THE RESORT LAKE TRANSPORTATION MODEL

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EXCECUTIVE SUMMARY

Resort Lake is the largest city of a rural county, located between two big cities, Fentonville and Little Stone. The interstate 49 (I-49) connects Resort Lake with those two neighboring cities. The terrain is mostly flat, and the city is approximately 14 square miles in area. The city developed a four-step travel forecasting demand for the year 2010. The model was based on travel survey data gathered in 2000. The city is going experiencing a significant growth in population and traffic in recent years. Thus, it needs a new travel demand forecasting model. The current work involved developing a travel demand forecasting model of Resort Lake for the year of 2030. The forecasting model was developed, problem areas were analyzed, and solutions to those problems were proposed. All these action items were accomplished in five tasks. The first task involves updating and validating the 2010 transportation network. The data on transportation network of the city and demographic structure were collected: A GIS layer consisted the year 2000 transportation network and another layer, TAZ had the demographic and network structure information. The transportation network was modified to reflect the layout of the 2010 road network with changes proposed in the Resort Lake Regional Travel Forecasting Model (2010). The activity system data of the Traffic Analysis Zones (TAZs) were also updated in this step. The forecasting model divides the city into eight TAZs, having six internal and two external zones. There is one employment center (Zone 1), two residential zones with a retirement community of multi and single family housing (Zone 2 and 3), one small industrial area (Zone 4), and two new land subdivisions that will be developed for single family housing. One of the major improvements was upgrading the whole Shoreline Highway in a collector road, which was forecasted to generate high traffic activity. Several other modifications such as moving centroid and adding new link were also made on the network.

The second task was to develop skim trees for determining the shortest paths from zone to zone. The task started with a validation process by joining the links of the Gozark Avenue in zone 1. Development of the 2010 base year skim tree was started by creating the travel time matrix by selecting the internal and external centroids. The intrazonal travel time matrix was developed by assuming that the travel time is one half of the travel time to the nearest zones. The travel time to walk and from the vehicle was assumed as one minute which is known as terminal time. The combining value of the shortest path and terminal time matrix developed the skim tree. Skim tree maps provided the shortest paths from a selected centroid to the other zones. Therefore, skim tree maps were generated for all the eight internal and external centroids. The output of this task is needed for the trip assignment which is the fourth step of the transportation demand modeling process.

The overarching goal of Task 3 was to forecast the demand of travel in the TAZs. Using the estimated 60,000 trips data of Resort Lake in the year 2010 and activity pattern of each TAZ, a total of six trip generation models were developed: three trip production models and another three attraction models for three trip purposes, home-based work (HBW), home-based other, and non-home-based (NHB) trips were developed. A stepwise regression method and rational judgment were employed to select the explanatory variables. The models were then applied to the activity system data of six TAZs and trip ends were estimated. Since the trip production and attraction were estimated separately, the models estimate unequal production and attraction data. To overcome this, the zone trip ends were normalized using TransCAD's *Balance* tool. The balanced trips were validated by comparing with the observed trips from the travel survey in the year 2010 using mean absolute percentage error and root mean squared error. The results of the validation yield an MAPE value of 7.34% and RMSE value of 323.12.

In Task 4, trip distribution, the second step of transportation demand modeling, was carried out. A doubly constrained gravity model was used to estimate the production and attraction trips of each zone. The gravity model requires friction factors for measuring travel impedance which was calibrated from the 2000 Resort Lake travel demand model. Production- attraction trip matrix was generated for three types of trip purpose which were Home Based Work, Home Based Other and Non-Home Based. The production-attraction table was converted into an origin-destination (O-D) format to get actual directions of trips between the zones. The trip length frequency distribution was generated from the O-D table which explains that very few short distance trips were generated, and medium length trips were high. Input and output trip attractions by zones do not show much differences. Home Based Work trips covers the highest portion of interzonal trips. The percentage of trip by purpose along the day shows that at AM peak period, a large portion of trips mainly generated due to HBW purpose where most of the NHB trips generated at the off-peak period. Therefore, trip distribution model gives an idea of varying purposes of generating trips for different time interval.

Task 5 involved assigning trips to the transportation network. Using User Equilibrium via iterative assignment, the network flows for the Resort Lake, i.e., OD matrix generated in Task 4, were estimated. A network flow map combining v/c ration and traffic flow were generated. The map showed congested situation on the Shoreline Highway and a Western link of the Resort Blvd. The PM peak period flows were validated by comparing estimated and observed traffic flows. Three screenlines were generated on the network to find the estimated flows.

Task 6 generated three possible alternatives to transportation problems identified in the previous model years and recommends the best alternative evaluating their performance. To accomplish this goal, first travel demand for the year 2030 were forecasted using the validated trip generation models for the year 2010 from Task 3. Then, future trip distribution table were generated using the trip distribution models for the year 2010 from Task 4, and flows were following the trip assignment model from Task 5. A flow map of the city in 2030 showed that Shoreline will heavily be congested in future due to growth in tourist traffic and population growth outside city limits.

There alternatives were carefully chosen keeping in mind that Shoreline Highway will gain significant traffic and could lead to unstable flow and thereby hurting the economic potential of the city. A no build alternative scenario was developed to help with the three alternatives, each having a set of changes to the current transportation network. The first alternative was based on upgrading the capacity of existing network by adding a new link to Resort Blvd. that extends the road and a new lane on either direction at the Shoreline Highway. The second alternative proposed to upgrade the Shoreline Highway to major arterial that will have added capacity to handle the uptick in the traffic on its links. Finally, the third alternative was proposed considering a demand management strategy and capacity upgradation: A new transit system was proposed serving all the internal zones of the city. All three alternatives were compared based on roadway performance measures such as v/c ratio, traffic flow, travel time, VMT, and VHT. General cost estimates were developed by incorporating present values estimates for capital projects, operating costs, and maintenance costs for the three alternatives. Although alternative 3 was found to be the most ambitious project in terms of cost efficiency, it outperformed others on roadway performance measures. The current bottlenecks of traffic safety and air quality were considered in selecting the best strategy. Based on a thorough evaluation of the alternatives, alternative 3 was chosen to help Resort Lake mitigate its transportation bottlenecks and create a vibrant, healthy, and sustainable city.

However, the new alternative transportation system will likely face challenges in garnering ridership. Since the city has limited sidewalk, it presumably has a meagre number of active transportation users. Convincing the automobile users to ride transit will be a challenging task. Then again, a new transit system should be followed by proper changes zoning laws with the aim of supporting economic growth and ensure access to transit. To ensure the residents have access to transit, first/last mile strategies like sidewalk improvement, signage, urban design elements that improve walkability, like tree-lined streets, decorative sidewalks, human-scaled building, and murals may be considered. The city could start free-transit service to encourage residents to try transit.

Although a new transit system is likely to face a multitude of challenges, the strategies mentioned here could help overcome some of them. A strong public-private partnership is needed to create the right environment for transit to flourish. Public awareness campaigns could be organized to attract people to transit. Transit may not provide panacea to all transportation and land use problems of Resort Lake, but it is the right step towards solving those problems.

CHAPTER 1:
INTRODUCTION

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Resort Lake is the largest city of a rural county, located between two big cities, Fentonville and Little Stone. The interstate 49 (I-49) connects Resort Lake with those two neighboring cities. The terrain is mostly flat, and the city is approximately 14 square miles in area. The city developed a four-step travel forecasting demand for the year 2010. The model was based on travel survey data gathered in 2000. The city is going experiencing a significant growth in population and traffic in recent years. Thus, it needs a new travel demand forecasting model. The current work involved developing a travel demand forecasting model of Resort Lake for the year of 2030. The forecasting model divides the city into eight TAZs, having six internal and two external zones. There is one employment center (Zone 1), two residential zones with a retirement community of multi and single family housing (Zone 2 and 3), one small industrial area (Zone 4), and two new land subdivisions that will be developed for single family housing. One of the major improvements was upgrading the whole Shoreline Highway in a collector road, which was forecasted to generate high traffic activity. Several other modifications such as moving centroid and adding new link were also made on the network. Zones 5 and 6 are expected to be developed with single family homes. Moreover, the external zones 7 and 8 are going to be expanded which will increase the influx of tourists through the city. Accommodating the increased vehicle trips, the city needs to raise the capacity of the highway. However, increasing roadway capacity attracts more vehicle trips, eventually the vehicle miles of travel will increase. Increasing VMT values are not expected as it hampers the air quality and public health. Therefore, the city requires some changes to the transportation system to solve upcoming transportation and land use challenges.

Based on observed and project growth, the Resort lake network from the year 2000 needs to be updated. Upon reviewing the future growth of the zones, the city proposed the following network improvements:

1. Shoreline Highway was upgraded between 3rd Street and 5th Street and between 2nd Street and 3rd Street to a collector which made all of Shoreline Highway a collector.

2. A new section of 2nd Street was added between Resort Blvd and Gozark Avenue which acted as a local street. The position of the centroid connection for TAZ 4 got changed by linking the new connector with the new section of 2nd Street.

3. A new section of 4th Street was added extending from Resort Blvd to reach TAZ 5.

4. Gozark Avenue was extended into TAZ 5 which intersected with 4th Street and extended about a quarter mile past 4th Street. The terminus of the quarter mile segment of Gozark Ave was the starting point of the centroid connector for TAZ 5. All the centroid connectors have a length of 0.25 mile.

The city is going experiencing a significant growth in population and traffic in recent years. Thus, it needs a new travel demand forecasting model. The current work involved developing a travel demand forecasting model of Resort Lake for the year of 2030.

CHAPTER 2: METHODS AND RESULTS

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2.1: Task 1

2.1.1 Summary:

Resort Lake is the largest city of a rural county, located between two big cities, Fentonville and Little Stone. The interstate 49 (I-49) connects Resort Lake with those two neighboring cities. The terrain is mostly flat, and the city is approximately 14 square miles in area. The data on transportation network of the city and demographic structure were collected: A GIS layer consisted the year 2000 transportation network and another layer, TAZ had the demographic and network structure information. The transportation network was modified to reflect the layout of the 2010 road network with changes proposed in the Resort Lake Regional Travel Forecasting Model (2010). The activity system data of the Traffic Analysis Zones (TAZs) were also updated in this step. The forecasting model divides the city into eight TAZs, having six internal and two external zones. There is one employment center (Zone 1), two residential zones with a retirement community of multi and single family housing (Zone 2 and 3), one small industrial area (Zone 4), and two new land subdivisions that will be developed for single family housing. One of the major improvements was upgrading the whole Shoreline Highway in a collector road, which was forecasted to generate high traffic activity. Several other modifications such as moving centroid and adding new link were also made on the network.

2.1.2 Objective:

The objective of the first task was to develop, enhance and validate the base transportation network for resort lake. The development of the transportation network was done by updating the Transportation and Activity systems.

2.1.3 Approach:

The 2000 transportation network (Figure 1) is a partial grid of primary and secondary streets where the primary street serves the vehicles to enter and exit the City. The city is divided into six Traffic Analysis Zones (TAZs). The City has two external zones, Zone 7 and Zone 8, connecting the City with Little Stone and Fentonville respectively (*1*).

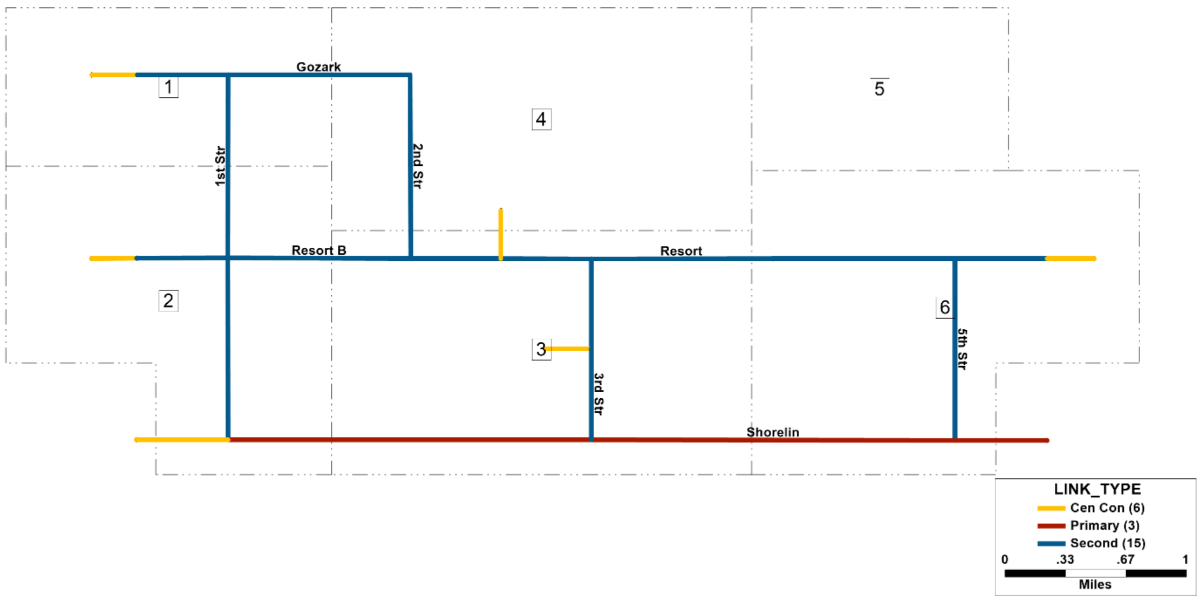


Figure 1. Resort Lake network year 2000

Based on observed and project growth the Resort lake network from the year 2000 was updated (Figure 2). Upon reviewing the future growth of the zones, the city proposed the following network improvements:

1. Shoreline Highway was upgraded between 3rd Street and 5th Street and between 2nd Street and 3rd Street to a collector which made all of Shoreline Highway a collector.
2. A new section of 2nd Street was added between Resort Blvd and Gozark Avenue which acted as a local street. The position of the centroid connection for TAZ 4 got changed by linking the new connector with the new section of 2nd Street.
3. A new section of 4th Street was added extending from Resort Blvd to reach TAZ 5.
4. Gozark Avenue was extended into TAZ 5 which intersected with 4th Street and extended about a quarter mile past 4th Street. The terminus of the quarter mile segment of Gozark Ave was the starting point of the centroid connector for TAZ 5. All the centroid connectors have a length of 0.25 mile.

