Network Connectivity for Low-Stress Bicycling

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When streets with high traffic stress—on which the mainstream population is unwilling to ride a bike—are removed, the remaining network of streets and paths can be fragmented and poorly connected. This paper describes the development of methods to visualize and to analyze the lack of connectivity in a low-stress bicycling network. A proposed measure to evaluate bicycling networks is the fraction of origin–destination pairs, which are connected without the use of high stress, without excessive detour, and with the origin–destination pairs weighted by travel demand. A new method is proposed to classify segments and crossings into four levels of traffic stress (LTS) on the basis of Roger Geller's classification of the cyclist population and Dutch design standards, which are known to attract the mainstream population. As a case study, every street in San Jose, California, was classified by LTS value. Maps that showed only lower stress links revealed a city divided into islands within which low-stress bicycling was possible, but these islands were separated from one another by barriers that could be crossed only with the use of high-stress links. The fraction was 4.7% of home-to-work trips up to 6 mi long that were connected at a low LTS value. The figure would almost triple if a modest slate of improvements were implemented to connect low-stress streets and paths with each other.

When bicycling is considered much of the population displays intolerance for the stress imposed by motor traffic, given the risk of injury. This intolerance is evidenced in the large difference in bicycle use between countries with and without widespread provision of bicycling infrastructure, such as cycle tracks (*1*) that separate cyclists from heavy traffic, as well as in surveys in which respondents cite traffic danger as one of the chief reasons not to ride a bike and in which they express a strong preference for bicycling on segregated paths and low-volume local streets (*2*).

Geller classified the adult population into four groups (*3*). His original estimates of each group's size are in parentheses, followed by estimates made later by Dill and McNeil (*4*):

- Strong and fearless (1%, 4%). Willing to ride in almost any traffic situation;
- Enthused and confident (7%, 9%). Willing to ride on busy, wide roads if a designated bicycling space (bike lane or shoulder) is provided;
- Interested but concerned (59%, 56%). Uncomfortable next to fast traffic or negotiating with traffic on busy roads; and
- No way, no how (33%, 31%). No interest in riding a bike.

The estimates by Geller (*3*) and by Dill and McNeil (*4*) had a basis in surveys in which people gave their reactions to biking in different traffic environments (e.g., on a four-lane arterial with a 35-mph speed limit, with bike lanes, and on streets with no on-street parking). Of those willing to use a bike, the interested but concerned group (elsewhere called "easy riders" or "traffic-intolerant riders") was estimated to represent more than 80% of all cyclists and potential cyclists (*5*). Thus it is no exaggeration to characterize the mainstream population as traffic-intolerant.

To attract more of the mainstream population to cycling, a primary concern should be the development of a network of low-stress routes that connect people's homes with destinations (e.g., workplaces, schools, shopping, recreation areas). In many American communities, it can be impossible to ride a bicycle between two given points without the use of links with high levels of traffic stress (LTS). For the traffic-intolerant population, this situation means that many destinations are inaccessible by bicycle.

It has been shown that in cases in which more bicycle route facilities are provided, more people ride a bike (*6, 7*). However, simply to measure miles of designated bike facilities can be misleading. Some designated bicycling facilities involve LTS values that most people will not tolerate, such as the bike lanes along the Camino del Norte in San Diego, California, which require cyclists to weave across one lane of 55-mph traffic and then ride in a pocket lane (i.e., a bike lane positioned between a right-turn lane and a through lane), with two lanes of fast traffic on their right and four lanes on their left. More important, if the lower stress links are not connected, trips from an origin to a destination cannot be completed without the use of at least some high-stress links.

The objective of the research reported here was to highlight the concept of low-stress connectivity as a means to evaluate a bicycling network and to develop tools to visualize and quantify low-stress connectivity. Planners know that the value of proposed bike network improvements often is related mainly to the connections they provide. This research provides a method to analyze that connectivity, which can then be used to help guide network development.

STREET SEGMENTS BY TRAFFIC STRESS

Connectivity becomes a problem in bicycling networks only when links with higher traffic stress links are removed. Therefore, a method is needed to distinguish links by their degree of traffic stress or by

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their degree of its opposite: comfort. Sorton and Walsh were perhaps the first to propose criteria for classification of road segments by comfort (*8*). They used three factors: traffic volume in the curb lane, traffic speed, and width of the curb lane (including any existing bike lane or shoulder). The criteria were chosen by an informal consensus of a large number of cyclists. The bicycle level of service model for road segments (*9*) and the bicycle compatibility index (*10*) build on their work to add the important effects of curbside parking and the availability of bike lanes. The model and the index use complex formulas estimated from ratings given by subjects to different road situations. Efforts to apply the same modeling approach to intersections were not as successful (*11*).

