Multi-Modal
Quality of Service Project

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SECTION 1

PROJECT OVERVIEW

PROBLEM STATEMENT

Traffic congestion keeps mounting in our urban areas, with seemingly limited ability to respond in manners that are effective at the local “planning” level. Because of the inability to provide enough capacity to satisfy demand and community highway level of service (LOS) standards, alternative approaches are being sought. TEA-21 has recently called for communities to provide a multi-modal transportation system in response to the increasing pressures of traffic congestion. To Florida’s credit, all of the state’s Metropolitan Planning Organizations have Mobility Management Plans - Congestion Management Systems - that call for alternative strategies to be addressed before additional lanes can be added. However, the state does not have a uniform method to evaluate the impact on a facility’s level of service and the currently available tools are not adequate to measure the impacts of non-auto modes. In other words, the pressure is increasing for local governments and planning organizations to respond to the issues of congestion by planning for multi-modal transportation systems but tools to assist in these efforts are not strong.

In general, the multi-modal performance measures in the Metropolitan Planning Organization’s Mobility and Congestion Management Plans are cursory at best – a confirmation of the lack of tools to help devise effective plans. The issue of a level of service or performance measure for the bicycling or walking environment is addressed in the Highway Capacity Manual (HCM) as the degree of discomfort to the user due to crowding of a facility. Unfortunately, this applies to only a small fraction of the collector and arterial network in the U.S.’s metropolitan areas and is inadequate for Florida’s needs. The end result is that many communities do not utilize multi-modal transportation options to ease congestion as there are no state approved methodologies to quantify the results or even measure the problem.

The evaluation of level and quality of service from a transit user perspective is currently deficient. Previous Highway Capacity Manual methods evaluate the performance of the transit trip only, but do not take into account any of the obstacles that must be overcome in order for a user to get on the transit vehicle. Many Florida transit properties have little or no sidewalk access to bus stops. Headways can be greater than 90 minutes, yet on paper these areas are credited with having transit service. No state accepted methodology is in use to measure this. New approaches that measure transit accessibility need to be developed, tested, and applied.

In an attempt at curbing congestion and urban sprawl, the State of Florida Legislature mandated a Transportation and Land Use Study Committee. Its January 15, 1999 report states in recommendation #4, "Local governments should be specifically encouraged to employ alternative techniques for measuring level of service, including multi-modal, vehicle miles traveled (VMT)-based, access-based, and zone-based approaches." It comments further in Section A: "FDCA and FDOT should work aggressively to provide technical assistance to local governments to employ these preferred level of service methodologies."

In Recommendation 3, the report directs the Legislature to amend F.S. 163.3180 to allow local governments to create Multi-Modal Transportation Districts (MMTD) in designated areas. In support of this, Comment B, states, "FDOT should develop methods for multi-modal performance measurement and provide them to local governments." It continues, "In addition, the use of single-mode, link-based LOS and concurrency management systems, which is the most common practice today, should be discouraged in favor of multi-modal, zone- or district-based LOS and concurrency management systems."

It further recommends that, "FDOT should consider multi-modal performance measure currently in use or under development elsewhere." Recommendation 3, Comment F, directs the Florida Department of Community Affairs to review proposed Multi-Modal Transportation Districts to ensure that it relies on a professionally acceptable multi-modal LOS methodology, and addresses transportation needs."

PROPOSED SOLUTIONS

In the summer of 1999, the Florida Department of Transportation, through its Systems Planning Office, initiated a research project to develop multi-modal quality of service tools for transit, pedestrian, and bicycle modes. The overall goal of the project is to help bring multi-modal analysis to the same level as highway analysis, enabling local governments, metropolitan planning organizations, and the Florida Department of Transportation to assess transit, pedestrian, and bicycle quality of service and adequately plan for these modes.

The impetus for this research project has been driven by a combination of factors: recent funding initiatives on the part of state and federal government; the realization that approaches to managing congestion and urban sprawl need to include multi-modal options; and the need of local governments to have analytical tools at their disposal to incorporate effective multi-modal planning. Earlier research by the FDOT Systems Planning Office in 1998 found two multi-modal level of service methodologies developed by teams of Florida Consultants to be in the forefront of other nationally accepted techniques. Sprinkle Consulting, Inc. (pedestrian and bicycle methodologies) and Kittelson & Associates, Inc. (transit methodologies) have been leading researchers in quality and level of service methodology development. The Florida Department of Transportation entered into contract with the University of Florida and both Sprinkle

Consulting, Inc. and Kittelson & Associates, Inc. to address the need for a planning level of quality of service analysis for Florida.

OBJECTIVES OF THE PROJECT

The overall purpose of this research project has been to help develop a quality of service analysis for transit, pedestrian, and bicycle modes. It has been driven by four major objectives which have shaped the research agenda since the summer of 1998, when the project began. These objectives are:

1. To perform a national literature search of multi-modal Level of Service methodologies in order to implement the best possible methodology in Florida.

2. To apply and validate Bicycle Level of Service and Roadside Pedestrian Condition techniques to measure the performance of corridor segments in two districts.

3. To apply and test new Highway Capacity Manual performance measures for transit in test districts.

4. To refine and evaluate latent bicycle and pedestrian demand model process in order to determine that adequate demand exists for proposed facility improvements.

The objectives have been accomplished, with the results integrated into the body of this report. In conjunction with the consultants for this project, the following tasks in the two primary subject areas have been addressed:

Bicycle/Pedestrian – Sprinkle Consulting, Inc.

- Defined the features of test areas
- Identified corridor(s) to analyze
- Defined the range of input variables
- Validated the pedestrian model

- Utilized the validated model to define the existing and projected performance
- Linked transit with Pedestrian Level of Service
- Updated, validated, and calibrated the Latent Demand Score Model
- Creating the follow-on research project to interface with Art-Plan
- Provided reporting, documentation, and technical assistance

Transit – Kittelson & Associates, Inc.

- Validated and applied new HCM performance measures for transit.
- Defined the features of highway corridors, transit route segments and other inputs.
- Identified corridor(s) to analyze.
- Defined level of acceptable accuracy and data requirements.
- Performed corridor analysis
- Utilized analysis technique to define the existing and projected performance.
- Linked transit with Bicycle/Pedestrian Latent Demand Model
- Creating the follow-on research project to interface with Art-Plan
- Provided reporting, documentation, and technical assistance

SECTION 2

LITERATURE REVIEW

INTRODUCTION

As part of the comprehensive project to research multi-modal quality of service at the planning level, the following literature review has been conducted to provide a summary of quality of service methodologies. The review is divided into three segments:

1. Assessment of issues and needs of quality of service methodology users, and descriptions of quality of service concepts;
2. Summary of current quality of service methodologies; and
3. A Comparative assessment for Florida.

ISSUES AND NEEDS

Several changes and initiatives have prompted more concern over the issue of multi-modal transportation systems in Florida. These include the following:

- The Florida State Legislature mandated a Transportation and Land Use Study Committee whose recommendations include that local governments should be encouraged to apply multi-modal measurement techniques to curb congestion and sprawl. Changes in legislation were suggested to allow for the creation of local Multi-Modal Transportation Districts. Further, the Committee recommended the Florida Department of Transportation and the Florida Department of Community Affairs provide technical assistance to local governments to apply preferred multi-modal performance methodologies.

- The Metropolitan Planning Organizations (MPO's) in Florida have Mobility/Congestion Management Plans that encourage alternative multi-modal strategies to be considered before automobile lanes can be added.

- Federal support for non-motorized transportation modes has increased, with TEA-21 routinely described as "the multi-modal bill." Bicycle and pedestrian facilities are encouraged in policies, planning, and design. The bill stipulates that transportation plans and programs must "provide for the development and integrated management and operation of transportation systems and facilities, including pedestrian walkways and bicycle transportation facilities…" (Community Transportation Association of America 1999).

- There is an increased awareness of the need for multi-modalism; this is supported by the TEA-21, along with others who are pushing for a change in transportation planning. According to the National Cooperative Highway Research Program (1997), all levels of government are now confronted with the need to adjust to a rapidly changing focus and constraints. This changing focus has added more complexity, data needs, and need for supportive analytical tools to the planning process overall. Improvement and better management of systems performance, along with managing growth in travel demand, are common objectives.

Despite these initiatives, Florida does not yet have a uniform method that it promotes to local and regional governments to evaluate multi-modal quality of service. This hinders local government's ability to adequately incorporate multi-modal choices into transportation policy, design, and planning activities. The end result is that many communities throughout Florida do not include multi-modal approaches because there are not readily acceptable or appropriate methodologies to adequately measure the problem or quantify results.

Some local governments are concerned about these recent initiatives and recommendations, questioning if statewide growth management concurrency requirements will change to standardize and require use of multi-modal performance methodologies. However, the focus appears to be on *developing* techniques, not standardization, to enable and support local government efforts for multi-modal planning by offering professionally acceptable techniques.

Another concern is the need to develop very "usable" analytical tools so that local governments can effectively incorporate multi-modal planning into long-range and comprehensive planning efforts. Tools are needed that are professionally valid yet remain flexible enough to be applied in the context of distinct local needs. Thus, the current focus is to encourage development of quality of service methodologies that hold relevance for transportation policy, design, and planning efforts in a variety of contexts that change with local conditions.

MULTI-MODAL QUALITY OF SERVICE CONCEPTS

The words, "quality of service" are often used interchangeably with "level of service" and "performance measures," yet caution is needed as the three sets of terms are distinct. According to the *Transit Capacity and Quality of Service Manual* (Kittelson et. al 1999d), the terms are simply defined as follows:

- Quality of Service: The overall measure or perceived performance of service from the passenger's or user's point of view.

- Level of Service: LOS is a range of six designated ranges of values for a particular aspect of service, graded from "A" (best) to "F" (worst) based on a user's perception.

- Performance Measures: A quantitative or qualitative factor used to evaluate a particular aspect of service.

The primary differences between performance measures and service measures are the following (Kittelson, et. al 1999d: 5-2):

- Service measures represent the passenger's or user's point of view, while performance measures can reflect any number of points of view.

- Service measures should be relatively easy to measure and interpret in order to be beneficial to users.

- Level of service grades (A – F) are typically developed and applied to service measures. The term has been used for over thirty years in the *Highway Capacity Manual.*

Also, performance measures are typically viewed as the "operator's" point of view, are more vehicle-oriented, and incorporate various utilization and economic measures. For example, operator-based performance measures usually reflect ridership and economic factors while vehicle-based performance measures include such factors as roadway capacity and traffic signal delay time (Kittelson et. al 1999c:2). In contrast, service measures are "person-oriented" to reflect the passenger or user's point of view.

To further illustrate the quality of service concept, the case of transit is explored, using examples from the *Transit Capacity and Quality of Service Manual* (Kittelson et. al 1999: 1-38/39). Generally, a person is faced with a decision whether or not to use transit or an alternative mode. There are two parts to this decision process:

1. The potential passenger will assess the availability of transit and whether transit is an option for the trip; and
2. The potential passenger will compare the comfort and convenience of transit to alternative modes.

The following five conditions affect transit availability; all of these conditions must be met in order for the potential passenger to consider transit as an option for the trip.

- Transit must be provided near one's trip origin;
- Transit must be provided near one's destination;
- Transit must be provided at or near the times required;
- Information on using the transit service must be available; and
- Sufficient capacity must be provided.

If these conditions are met, then transit is an option for the potential passenger; however, comfort and convenience issues are then considered. If these factors compare favorably with competing modes, then transit will be used. Some of the comfort and convenience factors affecting transit quality are (Kittelson et. al 1999d: 1-39):

- Reliability of the transit service (time required to arrive at their destinations)
- Total door-to-door travel time, as compared with alternative modes;
- The costs of using the transit service, compared with alternative modes;

- Safety and security of using the transit service, including accessing transit stops;
- Passenger amenities provided;
- Appearance and comfort of transit facilities and stops; and
- Passenger loads on the transit vehicles.

Any of these factors (and others identified by local transit systems operators and transportation planners) can be analyzed for a particular transit stop, route segment, or and entire system to generate a quality of service assessment. Level of service measures, typically the A through F range, can be applied at this point. However, it is important for transit system planners and operators not to focus entirely on the level of service range calculations as a variety of other factors influence quality of service that may not readily lend themselves to an “A – F” categorization.

SUMMARY OF QUALITY OF SERVICE METHODOLOGIES

Current Methodologies

There are difficulties, as reported by both users and researchers, with many of the current methodologies used for measuring multi-modal performance. The difficulties are primarily due to the limited scope of factors imposed by these methodologies. For example, the *Highway Capacity Manual* defines performance measures for bicycle and pedestrian environments simply as the degree of discomfort to the user due to overcrowding of the facilities. However, this measure may apply to only a small percentage of collector and arterial networks throughout urban areas (Guttenplan 1999:1); thus its applicability is severely limited. Other measures from the user’s point of view to assess quality of service are not standardized, or routinely utilized, leaving transportation planners with little or no feasible methodologies to use.

