were in the Work – Other and School – Other categories which makes sense since only 20% of the employees and 20% of the students make this trip. Let us explore the next step of the actual trip generation to gather some key insight on these trips.

Trip Array Generation

Now that we have our production and attraction vectors, we can use them to generate our trip arrays.

Model

Essentially we will be running an algorithm that follows the gravity model[3]. The gravity model assumes that trips produced at an origin and attracted to a destination are directly proportional to the total trip productions at the source and the attraction at destination. It includes a "friction" or "disutility" factor (F) that marks the impedance of making the trip. These impedances will alter how attractive a particular zone is relative to any point in the city. In our city, we determined that distance is the key friction factor.

Essentially the gravity model assigns trips based on how attractive and how accessible a zone is.

$$T_{ij} = \frac{A_j F_{ij} K_{ij}}{\sum_{All\ Zones} A_k F_{ij} K_{ik}} \times P_i$$

Where:
T_{ij} = trips produced at i and attracted at j
P_i = total trip production at i
A_j = total trip attraction at j
F_{ij} = a calibration term for interchange ij (1/Distance^2) in our model.
K_{ij} = a socioeconomic adjustment factor for interchange ij
i = origin zone
n = number of zones

In this model, we assume $K_{ij} = 1$ so there is no optional adjustment factor.

We will model this in MS Excel which has the handy tools of Mmult and Transpose to deal with vectors and matrices. In addition, the capacity to implement Visual Basic Code will help cut down much of the manual and repetitive tasks.

We will apply this model across all the trip types to determine the trip arrays for each type of trip. Please, refer to the **Home – Work, Home – School, Home – Other, Work – Home, School – Home, Other – Home, Other – Other, Work – Other, School – Other** tabs to a) see examples of the explanation in order to follow the discussion below and b) see the actual results.

Overview of Trip Array Generation

Since we are modeling the impedance by using distance, we will first need to determine the distance between two zones in our city. We have found the effective centers of the TAZ by averaging out coordinates and marking the center of the closes block unit. We can use the coordinates of this center to obtain the Euclidean distance between two TAZ. If we are traveling in the same TAZ (trip produced at i is attracted to i), we can use the value of

$$\frac{1}{\sqrt{(TAZ\ Area)}}.$$

This can then be multiplied by 1.2 which is about the correct ratio of actual miles traveled over the road in this city. Note that this distance is still in units of model block lengths. We will convert to miles at the end.

[3] Descriptions are obtained from the outline provided the class

The next step is to compute the Friction Factor in going from i to j. This is just

$$\frac{1}{Distance^2}.$$

We can then multiply the impedance array (F) by the attraction vector (A) to figure out the total relative attractiveness of a particular TAZ (i.e. calculate the $\sum AF$ component).

$$S = F * A$$

Here are the first few outputs,

S = F * A

1	381
2	1120
3	1196
4	1953
5	656

(Figure 17a – WorkBook: Phillydelphia.xlsm, Worksheet: Summary)

We can then continue with the calculation and determine the remaining components of the model including P / S, A^T, (P / S)*A^T, and (P / S)*A^T * F, which is our initial trip array.

Ideally, we want each row i of the trip array to sum to the associated P_i and each column j to sum to the corresponding A_j. This would preserve our original production / attraction vector initializations. In our model, the rows will in fact sum to P_i; however, the columns do not sum to the associated attraction. Hence, we must calibrate the attraction vector with an adjustment factor in an iterative way so that we can obtain this conservation property.

$$A_j = \frac{A_j A_{j,(k-1)}}{C_{j,(k-1)}}$$

Where:
$A_{j,k}$ = adjusted attraction factor for attraction zone (col) j , iteration k
$A_{j,o}$ = A_j (note: k = o)
$C_{j,k}$ = actual computed attraction total for zone j, iteration k
A_j = desired attractions for zone j
k = iteration number

We must iterate until $C_{j,k} = A_j$. We used code to run the iterations and on average it took about 7 iterations to get to within .5% of the desired A. The shortest iteration count was 6 and the largest was 14 iterations. The code to generate this can be found in the appendix.

Using this adjusted attractions vector, we can determine the total trip distribution. That is, we have a matrix that tells us exactly how many trips were made from zone i to zone j (See T = Trip Distribution section under the "Apply…Adjusted Attraction Vector" Header – Cell CB346). Here is part of the array.