One shortcoming of the bicycle compatibility index and bicycle level of service methods is that they rely on data that are not readily available—particularly for traffic volumes and lane widths. Another is that these methods respond to volume in the curb lane. Thus they lead to a perverse result in the form of a road diet that reduces to one lane a road that formerly had two through lanes in each direction, which even with the addition of bike lanes increases the calculated stress. Third, the bicycle level of service and the bicycle compatibility index models are black boxes in the sense that, even if all of the data are available for a street section, its classification cannot be known without complex calculations. Consequently, the ratings obtained from the bicycle level of service and bicycle compatibility index methods have little meaning to planners and citizens. Finally, and germane to this research, these methods are used to find an average comfort rating across the entire population, whereas what is needed are comfort or stress thresholds for the different populations in Geller's classification.

Because of these shortcomings, a new rating scheme is proposed for LTS (Table 1) with criteria for the stress threshold of the population segments identified by Geller. The new scheme drops Geller's "no way, no how" group and adds a fourth group to represent children, who exhibit less ability than adults to control a bike along a narrow course, negotiate with traffic, and cross streets safely. The criteria used are consistent with the traffic environments used by Geller (*3*) and Dill and McNeil (*4*) to classify the population, and they have their basis in a synthesis of earlier research. The criteria for LTS 2, which correspond to the mainstream, traffic-intolerant adult population, have their basis roughly in Dutch design guidelines (*12*), which are similar to those used in other European countries with high bicycle use, such as Denmark (*13*), and have proved successful to attract the mainstream population, for example, with 80% of the Dutch adult population reported to ride a bike weekly (*1*). Modifications were made to account for the experience of North American cities such as Davis, California, which have had success in the attraction of the mainstream population to bicycling.

Criteria for Road Sections

Cycle tracks and shared use paths, which offer a physically separate cycling zone, are classified as LTS 1. (However, they may have a higher traffic stress at intersection approaches and crossings, as described later.) Bike lanes and mixed traffic, in contrast, can present a full range of stress levels, given their characteristics.

Criteria for bike lanes are presented in Table 2. LTS limits are given for each of several factors. Empty cells in the table occur when a factor has a limiting value for some, but not all, levels of stress. For example, in Table 2, a bike lane's reach from the curb (the second factor) has a limiting value for LTS 1, 2, and 3 but not for LTS 4. When aggregation is done over factors, the factor with the worst LTS value governs the LTS value of the section, as in Sorton and Walsh (*8*). Thus, for example, if a road section meets LTS 3 criteria for one factor and LTS 1 or 2 criteria for the other factors, it is classified as LTS 3.

As a comparison of values listed in Table 2 shows, lower speed criteria apply in bike lanes next to parking lanes in which cyclists face a hazard on their right (car doors) as well as on their left. Also, alongside a parking lane, the variable used to represent availability of operating space is not bike lane width but rather its reach from the curb (i.e., the combined width of the bike lane, parking lane, and any marked buffer).

Dutch guidelines indicate that bike lanes are an appropriate treatment on roads with one through lane per direction but not on multilane roads. In a departure from the classification methods described earlier, the proposed criteria use as a key factor the number of through lanes, rather than the daily traffic volume. The reasoning is that if cyclists have their own lane, the volume of traffic in the neighboring lane is not so important; more critical is the turbulence and speeding that occur on multilane roads, along with a more confusing environment in which cyclists are more likely to go unnoticed. However, 2+2 lane roads with bike lanes can still qualify as LTS 2 if they are divided and have no parking.

Bike lane blockage also is introduced as a criterion, because it forces cyclists into mixed traffic. Field research in three commercial

TABLE 1 LTS Definitions

LTS Level	Description
1	Demands little attention to traffic from cyclists and attractive for a relaxing bike ride. Suitable for almost all cyclists, including children trained to safely cross intersections. On road sections, cyclists are either physically separated from traffic or are in an exclusive bicycling zone next to a slow traffic stream with no more than one lane per direction, or are in mixed traffic with a low-speed differential and demanding only occasional interactions with motor vehicles. Next to a parking lane, cyclists have ample operating space outside the zone into which car doors are opened. Intersections are easy to approach and cross.
2	Presents little traffic stress but demands more attention than might be expected from children. On road sections, cyclists are either physically separated from traffic or are in an exclusive bicycling zone next to a well-confined traffic stream with adequate clearance from a parking lane, or are on a shared road where they interact with only occasional motor vehicles with a low-speed differential. Where a bike lane lies between a through lane and a right-turn lane, it is configured to give cyclists unambiguous priority where cars cross the bike lane and to keep car speed in the right-turn lane comparable to bicycling speeds. Crossings are not difficult for most adults.
3	Offers cyclists an exclusive cycling zone (e.g., bike lane) requiring little negotiation with motor traffic, but in close proximity to moderately-high-speed traffic or mixed traffic requiring regular negotiation with traffic with a low speed differential. Crossings may be stressful but are still considered acceptably safe by most adult pedestrians.
4	Requires riding near to high-speed traffic, or regularly negotiating with moderate-speed traffic, or making dangerous crossings.