Similarly, much of the current transit quality of service methodological approach follows the *Highway Capacity Manual* guidelines of evaluating the performance of the transit trip only. Other factors, such as transit accessibility, including how the user accesses the transit vehicle, are rarely included. For example, many transit stops do not have adequate amenities, such as sidewalk access; other areas have extremely long waiting times (headways) yet these areas are considered to have transit service (Guttenplan 1999:1). The obstacles the user must overcome are rarely considered in this type of methodological approach, leaving an inadequate and unclear assessment of transit's quality of service.

Until recently, traditional concepts applied to highway and roadway policy, planning, and design have been "superimposed" to try to fit the needs of multi-modal planning. Rarely has this worked to the extent that effective quality of service methodologies are utilized to support planning and design for bicycle, pedestrian, and transit modes.

As part of the overall transportation planning process, considerations for multi-modal facilities have often been lacking due to the "quiet" nature and lack of knowledge of bicycle and pedestrian modes, in particular. For example, low trip volume, low space requirements as compared with motor vehicles' needs, and the inability of some travel demand models to account for these trips often commands less attention than other modes (Burrell 1995). What is needed are methodologies and tools that can bring the level of analysis for multi-modal to the same degree of confidence and usability as that for highway and roadway planning, yet take into account the distinct needs of multi-modal planning.

Quality of service methodologies are considered "supply-side" assessments - in other words, evaluation of existing facilities (Cambridge Systematics 1998a,b,c; Landis et. al 1997).

Thus, past assessments have oftentimes focused on factors such as overcrowding of facilities and transit vehicle performance, or the *quality of supply* of multi-modal facilities.

Supply-side assessments do not predict or estimate future demand. However, they are invaluable in providing information for decision-making regarding investments in improved or new multi-modal facilities. They are indicators of the quality and benefits to users - information that can be used to guide or justify provision of additional facilities. Quality norms and perceptions of quality are essential to effective transportation planning; as described by Pettinga (1991), quality can be assessed by usage, experience, and future values. Usage is determined by travelling time; experience is determined by safety and comfort; and future value is mostly determined by maintenance.

Comparatively, "demand-side" methods are used to generate quantitative estimates of demand for multi-modal facilities. A variation of demand models are relative demand potential methodologies, those methods that assess the potential demand levels rather than predict actual demand. Supply-side assessments can be used in tandem with some of the demand-side methods, especially when demand is associated with the quality of existing facilities. For example, the city of Olympia, Washington is considering measuring transit level of service through assessing the latent demand for transit service - - basically how many people want to travel through a corridor or segment, a demand estimation technique (Lazar 1998). Combining this with more traditional transit level of service indicators, the City hopes to generate information and direction for complying with the Washington Growth Management Act stipulation that transportation systems be measured and assessed.

There are numerous demand models in existence, for example: comparison studies (Wigan et. al 1998); aggregate behavior studies (Nelson and Allen 1997; Ridgway 1995);

Discrete Choice Models (Loutzenheiser 1997; Kitamura et. al 1997; Noland and Kunreuther 1995; Taylor and Mahmassani 1996); Regional Travel Models (Cambridge Systematics, Inc. 1994; Hunt, et. al 1998; Replogle 1996; Replogle 1995; Stein 1996); and Sketch Plan Methods (Ercolano et. al 1995; Ercolano 1997; Matlick 1996). It is beyond the scope of this study to provide a review of demand models; however, data and references to various sources about the models are incorporated into this report when relevant.

During this study, several quality of service, or related, methodologies were identified. While a few of these are not directly considered a quality of service methodology, they provide a useful supply-side analysis, or in some cases, a relative demand potential perspective that is used in conjunction with supply approaches. Also, it should be noted that quality of service literature for transit focuses on work by only a few researchers. The dominance of the Transit Level of Service technique is apparent in the literature. The pedestrian methodologies, while several attempts exist, have not produced validated models as exist for the bicycle mode; thus, the literature in this area is not as plentiful.

The format for the literature exploration is as follows: Supply-side Methodologies that summarize the (1) environment factors and (2) compatibility measures; and Relative Demand-Side Methodologies that summarize (1) facility demand measures.

Supply-Side Methodologies

<u>1. Environment Factors for Bicycle, Pedestrian, and Transit Modes</u>: These are “supply-side” approaches for measuring the quality of an area’s bicycle and pedestrian characteristics; typically these factors are used in conjunction with regional travel models. While substantial field data collection is required to develop environment factor ratings for local application

(Antonakos 1994), the factors are generally relevant to a variety of regions and area types (Cambridge Systematics, Inc. 1998b).

Environment factors can also be used for predicting transit trips as well as for bicycle and pedestrian modes, because the quality of the pedestrian environment can influence transit selection. A "Transit Friendliness Factor" was developed for the Triangle Transit Authority in Raleigh, North Carolina to predict automobile versus transit choice (Evans et. al 1997). Four elements were rated (on a scale of one to five): sidewalks, street crossings, transit amenities, and proximity to destinations. It was reported that including the transit friendliness factors greatly improved the model's ability to predict automobile versus transit trip selection (Cambridge Systematics, Inc. 1998a).

Portland, Oregon was one of the first areas to develop a pedestrian environment factor (PEF) system, incorporated with its regional travel model. Portland's PEF includes: sidewalk availability, ease of street crossing, terrain, and connectivity of the street and sidewalk system (Cambridge Systematics, Inc. 1994 and 1998a). The factors are ranked, with points ranging from 0 to 12; bicycle factors are added for an additional range of 0 to 15. Portland has reported success with improvements for predicting automobile versus pedestrian and bicycle mode split. Also, the significance of the scoring system is that the higher the PEF score, the more likely people choose walking, bicycling, or transit over automobile usage. In other words, there was a measurable relationship between the quality of the pedestrian environment and the travel mode choices being made (Parsons et. al 1993).

This relationship is powerful support for integrating pedestrian environment analysis into transportation planning efforts. For example, in the 1970's communities began to realize that in order for transit systems to operate effectively, conditions such as high-speed traffic, wide streets, and narrow sidewalks that make it difficult to operate convenient service for riders must be addressed. Instead of relying on transportation agencies to make decisions from the top down, communities have encouraged a more integrated process of merging traffic and transit concerns with development and environmental concerns. This "livable" community approach is detailed in the Transit Cooperative Research Program Report 33 (1998:3):

> "For the transit user, better management and design of streets (and other conditions) not only can improve reliability of service – by reducing the competition for street space among cars, buses, or light rail vehicles – but can also make it safer and more accessible for transit patrons….(these approaches) can be combined with other transit strategies to realize even greater social and economic impacts, whether it be revitalizing a downtown, restoring cohesiveness to a community, or creating new development opportunities."

Further, some travel demand methods are enhanced by incorporating pedestrian environment analysis (Turner et. al 1998). By merging "supply" with demand analysis to provide a more complete analysis of issues for bicycle, pedestrian, and transit facilities, cities are able to implement a more holistic or integrated approach to transportation planning.

Other areas have followed Portland's lead, applying environment factors to regional travel models. These include Washington, D.C. (Chesapeake Bay Foundation 1996) and Sacramento, California. Montgomery County, Maryland developed a different pedestrian and bicycle environment factor (PBEF) that includes five elements: amount of sidewalks, land use mix, building setbacks, transit-stop conditions, and bicycle infrastructure (Cambridge Systematics, Inc. 1994 and 1998b). Montgomery County reports a significant improvement in the performance of their regional travel model by including the pedestrian and bicycle environment factor.

2. Compatibility Measures for Bicycle, Pedestrian, and Transit Modes: Another type of supply-side or quality of supply approach is compatibility analysis. There are several types of compatibility approaches: pedestrian stress level and level of service assessments, bicycle stress level and level of service assessments, and transit level of service assessments.

Pedestrian compatibility approaches measure the quality of existing facilities for pedestrian travel, rather than forecasting demand for expanded facilities. Pedestrian approaches and methods are considerably less developed than for bicycle or transit modes (Dixon 1996; Khisty 1994; Landis 1998b). Yet the value of assessing pedestrian facilities is high as an important tool in improving the transportation planning process (FDOT 1992). Khisty (1994:49) points out several applications of pedestrian compatibility approaches: results can be used as a tool to guide decision makers in evaluating quality of facilities beyond quantitative measures of flow, speed, and density; the results identify ideal benchmarks; can be used as a planning tool to develop future routes; and results can be used in budgeting funds for improvements. Although pedestrian approaches and methodologies are still "emerging," the inclusion of the pedestrian element has long been recognized by some as vitally important, with the need to fully integrate the process of pedestrian facility planning into other planning activities such as comprehensive planning, subarea planning, and site plan review (JHK & Associates et. al 1987).

As part of a congestion management plan, the City of Gainesville, Florida incorporated level of service measures for pedestrian facilities. This methodology represents one of the more comprehensive approaches taken to date. A point system, ranging from 1 to 21 was used to evaluate actual roadway corridors for pedestrian suitability. The scores were then converted into an level of service range from A to F. The following criteria were used: Pedestrian facility type (dominant facility type, sidewalk width, off-street parallel alternative facility); Conflicts (number of driveways and sidewalks, pedestrian signal delay times, reduced turn-conflict implementations, crossing widths, speed of traffic, medians present); Amenities in Right-of-Way (buffers, benches or pedestrian-scale lighting, shade trees); Maintenance; and TDM and Multi-modal support (Dixon 1996).

Gainesville's method focuses on pedestrian facility conflicts, amenities, maintenance, and several other factors. Another pedestrian level of service and stress level method developed by Mozer (1998) focuses on facility design with speed, outside lane width, and volume as the primary criteria. Both methods have not been designed to be incorporated with travel demand models, in contrast to the environment factors approach.

Similar to Dixon's checklist of pedestrian travel conditions, the city of Fort Collins, Colorado provided a level-of-service standard for five areas of concern: Directness, Continuity, Street Crossings, Visual Interest and Amenity and Security. For each of these five areas brief descriptions were given in order to provide a scale, with level-of-service A representing the best pedestrian environment through level-of service F representing the worst pedestrian environment. It attempts to apply particular LOS standards to geographical areas of the Fort Collins community, determining a minimal level-of-service standard for that area. For example, the downtown business district, where compactness is an asset, would score highly on all LOS thresholds. This is a descriptive system that has not been statistically tested (Balloffet and Associates, 1996).

A different method developed by Romer and Sathisan (1997) combined factors to analyze entire pedestrian systems, rather than individual factors. Using the key variables in each of the three method elements (sidewalks, corner areas, and crosswalks), a balanced approach is attempted to provide an overall level of service assessment. A method used in Europe is to assess existing quality against desired quality, with less quantitative focus than level of service methodologies (Centre for Research and Contract Specialization 1993).

Lastly, at the behest of the Hillsborough County Metropolitan Planning Organization, Sprinkle Associates, Inc. assisted in the formation of a community-wide pedestrian system plan. With the expressed purpose of designing a mathematical model to quantify the perceived safety of the pedestrian environment, the Sprinkle methodology provided Hillsborough County with a method in which roadways could be prioritized for sidewalk construction and sidewalk retrofit. In the mid 1990's Hillsborough County searched for a "blueprint" in which to upgrade their pedestrian environment. Sprinkle's criteria for evaluating the pedestrian environment included six performance factors (of which three were considered significant) and were rigorously tested in Hillsborough County, Florida (The Hillsborough County MPO Pedestrian System Plan: Appendices, 1999). The factors, determined by group consensus, included:

1. The lateral separation between pedestrians and motor vehicle traffic
2. Outside (motor vehicle) lane volume
3. Effect of (motor vehicle) speed
4. Roadway (transverse) crossing inconvenience
5. Environmental amenities
6. Sidewalk surface condition

Designed to assess walking conditions (with or without the presence of sidewalks), it was based on a mathematical approach called the Roadside Pedestrian Condition model (RPC).

Hillsborough County streets were given level-of-service letter grades, ranging from A to F. Hillsborough County used this level-of-service ranking system to assist in evaluating and prioritizing their roadways for sidewalk retrofit and construction (1998 Hillsborough County MPO Pedestrian System Plan).

The concept of bicycle stress was first developed by the Geelong Australia Bikeplan team (Geelong Planning Commission 1978). Until that time, land sharing evaluations were done, but left an incomplete picture of bicycling conditions from the cyclist's point of view.

Thus, the concept of bicycling stress to minimize mental fatigue of long periods of riding along narrow, high speed and high volume roads and avoiding conflict with motor vehicles was conceived. While the original Australian stress procedure did not reflect the stress levels of individual roadway variables, the basic premise of minimizing both physical and mental effort and strain of bicyclists has remained the foundation for subsequent procedures (Sorton and Walsh 1994b).

There are a variety of bicycle stress level and level of service assessments (Niles 1996; turner et. al 1997), including the Bicycle Compatibility Index (BCI) developed for the Federal Highway Administration. It is an attempt to promote a methodology that can be widely applied by transportation planners and engineers to determine how compatible a roadway is for allowing operation of both bicycle and motor vehicle traffic (Cambridge Systematics, Inc. 1998c). It incorporates roadway variables with those bicyclists typically use to assess the "bicycle friendliness" of a roadway (Harkey et. al 1998a and b).