T = Trip Distribution = Q * F

	1	2	3	4	5	6	7
1	0	276	228	43	0	35	40
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	5	77	48	0	61	27
6	0	22	351	390	0	2973	673
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0

(Figure 17b – WorkBook: Phillydelphia.xlsm, Worksheet: Home - Work)

Now, we can figure how much distance is traveled as well, that is trip length distribution. Remember, we were working in units of unit block lengths. In order to convert from this measure to miles, we simply use the conversion factor of 0.316 to obtain the actual Distance Array (See D' section under the "Apply...Adjusted Attraction Vector" Header). We can then multiply the distance from i to j by the number of trips from i to j to determine the miles for each trip (See Triplength Distribution section under the "Apply...Adjusted Attraction Vector" Header).

Trip length Distribution (miles)

	1	2	3	4	5	6	7
1	0	148	346	98	0	121	210
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	11	106	54	0	84	91
6	0	66	679	468	0	1,759	1,375
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0

(Figure 17c – WorkBook: Phillydelphia.xlsm, Worksheet: Home - Work)

We can also determine the Person Trip Miles by dividing each distance traveled between i and j by the corresponding number of people moving from i to j. We use the number of trips from I to j as a proxy for the number of people moving from I to j since our assumption is that each trip is made by 1 individual (See PersonTripMiles section under the "Apply...Adjusted Attraction Vector" Header).

PersonTripMiles

	1	2	3	4	5	6	7
1	0.0	0.5	1.5	2.3	0.0	3.4	5.3
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	2.0	1.4	1.1	0.0	1.4	3.4
6	0.0	3.0	1.9	1.2	0.0	0.6	2.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(Figure 17d – WorkBook: Phillydelphia.xlsm, Worksheet: Home - Work)

The **Aggregation** tab of our model has all the trip information that reflects the aggregate of all the individual trip types.

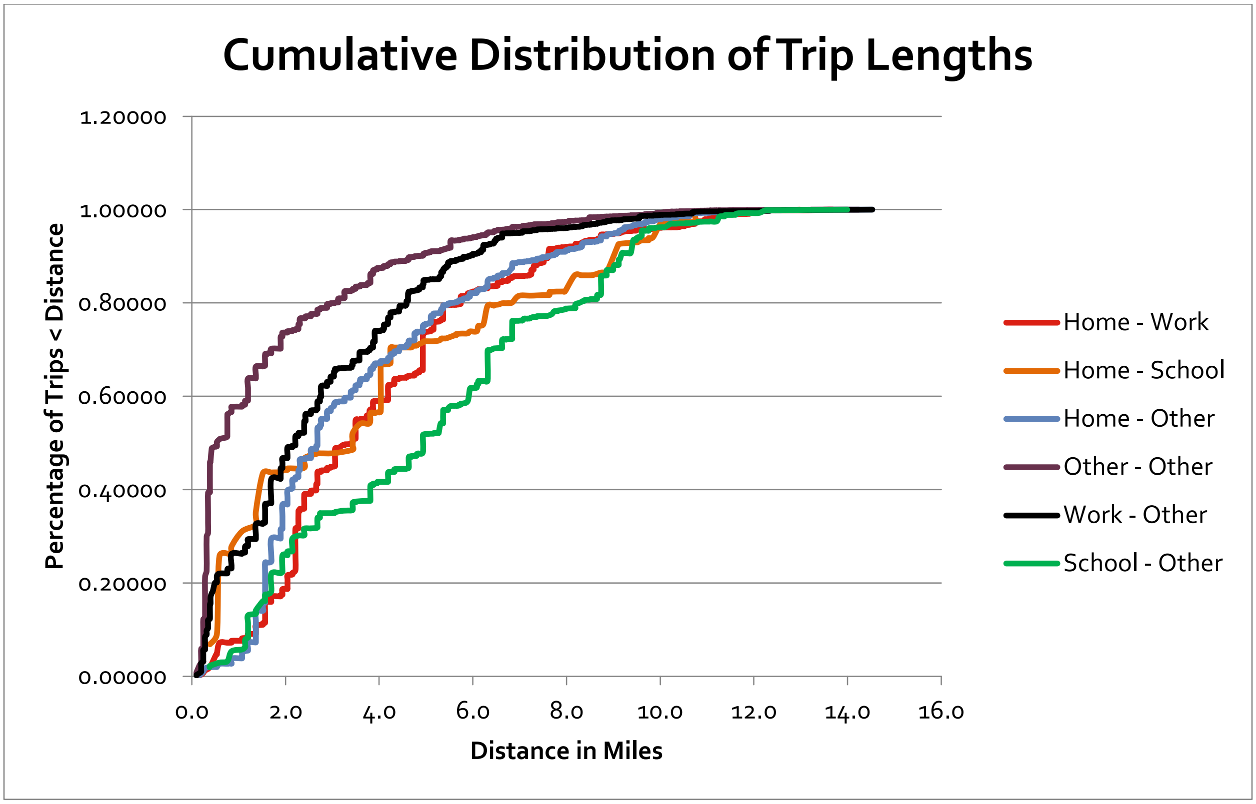
Now that we explained our methodology and took you through some examples, let us try to derive some insight from our findings.