TABLE 2 Traffic Stress Criteria for Bike Lanes

Lane Factor	Value by LTS Limit: LTS 1	LTS 2	LTS 3	LTS 4
Alongside a Parking Lane				
Street width (through lanes per direction)	1	na	2 or more	na
Reach from curb (sum of bike lane and parking lane width, including marked buffer and paved gutter)	15 ft or more	14 or 14.5 ft[a]	13.5 ft or less[a]	na
Speed limit or prevailing speed	25 mph or less	30 mph	35 mph	40 mph or more
Bike lane blockage (common in commercial areas)	Rare	na	Frequent	na
Not Alongside a Parking Lane				
Street width (through lanes per direction)	1	2, if directions are separated by a median	More than 2, or 2 without a median	na
Reach from curb (sum of bike lane and parking lane width, including marked buffer and paved gutter)	6 ft or more	5.5 ft or less	na	na
Speed limit or prevailing speed	30 mph or less	na	35 mph	40 mph or more
Bike lane blockage (typically applies in commercial areas)	Rare	na	Frequent	na

NOTE: na = not applicable.
[a]On noncommercial streets with speed limit ≤ 25 mph, any reach is acceptable for LTS 2 or 3.

zones in the Boston, Massachusetts, area found that 45% of cyclists had to leave the bike lane, because it was blocked for reasons such as double-parked cars, parking maneuvers, people getting into or out of cars, and stopped buses (*14*).

Criteria for mixed traffic sections are given in Table 3. Speed thresholds were lower than they were in cases in which cyclists had a bike lane. The finding was consistent with research that showed that cyclists felt less stress when in a marked bike lane than in a shared lane (*15, 16*) and was consistent with Dutch guidelines (*17*). Also consistent with Dutch guidelines, shared streets (i.e., streets without a marked centerline) were considered less stressful than shared lanes, provided that traffic volume was less than 3,000 to 4,000 vehicles per day. The lack of a centerline guided motorists to keep to the center, which effectively reserved the margins for bikes and emphasized that road space was meant to be shared.

Criteria for Intersection Approaches with Right-Turn Lanes

Right-turn lanes can create stressful weaving conflicts and confusion over right-of-way on intersection approaches with cyclists in mixed traffic or in a pocket bike lane. Criteria for intersection approaches with right-turn lanes are given in Table 4, with Dutch guidelines, which are consistent with the preferred practice given by AASHTO (*18*), used as a basis for LTS 2. For LTS 2, the cyclist's right-of-way at the merge point should be unambiguous, and traffic in the right-turn lane should be moving at or below the bicycling speed by virtue of a short turn lane and a sharp turn angle.

Where there is a right-turn lane and no pocket bike lane is marked, it is common behavior for through cyclists to use the right-turn lane, which works well if right-turn volume is low and the turn lane geometry ensures a low traffic speed.

Criteria for approaches with right-turn lanes apply to the entire block on which they are present.

TABLE 3 LTS in Mixed Traffic

Speed Limit	LTS Value by Category: No Marked Centerline and ADT ≤ 3,000 Vehicles per Day	Through Lanes per Direction: 1	2	3+
Up to 25 mph	1	2	3	4
30 mph	2	3	4	4
35+ mph	4	4	4	4

NOTE: ADT = average daily traffic.

Criteria for Crossings

Signalized crossings are assumed to present no additional traffic stress. However, unsignalized crossings can be a barrier if the street to be crossed has many lanes or carries fast traffic. Criteria for unsignalized crossings are presented in Table 5. Dutch criteria for unsignalized crossings (which apply equally to pedestrians and cyclists) do not allow crossings of more than two lanes. In this respect, the LTS 2 criteria depart from Dutch practice by allowing crossings of streets with up to four through lanes, as well as a turning lane in cases in which the speed limit is 30 mph or less. Such crossings may be unpleasant, perhaps unsafe (statistically speaking), and they may be a barrier to children. However, they are not a barrier to most American adults.

To apply the crossing stress classification to a network model that seeks paths that do not exceed a given stress level, one modeling device is to model all crossings as links. However, this approach greatly expands the network size. Instead, the stress involved to cross a main street was applied to the approaching blocks on the side street.

