Sensitivity Analysis of Factors Affecting Road Widening Thresholds

Carlos Alba and Edward Beimborn

Abstract:

The decision to widen a highway is often a complex matter involving considerations of traffic flow, community impacts and costs. The paper will discuss factors affecting reasonable thresholds in terms of traffic volumes for roadway widening. Sensitivity analysis are conducted of the capacity of two-lane highways using procedures of the 2000 Highway Capacity Manual, to find the target threshold levels for road widening and to determine how those levels are affected by different geometric and traffic conditions. Threshold volumes on two-lane highways were found to be sensitive to the number of access points per mile and to the percentage of no passing zones. Other factors like lane width, shoulder width, percentage of trucks and directional split had only limited effects across typical ranges found in urban areas.

The research also examined the geometry of intersections needed to handle the traffic volume on the approaching two-way streets. Using the Highway Capacity Software 2000 (HCS). In order to accommodate threshold traffic volumes, it was determined that a minimum of two approach lanes are needed at intersections of two-way streets. The actual type used would be based on economic and operational estimates.

In addition the effects of the connectivity of local residential streets on traffic volumes on nearby arterials are examined. For that purpose a method to assess how local connectivity affects nearby arterial traffic volumes was developed using a regional travel forecasting model to assess traffic shifts under different conditions on local and arterial streets. This was done using a case study of Tallahassee, Florida region. The study revealed that improved connectivity can reduce arterial traffic levels depending on the relative speed on the arterial vs. that on local roads and the extent to which the arterial road carries through traffic. Impacts are the greatest when the speed differential between the arterial and local streets is small and there is limited through traffic.

These results indicate that communities need to carefully consider access points and geometric factors to get the best performance of their highway system given a specific land-use pattern. Excessive access point density and poor street connectivity will reduce the ability of two-lane highways to accommodate traffic.
INTRODUCTION

Perhaps no issue is more controversial for local communities than roadway widening. On one hand, there is a desire to widen roadways to add capacity and to accommodate traffic growth while on the other hand residents and businesses along the roadway often express concern about the widening and its potential impacts on their communities. It is a complex decision involving tradeoffs between the needs of road users and residents. It is also an expensive process, since road widening involves substantial construction costs as well as utility relocation and right of way costs. Such projects can take a long time to resolve and can need to anything from no action taken to a complete widening of the roadway in question.

Many factors could affect this decision including environmental impact, costs, potential disruption of homes and businesses and traffic growth. All are important and individual projects consider the factors in different ways. This paper will examine the issue of traffic levels and how different factors might affect the choice of a volume threshold which would be used to indicate if the roadway would be congested in the future.

This paper will not resolve any of these disputes, but will provide insight into how different factors could affect the setting of objective standards for road widening traffic volume thresholds.

A capacity analysis was necessary to conducted to find threshold levels for congestion. The capacity analysis has two parts. The first deals with the study of two lane highways. A threshold level was defined and sensitivity analyses were conducted based on procedures in the Highway capacity manual to see how they affected the threshold. Secondly, since the capacity of a roadway also depends on the capacity of its intersections, several types of intersections are also analyzed using the Highway Capacity Software 2000. This paper is part of a larger work that analyzes the relationship between land use patterns and road widening (5).

Definition of Threshold Level

The purpose of the capacity analysis in this study is to find a demand volume for the full peak hour (V), for which the level of service is located in the boundary between LOS D and E. For this paper this was considered a threshold for road widening. That means that when traffic volumes exceed this value, consideration should be given to widening as a means to avoid congestion. Obviously other situations or level of service definitions could be used. A community or agency could adopt higher or lower standards as it wished. Similar procedures as used in this paper would be useful to determine how various factors affect the threshold. This volume is calculated for the most probable conditions and also with a sensitivity analysis.
The research also uses the factors that affect roadway performance as defined in the Highway Capacity Manual. This assumes that the HCM provides a valid method of determining level of service and properly represents the factors that influence level of service. As new editions of the HCM are prepared, other factors may be found that affect performance.

“A two-lane highway is an undivided roadway with two lanes, one for use by traffic in each direction. Passing a slower vehicle requires use of the opposing lane as sight distance and gaps in the opposing traffic stream permit.” (Highway Capacity Manual, 2000). Due to its geometric and operational characteristics the level of service in a two-lane highway is measured not only in terms of travel speed but also in the inconvenience generated by the formation of platoons.

