Chapter 19

Site Planning and Impact Analysis[1]

I. INTRODUCTION

This chapter covers two topics. *Site planning* is the process of placing a proposed development on a parcel of land and assessing different aspects of how it will be built and its compliance with a community's zoning code and comprehensive plan. *Transportation access and impact studies* analyze the likely changes and effects on the transportation system resulting from this new development site. Impact studies recommend on- and off-site transportation improvements to improve access to the site as well as mitigate expected impacts. They identify public safety requirements and the transportation needs of the site and the surrounding road system. Impact studies are often part of a state environmental impact review process, or for major developments, they could be subject to what is called the Development of Regional Impact (DRI) review process. [FHWA, 1992] Both site planning and impact studies are concerned with site trip generation, how these trips arrive and depart, and the paths taken through the transportation network to reach the site, although impact studies focus on these issues at a much finer level of detail.

Site planning and impact studies are an essential part of the development review process in that they assist private developers in the proposal preparation and public agencies in proposal review. They address a wide range of issues and concerns including defining preliminary site and development characteristics, obtaining access (driveway) permits, determining necessary transportation improvements, and preparing overall access management plans. Studies can help developers and permitting agencies to:

- Establish the basic characteristics of the development footprint.
- Assess the number, location, and design of access points.
- Forecast the transportation (traffic) impacts created by proposed development based on accepted practices.
- Determine needed transport improvements to accommodate proposed developments.
- Identify travel demand management strategies.
- Allocate funds in a cost-effective manner.
- Provide a basis for determining the developers' responsibility for on- and off-site improvements.

Site plan reviews provide the community with a means of linking proposed developments to desired development characteristics as defined in zoning codes and ordinances. They also provide critical input when determining the desirability and/or conditions on which variances to these ordinances will be granted. Transportation access and impact studies ensure that safe and convenient access is provided to development sites while maintaining mobility and safety on public roads and other surface transportation facilities. In addition, impact studies provide nearby property owners with a way of making sure that new development does not negatively affect access to their property, and thus downgrade their property values.

Methods for conducting impact studies have been well-defined for many years. However, current experience in many communities suggests that their scope should be broadened to ensure that, (1) adequate access is provided for transit riders and pedestrians/bicyclists, (2) access to a development site does not adversely affect the performance of the surrounding street system, and (3) site design and access do not add to visual blight of the surrounding street environment. In addition, in many communities, such studies not only lay out the physical changes needed to

[1] Portions of this chapter were originally written by Herbert S. Levinson, P.E., Transportation Consultant, New Haven, CT, USA and Icon Mentor, Region 2 Transportation University Center, City University, New York, NY. Changes made to this updated chapter are solely the responsibility of the editor.

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provide better and safer access to the site (for example, building a turn lane at the site entrance), but they also identify travel demand management (TDM) strategies to reduce the number of automobile-related trips generated by the site.

Given these concerns, the key questions in an impact analysis include:

- Can people reach the site safely and conveniently as pedestrians, bicyclists, transit riders, automobile drivers, and passengers?
- Do the site access design, internal circulation system, parking, and building arrangements allow safe and effective vehicle and people circulation and movement?
- Can access be provided without adversely affecting the performance of the surrounding roadways?
- Do planned improvements ameliorate present and future problems?
- Are there ways of reducing the demand for trips to the site?

An example of such concerns comes from the Virginia Department of Transportation (VDOT), which states that a traffic impact statement for a rezoning request should,

> *(1) assess the impact of a proposed development on the transportation system and recommend improvements to lessen or negate those impacts, (2) identify any traffic issues associated with access from the site to the existing transportation network, (3) outline solutions to potential problems, (4) address the sufficiency of the future transportation network, and (5) present improvements to be incorporated into the proposed development. [VDOT, 2014, 2015]*

Some transportation agencies have placed the transportation impact review process within a much broader policy context. Addressing these questions often requires a multimodal perspective, as well as a serious look at access management issues and other policy/sustainability opportunities. The Massachusetts Department of Transportation (MassDOT), for example, notes that its intent in impact reviews is to:

> *Ensure that the transportation impact review process reflects and advances the Commonwealth of Massachusetts' policy goals, in particular those that promote MassDOT's* Project Development and Design Guide Standards on Complete Streets, *the Global Warming Solutions Act, the Massachusetts GreenDOT Policy Initiative, the Mode Shift Initiative, the Healthy Transportation Compact, the Healthy Transportation Policy Directive, the Massachusetts Ridesharing Regulation, and Safe Routes to School policies. [MassDOT, 2012]*

California is another state that has adopted statewide policies relating to sustainability, energy conservation, and greenhouse gas emission reductions (see https://www.wildlife.ca.gov/Conservation/CEQA/Purpose).

The following section describes the administrative requirements for site planning and impact analysis. These requirements dictate the type of information that must be part of a study, and often establish the thresholds of when such a study is necessary. The next section offers definitions of key terms used in both site plan reviews and traffic impact studies. The next two sections discuss the specifics of site plan review and traffic impact analyses. More attention is given to traffic impact studies in that this is where most of the site-related transportation planning efforts occur. This section discusses key issues like the identification of analysis horizon years and performance measures; travel demand models and tools; and the analysis approaches for site-specific, corridor, and network impacts. The next section focuses on on-site transportation design options and strategies, including internal circulation networks and parking management. This is followed by a discussion of access management and the many different types of mitigation strategies that can be considered as part of an impact study. The final section presents a sample table of contents for a traffic impact study.

The Institute of Transportation Engineers (ITE) published a transportation impact analysis *Recommended Practice* in 2010 that provides a detailed, step-by-step description of the analysis process. It is not the intent to replicate the *Recommended Practice* in this chapter. Some key tables and figures from that reference will be used simply to illustrate the important characteristics of the impact analysis process. Interested readers should read this more detailed guide. [ITE, 2010] In addition, many of the mitigation strategies usually considered in a traffic impact study are described in more detail in other chapters of this handbook. Readers are referred to chapter 3 on land use and urban design, chapter 4 on environment and the community, chapter 6 on travel demand modeling, chapter 9 on road and highway planning, chapter 11 on parking, chapter 12 on transit planning, chapter 13 on pedestrian and bicycle planning, chapter 14 on travel demand management, and chapter 23 on transportation safety.

II. ADMINISTRATIVE REQUIREMENTS

Administrative rules and requirements established by governments provide the basic requirements for both a site plan review and a traffic impact study process. These vary by jurisdiction, depending on the community definition of what constitutes an impact. Importantly, site planning requirements are part of the zoning process and occur when a development of a certain size is proposed (see chapter 3 on land use and urban design).

ITE [2012] notes that traffic impact studies, as specified in rules and procedures, can be required when:

- The development will generate a specified number of daily trips.
- The development will generate a specified number of peak-hour trips.
- A specified amount of acreage is being rezoned.
- The development contains a specified number of dwelling units or amount of square footage.
- Financial assessments are required and the extent of impact must be determined.
- The development will require a significant amount of transportation improvements.
- A previous transportation impact analysis for a site has been deemed out of date.
- Development will occur in a sensitive area.
- The judgment or discretion of staff can be applied based on previous experience.

Some examples of thresholds that might trigger an impact study include:

Iowa Department of Transportation (IDOT). Two types of impact reports are possible. A *traffic impact letter* is required if the average annual daily traffic (AADT) is less than or equal to 500 vehicles, and the peak-hour volume is less than or equal to 100 trips. Volumes over these thresholds require a *traffic impact study*. [Iowa DOT, 2013]

California Department of Transportation (Caltrans). The following criteria are considered starting points for determining when a traffic impact study is needed for a state highway in California. [Caltrans, 2002] Such a study is needed when a project:

1) Generates over 100 peak-hour trips assigned to a state highway facility.
2) Generates 50 to 100 peak-hour trips assigned to a state highway facility, and affected state highway facilities are experiencing noticeable delay, approaching unstable traffic flow conditions (levels of service (LOS) "C" or "D").
3) Generates 1 to 49 peak-hour trips assigned to a state highway facility and where:
    a. Affected state highway facilities experience significant delay or unstable or forced traffic flow conditions (LOS "E" or "F"), or
    b. The potential risk for a traffic incident is significantly increased (that is, congestion-related collisions, nonstandard sight distance considerations, increase in traffic conflict points, and so forth), or
    c. There is a change in local circulation networks that impact a state highway facility (that is, direct access to state highway facility, a non-standard highway geometric design, and so forth).

Oregon Department of Transportation (ODOT). ODOT will likely request an impact study when, (1) the proposed development is within a quarter mile of the terminal of an interchange ramp, (2) the local development code requires that there be "adequate facilities" to serve the proposed development (often applies to "change of use" applications), (3) an ODOT preliminary review identifies operational or safety issues related to increased traffic or highway access at the development site, and/or (4) an approach to the state highway will be the development's only or primary access to the roadway network. [ODOT, 2014]

City of San Francisco, California. The city of San Francisco requires an impact study when a project:

1) Potentially adds at least 50 p.m. peak-hour person trips.
2) Potentially increases existing traffic volumes on streets in its vicinity by at least 5 percent.
3) Potentially impacts nearby intersections and/or arterials, which are believed to presently operate at level of service (LOS) "D" or worse.
4) Provides parking that would appear likely to be deficient relative to both the anticipated project demand and code requirements by at least 20 percent.
5) Has elements that have a potential to adversely impact transit operations or the carrying capacity of nearby transit services.
6) Has elements that have the potential to adversely affect pedestrian or bicycle safety or the adequacy of nearby pedestrian or bicycle facilities.
7) Would not fully satisfy truck loading demand on-site for an anticipated number of deliveries and service calls exceeding 10 daily trips. [City of San Francisco, 2015]

City of Tampa, Florida. The city of Tampa requires an analysis and mitigation of *critical links and intersections* adjacent to a development's major roadway network access point(s) when:

1) The average annual daily traffic (AADT) on the adjacent major roadway link(s) is less than 95 percent of the LOS "D" daily service capacity of the link and the subject development consumes more than 2 percent of the LOS "D" daily service capacity of the adjacent major roadway link(s), and capacity is available.
   or
2) The AADT of the adjacent major roadway link(s) is greater than or equal to 95 percent of the LOS "D" daily service capacity of the link and the subject development consumes more than 1 percent of the LOS "D" daily service capacity of the adjacent major roadway link(s), and capacity is not available.

An analysis of *roadway network impacts* is required when:

1) The AADT of the adjacent major roadway link(s) is less than 95 percent of the LOS "D" daily service capacity of the link and the subject development consumes more than 5 percent of the LOS "D" daily service capacity of the adjacent major roadway link(s).
   or
2) The AADT of the adjacent major roadway link[s] is greater than or equal to 95 percent of the LOS "D" daily service capacity of the link and the subject development consumes more than 2 percent of the LOS "D" daily service capacity of the adjacent major roadway link(s).

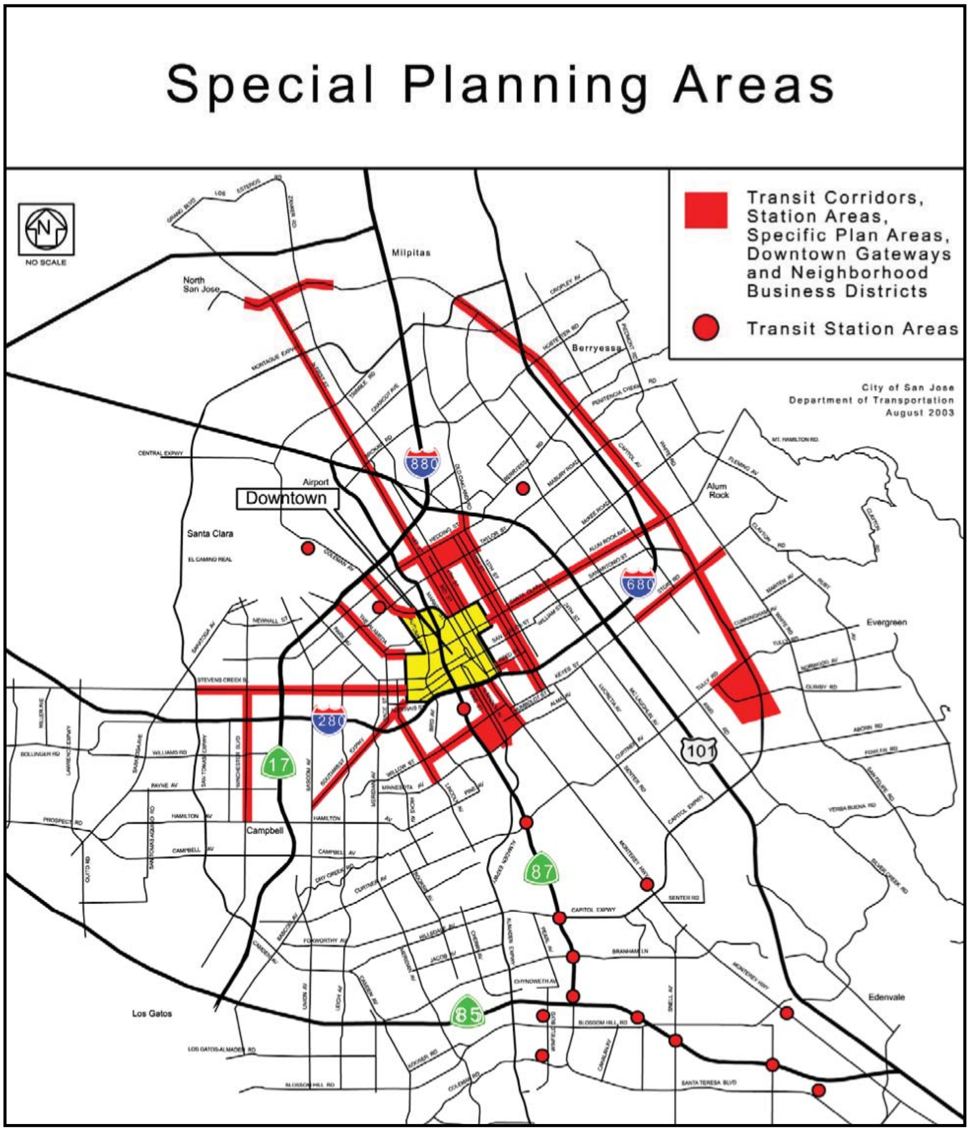
Enhanced network impact analyses are required when the AADT of a significantly impacted link (as identified in a network impact analysis) operates at greater than 120 percent of the LOS "D" daily service capacity of the link and the subject development traffic consumes more than 5 percent of the LOS "D" daily service capacity of the link. [City of Tampa, 2011]

Another way of defining impact analysis thresholds is for communities to identify when a traffic impact study is *not* required due to the nature of the development itself or because of local conditions (for example, developments designed to encourage transit use). A good example of this comes from Tampa where the following exclusions of the traffic impact study requirement are part of the planning rules. In Tampa, generally, any development that generates more than 100 net daily trip ends per day will likely have to undergo a traffic impact study unless the development is located in the Downtown Revitalization District, Urban Redevelopment District, or Urban Infill District, in which case the developer must pay the city's transportation impact fee (but does not have to commit to any specific action). If the project is in an approved Transportation Master Plan Area (for example, Tampa International Airport, Port of Tampa, or the University of South Florida), the developer must mitigate site impacts and otherwise conform to the city's land development code and comprehensive plan. Similarly, developments that are serviced by one or more "Primary Transit Facility" service areas must mitigate on-site impacts. Service areas are defined as within a one-fourth mile (0.4 km) of high-frequency bus transit routes, within one-third mile (0.54 km) of a bus rapid transit station, within one-half mile (0.8 km) of a rail transit station, and within one-third mile (0.54 km) of a transit center/transfer center.

Figure 19-1 shows a similar concept from San Jose, California, where areas near transit facilities and neighborhood business districts are identified for special treatment in the traffic impact study process. In planning terms, these are often called overlay districts as defined in zoning codes (see chapter 3 on land use and urban design).

Although one often sees different community threshold criteria for initiating a traffic impact study, ITE [2012] recommends a study be done for any project that generates at least 100 peak-hour vehicle trips per day. As noted, however, the context of such development is a critical consideration—small developments generating fewer trips than this may still require a site access and circulation review to ensure that access connections are located safely.

Figure 19-1. Special Districts for Traffic Impact Study Requirements, San Jose, California



Source: City of San Jose, 2009

III. DEFINITION OF KEY TERMS

Some key terms used in site planning and traffic impact analysis include:

- *Access management:* Strategies to manage the access to streets, roads, and highways from public roads and private driveways. Requires balancing access to developed land while ensuring movement of traffic in a safe and efficient manner.
- *Analysis hour:* A single hour for which a capacity analysis is performed on a system element.
- *Critical density:* The traffic density at which capacity occurs for a given facility.
- *Critical headway:* The minimum headway in the major traffic stream that will allow the entry of one minor-street vehicle.
- *Critical lane groups:* The lane groups having the highest flow ratio for a given signal phase.
- *Critical speed:* The speed at which capacity occurs for a segment.
- *Cycle failure:* A condition where one or more queued vehicles are not able to depart a signalized intersection.
- *Demand-to-capacity ratio:* The ratio of demand volume to capacity for a system element.
- *Design hour:* An hour with a traffic volume that represents a reasonable value for designing the geometric and control elements of a facility.
- *Design year:* A target year (usually 20 years) following the year the project is open to traffic.
- *Development traffic:* Traffic volumes generated by a development.
- *Directional distribution:* The directional split of traffic during the peak or design hour, commonly expressed as a percentage in the peak- and off-peak flow directions.
- *Fair share:* A strategy of sharing the mitigation costs of the impacts of development on transportation facilities through the cooperative efforts of public agencies and private developers or land owners.
- *Floor area ratio:* The ratio of the total floor area of a building or buildings on a parcel to the size of the parcel where the building or buildings are located.
- *Fully actuated control:* A signal operation in which vehicle detectors at each approach to the intersection control the occurrence and length of every phase.
- *Internal capture:* Trips internal to a development site that otherwise would have left the site.
- *Level of service (LOS):* A qualitative measure describing operational conditions in a traffic stream based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience.
- *Mitigation:* Measures to reduce adverse impacts on the environment, in the following order of preference:
    - Avoid the impact altogether by not taking a certain action or part of an action.
    - Minimize the impact by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts.
    - Rectify the impact by repairing, rehabilitating, or restoring the affected environment.
    - Reduce or eliminate the impact over time by preservation and maintenance operations during the life of the action.
    - Compensate for the impact by replacing, enhancing, or providing substitute resources or environments.
- *Opening year:* The year the project is scheduled to be open to traffic.
- *Pass-by trips:* Trips made by traffic already using adjacent roadways and enter the site as an intermediate stop on the way to another destination.