Application to San Jose, California

With the use of such criteria, every street and every path segment in the city of San Jose, California, were assigned an LTS value. A large majority (64%) of the street and path miles were classified as LTS 1,

TABLE 4 LTS Values for Intersection Approaches with Right-Turn Lanes

Configuration	LTS Value
With Pocket Bike Lane	
Single right-turn lane up to 150 ft long, starting abruptly while the bike lane continues straight, and intersection angle and curb radius such that turning speed is ≤15 mph.	2
Single right-turn lane longer than 150 ft starting abruptly while the bike lane continues straight, and intersection angle and curb radius such that turning speed is ≤20 mph.	3
Single right-turn lane in which the bike lane shifts to the left, but intersection angle and curb radius are such that turning speed is ≤15 mph.	3
Single right-turn lane with any other configuration; dual right-turn lanes; or right-turn lane along with an optional (through-right) lane	4
Without a Pocket Bike Lane	
Single right-turn lane with length ≤ 75 ft; intersection angle and curb radius limit turning speed to 15 mph.	(No effect on LTS)
Single right-turn lane with length between 75 and 150 ft; intersection angle and curb radius limit turning speed to 15 mph.	3
Otherwise	4

NOTE: There is no effect on LTS if the bikeway is kept physically separated from traffic, as on a shared-use path.

which reflected the prevalence of local streets, while 20% were rated as LTS 4.

The main data sources used were a regional path database and a regional street database, which provided the number of lanes, speed limit, and classification. Roads classified as residential were assumed to have no centerline and to have an average daily traffic volume of fewer than 3,000 vehicles. Field data collection on bike-lane width and right-turn lane configurations were carried out at selected points. Further information on data sources and data processing can be found in the project's final report (*19*).

VISUAL DISPLAYS OF CONNECTIVITY

Although most of the street-miles in the case study had a low LTS value, they tended to be poorly connected to one another. Between neighborhoods, the only connection often was a higher stress link. As a result, a map limited to low-stress links can have the appearance of ice floes, with clusters of connected segments separated from one another by high-stress barriers. An example in central San Jose displays obvious connectivity problems (Figure 1).

Another way to visualize connectivity of a network limited to low-stress links is to display clusters (i.e., sets of segments that connect to one another) in different colors, as illustrated in Figure 2. As can be seen, San Jose State University and San Jose City College belong to different clusters, which indicates that no route between them is classified as LTS 2 or lower. The boundaries between these islands of connectivity are barriers that can be crossed only by using a higher stress link.

TABLE 5 LTS for Unsignalized Crossings

Speed Limit of Street Being Crossed	Width of Street Being Crossed: Up to 3 Lanes	4–5 Lanes	6+ Lanes
Up to 25 mph	1	2 (1)	4 (2)
30 mph	1	2	4 (3)
35 mph	2	3	4
40+ mph	3	4	4

NOTE: Values in parentheses apply if there is a median pedestrian refuge.

A close look at Figure 2 reveals three main types of barriers. One barrier is made up of linear features that require grade-separated crossings (e.g., freeways, railroads, creeks). Because of the cost of grade-separated crossings, crossing points tend to be widely spaced. This practice in turn concentrates traffic, which leads to many multilane crossings, often with long, intersection-free approaches that foster high speed. Freeway crossings with high-speed on- and off-ramps are particularly stressful. However, freeway crossings that lack access ramps are particularly helpful for low-stress connectivity, as are footbridges that cross linear barriers. San Jose has 11 footbridges that link local streets severed by freeway construction and facilitate the search for low-stress routes.

A second common type of barrier consists of multilane, high-speed arterial streets for which a low-stress crossing demands a low-stress approach and safe crossing provisions, mainly traffic signals. Along some arterials, traffic signals are provided only at intersections with high-traffic cross streets, which themselves have a stressful cycling environment. At junctions with lower-volume streets that are signalized, the approaches often have been widened through the addition of right-turn lanes, which increases the traffic stress of the approach.

The third type of barrier consists of breaks in the street grid. In newer suburban areas, grids often are left incomplete deliberately to force through traffic to use arterials. An unfortunate side effect is that the incomplete grids also force through bikes onto the arterials. Permeable barriers (closed to cars but passable on a bicycle and on foot) are preferred, because they foster low-stress connectivity but do not enable cut-through motor traffic.

DETOUR CRITERIA AND POINT-TO-POINT CONNECTIVITY

Cyclists have a limited willingness to go out of their way to find a lower-stress bike route. One study of nonrecreational cyclists in Vancouver, British Columbia, Canada, found that 75% of cyclist trips were within 10% of the shortest distance possible on the road network, and 90% were within 25% (*20*). This small level of average detour is consistent with a 1997 study of bicycle commuters by Aultman-Hall et al., who also found, however, that people were more likely to go out of their way to take a route with more green cover and more bicycle-actuated signals (*21*). Broach et al. found that commuting cyclists in Portland, Oregon, were willing, on average, to add

FIGURE 1 Stress map: LTS 1 (green) and LTS 2 (blue) links only.