Level of service is calculated in the HCM 2000 based on two parameters: percent time-spent-following (PTSF) and average travel speed (ATS). PTSF reflects the convenience of travel and it is measured as the average percentage of time that vehicles spend following slower vehicles in a platoon. ATS is an indicator of mobility and it can be determined as the length of a highway segment divided by the average travel time of the vehicles present in both directions during a specific period of time.

The HCM defines two types of two-lane highways. The first one, Class I, is a two-lane highway in which drivers expect to reach high travel speeds. A major intercity route or a primary arterial connecting urban with suburban areas could be taken as an example for this category. Class II corresponds to two-lane highways that provide more accessibility than Class I. In this category drivers do not expect to travel at high speeds.

The sensitivity analysis presented in this paper considers principal arterials as two-lane, class I highways. In that case mobility is highly important and the level of service is calculated based on both the percent time-spent-following and the average travel speed using the criteria shown in Table 1:
Table 1: LOS Criteria for Two-Lane Highways in Class I
Source: Exhibit 20-2 HCM

For example, a road with a percentage spent following of 40 and an average travel speed of 55 mph will have a level of service B.

Figure 1 is the graphical representation of Table 1.

Figure 1: LOS Criteria (Graphical) for Two-Lane Highways in Class I
Source: Exhibit 20-3 HCM
A spreadsheet was developed to calculate the average travel speed, the percent time spend following, and the LOS for different traffic volumes and for the sensitivity analysis. The spreadsheet replicated the calculations process of the 2000 Highway Capacity manual and the highway capacity analysis software.

The purpose of the sensitivity analysis was to find out how each of the parameters used to calculate the average travel speed and the percent-time-spent-following affect the widening threshold. This is done varying one variable at a time and keeping all the others at a base case. Table 2 shows the base case values selected for the calculations. Most of these values are suggested in Chapter 12-Highway Concepts of the HCM 2000.

<table>
<thead>
<tr>
<th>Free Flow Speed Calculation</th>
</tr>
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<tbody>
<tr>
<td>Variable</td>
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<tr>
<td>Base Free Flow Speed (BFFS)</td>
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<tr>
<td>Lane Width</td>
</tr>
<tr>
<td>Shoulder Width</td>
</tr>
<tr>
<td>Access Points/mi</td>
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</table>

<table>
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<th>Demand Flow Rate Calculation</th>
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<tr>
<td>Variable</td>
</tr>
<tr>
<td>Peak Hour Factor (PHF)</td>
</tr>
<tr>
<td>Type of Terrain</td>
</tr>
<tr>
<td>Percentage of Trucks</td>
</tr>
<tr>
<td>Percentage of Recreational Vehicles (RVs)</td>
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<td>Type of Analysis</td>
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<table>
<thead>
<tr>
<th>ATS and PTSF Calculation</th>
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<tr>
<td>Variable</td>
</tr>
<tr>
<td>no-passing zones (%)</td>
</tr>
<tr>
<td>Directional split</td>
</tr>
</tbody>
</table>

Table 2: Base Case Values for Sensitivity Analysis

Although some of these parameters remain constant, others like lane width, shoulder width, access points per mile, percentage of trucks, percent of no-passing zones, and directional split take different values depending on the traffic and geometric conditions of the highway. Figures 2 through 7 show the behavior of each of these variables. Different traffic volumes were tested until a level of service between LOS D and E was achieved. After the sensitivity analysis was completed it was decided that a traffic volume of 1500 veh/h could be used as the threshold volume for the peak hour.
Several conclusions are drawn from Figures 2 to 7:

- As it is shown in Figure 2 and 3, lane width and the percentage of trucks do not have an important influence in the calculation of the threshold volume. Despite of the wide range of lane width values and percentages of trucks tested, the traffic volume necessary to reach the threshold volume is always 1514 veh/hr. This finding conflict with the common belief that the percentage of trucks has a big influence in the LOS. In the HCM 2000 the passenger-car equivalent for trucks $E_T$, obtained from Exhibit 20-9 or Exhibit 20-10, is very close to 1.0 especially when the flow rate is high and the type of terrain considered in the analysis is “Level.” If the road in question were located in ‘hilly’ or “mountainous” terrain, the effects of trucks would be greater.

- Shoulder width does not have an influence in the LOS estimation either unless, as shown in Figure 4, no shoulder is provided. In that case, the traffic volume needed to reach the threshold is 1314 veh/hr. For other shoulder width values, such as 2, 4 or 6 ft the traffic volume stabilizes at a number close to 1514 veh/h.

