SUPERSIZED INTERSECTIONS VS GRIDDED STREET NETWORKS: COMPARING CAPACITIES & PEDESTRIAN ACCOMMODATION.

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ABSTRACT

While few New Urbanists could justify crossing a six-lane arterial road with a four-lane collector road, such large intersections – with huge expanses of pavement and an environment unfriendly to pedestrians – are becoming increasingly more common across the county. Using Synchro 7 to simulate over 1,200 scenarios, the results of this study present a strong quantitative case against such intersections and the associated hierarchical road networks that generate them. Overall, accommodating even modest levels of pedestrian activity will drastically reduce vehicular capacity, and the typical mitigation strategies such as porkchop islands and 2-stage crossings have a very minimal effect. Our results also quantitatively confirm that an equivalent gridded street network of smaller intersections is superior both in terms of accommodating pedestrians and overall vehicular capacity.

INTRODUCTION

Six-lane arterial roads are becoming increasingly more common, and many collector roads have become four-lanes wide. When such roadways meet, the intersections are frequently constructed with double left turn lanes as well as dedicated right turn lanes. This not only results in large expanses of pavement but also facilities that expect pedestrians to traverse as many as nine lanes of traffic at once.

The creation of these expansive and pedestrian-unfriendly arterial/collector intersections is considered by many to be a result of hierarchical street patterns and the isolation of different land uses. With the "predict-and-provide" mindset used in conventional transportation planning, the main roads found on hierarchical street networks must continually be expanded and widened in order provide enough capacity for both the trips originating on the main roads themselves as well as traffic derived from the unconnected portions of the street network. With land uses often separated and spread out, the resulting increases in vehicle miles traveled and overall traffic congestion end up concentrated on the relatively small percentage of through-movement roads found in hierarchical street networks; and the consequence of meeting this traffic demand on such a limited subset of roads results in these overly large intersections that are not only a barrier for pedestrians and bicyclists but also a hindrance for good urban form and appropriate land use.

Another problem that many metropolitan areas are running up against is that commercial developers, not unexpectedly, like to situate themselves along these high volume roads. In many cases, this situation has forced cities and DOTs into attempting to better accommodate pedestrians on roads and at intersections primarily designed for vehicular mobility. Not unexpectedly, trying to accommodate pedestrians at such intersections will increase vehicle delay and degrade vehicle level of service; however, neglecting such accommodations in many locations can also be a safety issue and an equity concern. Accordingly, the first objective of this study is to consider the effect of accommodating pedestrians on these large arterial/collector intersections in terms of vehicle delay and vehicle level of service. Secondly, and perhaps more importantly, we will compare those results to what would transpire in a fully connected, gridded street network consisting of an equivalent number of total lanes but spread across six smaller intersections.

In his work during the early 1990s, Walter Kulash explained that a gridded street network would have a greater capacity than a sparse hierarchical system with the same lane-miles due to a deficiency of scale at large intersections resulting in the loss of green time caused by large numbers of left turning vehicles (1). Our study takes Kulash's influential and widely held premise to the next level with a much more detailed investigation that helps quantitatively answer the question of whether a grid of smaller street can adequately handle a similar level of traffic volume while also better accommodating pedestrians.

INTERSECTIONS ANALYZED

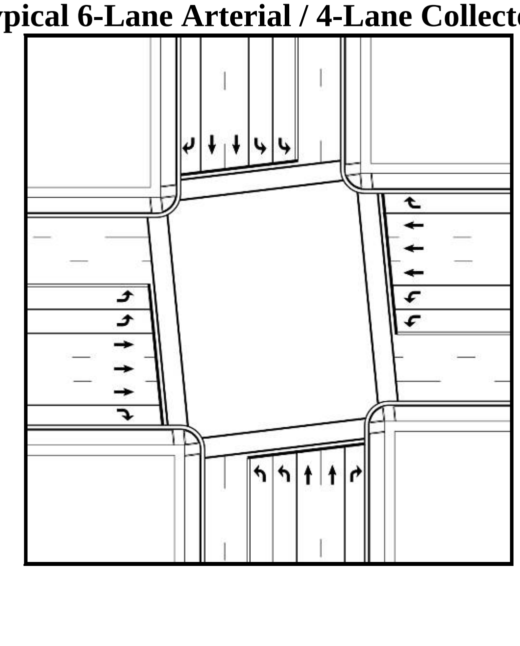
Attempting to mitigate congestion and delay, many municipalities continue to widen their existing roadways and intersections; case in point, there are many instances of a 6-lane arterial crossing a 4-lane collector located throughout the country. At such intersections, it is also not unusual to find turning volumes high enough to warrant double left turn lanes as well as dedicated right turn lanes. Combined these nine lanes of traffic would total 108' of pavement and could stretch more than 130' if the intersection were to have wider lanes, medians, and/or bike lanes. This trend – as well as the view held by most New Urbanists that a gridded network is not only friendlier to pedestrians but also more efficient in terms of capacity – is the impetus for this study.