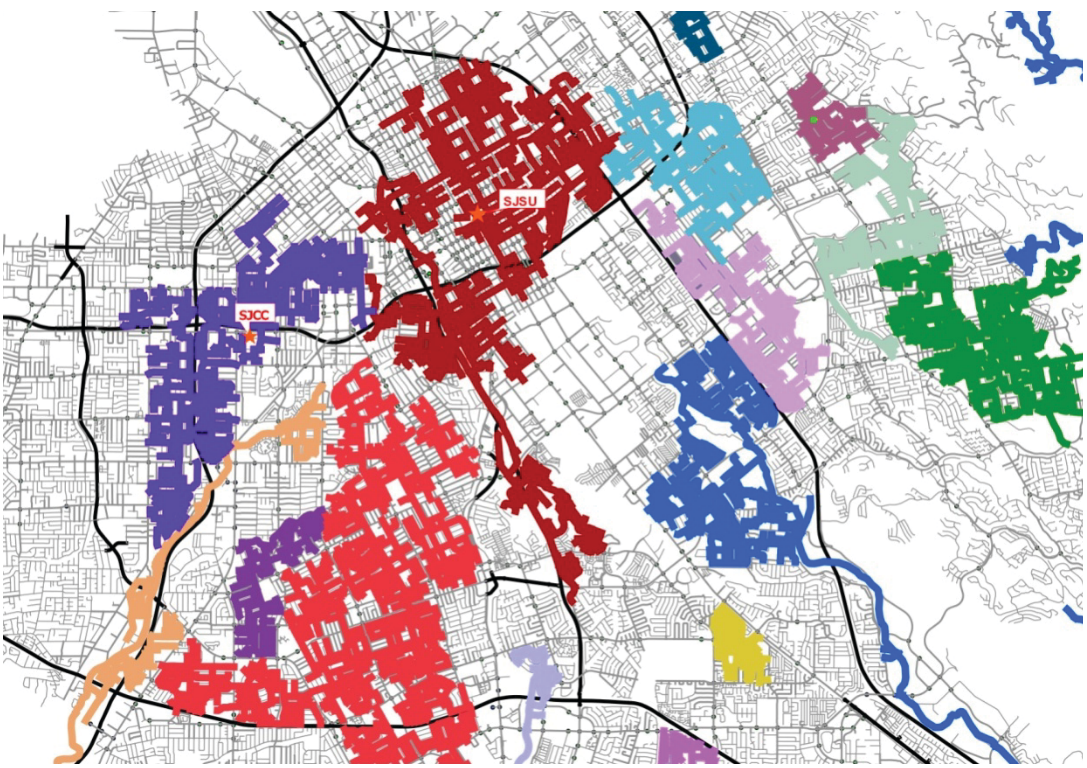

FIGURE 2 Selected connectivity clusters at LTS 2 [markers indicate San Jose State University (SJSU) and San Jose City College (SJCC)].

16% to their trip length to use a bike path and to add 11% to use a low-stress route along local streets (*22*). For noncommuting cyclists, those figures were 26% and 18%, respectively.

For this present study, two points were said to be connected at LTS k if a route connected them that avoided links with LTS > k and whose length, L_k, satisfied the following detour criterion:

$$\frac{L_k}{L_4} \leq 1.25$$

or

$$L_k - L_4 \leq 0.33 \text{ mi} \quad (1)$$

where L_4 is the shortest path with links of any level of stress on which bicycling is permitted. In other words, the low-stress route must not be more than 25% longer (or, for short trips, more than 0.33 mi longer) than the shortest route. Additional research would be of value to refine this criterion, including research to account for other factors that affect route choice (e.g., hills, frequent signal delay, natural beauty, crime).

When links are aggregated to form a route, weakest link logic is applied, in that the LTS value of a route equals the LTS value of the most stressful link. The process can be distinguished from the more common calculus in network analysis in which link costs (travel time, impedance) are summed.

The detour criterion is not accounted for when stress islands are mapped. Therefore, points that belong to the same cluster may actually not be connected, because they involve an excessive detour, as is the case for some of the clusters in Figure 2.

SUMMARY MEASURE OF CONNECTIVITY

In principle, it is possible to query every pair of points in the network to determine which pairs are connected at each LTS value. At the population level, results for these pairs should be weighted, and more weight given to origin–destination pairs used frequently. When a trip table (daily volume of trips between pairs of zones) is available, a summary measure of the capability of a bicycling network to provide connectivity at a given LTS value is the fraction of trips in the trip table whose origin and destination are connected at that LTS value. Mathematically,

$$cr_k = \frac{\sum_{i,j} T_{ij}\delta_{ijk}}{\sum_{i,j} T_{ij}} \quad (2)$$

where

cr_k = connectivity ratio for LTS k,
T_{ij} = number of trips per day from i to j, and
δ_{ijk} = 0/1 indicator of whether origin i is connected to destination j at LTS k.