- Access-Point Density has a considerable impact on the threshold estimation when the total number of access points per mile on both sides of the roadway is equal or greater than 30. Figure 5 shows that whenever the number of access points is 40 (an average of 264 ft), the traffic volume required to reach the widening threshold drops down to 1044 veh/hr.

- The threshold level is also sensitive to the percentage of no-passing zones. As it is seen in Figure 6 the threshold traffic volume is inversely proportional to the percentage of no passing zones. When no-passing zones are not used, the threshold traffic volume is 1646 veh/hr while when passing is restricted the volume to reach the threshold level drops to 1320 veh/hr.

- Directional Split, which is the last variable analyzed in the sensitivity analysis, does not affect the threshold calculation as shown in Figure 7. When the directional split is equal to 90/10 the threshold is slightly lower (1397 veh/h) than for the other directional split configurations.
Figure 2: Traffic Volume Vs Lane Width

Figure 3: Traffic Volume Vs Percentage of Trucks
Figure 4: Traffic Volume Vs Shoulder Width

Figure 5: Traffic Volume Vs Access Point Density
Figure 6: Traffic Volume Vs Passing Zones

Figure 7: Traffic Volume Vs Directional Split
The graphics generated from the sensitivity analysis show how to determine the threshold volume. Lane width and the percentage of trucks do not have any relevance for level terrain; the traffic volume at the threshold level will always be 1514 veh/h. Shoulder width, on the other hand, only affects the traffic volume if it is equal or less than 2 ft. However, since class I two lane highways with typical conditions usually have shoulders greater than 2 feet, this variable does not substantially affect the threshold volume selection.

Access Points per mile is one of the most influential factors for the traffic volume selection but for a number of 10 to 20 points per mile, which could be considered as a typical range, the traffic volume remains at 1514 veh/h. Access points are considered to be points that contribute to changes in travel speed. Intersections, driveways, or median openings on the opposite side that are expected to have a significant effect on traffic flow in the direction of interest may be included when determining access-point density. Thus access management policies can be viewed as an effective method to avoid road widening.

The percentage of no-passing zones was also considered as influential but, for typical conditions, for example with 20% no-passing zones, the traffic volume needed is equal to 1514 veh/hr.

Finally, the threshold volume is very steady for different directional split configurations and for 50/50, considered as the typical condition, the traffic volume is 1514 veh/h.

For all these reasons a conservative estimate for the threshold volume for two-lane highways on level terrain would be 1500 veh/h. This number represents the traffic volume in both directions of travel during the afternoon peak hour. Using a peak hour ratio one could convert this hourly volume into a 24-hour volume. Table 3, for example, shows peak hour ratios calculated from the automatic traffic recorded data for Wisconsin (District 2). The average of all these ratios either by day, functional class or county is close to 8.2. That means that the 1500 veh/h calculated above represent 8.2% of the daily traffic. Then, the daily volume would be 18,293 vehicles/day. With a consideration for some ride sharing, a useful value for the threshold volume is 20,000 person trips or 18,000 vehicle trips per day.

There are some obvious policy implications from these findings: First and foremost they show how access management policies can be used to get better performance from two lane highways.
## Table 3 Peak Hour Ratios for Wisconsin (District 2)