- *Peak hour:* The hour during the day when the maximum volume is using a facility. Used in determining directional distributions. Note that the peak hour of the adjacent street may not be the peak hour of the development.
- *Planning horizon year:* The target year for estimating traffic impacts.
- *Redevelopment site:* Any existing use that generates traffic and is intended to be developed at a different land-use density.
- *Service flow rate:* The maximum directional rate of flow that can be sustained on a given segment under prevailing roadway, traffic, and control conditions without violating the criteria for a specified level of service.
- *Sight distance:* The distance visible to the driver of a passenger vehicle measured along the normal travel path of a roadway from a designated location to a specified height above the roadway when the view is unobstructed by traffic.
- *Stopping sight distance:* The distance required by a driver of a vehicle, traveling at a given speed, to bring the vehicle to a stop after an object on the roadway becomes visible. It includes the distance traveled during driver perception and reaction times and the vehicle braking distance.
- *Traffic impact statement:* A document prepared in accordance with best professional practice and standards assessing the impact of a proposed development on the transportation system and recommending improvements to lessen or negate those impacts.
- *Transit-oriented development:* An area of commercial and residential development at moderate to high densities within 1/2 mile (0.8 km) of a station for heavy rail, light rail, commuter rail, or bus rapid transit transportation and includes the following: (a) densities of at least four residential units per acre and at least a floor area ratio of 0.4 or some proportional combination thereof; (b) mixed-use neighborhoods, including mixed housing types and integration of residential, office, and retail development; (c) reduction of front and side yard building setbacks; and (d) pedestrian-friendly road design and connectivity of road and pedestrian networks (see chapter 3 on land use and urban design).
- *Travel (or Transportation) demand management (TDM):* A combination of measures that reduce vehicle trip generation and improve transportation system efficiency by altering travel demand, including but not limited to the following: expanded transit service, employer-provided transit benefits, bicycle and pedestrian investments, ridesharing, staggered work hours, telecommuting, and parking management including parking pricing (see chapter 14 on parking).
- *Vehicle miles traveled (VMT):* Number of vehicles using a site times the average trip distance estimated from a network model. Used as a measure of impact on the road network, as well as input to air quality and energy impact analysis.

IV. SITE PLAN REVIEW DATA

The type of information accompanying a site plan review examines many different nontransportation items, such as legal ownership, a legal description of the property, preliminary dimensions of the development footprint, and the zoning and planning requirements for the site. With respect to the transportation components of a site plan review, and thus transportation-related data needs, the following guidelines from Seattle show typical inputs into a site plan submittal.

- Dimensions and right-of-way limits in addition to roadway widths of adjacent streets (by name), alleys, or other adjacent public property.
- Curbs, sidewalks, and street trees—type, location, and dimensions.
- Street and alley improvement type and dimensions (asphalt, concrete, gravel, and so forth).
- Location of the pedestrian path to each dwelling unit and the primary entrance to each building.

- Location and dimensions of all driveways, parking areas, and other paved areas (existing and proposed).
- Center elevation and developed roadway at 25 feet intervals if a change to access or parking is proposed. Identify existing and finished grade elevation of driveway at property line, and at garage entry, if a change to access or parking is proposed.
- Curb cut width and distance from adjacent property lines (label curb cuts as “existing” or “proposed”).
- Identify all physical restrictions to site access (utility poles, rockeries, street trees, Metro bus stops, and so forth) if a change to access is proposed. [City of Seattle, 2013]

In addition to these requirements, the city of Austin, Texas, requires more detail on the following site-related aspects.

- All driveway dimensions and design specifications, such as: driveway widths, driveway curb return radii, and profiles of finished grades; label on site plan when there are several proposed driveway approaches.
- Proposed operation of driveways on site plan (that is, one-way or two-way operation); identifying and labeling all physical barriers to vehicular access.
- On undivided roadways, show existing driveways on opposite side of street within 120 feet of site driveways, or indicate in a note if there are none.
- Physical obstructions (utility poles, trees, storm sewer inlets, and so forth) in the right-of-way, which could affect sidewalk/driveway locations.
- Dimensions of vertical clearance within fire lanes, including tree limbs, for all driveways and internal circulation areas on-site, where overhead clearance is restricted.
- All off-street and on-street parking; number of required and provided parking spaces including location, number and type (standard, compact, handicapped) of actual parking spaces; dimension parking stall depth and width, stall angle, aisle width, and width on internal driveways. Plan should number each parking space, show structural supports, turning radii, traffic circulation, ramp grades in parking garages, and the numbering and location of compact spaces.
- Reduction in on-site parking requirements assumed and the number of spaces credited.
- Handicapped parking spaces meeting state standards.
- Route of travel connecting all accessible elements and spaces on the site that can be negotiated by a person using a wheelchair and usable by persons with other disabilities (indicated by dotted lines, a shading pattern or other identifiable legend).
- Internal circulation system showing vehicular, bicycle, pedestrian paths, and connections to off-site access.
- Note on the plan indicating that each compact parking space must be identified by a sign stating “small car only” and signs posted on-site directing motorists to such spaces.
- Offstreet loading spaces, if required.
- Location and type of bicycle parking.
- Queue spaces or queuing areas for drive-through uses.
- Location and width of sidewalks on site plan, if required by the city of Austin.
- The location and design of all pedestrian sidewalk ramps related to the construction of this site. [City of Austin, 2014]

As can be seen by these two lists, the transportation-related data requirements for site plan review will vary from one community to another. Transportation planners involved with site plans need to be very familiar with the requirements as set forth by the community zoning and/or planning commission. Other examples of site plan review guidelines can be found at. [City of Alexandria, 2013; County of Fairfax, undated]

V. TRANSPORTATION ACCESS AND IMPACT ANALYSIS

An impact analysis should always begin by establishing the basic terms of reference with relevant public agencies and the developer or owner. These will include, at a minimum, defining the transportation need, identifying impact analysis thresholds as established in requirements, agreeing to a scope of analysis, defining study area limits, establishing the forecast hours (and days) to be analyzed, and defining the study horizon years. The set of feasible travel modes and acceptable methods of determining capacity and level of service should also be established.

The scope of traffic impact studies depends on the type, location, timing, and size of the proposed development. Where walk, bicycle, and transit trips are common (or have potential), both total person trips and vehicular trips should be analyzed. This involves estimates of mode split and vehicle occupancy. In addition, most site impact studies examine the access and movement of commercial vehicles delivering goods to a site. The types of information needed to reach appropriate traffic and development decisions normally include:

- Characteristics of the existing roadway and public transport systems.
- Characteristics of current and proposed nearby developments.
- Estimated future development traffic and access strategies.
- Combined traffic volumes on surrounding and approach roads.
- Traffic growth rates.
- Road system adequacy.
- System needs.
- Access plans.

With respect to access management, site access should maintain the operational integrity of the surrounding road system. This can be best achieved by applying access management principles and designs (see chapter 3 on land use and urban design and chapter 9 road and highway planning). Access management provides (or manages) access to land development while simultaneously preserving the flow of traffic on the surrounding road system in terms of safety, capacity, and speed. It consists of the systematic control of the location, spacing, design, and operation of driveways; median openings; interchanges; and street connections to a roadway. It also includes applications such as median treatments, auxiliary lanes, and the appropriate spacing of traffic signals. [Koepke and Levinson, 1992] An important access management objective is to ensure that the cumulative effects of a series of closely spaced developments do not deteriorate the safety and mobility associated with the surrounding road system.

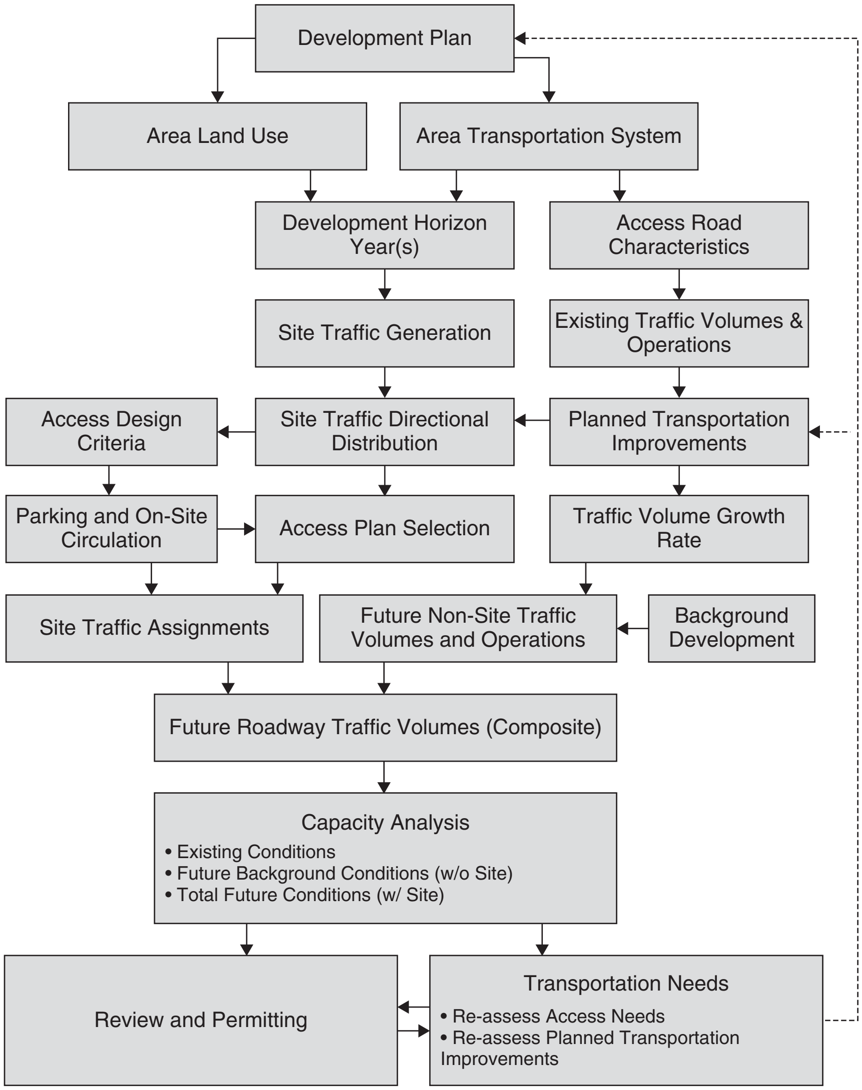
A. Traffic Impact Analysis Process

Figure 19-2 shows the major steps in a traffic impact analysis. [ITE, 2012] Each of these steps uses data and analysis tools that are discussed in other chapters (see, for example, chapter 2 on data analysis and chapter 6 on travel demand modeling). The key outcomes of this process, from the property owner's perspective, are the permits and other permissions granted by public agencies to build the development. Several of the key components of this analysis process are discussed in the following sections.

B. Study Area Boundaries

Study area boundaries should be based on the type of land use, size of development, street system patterns, and terrain. A frequently used method is to carry the analysis boundaries to locations where site-generated traffic will represent five percent or more of the roadway's peak-hour approach capacity. The study area should include critical (or congested) intersections on the adjacent road network. Table 19-1 gives guidelines for determining study area limits based on the size, type, and trip-generating characteristics of typical land uses. Note that the study area limits for a traffic impact study as shown in Table 19-1 would generally not account for the larger study area needed for a concurrency analysis, where a developer would pay a proportionate share for roadway/intersection improvements

Figure 19-2. Transportation Impact Analysis Process



Source: ITE, 2012

needed as a result of the proposed development. Also, traffic impact studies are usually done under the jurisdiction of local governments, but given that development impacts can extend beyond the local roadway network to the state highway system, it is important that local and state authorities coordinate in addressing study impacts and mitigation measures.

The criteria shown in Table 19-1 can sometimes be superseded at the discretion of the jurisdiction's transportation agency. In Massachusetts, for example, intersections or road segments meeting an impact statement threshold of five percent increase in traffic volume may be exempted from study if in the Massachusetts DOT's (MassDOT's) judgment:

- The intersection or segment operates acceptably today and the site development impact will not cause a capacity or safety mitigation need.

  or

- A mitigation for the intersection or segment has been previously identified and no further analysis is warranted (note that site-generated trip assignment may still be required for tracking or mitigation assessment purposes).

  or

- Other reasons are deemed appropriate by MassDOT. [MassDOT, 2014]

Table 19-1. Suggested Study Area Limits for Transportation Impact Analysis	
Development	**Study Area**
Fast-food restaurant	Adjacent intersection if corner location.
Service station, with or without fast-food counter	Adjacent intersection if corner location.
Mini-mart or convenience grocery with or without gas pumps	660 ft from access drive.
Other development with fewer than 200 trips during any peak hour	1,000 ft from access drive.
Shopping center less than 70,000 sq. ft. or Development w/peak-hour trips between 200 and 500 during peak hour	All signalized intersections and access drives within 0.5 mile from a property line of the site and all major unsignalized intersections and access drives within 0.25 mile.
Shopping center between 70,000 sq. ft. and 100,000 sq. ft. GLA or Office or industrial park with between 300 and 500 employees or Well-balanced, mixed-use development with more than 500 peak-hour trips	All signalized and major unsignalized intersections and freeway ramps within 1 mile of a property line of the site.
Shopping center greater than 100,000 sq. ft. GLA or Office or industrial park with more than 500 employees or All other development with more than 500 peak-hour trips	All signalized intersections and freeway ramps within 2 miles of a property line and all major unsignalized access (streets and driveways) within 1 mile of a property line of the site.
Transit station	0.5-mile radius.

Source: ITE, 2012

Alternatively, intersections or road segments that do not meet the five percent threshold might be included in the study area if in MassDOT's judgment:

- The intersection is highly congested, near or over capacity, and prone to significant operational deterioration from even a small increment in traffic.

  or

- The location is expected to have a significant impact to the state highway system.

  or

- There are local municipality requirements that call for an impact study.

  or

- There are special circumstances related to the location that merit review. [MassDOT, 2014]

In addition, for those studies conducted in urban areas, the study area description should discuss not only potentially affected major highways and roadways, intersections, and interchanges, but also pedestrian and bicycle facilities, and the public transit network that are part of (or could be part of) the study area's transportation system. For example, MassDOT's definition of an urban study area includes:

- Walking, bicycling, and public transit networks, with specific attention to connectivity, desire lines, and gap analysis in order to maximize travel choices and promote these modes. Consideration should be given to the appropriate level of analysis for transit, walking, and bicycling study areas. [MassDOT, 2012]

C. Horizon Years

The planning horizon year, that is, the future year for estimating traffic impacts, should be consistent with the size and build-out schedule of the planned developments and any anticipated major transportation system changes. Suggested horizon years are given in Table 19-2. A general guide is to set the planning horizon year for when proposed developments will be fully operational and meeting their market goals, usually three to five years after opening day.

Table 19-2. Suggested Study Horizons	
Development Characteristic	**Suggested Horizon Year(s)**
Small development (<500 peak-hour trips)	• Anticipated opening year, assuming full build-out and occupancy.
Moderate, single-phase development (500 to 1,000 peak-hour trips)	• Anticipated opening year, assuming full build-out and occupancy. • Five years after opening date.
Large, single-phase development (>1,000 peak-hour trips)	• Anticipated opening year, assuming full build-out and occupancy. • Five years after full build-out and occupancy. • Adopted transportation plan horizon year, if the development is significantly larger than that included in the adopted plan or travel forecasts for the area.
Moderate or large multiple-phase development	• Anticipated opening year of each major phase, assuming full build-out and occupancy of each phase. • Anticipated year of complete build-out and occupancy. • Adopted transportation plan horizon year, if the development is significantly larger than that included in the adopted plan or travel forecasts for the area. • Five years after opening date if completed by then and there is no significant increase (less than 15 percent) in trip generation from adopted plan or area transportation forecasts.

Source: ITE, 2012

D. Data on Existing (Background) Conditions

Existing transportation and land-use conditions near a proposed development are important inputs into a traffic impact study. Analyses should provide a clear picture of the market influence area of the proposed development and show how well roadways, transit facilities, and pedestrian/bicycle networks function currently. Key steps in conducting the existing conditions analysis include:

- Hold background meetings with relevant public agencies.
- Assemble and collate existing traffic, transportation, and land-use information.
- Conduct a field reconnaissance of physical and environmental features, transportation facilities, services, and conditions in the site environs.
- Conduct a travel time study to help define the “reach” and market for the proposed development.
- Obtain information on transit routes, coverage, frequencies, and ridership.
- Obtain data on pedestrian and bicycle routes and access information.
- Obtain existing roadway characteristics, such as width, travel lanes, traffic controls, and geometric features such as gradients, alignments, and signal lanes.
- Review traffic volume studies at key intersections during peak and off-peak periods for weekdays and weekends (daily and hourly).
- Assess existing service levels and transportation conditions (including volume-to-capacity comparison).
- Determine crash experience for at least a three-year period.

The existing conditions analysis and results should be presented in a clearly understandable manner, with the use of parcel location and land-use maps desirable. Bus routes and service coverage should be mapped. Daily traffic volumes are also useful in defining the exposure of a site to passing traffic. Peak-hour traffic flow maps showing intersection turning movements are essential. Travel lanes, traffic controls, and service levels should be mapped as well. Table 19-3 shows the data that should be collected as part of the background analysis.

Table 19-3. Suggested Background Data for Impact Analysis	
Category	**Data**
Traffic Volumes	• Current and (if needed for analysis) historic daily and hourly volume counts, including peak period counts (site and street peaks). • Recent intersection turning movement counts, including right-turns-on-red. • Seasonal variations. • Vehicle classification counts. • Peak period queue lengths. • Projected volumes from previous studies or regional plans. • Relationship of count day to both average and design days. • Posted speed limits. • Prevailing operating speeds. • Travel times.
Land Use	• Current land use, densities, and occupancy in vicinity of site. • Approved development projects and planned completion dates, densities, and land use types. • Anticipated development on other underdeveloped parcels. • Zoning in vicinity. • Absorption rates by type of development.
Demo-graphics	• Current and future population and employment within the study area by census tract or transportation analysis zone (as needed for use in site traffic distribution).
Transportation System	• Current street system characteristics, including direction of flow, number and types of lanes, right-of-way width, type of access control, and traffic control including signal timings, sight distances. • Roadway functional classification. • Route governmental justification. • Adopted local and regional plans. • Planned thoroughfares in the study area and local streets in vicinity of site, including improvements. • Transit service, usage, and stops. • Pedestrian and bicycle linkage, usage, and facilities (for example, sidewalks and bike paths). • Available curb and off-site parking facilities, and parking regulations. • Safety hazards. • Implementation timing, funding source and certainty of funding for study area transportation improvements (whether funded in current capital improvement program).
Other Transportation Data	• Origin-destination or trip distribution data. • Crash history (3 years, if available) adjacent to site and at nearby major intersections if hazardous condition has been identified.