If a large fraction of a region's daily trips can be made by bike at a low LTS, that bicycle network serves the mainstream population well. If not, it suggests that a lack of low-stress connectivity is hampering widespread bicycle use.

For the city of San Jose, the connectivity ratio at each LTS was calculated for work trips with the use of a trip table obtained from the local metropolitan planning agency. Three adaptations to Equation 2 were made in recognition of the nature of bicycling: the use of small geographical units, the discount of long trips, and the discount of short trips.

Regional trip tables normally use traffic analysis zones (TAZs) as the geographic unit of analysis. The TAZs were considered too large a geographic unit for bicycle routing, because many include internal barriers (e.g., freeways and arterials that lack low-stress crossings). As a result, one part of a TAZ may be connected to a low-stress route, while another is not. Therefore, demand data were disaggregated to census block level. Origins were allocated over blocks within a TAZ in proportion to block population. Destinations, too, were allocated over blocks in proportion to block area and an attraction coefficient that reflected the relative strength of the zoned land use in the attraction of trips, with the approach used in Furth et al. (*23*). Attraction coefficients were developed for almost 100 land use codes, which ranged from three for the downtown core area to 0.01 for single family residential units with 1-acre zoning.

Origins and destinations were placed at each census block's centroid, with connectors provided to all of the vertices of the street network surrounding or within a block. Block i was considered connected to block j if any of the vertices of block i were connected to any of the vertices of block j. In that way, for example, a business that fronted on a high-stress street could still be accessible at low stress if any vertex of the block it belonged to was incident to a low-stress link. The rationale was that, if people could find a low-stress route to any corner of the block of their destination, they could finish the trip by riding or walking along the sidewalk.

With this fine level of disaggregation, the evaluation of connectivity implied a search for the shortest paths between every vertex pair in the network of streets and paths. This process in turn required efficient data processing, given that the network used had 29,200 vertices.

Because the appeal of bicycling as a competitive mode of transportation declines at long distance, the sums in Equation 2 can be limited to block pairs no farther apart than, say, 4, 6, or 8 mi to focus on trips with the greatest potential for mode shift. Likewise, it makes sense to exclude block pairs so close to one another that walking is more convenient than bicycling. In the San Jose case study, in lieu of the application of a lower distance limit, block pairs within the same TAZ were excluded from the sums in Equation 2.

CASE STUDY RESULTS

The connectivity ratio for work trips in San Jose was calculated for 2011 conditions as well as for an improvement scenario with a slate of 67 improvements whose locations are shown in Figure 3. This slate was conceived through analysis of the map of connectivity clusters shown in Figure 2, with a view to connect clusters and create direct low-stress routes. Of these 67 improvements, 40 were spot treatments for intersection safety, 11 were short sections of connector path, 11 were striping and signage projects, 11 were short sections of connector path, and only five were longer cycle track projects. The prevalence of intersection and connector projects highlighted the important role that intersections play to create or remove barriers to low-stress cycling.

With the proposed slate of improvements, many of the connectivity clusters at LTS 2 combined to form a single large cluster, as shown