Overall, we analyzed the following intersections and permutations thereof:

1. Intersection of 6-Lane Arterial and 4-Lane Collector
    a. Without Pedestrian Accommodations or Pedestrian Signal Timing
    b. With the Following Mitigation Strategies and Pedestrian Signal Timing
        i. Pedestrian Signal Timing Only
        ii. Porkchop Islands
        iii. Two-Stage Crossing (i.e. median refuge island)
        iv. Porkchop Island and Two-Stage Crossing
2. Fully Gridded Network of Six Intersection with Equivalent Number of Through Lanes

As a baseline, a hypothetical intersection of a six-lane arterial and a four-lane collector was analyzed without any pedestrian traffic. The next set of analyses was performed with the same intersection, but included pedestrians every cycle and various pedestrian accommodations. All of the above 6-lane arterial / 4-lane collector intersections are signalized with an actuated coordinated signal, double left turn lanes (protected only phasing), and dedicated right turn lanes where right turn on red movements are allowed. The width of all lanes is 12', and a pedestrian walking speed of 3.5 feet per second was used in accordance with the 2009 Manual on Uniform Traffic Control Devices (MUTCD) (2). Thus, for the 108' baseline arterial crossing width, a pedestrian requires 31 seconds to cross the arterial in addition to the standard 7 second walk interval.

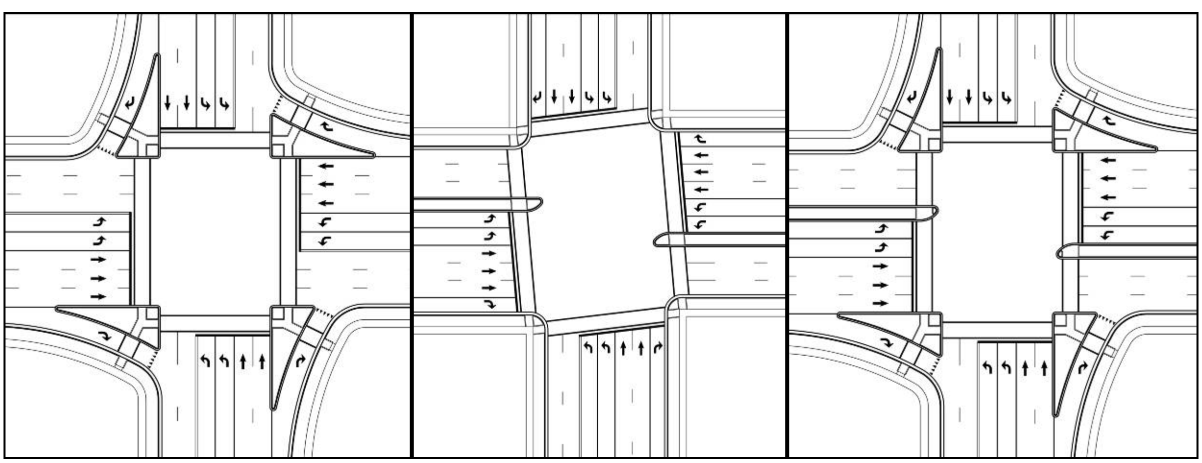
Figure 1 – Typical 6-Lane Arterial / 4-Lane Collector Intersection