Source: ITE, 2012 as edited

The credibility of a traffic impact study to a large extent will depend on the quality of the data collected. Generally, data on traffic volumes and turning movements should not be out-of-date by more than one year, which often requires the agency or a consultant to collect new data (see chapter 2 on data collection). The peaking behavior of adjacent streets, nearby major highways, and parking facilities is of particular interest.

Not only is it important to collect data that focuses on a site's potential impact (for example, turning movements), but it is also important to collect data on non-site traffic that provide a sense of how background traffic will change over time. In particular, through traffic with no origin or destination in the study area as well as traffic generated by all other developments in the study area should be estimated. Methods to do this are discussed later.

E. Performance Measures

The site impact-related performance measures of most concern to transportation planners are those required by administrative regulations, as well as those desired by local decision makers. Some examples are presented below.

City of Cambridge, Massachusetts. The city of Cambridge, Massachusetts, defines "substantial adverse impact on city traffic" and thus the data that must be provided, as: [City of Cambridge, 2014]

Project vehicle trip generation weekdays and weekends for a 24-hour period and a.m. and p.m. peak vehicle trips.

The definition of an impact consists of project-based trip generation in excess of:

- 2,000 weekday or weekend (24-hour) trips; or
- 240 peak hour (a.m., p.m., or Saturday midday) trips.

Change in level of service at identified signalized intersections.

An impact occurs with the following changes in vehicle level of service (VLOS) at intersections:

Existing Vehicle LOS	LOS with Project
VLOS A	VLOS C
VLOS B, C	VLOS D
VLOS D	VLOS D or 7% roadway volume increase
VLOS E	7% roadway volume increase
VLOS F	5% roadway volume increase

Increased volume of trips on residential streets.

An impact is defined based on two parameters. The first is the increase in project-induced traffic volume on any two-block residential street segment in the study area, in excess of:

Parameter[1]: Amount of Residential[1]	Parameter[2]: Current Peak-hour Street Volume (two-way vehicles)		
	<150 Vehicles per Hour (VPH)	150–400 VPH	>400 VPH
1/2 or more	20 VPH[2]	30 VPH[2]	40 VPH[2]
>1/3 but <1/2	30 VPH[2]	45 VPH[2]	60 VPH[2]
1/3 or less	(No max.)	(No max.)	(No max.)

Notes:

[1] Amount of residential for a two block segment as determined by first floor frontage.

[2] Additional project vehicle trip generation in vehicles per lane, both directions.

The second is the *increase of length of vehicle queues at identified signalized intersections*. A project-induced lane queue or increase in lane queue in excess of the amount allowed in the following table constitutes an impact:

Existing Queue	Queue With Project
Under 15 vehicles	Under 15 vehicles, or 15+ vehicles with an increase of 6 vehicles
15 or more vehicles	Increase of 6 vehicles

Lack of sufficient pedestrian and bicycle facilities.

Project impact was defined using three criteria:

Criterion 1: A project-induced increase in pedestrian delay at any study area crosswalk in excess of the amount allowed in the following table:

Existing Pedestrian Level of Service (PLOS)	With Project Must Have:
PLOS A	PLOS A
PLOS B	PLOS B
PLOS C	PLOS C
PLOS D	PLOS D or increase of 3 seconds
PLOS E, F	PLOS D

Safe Pedestrian Facilities are sidewalks, crosswalks or walkways on any publicly accessible street or right-of-way (ROW) which meet City design standards, including handicap treatments

Criterion 2: Safe pedestrian facilities must exist on any adjacent publicly accessible street or right-of-way (ROW); and they must connect to site entrances, interior walkways, and adjoining pedestrian facilities.

Safe bicycle facilities are on-street bicycle lanes or off-road paths along a publicly accessible street or right-of-way which meet city design standards.

Criterion 3: Where sufficient ROW currently exists, safe bicycle facilities must be in place or sufficient ROW must be preserved on any adjacent publicly accessible street or ROW, and they must connect to site entrances, interior pathways, and adjoining bicycle facilities.

Some examples of how other jurisdictions define "impact" are presented below.

Virginia DOT. The Virginia DOT focuses on three impact areas:

1) Development-generated forecast daily and peak-hour traffic volumes on the highway network in the study area, site entrances, and internal roadways, tabulated and presented on diagrams.
2) Delay and LOS (tabulated and presented on diagrams for each lane group).
3) If there is a significant potential for walking, bike, or transit trips either on- or off-site, analyses should be undertaken of pedestrian and bicycle facilities, and bus route or routes and segment(s) (tabulated and presented on diagrams, if facilities exist or are planned). [VDOT, 2015]

Atlanta Regional Commission, Atlanta, Georgia. The Atlanta Regional Commission (ARC) looks at a wide range of criteria when examining developments of regional impact (DRIs). The transportation elements of this review include:

- Traffic generated by the development.
- Capacity of the existing and proposed roads.
- Demand management strategies proposed by the developer.

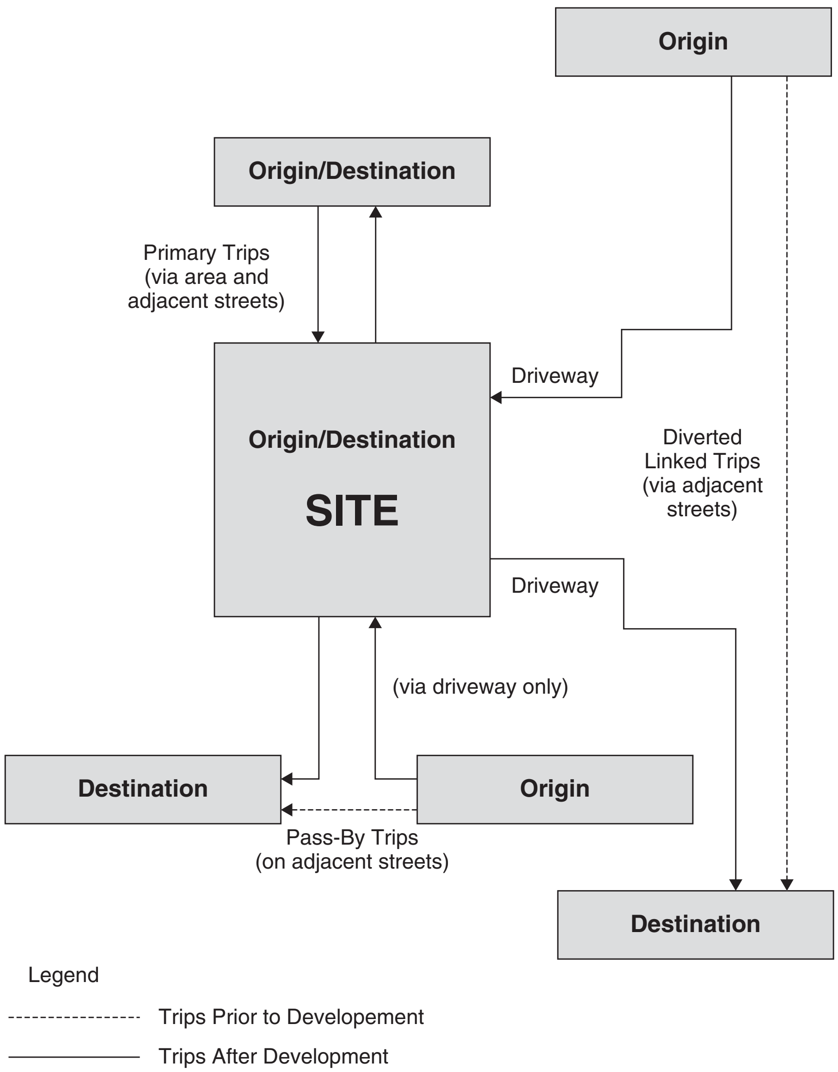
- Air-quality impacts of the DRI-generated traffic.
- Whether the DRI contributes to patterns of development that will reduce average daily miles traveled.
- Rapid transit availability. [ARC, 2013]

As described above, the metrics used for the decision-making process are wide-ranging and emphasize many different issues. Generally, similar direct impacts are measured in almost all cases, such as the number of trips generated, level of service on transportation facilities, and the like. In other cases, these metrics are used as input into further analysis to determine related impacts, such as the amount of motor vehicle-related pollutants generated. The data collected and the tools used for producing this information will clearly depend on information required by the decision-making process.

F. Travel Demand Analysis

Figure 19-3 shows three major kinds of trips that are part of a site demand analysis. The largest predicted volume will be the *primary origin–destination trips* to and from the development site. *Pass-by trips* are trips made to the site using an adjacent road. Vehicle pass-by trips are not new trips to the adjacent road, but do represent new trips to site driveways (and turning movements). *Vehicle-diverted trips* are those that are attracted to the site, but divert from

Figure 19-3. Trip Types for Impact Analysis



Source: ITE, 2012

nearby roads on the road network (not from roads adjacent to the site). Thus, diverted trips are not new to the overall network; they are simply redistributed from their original path.

In addition to these three trip types, there is an "internal capture" of trips for sites that are multiuse and often fairly large. Internal capture reflects those trips that according to the trip generation calculations would be estimated to arrive at the site, but are instead made by a person walking from one part of the site to another (for example, for a cup of coffee or lunch). As such, internal capture trips do not create new trips on the adjacent roads or at the site's driveways.

As an example, assume that a particular land use generates 435 trips as determined by a trip generation equation. Assume that the land use also attracts 40 pass-by trips coming to the site and 25 exiting the site. This means that the 435 driveway trips estimated from the trip generation step would really mean $435 - (40 + 25)$ or 370 new trips on the adjacent roads. Let's assume 10 percent of the trips are internal capture or $0.10 \times 370 = 37$ trips. This means that there will be a final estimated $370 - 37 = 333$ new trips on the adjacent road during the day due to the proposed development.

Anticipated travel demands, traffic volumes, and operating conditions should be developed for each planning horizon year. They should reflect likely growth in background traffic (and transit) volumes during the peak periods; planned changes in the roadways and public transport in the site environs; the type, size, and trip-generating characteristics of the planned development; directions of approach of site traffic volumes and their distribution on the surrounding road system; and combined (site plus background) traffic volumes on roadways and the site environs.

1. Background (Non-Site) Traffic Growth

Several methods can be used for estimating the future volumes of background traffic (see ITE's *Trip Generation Handbook* [ITE, 2012] and the example provided therein on background traffic growth). The simplest approach is to extrapolate from past trends, although this approach is strongly influenced by perturbations in the data (such as the effects of an economic recession). A more detailed approach is to identify major land developments in areas surrounding the proposed development site and assign estimated traffic from these sites to the adjacent road network. The most involved approach is to use a travel demand network model to estimate network link impacts (see chapter 6 for a discussion of travel demand models). Combining the first and second approaches may be desirable in some situations. However, in many major development impact studies, regional and local governments often require the use of computer-based network models to assess likely impacts. No matter which approach is used, the results should be checked for reasonableness. Each method should take into account changes in roadway and transit facilities, such as improving transit service frequency, increasing expressway or arterial roadway capacity, building new roadways, or introducing rail or bus rapid transit lines.

Growth trends. Examining local traffic volume growth trends (usually on an equivalent annual basis) works well for short timeframes (less than five years) especially where there is a good local traffic volume database. This approach is simple to use and can produce reasonable results. It is especially well-suited to small developments that will be open in a relatively short timeframe, such as banks and service stations. Generally, at least five years of data are needed. Estimates can be made more reliable by reviewing and comparing growth trends in population, vehicle registration, daily traffic volumes, and peak-hour traffic volumes. Each factor should be indexed to the base (existing) year.

Build-Up Method. This method is applicable where there are known projects in the planning horizon (usually five years or less). It involves treating each development (or series of contiguous developments) as a new development. The traffic these developments generate is then assigned to the road system for the design hours under consideration. This approach works best where there is good information on proposed developments. Most jurisdictions only consider approved development for the build-up method, specifically those development parameters that have been vetted and approved by a city or county.

Subarea Transportation Plan Volumes. Traffic volumes in transportation plans are usually estimated with the region's travel demand model, which is applied for an assumed transportation network and an assumed land-use pattern. This method is often used for large regional projects that are to be phased in over time. The method is particularly appropriate for use in large population areas and economic growth. Ideally, both daily and peak-hour traffic assignments should be made. With the addition of a new development site, the assumed model inputs might no longer be valid, so using subarea plan volumes needs to occur with caution.

In most cases, and especially for large developments, travel demand models are run with the development site becoming a new traffic analysis zone. This requires the coding of a more refined network. For regional developments, in many instances, the regional travel demand model is only used for trip distribution, that is, determining which direction trips are coming from or going to from the site. The use of the regional model to assign trips to the local roadway network (the so-called trip assignment process) can be done, if it is part of an agreed upon traffic methodology. However, in those instances, it is good practice to make sure that trips generated by the model match the ITE trip generation estimate for the project minus pass-by trips and internal capture.

Readers interested in additional information on travel demand modeling are referred to chapter 6. Some site-specific analysis aspects of the demand modeling process are discussed below.

2. Site Trip Generation

The number of trips to or from an activity center (person-trips) depends on the type and size of land use. The modes of travel will depend on the site location, development density, character of surrounding areas, and the availability and quality of alternative transportation options. The number of automobile driver (hence vehicle) trips depends on both mode split (percentage of travelers using each available mode of travel) and vehicle occupancy. Some of the key considerations in site trip generation include:

Person versus vehicle trips. ITE's multi-volume *Trip Generation* (9th edition) and many trip generation reports prepared by state and local agencies can provide reasonable estimates of the expected number of trips generated. [ITE, 2012] Trip generation rates are available for a variety of settings, although for suburban and exurban settings little or no transit or walk-in traffic is usually estimated. In settings with good transit and pedestrian access, the ITE vehicle trip rates can be adjusted downward to account for the likely percentage of a site's trips that would come as pedestrians or transit riders. Generally, any reduction in vehicle trips to account for pedestrian and transit riders would be agreed to as part of the traffic methodology and require supporting documentation from sites that have similar pedestrian and transit access.

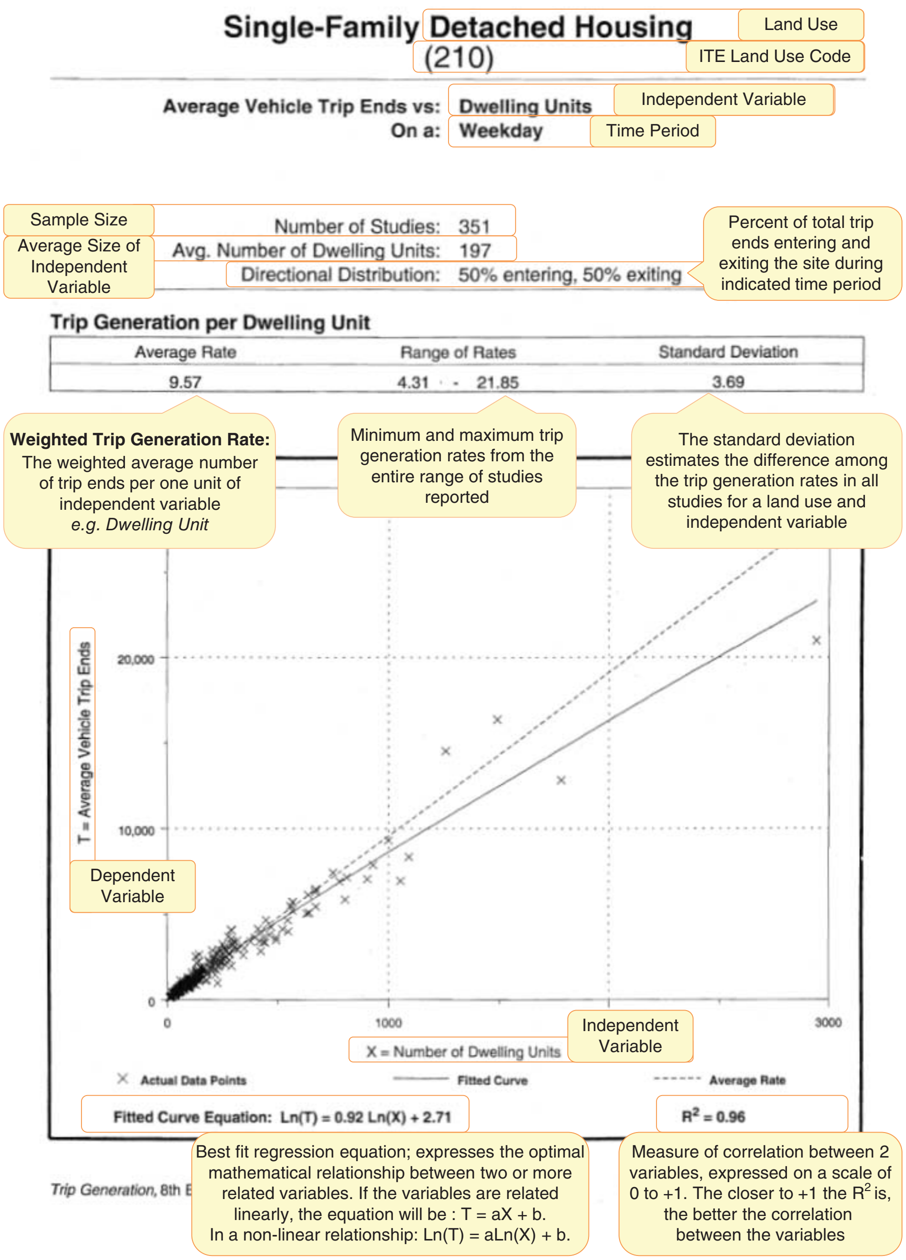
Trip rates. Trip generation estimates should be based on local rates for similar types of development. In some cases, it may be desirable to conduct trip generation studies at sites with similar characteristics. Alternatively, rates for similar development in other parts of a state or region may be used where applicable. The important variables in developing trip rates are the independent variables used to estimate trips generated, for example, number of dwelling units, thousands of retail square feet, and the like. Although such variables are given as part of trip generation handbooks and manuals, if it is desired to estimate jurisdiction-specific equations, the choice of the independent variables will be critical. Other means of estimating trip rates include:

- Regression equations can be used when (1) the independent variable lies within the range of data likely associated with the proposed development, (2) there are at least 20 data points, and (3) $R^2 \geq 0.75$. Equations should be used when the actual trip rates decrease as the development size increases. Examples include office buildings and shopping centers.
- Weighted average rates should be used when (1) there are at least three (preferably six) data points, (2) the independent variable lies within the ranges of the data points, and (3) R^2 is less than 0.75 or no equation is provided.
- Where the standard deviation is more than 110 percent of the weighted average (for example, the coefficient of variation), additional studies may be desirable (see chapter 2 on data analysis).