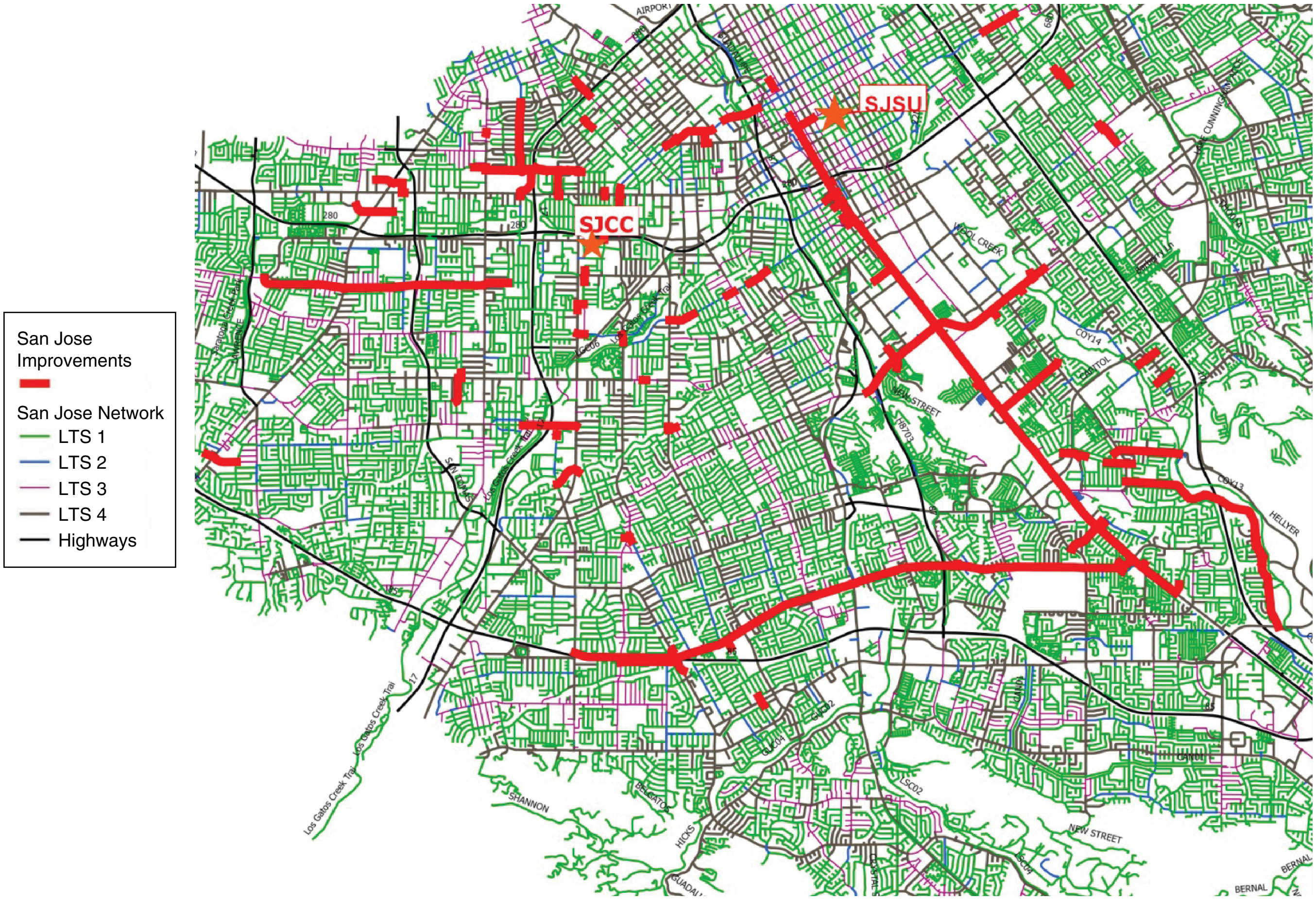

FIGURE 3 Locations of proposed improvements.

in Figure 4 (compare Figure 2). However, the large holes in this cluster made it such that many origin–destination pairs were still unconnected at LTS 2 as a result of the long detour involved. A large employment area north of the downtown remained outside the enlarged cluster.

Table 6 shows before–after comparisons of the connectivity ratio for work trips for the different levels of traffic stress with different distance limits. Poor connectivity at low-stress levels was clear in the base case, with only 0.4% of work trips up to 6 mi long connected at LTS 1, and only 4.7% connected at LTS 2. Under the improvement scenario, those figures rose to 1.0% and 12.7%, respectively, an increase by a factor of about 2.5.

In the base case, the far greater connectivity ratios at LTS 3 than at LTS 2 reflected the local policy to emphasize bike lanes on busy arterials, which represented most of the LTS 3 links. This policy can be contrasted with one that focuses on network development on lower-stress bike boulevards (i.e., routes on low-traffic streets) and cycle tracks. The even greater difference between LTS 3 and LTS 4 indicated that, in the current case, many barriers remained uncrossable, except at the highest LTS.

The poor low-stress connectivity in the base case undoubtedly was a big reason why San Jose's bicycle share for work trips over the previous decade was only 0.6% (*24*). The substantial increase in connectivity made possible by improvements that emphasized the use of connecting streets whose LTS value was already low showed considerable potential to increase bicycling mode share with modest investment.

CONCLUSIONS AND FURTHER RESEARCH

A new set of criteria was developed to classify streets by LTS value. The case study demonstrated that the criteria were readily understood, required only a modest amount of data, and resonated with planners that understood the ways in which the traffic environment tends to deter people from bicycling. Further research is needed to refine these criteria and extend them to other traffic situations not dealt with in this study (e.g., one-way streets and roundabouts).

Connectivity is a critical component of any transportation network, and this research demonstrated how poor it could be for bicycling networks limited to links with low traffic stress. Planners often propose bicycling improvements on the basis of increases in connectivity but lack ways to measure them. This research demonstrated methods to visualize and quantify low-stress connectivity, which gives planners valuable tools to evaluate the network impact of investments in bicycling facilities. These connectivity methods do not necessarily require use of the LTS classification scheme. They can be applied with any classification scheme that distinguishes high- and low-stress segments.