Detailing the mitigation strategies for the 6-lane arterial / 4-lane collector intersections, the porkchop islands incorporate right turn slip lanes in an attempt to reduce pedestrian crossing distances while improve intersection performance for vehicles. In terms of capacity, the benefit of adding a right turn slip lane is to reduce delay experienced by right turning vehicles by allowing them to bypass the traffic signal where they are either required to yield to conflicting traffic or allowed to make the turn without stopping in a "free right" condition. Conversely in terms of the pedestrians, the major disadvantage of a right turn slip lane is that many are designed with large curb radii that encourage high speeds and are at odds with safely accommodating pedestrians (3). There are however new design recommendations in right turn channelization attempting to address this issue such as those by the Federal Highway Administration (FHWA) that recommend a large approach radius and a tight end radius; this combination attempts to compel slower speeds and a narrower view angle so that approaching drivers can see both pedestrians and conflicting traffic (3).

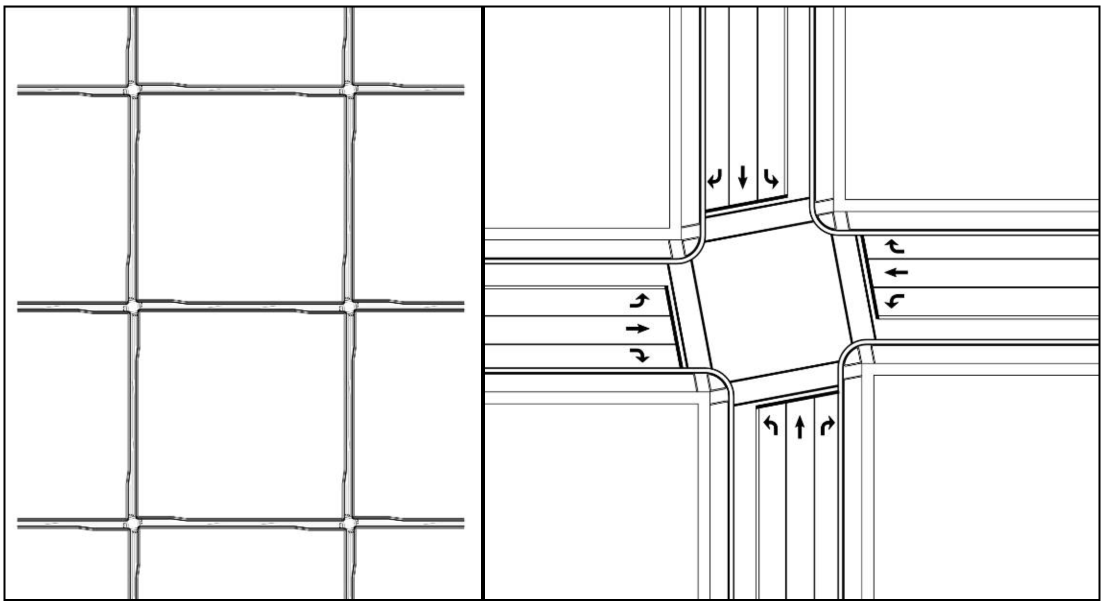
The two-stage arterial crossing mitigation strategy includes a median refuge island, which enables a two-stage pedestrian crossing sequence. When two-stage crossings are employed, the MUTCD allows pedestrian clearance times to be calculated from the nearest curb to "a median of sufficient width for pedestrians to wait" (2). It also requires median-mounted pedestrian signals along with pedestrian detectors if actuated operation is used in order to accommodate the pedestrian and keep them informed (2). This can be beneficial in reducing overall intersection delay in situations where the minor roadway has low volumes and the major roadway has very high volumes because the reduced pedestrian clearance time increases the available green time for the major roadway. While the MUTCD is vague on the recommended size of a pedestrian refuge area, the Oregon Bicycle and Pedestrian Plan is a little more specific in their design standards and recommends the island to be a minimum of 4' wide and preferably 8' or more (4). Accordingly, an 8' median was used for the analysis.

Figure 2 – Large Arterial / Collector Intersection with Right Turn Porkchop Islands, Two-Stage Arterial Crossings, and a Combination of Both, Respectively



The aforementioned series of six-lane arterial and four-lane collector intersections was then analyzed against a grid of two-lane roadways with an equivalent number of through lanes in each direction. Each intersection approach in the grid has one through lane, one left turn lane, and one right turn lane similar to the typical intersection design for many 'road diet' conversions. In order to maintain consistency between the larger intersections and the gridded network, we used 12' lanes, 10' turning radii, protected/permissive left turn movement phasing, and right turns on red allowed. We also did not include medians, bike lanes, or on-street parking. Also for the purposes of this analysis, each intersection was spaced a quarter-mile apart in order to limit the potential impact of queue spillback affecting vehicle delay and vehicle level of service results for each individual intersection.