Trip Demand

Figure 16 provided some very high level information about the trips in our city. We can now use the fleshed out model to draw some conclusions.

First we can look at the cumulative distribution of trip lengths. After combing through the data to find the data points with trip lengths > 0, we can determine how many trips are less than particular distances. This will serve as an indication of which types of trips are generally longer and which ones are generally shorter.

We can see the cumulative Distribution of trip lengths (we omit the trips home since they are directly proportion to the trips out and essentially redundant).



(Figure 18 - WorkBook: Phillydelphia.xlsm, Worksheet: Graph Data)

We can see that the trips from Other to Other are generally the shortest while the trips from School to Other are generally the longest. This makes sense because the schools are placed along the edges of the city whereas the "Other" attractions are interspersed throughout the city itself. In general, the to other trips are the shortest due to the central locations of these attractions.

It is interesting to note that the to school distribution initially starts off at a very short distance. This is due to the easy travel of the University student living on campus to class and other campus destinations. Travel then becomes generally longer as parents do have to travel farther to get their children to school. The fact that private schools are a bit removed from the residential areas explains the curve of this graph.

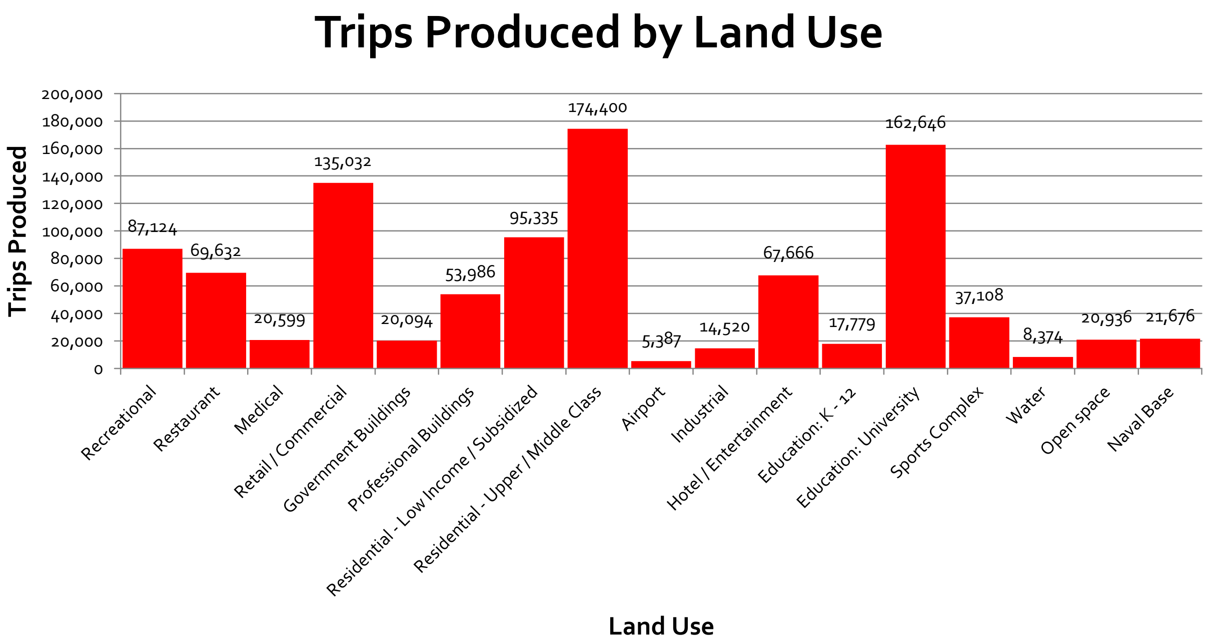
It is also informative to take a look at the distance by which certain percentages of trips are completed.

