# NETWORK CAPACITY CALCULATION FOR AREA TYPE

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**Prepared for:**

Oregon Department of Transportation

**Prepared by:**

Kimley-Horn and Associates, Inc.

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# INTRODUCTION

The Oregon Department of Transportation (ODOT) and Metropolitan Planning Organizations (MPO's) are cooperating in a program to improve travel demand modeling methods. One component of this program is the development of a standard methodology for estimating network capacity. Parsons Brinkerhoff Quade & Douglas, Inc. has developed a methodology for ODOT and the MPO's[1]. ODOT is planning to implement this methodology in the travel demand model for the Salem-Keizer urbanized area and in the congestion management system. Before the implementation can be completed, analysis is needed to calibrate the methodology based on "area type". The following is an excerpt from the methodology describing area type and its significance:

> *Area type is an important piece of information which may further characterize the links and affect the value specified for link capacity. Area type may be thought of as an additional dimension by which link capacity may be identified. The most appropriate way to introduce area type is by having a separate service flow rate for each area type. A service flow rate would be "looked up" based on area type of link. Similarly, area type may be used to stratify the green to cycle length values if these values differ by area*
>
> *Area type is one objective way of determining whether links are located in dense activity centers or in remote areas. By stratifying the service flow rates by area type, effects of pedestrian interaction, transit vehicle interaction, intersection spill-back, etc. can be accounted for on links in dense areas. Likewise, effects of significant interaction with vehicles leaving and entering driveways and parking lots in suburban area can be accounted for.*

The purpose of this analysis is to perform field measurement of service flow rates on urban arterial roadways in a variety of area types and correlate these values with area type data. The result will be area type adjustment factors that can be applied to the calculated service flow rates in order to calibrate network capacity. The hypothesis is that area type can be defined primarily by employment and population density. Other area specific conditions such as driveway density, pedestrian activity, and transit activity are also considered.

[1] Parsons Brinkerhoff Quade & Douglas, Inc. "Highway Network Capacity Specification, Draft Methodology". January, 1995.

# FIELD DATA COLLECTION

## Data Collection Methodology

Data required to calculate actual saturation flow was collected at six signalized arterial roadway intersections in the Salem-Keizer metropolitan area. At each location, two lanes on one of the arterial approaches were examined (an exclusive through lane and a shared through/turn lane). The six survey locations were chosen in order to obtain saturation flows in a variety of area types. Locations included both one-way and two-way arterial streets. Data was collected during both the AM and PM peak periods. Other data recorded at each location included signal timing, transit activity, adjacent driveway spacing, and the number of pedestrians crossing the receiving leg of turn movements which conflict with traffic on the subject approach. The locations included in this analysis are summarized in **Table 1**.

**Table 1**. Summary of Data Collection Locations

| Number | Intersection | Roadway Type | Approach | Lanes | Date | Time Period |
|---|---|---|---|---|---|---|
| 1 | Commercial St. at Kuebler Rd. | Two-Way | Southbound | Exclusive Through, Shared Through/Right | Tuesday, 4/15/97 | PM Peak |
| 2 | Commercial St. at Madrona Ave. | Two-Way | Northbound | Exclusive Through, Shared Through/Right | Wednesday, 4/16/97 | AM Peak |
| 3 | Commercial St. at Owens St. | One-Way | Southbound | Exclusive Through, Shared Through/Left | Wednesday, 4/16/97 | PM Peak |
| 4 | Commercial St. at Hoyt St. | Two-Way | Northbound | Exclusive Through, Shared Through/Right | Thursday, 4/17/97 | AM Peak |
| 5 | Ferry St. at Liberty St. | One-Way | Westbound | Exclusive Through, Shared Through/Right | Thursday, 4/17/97 | PM Peak |
| 6 | Mission St. at 25th St. | Two-Way | Eastbound | Exclusive Through, Shared Through/Right | Wednesday, 4/23/97 | PM Peak |

Saturation flow is defined as the maximum discharge rate during the green time. For operational calculations, saturation flows have units of passenger cars per hour of green time per lane (pcphgpl). When measured in the field, saturation flows have units of vehicles per hour of green time per lane (vphgpl). Each time a movement is started, a "start-up lost time" is experienced. Saturation flow is usually achieved after the fourth vehicle enters the intersection from a standing queue.