Figure 3 – Equivalent Gridded Street Network and Close-up of Smaller Grid Intersection



METHODOLOGY

The analysis was conducted using hypothetical signalized arterial/collector intersections in Synchro 7. Traffic volumes were varied in intervals of 400 vehicles per hour (vph) from 400 to 6,800 vph on the arterial and from 400 to 3,600 vph on the collector for a sum of 117 traffic permutations tested for each intersection and 1,287 combinations total. For the base analysis, the intersection was initially analyzed without timing the traffic signal for pedestrian crossings. The traffic signal was then timed for pedestrian crossings every cycle and reanalyzed. The pedestrian clearance times were recalculated for each intersection type thereafter. Synchro uses methodologies from the 2000 Edition of the *Highway Capacity Manual* (HCM) to determine intersection delay. Within the program, overall signal timing and cycle length were optimized to produce the least amount of delay for all approaches. As a practical limit, a max cycle length of 120 seconds was used in the analysis.

Table 1 displays the traffic volume distributions – derived from past data collection efforts – that were applied to the hypothetical intersections (5). A PM peak hour traffic distribution was used in the analysis with 60% of the arterial traffic heading eastbound and 40% of the traffic going westbound. It was assumed that the volume on the collector split evenly in the northbound and southbound directions.

Table 1 -- Traffic Volume Distribution

Roadway	Split	Left	Through	Right
Arterial Eastbound	60%	15%	75%	10%
Arterial Westbound	40%	15%	75%	10%
Collector Northbound	50%	10%	75%	15%
Collector Southbound	50%	15%	75%	10%

Intersection delay was then used to describe the quality of the facility in terms of vehicle level of service; level of Service (LOS) is a qualitative measure used to describe the condition of traffic flow and delay that ranges from LOS A to LOS F as described in Table 2 (6). Most municipalities consider LOS D as the maximum acceptable vehicle level of service. Beyond LOS D, the intersection tends to break down with large queue lengths and long delays (6).

Table 2 -- Signalized Intersection Vehicle Level of Service Criteria (6)

Level of Service	Average Stopped Delay*	Description
A	<10	Very low delay. Most vehicles do not stop.
B	10 to 20	Generally good progression. Slight delays.
C	20 to 35	Increased number of stopped vehicles
D	35 to 55	Noticeable congestion.
E	55 to 80	High delays and frequent cycle failures.
F	>80	Forced flow. Extensive queuing.

*Seconds per vehicle.

For the gridded network, the same traffic distributions and movements used in the arterial/collector analyses were used again, except that the volumes were distributed evenly amongst the roadways in the grid. In other words, the total volume of traffic entering the grid system was the same as the approaches to the large arterial/collector intersection.

RESULTS

While it is generally agreed that large arterial/collector intersections are unfriendly to pedestrians, these intersections are all too common in many parts of the country. As a result, many municipalities are attempting to better design for the pedestrian within the context of the existing hierarchy system and discovering that such pedestrian accommodations are difficult to manage without significantly degrading intersection capacity. Figure 4 compares vehicular level of service for the large arterial / collector intersection without any pedestrian signal timings to that for the same intersection with pedestrian accommodations.