The BCI selected several independent variables for their model, including: Presence of bicycle lane or paved shoulder and width, presence of a parking lane with more than 30 percent occupancy, type of roadside development, 85th percentile speed of traffic, curb-lane width, curb-lane volume, and other lane volume. The method has good validation techniques that improve its effectiveness and is considered an improvement by some researchers (Cambridge Systematics 1998a) upon earlier stress level work of Sorton and Walsh (1994a) and the Geelong Bikeplan Team (1978).

Sorton and Walsh (1994a and b) provided an earlier model to determine the stress level for bicyclists and bicycle compatibility of roadways. Building on three primary variables, curb-lane speed, curb-lane width, and peak hour volume, a bicycle level-of-service measure was developed. However, the model has been criticized for leaving out crucial factors, such as pavement conditions, roadways with bicycle lanes, and intersection density and volume (Cambridge Systematics 1998a).

In addition to the pedestrian compatibility approach developed by Gainesville, Florida, (Dixon 1996), a bicycle level of service measure was also developed and implemented. The LOS developed is more comprehensive than some of the earlier efforts, and reflects an improvement upon the works by Davis (1987), Epperson (1994), and Sorton and Walsh (1994). A point system was developed to evaluate roadway corridors, and then converted into an LOS range of A to F. Measures for the bicycle level of service included: basic facilities (outside lane width, off street facilities); conflicts (driveways and sidestreets, barriers, no on street parking, medians present, unrestricted sight distance, intersection implementation); speed; motor vehicles; maintenance; and TDM multi-modal facilities.

A less comprehensive model, yet providing an impressive checklist for assessing bicycle level of service measures is the Oregon Department of Transportation's "Project Impact on Bicycle Quality of Environment" (Oregon Department of Transportation 1996). Measurement factors included: bicycling environment from a continuity perspective, interruptions, barriers, and linkages. While the checklist does not provide for conversion into level of service ratings, it does provide an evaluation of many possible conditions that impact the bicyclist's travel experience.

The Interaction Hazard Score model was developed several years ago to provide a supply-side measure of the on-road bicycling environment (Landis 1994 and 1996). The model utilizes existing traffic and roadway data and variables to estimate the perceived hazard of bicycle and automotive compatibility. The interaction model was developed to overcome deficiencies of earlier models, such as Florida's Roadway Condition Index (Epperson 1994), the Segment Condition Index, and the Davis model's Bicycle Safety Index Rating (Davis 1987; Horowitz 1996).

Several factors influence a bicyclist's perception of interaction hazard: speed of the motor vehicle traffic, traffic characteristics, proximity of the bicyclist to motor vehicle traffic, and the volume of the motor vehicle traffic (Landis 1996). Cities throughout the U.S. utilize the interaction model, often translating the results into level-of-service categories for bicycle facility planning. It has prompted the acceptance of the perception of hazard as a valid level-of-service measure.

The Interaction Hazard Score model led to the development of the Bicycle Level of Service model (BLOS), designed to quantify the level of comfort or threat of roadway hazard that, in theory, is connected with the use of roadways. The model is statistically based, and reflects the effect on bicycle compatibility due to factors such as traffic volume, pavement surface conditions, motor vehicle speed and type, on-street parking, bike lane widths and striping, and roadway width (Landis 1998a). The BLOS model differs from others in that it provides a theoretical basis for testing. A study measuring the responses of 150 bicyclists in

Tampa, Florida was used as the baseline data for developing the model and software, which according to the developer, can be applied to the majority of roadways in the U.S. (Landis 1998). The BLOS is based solely on human responses to measurable roadway and traffic stimuli (Landis et. al 1996:120), rather than estimations or proxies as are some of the other stress level approaches.

Another approach at assessing bicycle facilities was formulated by Nelson and Allen (1997) to analyze existing data for 18 U.S. cities (Goldsmith 1992). The research was driven by the question: does providing bicycle facilities mean that people will use them? In other words, this research incorporates a “supply-side” approach to assessing facilities. A regression equation was used to test the research question with somewhat inconclusive results. The most statistically valid finding was the strength of the relationship between the miles of bicycle paths per 100,000 residents and the percentage of commuters using them – as the miles of paths increased, so did usage (as was expected). The researchers use these results to promote that a latent demand for bicycle facilities may only be tapped by providing bicycle facilities, as suggested earlier by researchers at the University of North Carolina Highway Safety Research Center (1994).

Existing measures of transit availability – a key measure of transit quality - typically overstate the degree to which transit service is available at a location. To overcome this, the Florida Department of Transportation contracted with Kittelson & Associates (1999a) to develop the FDOT Transit Level of Service (TLOS) indicator to address both the spatial and temporal aspects of transit availability. The TLOS indicator, which is software-based, uses percent person-minutes served, defined as the average percent of time that people have transit service available (over time) and accessible (spatially) to them (Kittelson & Associates 1999a and b).

An even more extensive quality of service measure was presented in *the Transit Capacity and Quality of Service Manual* (Kittelson & Associates, Inc. 1999d), the transit counterpart to the *Highway Capacity Manual*. It is broader than the Transit Level of Service indicator because it addresses factors other than accessibility and modes other than fixed-route transit; it is more generalized because it requires less detailed information, although it produces less precise results. However, the Transit Level of Service indicator is compatible with this national quality of service framework. The measures used in the Transit Capacity and Quality of Service framework are:

(1) Availability: Transit Stop (frequency, availability, passenger loads), Route Segment (hours of service, accessibility), System (service coverage, % person-minutes served indices);

(2) Quality: Transit Stop (passenger loads, amenities, reliability), Route Segment (reliability, travel speed, transit/auto travel time), and System (transit/auto travel time, travel time, safety) (Kittelson & Associates 1999a and d).

Relative Demand-Side Methodologies

<u>(1) Facility Demand for Bicycle and Pedestrian Modes</u>: The previous section focuses on "supply-side" approaches for gauging quality of existing facilities. The following type, facility demand, is a "relative demand potential" approach. This type of approach is one in which potential demand for facilities is assessed but actual predictions of demand levels are not. This type of approach is often used in conjunction with supply and quality analysis approaches. Two

types of facility demand potential models are discussed here: the Latent Demand Score Model and pedestrian indices.

The Latent Demand Score Model (LDS), developed by Landis (1996), incorporates both demand and supply factors in evaluating transportation facilities. Using the LDS method in conjunction with The LDS model provides an estimate of "latent" bicycle travel demand, defined as a measure of the relative amount of bicycle travel that would occur on a road segment if there were no bicycle travel inhibitions caused by motor vehicle traffic (Landis 1996:18). The LDS model analyzes the trip generation and proximity of activity centers to assess the potential demand for a facility, using probabilistic gravity model techniques (Landis and Toole 1996).

The LDS model only considers the demand-side potential of bicycle facilities. Thus, one disadvantage of the model is that current road conditions are not considered. However, using the LDS model with level of service assessments, the Interaction Hazard Score model, or other supply-side methods complement the LDS model and overcome these limitations. Cities throughout the U.S. have used the LDS model to help prioritize the expenditures for current and proposed bicycle facilities.

The Pedestrian Deficiency Index, developed by the City of Portland, Oregon, identifies areas in which the quality of existing facilities is low. The index is used in conjunction with the Pedestrian Potential Index that identifies locations with high potential for pedestrian use (Cambridge Systematics, Inc. 1998b). The Deficiency index builds on work by the 1000 Friends of Oregon's Pedestrian Environment Factors (PEF). The approach uses proxy data, based on data previously collected for other purposes, for estimating quality of specific street segments; in combination with the Pedestrian Potential Index, the city identifies projects in high demand areas or with significant deficiencies (City of Portland Oregon 1997).

Another effort to identify the potential number of pedestrian trips within a roadway corridor has been designed by the Washington State Department of Transportation. Dissatisfied with the Federal Highway Administration's pedestrian trip generation rates, an alternative methodology has been developed. Using trip generators and land use and population density factors, the method identifies those areas that have the highest pedestrian activity and indirectly, has the potential to identify those areas that need to be enhanced (Matlick 1996).

In summary, all of the methods explored represent varying degrees of improvement over past efforts. Supply-side methodologies (environment factors and compatibility measures) and relative demand-side methodologies (facility demand) each offer unique contributions and are oftentimes used in conjunction with each other to provide a more comprehensive assessment.

A shortcoming of current methodologies is the lack of consideration for parallel paths, trails, or sidewalk systems that are used or could be used, as transportation corridors. If safe and relatively direct paths can be provided away from vehicular traffic, then it is likely that bicycle and pedestrian mode choices would increase. Urban trails and other alternative routes may help create a shift in demand from vehicular usage to pedestrian and bicycle modes, yet little research has been conducted in this area.

COMPARATIVE ASSESSMENT FOR FLORIDA

Methodology Adjustment for Florida

As with any study, there are inherent limitations that constrain unlimited application of ideas, theories, and implementation. These pervasive constraints of time, resources, and data collection are recognized and addressed in the Florida Department of Transportation's Multi-Modal Quality of Service scope and workplan. The purpose of the project is fourfold:

1. To perform a literature search of multi-modal quality of service methodologies in order to implement the best possible methodology in Florida;
2. To apply and validate the Bicycle Level of Service and Roadside Pedestrian Condition techniques to measure the performance of corridor segments in two districts;
3. To apply and test new Highway Capacity Manual performance measures for transit in two districts; and
4. To refine and evaluate latent bicycle and pedestrian demand model process in order to determine that adequate demand exists for proposed facility improvements.

The following summarizes the most pertinent information identified during the literature review as it applies to adjusting the methodology for the study. There are three areas that were investigated to determine if the proposed methodology for Florida compared favorably with other methodologies in use: pedestrian conditions, bicycle level of service, and quality of service measures for transit.

Bicycle Conditions

Proposed model for the project: Describe the bicycling and walking environment at the planning level through the BLOS, Bicycle Level of Service technique. Also utilize the Bicycle and Latent Demand Score Method to describe bicycling demand at the planning level. Both of these approaches are to be applied by Sprinkle Consulting, Inc.

Comparative Analysis:

- The BLOS model is more theoretically based and statistically valid than other models, such as the Oregon Department of Transportation's Project Impact on Bicycle Quality of Environment, Sorton and Walsh's model, and the Bicycle Compatibility Index. The Gainesville, Florida model developed by Dixon is more comprehensives in terms of variables explored, but has not been designed to be statistically tested as the BLOS model has. In regards to adjusting the methodology for this segment of the study, it is advised that the variables included in the study be carefully considered before inclusion. Ideally, a greater range of variables would be examined; however, the limitations of time, resources, and data collection may not allow this.
- The Latent Demand Score method represents one of the most comprehensive techniques for estimating relative travel demand. The most obvious disadvantage to using the LDS is the inability of the model to define potential ridership. Also, because it considers only the demand-side of the equation, it should be combined with the BLOS/Interaction Hazard Score techniques or other methods to ascertain level of service conditions of existing roadway conditions.

Pedestrian Conditions

Proposed model for the project: Apply the Roadside Pedestrian Condition technique to assess and describe the walking and pedestrian environment at the planning level. The pedestrian methodologies are the least proven and represent an area where additional methodological refinement is needed.

Comparative Analysis:

- The Roadside Pedestrian Condition technique represents the best possible assessment technique, as of this date. It does have some limitations, however, as described by Harkey, et al. 1998a and Cambridge Systematics 1998b: The model suffers from the substantial subjectivity used in estimating the values for some of the variables, and the lack of consideration of exposure variables, such as the numbers of hazards, etc. Because the Interaction Hazard Score model overcomes some of these difficulties, possibly this portion of the study could be improved by substituting the approaches used in the IHS model, if it is feasible to do so. Also, examining Portland, Oregon's Pedestrian Environment Factor (PEF) system could provide ideas for improving the Roadside Pedestrian Condition technique as well since the PEF system is very inclusive. It is anticipated that refinement of the Roadside Pedestrian Condition technique will occur as part of the proposed project, ensuring an even more appropriate application.

Transit Quality of Service

Proposed model for the project: Utilize the FDOT Transit Level of Service Indicator and the Transit Quality of Service methodology to describe the availability and quality of transit at a planing level. Both of these approaches are to be applied by Kittelson & Associates, Inc.

Comparative Analysis:

- Both the FDOT Transit Level of Service Indicator and the Transit Quality of Service procedures represent comprehensive methods of transit availability and quality assessments. By incorporating the use of software, users are able to better understand and utilize output. The Transit Quality of Service procedures are presented as benchmarks for transportation planning throughout the U.S. As such, it is difficult to suggest major improvements on either procedure, other than to encourage the inclusion of as many factors as possible at the local application level. Of course, restraints of time and resources make it difficult to include all possible variables that reflect transit availability and quality; rather, the idea would be to design enough flexibility into the procedures to enable planners to change variables as needed to reflect local conditions.

Also, consideration of the interaction of transit with pedestrian and bicycle modes is vital to the project and should be a priority in the research design. Given the types of the methodologies proposed for the three modes – bicycle, pedestrian, and transit – it is likely that research interaction and compatibility will be high.