<table>
<thead>
<tr>
<th>Station</th>
<th>County</th>
<th>Highway</th>
<th>Functional Class</th>
<th>Sun Ratio</th>
<th>Mon Ratio</th>
<th>Tues Ratio</th>
<th>Wed Ratio</th>
<th>Thurs Ratio</th>
<th>Fri Ratio</th>
<th>Sat Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>45-0001, Grafton</td>
<td>Ozaukee</td>
<td>I-43</td>
<td>R Principal Arterial - Interstate</td>
<td>8.1</td>
<td>8.1</td>
<td>8.0</td>
<td>7.9</td>
<td>7.5</td>
<td>8.3</td>
<td>8.1</td>
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<tr>
<td>45-0239, Port Washington</td>
<td>Ozaukee</td>
<td>I-43</td>
<td>R Principal Arterial - Interstate</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>8.1</td>
<td>7.7</td>
<td>8.8</td>
<td>7.6</td>
</tr>
<tr>
<td>66-0001, Allenton</td>
<td>Washington</td>
<td>USH 41</td>
<td>R Principal Arterial - Other</td>
<td>7.6</td>
<td>7.8</td>
<td>7.8</td>
<td>8.5</td>
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<td>8.8</td>
<td>7.4</td>
</tr>
<tr>
<td>66-0051, West Bend Freeway</td>
<td>Washington</td>
<td>USH 45</td>
<td>R Principal Arterial - Other</td>
<td>9.3</td>
<td>9.3</td>
<td>9.1</td>
<td>8.8</td>
<td>7.8</td>
<td>8.4</td>
<td>9.3</td>
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<tr>
<td>67-0001, Menomonee Falls #1</td>
<td>Waukesha</td>
<td>STH 175</td>
<td>U Minor Arterial</td>
<td>8.6</td>
<td>8.5</td>
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<td>8.2</td>
<td>7.9</td>
<td>9.3</td>
<td>8.6</td>
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<tr>
<td>67-0003, Sunnyslope</td>
<td>Waukesha</td>
<td>I-94</td>
<td>U Principal Arterial - Interstate</td>
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<td>7.3</td>
<td>7.4</td>
<td>7.0</td>
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<td>8.0</td>
<td>7.7</td>
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<td>67-0004, Menomonee Falls #2</td>
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<td>USH 41-</td>
<td>U Principal Arterial - Other Freeways</td>
<td>8.4</td>
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<td>8.2</td>
<td>8.2</td>
<td>7.4</td>
<td>8.0</td>
<td>8.3</td>
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<td>67-0010, Crowbar Rd</td>
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<td>67-0011, Busse Rd</td>
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<td>8.3</td>
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<td>8.2</td>
<td>8.0</td>
<td>7.4</td>
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<td>67-6107, Mukwonago</td>
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<td>8.7</td>
<td>8.6</td>
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<tr>
<td>67-6113, Poplar Creek</td>
<td>Waukesha</td>
<td>USH 18</td>
<td>U Principal Arterial - other</td>
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<td>8.7</td>
<td>8.7</td>
<td>8.4</td>
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<td>10.7</td>
<td>8.6</td>
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<tr>
<td>67-6114, Sussex</td>
<td>Waukesha</td>
<td>STH 74</td>
<td>R Principal Arterial - Other</td>
<td>9.9</td>
<td>9.8</td>
<td>9.6</td>
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<td>10.0</td>
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<tr>
<td>64-0002, Lake Geneva</td>
<td>Walworth</td>
<td>USH 12</td>
<td>R Principal Arterial - Other</td>
<td>8.9</td>
<td>9</td>
<td>8.9</td>
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<td>8.5</td>
<td>8.8</td>
</tr>
<tr>
<td>64-0348, Delavan</td>
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<td>I-43</td>
<td>R Principal Arterial - Interstate</td>
<td>7.7</td>
<td>7.8</td>
<td>7.7</td>
<td>7.9</td>
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<td>8.3</td>
<td>7.5</td>
</tr>
<tr>
<td>51-0001, Kilbournville</td>
<td>Racine</td>
<td>I-94</td>
<td>R Principal Arterial - Interstate</td>
<td>7.1</td>
<td>7.1</td>
<td>7.0</td>
<td>7.1</td>
<td>7.1</td>
<td>7.7</td>
<td>7.0</td>
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<tr>
<td>30-0004, State Line</td>
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<td>I-94</td>
<td>R Principal Arterial - Interstate</td>
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<td>6.9</td>
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<td>30-6109, Salem</td>
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<td>STH 50</td>
<td>R Principal Arterial - Other</td>
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<td>30-6117, Somers</td>
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<td>R Principal Arterial - Interstate</td>
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<td>6.9</td>
<td>7.2</td>
<td>7.8</td>
<td>6.8</td>
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</tbody>
</table>

**Average**

8.3 8.3 8.2 8.2 7.6 8.4 8.2
Intersections

Once the capacity of a two-lane highway under typical conditions was calculated the next step was to determine the geometry of the intersections needed to handle the traffic volume on the approaching two-way streets. A total of seven intersections were analyzed using the Highway Capacity Software 2000 (HCS). While most of the parameters were kept constant for all the intersections, others like the number of lanes and the phase combinations were modified. The following is a list of values used in this analysis for all the intersections.

- Lane width: 12 ft
- Volume: 1500 veh/h (750 veh/h for each approach).
- Pct Heavy Vehicles: 10%
- Peak Hour Factor: 0.90
- Grade: 0%
- Green time: 43 sec
- All Red: 2 sec
- Cycle time: 90 sec

The seven alternatives were developed in such a way so that the first alternatives would have the poorest geometric conditions. Other alternatives have geometric conditions that ensure enough capacity to accommodate the threshold volume calculated in the sensitivity analysis. For example, in alternative 1, the through, left, and right turning movements share one single lane per approach. Alternative 5 on the other hand, has an exclusive lane for through, left and right turning movements. Figures 8 through 11 show the traffic volumes and the geometric configuration of each of the alternatives which had an acceptable level of service.