The trip rates and trip equations set forth in the ITE *Trip Generation* report and the procedures in the ITE *Trip Generation Manual* are often used by transportation agencies. In some instances, these rates are augmented by additional research (see [Daisa et al., 2013], for example). Equations are preferable to rates where they are available and have high statistical relationship among the key variables. Figure 19-4 shows some of the information that can be found in the ITE *Trip Generation Manual*. [ITE, 2012]

Analysis hours. Analyses should be done for the hours of the day when the maximum combined traffic volumes occur on the surrounding road network. They should consider the periods when normal background highway traffic is at a peak as well as when site traffic volumes peak. Given the different activities that occur on individual sites, the study time periods may vary for residential, office, industrial, retail, and recreational developments. Typically, analyses should be done for weekday a.m. and/or p.m. peak hours; however, in some situations, such as major retail developments, Saturday or Sunday peaks should be analyzed. The p.m. peak hour for schools in many instances does not coincide with the surrounding roadway network p.m. peak hour, as the school p.m. peak hour is generally 2–4 p.m. and the surrounding roadway network p.m. peak hour is generally 4–6 p.m. As such, school p.m. peak-hour traffic counts and operational analyses may need to account for this offset from the traditional peak-hour analyses.

Figure 19-4. ITE Trip Generation Manual Example



Source: Florida DOT, 2014

Typical time periods that generate peak traffic flows for selected land uses are shown in Table 19-4. Evening hours from 7:00 p.m. to 10:00 p.m. that sometime generate heavy traffic volumes at regional shopping centers should also be studied.

Multiuse developments: Multiuse or mixed-use developments bring together office, retail, recreational, and/or residential uses in a single project. Six land uses are the most frequent components of multiuse sites: office, retail, restaurant, residential, cinema, and hotel. This mix of land uses fosters internal travel among various activities, either by car or walking, which reduces the number of vehicle trips entering and leaving the development as compared to the sum of the trips generated by the individual land uses. The number of internal trips (that is, internal capture) varies with the type and size of each use. Past experience suggests that about 20 to 30 percent of the trips to and from retail areas come from office buildings, with the percentages differing for the noon time and p.m. peak hours. Smaller amounts of interchange take place between retail and residential and office and residential. Reported internal capture rates for multiuse centers are shown in Tables 19-5 to 19-8 from NCHRP Report 684, *Enhancing Internal Trip Capture Estimation for Mixed-Use Developments*. [Bochner et al., 2011]

Table 19-4. Typical Peak Traffic Flow Hours for Selected Land Uses		
Land Use	**Typical Peak Hours**	**Peak Direction**
Residential	7:00–9:00 a.m. weekdays	Outbound
	4:00–6:00 p.m. weekdays	Inbound
Regional Shopping	5:00–6:00 p.m. weekdays	Total
	1:00–2:00 Saturdays	Inbound
	4:00–5:00 Saturdays	Outbound
Office	7:00–9:00 a.m. weekdays	Inbound
	4:00–6:00 weekdays	Outbound
Industrial	Varies with employee shift schedule	–
Recreational	Varies with type of activity	–

Source: ITE, 2012

Table 19-5. Proposed Unconstrained Values for Distribution of Internal Trip Destinations for Exiting Trips, A.M. Peak Period, %

	Destination Land Use					
Origin Land Use	**Office**	**Retail**	**Restaurant**	**Residential**	**Cinema**	**Hotel**
Office	N/A	28%	63%	1%	N/A	0%
Retail	29%	N/A	13%	14%	N/A	0%
Restaurant	31%	14%	N/A	4%	N/A	3%
Residential	2%	1%	20%	N/A	N/A	0%
Cinema	N/A	N/A	N/A	N/A	N/A	N/A
Hotel	75%	14%	9%	0%	N/A	N/A

Source: Bochner et al., 2011, Reproduced with permission of the Transportation Research Board.

Table 19-6. Proposed Unconstrained Values for Distribution of Internal Trip Destinations for Exiting Trips, P.M. Peak Period, %

	Destination Land Use					
Origin Land Use	**Office**	**Retail**	**Restaurant**	**Residential**	**Cinema**	**Hotel**
Office	N/A	20%	4%	2%	0%	0%
Retail	2%	N/A	29%	26%	4%	5%
Restaurant	3%	41%	N/A	18%	8%	7%
Residential	4%	42%	21%	N/A	0%	3%
Cinema	2%	21%	31%	8%	N/A	2%
Hotel	0%	16%	68%	2%	0%	N/A

Source: Bochner et al., 2011, Reproduced with permission of the Transportation Research Board.

Table 19-7. Proposed Unconstrained Values for Distribution of Internal Trip Origins for Entering Trips, A.M. Peak Period, %

	Destination Land Use					
Origin Land Use	**Office**	**Retail**	**Restaurant**	**Residential**	**Cinema**	**Hotel**
Office	N/A	32%	23%	0%	N/A	0%
Retail	4%	N/A	50%	2%	N/A	0%
Restaurant	14%	8%	N/A	5%	N/A	4%
Residential	3%	17%	20%	N/A	N/A	0%
Cinema	N/A	N/A	N/A	N/A	N/A	N/A
Hotel	3%	4%	6%	0%	N/A	N/A

Source: Bochner et al., 2011, Reproduced with permission of the Transportation Research Board.

Table 19-8. Proposed Unconstrained Values for Distribution of Internal Trip Origins for Entering Trips, P.M. Peak Period, %						
	Destination Land Use					
Origin Land Use	**Office**	**Retail**	**Restaurant**	**Residential**	**Cinema**	**Hotel**
Office	N/A	8%	2%	4%	1%	0%
Retail	31%	N/A	29%	46%	26%	17%
Restaurant	30%	50%	N/A	16%	32%	71%
Residential	57%	10%	14%	N/A	0%	12%
Cinema	6%	4%	3%	4%	N/A	1%
Hotel	0%	2%	5%	0%	0%	N/A

Source: Bochner et al., 2011, Reproduced with permission of the Transportation Research Board.

Activities in central business districts (CBDs) and other densely developed districts usually draw many patrons from nearby origins. In these cases, rather than dealing with internal capture, the primary destinations for each use should be estimated. Retail stores and restaurants, for example, may draw large numbers of patrons from nearby offices and would have vehicle trip generation rates considerably less than those cited in the ITE manuals.

3. Pass-By Trips

As noted earlier, some of the trips generated by new developments will come from currently passing traffic. These pass-by trips have the effect of reducing the anticipated development-generated traffic volumes on the surrounding road system, although the access (driveway) volumes into a site would remain unchanged.

Trips diverted to boundary roads from other roadways to reach a site would not add traffic to the roadways in an area, but may increase traffic on the roads serving a site. These diverted trips are normally treated as part of a site's generated traffic; pass-by trips are deducted from the boundary road traffic.

The proportion of a site's traffic coming from the passing traffic depends on the type and size of development, and whether an activity is a destination in itself or merely a stop along a trip path, for example, an office building versus a gas station. (Up to 50 percent of all trips to a service station have been found to be travelers passing by rather than people who made a special trip to the gas station). Generally, as developments increase in size, there is a corresponding reduction in the proportion of pass-by traffic. This is apparent from the percentages reported for shopping centers as shown below.

Net square feet of floor space for shopping centers	Percent of pass-by trips
<100,000	40%
100,000–250,000	30%
250,000–500,000	25%
500,000–750,000	22%
Over 750,000	20%

The percentages of pass-by trips for various land uses are reported in ITE's *Trip Generation* [2012]. Because of limited data and high variability, adjustments should be applied carefully.

Travel demand management (TDM) impacts. The primary purpose of TDM strategies is to influence travel demand, usually targeted at reducing the number of single-occupant vehicles accessing a site during peak periods. They work best in activity centers with a large employment base, often with a single or only a few employers. Employer-based TDM programs normally include preferential parking for vanpools and carpools, company endowment of vans, transit passes, ridesharing coordination at large employers, and flextime. Public sector incentives include free parking at freeway interchanges, financial support of public transport, provision of HOV and high-occupancy toll lanes, and developer agreements to encourage ridesharing (see chapter 14 on travel demand management).

As part of the trip generation analysis, summary tables should list each type of land use, its size, and proposed vehicle trip generation rates for daily, a.m./p.m. peaks, and other peak periods of interest. Deductions may then be necessary for internal trips and multiuse sites, TDM actions, and activities displaced by the development.

In some cases, trip reduction policies have been adopted by transportation agencies and are encouraged as part of the traffic impact study. In Massachusetts, for example, the state's *Mode Shift Initiative* has established a statewide mode shift goal of tripling the share of travel by bicycling, transit, and walking. All elements of the site impact analysis and the project proposal—trip generation, mode split, trip distribution, adjustment factors, parking, siting, and others—must show how the proposed mitigation will help achieve this target.

In Calgary, Alberta, active transportation modes such as walking and bicycling must be considered as part of the impact analysis. Where expected volumes cannot be forecast, default values are to be used, including:

- *Very Low-Impact Areas*: 10 pedestrians/hour and 5 bicycles/hour.
- *Low-Impact Areas*: 25 pedestrians/hour and 10 bicycles/hour.
- *Moderate-Impact Areas:* 50 pedestrians/hour and 20 bicycles/hour. [City of Calgary, 2011]

The review is also to include a qualitative assessment of the connectivity of the proposed development to the region's primary transit and cycling network, and the regional pathway system.

Freight or goods movement. The following questions relating to truck movements in the study area should be considered in the analysis:

- What is the existing percentage of trucks in the study area?
- Are there existing truck safety issues in the study area? Will the proposed development sustain or improve these conditions?
- How will the specific land uses and businesses for the proposed development affect truck trip generation?
- When will the peak hour of truck trip generation occur?
- How will trucks be routed and circulated on-site and off-site?
- How will queuing at driveways and intersections be affected by truck trip generation?
- Will truck trip generation adversely impact site access?
- Will there be sufficient truck turning radii?
- Will a separate truck access point be needed to minimize conflicts between trucks and other vehicles?
- Will deceleration lanes at the site access point be needed to maintain safety?
- How will trucks affect access, circulation, and operations at the proposed development's access points? For the entire study area? [City of Fontana, 2003; McRae et al., 2006]

Freight planning and in particular truck trip generation is discussed in chapter 22 on freight planning.

4. Site Trip Distribution

The direction of approach of vehicle and transit trips should be estimated for the roadways entering the site environs. Trip distribution for proposed developments can be determined from zip code data, census data, market research, travel demand forecasting models, existing travel patterns, and/or the location of complementary land uses. The relative magnitudes of site-generated traffic should be assigned to the boundary roads and access points based on the specific building footprints and the relative square footage of development at various locations at a development site. Trip distribution will depend upon site-specific factors, such as:

- Existing travel patterns.
- Type and size of the proposed development.

- Size of the influence areas.
- Surrounding land uses.
- Locations of competing developments (for example, shopping centers).
- Population and purchasing power distribution.
- Transport system availability, characteristics, and travel times.
- Planned transportation improvements.

Because a combination of these factors will likely be found at any particular site, local codes and ordinances should not require the use of specific traffic distribution techniques. The analyst should be allowed to exercise appropriate judgment, although assumptions and methods of analysis should be clearly stated.

The Oregon DOT identifies three methods that can be used to distribute trips in the study area. [ODOT, 2014]

Analogy Method. The analogy method uses traffic information from a similar development to predict trip distribution for the proposed development. This can be accomplished by various methods including driver surveys, license plate origin-destination studies, and driveway turning movement counts. This method is generally acceptable for small to midsized developments such as:

- Fast-food restaurants where a competing establishment is near the site.
- Service stations where traffic volumes on the adjacent streets are similar to those forecasted at the site.
- Motel sites near an existing motel.
- Residential developments on the fringe of an urban area.
- Sites to be developed for residential use, where the tract is one of the few vacant parcels in a developed area.
- Occupied buildings located in an office complex being developed by phases.

Travel Demand Model. A travel demand model can be effective in estimating traffic distribution patterns, especially for very large developments where a large number of trips is to be generated or attracted. Because travel demand models are typically developed in conjunction with a transportation system plan and comprehensive plan, they can provide a reliable forecast for fast-growing urban areas. The traffic analysis zone (TAZ) containing the proposed development should be investigated closely to ensure land uses, development densities, and trip-making characteristics are modeled consistent with existing conditions (see chapter 6 on travel demand modeling). The steps for using a travel demand model include:

- Interpolate the land-use and socioeconomic data sets to project conditions for the build-out year of the development phase or project.
- Verify that the transportation network includes only existing plus committed facilities.
- Create a new traffic analysis zone for the proposed project. Within this new zone, input the amount of development proposed for the project. Apply the model to determine the project traffic distribution.
- Determine total trips generated by the new zone, so that the percentage of project trips assigned by the model can be determined.
- If there are additional roadways that should be part of the study area network and are not included in the model, then a post-model adjustment can be made to distribute traffic to these facilities.
- Calculate the percentage of trips assigned to each roadway segment in the project vicinity.
- Multiply the percentage of project traffic by the external trips generated. [GRTA, 2013]

Surrogate Data. Surrogate data uses related information other than direct causal variables to represent the influence and impacts of a development on the distribution of trips to and from a site. An example is using the distribution of residential population in the region or study area as a surrogate for the direction of trips approaching office and retail land uses. For example, if 50 percent of the residential population relating to a site location is found southeast of the site, one can assume that 50 percent of the site trips would be coming from this direction. This method can accurately estimate trip distribution when used cautiously and for appropriate land uses. It also requires a database of usable socioeconomic and demographic information for various parts of the city.

In cases where market analyses have been conducted for a property or development, it may be appropriate to use the results of this analysis as a means of developing project traffic distribution. This information can be used at the discretion of the applicant, but should be approved by the reviewing agency prior to proceeding with the study.

A synthesis of traffic impact analysis procedures for the Oregon DOT examined best practices in the different methods and tools used by communities and consultants to do site impact studies. Some of the methods used to distribute traffic volumes included:

- Regional travel demand model.
- Existing street circulation system and a review of the existing traffic volumes, circulation patterns, and intersection turning movements.
- Market analysis provided by the retail store.
- Surveys of those who will be using service to determine residence location (by zip code) and mode of transportation.
- Population density and traffic analysis judgment.
- Percentage of local trips versus regional trips and analysis of the distribution of local traffic of residential areas. [McRae et al., 2006]

The report showed that the trip distribution forecasts for two of the sites were within 20 percent of the actual trip distribution after the development was built. New access control, no infrastructure improvements, and stagnant economic growth in the site vicinity were used to explain why this difference occurred. The report concluded that not including expected or predicted other development in the traffic impact study can have a significant effect on trip distribution estimates, especially if the site is not built as assumed.

The Washington State DOT encourages the use of scenarios, especially for large development sites, to account for possible other development impacts. Scenarios can range from simple "existing conditions with and without project," to more complex analyses where scenarios could include: existing, opening year with and without the project, interim years with and without the project, and design year with and without the project. [Washington State DOT, 2004] The DOT recommends for interim scenario networks that only projects or developments within the forecasting process having the highest probability of occurring within a 10-year horizon be included in the analysis. The city of San Jose recommends a "cumulative conditions" scenario to determine the combined effect of multiple pending projects or foreseeable developments with individually limited impacts on the transportation system. [City of San Jose, 2009]

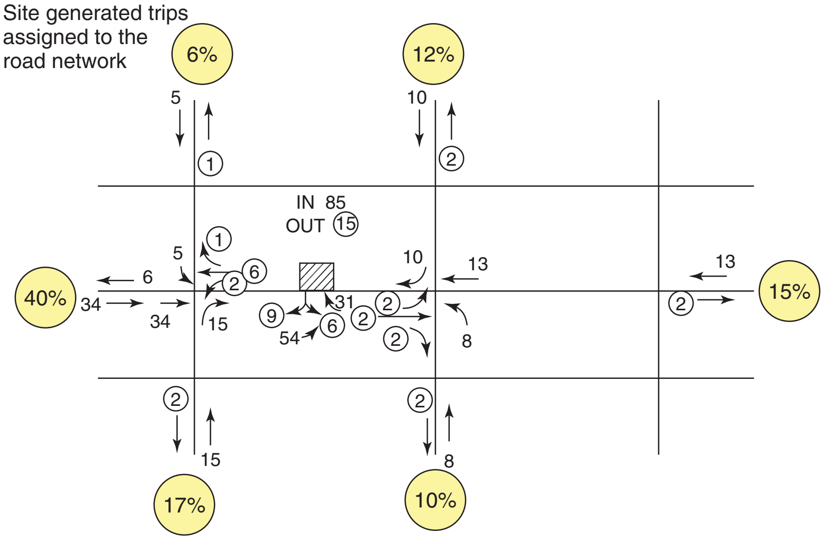
Trip distribution should be expressed as percentages by direction (see Figure 19-5). A table should be prepared showing directions of approach for each community within the trade area. These percentages and their resulting assignment to the road network should then be applied to the anticipated site trip generation to obtain design plans for each part of the road system.

Where transit and walk-in traffic is likely, directions of approach should be estimated for each mode. This requires modal allocations of person trips for each analysis area. The relative origins for each mode can then be assigned to roadways, transit routes, and walkways. In the immediate site environs, transit riders should be assigned to specific bus stops and rail stations, if appropriate. Walk-in trips, which are mainly from nearby areas, should be assigned to the street crossings and walkway system serving the site.

5. Trip Assignment

The combined (composite) traffic volumes for public street and site access roadways should be developed for each future condition analyzed. This involves adding the component of future background traffic and the expected site traffic on each network link and making needed adjustments for pass-by traffic. The traffic volumes should show each

Figure 19-5. Example Trip Distribution for Site Impact Analysis



Source: FHWA, 1985

traffic flow for through, left, and right turns. Anticipated pedestrian flows can be superimposed on these diagrams. They should be plotted on site maps and checked for reasonableness. These resulting combined peak-hour traffic volumes should be compared with the available roadway capacity to assess system adequacy, the need for roadway improvements, and the design of site access points. This comparison is done by assigning trips to the transportation network.