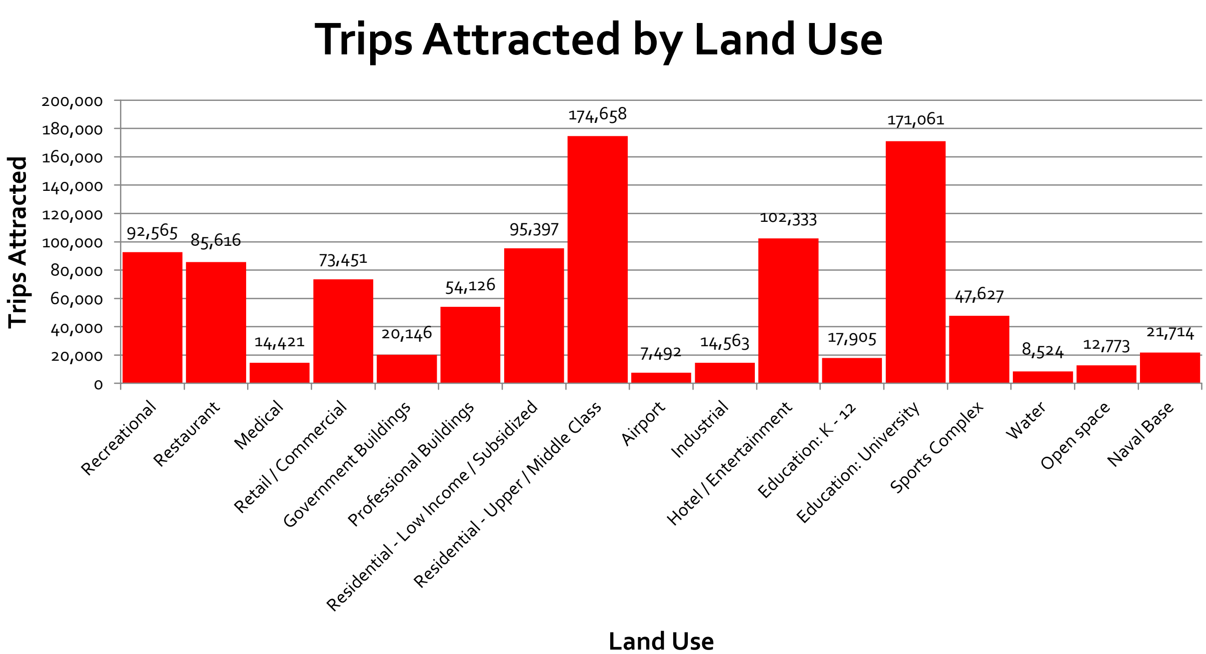
Trip Type	Average	At 90%
Home to Work	3.4	7.6
Home to School	3.4	8.9
Home to Other	2.7	7.6
Other to Other	0.5	4.8
Work to Other	2.2	5.9
School to Other	4.9	5.9

(Figure 19 - WorkBook: Phillydelphia.xlsm, Worksheet: Graph Data)

The Other to Other trips reach the average at just .5 miles. This means half the Other to Other trips are simply a half mile from the origin. The Home to Work trips seem to be the most linear. Half the trips are less than 3.4 miles, and about 90% are under 7.6 miles. These trips are generally longer than other trips. Although the densest areas of employment are at the heart of the city, there are still many trips that need to be made to all fringe areas as well (naval base, industrial, schools, etc.) This could explain the pattern seen in this graph.