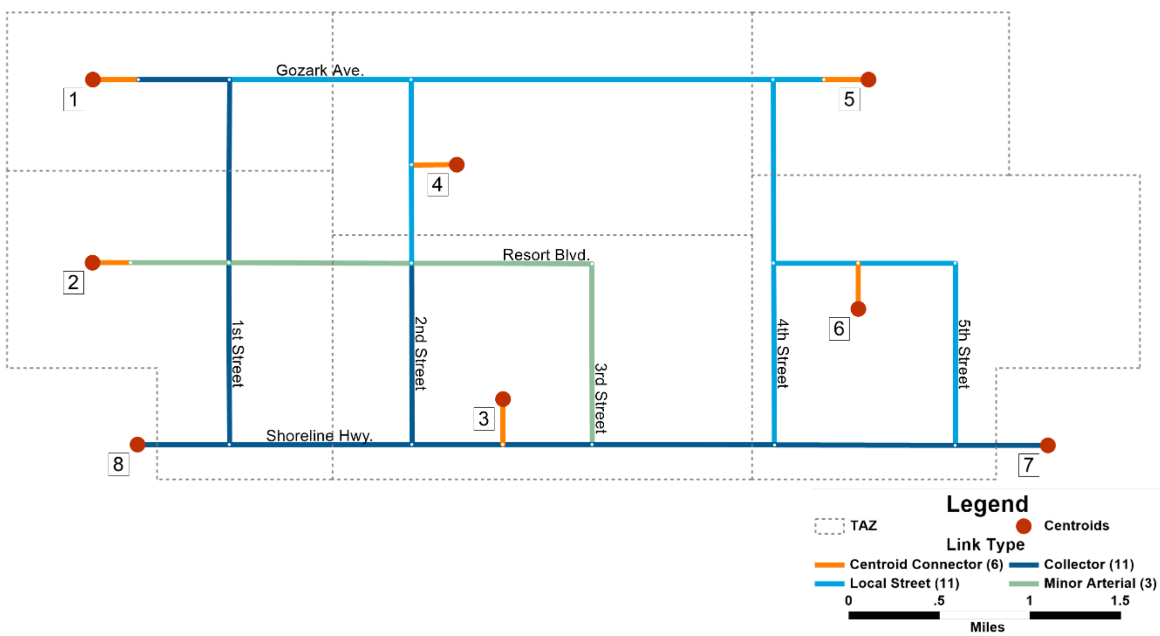


Figure 2. Updated base year Resort Lake network

The updated base year Resort Lake network is a combination of collector and local streets where a single minor arterial serves as an entering the exiting street of the City. The facility characteristics (e.g., speed, lane numbers, capacity, color of the link) was changed according to the project description (*1*) (Table 1)

Table 1. Resort Lake Transportation Network Characteristics

Link Type	Speed (mph)	Lanes	Capacity per Lane (vehicles per hour)	Legend Color
1.Freeway	60	2	1800	Red
2.Primary Arterial	60	2	1200	Yellow
3. Major Arterial	45	2	900	Dark Green
4.Minor Arterial	45	1	600	Light Green
5.Collector	30	1	600	Dark Blue
6.Local Street	15	1	300	Light Blue
7.Centroid Connector	25	9	1000	Orange

2.1.4 Results:

Travel time of each link was calculated by dividing the length of the link with the assigned speed (Table 2). Same procedure was followed for both direction of a link. The travel time is same in both direction as the link length and the speed are same.

Table 2. Resort Lake transportation network data

ID	Direction	Group code	Link Type	Length	AB/BA Speed (mile/h)	AB/BA Lanes	AB/BA Capacity (vehicles per hour)	Road Name	AB/BA Travel Time (min)
2	0	7	Centroid Connector	0.25	25	9	9000		0.6
7	0	5	Collector	0.50	30	2	1200		1
8	0	5	Collector	0.50	30	2	1200	Shoreline	1
9	0	5	Collector	1.00	30	2	1200	Shoreline	2
10	0	5	Collector	1.00	30	2	1200	Shorelinee	2
11	0	5	Collector	1.00	30	1	600	1st Str	2
13	0	6	Local Street	1.00	15	1	300	5th Str	4
14	0	7	Centroid Connector	0.25	25	9	9000	Resort B	0.6
15	0	4	Minor Arterial	1.00	45	1	600	Resort B	1.33
17	0	4	Minor Arterial	1.00	45	1	600	Resort B	1.33
21	0	5	Collector	1.00	30	1	600	1st Str	2
22	0	6	Local Street	0.50	15	1	300	2nd Str	2
24	0	5	Collector	0.50	30	1	600	Gozark	1
25	0	6	Local Street	1.00	15	1	300	Gozark	4
29	0	4	Minor Arterial	1.00	45	1	600	3rd Str	1.33
30	0	5	Collector	0.50	30	2	1200	Shorelin	1
31	0	5	Collector	1.00	30	1	600		2
32	0	5	Collector	1.00	30	2	1200	Shorelin	2
33	0	6	Local Street	1.00	15	1	300		4
34	0	6	Local Street	0.50	15	1	300	Resort B	2
35	0	6	Local Street	0.50	15	1	300	Resort B	2
37	0	5	Collector	0.50	30	2	1200	Shoreline	1
40	0	6	Local Street	0.50	15	1	300	2nd Str	2
41	0	7	Centroid Connector	0.25	25	9	9000		0.6
42	0	7	Centroid Connector	0.25	25	9	9000		0.6
44	0	6	Local Street	2.00	15	1	300		8
45	0	6	Local Street	0.25	15	1	300		1
46	0	6	Local Street	1.00	15	1	300		4
47	0	7	Centroid Connector	0.25	25	9	9000	Gozark A	0.6
48	0	7	Centroid Connector	0.25	25	9	9000		0.6
49	0	6	Minor Arterial	0.50	45	1	300	Resort B	0.67

2.2 Task 2

2.2.1 Summary:

The purpose of the task was to develop skim trees for determining the shortest paths from zone to zone. The task started with a validation process by joining the links of the Gozark Avenue in zone 1. Development of the 2010 base year skim tree was started by creating the travel time matrix by selecting the internal and external centroids. The intrazonal travel time matrix was developed by assuming that the travel time is one half of the travel time to the nearest zones. The travel time to walk and from the vehicle was assumed as one minute which is known as terminal time. The combining value of the shortest path and terminal time matrix developed the skim tree. Skim tree maps provided the shortest paths from a selected centroid to the other zones. Therefore, skim tree maps were generated for all the eight internal and external centroids. The output of this task is needed for the trip assignment which is the fourth step of the transportation demand modeling process.

2.2.2 Objective:

The goal of task 2 was to compute a travel time matrix for demand forecasting and to use the skim trees to check the errors of the network.

2.2.3 Approach:

Validation of the Network

The validation of the network was done by joining the links of Gozark Avenue (Figure 3). The change in the network allowed the Gozark Avenue to connect with the centroid of zone 1.

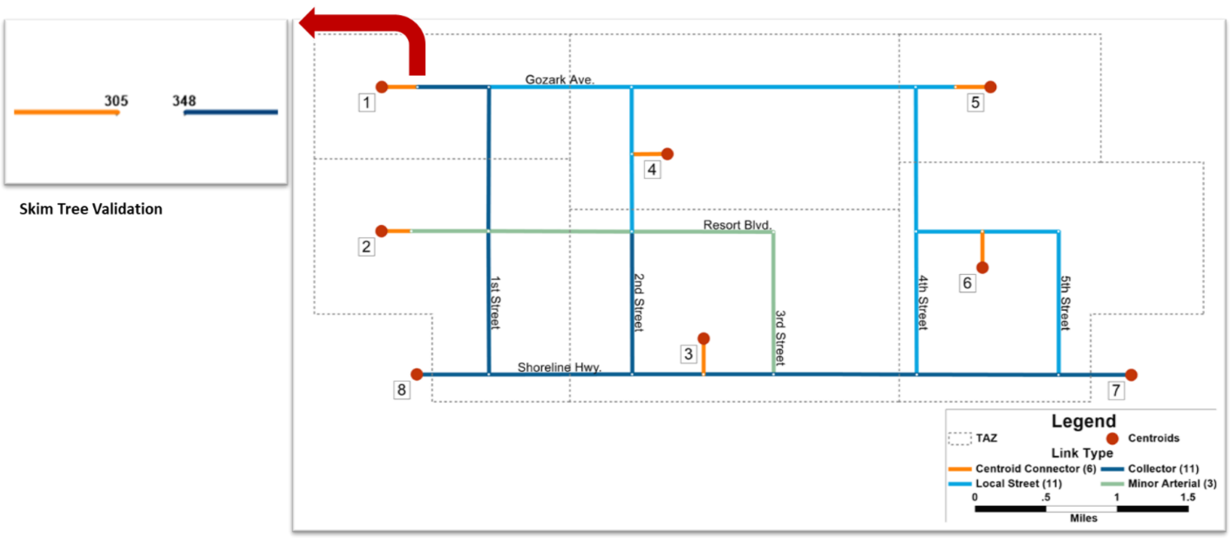


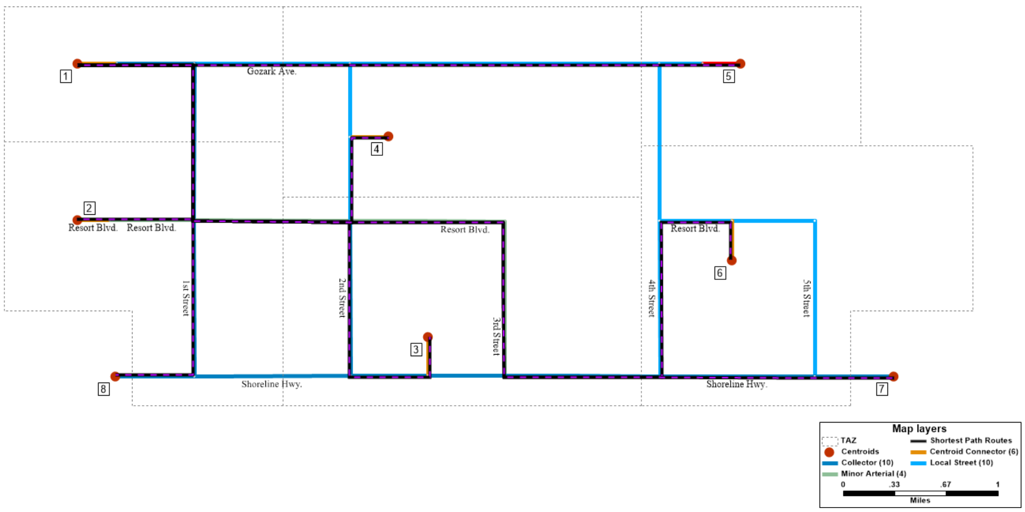
Figure 3. Validation of the network

Developing Skim Tree

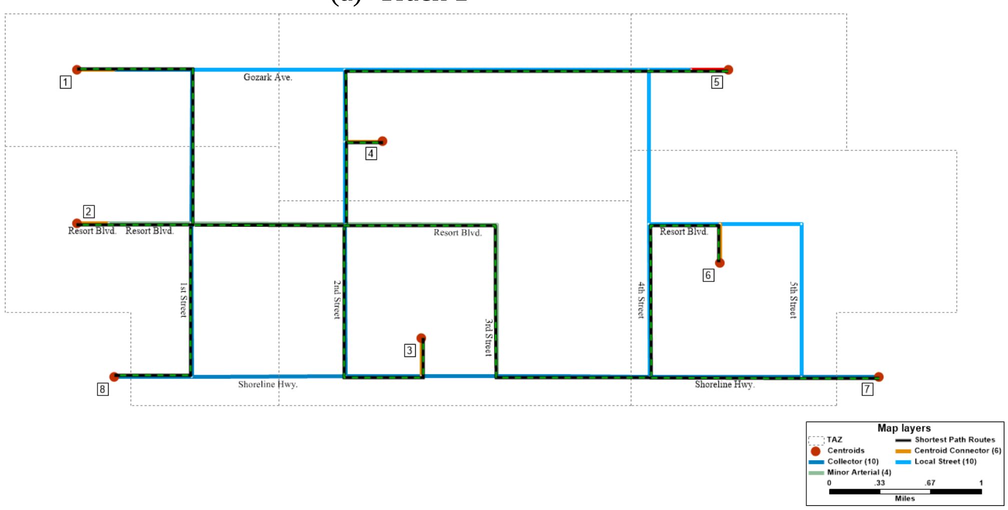
Skim tree is an algorithm to calculate the set of shortest routes from an origin to all other points in a network. The times on the individual links comprising the minimum time route was added to obtain the travel time between a pair of zones, and this is repeated for every pair of zones. A 'skim tree' usually refers to the matrix of interzonal travel time (*6*). Skim trees for each centroid (1 to 8) were developed graphically. (Figure 4 (a-h))

Shortest Path Travel Time and Terminal Time

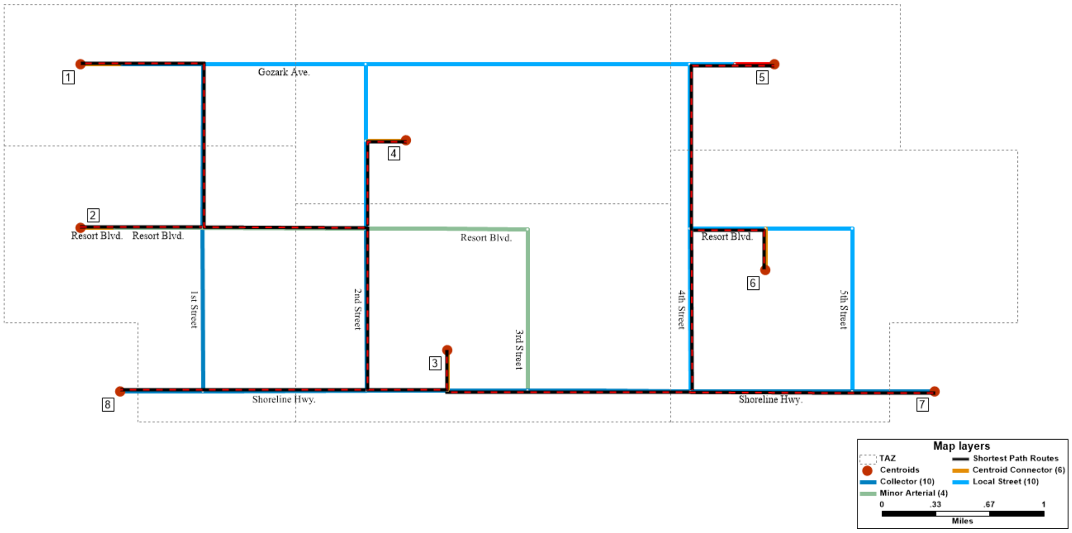
The interzonal travel time was assumed to be one -half of the travel time to the nearest zone. The terminal time of walking to and from the vehicle were assumed 1 minute. Thus, the interzonal shortest path and the terminal time combinedly generates the skim tree.