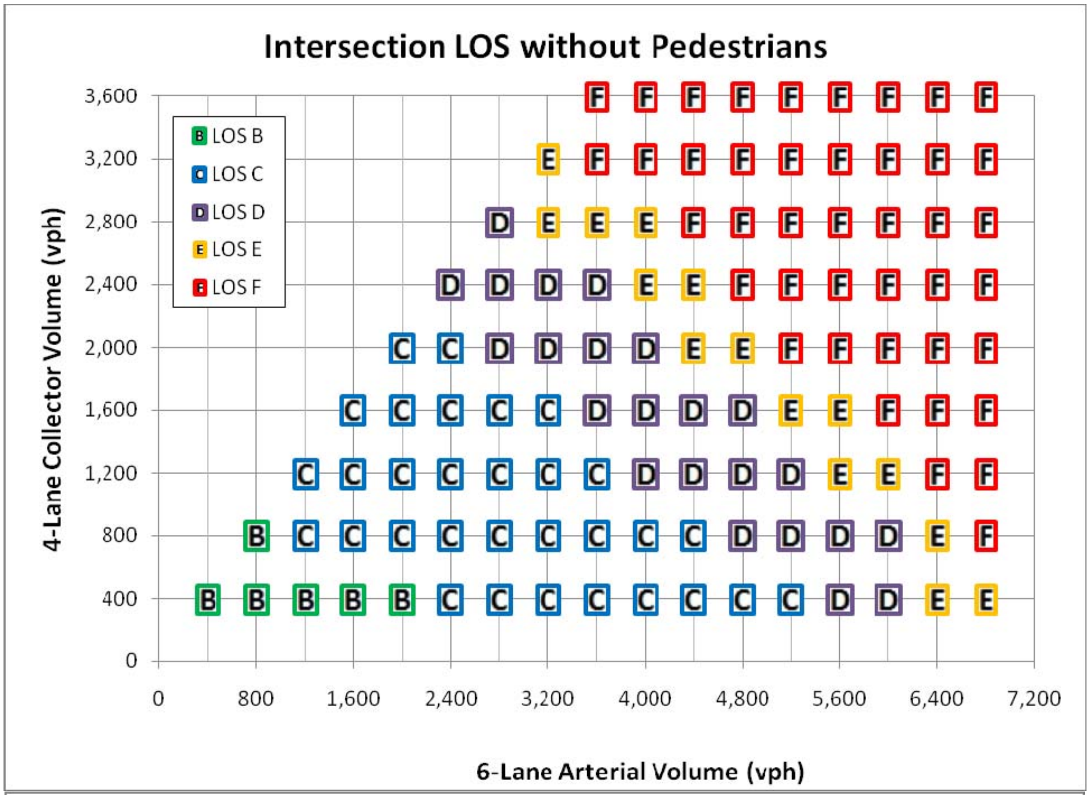
More specifically, when the traffic signal timing was modified to include pedestrian crossings every cycle, we found that 42 volume combinations of the 117 volume combinations degraded by at least one vehicle level of service. Of those 42 combinations, nine dropped two levels of service, and one dropped three levels of service. In terms of intersection capacity, 22 volume combinations dropped from an acceptable vehicle level of service (LOS D or better) to what most municipalities would qualify as an unacceptable vehicle level of service (LOS E or LOS F). Furthermore, the intersection was over capacity, regardless of the collector volumes, when the arterial reached 4,400 vph even though the intersection without pedestrian signal timings could reach 6,000 vph on the arterial before capacity.

Various mitigation techniques – such as porkchop islands and two-stage crossings with medians – seek to address this reduction in capacity while still accommodating the pedestrian. Figure 5 shows that both individually and in combination, these techniques make only very minimal improvements to intersection performance and capacity. The results effectively suggest that, except at combinations of the smallest vehicle volumes, conventional traffic engineering makes accommodating pedestrians while at these large intersections a very difficult proposition.

Although slight improvements in vehicle level of service were seen with each mitigation technique, most New Urbanists would argue that these solutions are barely even Band-Aids and simply a symptom of an overall broken system of street network design. Another possible answer is a gridded street network, and the results in Figure 6 show that a grid network is more efficient in terms of capacity, even when including pedestrian crossings every cycle. When compared to the large arterial/collector intersection with pedestrians, we found that 86 volume combinations improved by at least one vehicle level of service in the gridded network. Of those 86 combinations, 35 improved by two levels of service and four improved by three levels of service. In terms of intersection capacity, 29 volume combinations improved from a failing vehicle level of service (LOS E or F) to an acceptable vehicle level of service (LOS D or better). Furthermore, the grid system can handle up to 6,800 vph in the east-west direction of travel where the arterial could only handle 4,000 vph in the arterial/collector intersection when including pedestrians.

It should be noted that the levels of service depicted in Figure 6 represent the capacity of the grid but do not necessarily represent the amount of delay experienced by a driver as they traverse the full network. In other words, it is fair to say that in some cases, vehicle traffic moving completely through the gridded network might experience more overall delay than found with a single large intersection; however, in terms of overall vehicle capacity as well as accommodating pedestrians, the grid significantly outperforms the single large intersection.