In summary, the models proposed for the project appear to be the most suitable, in comparison with other quality of service techniques and approaches currently in use in the U.S. and in other countries. Within the U.S. it is generally regarded, according to the majority of organizations and researchers contacted (see "Contacts" in the subsequent section of this report), that the models developed by Sprinkle Consulting, Inc. and Kittelson & Associates, Inc. represent the "state-of-the-art." As with any proposed research, there are always potential improvements, including expansion of the scope of the study. For example, in the previous section of this report, the absence of research on the effect of "off-road" conditions on inducing bicycle and pedestrian usage was mentioned. Ideally, consideration of these variables could be included (parallel paths, trails, or superwide sidewalks, etc.). If the limits of time and resources prohibit their inclusion, this would represent a potentially valuable area of future research, both regarding the impact of these conditions on latent demand as well as quality of service supply-side assessments. Areas of future study should, consequently, be explored in 1) an areawide analysis of pedestrian and bicycle transit level-of-service; 2) the development of simulation models for bicycle and pedestrian predicted mode shift; 3) expanding the multi-modal level-of-service interface through ART-PLAN linkages.

CONTACTS

During the course of this research, numerous organizations, databases, and researchers were contacted, including the following:

1. Article First: Index of articles from 12,500 journals
2. PapersFirst: Index of papers presented at conferences
3. ECO: Electronic Collections Online
4. WorldCat: Books and articles
5. Engineering Index, Compendex* Plus
6. U.S. Department of Transportation (Rita Kelly) www.bts.gov/index.html
7. Northwestern University www.library.nwu.edu/transportation
8. University of California at Berkeley www.lib.berkeley.edu/itsl/
9. University of Leeds www.leeds.ac.uk/civil/research/research.html
10. London Institute of Transport
11. Delk University, The Netherlands
12. London Cycling Campaign
13. Velo Mondial 2000 World Bicycle Conference
14. Texas Transportation Institute (Shawn Turner, Gordon Shrunk, Lisa Day)
15. University of North Carolina (Wayne Pein, David Harkey)
16. Virginia Department of Transportation (Susan Simmers)
17. Delaware Department of Transportation (Liz Holloway)
18. City of Portland, Oregon, Pedestrian Transportation Program
19. Wisconsin Department of Transportation
20. City of Madison, Wisconsin
21. Florida Department of Transportation
22. New York Department of Transportation (James Ercolano)
23. Washington State Department of Transportation (Julie Mercer Matlick)
24. Sprinkle Consulting, Inc.
25. David Davies Associates
26. Kittelson & Associates, Inc.
27. Federal Transit Administration www.fta.gov
28. Transit Cooperative Research Program, Louis Sanders, Tcrp@apta.com
29. Community Transportation Association of America, Jessica McCann, Mccann@ctaa.org
30. The Transit Center, Resources@Transit-Center.com
31. American Public Transit Association, info@apta.com
32. Institute for Transportation Research and Education, North Carolina State University
33. National Transit Institute, stparker@rci.rutgers.edu
34. University Transportation Centers Program, utc@rspa.dot.gov
35. Cambridge Systematics, Inc.

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SECTION 3

PEDESTRIAN QUALITY OF SERVICE STUDY

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INTRODUCTION

In recent years there have been initiatives in metropolitan areas throughout the United States to create more livable communities where walking and bicycling are encouraged and accepted as legitimate forms of transportation. Characteristic of these efforts is the reintroduction of bicycle lanes and sidewalks to the streetscapes, complete with street furniture, landscaping, pedestrian-scaled lighting, and other features making the public right-of-way more inviting for people to travel by bicycle or on foot. The transportation planning and engineering community has recently been attempting to provide analysis and design methods to help create more “livable” streets and roadway environments.

Historically, compared to the level of research that has been done for motorized transportation, there has been relatively little study and analysis of the factors that affect the quality of the walking environment. Evaluating the performance of a roadway section for the walking mode is far more complex in comparison to that for the motor vehicle mode. Whereas operators of motor vehicles are largely insulated in their travel environment and hence are influenced by relatively few factors, the pedestrian is relatively unprotected and is subject to a host of environmental conditions.

In general, planners and engineers have not yet come to consensus on which features of a roadway environment have statistically reliable significance to pedestrians. There have been several recent initiatives by planners to develop “walkability audits”; however, these measures generally include the myriad of features of the entire roadway corridor environment (including conditions at intersections) and they have not yet been statistically tested or widely applied. There is general consensus that pedestrians' sense of safety / comfort within a roadway corridor is based on a complex assortment of factors: personal safety (i.e., the threat of crashes), personal security (i.e., the threat of assault), architectural interest, pathway or sidewalk shade, pedestrian-scale lighting and amenities, presence of other pedestrians, conditions at intersections, and etc. The list is extensive.

Complexity of the issue, however, should not deter attempts to model pedestrians' response in the roadway environment, even if it is for one aspect or component of a roadway corridor. Elected representatives, public officials, transportation planners and engineers need the capability to determine a roadway's performance with regard to accommodating pedestrian travel. Roadway designers need solid guidance on how to better design pedestrian environments: how far sidewalks should be placed from moving traffic; when, and what type of buffering or protective barriers are needed; how wide the sidewalk should be; and etc.

The purpose of this study, therefore, was to focus on, and identify those factors within the right-of-way that *significantly influence* the pedestrian's feeling of safety and/or comfort. The collection of these factors into a mathematical expression, tested for statistical reliability, thus provides a measure of the roadway segment's level of service to pedestrians. A key application of this measure is to help planners and roadway engineers make informed decisions when designing or choosing the appropriate cross section for any given roadway – a cross section that meets pedestrians' basic need to feel safe and comfortable while walking. As such, the measure presented in this paper only solves one piece of the puzzle, albeit an important one – many other factors also influence a pedestrian's (enjoyment of the) walking experience. These factors should be studied further to improve the body of knowledge on this subject.

The researchers of this study acknowledge that intersection conditions also have a significant bearing on the pedestrians' total roadway corridor experience, and must also be studied. Further, they believe that a measure(s) must be developed to be combined with this roadway segment performance measure. In fact the research sponsor, the Florida Department of Transportation, is using this research team to develop intersection performance measure(s) as phase II of this Study. The Federal Highway Administration is beginning a similar study initiative.

MEASURES OF THE PEDESTRIAN ENVIRONMENT

Dan Burden, a leading national advocate for more walkable communities and transportation systems, articulates for many that the pedestrian in the roadside environment is subjected to a multitude of factors significantly affecting his/her feeling of safety, comfort, and convenience. Accordingly, we may classify these factors under three general performance measures describing the roadside pedestrian environment; 1) sidewalk capacity, 2) quality of the walking environment, and 3) the pedestrian's perception of safety (or comfort) with respect to motor vehicle traffic. These three are briefly outlined below.

The first performance measure, *sidewalk capacity*, was developed in the early 1970's by Fruin *(1)*. His method, as formalized in the *Highway Capacity Manual (2)*, is the only established method of quantifying sidewalk capacity. However, this performance measure is limited in its applicability: it only evaluates conditions for an existing (or a planned) sidewalk and then, only from the perspective of "walking space" or effective sidewalk width available to the pedestrian. Additionally, it cannot be used to evaluate and prioritize roadways for sidewalk retrofit construction, a prevalent need currently in the United States. This is an important limitation. It is estimated that typically less than 20% of the collector and arterial network of U.S. metropolitan areas have sidewalks. Furthermore, it is estimated that less than approximately 3% of roadways have pedestrian activity levels that can be effectively measured by Fruin's capacity method.

Currently, there is no established approach for the second measure, that of the *quality*, or enjoyment aspect of the walking environment. Several researchers and a number of planners have proposed qualitative measures of the *total quality* of the walking experience. Their approaches include numerous qualitative assessments relating to the pedestrian's *enjoyment* of the walking experience (e.g., convenience of the walking experience and the perception of personal security). Works by Sarkar *(3,4)*, Khisty *(5)*, Dixon *(6)*, Crider *(7)*, and others are examples of methods that include a mixed combination of some factors of all three performance measures. However, most of these methods require the presence of a sidewalk to be applicable. And, while the qualitative measure of a pedestrian's enjoyment of the walking experience is important to provide a complete picture of the walking environment and to design an "inviting" sidewalk, it is a separate measure of effectiveness and must be developed and calibrated, if possible, separately from the sidewalk capacity or safety perception measures.

The third measure, the perceived safety or comfort (with respect to the presence of motor vehicle traffic) has until now, not been quantified as a stand-alone performance measure. The common expression of pedestrians concerning how well a particular street or road accommodates their travel is from a perspective of safety and/or comfort. "It's a dangerous place to walk" or "it's fairly safe and comfortable" is the way they articulate their views of the roadway. This measure is the subject of our research, hence this paper. Considering only the roadway environment (i.e., excluding intersection conditions), the factors thought to *significantly* affect pedestrians' sense of safety or comfort include: presence of a sidewalk, lateral separation from motor vehicle traffic, barriers and buffers between pedestrians and motor vehicle traffic, motor vehicle volume and composition, effects of traffic speed, and driveway frequency and access volume, among other factors.

The perception of safety and/or comfort is a qualitative measure of effectiveness recognized by the *1994 Highway Capacity Manual*. The *Manual* states (on pages 1-4 and 1-5), *"The concept of level-of-service uses qualitative (emphasis added) measures that characterize operational conditions within traffic the stream and their perception by (the facility users)…descriptions of individual levels of service characterize these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience" (emphasis added) for the facility type."* With respect to measures of effectiveness, the *Manual* states, *"For each type of facility, levels of service are defined on the basis of one or more operational parameters that best describe operating quality (emphasis added) for the facility type" (2)*. This is the direction of our (measure of effectiveness) effort to model the roadway walking environment.

Therefore, a calibrated, transferable model is needed to objectively reflect, "the perceived safety or comfort of pedestrians along a roadway segment" using measurable traffic and roadway variables. In response to this need, the *Pedestrian Level of Service Model* outlined herein has been developed. The *Model* is objective, transferable, and applicable at the roadway segment, and ultimately, when combined with an intersection level of service measure, applicable at the facility corridor and network levels. It evaluates roadside walking conditions *regardless* of the presence of a sidewalk. It can also demonstrate the impact of adding or improving sidewalks. It uses common, measurable traffic and roadway variables for economy of data collection, accuracy, and reliable and repetitive application. The Model is designed to evaluate a roadway segment; it does not include intersections and their complex conditions that are the subject of separate research initiatives.

DESIGN OF THE RESEARCH

This research initiative by the Florida Department of Transportation placed people in actual traffic and roadway conditions to obtain real-time feedback. Although a virtual reality, or simulation approach was briefly considered by the researchers due to its advantage of safety to the participants, it was not pursued because of the approach's inability to include and/or replicate all response stimuli of the roadway environment. Accordingly, 1) a special event was created to place a significant number of people on a walking course of typical roadways in a typical U.S. metropolitan area, 2) obtain their real-time response to the roadway environment stimuli, and 3) create and test a mathematical relationship of measurable factors to reflect the Study participants' reactions. The following sections outline this approach.

Participants

Nearly 75 people participated in the first (i.e., the course-walking) portion of the study. The participants represented a broad cross section of age, gender, experience level, and geographic origin. Participants' ages ranged from 13 to 69. Due to the potential hazards of walking in urban-area motor vehicle traffic, children younger than age 13 were not permitted to participate. The gender split of the study group was forty-seven (47) percent female and fifty-three (53) percent male. The researchers and Sponsor sought participant diversity in both geographic origins and walking experience. Accordingly, the study test course was located in Pensacola, Florida - a metropolitan area with significant in-migration. The average participant had lived in areas *other* than the Pensacola Bay region for the majority [approximately seventy-three (73) percent] of their life.

There was a considerable range of walking experience among the participants. There was a significant number who made relatively few walking trips (hence, mileage) and there were some who reported that they walked extensively virtually every day of the week. Average distances walked per week ranged from a low of 1.6 kilometers (one mile) to a high of 79 kilometers (48 miles).

The Walking Course

A walking course was designed to subject the participants to a variety of traffic and roadway conditions. The course included road segments with traffic and roadway conditions typical of U.S. metropolitan areas. Approximately 8 km (5 mi) in length, the looped course consisted of 24 road segments (48 directional segments) with near equal lengths, but with varying traffic and roadway conditions. Although the majority of the segments were collectors and arterials, some segments were local streets. During the walking event stage of the study, traffic volumes ranged from a low of 200 average daily traffic (ADT) to a high of 18,500 ADT. The percentage of heavy vehicles [as defined in the *Highway Capacity Manual* (2)] ranged from 0 to 3 percent. Traffic running speeds ranged from 25 to 125 km/hr (15 to 75 mi/hr). The roadway cross-sections included two to four lanes in forms of one way, undivided, divided, and continuous left-turn median lane configurations. The walking course included both curb and guttered as well as open shoulder cross-sectioned roadbeds. Some segments also had striped shoulders and some included designated bicycle lanes.