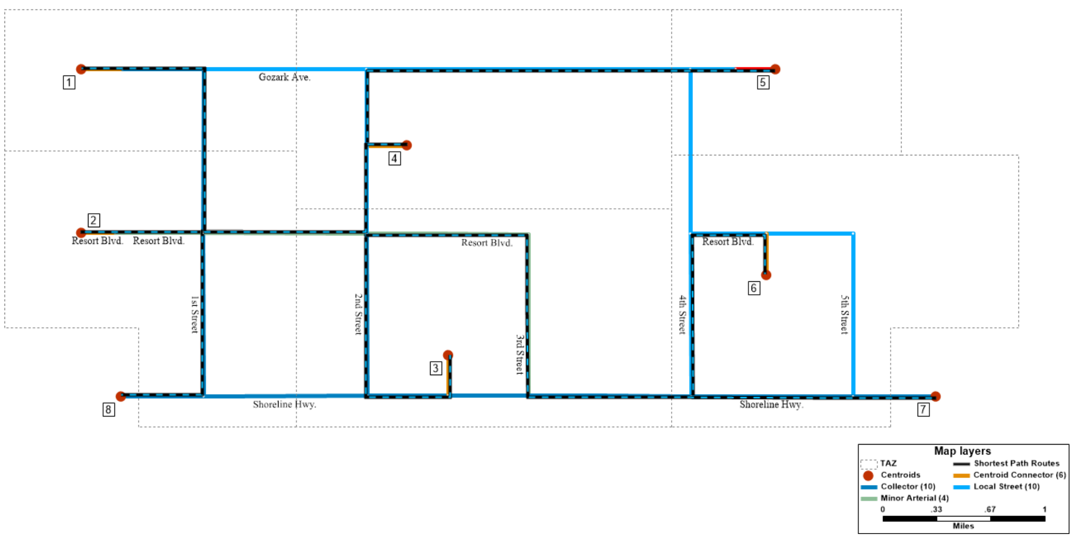
(a) Track 1



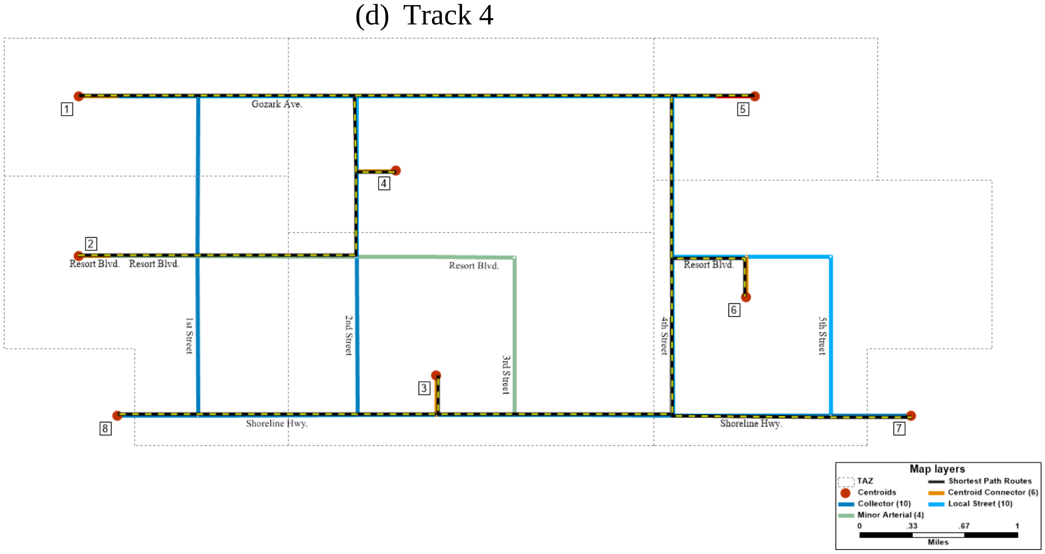
(b) Track 2



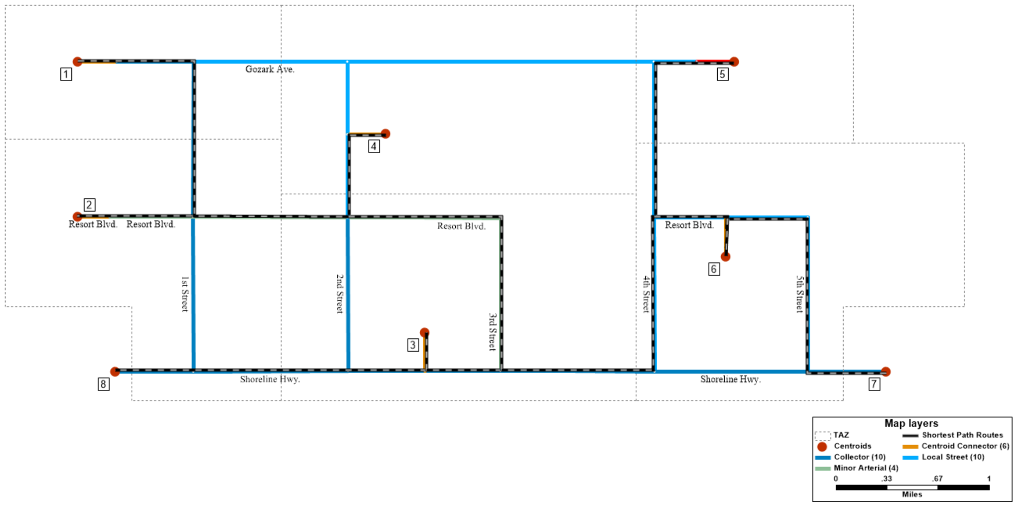
(c) Track 3



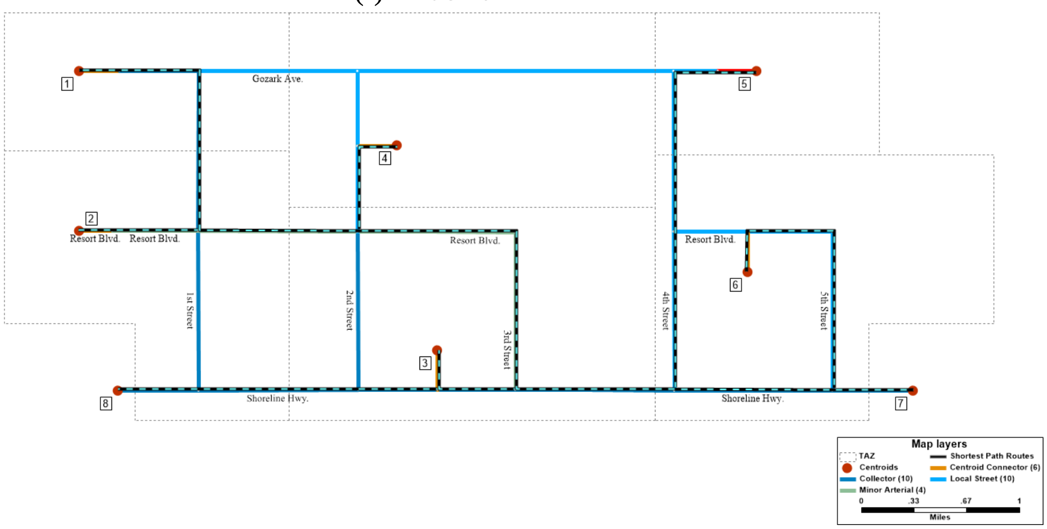
(d) Track 4



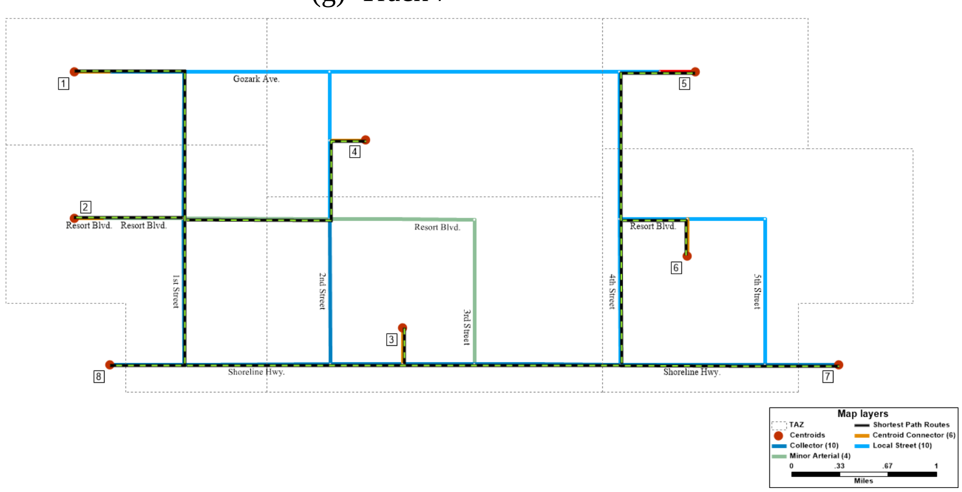
(e) Track 5



(f) Track 6



(g) Track 7



(h) Track 8

Figure 4. Skim tree for all TAZ centroids

2.2.4 Results:

Skim tree generally builds a matrix containing the zone to zone shortest path in respect of travel time. (Table 3) shows that the intrazonal travel time of zone 2 has the lowest travel time, where the travel time is the highest from zone 2 to zone 5.

Table 3. Inter- and intrazonal travel times

Zone	1	2	3	4	5	6	7	8
1	3.87	5.87	9.54	8.53	16.20	17.21	13.61	7.60
2	5.87	3.28	7.20	6.20	17.20	14.87	11.27	5.27
3	9.54	7.20	3.70	7.20	14.21	11.21	7.61	5.60
4	8.53	6.20	7.20	3.85	13.20	14.87	11.27	7.93
5	16.20	17.20	14.21	13.20	6.10	9.20	13.60	17.61
6	17.21	14.87	11.21	14.87	9.20	4.95	8.60	14.61
7	13.61	11.27	7.61	11.27	13.60	8.60	4.55	11.01
8	7.60	5.27	5.60	7.93	17.61	14.61	11.01	3.22

2. 3 Task 3

2.3.1 Summary:

The overarching goal of Task 3 is to forecast the demand of travel in the TAZs. Using the estimated 60,000 trips data of Resort Lake in the year 2010 and activity pattern of each TAZ, a total of six trip generation models were developed: three trip production models and another three attraction models for three trip purposes, home-based work (HBW), home-based other, and non-home-based (NHB) trips were developed. A stepwise regression method and rational judgment were employed to select the explanatory variables. The models were then applied to the activity system data of six TAZs and trip ends were estimated. Since the trip production and attraction are estimated separately, the models estimate unequal production and attraction data. To overcome this, the zone trip ends were normalized using TransCAD's *Balance* tool. The balanced trips were validated by comparing with the observed trips from the travel survey in the year 2010 using mean absolute percentage error and root mean squared error. The results of the validation yield an MAPE value of 7.34% and RMSE value of 323.12.

2.3.2 Objective:

The objective of task 3 was to develop trip generation (production and attraction) models using the regression analysis with socio-demographic variables. The models were developed for three types of trip purposes which are home-based work (HBW), home-based other (HBO) and non-home based (NHB).

2.3.3 Approach:

Updating the Zonal Characteristics:

The study area is a rural, flat terrain region which is divided into eight Traffic Analysis Zones (TAZ). Zone 1 mainly forms with the employment centers where zones 2 and 3 are residential area containing mainly a retire community. Several boat repairing shops and manufacturing companies are situated in zone 4. Zones 5 and 6 are yet to be developed and are expected to have a growth of single-family homes there. Zones 7 and 8, are two external zones that connect the city with the east and west region, respectively. Therefore, the zonal characteristics (e.g. population, labor force, total number of cars etc.) was updated according to the zones (Table 4) (*1*).

Table 4. Resort Lake Zonal Characteristics

Zone	POP	LABF	CARS	HINC	HH	EIND	ERET	EOTH	ETOT	AREA
1	3000	1100	900	29580	700	400	150	1000	1559	1.56
2	1550	1300	600	44580	800	300	225	1300	1825	2.53
3	3500	1200	2500	83100	1000	0	350	250	600	3.10
4	0	0	0	0	0	1400	150	200	1750	2.83
5	2450	1400	2000	49500	950	0	100	50	150	1.27
6	5000	1800	2250	57000	1550	0	425	500	925	3.09
Total	15500	6800	8250		5000	2100	1400	3300	6800	14.38

POP = zone populations, persons

LABF = labor force (by residence), persons

CARS = total cars in zone, cars

HINC = median zone household income, dollars

HH = number of households in zone, households

EIND = basic employment, persons (includes agricultural and industrial)

ERET = retail employment, persons

EOTH = other employment, persons

ETOT = total zone employment, persons

AREA = zone area, sq. miles

The zonal characteristics explains that zone 3 has the highest person per household and number of cars as being a residential zone (Table 5). However, the number of workers per household is higher in zone 6 than any other zones. Zone 1 is a commercial area, so it has a higher number of total employees.

Table 5. Zonal characteristics

Type	**Zone**					
	1	**2**	**3**	**4**	**5**	**6**
Person/HH	4	2	4	0	3	3
Workers/HH	2	2	1	0	1	3
Total Employees/HH	2	2	1	0	0	1
Cars/HH	1	1	3	0	2	1

2.3.4 Result:

Trip Generation Models:

Trip generation (both production and attraction) models were developed based on the zonal characteristics data (Table 4). The overarching goal of trip generation models are to estimated trips attracted and produced in zones, i.e., TAZs. For the purposes of the travel demand modeling, three trip purposes were identified:

1. Home-based work (HBW): Trips where home and work make two ends of the trip.

2. Home-based other (HBO): Trips where home is one end and the other end is non-work related. The other end can be places of shopping, educational institutions, and social visits.

3. Non-home based (NHB): Trips where trips start and end at non-home location, for instance, a work to shopping is an NHB trip.

There are two commonly used method is estimating trip generation: cross-classification and regression models. The present study used linear regression method to estimate trips produced and attracted in each zone. The regression models can accommodate any number of variables as opposed to cross-classification model that can only handle a limited number of variables (*10*).

Ordinary Least Squares

The least-squares method estimates regression the parameters in a regression model by producing a straight line drawn through the points so that the sum of squared deviations between the observed values and the fitted line is minimized (*8*). The line is represented by the equation:

$$\hat{y} = b_0 + b_1 x \qquad (1)$$

Where,

b_0= *y*-intercept,

b_1= slope,

and $\hat{y}$ = the value of *y* determined by the line.