Trip assignment involves determining the amount of traffic that will follow certain paths in a roadway network. The trip assignment will illustrate the project-generated trips, by direction and turning movement, on each roadway segment of the study area. The procedure consists of assigning the project-generated traffic to the roadway network according to the trip distribution for each proposed land use, accounting for any turning movement restrictions (for example, one-way streets, ramps, movement restrictions and raised median islands, and so forth), or other unique roadway characteristics including excessive congestion. If using a travel demand model, this process is simply part of the modeling effort. If assigning trips manually to the network, several factors should be considered:

- Traffic assignment should consider logical routings, available roadway capacities, turning movements, and expected travel times (the basic goal of trip assignment is to follow the least travel time path).
- Multiple paths between origins and destinations should be used to achieve realistic results (assuming multiple paths exist).
- Assignments for future years should consider likely land use and traffic conditions in the target year.
- Assignments should be carried through the external site access points and, in large projects, on the internal roadways.
- When a site has more than one access point, logical routing and multiple paths should be used to obtain realistic driveway volumes. [ITE, 2010]

Readers are referred to [Giaimo, 2001] for a good reference on traffic assignment procedures as applied in site impact analysis.

VI. ANALYSIS PROCEDURES

The type and extent of analysis will depend not only on the characteristics of the development itself, but also on the types of improvements likely to be considered. Typical improvements are shown in Table 19-9 and are described further in ITE [2010].

Table 19-9. Typical Site Transportation Improvements
Roadways
• Install a traffic signal or roundabout. • Coordinate signals on common cycles along boundary and approach roads. • Provide right-and/or left-turn lanes. • Add through lanes. • Expand and/or improve intersections. • Channelization, such as turn lanes or raids. • Frontage improvements. • Install two-way left-turn lanes, where appropriate. • Install physical median (the median may be discontinued to allow only left turns into development of minor streets, or provide all movements at intersection). • Remove shrubbery or otherwise improve sight distance. • Widen access drives. • Consolidate or close driveways (develop shared access driveways). • Limit access drives to right turn exits only. • Establish one-way access drives. • Construct a "backage" road. • Widen and/or locate interchange ramps. • Construct "flyovers" or "flyunders" along artery at major junctions. • Reconfigure freeway interchange. • Construct new freeway interchange.
Transit
• Add bus stops/ shelters. • Install a new bus route. • Improve bus service frequency. • Route buses to stops at heart of development. • Establish a transit center within a development. • Develop a new bus rapid or light rail transit route with good pedestrian access to development.
Pedestrians/Bicyclists
• Provide sidewalks on perimeter road. • Install crosswalks, preferably with a central refuge area. • Accommodations for bicycles such as bike lanes, bike boulevard treatments, bike parking. • Construct walks from surrounding roads to development. • Construct weather-protected skyways that connect developments with express transit way stations, or avoid major highway crossing.
Travel Demand Management
• Create transportation management association (TMA). • Establish rideshare programs, subsidized if possible. • Limit and/or price commuter parking. • Carpool incentives, such as preferred parking. • Consider flex-time and telecommute work programs, where appropriate.

Source: ITE, 2010

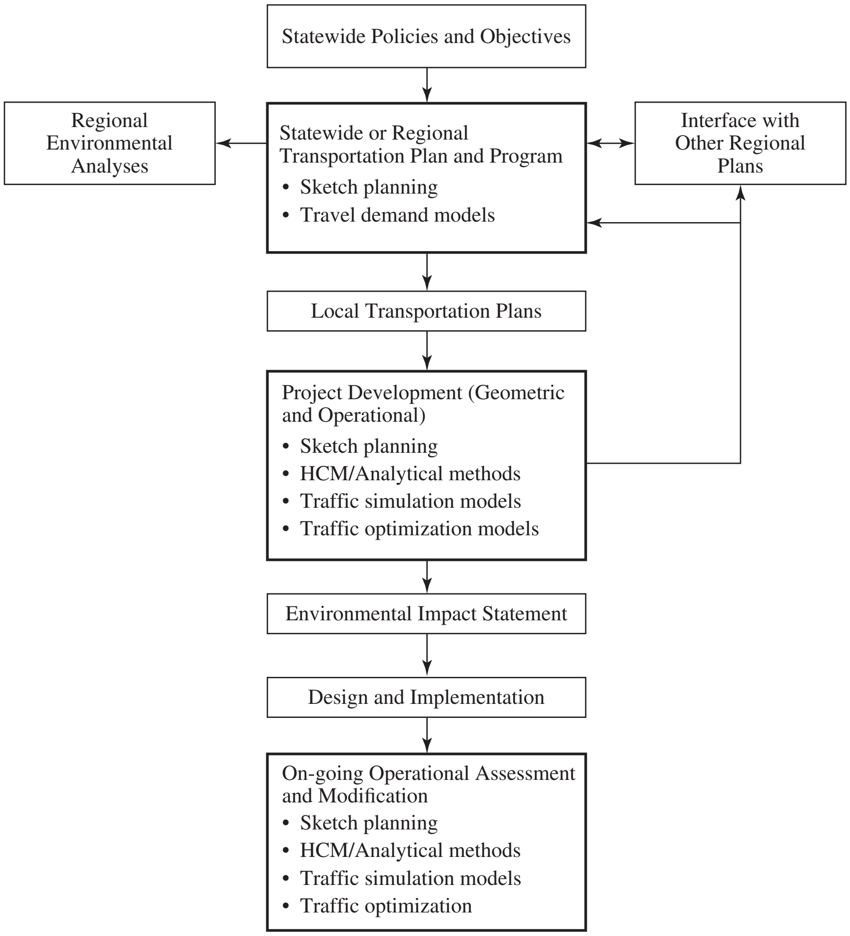
Anticipated traffic, transit, and pedestrian volumes provide the basis for assessing the workability of the existing transportation and recommended improvements. When improvements are added, service-level computations can indicate how well the facilities operate. This is often an iterative process depending on the scale of developments and the amount of background traffic growth. Ideally, needed improvements should be consistent with those planned or programmed by public agencies. Multimodal assessments are essential in densely developed areas and for large mixed-use or commercial developments.

A. Choice of Models or Tools

The selection of analysis tools and methods will depend on the evaluation criteria agreed upon at the beginning of the study. In most cases, some measure of level of service and quality of service is used to estimate system impact. In the United States, this usually means using procedures from the Transportation Research Board's *Highway Capacity Manual* (HCM) [TRB, 2010] and the *Transit Capacity and Quality of Service Manual* (TCQSM). [Kittelson et al., 2013a] In addition, there are specialized methods and approaches for active transportation modes.

The FHWA *Traffic Analysis Toolbox*, Volume 2, provides a methodology for selecting traffic analysis tools. [Jeannotte et al., 2004] Figure 19-6 shows the relationship among the many different traffic analysis tools used by transportation engineers and planners. The different types of tools, as excerpted from the report, were described in the *Toolbox* as:

Figure 19-6. Overview of the Traffic Analysis Process



Note: Boxes outlined by a bold line represent the primary realm of application of traffic analysis tools.

Source: Jeannotte et al., 2004

Sketch-Planning Tools. Sketch-planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements. They allow for the evaluation of specific projects or alternatives without conducting an in-depth engineering analysis. Sketch-planning tools perform some or all of the functions of other analytical tools using simplified techniques and highly aggregate data.

Travel Demand Models. Travel demand models have specific analysis capabilities, such as the prediction of travel demand and the consideration of destination choice, mode choice, time-of-day travel choice, and route choice in the highway network. These are mathematical models that forecast future travel demand based on current conditions and future projections of household and employment characteristics.

Analytical/Deterministic Tools (HCM-Based). Most analytical/deterministic tools implement the procedures of the HCM. The HCM procedures are closed-form, macroscopic, deterministic, and static analysis procedures that estimate capacity and performance measures to determine level of service (for example, density, speed, and delay). They are closed-form because they are not iterative. The practitioner inputs the data and the parameters and, after a sequence of analysis steps, the HCM procedures produce a single answer. Analysis/deterministic tools are good for analyzing the performance of isolated or small-scale transportation facilities; however, they are limited in their ability to analyze network or system effects.

Traffic Signal Optimization Tools. Similar to the analytical/deterministic tools, traffic optimization tool methodologies are mostly based on the HCM procedures. However, traffic optimization tools are designed to develop optimal signal phasing and timing plans for isolated signal intersections, arterial streets, or signal networks. This may include capacity calculations, signal cycle length, signal split optimization (including turn phasing), and coordination/offset plans.

Table 19-10. Comparison of Analysis Tools and Spatial Application

Analytical Context/ Geographic Scope	Sketch Planning	Travel Demand Models	Analytical/ Deterministic Tools (HCM-based)	Traffic Optimization	Macro Simulation	Meso Simulation	Micro Simulation
Planning							
Isolated Intersection	o	o	●	Ø	o	o	o
Segment	●	o	●[1]	o	Ø	Ø	Ø
Corridor/Small Network	Ø	●	o	Ø	Ø	Ø	Ø
Region	Ø	●	N/A	N/A	N/A	N/A	N/A
Design							
Isolated Location	N/A	N/A	●	●	●	Ø	●
Segment	N/A	o	●	Ø	●	●	●
Corridor/Small Network	N/A	Ø	o	o	●	●	●
Region	N/A	Ø	N/A	N/A	o	o	Ø
Operations/Construction N/A							
Isolated Location	N/A	N/A	●	●	●	Ø	●
Segment	Ø	o	●	●	●	●	●
Corridor/Small Network	N/A	Ø	o	Ø	●	●	●
Region	N/A	Ø	N/A	N/A	Ø	o	Ø

● Specific context is generally addressed by the corresponding analytical tool/methodology

Ø Some of the analytical tools/methodologies address the specific context and some do not.

o The particular analytical tool/methodology does not generally address the specific context.

N/A The particular methodology is not appropriate for use in addressing the specific context.

[1] For linear networks.

Source: Jeannotte et al., 2004

Macroscopic Simulation Models. Macroscopic simulation models are based on the deterministic relationships among flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic simulation models were originally developed to model traffic in transportation subnetworks, such as freeways, corridors (including freeways and parallel arterials), surface-street grid networks, and rural highways.

Mesoscopic Simulation Models. Mesoscopic models combine the properties of both microscopic (discussed below) and macroscopic simulation models. As in microscopic models, the unit of traffic flow for mesoscopic models is the individual vehicle. Similar to microscopic simulation models, mesoscopic tools assign vehicle types and consider driver behavior, as well as their relationships with roadway characteristics. Mesoscopic model travel prediction takes place on an aggregate level and does not consider dynamic speed/volume relationships.

Microscopic Simulation Models. Microscopic simulation models simulate the movement of individual vehicles based on car-following and lane-changing algorithms. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over brief time intervals (for example, 1 second or a fraction of a second). In many microscopic simulation models, the traffic operational characteristics of each vehicle are based on well-known influences on vehicle dynamics of such things as road grade, horizontal road curvature, and pavement superelevation.

Each tool and method has its own application context. Table 19-10, for example, shows the usefulness of each of the analysis tools with respect to the scale of analysis; Table 19-11 shows the relationship between the tools and type of facility; and Table 19-12 shows similar information for different performance measures.

Table 19-11. Comparison of Analysis Tools and Facility Type

Facility Type	Sketch Planning	Travel Demand Models	Analysis/ Deterministic Tools (HCM-based)	Traffic Optimization	Macro Simulation	Meso Simulation	Micro Simulation
Isolated intersection	o	Ø	●	●	●	●	●
Roundabout	o	o	●	o	Ø	o	Ø
Arterial	●	●	●	●	●	●	●
Highway	●	●	●	Ø	●	●	●
Freeway	Ø	●	●	Ø	●	●	●
HOV lane	Ø	●	Ø	o	●	●	●
HOV bypass lane	o	●	o	Ø	Ø	Ø	●
Ramp	Ø	●	●	●	●	●	●
Auxiliary lane	o	o	Ø	Ø	●	●	●
Reversible lane	o	Ø	●	●	●	●	Ø
Truck lane	o	●	Ø	Ø	Ø	o	●
Bus lane	o	●	o	o	Ø	o	●
Toll plaza	o	Ø	Ø	o	o	o	●
Light rail line	o	●	o	o	o	o	●

● Specific context is generally addressed by the corresponding analytical tool/methodology.

Ø Some of the analytical tools/methodologies address the specific context and some do not.

o The particular analytical tool/methodology does not generally address the specific context.

N/A The particular methodology is not appropriate for use in addressing the specific context.

Source: Jeannotte et al., 2004

Table 19-12. Comparison of Analysis Tools and Performance Measures							
Measure	**Sketch Planning**	**Travel Demand Models**	**Analytical/ Deterministic Tools (HCM-based)**	**Traffic Optimization**	**Macro Simulation**	**Meso Simulation**	**Micro Simulation**
LOS	o	Ø	●	●	Ø	Ø	Ø
Speed	●	●	●	●	●	●	●
Travel time	Ø	Ø	●	●	●	●	●
Volume	●	●	●	●	●	●	●
Travel distance	o	o	o	o	o	●	●
Ridership	o	Ø	o	o	●	Ø	Ø
Average vehicle occupancy	o	●	o	o	o	o	o
V/C ratio	o	●	●	Ø	Ø	Ø	Ø
Density	o	o	●	●	●	●	●
VMT/PMT	Ø	●	Ø	Ø	●	●	●
VHT/PHT	Ø	●	Ø	Ø	●	●	●
Delay	Ø	●	●	●	●	●	●
Queue length	o	o	●	●	●	●	●
# of stops	Ø	o	o	o	o	o	●
Crashes	Ø	o	o	o	o	Ø	Ø
Incident duration	Ø	o	o	o	o	Ø	Ø
Travel time reliability	Ø	o	o	o	o	Ø	Ø
Emissions[1]	Ø	o	o	o	o	Ø	Ø
Fuel consumption[1]	Ø	o	o	o	Ø	Ø	Ø
Noise	Ø	o	o	o	o	o	o
Mode split	o	●	●	Ø	Ø	Ø	Ø
Benefit/cost	Ø	o	o	o	o	o	o

● Specific context is generally addressed by the corresponding analytical tool/methodology.

Ø Some of the analytical tools/methodologies address the specific context and some do not.

o The particular analytical tool/methodology does not generally address the specific context.

N/A The particular methodology is not appropriate for use in addressing the specific context.

[1] Most emissions models are post processing models that use the input from the models in this table to estimate emissions and fuel consumption. In addition, the state-of-the-art of travel demand models has progressed significantly since this table was developed.

Source: Jeannotte et al., 2004

Transportation planners should be aware of the strengths and weaknesses of each type of model and tool that can be used for impact analysis. In some cases, jurisdictions provide guidance on which tools are acceptable. Washington State DOT, for example, provides the following information on acceptable tools for travel impact analysis:

- *Freeway Segments*: Highway Capacity Manual/Software (HCM/S); operational and design analysis—macroscopic, mesoscopic, and microsimulation.
- *Weaving Areas*: Design manual (DM), HCM/S, operational and design analysis, microsimulation.
- *Ramps and Ramp Terminals:* HCM/S, operational and design analysis, DM, microsimulation.
- *Multilane Highways*: HCM/S; operational and design analysis—macroscopic, mesoscopic, and microsimulation.
- *Two-Lane Highways:* HCM/S, operational and design analysis.

- *Intersection, Signalized:* Sidra, Synchro, SimTraffic, HCM/S, Vissim.
- *Intersection, Roundabout:* Sidra, Rodel, HCM, Vissim.
- *Corridors:* Sidra, Synchro, SimTraffic, HCM, Vissim.
- *Stop-Controlled Intersections:* HCM/S for capacity, DM Chapter 1330 and the MUTCD for signal warrants (if a signal is being considered).
- *Transit:* HCM/S, operational and design analysis, *Traffic Manual*.
- *Pedestrians:* HCM/S.
- *Bicycles*: HCM/S.
- *WSDOT Criteria/Warrants:* MUTCD (signals, stop signs), *Traffic Manual* (school crossings), DM Chapter 1040 (freeway lighting, conventional highway lighting).
- *Channelization:* DM. [WSDOT, 2014, 2015]

The following discussion on the analysis of facility performance focuses on three types of facilities: intersections, road segments and corridors, and networks. Many of the models and tools described above can be used for analyzing facility and system performance at different scales of analysis.

B. Intersections

All intersections likely to be significantly impacted by the addition of project-generated traffic, that is, those now likely to experience operational problems or where a traffic signal warrant threshold might be triggered, should be part of the impact analysis. The HCM and accompanying software provides a methodology for assessing the level of service impact on intersections. [TRB, 2010] The reader is directed to this manual for a detailed discussion of the methods and approaches for estimating level of service. For intersection analysis the concept of a "lane group" is important. A lane group is a lane or group of lanes designated for separate analysis, which includes lanes that exclusively serve one movement through the intersection as well as each lane that is shared by one or more movements.

Table 19-13 shows the level of service for signalized intersections as defined in the amount of delay (seconds/vehicle) and the volume-to-capacity ratio of approaching intersection legs. Note that any volume-to-capacity ratio greater than 1.0 is considered LOS F. To give some sense of the type of data that is needed to estimate intersection level of service, Table 19-14 shows required data and the basis upon which the data are input into the calculations.

Level of service impacts should be estimated for transit, bicycles, and pedestrians as well as for automobiles. A variety of methods are used to define the performance of pedestrian and bicycle facilities, including an approach found in the HCM. Transit level of service can be analyzed with the TCQSM. Table 19-15 shows the LOS score and corresponding level of service based on what travelers have defined as being important aspects of walking and bicycling. Based on the perceived desirable characteristics of active transportation options, the HCM software package produces the score shown in the table. Some sense of these characteristics is shown in Table 19-16, which lists the input data for this process.

Table 19-13. Level of Service for Signalized Intersections

Control Delay (s/veh)	LOS by Volume to Capacity Ratio ≤1.0
≤10	A
>10–20	B
>20–35	C
>35–55	D
>55–80	E
>80	F

Source: TRB, 2010, Reproduced with permission of the Transportation Research Board.