There were a variety of typical metropolitan area roadside conditions within the course. For example, some of the segments were very urban in character with mixed combinations of on-street parking, landscaped buffers, street trees, and buildings adjoining the sidewalks with structures and awnings covering the sidewalks. Some segments were more suburban or rural in nature with roadside characteristics ranging from no sidewalks to sidewalks directly adjoining the travel lanes, to sidewalks with intervening buffers of various widths.

The walking course passed through a spectrum of land development forms and street network patterns found in the U.S. metropolitan areas. Retail commercial development forms ranged from large retail shopping centers to small convenience strip centers. Some segments had office buildings or other professional service establishments fronting them. Other land uses included churches, auto dealerships, banks, sit-down and fast-food restaurants with drive-throughs, professional and personal care businesses, car repair shops, and light industrial areas. In the residential portions there was also an array of development forms directly adjoining the course. Residential dwellings included apartment and condominium units and other forms of attached dwelling units. Some course segments had single-family homes directly fronting them. Portions of the course passed through traditional grid street patterns; other parts ran through curvilinear street-forms. Neighborhoods represented a mix of income levels.

Participant Response

The real-time data collection activity of the study was promoted as an event entitled the *FunWalk for Science*, with prize drawings and gifts as incentives for participation. Volunteer participants were recruited using a broad-based, area-wide, multimedia approach that included newspaper notices and articles, radio announcements, and direct mailings by and to numerous organizations and businesses. Displays with brochure-registration forms were deployed at area retail sports outlets, health clubs, colleges, government office lobbies, major employers, and bicycle shops.

The need for a large number of volunteer walkers mandated a weekend testing period. Accordingly, the *FunWalk for Science* was scheduled for the morning of one of the busier (from a traffic-volume standpoint) Saturdays of the year in Pensacola, March 18th. To ensure that all participants experienced uniform motor vehicle traffic volumes, the event was run during a single time block in the mid-morning. The participants first updated or completed registration forms that included a variety of demographic questions. They were then briefed in groups as to the purpose and rules of walking the course. Following the briefings, walkers were then sent to two starters who released them onto the course individually at one-minute intervals, in opposite directions. Although the participants were briefed on the course configuration and had instructions for completing the response cards, course proctors were also deployed at strategic points throughout the course. The proctors consisted of staff from the West Florida Regional Planning Council, the Florida Department of Transportation, the University of Florida, SCI, Inc., and a number of regional bicycle and pedestrian coordinators from throughout Florida. The proctors ensured that temporal spacing between walkers was maintained and that the participants were independently completing the response cards as they walked each segment. Participants were encouraged to reflect on their accumulating experience and re-grade any previously walked segments as they proceeded through the course.

The study's purpose was to evaluate the quality, or level of service, of the roadway segments, not the intersections. Accordingly, the participants were instructed to disregard the conditions at intersections and their immediate approaches. They were also encouraged to exclude from their consideration the surrounding aesthetics. They were to include only conditions within, or directly adjoining, the right-of-way. The participants evaluated on a 6-point ("A" to "F") scale how safe / comfortable they felt as they traveled each segment. Level "A" was considered the most safe / comfortable (or least hazardous). Level "F" was considered the least safe / comfortable (or most hazardous).

REDUCTION AND ANALYSIS OF DATA

The study design yielded approximately 1700 initial observations coincident with a myriad of traffic and roadway conditions throughout the walking course. The resulting data was compiled into both spreadsheet and Statistical Analysis Software (SAS) program databases for extensive analyses. Response outliers and trends were identified resulting in 1250 observations and 21 roadway sections (42 directional segments) available for further analysis of the specific effect of traffic and roadway variables.

An interesting response trend was also identified, ultimately determined to be that of response (or scoring) fatigue. A slight diminishing scoring trend was evident. Course length was not a factor (the average total duration of the participant's course experience was approximately 2 hours) due to the clearly constant slope of the response trend. Presentation order of the segments was not a source of the trend either, since the course presented a variety of traffic, roadway, and urban forms in a random distribution. Since the participants walked the course in two direction groups, the averaging of the responses allowed for removal of the fatigue trend, thus Pearson Correlations among the traffic and roadway variables and stepwise regression of the dependant variable was possible using the non-biased (averaged) responses for correlation.

Model Development

Several Pearson Correlation analyses were run using the SAS program on a variety of traffic and roadway variables. Not surprisingly, several variables exhibited some co-linearity. However, the co-linearity was not enough to preclude the inclusion of some co-linear variables into the *Model* due to notable exceptions. For example, while in some cases the presence and width of sidewalks and buffers correlated with increasing speed, in many cases it did not, reflecting that the current practice of roadside design (and/or provision of sidewalks and buffers) is not consistent with providing a uniform level of pedestrian safety and comfort throughout transportation systems.

A "long list" of potential *primary* independent variables influencing pedestrians' sense of safety or comfort within the roadway was generated, and then tested (along with numerous other potential factors) in the stepwise regression portion of the *Model's* development. The long list was generated based on: 1) the results of the aforementioned Pearson Correlation analyses; 2) the variables (and model terms) identified by group consensus and confirmed during the development of the earlier *Roadside Pedestrian Conditions (RPC) Model* [developed for the Tampa metro area MPO's *Hillsborough County MPO Pedestrian Plan* (*8*)], which is currently the basis for several major metropolitan area pedestrian plans; and 3) extensive iterative testing of segment groupings with common levels of independent variables [wherein additional variables were identified which potentially could further explain the variation of the dependant variable (the pedestrians' ratings of safety / comfort)]. The resulting long list of primary factors included, *but was not limited to*:

1) Lateral separation elements between pedestrians and motor vehicle traffic, including,

- Presence of sidewalk
- Width of sidewalk
- Buffers between sidewalk and motor vehicle travel lanes
- Presence of barriers within the buffer area
- Presence of on-street parking
- Width of outside travel lane
- Presence and width of shoulder or bike lane

2) Motor vehicle traffic volume
3) Effect of (motor vehicle) speed
4) Motor vehicle mix (i.e., percentage of trucks)
5) Driveway access frequency and volume

The factors listed above were considered the most probable *primary* factors affecting pedestrians' sense of safety. As such, they are the basis for the preliminary structure and testing of the *Pedestrian LOS Model* represented in the following mathematical expression:

$$\text{Pedestrian LOS} = a_1 f\,(\text{lateral separation factors}) + a_2 f\,(\text{traffic volume}) + a_3 f\,(\text{speed, vehicle type}) + a_4 f\,(\text{driveway access frequency and volume}) + a_n f\,(x_n) + \ldots + C \quad (1)$$

The researchers conducted step-wise regression analyses using the 1315 real-time observations. Numerous variable transformations and combinations of the factors were tested. Table 1 shows the best model form and it's terms' coefficients and T-statistics. The correlation coefficient (R^2) of the best-fit model is 0.85 based on the averaged observations from the 42 directional segments (see Figure 1 for a plot of predicted *Pedestrian LOS* versus mean observed values). The coefficients are statistically significant at the 95 percent level. Thus, the following *Model* was developed:

$$\text{Ped LOS} = -\,1.2021 \ln (W_{ol} + W_l + f_p \text{ x } \%OSP + f_b \text{ x } W_b + f_{sw} \text{ x } W_s) + 0.253 \ln (Vol_{15}/L) + 0.0005\ SPD^2 + 5.3876 \quad (2)$$

Where:

W_{ol} = Width of outside lane (feet)

W_l = Width of shoulder or bike lane (feet)

f_p = On-street parking effect coefficient (=0.20)

%OSP = Percent of segment with on-street parking

f_b = Buffer area barrier coefficient (=5.37 for trees spaced 20 feet on center)

W_b = Buffer width (distance between edge of pavement and sidewalk, feet)

f_{sw} = Sidewalk presence coefficient

$$= 6 - 0.3W_s \quad (3)$$

W_s = Width of sidewalk (feet)

Vol_{15} = average traffic during a fifteen (15) minute period

L = total number of (through) lanes (for road or street)

SPD = Average running speed of motor vehicle traffic (mi/hr)

TABLE 1 Model Coefficients and Statistics

Model Terms	Coefficients	T-statistics
Lateral Separation Elements:		
ln(LS)	- 1.2021	- 10.072
Motor Vehicle Volume:		
ln (Vol_{15}/L)	0.253	3.106
Speed and MV type:		
SPD^2	0.0005	2.763
Constant	5.3876	11.094
Model Correlation (R^2)	0.85	

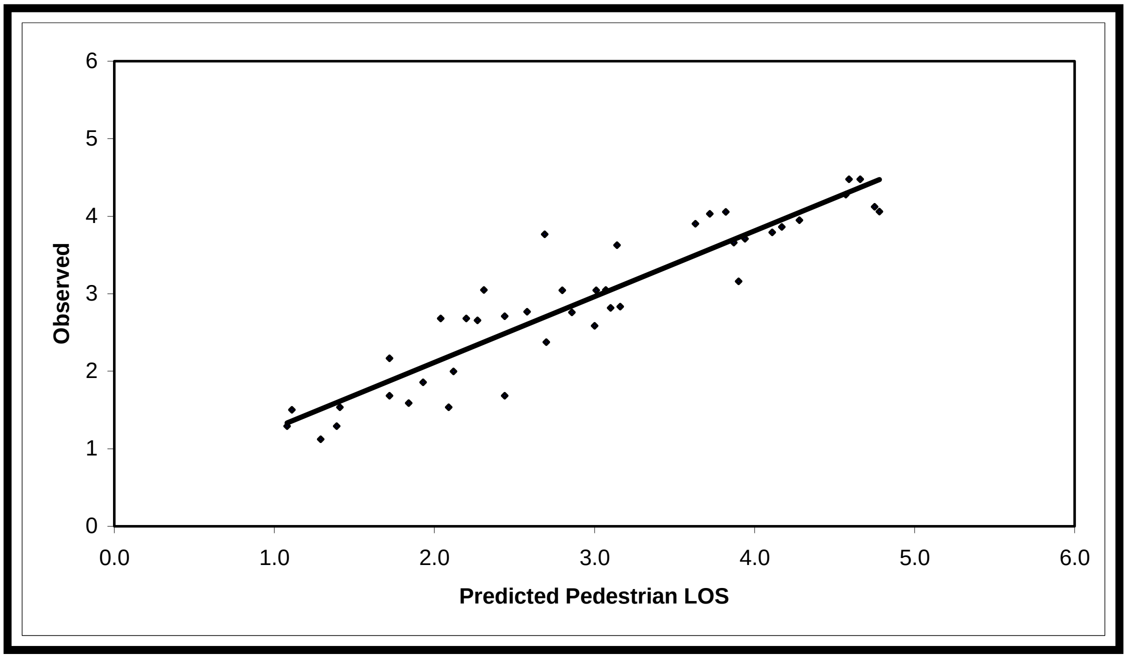

FIGURE 1 Residual plot of predicted and standardized residuals

The *Pedestrian LOS Model* equation was created with a statistical significance at the 95% level. The factor, "driveway access frequency and volume", while included in the step-wise regression analyses, was not found to be statistically significant at that level.

Table 2 below may be used as a basis for stratifying the *Model's* numerical result into a pedestrian level of service class when it is applied to a particular roadway segment. It should be noted that this stratification was pre-determined as the responses gained in the Study were based on the standard U.S. educational system's letter grade structure (with the exception of Grade "E").

TABLE 2 Level of Service Categories

Level-of-Service	Model Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

Discussion of Model Terms

The terms of the calibrated model were developed and refined through extensive variables transformation testing and regression. The following briefly outlines some of the aspects of the terms and how the dependant variable responds to them.

Presence of a Sidewalk and Lateral Separation

Having a safe, separate place to walk alongside the roadway is fundamental in pedestrians' sense of safety and comfort in the roadway environment. This sense of safety or comfort is strongly influenced by the presence of a sidewalk. Furthermore, as the calibrated *Model* confirms, the value of a sidewalk varies according to its location and buffering (i.e., the lateral separation) relative to the motor vehicle traffic. In general, as the lateral separation increases, the pedestrian's comfort or sense of safety also increases (see Figure 2). Additionally, when a barrier such as on-street parking, a line of trees, or a roadside swale is present in the buffer area between motor vehicle traffic and the pedestrian, the pedestrians' sense of protection, hence safety, is improved (see Figure 3). Finally, the *frequency* of parked cars, trees, or an increase in the depth of the intervening roadside swale would further improve the sense of safety.

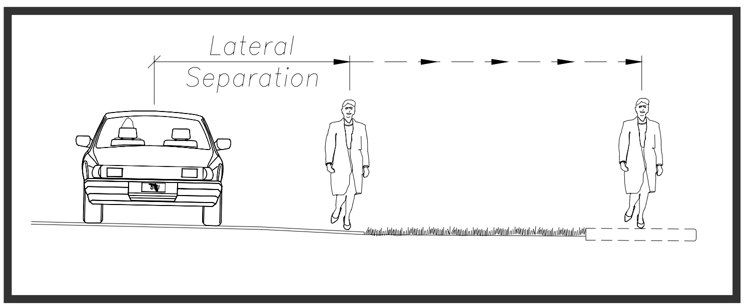

FIGURE 2 Effect of lateral separation.