Table 4 is a summary with the results from the capacity evaluation of the intersections. From Table 4 it appears that Alternatives 1, 3 and 4 (not shown) do not have sufficient capacity to handle the demand traffic volume of 1500 veh/h. These intersections all have only one through traffic lane. In order to accommodate threshold traffic volumes, two through lanes are needed. The actual type used would be based on economic and operational estimates. Thus, to accommodate threshold volumes, the intersections would have to provide at least two lanes for the through movement as for intersections in alternatives 2, 5, 6 and 7 as shown in Figures 8-11.
<table>
<thead>
<tr>
<th>Alternative</th>
<th>Cycle Length (sec)</th>
<th>Approach Delay (sec/veh)</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>146.9</td>
<td>F</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>22.6</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>156.8</td>
<td>F</td>
</tr>
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<td>4</td>
<td>90</td>
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<tr>
<td>7</td>
<td>90</td>
<td>15.1</td>
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</tr>
</tbody>
</table>

Table 4: Intersection level of service analysis results
Figure 8: Intersection Type 2

Figure 9: Intersection Type 5
Figure 10: Intersection Type 6

Figure 11: Intersection Type 7
Network Connectivity

Analyses were also conducted of how the connectivity of local residential streets relates to the traffic volumes on nearby arterials. Often two lane roadways have to be used for short trips because of poor connectivity between areas within neighborhoods. The hypothesis of this portion of the work is that improved connectivity of neighborhood streets will reduce the traffic volumes on nearby arterials. For that purpose a method to assess how local connectivity affects nearby arterial traffic volumes was developed. Detailed network descriptions of local streets and land use were used with in conjunction with a regional travel forecasting model to assess traffic shifts under different conditions on local and arterial streets. This was done using a case study of Tallahassee, Florida region. This paper is part of a larger work that analyzes the relationship between land use patterns and road widening.

Network Construction: The process used in this phase of the study involved the development of a detailed travel demand analysis of local street networks as part of a regional travel demand model. Local streets were coded in greater detail to show existing street patterns and then new links were added to provide better connectivity.

The arterial corridor selected for this analysis was divided in 44 segments. Figure 12 shows the western portion of the area before and after connectivity was improved. The original network of the City of Tallahassee had to be expanded to add all roads within the study area. Local roads were coded using the General Network Editor (GNE) as two-way streets. Speed was set at 15 and 25 mph for the local roads. Since the speed on the arterial will also have an impact on the travelers route selection it was set to: 25 mph, 30 mph, 40 mph and 50 mph. Multiple runs were made with different combinations of speeds to determine how they would affect flows. Major intersections were left as intersections with delay and new intersections connecting local streets were set as intersections without delay.

A final part of the study was a determination of the number of though trips in the study area, i.e. external-external trips. E-E trips were calculated using the select link analysis technique available in QRS II.

Full capacity constrained travel demand analyses of the Tallahassee network were conducted with the two networks using QRSII software. This process assigns traffic to the shortest travel paths on the network considering congestion levels and intersection delay. These were done multiple times with different initial speed combinations to determine how arterial traffic varies with changes in local connectivity.
FIGURE 12: Western Portion of the Tallahassee Study Area before and after connectivity improvements
**Results:** The traffic volume differences were compared for segments along the arterial. These almost always show a volume reduction for the connected network. The magnitude of the reduction depends on the relative speed of the arterial vs. that on the local roads. Very few arterial segments experienced a traffic volume increase.

The traffic impact along the arterial can be compared by looking to the traffic volume of the 44 segments considered in the analysis as shown in Figure 13. Figure 13 illustrates the decline in traffic on the arterial with improved connectivity based on the speed assumptions. Traffic declines along much of the route and the impact depends on local land use along the route, especially employment in sub zones.

The traffic volumes changes show how improvements in connectivity of the local streets reduce traffic volumes along the principal arterials as in Figure 14. The amount of reduction depends on the relative speed assumed on the arterials vs. that on local streets. When the initial speed on the residential streets is assumed to be 25 mph, more travelers will use the local streets instead of the arterial to reach their destinations. Consequently, there will be a larger traffic volume reduction on the arterial. In contrast, when the initial speed on the residential street is assumed to be 15 mph, fewer travelers will take the local roads to complete their trips and there will be a lower traffic reduction on the arterial. This occurs because of the path finding process of the travel demand software. Travelers are assigned to the minimum time path between their origin and destination. If there is a large speed differential, the shortest time path is shifted to the higher speed links and away from the slower links. If the speeds are nearly the same travelers will use the shortest distance paths and will use more internal links.