FIGURE 4 -- ARTERIAL/COLLECTOR LOS WITHOUT PEDS AND WITH PEDS



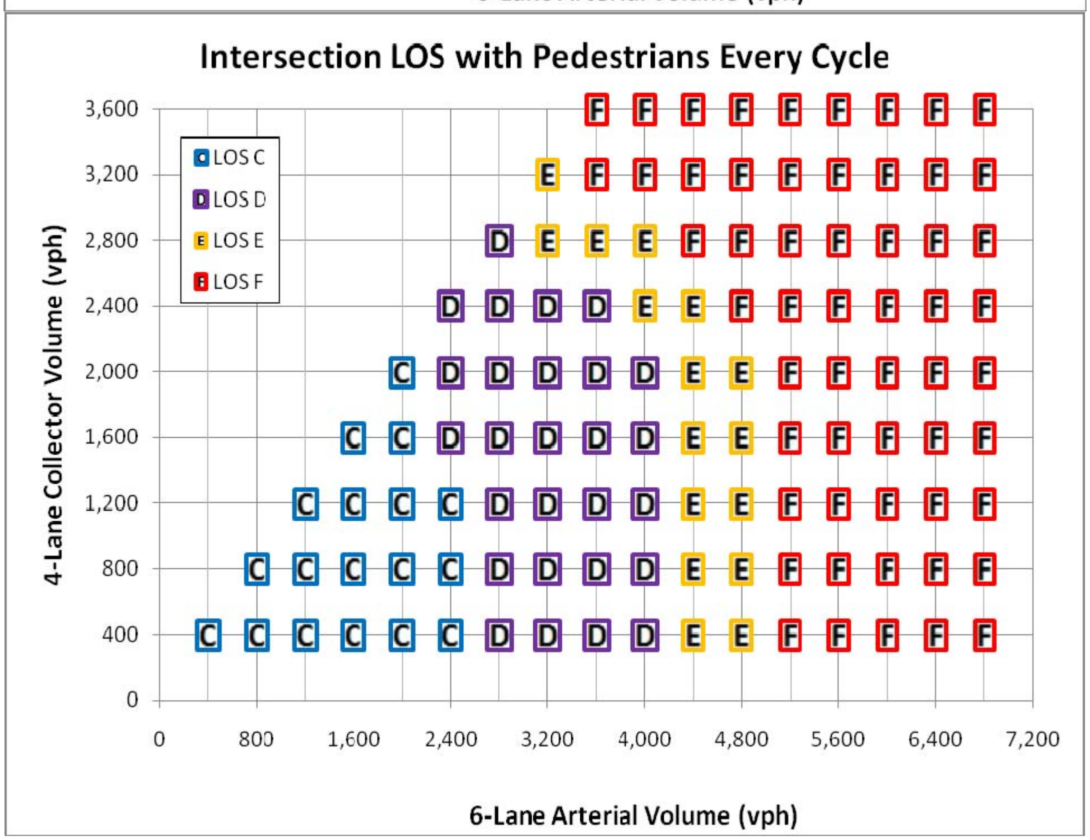


FIGURE 5 -- PORKCHOP LOS, TWO-STAGE CROSSING LOS, AND COMBINATION LOS.