The data required to calculate saturation flow was collected based on the procedure described in the Highway Capacity Manual (HCM)[2]. The data collection procedure is described below: Using a stop watch, time was started at the beginning of green for the subject movement. Time was recorded when the rear axle of the fourth vehicle crossed the stop bar ($t_4$) and when the last vehicle in the queue at the beginning of green crossed the stop bar ($t_n$). The total number of vehicles stopped in the queue at the beginning of green ($n$) was recorded.

[2] Transportation Research Board. Highway Capacity Manual, Special Report 209. October 1994. Appendix 9-IV.

As described in the HCM, to obtain a statistically significant value for saturation flow, it is necessary to record data for a minimum of 15 cycles with more than 8 vehicles in the initial queue. Data for cycles that did not have an initial queue of 8 or more vehicles was not included in the calculation of prevailing saturation flows. Field data sheets for each location are included in the **Appendix** of this report.

# SATURATION FLOW RESULTS

## Saturation Flow Calculation

Saturation flows were calculated for each approach at each study intersection using the methodology below.

The saturation flow is the inverse of the average time headway per vehicle. Adjusting for units, this relationship is shown below in **equation (1)**.

$$s = \frac{3600}{h} \qquad (1)$$

where

$s$ = saturation flow (vphgpl)
$h$ = average time headway (sec/veh)

The average time headway per vehicle is obtained directly from the data collected. **Equation (2)** yields the average time headway for one cycle.

$$h = \frac{(t_n - t_4)}{(n-4)} \qquad (2)$$

where

$t_n$ = time when the rear axle of the last vehicle queued at the beginning of green crosses the stop bar (sec)
$t_4$ = time when the rear axle of the 4th vehicle queued at the beginning of green crosses the stop bar (sec)
$n$ = number of vehicles queued at the beginning of green

## Lost Time Calculation

After a signal turns green, the first several vehicles in the queue experience start-up losses that result in their movement at less than the saturation flow rate. It was assumed that saturation flow occurred after the fourth vehicle.

## Summary of Saturation Flow Results

Resulting saturation flows, green time to cycle length ratios (g/C), number of cycles observed, and headways for each location are summarized in **Table 2.**

**Table 2.** Summary of Saturation Flow Results

| Location | Lane Type | g/C | Number of Cycles | Average Time Headway (sec/veh) | Saturation Flow (vphgpl) |
|---|---|---|---|---|---|
| 1. Southbound Commercial Street at Kuebler Road | | | | | |
| | Exclusive Through | 0.36 | 20 | 1.73 | 2077 |
| | Shared Through/Right Turn | 0.36 | 16 | 1.93 | 1861 |
| 2. Northbound Commercial Street at Madrona Avenue | | | | | |
| | Exclusive Through | 0.52 | 19 | 1.95 | 1843 |
| | Shared Through/Right Turn | 0.52 | 19 | 1.82 | 1981 |
| 3. Southbound Commercial Street at Owens Street | | | | | |
| | Exclusive Through | 0.68 | 15 | 2.00 | 1802 |
| | Shared Through/Left Turn | 0.68 | 14 | 1.98 | 1817 |
| 4. Northbound Commercial Street at Hoyt Street | | | | | |
| | Exclusive Through | 0.76 | 18 | 1.71 | 2103 |
| | Shared Through/Right Turn | 0.76 | 17 | 1.89 | 1900 |
| 5. Westbound Ferry Street at Liberty Street | | | | | |
| | Exclusive Through | 0.45 | 18 | 2.09 | 1721 |
| | Shared Through/Right Turn | 0.45 | 22 | 2.21 | 1629 |
| 6. Eastbound Mission Street and 25th Street | | | | | |
| | Exclusive Through | 0.46 | 16 | 1.80 | 1998 |
| | Shared Through/Right Turn | 0.46 | 17 | 1.97 | 1826 |

Study results show saturation flows ranging from 1629 vphgpl to 1981 vphgpl for shared through/turn lanes with an average saturation flow rate of 1835 vphgpl. The saturation flow rates for exclusive through lanes ranged from 1721 vphgpl to 2103 vphgpl with an average rate of 1924 vphgpl.

# AREA TYPE AND SATURATION FLOW RELATIONSHIP

Observed saturation flow rates were compared to area type characteristics to determine any correlation. Area type in this analysis was assumed to be defined primarily by employment and population density.