The coefficients b_0 and b_1 are derived in a way that we minimize the sum of squared deviations:

$$\sum_{i=1}^{n} (y_1 - \hat{y})^2$$

A stepwise regression was used to develop the regression equation for trip generation and trip attraction by trip purpose. The method involves an iterative process where a series of tests (e.g. T-tests) are conducted to find a set of explanatory variables that have statistical bearing on the dependent variable. This method is superior to one-step multiple regression, forward and backward selection methods because of its ability to better handle multiple explanatory variables (*10*). An Alpha-to-Enter significance level, $\alpha = 0.15$ was chosen to decide on the independent variables to enter into the model. Regression results can be analyzed using Adjusted R Square, model coefficients (magnitudes and signs), t-statistics for each predictor and their corresponding statistical significance. Along with step-wise regression, rational judgment was also used to find the appropriate predictors. For instance, for the NHB attraction model both number of households and zone population were found statistically significant predictor of NHB trips. However, they are co-related, a high number of households will translate into high population in a zone. Thus, the variable that has less statistically significance, population in this case, were omitted from the model (Table 6). All the variables in the trip generation models are statistically significant at the 95% confidence level. Note for variable description move to Task 3, the section below Table 3.

High values of adjusted R-square suggest that models have high explanatory power in explaining the variation in trip produced and attracted, and they are “good” fit models. The explanatory variables in the regression model make intuitive sense. For instance, positive sign on HINC and HH in the HBW production model mean that income and number of households are positively correlated with home-based work trips, which is valid: zones with higher income and higher number of households are likely to make more home to work trips and vice-versa (Table 6) . A negative sign on EIND in the NHB attraction model indicate that higher number basic employment is associated with lower number of NHB trips attracted. Basic industries as opposed to non-basic ones are export-oriented, with service area extending beyond the boundary of the host region may have workers commuting outside the region.

Table 6: Trip Generation Models

Model	Parameter	Estimate	Std. Error	t-statistic	R-Square
HBW Production	Constant	31.238	103.1	0.303	0.994
	HINC	0.008	0.003	2.437	
	HH	1.924	0.188	10.234	
HBW Attraction	Constant	46.027	223.056	0.206	0.957
	ETOT	1.726	0.192	9.000	
HBO Production	Constant	1367.57	818.486	1.671	0.890
	HH	4.362	0.977	4.461	
HBO Attraction	Constant	-627.415	575.479	-1.09	0.978
	EOTH	1.872	0.569	3.292	
	ERET	19.688	2.084	9.449	
NHB Production	Constant	141.135	300.511	0.470	0.993
	EOTH	2.570	0.186	13.831	
	Area	280.597	115.814	2.423	
	POP	0.300	0.055	5.479	
NHB Attraction	Constant	1651.095	85.401	19.333	0.999
	EIND	-1.377	0.079	-17.44	
	ERET	6.378	0.199	32.043	
	HH	0.411	0.104	3.958	

Trip Balancing:

Separate trip generation models were used to predict productions and attractions. Therefore, the process creates a discrepancy between the number of trips produced in a zone and the number of trips attracted to a zone. To equal the number of attractions with the number of productions, balancing methods are provided (Table 7) (*6*).

Table 7. Balanced trip ends by trip purpose year 2010

Zone	HBW		HBO		NHB	
	Production	Attraction	Production	Attraction	Production	Attraction
1	1625	2719	4421	4203	4049	2346
2	1942	3194	4857	6244	4658	3004
3	2647	1081	5729	6740	2704	4297
4	31	3064	1368	2703	1449	680
5	2271	305	5511	1437	1359	2681
6	3488	1641	8128	8687	3791	5002

Trip ends estimated from the regression models were compared with observed survey data from 2010 travel survey. The mean absolute percentage error (MAPE) and root mean squared error values were computed for each model (Table 8) (*12*-*13*).

The percentage error was computed using the following equation:

The percentage error = $\frac{A_t - F_t}{A_t} \times 100$ (2)

The absolute percentage error is $(\mathrm{APE}_t) = \left| \frac{A_t - F_t}{A} \right| \times 100$ (3)

MAPE is computed using the equation, $\mathrm{MAPE} = \sum_{t=1}^{N} \mathrm{APE}_t / N$ (4)

Where N = Number of observations
A_t = Actual value
F_t = Forecasted value
is computed using the RMSE is a measure of the differences between values estimated by a model and those actually observed. The equation for calculating RMSE is:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}} \qquad (5)$$

Where, P_i = Predicted value

O_i = Observed value

n = Number of observations

Table 8. Trip generation model validation

Model	MAPE	RMSE
HBW Production	4.63%	99.79
HBW Attraction	7.16%	260.72
HBO Production	12.54%	956.77
HBO Attraction	14.89%	481.23
NHB Production	3.85%	118.07
NHB Attraction	0.96%	22.15
Average Error	**7.34%**	**323.12**

Daily trips per person were calculated for production and attractions which are segmented into Home Based Work (HBW), Home Based Other (HBO) and Non-Home-Based (NHB) trips. The residential area in zone 2 shows a higher number of daily trips in most of the trips (Table 9).

Table 9. Daily trips per person

Zone	HBW Production	HBW Attraction	HBO Production	HBO Attraction	NHB Production	NHB Attraction
1	1	1	2	2	1	1
2	1	2	4	4	3	2
3	1	0	2	2	1	1
4	0	0	0	0	0	0
5	1	0	2	1	1	1
6	1	0	1	2	1	1

Home Based Other trips are higher than all other types of trips for daily trips per household (Table 10). The residential zones (zone 2 and 3) produce and the commercial area in zone 1 attracts most of the daily trips per household.

Table 10. Daily trips per household

Zone	HBW Production	HBW Attraction	HBO Production	HBO Attraction	NHB Production	NHB Attraction
1	3	5	8	7	6	3
2	2	4	7	8	6	4
3	3	1	7	7	3	4
4	0	0	0	0	0	0
5	2	0	6	2	1	3
6	2	1	5	6	2	3

Zone 5 produces and attracts the higher number of daily trips per employee (Table 11). Most of the production and attraction trips generate for home based other purposes.

Table 11. Daily trips per employee

Zone	HBW Production	HBW Attraction	HBO Production	HBO Attraction	NHB Production	NHB Attraction
1	1	2	4	3	3	1
2	1	2	3	3	2	2
3	5	2	11	12	5	7
4	0	2	0	1	1	0
5	15	2	36	12	8	18
6	4	2	8	9	4	5

Zone 4 shows a high percentage of attraction trips for home-based work and home- based other purposes where it also produces a high percentage of non- home- based trips (Table 12). On the other hand, the production trips due to home-based work and home- based other purposes are higher in zone 5.

Table 12. Base year share of trips by trip purpose

Zone	Trip Purpose					
	HBW Production	**HBW Attraction**	**HBO Production**	**HBO Attraction**	**NHB Production**	**NHB Attraction**
1	8.24%	14.65%	25.17%	21.97%	19.45%	10.53%
2	7.63%	11.86%	23.31%	25.42%	19.07%	12.71%
3	11.09%	4.52%	27.10%	28.34%	11.29%	17.66%
4	0.00%	43.66%	0.00%	25.35%	21.13%	9.86%
5	16.12%	2.20%	39.56%	13.19%	9.16%	19.78%
6	11.88%	5.09%	23.77%	29.54%	12.73%	16.98%

The matrix of inter and intra zonal travel times shows that travelers going from zone 4 to zone 8 requires the highest time where intra-zonal travel time for zone 8 has the lowest value (Table 13).

Table 13.Inter and intra-zonal travel times

Zone	1	2	3	4	5	6	7	8
1	2.87	4.87	8.54	7.53	15.20	16.20	12.60	6.60
2	4.87	2.28	6.20	5.20	16.20	13.87	10.27	4.27
3	8.54	6.20	2.70	6.20	13.20	10.20	6.60	4.60
4	7.53	5.20	6.20	2.85	12.20	13.87	10.27	6.93
5	15.20	16.20	13.20	12.20	5.10	8.20	12.60	16.60
6	16.20	13.87	10.20	13.87	8.20	3.95	7.60	13.60
7	12.60	10.27	6.60	10.27	12.60	7.60	3.55	10.00
8	6.60	4.27	4.60	6.93	16.60	13.60	10.00	2.22

2.4 Task 4

2.4.1 Summary

Trip distribution is the second step of transportation demand modeling. Doubly constrained gravity model was used to estimate the production and attraction trips of each zone. The gravity model requires friction factors for measuring travel impedance which was calibrated from the 2000 Resort Lake travel demand model. Production- attraction trip matrix was generated for three types of trip purpose which are Home Based Work, Home Based Other and Non-Home Based. The production-attraction table was converted into an origin-destination (O-D) format to get actual directions of trips between the zones. The trip length frequency distribution was generated from the O-D table which explains that very few short distance trips were generated, and medium length trips were high. Input and output trip attractions by zones do not show much differences. Home Based Work trips covers the highest portion of interzonal trips. The percentage of trip by purpose along the day shows that at AM peak period, a large portion of trips mainly generated due to HBW purpose where most of the NHB trips generated at the off-peak period. Therefore, trip distribution model gives an idea of varying purposes of generating trips for different time interval.

2.4.2 Objective:

Apply and validating a calibrated gravity model for the Resort Lake was the purpose of task 4.

2.4.3 Approach:

The Gravity Model

In task 4, doubly constrained gravity model was applied to generate the origin-destination table. The gravity model acts like Newton's theory of gravity. In this model, the trips produced at an origin and attracted to a destination are assumed to be directly proportional to the total trip productions at the origin and the total attractions at the destination. Singly constrained model result in only trip attraction balancing, while doubly constrained model involves both productions and attractions (*5*)

Standard form of gravity model:

$$T_{ij} = \frac{AjF\ ijKij}{\sum AjF\ ijKij} x\ P_i \qquad (6)$$

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, (friction factor) or travel time factor ($F_{ij} = C/t_{ij}\ n$)

C= calibration factor for the friction factor

K_{ij} = a socioeconomic adjustment factor for interchange ij

i = origin zone

n = number of zones

Friction Factors

The "friction factor" (F) is a calibrating term that represents the impedance of a person to make trips of various duration or distances. The general friction factor indicates that as travel times increase, travelers are increasingly less likely to make trips of such lengths. Calibration of the gravity model involves adjusting the friction factor. The friction factors are provided according to trip purpose which were calibrated from Resort lake travel demand model of the year 2000 (Table 14). The value of the friction factor was considered '1' for the travel times greater than 20 minutes (*1*).

Table 14. Friction Factors

Time (minutes)	HBW	HBO	NHB	Time (minutes)	HBW	HBO	NHB
1	25	50	30	11	5	8	7
2	18	35	25	12	4	7	6
3	15	25	20	13	3	6	5
4	13	20	17	14	2	5	4
5	11	18	15	15	1	4	3
6	10	16	13	16	1	3	2
7	9	14	11	17	1	2	1
8	8	12	10	18	1	1	1
9	7	10	9	19	1	1	1
10	6	9	8	20+	1	1	1

The productions and attractions for each trip purpose were estimated in this step (Table 15). Production-attraction table of trips expresses the directions of going from the trip productions to the attractions. Intra zonal trips of zone 6 showed the highest number of home-based work (HBW) trips, where there were no HBW trips from zone 4 to zones 5 and 6.

Table 15. Production-Attraction matrix for HBW trips

Zone	**1**	**2**	**3**	**4**	**5**	**6**
1	715	501	73	324	2	10
2	589	768	105	456	3	21
3	671	824	314	734	9	96
4	8	9	2	12	0	0
5	333	319	146	851	157	466
6	404	773	441	688	133	1049

In the case of home-based other (HBO) trips, again the highest number of trips were observed from zone 6, while lowest trips were observed for vehicles going from zone 4 to zone 5 (Table 16).

Table 16. Production-Attraction matrix for HBO trips

Zone	1	2	3	4	5	6
1	1531	1435	779	423	57	196
2	1015	1834	1003	519	35	450
3	695	1266	2210	561	108	889
4	219	380	325	263	34	146
5	454	394	963	523	755	2421
6	287	934	1460	413	447	4587

Zone 6 followed the same pattern of having the highest intra-zonal trips for non-home- based purposes, but the lowest number of trips was observed when zones 5 and 2 are the production and attraction zones respectively (Table 17).

Table 17. Production-Attraction matrix for NHB trips

Zone	1	2	3	4	5	6
1	1125	1014	1087	190	383	250
2	792	1269	1247	232	180	939
3	214	314	1022	88	324	741
4	160	249	377	108	272	284
5	28	17	119	23	616	556
6	30	142	444	40	905	2231

Conversion of PA to OD

Before starting the procedure of trip assignment, the production-attraction trip table must be converted into an origin-destination format to get actual directions of trips between the zones. Production-attraction table of trips expresses the directions going from the trip productions to the attractions but the real directions from origin to destination are not reflected by the P-A table. So, the P-A to O-D procedures of TransCAD converts the productions and attractions to origins and destinations for all types of trip purpose (*5*)

In this project, it was assumed that most of the trips in the 24- hour period was paired with an equivalent trip in the reverse direction. Network capacities are temporal measures. So, an appropriate time specific trip table (Table 18) was developed for formal assignment (*1*).

Table 18. Time of day distribution of trips by purpose

Analysis Period	HBW		HBO		NHB	
Time (Hour)	PA	AP	PA	AP	PA	AP
AM Peak Period (7-8 AM)	0.15	0.00	0.04	0.01	0.03	0.03
PM Peak Period (5-6 PM)	0.03	0.10	0.03	0.05	0.04	0.04
Off-peak (all other times)	0.17	0.20	0.33	0.33	0.34	0.34

The vehicle occupancy rates by trip purpose were gathered from the Resort Lake travel survey (Table 19) which is important for the conversion of PA matrix to OD matrix.

Table 19. Base year vehicle occupancy rates by trip purpose

Type	Trip Purpose	Average Vehicle Occupancy
HBW	Home based work	1.10 persons/vehicle
HBO	Home based other	1.40 persons/vehicle
NHB	Non-home based	1.20 persons/vehicle

2.4.4 Results:
The graph (Figure 5) generated for Trip length distribution by trip purpose, shows the common shape of general trip length distribution graph. Usually, a trip length distribution plotting combines with two cost functions, a power function followed by an exponential function. The trip length distribution pattern explains that there are very few short trips. On the other hand, large number of medium length trips are observed. After achieving the peak, the number of trips decreases with the increase of time.

The exponential function, f(Cij) = $e^{-\beta Cij}$

The power function, f(Cij)= Cij^{-n}

Here, n and β are parameters for calibration.