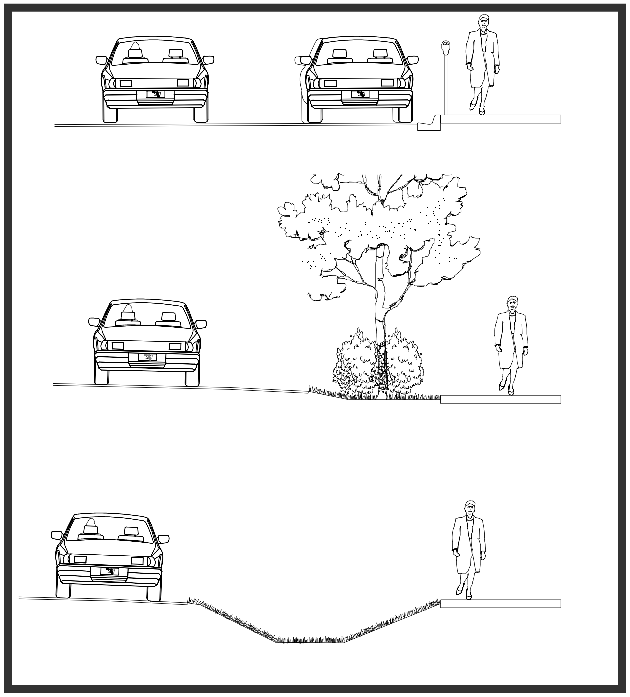

FIGURE 3 Typical barriers within the roadside buffer.

The mathematical expression that reflects these elements of lateral separation, barriers, buffers, and presence of a sidewalk is expressed as follows:

$$LS = W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s \quad (4)$$

Where:

W_{ol} = Width of outside lane (feet)

W_l = Width of shoulder or bike lane (feet)

f_p = On-street parking effect coefficient

%OSP = Percent of segment with on-street parking

f_b = Buffer area barrier coefficients

W_b = Buffer width (distance between edge of pavement and sidewalk, feet)

f_{sw} = Sidewalk presence coefficient

W_s = Width of sidewalk (feet)

Examples of how the lateral separation elements are used to quantify some typical roadway cross-sections are illustrated below.

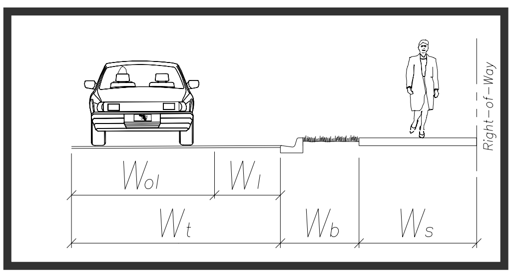

FIGURE 4 Buffers and sidewalk.

Figure 4 above shows a curbed cross-section with no vertical barriers in the horizontal buffer area between the travel lane and sidewalk. Note that there is no on-street parking, therefore the %OSP term equals zero. Thus for this scenario, the lateral separation term is given by:

$$LS = W_{ol} + W_l + f_b \times W_b + f_{sw} \times W_s \qquad (5)$$

In the case where there is on-street parking, as is illustrated in Figure 5, its effect as a barrier is quantified as in Equation (6). Note that there is no striped shoulder or landscape buffer, therefore the W_l and W_b terms equal zero. Thus, the lateral separation term is simplified to:

$$LS = W_{ol} + f_p \times \%OSP + f_{sw} \times W_s \qquad (6)$$

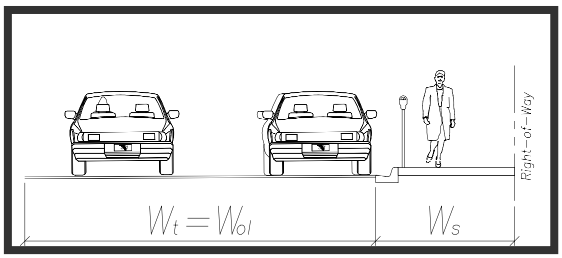

FIGURE 5 Lateral separation with on-street parking.

This section introduced the elements of lateral separation and their mathematical expression. The next sections describe the other two statistically significant terms of the *Pedestrian LOS Model*.

Motor Vehicle Volume

The frequency of motor vehicles passing pedestrians, represented by the outside lane volume, was also found to be a significant factor. As passing frequency increases, the pedestrians' feeling of safety decreases. The effect of traffic volume is calculated by the following:

$$\text{Traffic Volume} = \frac{Vol_{15}}{L} \qquad (7)$$

where:

Vol_{15} = average traffic during a fifteen (15) minute period

L = total number of (thru) lanes (for road or street)

This effect on the walkers in the Study was found to be statistically significant. Transformations of this variable and subsequent stepwise regressions revealed that at lower traffic volumes, changes in the independent variable produced significant changes in the dependant variable. At higher volumes, however, there was less sensitivity; hence the natural log mathematical form of this term.

Effect of Speed

Similarly, the speed of motor vehicle traffic was confirmed as significantly affecting pedestrians' sense of safety. As speed increases, pedestrian discomfort increases. It was determined that the dependant variable had an exponential relationship with the average running speed of the motor vehicle traffic, somewhat similar to that relationship discovered during the development of the *Bicycle Level of Service Model* (*9*), which has been incorporated into Florida's multi-modal level of service analysis guidelines (*10*).

Driveway Access Frequency and Volume

Along a roadway segment, uncontrolled vehicular access to adjoining properties (i.e., driveway cuts) was thought to reduce the pedestrian sense of safety. This transverse feature represents a similar "turbulence" or hazard to the pedestrian as to motor vehicle operators. Accordingly, as the number of driveways increases, a corresponding decrease in the perceived safety to the pedestrian was expected. Affecting this perception of safety is the volume of vehicles accessing the driveways. However, step-wise regression analyses revealed that this effect was not statistically significant at the 95 percent confidence level.

FINDINGS AND IMPLICATIONS

The result of this initial research sponsored by the Florida Department of Transportation is the development of a reliable, statistically calibrated pedestrian level of service model suitable for application not only in Florida metropolitan areas, but also throughout North America. The *Pedestrian LOS Model* provides a measure of a roadway segment's performance with respect to pedestrians' primary perception of safety or comfort; as such it serves as the basis for the Florida Department of Transportation's state-wide multi-modal (particularly for the pedestrian mode) level of service evaluation techniques. However, it can also be used to greatly influence roadway cross-sectional design and it can also help evaluate and prioritize the needs of existing roadways for sidewalk retrofit construction; applications for which the *Model's* precursor, the *Roadside Pedestrian Conditions Model,* has been successfully used. Further, the *Pedestrian LOS Model*, when coupled with the *capacity* (Fruin) measure and a *quality* performance measure (i.e., "Walkability Audit" to assess the enjoyment and convenience of the walking experience – in the case of an existing sidewalk) "completes the picture" of the roadside walking environment.

ACKNOWLEDGEMENT

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TABLE TITLES AND FIGURE CAPTIONS

TABLE 1 Model Coefficients and Statistics

TABLE 2 Level of Service Categories

FIGURE 1 Residual plot of predicted and standardized residuals

FIGURE 2 Effect of lateral separation.

FIGURE 3 Typical Barriers within the Roadside Buffer.

FIGURE 4 Buffers and sidewalk.

FIGURE 5 Lateral separation with on-street parking.

SECTION 4

GENERAL TRANSIT CONCEPTS

Author: John Karachepone, Paul Ryus

TRANSIT LEVEL OF SERVICE DEVELOPMENTS

Transit Capacity & Quality of Service Manual, First Edition (TCQSM)

Transit Cooperative Research Program (TCRP) project A-15 developed a transit quality of service framework for assessing transit service from the passengers' point of view. The framework includes three service measures of transit availability (frequency, hours of service, and service coverage) and three service measures of transit comfort and convenience (passenger loads, reliability, and transit-auto travel time).

The full framework appears in the *Transit Capacity and Quality of Service Manual,* First Edition (TCRP Web Document 6), which was released in May 1999. Four of the six service measures will also appear in the transit chapters of the *Highway Capacity Manual 2000.* (Measures that are primarily system-oriented—service coverage and transit-auto travel time—will be discussed but will not be presented as service measures in the HCM2000.)

To fully describe service availability at the system level using the TCQSM method requires calculating all three measures: frequency (how often service is provided), hours of service (how long service is provided), and service coverage (where service is provided). At the transit stop and route/corridor level, service coverage drops out as a factor, since service exists wherever there are routes and stops. When analyzing individual hours, hours of service may also be dropped as a factor, since service frequency is zero during hours when service is not provided. However, when only one hour of a day is analyzed (e.g., a peak hour), relying solely on service frequency as a measure of transit availability risks not measuring the full picture: even if good service is provided during the peak hour, service may not be available for the return trip, or an unreasonably long wait may be involved.

Pedestrian access is an indirect factor in determining service coverage LOS, but otherwise does not directly enter into the determination of transit availability LOS. The TCQSM acknowledges and discusses the importance of pedestrian access. However, as there were no methods existing at the time that, in the project team's opinion, adequately provided a quantitative evaluation of pedestrian access, that factor was not incorporated as a specific LOS measure. Table 1 presents the levels of service for frequency and hours of service given in the TCQSM.

Table 1
TCQSM Level of Service Ranges for Frequency and Hours of Service

Measure	Units	A	B	C	D	E
Frequency	buses/hour	>6	5-6	3-4	2	1
Hours of Service	hours/day	>18	17-18	14-16	12-13	4-11

The TCRP has authorized a continuation project, TCRP A-15A, that will develop an expanded second edition of the TCQSM that will be ready in early 2002. The scope of work for the project indicates that the project panel is not yet entirely comfortable with the quality of service (QOS) framework and that changes could be made in the second edition. Specific items to be addressed in A-15A include:

- field testing the QOS framework in four locations (large urbanized area, medium urbanized area, small urbanized area, and rural area), obtaining the response of senior transit managers and elected officials to the QOS evaluation;
- suggesting measurement enhancements for the system availability and coverage measures, including but not limited to the Florida Transit Level of Service (TLOS) Indicator; and
- possibly developing a utility-based measure of quality of service (some kind of weighted index) in year two of the project.

User feedback thus far has generally supported the framework, although there has been debate about the on-time performance thresholds used for service reliability LOS, as well as the population and employment densities used to define the "transit supportive area" used for service coverage LOS. The project panel appears to desire a consolidation of the six measures, if shown to be feasible. The A-15A project will solicit additional user feedback via various means, particularly the World Wide Web; this feedback will be incorporated into the evaluation of the quality of service framework.

In two years, a number of outcomes could result:

- the current QOS framework could stay essentially the same, with possible modifications to specific threshold values and definitions;
- the current six measures could be reduced to a smaller number of measures, which could include new measures such as TLOS and/or a utility-based measure; or
- an entirely new QOS measurement system could be developed.

It should be noted that any change would mean that the transit quality of service frameworks presented in the HCM2000 and the TCQSM would no longer be consistent. However, since the transit material in the HCM2000 is supposed to be a subset of material in the TCQSM, the TCQSM measures should be considered to be the "official" measures.

Florida Transit Level of Service

The FDOT Public Transit Office sponsored a project to develop a measure of transit service availability and software to evaluate it. The result was the Florida Transit Level of Service (TLOS) software, which was released in April 1999. The TLOS performance measure is percent person-minutes served (also known as the "TLOS indicator"), which incorporates service frequency, hours of service, and service coverage into a single measure, and—on an area-wide level—also addresses population and employment density. The existence and quality of pedestrian connections to transit stops also can be included as a factor.

As an illustration of how the TLOS indicator works on an area level, consider a neighborhood served by a bus route along one side. For the sake of this example, assume that only half of the neighborhood lives within ¼-mile walk distance of a bus stop, because of a combination of limited street connections to the transit street and a less-than-ideal pedestrian environment. As a result, only half of the people in the neighborhood (the half living within walking distance of a transit stop) have access to transit service.

Further assume that ideal bus service for the area is considered to be service every 10 minutes; i.e., each bus provides a window of 10 minutes during which the transit mode can be accessed by the people within the neighborhood that live within walking distance of a transit stop. If service is actually provided every 20 minutes, then transit service is only available for half of each hour (three buses per hour times 10 minutes per bus, divided by 60 minutes per hour). Over the course of an hour, the TLOS indicator value for the neighborhood is 25% (50% of the people have service for 50% of the hour). If, over the course of the day, transit service were offered for 12 hours (half a day), the daily TLOS indicator for the neighborhood would be 12.5% (50% of the people have service for 50% of the hour for 50% of the hours during a day).

The TLOS measure was pilot tested in Tallahassee and found to produce results consistent with the transit availability measures presented in the TCQSM. A method was also developed for equating TLOS values with the levels of service for service frequency and hours of service shown in the TCQSM. Two continuation contracts have been issued for the TLOS project. Version 2 of the software, scheduled to be completed in January 2000, will enhance current software features, allow the measurement of the TCQSM availability levels of service, and add a transit marketing (address matching) component. Version 3, scheduled to be completed in June 2000, will allow the calculation of transit travel times.