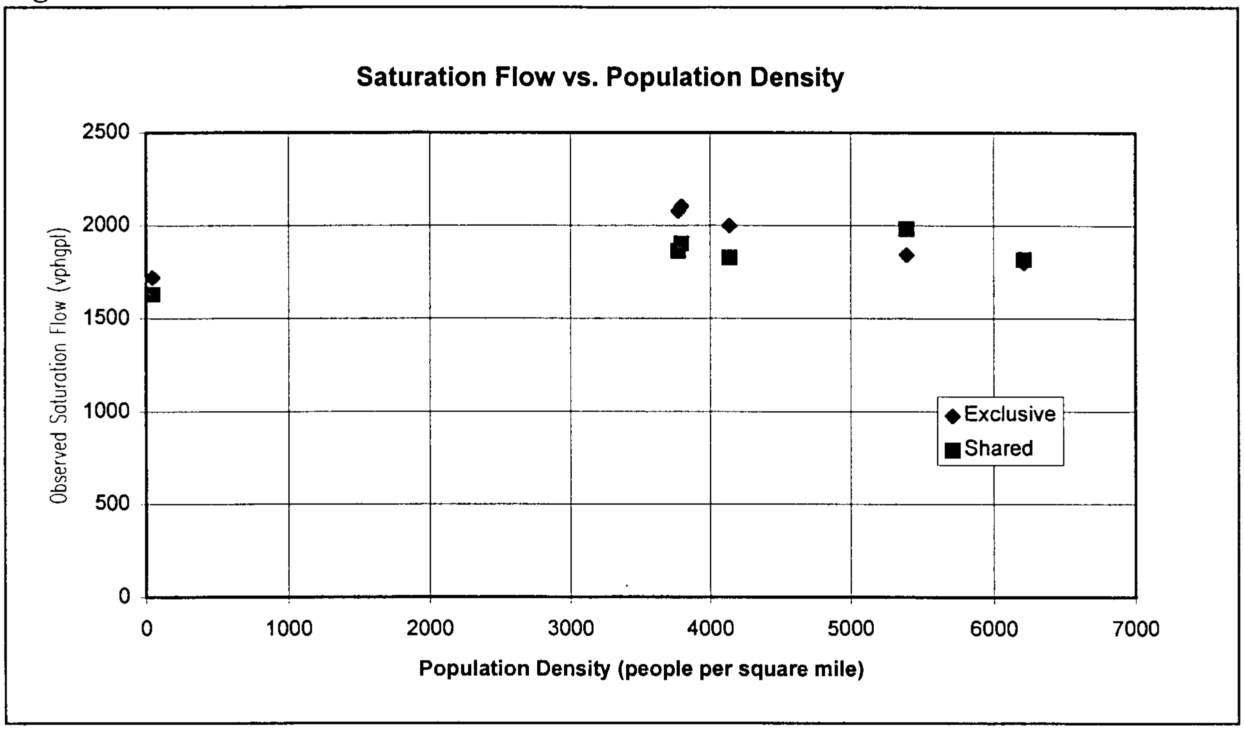
## Population and Employment Density

The observed saturation flow results were compared to population and employment density to determine if a correlation exists. Density for a specific location was determined by calculating the weighted average of population, employment, and combined population and employment densities based on the area of adjacent Transportation Analysis Zones (TAZ's). **Table 4** shows the average densities for each intersection. The average densities were plotted versus saturation flow rates in **Figures 1-3**. The densities for the TAZ's adjacent to each intersection, as well as the average density calculations are included in the **Appendix** of this report.