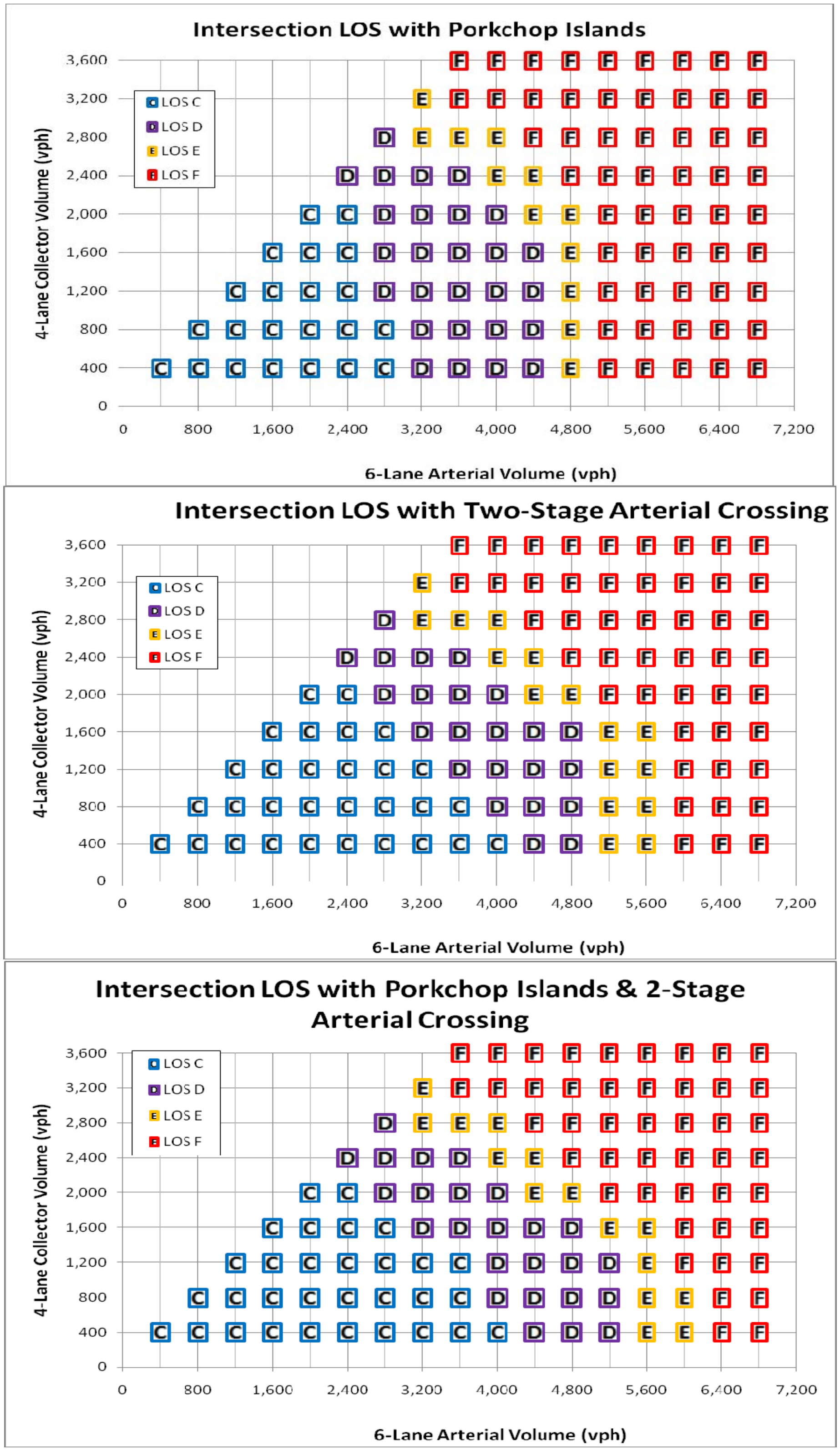
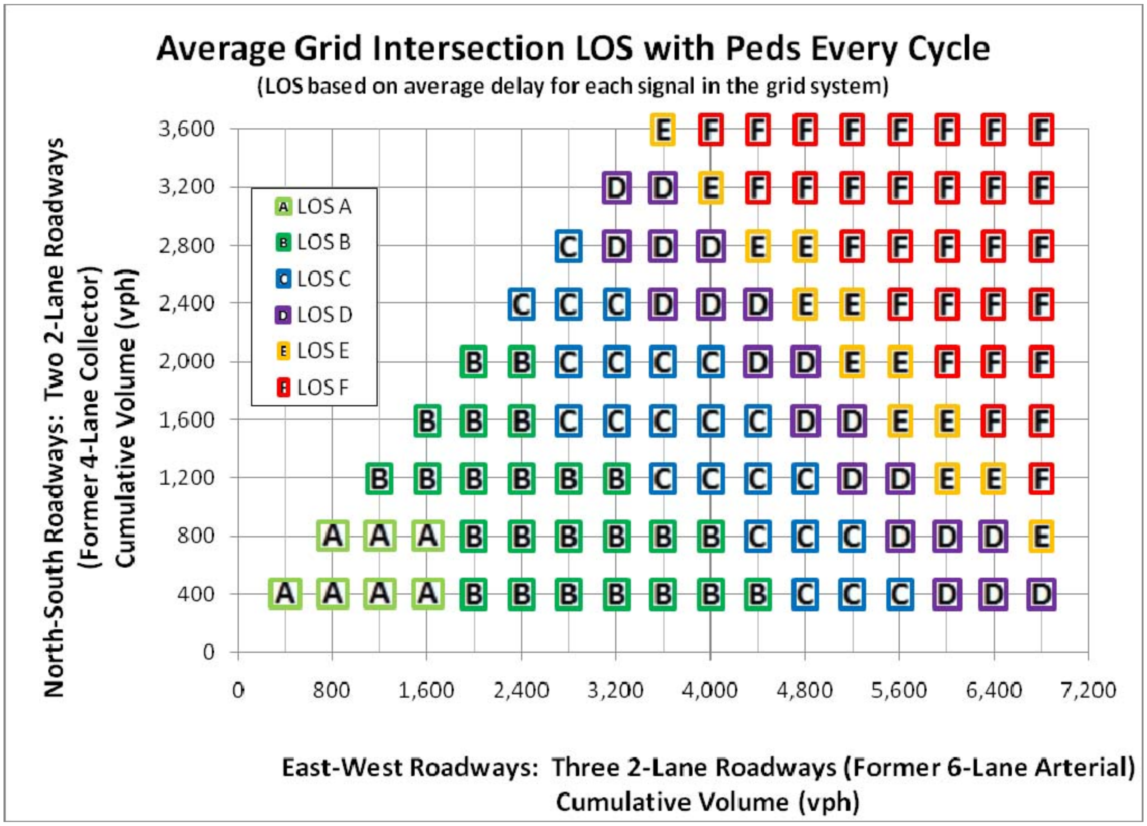