We can delve further into which land uses produced and attracted much of the trips



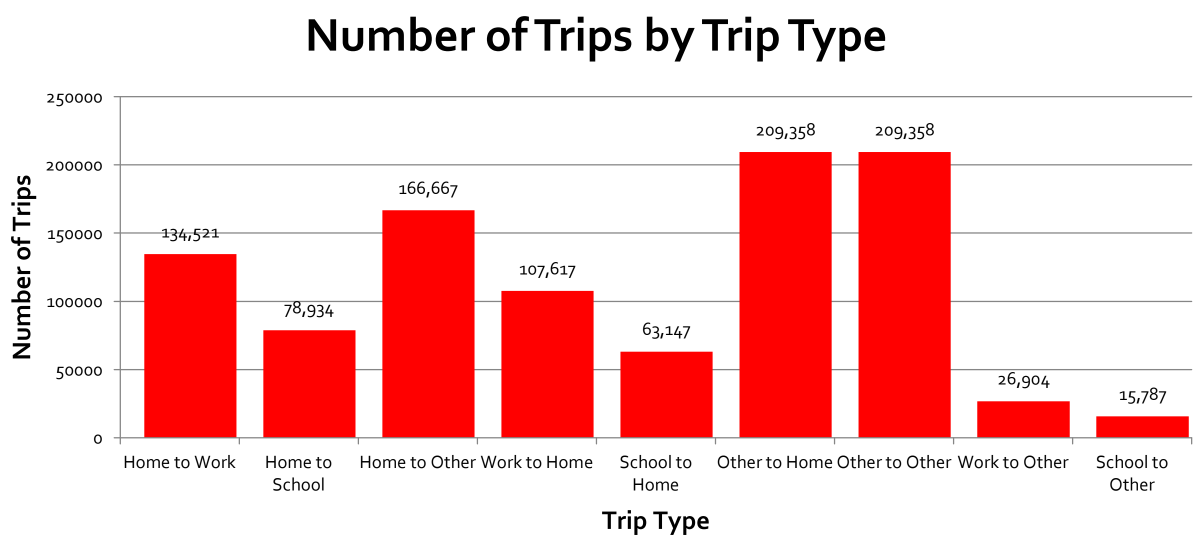


Summary

The **Aggregation** tab provides the high level stats. The **Graph Data** tab and the **9 individual trip type** tabs contain the drivers.

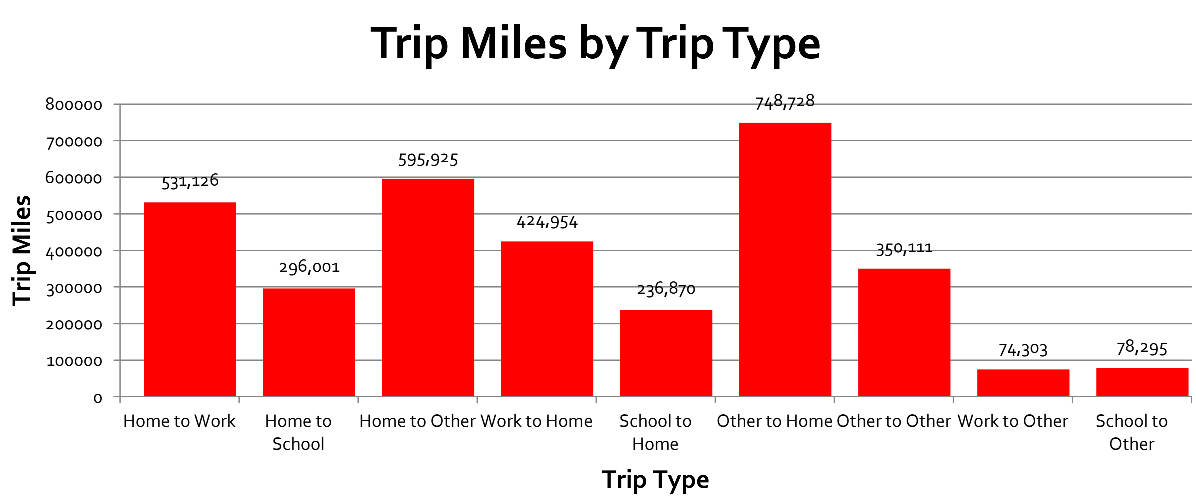
Total trips: 1,012,293

In a population of 250,000 residents, this is about 4 trips per person. This is a reasonable ratio (even when excluding the individuals in the population who cannot drive) since most of the city is employed or in school and must make a minimum of 2 trips per day. It is wholly conceivable that these individuals then make other trips before returning home or after returning home. In addition, the population of unemployed and elderly still need to make trips too.