**Table 4.** Summary of Population, Employment, Combined Densities

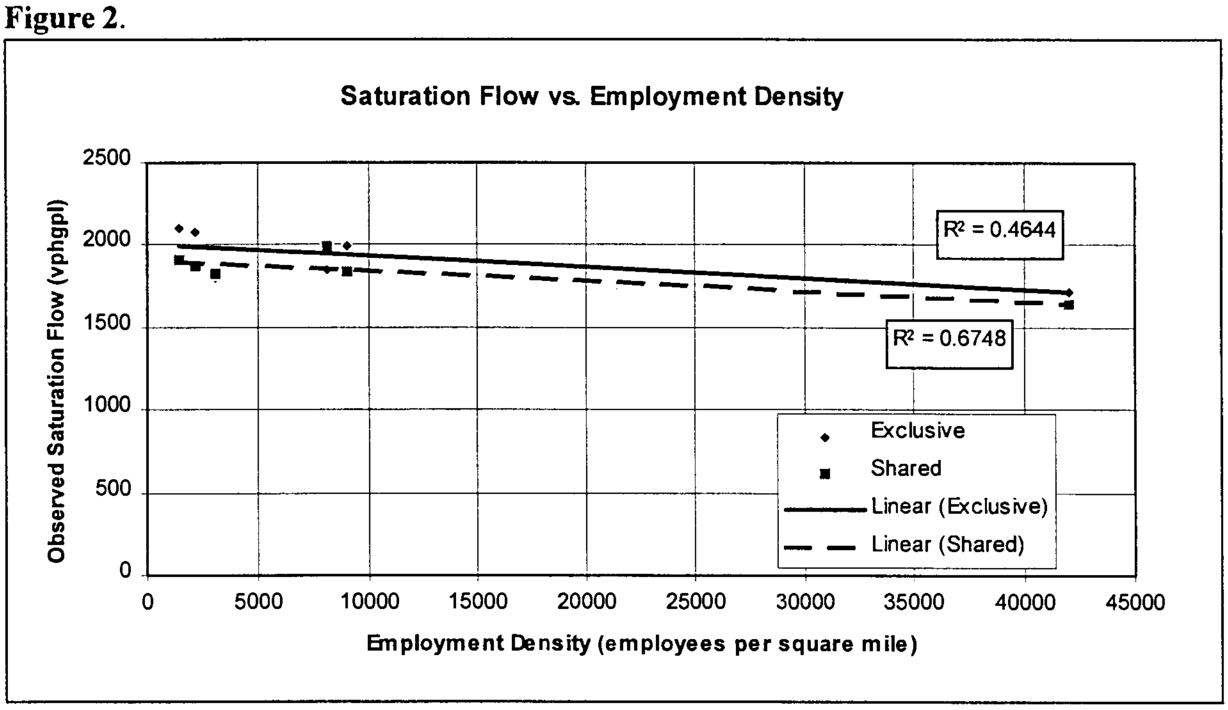
| Location | Population Density (people per sq. mi.) | Employment Density (employees per sq. mi.) | Combined Pop. + Emp. Density |
|---|---|---|---|
| 1. Southbound Commercial St. at Kuebler Rd. | 3774 | 2171 | 5945 |
| 2. Northbound Commercial St. at Madrona Ave. | 5393 | 8162 | 13555 |
| 3. Southbound Commercial St. at Owens St. | 6214 | 3120 | 9334 |
| 4. Northbound Commercial St. at Hoyt St. | 3797 | 1422 | 5218 |
| 5. Westbound Ferry St. at Liberty St. | 45 | 42033 | 42078 |
| 6. Eastbound Mission St. and 25th St. | 4853 | 4138 | 8991 |

**Figure 1.**




No clear relationship was observed between population density and saturation flow, as illustrated in **Figure 1.**

**Figure 2.**



As shown in **Figure 2**, saturation flows generally reduced with increased employment density. In addition, saturation flow in shared lanes was in most cases lower than saturation flow in exclusive through lanes. This was expected as traffic in shared lanes is often slowed by turning vehicles.