Table 19-14. Data Inputs to Estimate Intersection Automobile Level of Service		
Data Category	**Input Data Element**	**Basis**
Traffic characteristics	• Demand flow rate	By movement
	• Right-turn-on-red flow rate	Approach
	• Percent heavy vehicles	Movement group
	• Intersection peak-hour factor	Intersection
	• Platoon ratio	Movement group
	• Upstream filtering adjustment factor	Movement group
	• Initial queue	Movement group
	• Base saturation flow rate	Movement group
	• Lane utilization adjustment factor	Movement group
	• Pedestrian flow rate	Approach
	• Bicycle flow rate	Approach
	• On-street parking maneuver rate	Movement group
	• Local bus stopping rate	Approach
Geometric design	• Number of lanes	Movement group
	• Average lane width	Movement group
	• Number of receiving lanes	Approach
	• Turn bay length	Movement group
	• Presence of on-street parking	Movement group
	• Approach grade	Approach
Signal control	• Type of signal control	Intersection
	• Phase sequence	Intersection
	• Left-turn operational mode	Approach
	• Dallas left-turn phasing option	Approach
	• Passage time (if actuated)	Phase
	• Maximum green (or green duration, if pre-timed)	Phase
	• Minimum green time	Phase
	• Yellow change	Phase
	• Red clearance	Phase
	• Walk	Phase
	• Pedestrian clear	Phase
	• Phase recall	Phase
	• Dual entry (if actuated)	Phase
	• Simultaneous gap-out (if actuated)	Approach
Other	• Analysis period duration	Intersection
	• Speed limit	Approach
	• Stop-line detector length	Movement group
	• Area type	Intersection

Movement: one value for each left-turn, through and right-turn movement.

Approach: one value for the intersection approach.

Leg: one value for the intersection leg (approach plus departure sides).

Intersection: one value for the intersection.

Phase: one value or condition for each signal phase.

Source: TRB, 2010, Reproduced with permission of the Transportation Research Board.

Table 19-15. Intersection Multimodal Level of Service for Walking and Bicycling	
Level of Service	**LOS Score**
A	≤2.00
B	>2.00–2.75
C	>2.75–3.50
D	>3.50–4.25
E	>4.25–5.00
F	>5.00

Source: TRB, 2010, Reproduced with permission of the Transportation Research Board.

Table 19-16. Data Inputs to Estimate Intersection Non-Automobile Level of Service			
Data Category	**Input Data Element**	**Pedestrian**	**Bicycle**
Traffic characteristics	• Demand flow rate of motorized vehicles	Movement	Approach
	• Right-turn-on-red flow rate	Approach	
	• Permitted left-turn flow rate	Movement	
	• Mid-segment 85th percentile speed	Approach	
	• Pedestrian flow rate	Movement	
	• Bicycle flow rate		Approach
	• Proportion of on-street parking occupied		Approach
Geometric design	• Street width		Approach
	• Number of lanes	Leg	Approach
	• Number of right-turn islands	Leg	
	• Width of outside through lane		Approach
	• Width of bicycle lane		Approach
	• Width of paved outside shoulder (or parking lane)		Approach
	• Total walkway width	Approach	
	• Crosswalk width	Leg	
	• Crosswalk length	Leg	
	• Corner radius	Approach	
Signal control	• Walk	Phase	
	• Pedestrian clear	Phase	
	• Rest in walk	Phase	
	• Cycle length	Intersection	Intersection
	• Yellow change	Phase	Phase
	• Red clearance	Phase	Phase
	• Duration of phase serving peds and bikes	Phase	Phase
	• Pedestrian signal head presence	Phase	
Other	• Analysis period duration	Intersection	Intersection

Source: TRB, 2010, Reproduced with permission of the Transportation Research Board.

The city of Cambridge, Massachusetts, provides an example of a pedestrian and bicycle methodology that includes more than just the HCM material. [City of Cambridge, 2014] The city requires an analysis of pedestrian level of service for the a.m. and p.m. peak hour of pedestrian demand at all study area intersections and crosswalks that have project vehicle trips and project pedestrian trips accessing transit. The results are to be reported for each crosswalk. In addition, pedestrian crossing gaps at unprotected crosswalks are to be analyzed (those without signal or stop control) as well as midblock crosswalks. The minimum acceptable gap at each crossing and thus the number of gaps available during the peak hour is computed as:

$$G_{min} = (W/S) + R \tag{19-1}$$

where,

- W = crossing distance (ft)
- S = walking speed (3.5 ft/sec. unless otherwise approved)
- R = pedestrian start-up time (3 sec. unless otherwise approved)

A yielding survey (a survey of number of vehicles yielding right of way to a pedestrian) should be conducted when the number of minimum gaps falls below 60/hour; and an analysis should be done of pedestrian access to/from the site within a one-block radius and along principal access routes (to and from transit, parking, nearby retail, and so forth).

For bicycles, the analysis should:

- Identify conflicting vehicle turning movements at all study area intersections where bicycle facilities are present or peak-hour bicycle volume exceeds 10 on any approach.
- Evaluate bicycle access to the site along streets and at intersections along all paths where vehicle trips are distributed or on likely suitable alternatives including roadway cross sections, presence of bicycle facilities, and ability to install new on- and off-street bike facilities.
- Evaluate available bicycle parking on- and off-site, including access to parking, quality of facilities, and site security.

Readers interested in other methods for assessing the performance of pedestrian and bicycle facilities should see chapter 13.

Transportation safety should be part of every impact study. For example, the Virginia DOT [2014] requires a crash history for roadway segments or intersections that compares the overall crash record for similar locations, with particular attention to severe crash density and rates. For longer segments, corridors should be divided into sections of similar configuration and environments (for example, cross sections, terrain, and adjacent land-use/driveway density). The analysis should be a trial and error refinement of the most important causal factors. Histograms or counts of the total crashes, deaths plus injuries, and collision types (summing to total crashes) should be presented as part of the crash analysis. Readers are referred to chapter 23 for additional ways to assess safety performance.

Some jurisdictions also require a queue analysis as part of the intersection assessment (a queue is a line of vehicles waiting to enter the intersection). In Massachusetts, for example, both a 50th (average) and 95th percentile "Back of Queue" calculation needs to be provided as part of the study, including graphical representations of 50th and 95th percentile queue lengths at select study intersections. Queue analysis can be conducted using Highway Capacity Software or with proprietary software (such as Synchro™).

Table 19-17 shows a typical report on intersection analysis from the Oregon DOT [2014]. Note this illustration is only for automobile level of service and does not include impacts for non-automobile users.

Per Oregon DOT's impact study requirements, if a new signal is being proposed, the traffic impact study should investigate whether the impact:

- Clearly indicates the need for a traffic signal.
- Downgrades the ability of existing, planned, and proposed public roads to accommodate the traffic away from the state facility.
- Affects study area intersections. [ODOT, 2014]

Table 19-17. Example Traffic Operations Impact for Traffic Impact Report, Oregon DOT					
		Weekday PM Peak Hour		**Saturday Mid-day Peak Hour**	
Interconnection	**Max. Operating Standard**	**LOS**	**V/C**	**LOS**	**V/C**
SW Boones Ferry Rd/SW Tualatin Rd	0.99	B	0.63	Not analyzed	Not analyzed
SW Boones Ferry Rd/ SW Martinazzi Ave.	0.99	D	0.97	B	0.68
I-5 NB Ramp Terminal/SW Nyberg Rd.	0.85	C	0.71	E	0.88
SW Martinazzi Ave/North Site Dr.	E	C	0.24	C	0.19
SW Sagert St./SW Martinazzi Ave.	D	F	N/A	Not analyzed	Not analyzed

Note: LOS and V/C reported for the highest delay of critical movement

Source: ODOT, 2014

In addition, proposed right or left turn lanes at unsignalized intersections and private approach roads must meet the installation criteria in the adopted design manual.

From the perspective of travel safety, most impact guidelines require that adequate intersection sight distance be provided at all study intersections and highway approaches. Intersection sight distance is the standard for the location of approaches to a highway; stopping sight distance is a lower standard that may be used in some cases. Sight distance should meet the jurisdiction's design standards or those adopted from other sources (such as AASHTO's *A Policy on Geometric Design of Highways and Streets*).

The actions proposed for intersection mitigation should be identified and explained in the impact report. Transportation system improvements should be recommended for all locations predicted to fail a performance measure, and should include at least intersection geometry improvements, signal controls and equipment, signal timing, pavement markings, and curb cut locations; pedestrian crossing markings, pedestrian signals, and sidewalks; and bicycle lanes, bicycle signals, off-street bicycle facilities, and the like. Transit-related actions that are oriented to intersection performance should also be included.

C. Corridors

Freeway and arterial corridors could be affected by the additional traffic generated by a new development. The HCM defines three types of highways that could conceivably be part of an affected corridor for the impact study: freeways, uninterrupted flow highways, and interrupted flow roadways. Interrupted flow roadways are those with intersections. As noted by the Florida DOT, "It is widely recognized that signalized intersections are the arterial's primary capacity constraint; it is appropriate to place more emphasis on the intersections' characteristics than midblock characteristics. Generally, midblock segments have capacities far exceeding those of major intersections and it is rare for significant delays to occur midblock. By weighting the effects of intersections more heavily, a more accurate aggregate estimation is possible." [FDOT, 2013]

In San Jose, California, the traffic impact analysis regulations require an assessment of freeway segments if the project is expected to add traffic equal to at least one percent of the freeway segment's capacity. [City of San Jose, 2009] Freeway segments are evaluated using a procedure based on the density of traffic flow found in the HCM. Density is expressed in passenger cars per mile per lane. For calculating the percentage of project-generated traffic based on the freeway segment capacity, the following ideal capacities are used: 2,200 vehicles per hour per lane (vphpl) for four-lane freeway segments and 2,300 vphpl for six-lane or larger freeway segments. For five-lane freeway segments, 2,200 vphpl is used for the two-lane direction and 2,300 vphpl for the three-lane direction.

The Florida DOT has developed planning software for both arterials and freeways that implement many of the concepts in the HCM as well as the TCQSM. [FDOT, 2013] For example, ARTPLAN is FDOT's multimodal conceptual planning software for arterial facilities that is based on the HCM's urban streets methodology. For automobile estimates, it provides a simplified LOS analysis of the through movement on a road segment or at a signalized intersection. ARTPLAN utilizes average travel speed solely as the service measure. For bicycles and pedestrians, ARTPLAN uses the planning application of the bicycle LOS methodology and the pedestrian methodologies in the HCM. For bus, ARTPLAN is the conceptual planning application of the TCQSM methodology applied to bus route segments and roadway facilities. It should be noted that the FDOT ARTPLAN software is a generalized tool for assessing LOS, since there are a large number of default assumptions (that is, peak-hour travel characteristics) used in deriving the LOS. The FDOT software provides a good tool for those interested in looking at both automobile and non-automobile travel flows on a network. For use in traffic impact analysis, however, the user of the tool needs to be aware of the key differences between the tool and the HCM, which the guidance document clearly articulates.

The approaches to highway/roadway capacity and level of service estimation are covered in more detail in chapter 9 on roadway and highway planning. Readers should refer to this material because it provides the analysis foundation for determining the impact of new trips being generated on roadway performance. However, several concepts relating to transit level of service will be discussed here because site-related impacts on transit service will likely occur on a corridor basis, not at the intersection or network level.

Transit-related impacts due to a new development present both positive and potentially negative effects (if not mitigated). The positive effect is the additional riders that will now use transit to and from the site, in the process both reducing expected automobile trips and adding new revenues to the transit system. The negative effect from a corridor perspective is that a new stop (or stops) or a deviation of the route into the development site will add additional time to the bus trip time and possibly reduce the level of service to the other riders in the corridor. Mitigating this effect might require an additional bus added to the route to maintain required headways.

The following discussion focuses on two transit impacts—the need for transit amenities at the new development site to attract transit riders, and the potential impacts on the corridor transit service.

1. On- or Near-Site Transit Service Characteristics

The types of amenities provided at a bus stop (for example, at the new development site) can influence travelers' desires to ride transit. For example, as noted in the TCQSM, the value of time and how it is perceived with respect to transit service is a contributing factor in one's decision to use transit. Table 19-18 shows the relative weight in terms of value of time of different transit amenities. As can be seen, paying attention to the environment within which transit riders travel can be critical to the success of a site impact mitigation strategy.

Figure 19-7 shows a potential transit rider decision-making process that provides a good indication of the desired types of amenities and service characteristics. For example, the second box in the figure suggests that bus stop locations in reference to a new development are key indicators of transit desirability. The third box suggests the same for schedule information. This figure can be used to determine different mitigation strategies that might be part of an overall TDM program for a proposed development site.

Table 19-19 shows the amount of time it takes on average for a person to cross a road of varying number of lanes to reach a transit stop on the other side. Not only does this add to the access time for a person to reach a transit stop, but it also affects the amount of time a traffic signal must provide for safe crossing.

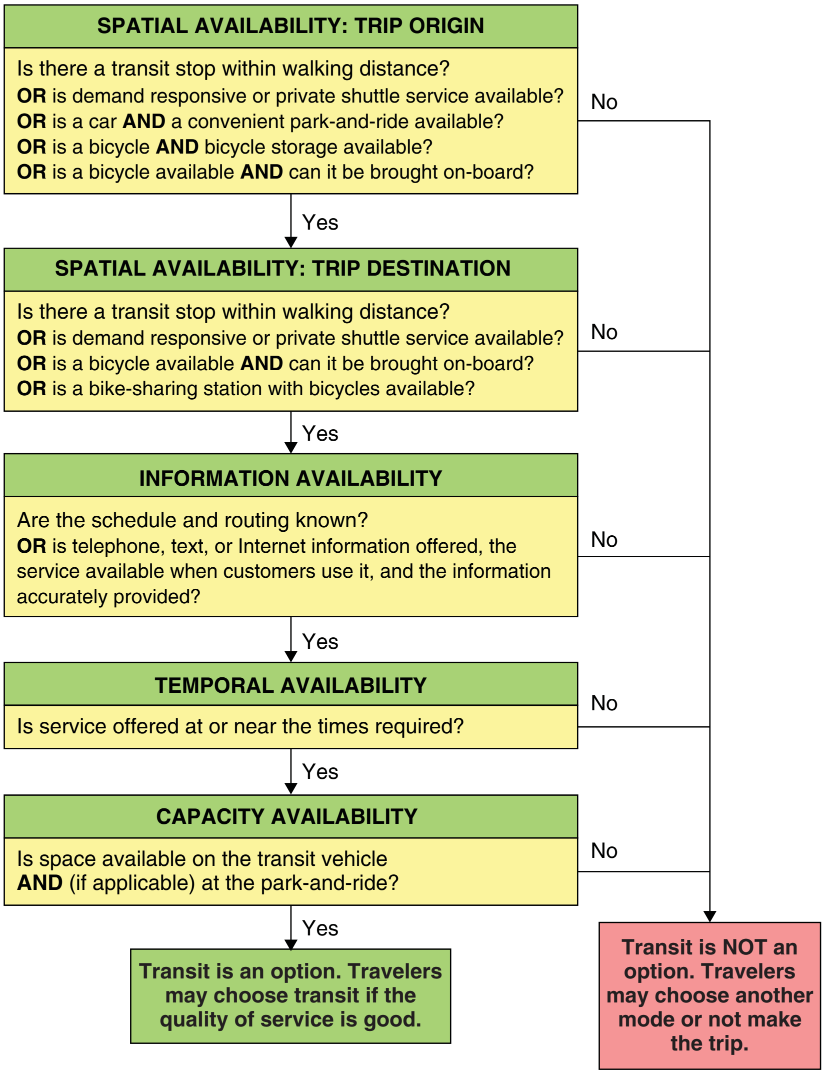
Table 19-18. Relative Weights of Transit Amenities According to Riders

Amenity	In-vehicle Travel Time Equivalent (mins)
Shelter with roof and end panel	1.3
Basic shelter	1.1
Lighting	0.7
Molded seats	0.8
Flip seats	0.5
Bench	0.2
Dirty bus stop	−2.8

Note: Positive values indicate a positive feature

Source: Kittelson et al., 2013b, Reproduced with permission of the Transportation Research Board.

Figure 19-7. Transit Availability Factors



Source: Kittelson et al., 2013b, Reproduced with permission of the Transportation Research Board.

Table 19-19. Average Pedestrian Street Crossing Delay: Signalized Crossings

	Transit Street Crossing Distance							
Lanes	1	2U	2D	3	4U	4D	5	6D
Feet	15	24	28	36	48	54	60	78
Meters	4.6	7.3	8.5	11.0	14.6	16.5	18.3	23.8
Assumed cycle length (s)	60	60	60	90	90	120	140	180
Assumed WALK time (s)	7	7	7	7	7	7	7	9
Delay (s)	20	20	20	35	35	50	59	78
Delay exceeding 30 secs.	0	0	0	5	5	20	29	48

U – undivided D – Divided (with raised median or other pedestrian refuge)

Source: Kittelson et al., 2013b, Reproduced with permission of the Transportation Research Board.

Studies reported in Kittelson et al. [2013b] suggest that most transit riders will walk 0.25 mile (400 m) or less to bus stops, or about five minutes. A 2010 study in Montreal found somewhat longer walking distances; about half of those walking to bus stops walked more than 0.25 mile. For rail stations, one can assume a reasonable walking distance is about 0.5 miles (800 m), although this will vary from one locale to another. As suggested by Table 19-18, an unsafe or poorly maintained pedestrian environment, no matter how close to the stop, will discourage transit ridership.

In addition, those wishing to encourage bicycle transportation should examine ways of incorporating bicycles into transit services. Many bicyclists want to bring their bicycle with them on board transit vehicles (in 2011, about 74 percent of new U.S. buses were equipped with exterior bicycle racks, up from 32 percent in 2001). Bicycle racks allow bicyclists to transfer to a bus and use transit to access a site some distance away. Alternatives to bringing bikes on board transit vehicles include providing bicycle storage at the boarding stop and bike-sharing programs.