FIGURE 6 -- GRID PERFORMANCE



CONCLUSIONS

While few New Urbanists would ever advocate for a large intersection such as the one resulting from a 6-lane arterial and a 4-lane collector, the results of this study present a strong quantitative case against such intersections on two key levels. Firstly, our results demonstrate that accommodating even modest levels of pedestrian activity will drastically reduce vehicular capacity. Moreover, the typical mitigation strategies intended to correct such problems – such as porkchop islands and 2-stage crossings with a median – have very minimal effect on intersection functionality. Secondly, our results also confirm that a gridded street network of smaller intersections is superior both in terms of accommodating pedestrians but also in terms of overall vehicular capacity.

Overall, a gridded street network of two-lane roadways can accommodate both pedestrians in addition to much higher volumes of vehicles as compared to the large arterial/collector single intersection. The superiority in capacity even holds when the grid system is compared against the arterial/collector without any pedestrian accommodations whatsoever. This research presented results in terms of vehicle delay and vehicle level of service; while not ideal in terms of truly understanding the impact of these large intersections in a complete urban environment, these results should instead be used to clarify many of the misconceptions that conventional traffic engineers have with regard to such large arterials/collectors intersections.

Additional benefits of the grid system include real-time route decisions, increased levels of walking and biking, reduced vehicle speeds, and as some recent research is showing, safer roadways for all users (7, 1, 8). Critics may point out that the grid system increases overall vehicle delays for through traffic. The analysis done as part of this study agrees with this assertion; however, the analysis is limited in that it assumes all trips begin outside the grid, travel through the grid, and then exit the grid. Although this assumption was necessary in order to keep the volumes constant between the grid and arterial/collector analysis, we need to keep in mind that grids allow many trips to begin and end within the grid itself in addition to helping structure improved land use form. A gridded street network system offers real-time route decisions where pedestrians, bicyclists, and drivers – in addition to emergency vehicles – can find alternate routes based on current conditions while also facilitating shorter trips with more direct travel for any given pair of origins and destinations, which encourages walking and biking as a substitute for car travel (1, 8).

Although very slight improvements in vehicle level of service were seen with the typical large intersection mitigation strategies, the results in this paper present a strong case for solutions – such as a gridded street network of smaller intersections – that help both resolve the localized pedestrian and capacity issues while providing a better foundation for what is currently an inefficient transportation system of hierarchical street networks.

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