**Figure 3.**

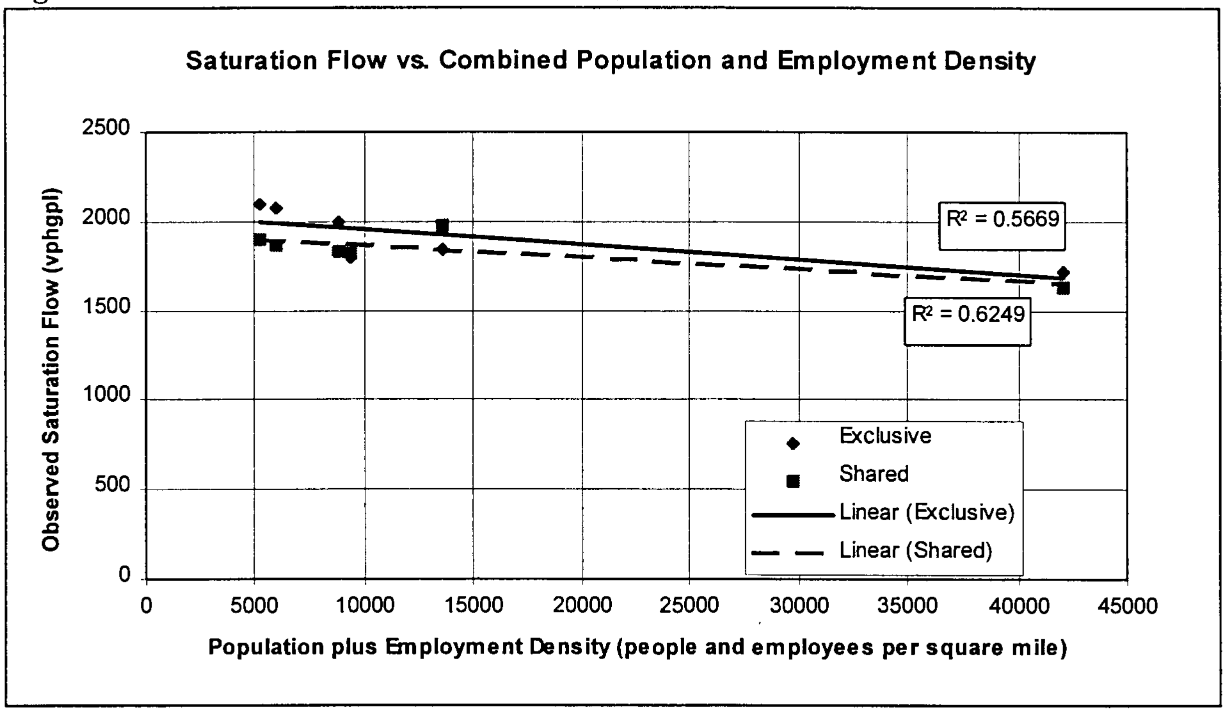



**Figure 3** illustrates results similar to **Figure 2**. Although a slight downward trend did occur in saturation flow as combined employment and population density increased, it is apparent that more surveys would need to be performed in order to obtain a more accurate correlation. A wider range of area types should also be examined.

# Other Characteristics

Characteristics other than density which can affect saturation flow rates are driveway spacing and volume, pedestrian activity, and transit activity. Although these characteristics are likely to be directly related to density, each was compared independently to the saturation flow data to determine if any strong correlation exists.

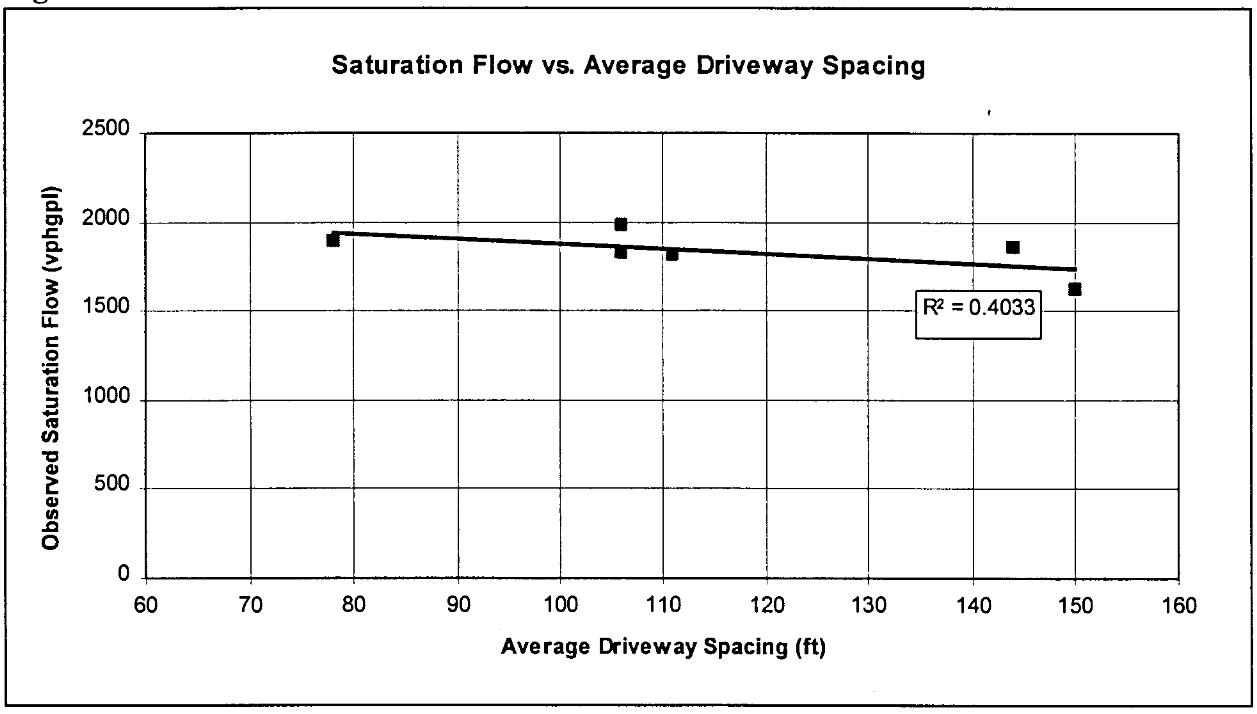
## Driveways

The distance from the stop bar to each driveway along the subject approach was measured at each study location to determine the average driveway spacing. **Table 5** summarizes the average driveway spacing for each location. The average spacing was plotted against the observed saturation flow rates for the shared through/turn lanes in **Figure 4** to determine if a relationship exists.