2. Off-Site Transit Corridor Performance Characteristics

The TCQSM provides detailed explanations of how transit capacity and service performance can be analyzed. In addition, readers are referred to chapter 12 on transit planning for a similar discussion. The key concepts in the TQCSM as they relate to corridor transit performance include:

- Transit capacity is defined by how many people and buses can move past a given location during a given time period under specified operating conditions; without unreasonable delay, hazard or restriction; and with reasonable certainty.
- Capacity can be determined for both buses and persons, and it can be determined both as a maximum capacity, maximizing throughput without regard for reliability or operational issues, and as a design capacity, the number of buses or persons that can be served at a desired quality of service.
- Vehicle speed represents how quickly people and buses can move from one location to another.
- Reliability deals with how well the transit schedule is adhered to.
- Bus transit corridor capacity is constrained by the ability of bus stops and facilities to serve buses and their passengers, the number and type of buses operated, and the distribution of passenger demand.
- Dwell time, the amount of time a bus stays at a stop to allow riders to board and disembark, can vary significantly from one bus to the next. This is due to variations in passenger demand among the routes serving a given stop, variations in demand from one trip to the next on a given route, and variations in the time required to serve a given number of passengers getting on and off the vehicle.
- Potential sources of time variation include: passengers with mobility challenges, individuals with baby strollers or other large conveyances, people with luggage, and so on. Such individuals take significantly longer to board and alight than the average passenger. In saturation conditions, passenger standing loads on some arriving buses could result in longer passenger boarding and alighting times. Passengers loading and unloading bicycles from bus-mounted bicycle racks; passenger questions to the bus driver; and fare payment issues (for example, defective fare media, passengers looking for change or fare cards in their pockets) can each cause service delays.
- The capacity of a corridor bus route is determined by the capacity of the critical stop along the facility. The critical stop will be the bus stop used by all buses that has the lowest capacity.
- As more vehicle loading areas are added to a bus stop, the greater the likelihood that one or more loading areas will be blocked or will block other loading areas. Therefore, the extra capacity provided by another loading area drops with each additional loading area added to the stop.
- When right turns are allowed from the curb lane, queues of cars waiting to turn right may block bus access to a near-side stop. Queues of cars may also block bus access to a far-side stop, but if another lane is available and traffic permits, buses may be able to change lanes to move around the queue. Or “queue jump lanes” can be constructed to allow buses to bypass the congested location. To the extent that buses are blocked, however, some of the traffic signal green time that would otherwise be available for bus movement into the bus stop is made unavailable, reducing the overall stop capacity.
- Bus stop location influences bus speeds and capacity, particularly when other vehicles can make right turns from the curb lane (which is typical, except for certain kinds of exclusive bus lanes and at intersections with one-way streets where right turns are prohibited). Far-side stops have the least negative impact on speed and

capacity (as long as buses are able to avoid right-turn queues on the approach to the intersection), followed by mid-block stops, and near-side stops.

- A traffic signal located in the vicinity of a bus stop and its loading areas will serve to meter the number of buses that can enter or exit the stop. For example, at a far-side stop (or a midblock stop downstream from a traffic signal), buses can only enter the stop during the portion of the hour when the signal is green for the street that the stop is located on. The lower the green time provided to the street, the lower the capacity, and the longer a bus is likely to wait for the traffic signal to turn green again.
- Similarly, at a near-side stop, a bus may finish loading passengers but have to wait for the signal to turn green before leaving the stop. As a result, the bus occupies the stop longer than if it would have if it could have left immediately, and capacity is lower as a result. Due to the nature of bus operations, shorter traffic signal cycle lengths offer more opportunities for buses to move through a given signal during the course of an hour. In comparison, at unsignalized locations well away from the influence of upstream traffic signals, buses can enter and exit stops immediately, subject to traffic.
- The benefits of providing traffic signal preemption strategies, that is, allowing buses to get a green light upon arrival depends on a complex set of interdependent variables, including whether the signal system along the route was already optimized before application. Documented travel time savings from traffic signal applications in North America and Europe have ranged from 2 percent to 18 percent, depending on the length of route, traffic conditions, bus operations, and the strategy deployed. Travel time savings of 8 percent to 12 percent have been typical. The reduction in bus delay at signals has ranged from 15 percent to 80 percent. [Kittelson et al., 2013c]

The concept of level of service is used in transit planning in two ways. First, transit can be included in the multimodal level of service. If done, Table 19-20 shows the types of factors that can be included in the analysis.

Table 19-20. Transit Factors Included in the Multimodal Level of Service Measure

Item	Potential Sources
Transit Operations Data	
Frequency	• Timetables
Average excess wait time (mins)	• Archived Automatic Vehicle Location (AVL) data, field data
Average passenger load factor	• Archived AVL data, field data, transit agency vehicle data
Average transit travel speed (mph)	• Timetables, HCM methods, TRB Quality Manual, field data
Average passenger trip length (miles)	• Default, National Transit Database (NTD), field data for NTD, archived automatic passenger counter (APC)/smart card
Transit Amenity Data	
Percent stops in segment with shelter	• Field data, transit agency infrastructure database
Percent stops in segment with bench	• Field data, transit agency infrastructure database
Pedestrian Environment Data	
Sidewalk width (ft)	• Field data, aerial photos, infrastructure database
Buffer width from sidewalk to street (ft)	• Field data, aerial photos
Presence of continuous barrier	• Field data, aerial photos
Outside lane, shoulder, and bicycle lane widths	• Field data, aerial photos, infrastructure database
Number of through travel lanes in analysis direction (lanes)	• Field data, aerial photos, infrastructure database
Motorized vehicle flow rate (veh/h)	• Traffic counts
Motorized vehicle running speed (mph)	• Field data, HCM methods, simulation

Source: Kittelson et al., 2013b, Reproduced with permission of the Transportation Research Board.

Table 19-21. Passenger Loads and Quality of Service	
Standing Passenger Space	**Passenger Perspective**
>10.8 sq. ft/passenger >1.0 sq. meters/passenger	• Passengers area able to spread out. • Many/all passengers are able to sit, when vehicles provide a relatively high number of seats.
5.4–5.3 sq. feet/passenger 0.5–1.0 sq. meter/passenger	• Comfortable standing load that retains space between passengers.
4.3–5.3 sq. feet/passenger 0.40–0.49 sq. meter/passenger	• Standing load without body contact. • Standees have similar amount of personal space as seated passengers.
3.2–4.2 sq. feet/passenger 0.30–0.39 sq. meter/passenger	• Occasional body contact. • Standees have less space than seated passengers.
2.2–3.1 sq. feet/passenger 0.20–0.29 sq. meter/passenger	• Approaching uncomfortable conditions for North Americans. • Frequent body contact and inconvenience with packages and briefcases.
<2.2 sq. feet/passenger <0.20 sq. meter/passenger	• Crush loading conditions.

Source: Kittelson et al., 2013b, Reproduced with permission of the Transportation Research Board.

The second measure is illustrated in Table 19-21, which represents a quality of service metric, in this case, the level of comfort for those riding the transit vehicles. Several other measures similar to this are found in the TCQSM.

The analysis of transit service as part of a site impact analysis needs to balance the desire to serve new riders at the development site with the potential impacts on corridor service. In almost all cases, the transit agency will make changes to its service to provide transit access to the site, with possible contributions from the developer.

D. Network/Capacity Analysis

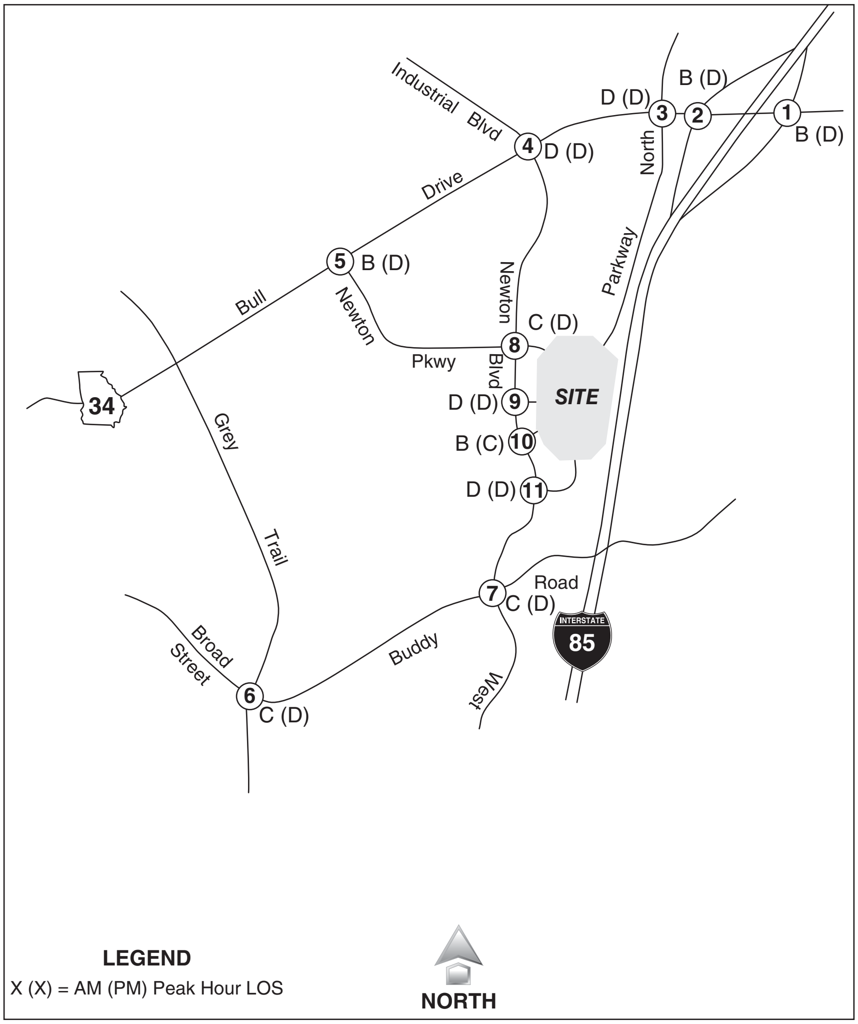
For major developments, in particular, projects will often have off-site road network impacts. These road segments and intersections would have been identified earlier in the process when the study area boundaries were established. For example, as per the development of regional impact (DRI) guidelines from the Georgia Regional Transportation Authority (GRTA), the study network, at a minimum, is to include all access points and/or all accesses on major roads and extend in each direction to the nearest intersection with a major roadway. [GRTA, 2013] All intersections between the development site and these endpoints will be included in the study network.

To determine if additional intersections are required, GRTA recommends a travel demand model be used to assign project-related trips to the network and then compare project traffic assignments to the adjusted two-way generalized roadway service volumes at the appropriate level of service standard. Where the gross number of trips generated by a proposed development exceeds 7 percent of the two-way, daily service volumes at the appropriate level of service standard, the segment will be included in the study network. All signalized intersections and any major unsignalized intersections, which are located within or at either end of roadway segments, are to be included in the study network as well.

Figure 19-8 illustrates how intersections and road segments far from the development site itself might be affected by development-generated traffic.

Once the affected locations have been identified and the traffic volumes assigned, the planner can use any of the tools mentioned above from the Washington State DOT and many others to analyze the impacts of the development traffic. The results of all the analyses discussed above are then summarized and used as the basis for identifying mitigation strategies and other actions that will reduce the impact of the development on the transportation system.

Figure 19-8. Illustration of Network Impacts of Development-Generated Traffic



Source: ITE, 2010

VII. ON-SITE TRANSPORTATION ELEMENTS

As part of the site plan review process and subsequent traffic impact studies, the traffic engineer and planner need to be concerned about transportation-related site design considerations. As noted earlier, this would include such things as the location and design of vehicular and pedestrian/bicycle access points and proposed road improvements, the location and adequacy of parking areas, and the design of traffic circulation and control within the site and with adjoining properties.

The location of buildings on a specific site, also known as the building footprint, is an important urban design issue that can affect many different transportation considerations. For example, clustering buildings within a development encourages walk trips among buildings, reduces walking distances to buildings and transit stops, and reduces the visual clutter associated with strip development. These objectives can sometimes be achieved by inverting the building footprints so buildings lie close to intersecting arterial streets, where transit can more easily be provided. Two other important design considerations are discussed below.

A. Internal Circulation

The effective internal circulation of cars, trucks, pedestrians, and bicyclists is one of the key factors in making the development a success. The planning for this circulation begins with the placement of the building footprints and the provision of sidewalks and bicycle paths. Site planning review often examines the proposed locations of the buildings (for example, is the front of the building close to prospective bus stops? Is parking in front or behind the building? Are buildings close enough together to encourage walking among them?). This along with the overall density of the buildings is often the subject of discussions between the developer and the government agency reviewing the plans.

Once the basic pattern of building footprints has been established, the next step is designing an effective circulation system, one that not only connects the buildings but also connects to the local transportation system. Depending on the jurisdiction, the standards for road, sidewalk, and bike path designs will be established by the planning agency (for example, through subdivision regulations) or be approved by the same agency for application on the site. Design standards relate to such things as lane width, acceptable grades, drainage features, buffer distances between lanes and sidewalks, accepted intersection design controls, and the like.

At a minimum, the site plan review process should include:

- Internal circulation designs that allow all vehicular and non-vehicular circulation to occur on-site rather than spilling over onto adjacent streets.
- Entrance and exit locations, required lanes, and required queuing distances.
- Internal roadway circulation systems to carry motor vehicles, bicycles and pedestrians between access points and parking areas, pick-up/drop-off points, and drive through lanes.
- On-site truck service bays, routes, turning points, and roadway access points (that might be separate from the general access points).
- Appropriate building entrance locations, major parking areas, and pedestrian and bicycle routes.
- On-site landscaping and utility risers to minimize sight distance obstructions. [ITE, 2010]

1. Access Points

One of the most important concerns for those reviewing site plans will be the location and design of the site's access points. It is at these locations where much of the impact on the operations, safety, and efficiency of the local road network will occur. The design of the access points should be based on accepted design standards that reflect such things as the angle of entry (conducive to safe and efficient entry and exit from the site); width (to allow all types of vehicles to operate safely); sight distance (provide for safe operations given local road side conditions); driveway spacing (far enough apart to provide efficient and safe access and exit to local roads); and landscaping elements, utilities, and accessible parking stall space requirements.

ITE [2010] provides the following guidance on access locations:

- Adequate spacing should be maintained from adjacent street and driveway intersections in order to minimize driveway blockage by queues.
- If signalized, the access point should be located to facilitate traffic signal progression past the site.
- Driveways should intercept traffic approaching the site as efficiently as possible.
- Adequate inbound and outbound capacity must be provided in proportion to the distribution of site traffic. A capacity analysis, gap check, or lane adequacy check should be conducted for each access location.
- Two-day driveways should intersect local streets generally at 75- to 90-degree angles.
- The capacity of on-site intersections should be sufficient to prevent traffic backing up onto adjacent streets.
- Traffic safety should be a prime consideration in all access point designs, with special emphasis given to sight distance and stopping sight distance.

2. Complete Streets

Several cities have adopted standards that reflect a Complete Streets or context sensitive solutions (CSS) philosophy toward design (see chapter 9 on road and highway planning). Such an approach recognizes the need to plan and design for all users of the street, and usually adopts a road classification scheme that is different from the traditional functional

Figure 19-9. Differing Desires on Road Design Characteristics, Charlotte, North Carolina

		Pedestrians	Cyclists	Motorists	Transit*	Neighbors
Motorists Want Reduced Delays/Increased Capacity						
The following elements can increase a street's capacity and/or potentially reduce motorists' delay:						
More Travel Lanes	Each additional travel lane increases the street's capacity, especially at intersections; the mix of through and turn lanes can, up to a point, allow an intersection to process more traffic	Negative Impact	Mixed Impact or Use with Caution	Positive Impact	Positive Impact	Mixed Impact or Use with Caution
Design Consistency	By providing a consistent design (number of travel lanes, e.g.,), motorists don't have to unexpectedly stop or merge; however, this may be difficult to achieve	Mixed Impact or Use with Caution	Mixed Impact or Use with Caution	Positive Impact	Mixed Impact or Use with Caution	Negative Impact
Grade-Separated Intersections	Allows uninterrupted flow; particularly useful for high volume intersections, but destroys urban context for other users	Negative Impact	Mixed Impact or Use with Caution	Positive Impact	Mixed Impact or Use with Caution	Negative Impact
Unsignalized Intersections	May mean less delay for the higher-volume leg, but more delay for the lower-volume leg; in general, fewer signals means less delay on thoroughfares, but may also mean less connectivity	Mixed Impact or Use with Caution	Mixed Impact or Use with Caution	Mixed Impact or Use with Caution	Positive Impact	Mixed Impact or Use with Caution

◆ - Positive Impact ◆ - Negative Impact ◆ - Mixed Impact or Use with Caution ◇ - Neutral

Source: Charlotte Department of Transportation, 2007

classification based on a road hierarchy (see chapter 2 on data analysis). For example, Charlotte, North Carolina, has adopted urban street design guidelines for both public roads and roads/streets that are to be built in large development sites. [Charlotte Department of Transportation, 2007] The design guide is based on five street types: main streets, avenues, boulevards, parkways, and local streets. Figure 19-9 shows the basis for this Complete Streets approach to designing roads in that it recognizes road users often have very different perspectives on what is desirable. The design guide has many more figures like this for all of the characteristics desired by five major participants—pedestrians, cyclists, motorists, transit riders, and neighbors.

Using local streets as an example, the design guide notes there is more than one cross-section option available: a "narrow" cross section and a "wide" cross section, both of which have traffic volumes and speeds that are relatively low. The context for this type of road is a land use that is more commercial or a mixed-use type of environment, having limited off-street parking nearby, where short-term visitors are likely, and thus there could be a high demand for on-street parking. This might not be the case for an office park environment where surface parking is offered off-street.

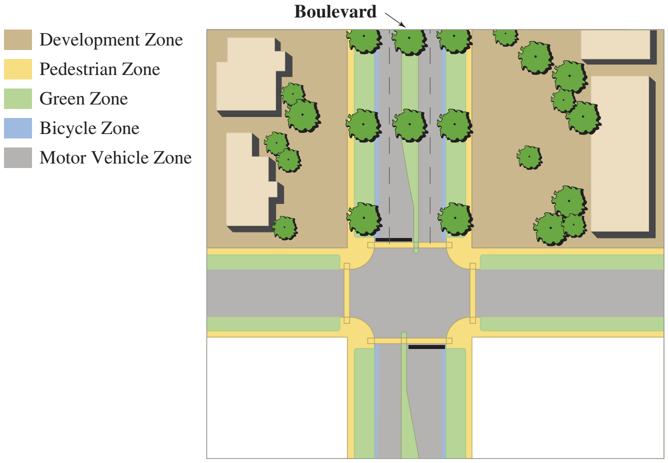
The design guide illustrates different intersection designs based on the desired characteristics of different entering road types. Figure 19-10, for example, shows the intersection characteristics for a boulevard-type road intersecting with other road types, and the desired characteristics relating to development, pedestrians, landscaping, bicycles, and traffic movement. These design concepts are accompanied by a desired level of service for possible combinations of street types and for different road users (see Table 19-22).