Table 20. Trip length frequency distribution

Travel Time	HBW	HBO	NHB	Total
0-5	3948	12875	7561	24384
5-10	3962	9793	6235	19990
10-15	3025	5920	3328	12273
15+	1071	1423	888	3382
Total	12006	30011	18012	60029

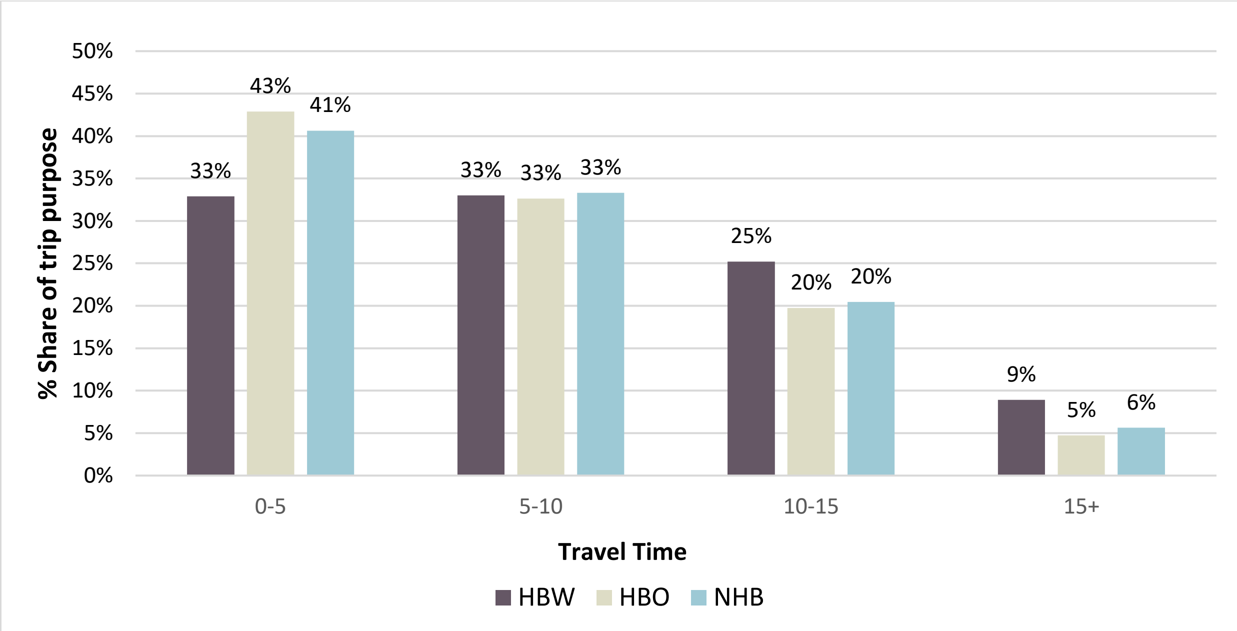


Figure 5. Trip length distribution by trip purpose

From the perspective of trip attraction, zone 6 shows the highest number of input and output compared with other zones (Table 21). On the other hand, zone 5 is the lowest attraction zone for both input and output trips. The difference between the input the output trip attraction is very low for all the zones.

Table 21. Trip attractions input vs output

Zone	Input	Output	Difference
1	9269	9270	1
2	12442	12442	0
3	12117	12117	0
4	6448	6448	0
5	4422	4420	2
6	15330	15332	2
Total	**60028**	**60029**	**1**

The interzonal trips carry a higher portion of HBW, HBO, and NHB trips comparing with the intrazonal trips (Table 22). Moreover, interzonal HBW trips cover around 75% of total trips comparing with the intrazonal HBW trips. So, most of the trips are generated due to employment purpose and those trips are mainly inter-zonal.

Table 22. Number and percentage of interzonal and intrazonal trips by purpose

Zone	HBW		HBO		NHB	
	Number of trips	%share	Number of trips	%share	Number of trips	%share
Interzonal	8991	74.89%	18831	62.75%	11641	64.63%
Intrazonal	3015	25.11%	11180	37.25%	6371	35.37%
Total	**12006**	**100.00%**	**30011**	**100%**	**18012**	**100.00%**

There is an influx of HBW trips during the first part of the day, but at mid-day NHB domains the region (Table 23). At PM peak period HBO trips are highest than other purposes. The scenario explains that, at AM peak period most of the trips are happened to the employment zone. Again, the peak of NHB trips at off-peak time explains that at that time there will be less trips around the residential zones.

Table 23. Number and percentage of trips by purpose in time of day period

Time of Day	HBW	% of HBW	HBO	% of HBO	NHB	% of NHB
AM Peak	2094	55.46%	1247	34.60%	993	40.30%
PM Peak	1355	35.88%	1716	47.61%	932	37.82%
Off-peak	327	8.66%	641	17.79%	539	21.88%
Total	**3776**	**100.00%**	**3604**	**100.00%**	**2464**	**100.00%**

2.5 Task 5

2.5.1 Summary:

This task involves assigning trips to the transportation network. Using User Equilibrium via iterative assignment, the network flows for the Resort Lake, i.e., OD matrix generated in Task 4, were estimated. A network flow map combining v/c ration and traffic flow were generated. The map showed congested situation on the Shoreline Highway and a Western link of the Resort Blvd. The PM peak period flows were validated by comparing estimated and observed traffic flows. Three screenlines were generated on the network to find the estimated flows.

2.5.2 Objective:

The objective of task 5 was to estimate the origin -destination vehicle trip table on basis of base network for River Lake and validating the estimated link flows with and travel time with the observed flow.

2.5.3 Approach :

External Station Trip Interchanges

In task 4, all demand analysis was done only considering the internal zones. However, two external zones help to model the trips crossing the city boundary. The number of trips in and out of the external zones was estimated by performing a cordon survey. The trip matrix was developed for PM (5 pm t0 6 pm) peak period (Table 24). AM period was assumed to experience the same trips but transposed (Table 25), the 10% of the PM period OD flows were experienced in off-peak period (Table 26) (*1*).

Zone to zone O-D flows in PM peak

Table 24. Zone to zone O-D flows in PM peak

Zone	1	2	3	4	5	6	7	8
1	226	183	148	30	61	64	50	100
2	174	257	194	42	52	150	50	100
3	87	121	214	42	58	146	50	50
4	62	87	116	22	115	98	100	200
5	27	19	44	28	93	137	50	50
6	24	74	110	28	170	496	100	100
7	0	0	50	0	50	100	0	1000
8	50	50	50	0	0	0	1100	0

Table 25. Zone to zone O-D flows in AM peak

Zone	1	2	3	4	5	6	7	8
1	250	188	79	80	22	19	0	50
2	203	280	108	111	15	62	0	50
3	183	234	203	159	36	98	50	50
4	24	33	31	19	20	21	0	0
5	80	70	60	168	93	181	50	0
6	88	193	158	141	123	496	100	0
7	50	50	50	100	50	100	0	1100
8	100	100	50	200	50	100	1000	0

Table 26. Zone to zone O-D flows in off-peak period

Zone	1	2	3	4	5	6	7	8
1	86	67	37	21	12	10	5	10
2	69	98	51	29	8	32	5	10
3	54	70	87	36	18	46	5	5
4	12	17	17	9	10	11	10	20
5	21	16	22	34	39	65	5	5
6	20	52	55	30	56	194	10	10
7	0	0	5	0	5	10	0	100
8	5	5	5	0	0	0	110	0

User Equilibrium Assignment

The user equilibrium assignment is based on Wardrop's first principle, which states that “no driver can unilaterally reduce his/her travel costs by shifting to another route”. According to the Wardrop's first principle it is assumed that drivers have perfect knowledge about travel costs on a network and choose the best route. This assumption is the basis to determine user equilibrium (*7*).

$$\text{Minimize } Z = \sum_a \int_0^{x_a} t_a\ (x_a)dx \qquad (7)$$

$$\text{Subject to } \sum_k f_k^{TS} = q_{rs} : \forall\ r, s$$

$$x_a = \sum_r \sum_a \sum_k \delta_{a,k}^{r\ s} f_k^{r\ s} : \forall a$$

$$f_k^{r\ s} \geq 0\ : \forall\ k, r, s$$

$$x_a \geq 0 : \text{a} \in \text{A}$$

Where k is the path, x_a equilibrium flows in link a, t_a travel time on link a, $f_k^{r\ s}$flow on path k connecting O-D pair r-s, q_{rs}trip rate between r and s .

The Frank–Wolfe Algorithm

In Frank–Wolfe algorithm a linearized sub-problem is solved to get a good descent direction and finds a new solution by searching linearly.
The procedure starts with selecting a suitable initial set of current link costs, usually free flow travel times Ca (0). All flows are initialized as V_a^0=0 and n=0. The set of minimum cost trees is built with the current costs and n becomes n+1. The whole matrix is loaded as all or nothing to obtain a set of auxiliary flows Fa. Then the current flow is calculated as $V_a^n = (1-\varphi)\, V_a^{n-1} + \varphi\text{Fa}$, choosing φ such that the value of the objective function Z is minimized. Then, a new set of current link costs are calculated based on the flows V_a^n (*7*).

Convergence Criteria: Relative Gap
Relative gap is a good convergence indicator to decide whether to stop or to proceed (*7*).

$$\text{RG} = \frac{\sum V_a\, c_a - V_a^{AON} c_a}{\sum V_a\, c_a} \qquad (8)$$

Where, where c_a is the cost (time) at the current flow on link *a*; V_a^{AON} is the all-or-nothing flow on link *a* and V_a is the current flow on link *a*.

Performing Trip Assignment

The User Equilibrium (UE) assignment in TransCAD is by default the N-Conjugate Modification of the Frank-Wolfe algorithm. In the task, the procedure started with an initial All or Nothing (AON) assignment using initial minimum path skim trees, and then link performance functions were iteratively applied to update link travel times. The network paths are updated by using the link travel times. The Bureau of Public Roads (BPR) function was used in this step where alpha and beta were considered as 0.15 and 4, respectively. Therefore, a new assignment was computed with an AON assignment with the updated paths. A line search using the current AON loading and the prior assignment was used to determine the weight by which to combine the two sets of link flows into a new solution for the next iteration. Relative Gap of 0.0001 was selected as the convergence. (*1*)

2.5.4 Results:

The performance measures were obtained from the model after completing the trip assignment procedures (Table 27). Statistical analysis was done to observe the link-level performance like travel time, speed, and VC ratios, at the same time network-level performances were analyzed from VMT and VHT.

Table 27. Statistical summary of the performance measures

Metric	Max.	Min	Median	Std. Deviation
AB Travel Time	17.48	0.60	2.10	4.05
BA Travel Time	9.34	0.60	2.22	2.51
AB VMT	1617.8	43.1	318.6	373.4
BA VMT	1342.7	56.2	303.4	331.0
AB VHT	468.3	1.7	16.0	89.1
BA VHT	228.9	3.5	20.6	57.4
AB Speed	42.8	3.4	16.1	9.7
BA Speed	44.0	3.5	16.1	10.1
AB Flow	1608	105	636	379
BA Flow	1600	105	534	386
AB VOC	2.68	0.02	0.97	0.74
BA VOC	2.67	0.04	0.93	0.74

Flow map and V/C ratio

The flow map developed (Figure 6) for the base year 2010, shows the link flows in both directions. The red links show high v/c ratios of more than 2.5 where yellow links have v/c ratio ranges from 1 to 2. Green links are serving with a v/c less than 1. The shoreline highway shows the most congested flow since most of the links in that highway have high flow rate and v/c ratio.

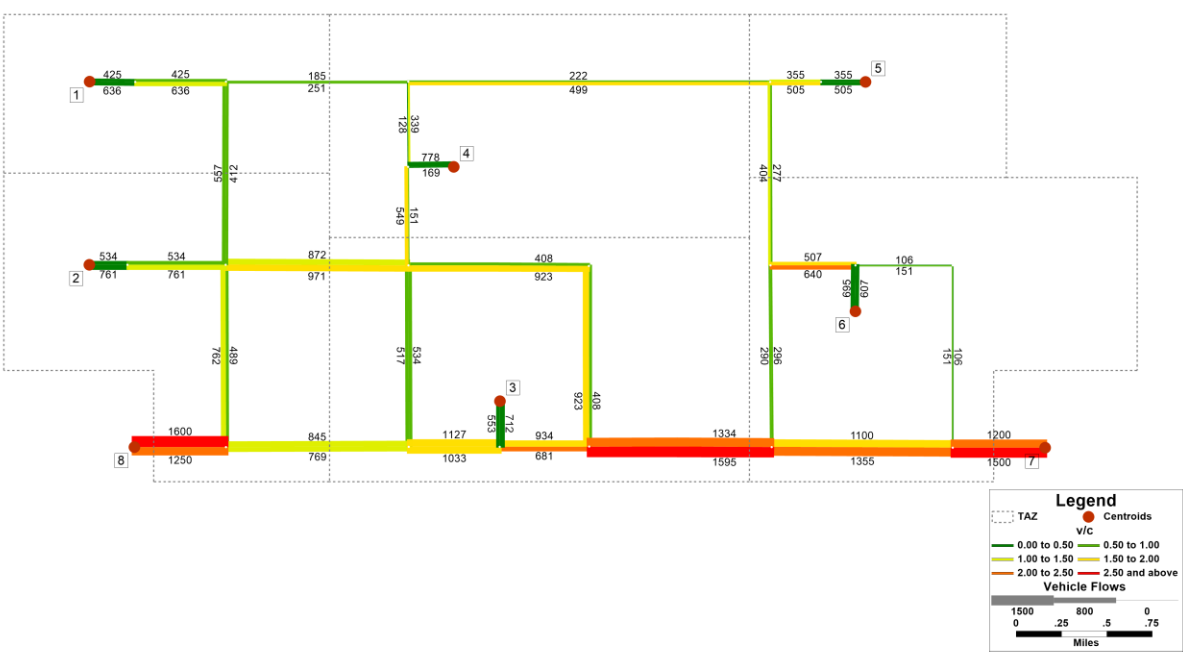


Figure 6. Estimated Flows for the PM Peak Period with 2010 network

Validation of Network Performance

A screenline is an imaginary line on a map across a link to measure the total number of trips that crosses the line. Screenline analysis provides a means of comparing the results of a traffic assignment with traffic count data with the observed data.

Selecting Screenline Locations

The map containing the observed flows for the PM peak period with 2010 network updates (Figure 8), had some difference comparing to the generated model of the project. The shape of the TAZ areas was different from the computed model. Therefore, the location of the centroids of internal zone 2 and external zone 8 had different positions on the network. However, three screenlines were drawn to compare the flows with varying v/c ratio (Figure 7). The first screenline was drawn on the extended link of Gozark Ave in zone 5 as the link shows the v/c ratio ranging from 1 to 2.The Shoreline Highway between 3rd and 4th street has a high value of v/c ratio, so the second line was drawn over that link. The third line was drawn on the linking road of Gozark Ave and Resort Blvd for having a lower v/c ratio.