**Table 5.** Summary of Average Driveway Spacing and Pedestrian Activity

| Location | Saturation Flow (Exclusive) (vphgpl) | Saturation Flow (Shared) (vphgpl) | Average Driveway Spacing (feet) | Pedestrian Activity (peds/hr) |
|---|---|---|---|---|
| 1. Southbound Commercial St. at Kuebler Rd. | 2077 | 1861 | 144 | 5 |
| 2. Northbound Commercial St. at Madrona Ave. | 1843 | 1981 | 106 | 0 |
| 3. Southbound Commercial St. at Owens St. | 1802 | 1817 | 111 | 4 |
| 4. Northbound Commercial St. at Hoyt St. | 2103 | 1900 | 78 | 3 |
| 5. Westbound Ferry St. at Liberty St. | 1721 | 1629 | 150 | 36 |
| 6. Eastbound Mission St. and 25th St. | 1998 | 1826 | 106 | 0 |

**Figure 4.**

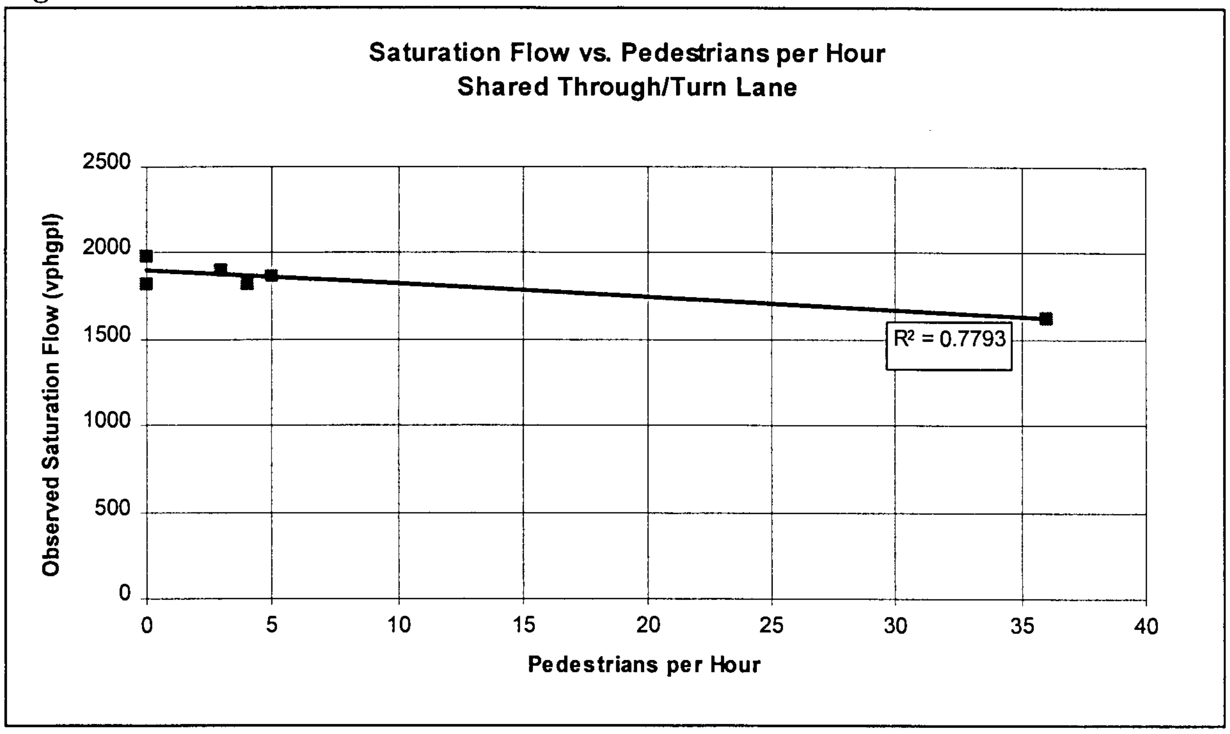



It was expected that with a decrease in driveway spacing, there would be a decrease in the saturation flow rate due to interference by driveway activity. However, this trend was not observed at the locations included in this study.