Other design guides similar to Charlotte's include: [Boston Transportation Department, 2014; City of New York, 2013; Maricopa Association of Governments (MAG), 2011; National Association of City Transportation Officials (NACTO), undated]. See chapter 9 for more discussion on Complete Streets.

B. Parking Management

The provision of parking is one of the most important decisions that a developer makes and the public review agency reviews. Many critiques of parking supply, especially in the suburbs, have concluded that "free" parking has had a significant effect on the predominance of the single-occupant vehicle for work trips. Many administrative guidelines for site plan review and for traffic impact studies point to parking as one of the key components for the review. As an

Figure 19-10. Example Site Intersection Design Characteristics, Charlotte, North Carolina



Boulevard Intersections
Diagram reflects possible scenarios and intersection may vary slightly in design.
For specific information refer to the guideline on Table 4.3

Boulevards

Development Zone:	Land uses and design will vary, but setbacks will likely be deeper than on Avenues and frontage will not always be directly onto the street; in all cases, good physical connections to the street are still important.
Pedestrian Zone:	Although the balance shifts away from a pedestrian orientation, pedestrians need to be able to travel safely along the Boulevard. This zone should always include sidewalks of adequate width for the adjacent and surrounding land uses.
Green Zone:	Higher speeds and volumes on Boulevards require significant attention to this zone. To serve the important buffer function between pedestrians and vehicles, as well as enhancing the street for other users, this zone should include grass, landscaping, and shade trees in spacious planting strips and medians. Where a parking zone on a parallel access street is used, the Green Zone should also extend to the area between the parking and the pedestrain zones (back of sidewalk).
Parking Zone:	Given the emphasis on traffic flow and development characteristics, this zone should generally be removed from the main vehicle zone; it should either be nonexistent or placed on an access street.
Exclusive Bicycle Zone:	Given the higher speeds and volumes on Boulevards, this zone should get strong consideration for treatment to increase cyclists' safety. Cyclists are generally not comfortable in mixed traffic on these types of streets.
Motor Vehicle Zone:	A very important zone since the Boulevard shifts more toward an auto-orientation; the number of travel lanes will vary by capacity needs, although the impact to other users should be considered in that decision.

Source: Charlotte Department of Transportation, 2007

example, the city of Alexandria, Virginia, has included the following language in its site impact analysis guidelines. The city will look for:

- Measures to reduce the reliance on single-occupancy vehicles by employees and others who will travel to and from the proposed use which may include parking fee structures tailored to discourage single-occupancy vehicles, proscription of tenant-employer subsidy of parking costs for single-occupancy vehicles, time and other access restrictions to parking spaces in on-site parking facilities, and programs to support and encourage the utilization of alternative transportation modes.
- Use and accessory use design options, which reduce reliance on single-occupancy vehicles by employees and others who will travel to and from the proposed site, such as the provision of less parking area than that

Table 19-22. Desired Level of Service for Different Intersection Combinations, Charlotte, North Carolina				
Element	**Main Street Approach to Blvd/ Main Intersection**	**Avenue Approach to Blvd/Avenue Intersection**	**Blvd/Blvd Intersection or Blvd. Approach to Other Intersection Types**	**Parkway Approach to Blvd/Parkway Intersections**
Level of Service (LOS)				
Pedestrian	LOS B for the entire Blvd/Main intersection	LOS B for the entire Blvd/Avenue intersection	LOS C for the entire Blvd/Blvd intersection	LOS D for the entire Blvd/Parkway intersection
Bicycle	LOS B for the entire Blvd/Main intersection, using the average LOS value of only the Blvd approaches	LOS B for the entire Blvd/Avenue intersection	LOS C for the entire Blvd/Blvd intersection	LOS C/D for the entire Blvd/Parkway intersection
Motor Vehicle V/C Threshold	0.95, for two consecutive a.m. or p.m. hours, for the entire Blvd/Main intersection	0.95 for two consecutive a.m. and p.m. hours, for the entire Blvd/Avenue intersection	0.95 for both one a.m. and one p.m. hour, for the entire Blvd/Blvd intersection	0.95 for both one a.m. and p.m. hour, for the entire Blvd/Parkway intersection
Median	Atypical, but allowable under special circumstances	Atypical. When provided, should be a minimum of 6 feet at intersections (8 feet preferred if Avenue approaches have land uses likely to generate heavy pedestrian traffic)	Should be provided with a minimum 6 feet at the intersection; 8 feet minimum at Main Streets and at Avenues if the Avenue approaches have land uses likely to generate pedestrian traffic across the Boulevard.	Yes, preferably 9 feet wide at the intersection; preferably 6 feet minimum (for pedestrian refuge)

Source: Charlotte Department of Transportation, 2007

required under the provisions of this ordinance, shared parking arrangements, the incorporation of residential units (in the case of proposed commercial uses) and other analogous design features.

- Extent to which adjacent neighborhoods may be affected by vehicles associated with the proposed use which park on the public streets, current availability of off-site, off-street parking in the vicinity of the proposed use, and such other design and operational characteristics of the proposed use as the council may determine substantially affect the parking overflow associated with the proposed use. [City of Alexandria, 2013]

Many different strategies have been implemented to manage the supply of parking, ranging from a sharing parking program to variable pricing depending on the time of day and the level of occupancy in the structure or lot. Chapter 11 examines all aspects of parking, including the use of parking strategies as part of a TDM program.

C. Access Management

Key elements of access management include defining allowable access for various types of roadways, establishing spacing of traffic signals and driveway connections, providing a way to grant variances when reasonable access cannot otherwise be provided, and establishing a means of enforcing standards. The degree of access control and management is determined by statute, deed, zoning, and by operational and geometric design standards. Comprehensive statewide access management codes are found in many U.S. states. Access management codes and ordinances specify when, where, and how access can be provided to developments along a roadway. Access classification systems, an integral part of these programs, define the relevant access with spacing guidelines and relate the allowable access to each roadway's purpose, importance, and functional characteristics.

A functional classification system provides the starting point in assigning highways to access categories. Modifying factors include development density, driveway density, and geometric design features, such as the presence or absence of a median. A general framework that relates allowable access to functional roadway classes is based on seven access categories, which include:

1) Full control of access (freeways).
2) Access at public street intersections only (expressways).
3) Right-turn access only.
4) Right and left turns in, and right turns out.
5) Right and left turns in and out with turning lanes.
6) Right and left turns in and out with left-turn lanes optional.
7) Locating and designing access based on safety requirements only.

For each type of access, traffic signal spacing guidelines will often be available from the state or local transportation agency. Additional guidelines are set forth in [Rose et al., 2005; VTrans, 2015; TRB, 2015]. Also, see chapter 3 on land use and urban design, chapter 9 on road and highway planning, and chapter 17 on corridor planning.

The location and design of access points depends on whether there is an active access management program for the surrounding roads. Driveways or connections are an important consideration in reinforcing the functional classification of a roadway. In many instances, this is more important than the spacing of intersections. The circulation plan for a development should coordinate site access with that allowed on surrounding roads, assure safe and efficient access between the site and surrounding roads, distribute traffic to parking areas, and allow convenient pedestrian access between parking places and buildings. If the site has sufficient density and the travel patterns are conducive to public transit, transit services should be provided.

An important access objective is to manage left-turn movements by simplifying intersections where driveways intersect with public highways and internal site roads. Possible strategies include channeling the intersections, installing a median within the driveway, eliminating left turns onto the public highway, and sufficiently separating internal roads from the public highway to reduce conflicts and increase storage distances.

VIII. IMPLEMENTATION ACTIONS/STRATEGIES

A. Applications and Permits

Preparation of applications and access permits is often an important complement to transportation impact studies. Access plans should reflect access spacing and other requirements set forth in access management programs. A permit application procedure usually requires the following information:

1) Access classification of the roadway on which access is requested.
2) Type of access requested relative to the allowable and types of access.
3) Relevant spacing standards.
4) Highway and intersection capacity.
5) Geometric design considerations.
6) Type of proposed traffic control.
7) Need, if required, for any variances to permit criteria.

The procedures should include guidelines for access denial, where alternative access that is better for overall traffic safety and operation is available.

A similar procedure can be followed in determining the type of control for a specific access point. Key considerations include whether the location meets traffic signal warrants and established traffic signal spacing criteria in order to provide efficient arterial roadway signal progression.

B. Transportation Management Associations

The concept of transportation management association (TMA) strategy is important to many communities. TMAs are usually nonprofit groups formed by major employers or developers to provide mobility services to their members. Most existing TMAs are found in areas of high suburban traffic congestion, where there are large activity centers, or in rapidly growing urban office complexes. Typical responsibilities include coordinating a staggered work-hours (or flex-time) program, managing a ridesharing program, managing a shuttle bus system to commuter stations, administering parking management programs, and instituting traffic flow improvement programs.

TMAs generate their revenues through membership dues and individual or voluntary assessments. Some operate their own services, while others contract with professional transportation service consultants. They share a common goal, to improve public mobility, and they provide a forum for cooperative public and private decision-making. See chapter 18 on local and activity center for additional information on TMAs.

C. Transportation Management Plan (TMP)

A TMP is defined as "a site-specific plan of TDM strategies to encourage residents and employees to take public transportation, walk, bike, or share a ride, as opposed to driving alone." [City of Alexandria, 2013] In the city of Alexandria, Virginia, the TMP is required by ordinance through the city's development review process, depending on the size of the development. A TMP is needed for every development exceeding the following thresholds:

- Residential: 20 dwelling units or more.
- Commercial: 10,000 square feet or more.
- Retail: 10,000 square feet or more.
- Hotel: 30 rooms or more.
- Industrial: 30,000 square feet or more.
- Mixed Use: Each use is separately assessed.

Fees are also assigned by development type. For example, for July 1, 2014–June 30, 2015, the standardized city TMP fund rates were:

- Commercial: $0.258 per square foot.
- Residential: $82.418 per dwelling unit.
- Retail: $0.206 per square foot.
- Hotel: $41.209 per room.
- Industrial: $0.103 per square foot.

The funds raised from these fees help pay for the TMP program, including a TMP coordinator. Smaller developments can join a citywide TMP program; medium-sized developments can join the city program or partner with an adjacent TDM program; and larger developments can partner with an adjacent TMP program or create their own.

Importantly, the city requires that annual surveys be done of residents and employees of TMP properties to measure the effectiveness of the transportation strategies carried out by TMP properties. A TMP coordinator is required to spend funds to support the mode share goals stated in the development's TMP. Every TMP includes a combination of program components to mitigate vehicular traffic, including transit subsidies, incentives for carpool/ vanpool/shuttles, car share and bike share memberships, and marketing.

The Alexandria program illustrates an important part of a site mitigation program, that is, following up to make sure required improvements were made and that they are successful.

IX. REPORT ORGANIZATION

The exact table of contents for a site impact statement will vary from one jurisdiction to another and will be found in the administrative rules and regulations for that jurisdiction. As an example, the following outline for a site impact study comes from the Washington State DOT [2014].

Executive Summary

Introduction

- Description of the proposed project with purpose and need.
- "Traffic Impact Analysis Methods and Assumptions" summary.
- Map of project location.
- Site plan, including all access to state highways (site plan, map).
- Circulation network, including all access to state highways (vicinity map).
- Land use and zoning.
- Phasing plan, including proposed dates of project (phase) completion.
- Project sponsor and contact person(s).
- References to other traffic impact studies.
- Other mitigation measures considered.

Traffic Analysis

- Traffic impact analysis methods used.
- Existing and projected conditions of the site: posted speed, traffic counts (to include turning movements), sight distance, channelization, design deviations, pedestrian and bicycle facilities, design vehicle, and traffic controls, including signal phasing and multi-signal progression, where appropriate (exhibit(s)).
- DHV and ADT, project trip generation and distribution map, including references and a detailed description of the process involved in forecasting the projected trips, including tables.
- Project-related transportation mode split, with a detailed description of the process involved in determining transportation mode split.
- Project-generated trip distribution and assignment with a detailed description of the process involved in distributing and assigning the generated traffic, including exhibit(s).
- If intersection control additions are employed and traffic signals are assumed, include functionality and warrant analyses. With roundabouts or signals, include existing conditions, cumulative conditions, and full-build of plan conditions with and without project.
- Safety performance analysis.

Conclusions and Recommendations

- Quantified or qualified LOS, quality of service (QOS), and other appropriate measures of effectiveness of impacted facilities with and without mitigation measures.
- Predicted safety performance with and without mitigation measures.
- Mitigation phasing plan with dates of proposed mitigation measures.

- Defined responsibilities for implementing mitigation measures.
- Cost estimates for mitigation measures and financing plan.

Appendices

- Description of traffic data and how data was collected and manipulated.
- Description of methodologies and assumptions used in analyses.
- Worksheets used in analyses; for example, signal warrants, LOS, QOS, and traffic count information.
- If microsimulation is used, provide a copy of the Confidence and Calibration Report.

An example of a site impact review outline for different development sizes is shown in Table 19-23. This proposed table of contents comes from Alexandria, Virginia, where a great deal of emphasis is placed on mitigating expected traffic impacts through TDM programs.

X. SUMMARY

Site planning for new development is a process used throughout the United States and in many other countries. An important tool in gauging the impacts of this new development is the use of traffic impact studies. The impacts of this new development on the local transportation system and on surrounding communities are of interest not only to transportation agencies, but also to a range of public groups and stakeholders. Site planning and impact studies are designed to give a community the opportunity to examine what is being proposed and to understand the mitigation strategies that are going to be applied. In many ways, site planning and traffic impact analysis are similar to other transportation planning processes. They start with the identification of goals, objectives, and performance measures; and use models and tools to determine trip generation, trip distribution, mode split, and trip assignment. They are also similar to other transportation planning processes in defining or recommending a set of improvements. However, the boundaries of the study area are much smaller than other planning efforts, and the involvement of the local community is often much greater.

This chapter described the major steps in site planning and traffic impact analyses as they relate to transportation. It also discussed the different types of mitigation strategies that can be considered, both on- and off-site. These strategies include both physical engineering changes (such as to a new road access) and actions to encourage non-automobile access to the site.

The transportation system serving a proposed development site should provide the facilities and services that permit safe and efficient travel by various means of travel. Site plan review and traffic impact analysis both emphasize the importance of assessing transportation access and site impacts when examining the potential effects of new development. State and local transportation and planning agencies have established administrative guidelines that direct the type of information that is to be produced as part of the planning process. These guidelines vary across the United States and other countries, depending on the primary issues of concern. All guidelines include some element of road performance, for example, volume-to-capacity ratios, vehicle delay, levels of service, vehicle miles traveled, and road safety. Respective analyses need to be performed on approaches to key roadways, internal roads and impacts on adjacent developments. Transit, pedestrian and bicyclist service levels should also be computed and assessments performed.

Analyses should focus on the following scenarios, at a minimum: (1) existing conditions—base year, (2) future conditions with build-out (site development), and (3) future conditions with site development and proposed access improvements. Depending on the size of the development and the proposed phasing of implementation, intermediate horizon years might be analyzed as well. Many jurisdictions also require future background conditions without the site development, in order to provide a basis for background improvements needed before project traffic volumes are considered.

The extent and level of detail in a site impact analysis will depend on the size and type of development. Roadway analyses should be done for each key intersection along approach and boundary roads, including site access points. Experience has shown that access points usually can be designed to accommodate anticipated demands. However, more critical conditions may arise at public road intersections in the site environs as a result of heavy turning movements, multi-phase traffic signals and the inability to add more travel lanes.

Table 19-23. Example of a Site Impact Report Contents, Alexandria, Virginia

	Development Size		
	Small	Medium	Large
Introduction			
Project Description	X	X	X
Project Study Area	X	X	X
Methodology	X	X	X
Existing Conditions			
Existing Transit Facilities	X	X	X
Existing Bicycling and Pedestrian Mobility	X	X	X
Existing Roadway Network	X	X	X
Existing Traffic Volumes	X	X	X
Existing Capacity Analysis	X	X	X
Future Conditions Without Development			
Planned Background Improvements	X	X	X
Future Transit Facilities		X	X
Future Bicycling and Pedestrian Mobility		X	X
Future Roadway Network	X	X	X
Future without Development Traffic Volumes	X	X	X
Future without Development Capacity Analysis	X	X	X
Future Conditions With Development			
Site Access	X	X	X
Site Trip Generation	X	X	X
Site Trip Distribution	X	X	X
Future with Development Traffic Volumes	X	X	X
Future with Development Capacity Analysis	X	X	X
Multimodal Mitigation Summary			
Parking Demand Analysis		X	X
Overview		X	X
Parking Supply		X	X
Parking Demands		X	X
Parking Summary		X	X
Shared Parking-Existing Occupancy		X	X
Shared Parking-Future Peak Demand by Land Use		X	X
Transportation Management Plan			
Conclusion			

Source: City of Alexandria, 2013

The analyses should address questions such as:

- How well does the existing transportation system work?
- What roadway, transit, and pedestrian improvements are necessary to serve the development?
- How well will the transport system work with proposed improvements? What are their service levels?
- Can people reach the development conveniently and safely?
- Are the roadways, access drives, and site circulation system clear and easy to use?
- Are sight distances adequate?
- Are there sufficient gaps in roadway traffic to let vehicles and pedestrians cross roadways safely?
- Is transit service available, and does it enter the development site?
- Are stops conveniently located near major trip generators?
- Do stops and stations provide sufficient amenities for passengers? Can they handle the peak demands?
- Is transit service frequent, and does it reach places that passengers want to reach?
- Are major transit stops conveniently connected to major developments?
- Can pedestrians safely and conveniently reach the development from surrounding areas?
- Are pedestrian crossings protected by traffic control signals?
- Do median islands provide adequate pedestrian refuge?
- Are the parking areas conveniently placed in relation to access points and major buildings?
- Are walking distances from parking areas to buildings and between buildings as short as possible?
- Are there enough parking spaces to meet anticipated needs?
- Are there suitable provisions for service and delivery vehicle access?
- Are neighborhood impacts minimized?
- What are the visual and urban design implications of proposed improvements?

The types of mitigation strategies proposed for a site will include, at a minimum, physical changes to the road network. Increasingly, mitigation strategies also include transit, pedestrian, bicyclist, and transportation demand management actions. Many jurisdictions have adopted access management policies that guide how access to the road network will occur. Any site access designed through the site planning process will need to be consistent with these policies.

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