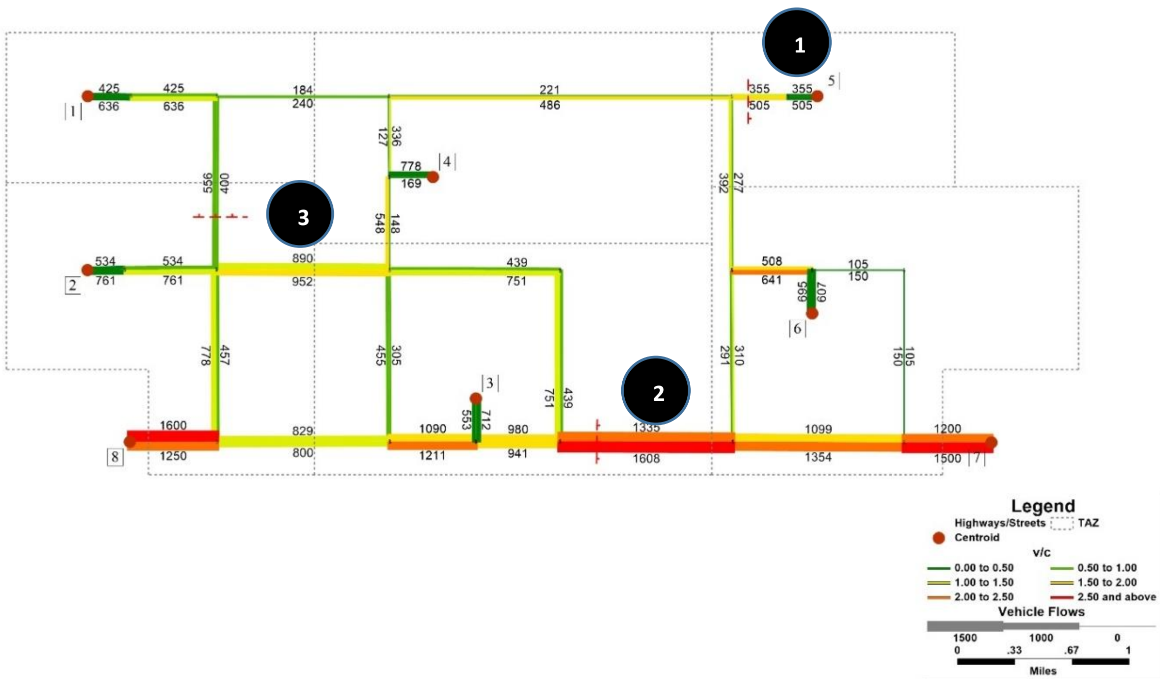


Figure 7. Screenline validation for the PM Peak Period with 2010 network

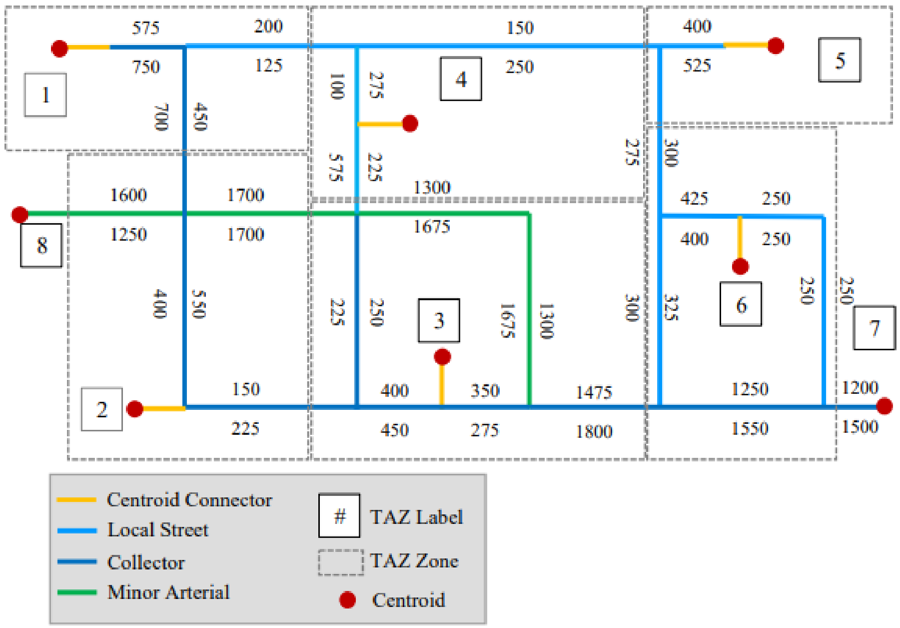


Figure 8. Observed Flows for the PM Peak Period with 2010 network updates

The inflow and outflow values obtained from the screenlines were compared with the observed flow for PM peak period. The value of MAPE was highest for the third screenline (Table 28). The location of the line was near zone 2 which had a different shape of the TAZ area from the estimated model. The value of MAPE shows that the estimated trip generation models represent a good validity comparing with the observed value.

Table 28. Comparison estimated and observed flows

Screenline	Inflow		MAPE	Outflow		MAPE
	Estimated	Observed		Estimated	Observed	
1	355	400	11.25%	505	525	3.81%
2	1335	1475	9.49%	1608	1800	10.67%
3	556	700	20.57%	400	450	11.11%

2.6 Task 6

2.6.1 Summary:

Task 6 generates three possible alternatives to transportation problems identified in the previous model years and recommends the best alternative evaluating their performance. To accomplish this goal, first travel demand for the year 2030 were forecasted using the validated trip generation models for the year 2010 from Task 3. Then, future trip distribution table were generated using the trip distribution models for the year 2010 from Task 4, and flows were following the trip assignment model from Task 5. A flow map of the city in 2030 shows that Shoreline will heavily be congested in future due to growth in tourist traffic and population growth outside city limits. There alternatives were carefully chosen keeping in mind that Shoreline will gain significant traffic and could lead to unstable flow and thereby hurting the economic potential of the city. A no build alternative scenario was developed to help with the three alternatives, each having a set of changes to the current transportation network. The first alternative was based on upgrading the capacity of existing network by adding a new link to Resort Blvd. that extends the road and a new lane on either direction at the Shoreline Highway. The second alternative proposed to upgrade the Shoreline Highway to major arterial that will have added capacity to handle the uptick in the traffic on its links. Finally, the third alternative was proposed considering a demand management strategy and capacity upgradation: A new transit system was proposed serving all the internal zones of the city. All three alternatives were compared based on roadway performance measures such as v/c ratio, traffic flow, travel time, VMT, and VHT. General cost estimates were developed by incorporating present values estimates for capital projects, operating costs, and maintenance costs for the three alternatives. Although alternative 3 was found to be the most ambitious project in terms of cost efficiency, it outperformed others on roadway performance measures. The current bottlenecks of traffic safety and air quality were considered in selecting the best strategy. Based on a thorough evaluation of the alternatives, alternative 3 was chosen to help Resort Lake mitigate its transportation bottlenecks and create a vibrant, healthy, and sustainable city.

2.6.2 Objective:

The objective of task 6 was to use the validated base year trip generation models to predict the network condition in Resort Lake for 2030. Three possible alternatives were generated to improve the identified problems in the model of 2030. Therefore, an alternative was chosen among those three models based on the performance measures.

2.6.3 Approach:

Forecasting Activity System for 2030

In 2030, development of new residential suburbs is expected to be developed in zones 7 and 8. The city is expecting a residential growth in TAZ 5 while employment growth is going to be happen in TAZ 4 and in TAZ 2. So, the growth of the Resort city demands a projection of demographic characteristics to be added in the zones (Table 29) (*1*).

Table 29. Resort Lake zonal characteristics for 2030

Zone	POP	LABF	CARS	HINC	HH	EIND	ERET	EOTH	ETOT	AREA
1	3000	1200	800	33000	700	400	200	1100	1700	1.56
2	2000	1700	900	52500	1000	500	350	1650	2500	2.53
3	3500	1300	2700	81000	1000	0	350	250	600	3.1
4	0	0	0	0	0	2300	300	800	3400	2.83
5	5000	2400	2800	55500	1750	0	250	250	500	1.27
6	5700	2000	2500	61500	1750	0	550	550	1100	3.09
TOTAL	19200	8600	9700	283500	6200	3200	2000	4600	9800	14.38

The origin-destination table was re-created to observe the number of trips for the PM (5pm to 6pm) peak period.

2.6.4 Results:

No build alternative

A no-build alternative was developed that reflected no new addition of links or any capacity expansions. The validated trip generation models were used there to forecast trip attractions and productions. Therefore, a doubly constrained gravity model was applied to determine the origin-destination table after balancing the trips for different purposes. The user equilibrium method was applied for trip assignment. There was no validation exercise done by the screenlines as the model was developed for the year2030.

The flow map was generated to observe the flow pattern for the PM (5 pm to 6 pm) peak period. The width of the lines (Figure 9) showed on the links indicates the flow with values where the color ranges show the variation of v/c ratios over the links. The red links represent higher v/c ratios of more than 2.50 where yellow links have moderate v/c ratios, between 1 and 2. The green links are of v/c ratios less than 1. Therefore, the flow pattern and v/c ratio over links imply that the Shoreline Highway has the most traffic congestion with an unstable flow. Besides, some portion of Gozark avenue and Resort Blvd has a sign of congestion. However, the focus of selecting alternatives was centered on the mitigating the congestion in the Shoreline Highway.

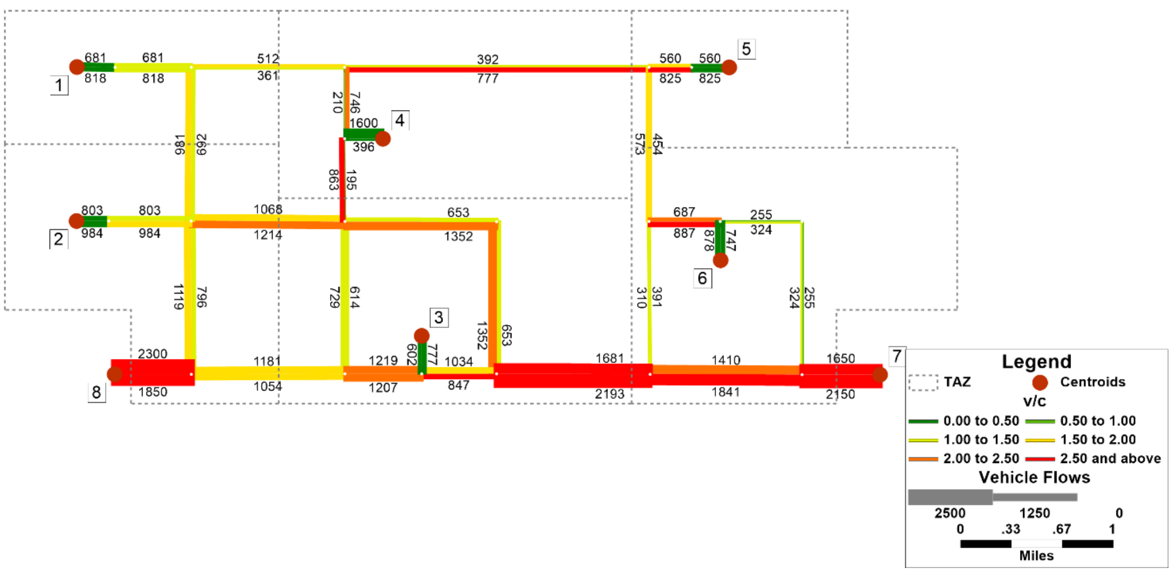


Figure 9. Flow map in PM peak for no build alternative

Alternative 1: Addition of new network link

Alternative 1 comprises two types of changes to mitigate the congestion in the Shoreline highway (Figure 10). The two changes include:

- Addition of a new network link to join the Resort Blvd.
- Addition of a lane throughout the Shoreline highway while keeping the link type collector as before.

Therefore, the shortest paths between all origins and destinations were found by developing skimtrees. Validated trip generation models were applied for different trip purposes. Trip balancing was done before progressing the trip distribution step. Production- attraction tables were produced using the doubly constrained gravity model. The origin-destination table was produced for PM (5 pm to 6 pm) peak period. After completing the step of trip-assignment the flow pattern and v/c ratio were observed.

Figure 10. Network improvement for alternative 1

Flow pattern and v/c ratio analysis

The flow width and v/c ratio both have decreased due to the changes in the network (Figure 11). Therefore, the congestion has improved in the Shoreline highway. The new added link serves the vehicles to move directly from zone 3 to zone 6. The travelers do not need to use the Shoreline highway so the changes in the network help to mitigate the congestion in the Shoreline highway. However, there is still some congestion in zones 5 and 6 with a high v/c ratio. So, another alternative must be tried to minimize the congestion.

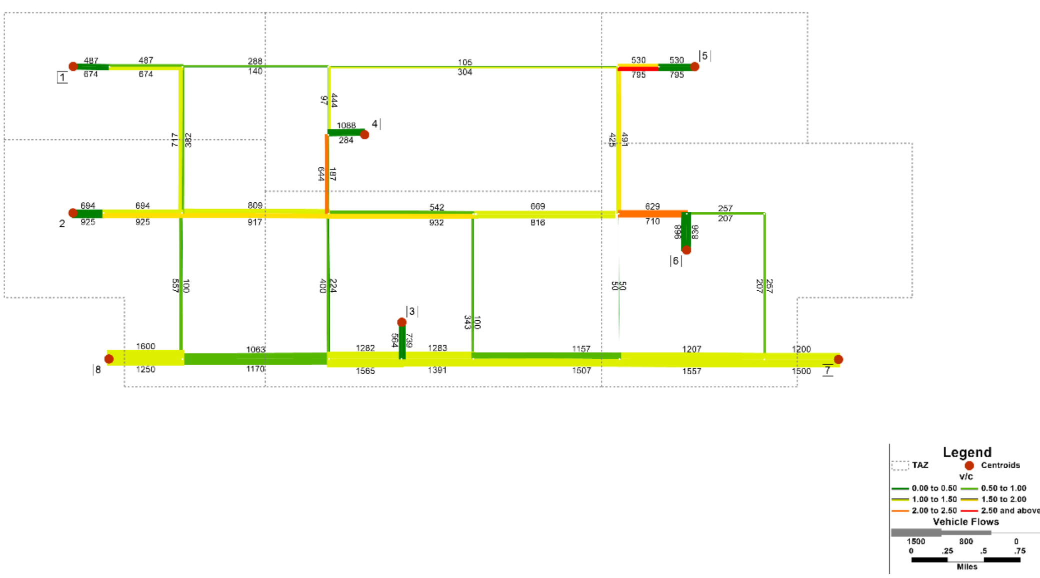


Figure 11. Flow map in PM peak for first alternative

Alternative 2: Upgrading the Shoreline highway from collector to major arterial

The change that was made in the 2nd alternative was to upgrade the Shoreline highway from collector to major arterial to increase the capacity and speed of the highway (Figure 12). The two external zones of the city, zones 7 and 8 are expected to be developed in future. Therefore, the influx of tourists through the city is expected to be increased so the capacity of the Shoreline highway needs to be increased at the same time. Upgrading the road from collector to major arterial increases the capacity of the road from 600 veh/hr to 1800 veh/hr.