User feedback thus far has been mostly that (1) the measure requires a lot of work to calculate, (2) it is not immediately intuitive, and (3) that it only addresses access to transit service, and not how long it takes to get between places using transit. The first issue is true on an area-wide level, where the number of people who have access to transit must be determined, but not at the route/corridor or stop levels, where the service coverage aspect goes away, leaving only frequency and hours of service to be determined. At the route/corridor and stop levels, TLOS can (and has) been easily measured using a simple spreadsheet. With respect to the second issue, the TLOS indicator is less intuitive than measures such as frequency and hours of service, but unlike an index measure, the results can still be visualized and simply explained (TLOS is the amount of transit service available to an area compared to an ideal). Version 3 of the software will address the third issue.

Since TLOS can be equated with TCQSM levels of service, particularly at the corridor and point levels, and since it is at least being considered for inclusion into the second edition of the TCQSM, it is appropriate to evaluate both the TLOS and the TCQSM measures as part of this Multi-Modal LOS project.

FDOT'S LEVEL OF SERVICE TABLES

Introduction

The FDOT Systems Planning Office has developed and maintained for some time a series of tables that relate service volumes on a roadway facility to levels of service. These tables incorporate planning-level implementations of existing HCM procedures. FDOT would like to make these tables multi-modal, by providing additional planning-level LOS procedures for pedestrians, bicycles, and transit.

FDOT Concepts

The Systems Planning Office has developed several concepts of how fixed-route bus LOS could be incorporated into the generalized tables for arterial roadways, for the peak hour in the peak direction. Under the current concept, level of service would be based on buses per hour and the amount of sidewalks provided along the arterial, as shown in Table 2. It should be noted that for streets with sidewalk on both sides (bottom row in Table 2), the Bus LOS is the TCQSM LOS for frequency (see Table 1).

Table 2
Current FDOT Concept for Bus LOS

Sides of Street with Sidewalk	Percent of Facility with Sidewalk*	A	B	C	D	E
1 or 2	0-84%	**	**	>4	3-4	2
1	85-100%	**	>5	4-5	2-3	1
2	85-100%	>6	5-6	3-4	2	1

Values are frequency (buses per hour)
*Percent of facility with sidewalk is to be estimated. 85 to 100% is a continuous or near continuous sidewalk facility.
**Cannot be achieved

FDOT has developed a similar concept for pedestrian LOS, based on hourly vehicular volume in the curb lane, as shown in Table 3. Based on discussions with FDOT Systems Planning staff, the row that would result in the highest LOS would be used (i.e., if one side of a street had 100% sidewalks and the other side 40% sidewalks, the one-side, 85-100% row would be used).

Table 3
Current FDOT Concept #2 for Pedestrian LOS

Sides of Street with Sidewalk	% of Facility with Sidewalk	A	B	C	D	E
1	0-84%	**	**	**	100	200
1	85-100%	**	300	500	700	900
2	0-49%	**	**	**	100	200
2	50-84%	**	**	300	500	700
2	85-100%	300	500	700	900	1100

Values are veh/h in the curb lane
**Cannot be achieved

The Passenger's Perspective

Service frequency is a component of all three measurement systems, TCQSM, TLOS, and the current FDOT bus LOS concept. From the perspective of transit passengers within a corridor, is this the best measure to use?

From the perspective of passengers traversing the corridor on transit, who neither board nor alight within the corridor, the service frequency provided within the corridor is not particularly important, nor is the presence of sidewalks in the corridor. More important to these passengers is the service frequency provided at their trip origin, which may be different than the corridor's service frequency. Indirectly, service frequency may be important in that it measures the degree to which transit priority measures may be appropriate. Also indirectly, the presence of sidewalks influences the number of destinations that are *potentially* available to passengers. However, within the corridor, travel time or speed a more important factor to passengers already on a bus than either service frequency or sidewalk existence. Delay due to congestion (which influences bus travel time and speed) can be measured indirectly by arterial LOS: the greater the number of vehicles on the arterial, the greater the delay to those vehicles (including buses), and thus the greater the delay to the passengers on those buses.

From the perspective of passengers boarding or alighting in the corridor, service frequency is definitely important. Depending on the kind of land use adjacent to the corridor, the existence of sidewalks along the arterial may or may not be important. In a residential area, most passengers will arrive at bus stops from side streets, rather than from along the arterial itself. As long as bus stops are located at intersections (as is typical), these passengers will never need to use sidewalks along the arterial. In comparison, in an office or commercial environment, most passengers will arrive from points along the arterial itself. In these cases, the existence of sidewalks is important. This factor is incorporated into the current FDOT pedestrian LOS concept.

Since passengers boarding or alighting in the corridor will need to cross the arterial street at some point during their round trip, their ease of crossing the street is another important factor. Traffic volumes partially influence the degree of difficulty of crossing streets, but the width of the street and the type of pedestrian crossing control provided also play a role. The FDOT pedestrian LOS measure, therefore, partially accounts for the ease of crossing streets.

All passengers will consider whether transit service will be available for their return trip, before deciding to use transit for the first half of the trip; therefore, hours of service should be incorporated into at least a daily measure of bus LOS, even if not incorporated into a peak hour measure. However, hours of service are not part of the current FDOT bus LOS concept.

There is no question that the quality (or very existence) of pedestrian access to transit plays an important role in one’s decision to use transit. However, it can be questioned why pedestrian LOS should be incorporated into transit LOS, when a separate pedestrian LOS measure is proposed. The measure of pedestrian accessibility proposed to be incorporated into bus LOS does not reflect an aspect of accessibility important to all passengers boarding or alighting within the corridor—the ease of crossing the street with transit service.

In contrast, freeway LOS, for example, does not depend on whether the arterials one uses to access the freeway are congested or uncongested; the measure simply determines how well the freeway itself operates. Similarly, bus passengers who were already on the bus when it entered the corridor do not care about the quality of the pedestrian environment within the corridor, as long as they are not getting off the bus within the corridor. If a passenger does get off the bus, the pedestrian LOS provides the measure of pedestrian conditions in the area, just as an arterial LOS provides the measure of conditions off of the freeway.

Consider the following examples:

- Bus LOS "A"/Ped LOS "E": Bus service is excellent, but people boarding or alighting in the corridor have great difficulty accessing it.
- Bus LOS "A"/Ped LOS "A": Bus service is excellent and people in the corridor can easily access it.
- Bus LOS "E"/Ped LOS "A": People can easily walk to bus stops, but have no incentive to take the bus.
- Bus LOS "E"/Ped LOS "E": An auto-dependent corridor.

As illustrated above, separate bus and pedestrian levels of service can provide the answers one is looking for, without requiring the double-counting of pedestrian LOS within bus LOS. Also, from a transit agency's perspective, incorporating the lack of sidewalks as a factor that lowers bus LOS could be seen as unfair, since transit agencies have little (if any) control over whether sidewalks are provided along streets. Similarly, from a roadway agency's perspective, service frequency is a factor they have no control over. Having separate measures makes it easer to understand which factors are creating a poor bus LOS.

RECOMMENDATIONS

The various perspectives of bus users in the corridor can be addressed by separate bus, pedestrian, and vehicle LOS measures. Bus LOS measures the quality of bus service offered to passengers boarding and alighting in the corridor. Pedestrian LOS partially measures the ease of accessing the offered bus service. Vehicle LOS measures the service quality perceived by passengers aboard buses traveling in the corridor. Having separate measures makes it easy to identify the cause(s) of poor bus LOS.

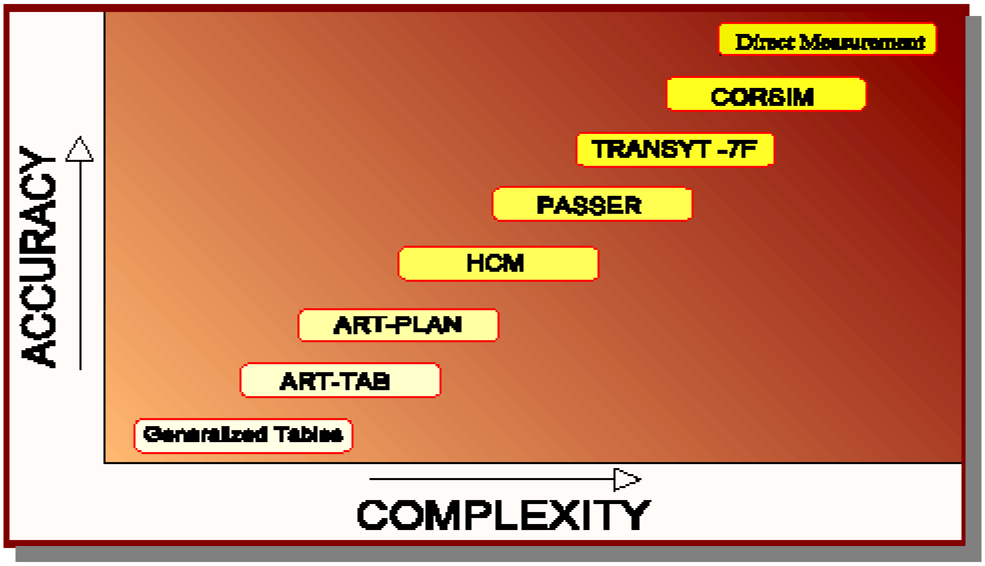
Nevertheless, there is no harm in incorporating a measure of pedestrian accessibility into bus LOS, since the same conclusion regarding access to the transit mode will be reached whether two separate bus and pedestrian measures are used, or one measure incorporating aspects of each is used. Further, incorporating a pedestrian accessibility factor into bus LOS helps acknowledge the importance of good pedestrian facilities in supporting transit usage. Therefore, we take no exception to FDOT's proposed bus LOS table.

Relationship of Proposed Table to Other Methods

FDOT's proposed bus LOS values given in Table 2 take the TCQSM service frequency LOS thresholds as a base, but reduce the LOS depending on how well the corridor is served by pedestrian facilities. The proposed values can also be converted into equivalent TLOS values using the method described in the *TLOS Software Final Report.*

FDOT's table-generating spreadsheets are part of a hierarchy of analysis tools. As one moves up the hierarchy, more detailed information is required, but more accurate results are achieved. Figure 1, taken from FDOT's *1998 Level of Service Handbook*, illustrates the hierarchy of roadway tools.

Figure 1
Hierarchy of FDOT Analysis Tools for Roadways



A similar hierarchy could be developed for bus and transit tools, each with increasing levels of complexity. One possible concept is illustrated in Table 5.

Table 5
Hierarchy of Transit Analysis Tools

Tool	Bus Inputs	Bus Factors Addressed	Ped Access Evaluation Method	Applications
Generalized Tables	• Frequency	• service availability	sidewalk percentage	• TCQSM/HCM-compatible planning-level corridor assessment of availability
ARTPLAN	• frequency • hours of service	• service availability	sidewalk percentage and crossing inconvenience	• more detailed TCQSM/HCM-compatible planning-level corridor assessment of availability
TLOS Spreadsheet	• frequency by hour • bus stop spacing • ped access spacing • ped environment	• service availability	TLOS values adjusted by pedestrian factors	• TLOS-compatible planning-level corridor assessment of availability
TCQSM	• frequency • hours of service • bus stop locations • ped connectivity • population	• service availability • persons served • pop density	service coverage area excludes areas with no ped access	• simplified operations-level assessments of transit availability, comfort, and convenience
TLOS Software	• detailed schedules • bus stop locations • street network • transit network • ped environment • population & jobs	• service availability • persons served • pop/job density • influence of parallel and cross-street transit service	TLOS software accounts for walk distances along street and pathway network, and areas that are “ped-unfriendly”	• detailed assessments of transit availability • transportation model refinement • community quality of life assessments

At the lowest level of detail, the generalized tables, service frequency is used to determine LOS at a bus stop or corridor level. Pedestrian accessibility is accounted for by lowering the LOS to reflect an absence of sidewalks along the arterial.

ARTPLAN allows one to provide more detailed information, rather than apply the defaults used by the generalized tables. Recommended items to add to ARTPLAN that would provide more detail than the generalized tables include hours of service and a measure of pedestrians' difficulty of crossing a wide or busy street.

The next level of detail is a planning-level spreadsheet to measure the TLOS indicator at a bus stop or corridor level for an hour or a day. If desired, levels of service can be determined by converting frequency and hours of service thresholds into equivalent TLOS indicator values. Pedestrian access to transit is evaluated based on bus stop spacing, pedestrian access spacing onto the arterial, and a measure of the pedestrian environment.

At the TCQSM level, levels of service for frequency, hours of service, and service coverage can be calculated relatively easily at a bus stop, corridor, or system-wide level. Pedestrian access is accounted for when determining service coverage—areas with no or poor pedestrian access are not considered to be served by transit.

At the highest level of detail, the TLOS software uses detailed information about bus schedules, pedestrian environment, and population and job locations to provide a very good assessment of transit accessibility.