External-External trips account for an important percentage of the total vehicles traveling along the corridor. Changes in connectivity will reduce trips on the arterial by a fixed amount, but it will appear as a low percentage reduction if there is a lot of through traffic and as a high percentage if there is little through traffic. There are two numbers, provided percentage reduction in total traffic (including E-E trips) and percent reduction in local traffic (without E-E trips). This is illustrated in Figure 15.

Figure 15 provides a different interpretation for the traffic volume reduction on the arterial. In this case the traffic impact is measured as a percentage for the two scenarios: with or without external-external trips. When the speed on the local roads and the arterial are similar the traffic volume reduction on the arterial is higher. In this case, an 85% reduction of local trips (51% of all trips) on the arterial occurs when the speed on the arterial and the local roads is 25 mph.
Figure 13: Traffic Volumes Before and After Connectivity (Speed on the Arterial = 30 mph, Speed on Local Roads = 25 mph)

Figure 14: Traffic Volume Before and After Connectivity (Speed on the Local Roads = 25 mph)
This analysis demonstrates that arterials could experience reductions in local traffic with better neighborhood street connectivity depending on the speeds on both the local roads and the arterial. The effect varies from 4.0% when there is a large speed differential to 85.6% when speeds on the local roads and the arterial are equal. The major benefit of street connectivity is that it redistributes traffic on a network providing an overall increase in the capacity of the system. Consequently, improving street connectivity of residential streets could reduce the need for arterial highway widening by providing more options for local trips.

Nonetheless, there is a critical balance between connectivity and through traffic. Enough connectivity has to be provided so that residents of a neighborhood can easily move to all edges of the neighborhood and adjacent land uses but not to an extreme so that residential streets become attractive choices for through traffic. The question remains open regarding how much traffic neighborhood streets could take so that they do not become attractive choices for through traffic. In that respect more studies about design criteria, safety and livability levels of residential areas with interconnected street patterns are needed so that an appropriate level of traffic will occur.
Conclusions

Threshold volume was defined as the boundary between level of service D and E on a two-lane highway. A sensitivity analysis showed that the following factors are critical for getting the most effective use of two-lane highways based on calculated threshold volumes.

- Threshold volumes are sensitive to the number of access points along a two-lane roadway. This number should not be equal or greater than 30 per mile or a separation between access points should be more than an average of 330 ft. Local governments would do well to control access to their roads as a means to reduce the needs for road widening.

- The percentage of no-passing zones should be 20% or lower. Even though this percentage is often set for safety purposes it is the most critical variable in the LOS estimation.

- Shoulder width and directional split do not have a major influence in the LOS as long as the shoulder width is 2 ft or more and the directional split is 80/20 or lower. When the directional split is 90/20 the LOS threshold of a two-lane highway could drop substantially.

With these conditions, it was determined that the threshold volume for a two way street was 1500 vehicles per hour in both directions. Using time of day factors from traffic counts, this translates into a daily volume of 18,293 vehicles per day or about 20,000 person trips per day.

Since the capacity on a network also depends on the capacity of its intersections it is important to find the minimum operational conditions of the intersections required to accommodate the threshold volumes. Using the Highway Capacity Software (HCS) it was determined that for an intersection to accommodate threshold volumes, at least two approach lanes are needed in each direction, one that shares the through and the right turning movement and the other with shared through and left turning movement.

It is also clear that planning for better street connectivity can avoid or delay the need for roadway widening in growing areas. Its effectiveness depends on the speed differences between travel on the arterial vs that on local streets and on the amount of through traffic on the arterial. Residential and central business districts that have interconnected street patterns may be able accommodate more traffic. This is very difficult to do after the fact and needs to be considered as development projects are considered. Sound planning practice should encourage good connectivity in multiple directions for new developments. If this occurs at the time of development, arterials can be more cost effective and mobility can be improved local areas.
Results from this paper reveal that road widening can be avoided or postponed if communities can take steps to control access along their arterials and to provide better connectivity of local streets can help spread out traffic volumes more efficiently throughout a network. Road widening does not to be inevitable, its impacts can be reduced with proper planning and policy.

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