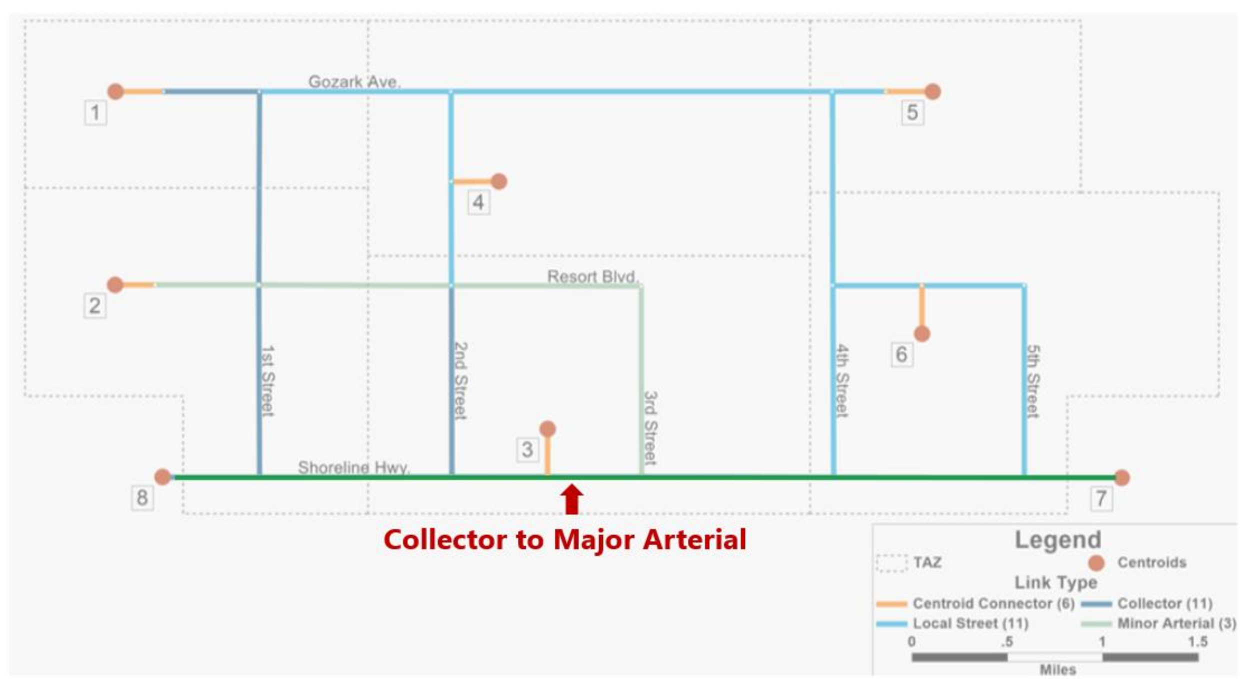


Figure 12. Network improvement for alternative 2

Flow pattern and v/c ratio analysis

The flow map of the PM (5 pm to 6 pm) peak period for the second alternative shows that after upgrading the Shoreline highway from collector to major arterial the flow has increased in most of the links (Figure 13). Therefore, the v/c ratio in most of the links of the network becomes less than 1. The congestion of Shoreline highway is mitigated in a better way than the first alternative. Zones 5 and 6 still has some congestion with a high v/c ratio. This problem leads to think for a third solution of this problem.

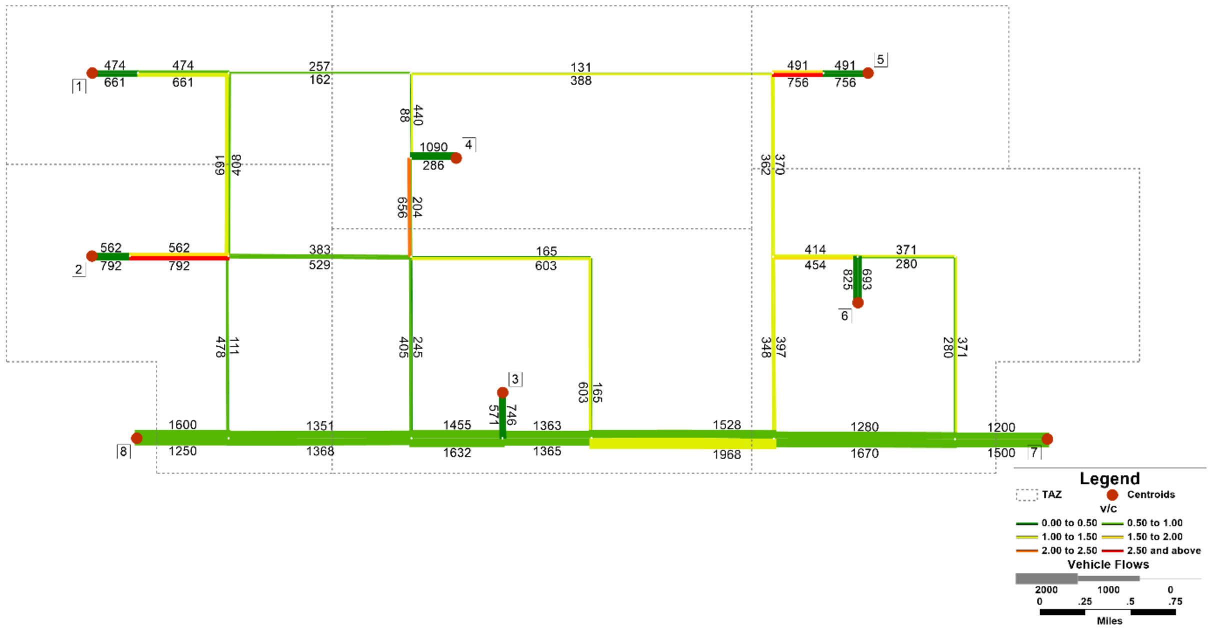


Figure 13. Flow map in PM (5 pm to 6 pm) peak for second alternative

Alternative 3: Introducing new bus transit

Alternative 3 contains two types of changes to mitigate the congestion in the Shoreline highway (Figure 14). The two changes include:

- Introduction of a new bus transit
- Addition of a lane throughout the Shoreline highway while keeping the link type collector as before.

The base model does not have any transit services, So, in this alternative the first change was made by introducing a new bus transit to follow the strategy of traffic management. The new assigned route is showed by the red dotted line in the map (Figure 14). In the Resort lake city, zone 1 contains most of the employment centers. So, the bus routing is designed to start from zone 1 at 5 pm which is the starting time of PM peak period. Zones 2 and 3 are served afterwards. Zone 5 and zone 6 are not developed yet and are expected to be developed with single family homes in the future. So, the bus route is connected to zone 5 and 6 and makes a round trip.

Figure 14. Network improvement for alternative 3

The transit system is considered to serve 15% of the demand for all the interzonal and intrazonal trips (*8*).Therefore, the O-D table (Table 33) was modified to get a 15% less demand of trips to the zones. Please refer to the section **Cost Calculation** to find the relevant information.

The second change in the network was to add a lane on the Shoreline highway without changing the link type (Figure 14). New residential suburbs are going to be developed in the east and westside of the city and an increased influx of tourists are expected in future.

Flow pattern and v/c ratio analysis

The flow map (Figure 15) of the PM (5 pm to 6 pm) peak period for the third alternative shows that the v/c ratio is less than 1 in most of the links and there is an improvement of congestion in zone 5 and zone 2. Both the zones (5 and 2) experiences a decreased value of v/c. So, this set of changes are serving the best scenario among all the alternatives in respect of flow and v/c ratio.

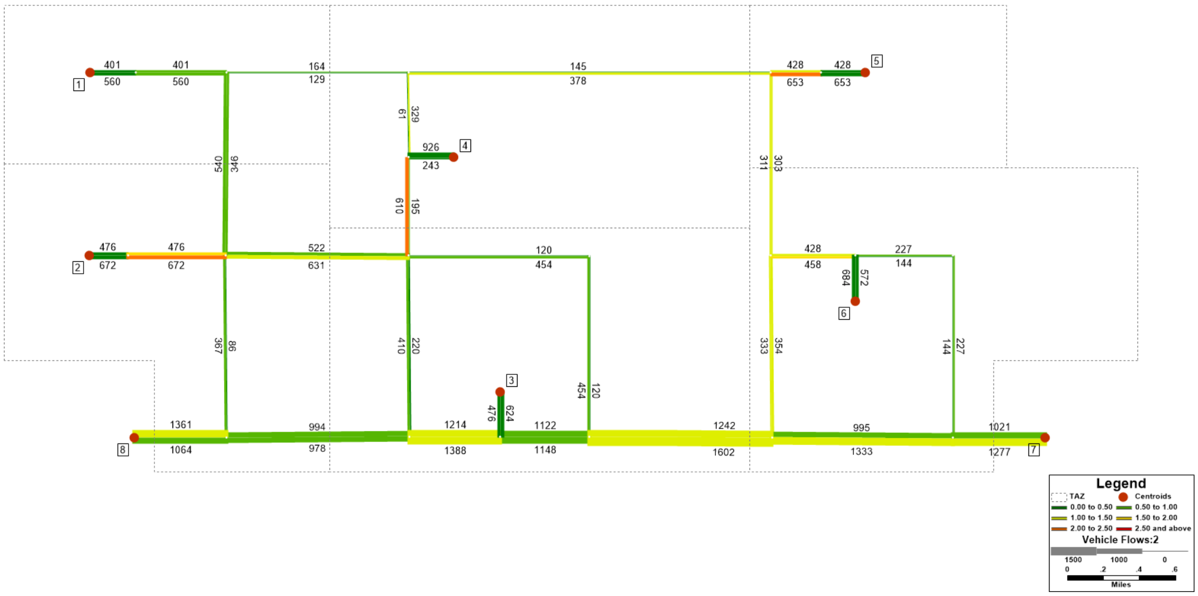


Figure 15. Flow map in PM peak for third alternative

Cost Calculation:

General cost estimation was developed for each of the alternatives. The cost calculation contains the present value of estimating operating costs and maintenance costs (Table 30). It was considered that-

1. Maintenance costs are required for the links that remain unchanged for 10 or more years.
2. Rehabilitation costs are required for the links that remain unchanged for 10 or more years.
3. New and upgraded links do not require rehabilitation or maintenance costs.

Table 30. Future Infrastructure Improvement Cost Estimates

Current Road Type	Freeway	Primary	Major	Minor	Collector	Local
Road ($ per lane-mile for 2-way links						
New facility	500,000	300,000	225,000	150,000	100,000	50,000
Additional lane	300,000	200,000	100,000	100,000	50,000	25,000
Upgrade	600,000	200,000	200,000	100,000	50,000	NA
Intersections ($, one per link)						
New intersection	600,000	100,000	100,000	75,000	75,000	25,000
Upgrade	500,000	200,000	100,000	100,000	50,000	NA

Grade separation	NA	300,000	300,000	150,000	150,000	NA
Maintenance ($ per lane-mile, after 10 years)						
Existing facility	100,000	80,000	70,000	50,000	20,000	10,000
Rehabilitation ($ per lane-mile, after 20 years)						
Existing facility	250,000	150,000	110,000	75,000	50,000	25,000
Note: If facility is not upgraded, apply maintenance fees after 10 years and rehabilitation fees after 20 years.						

Table 31. Rehabilitation costs for links

Road Type	Total length (mile)	No. of lanes	Maintenance ($ per lane-mile, after 10 years)	Rehabilitation cost ($ per lane-mile, after 20 years)	Total Cost, $
Local Street	7.25	1	$ 10,000	$ 25,000	$ 2,53,750
Collector	3.5	1	$ 20,000	$ 50,000	$ 2,45,000
Minor Arterial	3.5	1	$ 50,000	$ 75,000	$ 4,37,500
Total	$9,36,250				

Alternative 1: Adding a new network link in zone 3 to join the Resort Blvd and adding an additional lane throughout the collector road of the Shoreline Highway

1. Adding an additional lane throughout the collector road of the Shoreline Highway

Cost of adding an additional lane for collector ($ per lane-mile for 2-way links) = $50,000

Total length of the Shoreline highway = 5 mile

Cost of additional lane = $2,50,000

Cost of upgrading intersection = $ 2,50,000

10% increased cost for constructing along the lake front = $50,000

Total cost of adding lane in the Shoreline highway= $2,50,000 + $ 2,50,000 + $50,000

= $5,50,000

2. Adding a new network link (Minor Arterial) in zone 3 to join the Resort Blvd:

Cost of adding new facility for Minor Arterial ($ per lane-mile for 2-way links) = $1,50,000

Total length of the new network link = 1 mile

Cost of new intersection for Minor Arterial = $75,000

Cost of upgrading for Minor Arterial = $1,00,000

Total cost of adding a new network link = $1,50,000 + $75,000 + $1,00,000 =$ 3,25,000

Total Cost for alternative 1 = Adding lane + Adding a network link + Maintenance and Rehabilitation Cost

= $5,50,000 +$3,25,000 + $9,36,250 = **$18,11,250**

Alternative 2: Upgrading the Shoreline Highway from Collector to Major Arterial

1. Upgrading the Shoreline highway from Collector to Minor Arterial:

Cost of upgrading a link from Collector to Minor Arterial ($ per lane-mile for 2-way links) = $5,00,000

Cost of upgrading intersection = $ 1,00,000*5 = $5,00,000

10% increased cost for constructing along the lake front = $1,00,000

Total cost of upgrading the Shoreline highway from Collector to Minor Arterial = $5,00,000 + $5,00,000 + $1,00,000 = $11,00,000

2. Upgrading the Shoreline highway from Minor to Major Arterial:

Cost of upgrading a link from Minor to Major Arterial ($ per lane-mile for 2-way links) = $10,00,000

Cost of upgrading intersection = $ 1,00,000*5 = $5,00,000

10% increased cost for constructing along the lake front = $1,50,000

Total cost of upgrading the Shoreline highway from Minor to Major Arterial = $10,00,000 + $5,00,000+ $1,50,000 = $16,50,000

Total Cost for alternative 2 = Upgrading Collector to Minor Arterial + Upgrading Minor to Major Arterial+ Maintenance and Rehabilitation Cost

= $11,00,000+ $16,50,000 + $9,36,250

= $36,86,250

Alternative 3: Adding an additional lane throughout the collector road of the Shoreline Highway and introducing bus transit for the peak hour (5pm to 6pm)

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1. Adding an additional lane throughout the collector road of the Shoreline Highway:

Cost of adding an additional lane for collector ($ per lane-mile for 2-way links) = $50,000

Total length of the Shoreline highway = 5 mile

Cost of additional lane = $2,50,000

Cost of upgrading intersection = $ 2,50,000

10% increased cost for constructing along the lake front = $50,000

Total cost of adding lane in the Shoreline highway= $2,50,000 + $ 2,50,000 + $25,000

= $5,25,000

2. Introducing bus transit for the peak hour (5pm to 6pm):

The transit system is considered to serve 15% of the demand for all the interzonal and intrazonal trips. The total number of trips by bus was calculated by reducing the trip numbers of the origin-destination table (Table 32) by 15% for all zones (Table 33)

Table 32. OD Trips per person

Zone	1	2	3	4	5	6
1	173	150	111	37	73	61
2	153	334	168	51	71	101
3	68	102	136	50	58	112
4	77	108	131	23	209	146
5	36	22	45	60	209	179
6	24	51	83	45	199	431

Table 33. 15% of OD demand for the bus service

Zone	1	2	3	4	5	6
1	0	28.125	37.4625	51.3375	79.3875	57.1875
2	206.55	0	25.2	61.2	63.9	75.75
3	81.6	149.175	0	52.5	43.5	67.2
4	14.4375	44.55	73.6875	0	242.9625	147.825
5	17.55	14.025	35.4375	18	0	255.075
6	15.3	40.1625	77.8125	20.25	29.85	0
Sum	335.4375	276.0375	249.6	203.2875	459.6	603.0375

Total trips for bus transit = 2127

Total cost per person-mile= 2127*2000

=$4254000

Total cost for alternative 3 **= $** 5,25,000 + $4254000+ $9,36,250 = **$57,15,250**

Table 34. Summary of cost calculation for the three alternatives

Models	Total Cost
Alt 1	$18,11,250
Alt 2	$36,86,250
Alt 3	$57,15,250

The summary result shows that, alternative 1 requires the lowest cost to change the network where alternative 3 shows the highest improvement cost.