(Figure 19 - WorkBook: Phillydelphia.xlsm, Worksheet: Graph Data)

Total Trip Miles: 3,336,312

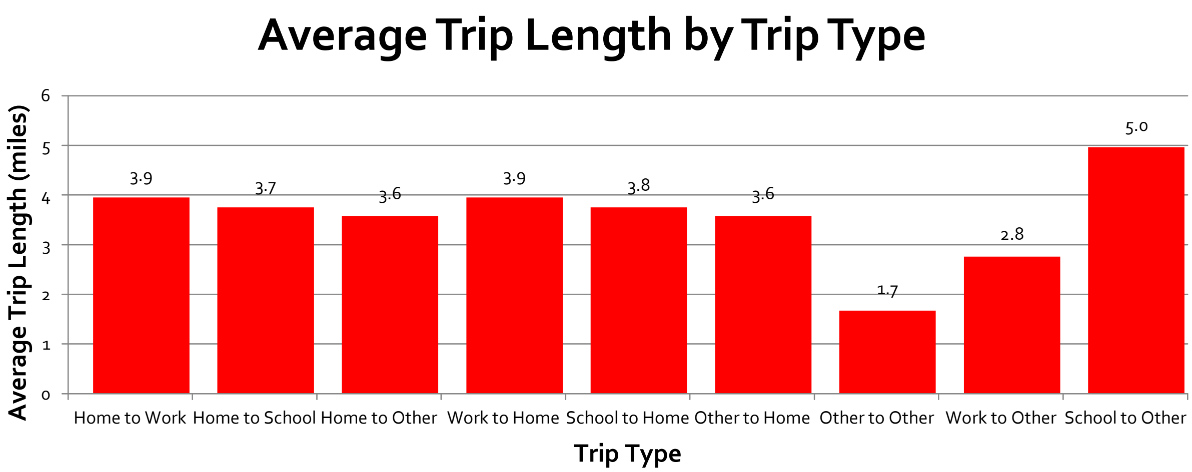


(Figure 20 - WorkBook: Phillydelphia.xlsm, Worksheet: Graph Data)

The total miles of all the trips is 3,336,312 miles. The trip type with the most miles attributed to it is from other to home. From home to other and from home to work are the next heavy users of miles. It is interesting to note that very few miles are driven from work to other and school to other. This makes sense because only 20% of employees / students make this trip.

We should expect to see the same trends in both the trip numbers and the trip miles. Comparing these two graphs, we see that the number of trips is good relative indicator of the number of miles that will be covered. This holds for every trip type besides the other to other. As noted in the design of the city, the "Other" attractions are placed quite close to many of the points on the map including numerous "Other" TAZ. Since quite a numbers of trips go from other to other and the mile cost of the trip is relatively low, the total trip miles for other to other is small. This is better indicated in the average trip length graph.

Average Trip Length: 3.29 miles.



(Figure 21 - WorkBook: Phillydelphia.xlsm, Worksheet: Graph Data)

The average trip length is 3.29 miles. On average drivers must drive the least when going from other to other. School to other is the longest distance on average which makes sense since the schools are located along the borders of the city. Conversely, work to other is fairly short on average due to the proximity of the "Other" attractions to the dense centrally located employment zones. All the other trips hover around the average. For these, the number of trips will determine the total miles traveled.

Further Analysis

Excel Model

Please refer to the excel model for further detail.

Here is brief explanation of the how the model works. I will explain Tab by Tab.

- Map: This has the map of our city. It is interactive in the sense that you change the key of the square blocks (cells) to another land use key. This will auto populate all relevant information about that TAZ and land use.
- Breakdown: This has all the relevant breakdowns of the city. This includes land use and area breakdowns, development breakdowns, residential breakdowns, floor space and employment breakdowns, student breakdowns, age breakdowns, and trip destination breakdowns. The blue numbers are the inputs that can be fiddled with. The black numbers are calculations – do not touch. Most values used in this model are driven from an estimated density of a region.
- TAZ: All relevant information about each TAZ can be found here including its key, its area, its coordinates, and more. There is also a land use table with more detail. Once again, blue numbers are tunable inputs while black numbers are calculations derived from the inputs.
- Summary provides the high level overview of the trips in the city.
- P & A Vectors show the generation of the Production and Attraction Vectors. There is greater detail within this tab on how some of the decisions about trips were made.
- 9 trip type tabs: Each of these tabs goes through the process of generating a trip array. This includes calculating the friction factor, generating an initial trip array, adjusting the attraction vectors until we get to a specified error threshold, then combing the trip matrices to aggregate all relevant trips (trips whose distances are greater than 0).
- Graph data: Provides the relevant data that are drivers for the graphs presented here. This includes the cumulative distribution of trip lengths and the trip breakdowns.
- Aggregation: Aggregates the 9 trip type tabs to view the data more holistically.