## Pedestrian Activity

Pedestrians were counted at each location during the data collection period. Pedestrians which would impede a turning movement were counted (those which crossed adjacent to the shared through/turn lane). An hourly pedestrian rate was calculated for each location and was compared to the saturation flow for the shared lane. The calculated pedestrian rates for each location were previously shown in **Table 5**. **Figure 5** shows a graphical comparison of the observed saturation flow rate for the shared lane and the pedestrian rate.

Figure 5.




As seen in **Figure 5**, the general trend was for saturation flow in the shared through/turn lane to decrease as pedestrian traffic increased. This relationship was expected due to the fact that pedestrians can impede turning movements, thus reducing the flow rate for that approach. Pedestrian volumes had the strongest correlation with saturation flow of all of the area type variables collected. However, using pedestrian activity as a method to calculate an area factor would be difficult to implement, given the required pedestrian data. More locations should be surveyed to more accurately determine the specific correlation between pedestrian activity and saturation flow.

## Transit Activity

Transit vehicles were counted for each location during the data collection period. Each location surveyed had 1-3 vehicles per hour, and therefore a range was not available to examine any correlation between saturation flow and transit activity. It would be necessary to study intersections with a wide range of transit activity to determine if a correlation exists.

# CAPACITY CALCULATIONS

Capacities for the through lanes on each subject approach were calculated using three different analysis techniques:

1. **PB Methodology.** Capacity was calculated using **equation 3** below, from the "Highway Network Capacity Specification, Draft Methodology". Left turn capacity was not considered in this analysis.

$$C = L \cdot (g / C) \cdot 1900 \qquad \textbf{(3)}$$

where

$C$ = capacity (vph)
$L$ = number of through lanes
$g/C$ = green to cycle ratio

2. **Highway Capacity Manual Methodology.** The HCM methodology for capacity analysis at signalized intersections was used to determine the capacity of the lane group. Several characteristics of the intersections where assumed in order to allow calculation of capacity, including the heavy vehicle percentage and the proportion of right turns. Highway Capacity Software was used to simplify this analysis.

3. **Observed Capacity.** Capacity was calculated by applying g/C to the observed saturation flows for each lane. This is represented by **equation 4**:

$$C = (g / C) \cdot \left[\sum s_i\right] \qquad \textbf{(4)}$$

where

$C$ = capacity (vph)
$g/C$ = green to cycle ratio
$s_i$ = observed saturation flow for ith lane (vphgpl)

The resulting capacities for each location are summarized in **Table 5**. Calculations are included in the appendix of this report.

**Table 5.** Summary of Capacity Results

| Location | Capacity (vph) | | |
|---|---|---|---|
| | **PB Method** | **HCM Method** | **Observed** |
| 1. Southbound Commercial Street at Kuebler Road | 1368 | 1347 | 1418 |
| 2. Northbound Commercial Street at Madrona Avenue | 1976 | 1929 | 1988 |
| 3. Southbound Commercial Street at Owens Street | 2584 | 2551 | 2461 |
| 4. Northbound Commercial Street at Hoyt Street | 2888 | 2803 | 3042 |
| 5. Westbound Ferry Street at Liberty Street | 1710 | 1502 | 1508 |
| 6. Eastbound Mission Street and 25th Street | 1748 | 1711 | 1759 |

Observed capacities were generally slightly higher than those calculated using the PB methodology. The exception is the downtown intersection (Location 5. WB Ferry St. at Liberty St.), where the observed capacity was significantly lower than the PB capacity. This is likely due to the impact of the area type on capacity. The HCM capacities were slightly lower than the PB capacities due to the additional saturation flow reduction factors for heavy vehicles and right turns. At Location 5, a further reduction was made in the HCM capacity because the intersection is located in the Central Business District.