Performance Measures

The column bars show (Table 16) the comparison of the models according to the Vehicles Miles of Travels (VMT) values. The no-build alternative has a VMT of near to 38,000 miles. All the alternative models have their VMT less than the lower than the no-build alternative. Alternative 2 shows the highest VMT of 28,000 miles among all the alternatives where alternative 3 has the lowest VMT of 23,000 miles. The increased value of VMT leads to more emission of greenhouse gases which makes an adverse effect on the air quality. Therefore, the green environment requires to decrease the Vehicle Miles of Travel (*9*).

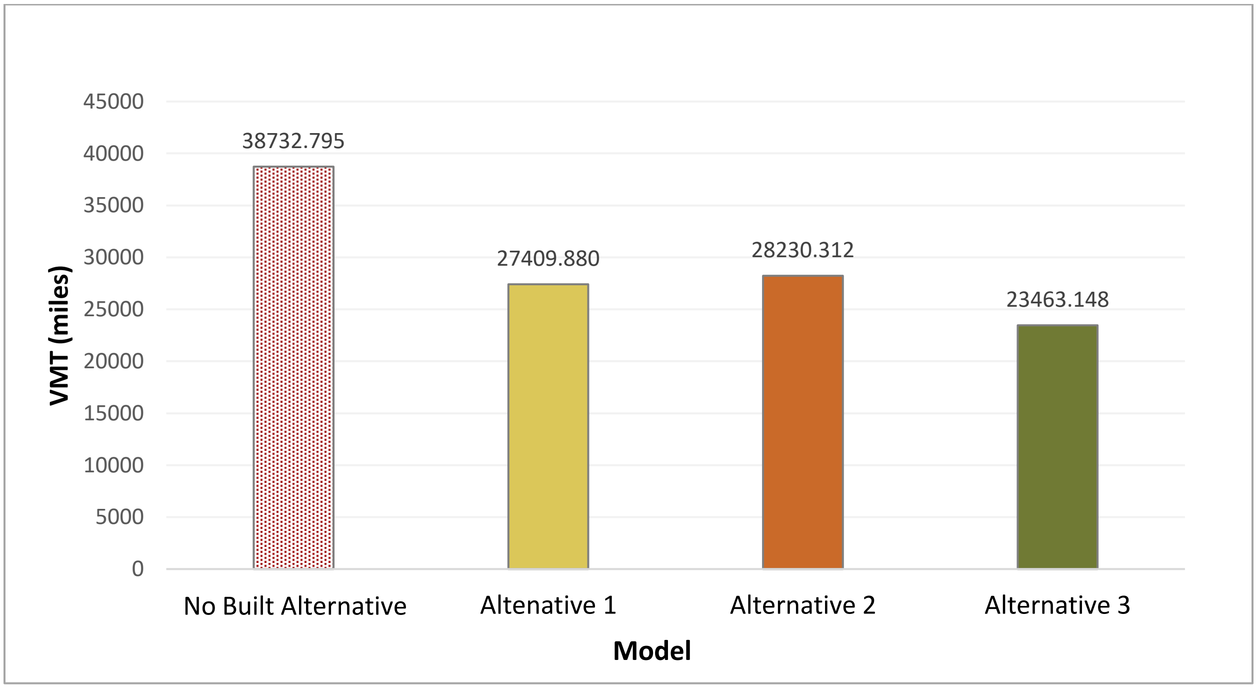

Figure 16. Model comparison using VMT

All three alternative models were evaluated in respect of performance measures that include network-level parameters like Vehicles Miles per Travel (VMT) and Vehicle Hours of Travel (VHT), link-level like travel time on Shoreline highway in both directions (Table 35). Besides, the costs for changing the network of each alternative were compared. Although alternative 3 requires a higher amount of costs than other models, it shows the best performance in respect of VMT, VHT, and travel time. Therefore, alternative 3 indicates a better environment and public health by providing lower VMT and VHT values. On the other hand, alternative 1 requires the lowest improvement costs but has the highest VHT and travel time.

Table 35. Model comparison

Performance Measure	Alternative 1	Alternative 2	Alternative 3
VMT	27409.88	28230.31	**23463.15**
VHT	1689.65	1513.58	**1277.86**
AB Travel Time on 4 miles of Shoreline Hwy. (Minutes)	12.91	11.99	**7.76**
BA Travel Time on 4 miles of Shoreline Hwy. (Minutes)	11.99	7.76	**7.08**
Cost	**1.8 million**	3.6 million	5.7 million

Rationale for Selected Alternative:

Three major challenges for Resort Lake are traffic congestion, air quality, traffic safety. With the recent upsurge in economic activity and tourist traffic and new subdivision on Zone 5 and 6, the traffic flows in the city are likely to increase. New subdivision on two TAZs will bring in more people and thereby more trips will be generated. As the economy is growing, more tourists are going to flock into the city to enjoy the beauty of the Beaver Lake. All these will likely strain the capacity of the existing network causing unstable traffic flows and congested roadways. While the needs added capacities, precautions are needed to make the improvement does not happen at the cost of environment. Adding capacities may backfire since expansion of transportation may induce demand and result in induced traffic. This phenomenon known as induced demand follow the basic economic principle of demand and supply: There will uptick in demand as supply increase. Added capacities will bring new road users and some users will shift their time and route to make the best use of expansions. Empirical evidence suggests that transportation expansion projects can lead to higher vehicle miles of travel, worsening the air quality with ozone gases, e.g., carbon-monoxide and nitrogen oxides. Thus, proper care should be given to the air quality issue while deciding on the alternatives, which is already is a cause of concern for the city.

High automobile dependency is associated with high environment and economic externalities (*14*). Increase in VMT due to high automobile usage could frustrate the efforts to tackle climate change with more greenhouse gases in the atmosphere. Then again, automobiles are not energy efficient, demands non-renewable energy that exerts pressure on oil extraction and thereby putting biodiversity and overall natural environment to danger (*14*). With the global rise in temperature, an uptick of the burning of fossil fuels are contributing to urban heat islands. Empirical research shows that active transportation especially transit improves air quality and help address climate change challenges (*15-17*). An efficient and reliable public transportation system will help the air quality challenges faced by the city.

In addition to air quality, traffic safety is also a major concern for the city. Since there is no transit service and inadequate sidewalk in the city, the city is completely automobile-oriented: The upsurge in traffic causing congestion in the network will likely worsen the traffic safety. So, any strategy that improves traffic safety should be given priority. Travel demand management strategies such as new transit system can be pivotal in lowering demand and reducing the number of vehicles plying on the street because of its high capacity and the need for limited road space.

The city, which has a retirement village need to create places where social interactions happen. Transit could provide several social benefits in this regard. The city houses a retirement village in Zone 2 and 3, and the county itself is inhabited by retired people. A place with a substantial share of aged residents is likely pose mobility challenges for some residents. A transit could be a viable alternative in this city providing the necessary accessibility for people who are too old to drive or too sick to drive. This also helps address the issue of social equity, providing new mobility option for the captive riders. Additionally, since retired people often suffer from isolation and loneliness, the promotion of transit could help develop greater sense of community and promote healthy community living. The tourists visiting the city would also be able to make use of the service to get to the Beaver Lake. Further. the two subdivision in Zone 5 and 6 where new single-family housing will be developed can be benefitted from a new transit system.

Although the alternative 3 will incur the highest cost to implement, studies show that transit follows economies of scale. While depending largely on the subsidies from the government, when ridership spikes per capital cost of providing transit service decreases greatly (*18*). An efficient and reliable transit can in fact prove to cost effective. A 10% increase in transit capacity increases costs by less than 10% (*18*)

Considering the negative externalities caused by high automobile usage, for a city like Resort Lake which is experiencing recent population and economic growing, reduction in automobile usage and promotion of sustainable transportation such as transit should be a priority. Since alternative 3 has a demand management strategy in the form of a new transit system serving all the internal zones of Resort Lake, this is ideal option for mitigating current transportation bottlenecks—traffic congestion, air quality, and traffic safety— as well as creating more livable and sustainable city.

CHAPTER 3: RECOMMENDATION & CONCLUSION

CHAPTER 3: RECOMMENDATION AND CONCLUSION

The 2030 travel demand forecasting model developed in the projects traffic congestion on the Shoreline Highway. With the increase of tourist traffic into the city, and economic and population growth within and outside the city limits demand for a sustainable transportation option for the city of Resort Lake. The city is also going to have an increase in Zone 5 and 6 with single family housing. Considering the current transportation bottlenecks and land use challenges, alternative 3 with a new transit service traversing all six internal TAZ's was proposed as the best alternative. Currently the city does not have a public transportation system, yet the city houses a retirement village with potentially mobility-challenged residents. The new alternative transportation will demand for travel, which is a dire need for a city that is going through transformation. Merely adding capacities by adding new roads or new links to mitigate traffic congestion would not solve the problem in the long run, rather there is a grave danger of induced demand, resulting induced traffic. The city needs a green and sustainable alternative to automobile: Transit is idea option because its ability to help move large number of people using minimal road space.

However, the new alternative transportation system will likely face challenges in garnering ridership. Since the city has limited sidewalk, it presumably has a meagre number of active transportation users. Convincing the automobile users to ride transit will be a challenging task. Then again, a new transit system should be followed by proper changes zoning laws with the aim of supporting economic growth and ensure access to transit. To ensure the residents have access to transit, first/last mile strategies like sidewalk improvement, signage, urban design elements that improve walkability, like tree-lined streets, decorative sidewalks, human-scaled building, and murals may be considered. The city could start free-transit service to garner transit ridership.

Although a new transit system is likely to face a multitude of challenges, the strategies mentioned here could help overcome some of them. A strong public-private partnership is needed to create the right environment for transit to flourish. Public awareness campaigns could be organized to attract people to transit. Transit may not provide panacea to all transportation and land use problems of Resort Lake, but it is the right step towards solving those problems.

REFERENCES

1. Projection Description, 2010 Resort Lake Travel Demand Model

2. Garber, N. J., & Hoel, L. a. (2009). *Traffic and highway engineering*. *Usa* (p. 326). https://doi.org/10.1061/(ASCE)HY.1943-7900.0000746.
3. https://www.caliper.com/tctraveldemand.htm
4. Evans S. (1973), A Relation Between the Gravity Model for Trip Distribution and The Transportation Problem in Linear Programming, Transportation Research, vol. 7, issue 1 (1973) pp. 39-61
5. Duffus, L.N., Sule Alfa, A. & Soliman, A.H. The reliability of using the gravity model for forecasting trip distribution. Transportation 14, 175–192 (1987). https://doi.org/10.1007/BF00837528
6. Matthew T., Transportation network design, http://www.princeton. edu/~alaink/Orf467F15/TransportationNetworkDesign_ Mathew.pdf (odczyt z dnia: 14.02.2017).
7. Ortuzar J de D, Willumsen LG. Modeling transport. New York: Wiley, 1994.
8. Bianco, M. J. (2000). Effective Transportation Demand Management: Combining Parking Pricing, Transit Incentives, and Transportation Management in a Commercial District of Portland, Oregon. *Transportation Research Record*, *1711*(1), 46–54. https://doi.org/10.3141/1711-07
9. Venigalla, M. M., A. Chatterjee, and M. Bronzini. A Specialized Equilibrium Assignment Algorithm for Air Quality Modeling (1991). Transportation Research: Part D, Vol. 4, No., 1, pp. 29–44.
10. Northwest Arkansas Regional Planning Commission (2007). *Northwest Arkansas Regional Travel Demand Model Development.* Retrieved from http://www.nwarpc.org/pdf/Federal%20Review/ModelReport.pdf

11. Lowther, J., Keller, G., & Warwick, B. (1997). Statistics for Management and Economics. *The Journal of the Operational Research Society*. https://doi.org/10.2307/3010500
12. Goodwin, P., & Lawton, R. (1999). On the asymmetry of the symmetric MAPE. *International journal of forecasting*, *15*(4), 405-408.
13. Chai, T., & Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE)?–Arguments against avoiding RMSE in the literature. *Geoscientific model development*, *7*(3), 1247-1250.
14. Davis, A. Y., Pijanowski, B. C., Robinson, K., & Engel, B. (2010). The environmental and economic costs of sprawling parking lots in the United States. *Land Use Policy*, *27*(2), 255-261.
15. Tiwari, G. (2001). Pedestrian infrastructure in the city transport system: a case study of Delhi Geetam Tiwari. *Editorial board*, *7*(4), 13-18.
16. Nieuwenhuijsen, M. J., & Khreis, H. (2016). Car free cities: Pathway to healthy urban living. *Environment international*, *94*, 251-262.
17. Sovacool, B. K., & Brown, M. A. (2010). Twelve metropolitan carbon footprints: A preliminary comparative global assessment. *Energy policy*, *38*(9), 4856-4869.
18. Montana Department of Transportation (2010). Hamilton Area Transportation Plan. Retrieved from https://www.mdt.mt.gov/pubinvolve/hamilton/docs/final_report.pdf