Other Avenues of Analysis

There are other avenues of analysis that we could have considered.

The friction factor ($1 / D^2$) and the distance calculations (1.2* Euclidean Distance and $\sqrt{area}$) are factors that can have substantial downstream effects. Our choice here essentially created the type of distribution that we saw. Perhaps we can look at other types of friction factors or more accurate distance calculations in order to come up with a better analysis. The best approach would be to look at historicals and ascertain our model assumptions and key drivers from that.

Appendix

Relevant Code

Generation of $A_{adjusted}$

```
'Calculating the Adjusted A's
Sub Iterate()

Dim Count As Integer
Dim Threshold As Double

Count = 0
Threshold = 0.005

While (Application.Max(Range("CI416:CI479")) > Threshold)
    Application.ScreenUpdating = False
    Range("CE416:CE479").Copy
    Range("CF416:CF479").PasteSpecial (xlPasteValues)
    Range("CG416:CG479").Copy
    Range("CD416:CD479").PasteSpecial (xlPasteValues)

    Count = Count + 1
Wend

    Application.CutCopyMode = False
    Application.ScreenUpdating = True
    Range("CL416") = "Count"
    Range("CM416") = Count
    Range("CL417") = "Max Abs Error"
    Range("CM417") = Application.Max(Range("CI416:CI479"))

End Sub
```

Generation of the X's

```
'Putting Xs on the Map
Sub MarkCenter()

For i = 1 To 64
    CurRow = ActiveCell.Row

    x = ActiveCell.Value
    y = ActiveCell.Offset(0, 1).Value

    Sheets("Map").Select
    Range("B3").Select

    ActiveCell.Offset(y, x).Select
    With Selection.Borders(xlDiagonalUp)
        .LineStyle = xlContinuous
        .Color = -16758292
        .TintAndShade = 0
        .Weight = xlThick
    End With
    With Selection.Borders(xlDiagonalDown)
        .LineStyle = xlContinuous
        .Color = -16758292
        .TintAndShade = 0
        .Weight = xlThick
    End With

    Sheets("TAZ").Select
    CurRow = CurRow + 1

    Range("H" + CStr(CurRow)).Select
Next i

End Sub
```

Compiling all the Relevant Trips and their Lengths

```
'Getting the Distances and putting the corresponding number of trips next to it
'START IN THE TAB YOU WANT TO DO....MAKE SURE YOUR "DEST_COL" is set correctly!!!
Sub Aggregate_DistAndTrips()

Dim Dest_RowVal As Integer
Dim Dest_ColLet As String

Dim Origin_Col_Start As String
Dim Origin_Dist_Row_Start As Integer
Dim Origin_Trips_Row_Start As Integer
Dim OriginCell_Dist As String
Dim OriginCell_Trips As String

Dim Trip_Tab As String
Dim Distance As Double

Trip_Tab = ActiveSheet.Name
Origin_Dist_Row_Start = 486
Origin_Trips_Row_Start = 348
Origin_Col_Start = "CD"

'SET THIS CORRECTLY
Dest_ColLet = "ES"

N = 64

Application.ScreenUpdating = False

For i = 1 To N
        Dest_RowVal = (i - 1) * 64 + 4

        Worksheets(Trip_Tab).Range(Origin_Col_Start + CStr(Origin_Dist_Row_Start) + ":" + Origin_Col_Start +
CStr(Origin_Dist_Row_Start + N - 1)).Offset(0, i - 1).Copy
        Worksheets(Trip_Tab).Range(Dest_ColLet + CStr(Dest_RowVal)).PasteSpecial (xlPasteValues)
        Worksheets(Trip_Tab).Range(Origin_Col_Start + CStr(Origin_Trips_Row_Start) + ":" + Origin_Col_Start +
CStr(Origin_Trips_Row_Start + N - 1)).Offset(0, i - 1).Copy
        Worksheets(Trip_Tab).Range(Dest_ColLet + CStr(Dest_RowVal)).Offset(0, 1).PasteSpecial (xlPasteValues)

Next i

Application.ScreenUpdating = True

End Sub
```