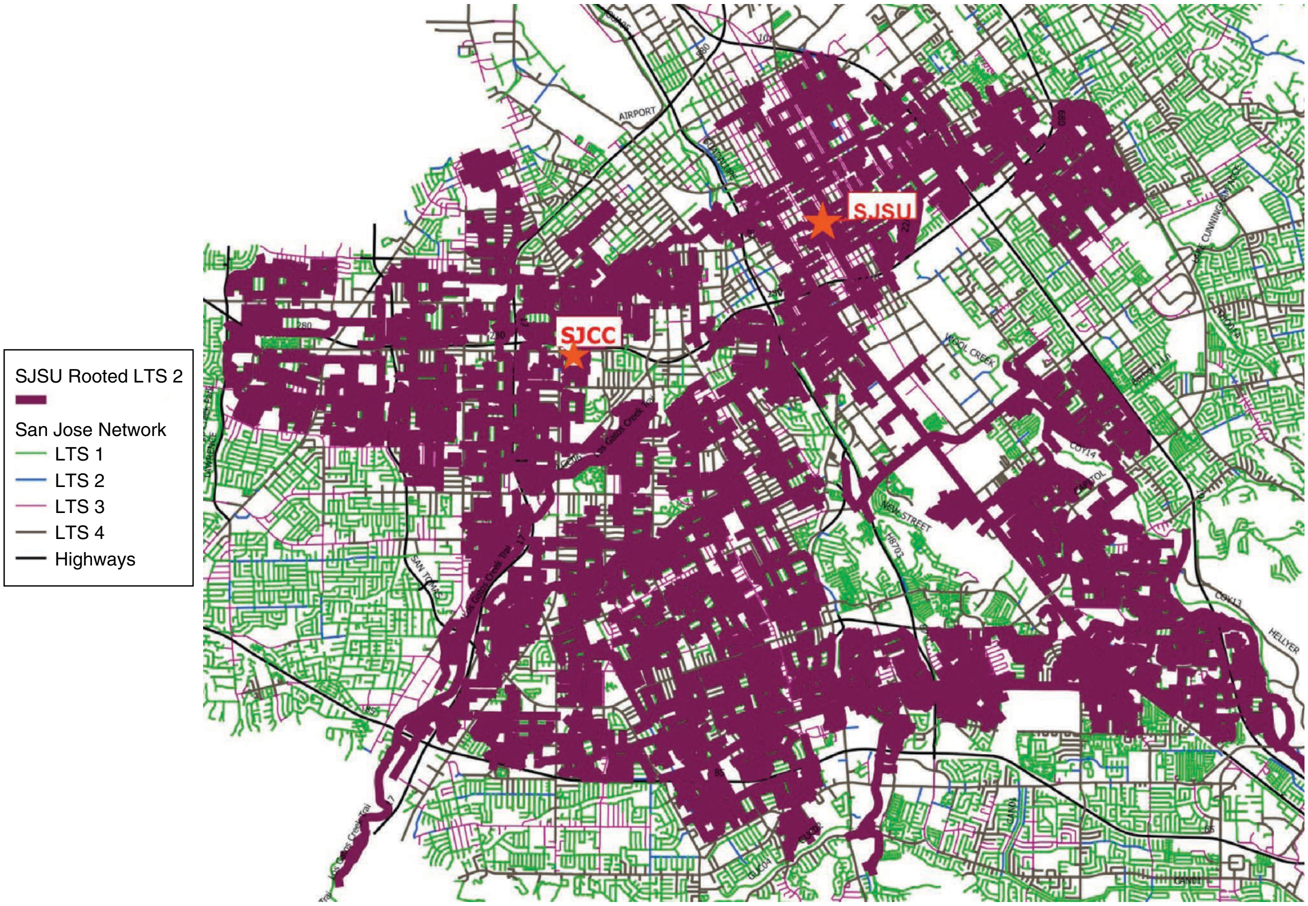

FIGURE 4 Central connectivity cluster at LTS 2 with proposed slate of improvements.

Connectivity was analyzed in this study through the use of work trips. The approach can be applied to trips of all types, including safe routes to school. It would be interesting to research the possibility of developing practical connectivity measures that do not require trip tables, which would reduce substantially the computational burden involved.

TABLE 6 Fractions of Work Trips Connected by LTS Level

	Work Trips Connected by Trip Length			
LTS Level	<4 mi	<6 mi	<8 mi	All
Existing Case				
1 (%)	0.7	0.4	0.3	0.2
2 (%)	7.7	4.7	3.4	2.2
3 (%)	22.6	16.4	13.2	8.9
4 (%)	100.0	100.0	100.0	100.0
Total trips	78,673	136,652	189,439	292,396
Improvement Scenario				
1 (%)	1.7	1.0	0.8	0.5
2 (%)	14.9	12.7	11.1	7.9
3 (%)	27.4	22.7	20.0	14.6
4 (%)	100.0	100.0	100.0	100.0
Total trips	78,673	136,652	189,439	292,396

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