# AREA TYPE ADJUSTMENT FACTOR

In order to capture the impact area type has on network capacity in travel demand models, an adjustment factor was developed which can be applied to the service flow rates calculated in the PB model. This area type factor, $f_{area}$, would be added to **equation 3** as shown below to create **equation 5.**

$$C = f_{area} \cdot L \cdot (g / C) \cdot 1900 \tag{5}$$

where

$C$ = capacity (vph)
$farea$ = area type adjustment factor
$L$ = number of through lanes
$g/C$ = green to cycle ratio

## Values of $f_{area}$

The following methodology was used to calculate values for $f_{area}$ as a function of both combined employment and population density and the number of through lanes:

The area type factor, $f_{area}$, relates the capacity calculated using the PB methodology shown in **equation 3** ($C_{pb}$) to the capacity calculated based on the observed saturation flows ($C_{obs}$). This relationship is shown in **equation 6.**

$$C_{obs} = f_{area} \cdot C_{pb} \tag{6}$$

where

$C_{obs}$ = capacity based on observed saturation flows (vph)
$farea$ = area type adjustment factor
$C_{pb}$ = capacity calculated using PB methodology (vph)

$C_{obs}$ was calculated for a range of densities by obtaining saturation flows from the fitted lines in **Figure 3**. $C_{obs}$ was also calculated for approaches of one, two, three, and four through lanes by summing the appropriate combinations of saturation flows for exclusive and shared lanes. $C_{pb}$ was calculated from **equation 3** for one, two, three, and four through lanes. The values for area type factor, $f_{area}$, were determined by inserted the calculated values for $C_{obs}$ and $C_{pb}$ into **equation (6)** and solving for $f_{area}$. The resulting values for $f_{area}$ are summarized in **Table 6.**

**Table 6.** Values of Area Type Adjustment Factor, $f_{area}$

| Combined Population and Employment Density (residents and employees per sq. mi.) | Number of Through and Shared Through/Right Turn Lanes | | | |
|---|---|---|---|---|
| | 1 Lane | 2 Lanes | 3 Lanes | 4 Lanes |
| 5,000 | 1.00 | 1.03 | 1.04 | 1.04 |
| 10,000 | 0.98 | 1.01 | 1.02 | 1.02 |
| 15,000 | 0.96 | 0.99 | 0.99 | 1.00 |
| 20,000 | 0.95 | 0.97 | 0.97 | 0.98 |
| 25,000 | 0.93 | 0.95 | 0.95 | 0.96 |
| 30,000 | 0.91 | 0.93 | 0.93 | 0.93 |
| 35,000 | 0.89 | 0.91 | 0.91 | 0.91 |
| 40,000 | 0.88 | 0.89 | 0.89 | 0.89 |
| 45,000 | 0.86 | 0.87 | 0.87 | 0.87 |

* May include shared through/left turn lanes on one-way streets.

The values in **Table 6** reflect the reduction in capacity observed as density increased. Factors were less than one for all locations with combined population and employment densities greater than 20,000 per square mile.

In determining these factors, it was assumed that the right-hand lane was always a shared through/right turn lane. In locations with exclusive right turn lanes, the area type adjustment factors would be slightly lower. The factors in **Table 6** provide a conservative estimate of capacity.

Capacity of exclusive left turn lanes was not included in this analysis. The factors in **Table 6** apply only to capacity for through and right turn movements.

Capacity of shared through/left turn lanes on two-way streets was not examined in this analysis. It is expected that roadways which allow permitted left turns from a shared through lane would have a further reduction in capacity.

The values in **Table 6** are based on a limited number of samples and should be used with caution. Additional data collection should be completed at locations ranging in density (15,000 to 40,000 persons and employees per square mile) to verify the relationship between density and saturation flow illustrated in **Figure 3.** Values for $f_{area}$ shown in **Table 6** should be updated if additional data collection is completed.

# CONCLUSIONS

An area type factor, $f_{area}$, was developed which can be applied to the capacities calculated in the PB model for through and shared through/right turn lanes. The purpose of this factor is to model the impact area type has on network capacity in travel demand models. Values of $f_{area}$ as a function of combined population and employment density and the number of through lanes are presented in **Table 6**.

The values for $f_{area}$ were determined by correlating saturation flows in through lanes and shared through/right turn lanes to density. Actual saturation flows were determined on approaches to six arterial intersection in the Salem/Keizer metropolitan area. The observed saturation flows were plotted against the density. Two trends were observed:

1. Saturation flow generally decreased as combined population and employment density increased.
2. Saturation flows for shared through/turn lanes were generally lower than saturation flows for exclusive through lanes.

While it was possible to calculate values of $f_{area}$ from the data collected, they are based on a limited number of samples and should be used with caution. Additional data collection should be completed at locations ranging in density density (15,000 to 40,000 persons and employees per square mile) to verify the relationship between density and capacity.

# APPENDIX