SECTION 5

MULTI-MODAL LEVEL OF SERVICE CONCEPTS/ APPROACH TO TRANSIT QUALITY OF SERVICE METHODOLOGY

Author: John Karachepone, Paul Ryus

INTRODUCTION

The recognition of the need to have uniform methods to evaluate level of service of non-auto modes has resulted in the Multi-Modal Level of Service research project. Additionally, legislative actions in Florida have necessitated the development of preferred methodologies and tools for the evaluation of level of service and performance measurement for all modes. This technical memorandum addresses the issue of a planning level transit quality of service (Transit QOS) determination. At the same time separate research is being conducted to develop quality of service concepts for the bicycle and pedestrian modes.

The methodology for the determination of quality of service for the automobile mode is described in the Florida Level of Service Handbook. It is anticipated that this research will lead to a revised Level of Service Handbook that addresses and integrates all modes. This memorandum attempts to set a framework for the integration of all modes in the level of service handbook and focuses on transit quality of service.

The Transit Capacity and Quality of Service Manual (TCQSM) and Florida's transit level of service(TLOS) indicator methodologies are used as the starting point for determination of an acceptable planning level methodology. A model application is needed which identifies the relationship between the quality of service factors which are important from a user perspective. This model should be amenable to a spreadsheet application.

The proposed methodology and analysis presented here is designed for and limited to scheduled fixed route bus transit service only. At this initial stage, the methodology attempts to address measures of transit availability and accessibility at the route segment level. At a later time, enhancements or additional methodologies to evaluate performance for a bus system (area-wide analysis level) and/or a bus stop (point level) may be provided.

This section first presents the existing construct of ART-PLAN, the methodology for assessing quality of service for the automobile mode, developed by the Florida Department of Transportation (FDOT). Then, the quality of service construct for transit from the Transit Capacity and Quality of Service Manual (TCQSM) is presented. The pedestrian quality of service construct from the research conducted by Sprinkle Consulting Inc. is summarized in the third section. The fourth section of the memorandum identifies the types of information that are available to planners from the Gainesville and Orlando transit systems, which are the prototype systems used in this research. The next section presents a discussion of various factors taken into consideration in developing a planning level methodology for measuring transit quality of service. The sixth section of this Memorandum presents a recommended method for the determination of quality of service for bus route segments and provides a flow diagram for the methodology. The last section is a brief summary.

AUTOMOBILE MODE – ART-PLAN CONSTRUCT

The 1998 Level of Service Handbook is a document that provides planning level methodologies to determine the level of service for the automobile mode on arterials, freeways, highways in uninterrupted flow conditions, and roadways off the state system. These methodologies are executed through computer spreadsheet programs which form a part of the handbook. Additionally, the handbook identifies the level of service standards adopted for the Florida Intrastate Highway System. The 1998 Level of Service Handbook is based on methodologies established in the 1997 Highway Capacity Manual and is limited to the automobile mode.

The automobile users perception of quality of service is related to the service volume of the roadway. A maximum service volume (for a given set of roadway, traffic, and intersection control conditions) can be associated with each level of service for the automobile mode. This maximum service volume is the highest volume of traffic on the roadway at the specified level of service. As traffic volumes increase and the maximum service volume of the roadway is reached, users perceive the quality of service they receive as poorer. In the case of signalized intersections, as delays increase, the quality of service one experiences becomes worse. On urban arterial streets, travel speed is the service measure that users associate with quality of service. Under given conditions, delay at signalized intersections becomes greater and travel speeds along arterial streets becomes slower as traffic volumes approach the maximum service volume. Thus, for the automobile mode, the service volume of the roadway (or highway) has a direct relationship with quality of service.

The Level of Service Handbook presents a planning- level analysis methodology for determining the level of service on an urban arterial. This methodology when executed through a computer spreadsheet is known as ART-PLAN. Table 1 lists the data required to determine the level of service on an urban arterial. The ART-PLAN model can be used to determine maximum service volumes at different levels of service for a given set of roadway, traffic and intersection control conditions.

Table 1: ART-PLAN Data Input

Category	Input Data Item	Default Value Available?	Comments
Traffic Variables	Planning Analysis Hour Factor, K100	Yes	Local observed value preferred.
	Directional Distribution, D	Yes	Local observed value preferred.
	Peak Hour Factor, PHF	Yes	Local observed value preferred.
	Percent Turns from Exclusive Lanes	Yes	Local observed values preferred.
	Annual Average Daily Traffic (AADT)	None	If peak hour volume is available by approach, this input data may be omitted.
	Peak Hour Directional Volume	None	This input, while not required if a daily or AADT volume is available, is recommended.
Roadway Variables	Number of Through Lanes in Peak and Off-peak Directions	None	Required Input.
	Arterial Classification	None	Required Input.
	Area Type	None	Required Input.
	Free Flow Speed	None	Required Input.
	Length	None	Distance between each signalized intersection required.
Category	**Input Data Item**	**Default Value Available?**	**Comments**
Signalization Variables	Arrival Type	None	Required Input.
	Signal Type	None	Required Input.
	Signals per Mile	None	Required Input.
	Cycle Length	Yes	Required Input.
	Effective g/C ratio	Yes	Local observed value from each signalized intersection preferred.

The arterial analysis method can be summarized in the flow chart illustrated on Figure 1. The input parameters identified in Table 1 are used in computing running time, delay time and average travel speed. The calculated average travel speed is then compared against threshold speeds to determine the level of service.

TRANSIT MODE - TRANSIT QUALITY OF SERVICE CONSTRUCT

For automobiles on an arterial, a single performance measure (average travel speed) yields a measure of quality of service for a facility. In the case of transit, however, multiple performance measures are used, each giving a separate measure of quality of service. The Transit Capacity and Quality of Service Manual (TCQSM) provides methodologies to determine quality of service based on the framework identified in Table 2. There are two categories available: availability, and comfort and convenience. For a route segment, hours of service and accessibility are the performance measures which describe availability of service. The comfort and convenience performance measures are reliability, travel speed and the ratio of transit to automobile travel time. It should be noted that the comfort and convenience performance measures can exist only with the availability or existence of transit service.

Unlike the automobile quality of service construct, the transit quality of service construct does not have as strong a relationship to capacity. The performance measures used to determine quality of service for transit do not provide enough information to determine “transit capacity”. Additionally, the travel speed experienced by a motorist in a passenger vehicle is related to transit speed in that the travel speed of an automobile on the roadway is often the maximum transit speed that can be achieved if there were no transit stops on the roadway. In reality, transit travel speed (and conversely transit travel time) is affected by the number of transit stops, distance between transit stops, and number of boarding and alighting passengers.

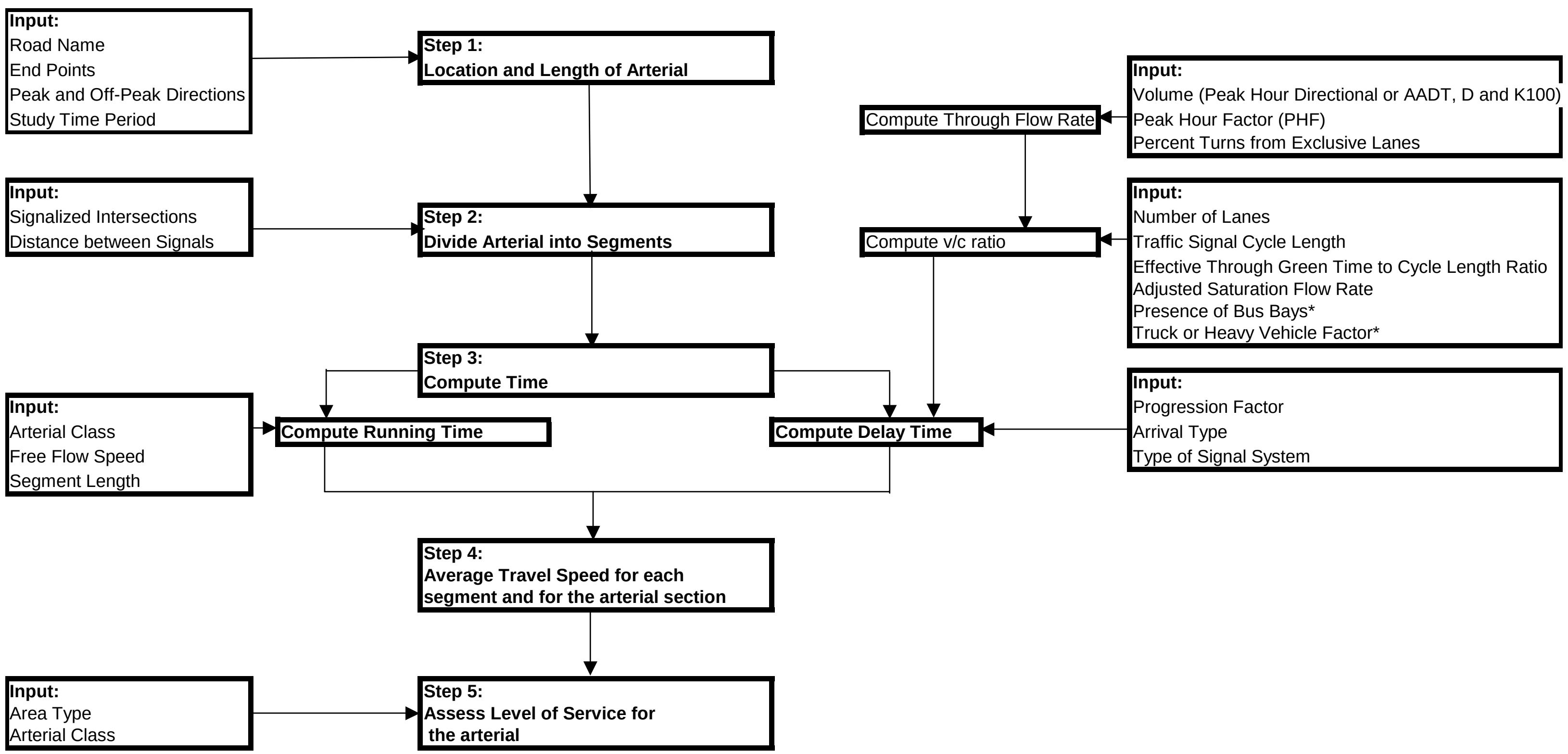
Another important difference is that the automobile mode is nearly always available throughout the day. The transit mode at any location is available only when the transit vehicle arrives and stops at that location. The quality of service that the transit mode provides is only relevant to users to whom the transit vehicle is available. Therefore, transit availability is the foremost consideration in the determination of transit quality of service.

Table 2: Transit Quality of Service Framework

Category	**Service and Performance Measures**		
	Transit Stop	**Route Segment**	**System**
Availability	Frequency[1]	Hours of service[1]	Service coverage
	Accessibility	Accessibility	Percent person-minutes of availability index
	Passenger loads		
Comfort and convenience	Passenger loads[1]	Reliability[1]	Transit/auto travel time
	Amenities	Travel speed	Travel time
	Reliability	Transit/auto travel time	Safety

1 Service measure that defines the corresponding levels of service in HCM2000 Chapter 27.
Source: Final Draft Exhibit 14-23, Highway Capacity Manual 2000; Transportation Research Board, October 1999.

Figure 1: Arterial Analysis Flow Chart



Note: Input variables marked with an "*" are proposed enhancements to the ART_PLAN methodology for multi-modal considerations.
Other non-automobile/transit data input i Outside lane width
Paved shoulder width
Presence of sidewalk
Lateral separation (distance) between sidewalk and outside lane

Quality of service is determined for roadway segments which are largely homogenous in character. A comparative assessment of transit quality of service would focus on a transit route segment. This is a portion of a transit route where bus stops are spaced at a consistent interval and the bus service is provided at consistent headways. The availability of transit service on a route segment is primarily determined by hours of service (Table 2). Since route segments (other than express routes) include stops, for which frequency is the measure, frequency should also be considered in evaluating the availability of transit service on a route segment. A secondary consideration is accessibility. Accessibility to transit relates to the availability of multiple modes of access, and quality of the mode of access to transit. The quality of access for example, may be defined by the presence and quality of sidewalks, legal compliance with the ADA, presence of bicycle facilities and, presence and occupancy of parking lots. Service frequency is the primary measure at each transit stop. Similarly, the comfort and convenience factor for route segments is primarily determined by reliability and on a secondary basis by transit travel speed and the ratio of transit to auto travel time. The TCQSM provides level of service thresholds for many of the performance measures. For route segments, the area of interest, level of service thresholds are provided in the TCQSM for the primary performance measures of "Hours of Service" and "Reliability".

PEDESTRIAN MODE – QUALITY OF SERVICE CONSTRUCT

Pedestrian quality of service, based on the SCI method, along a roadway segment depends on a composite index that considers the impact of numerous factors on quality of service. The pedestrian quality of service is dependent on the following factors:

- lateral separation of pedestrians from motor vehicle traffic,
- presence of physical barriers and buffers,

- outside lane traffic volume, and
- effect of motor vehicle speed and type (in particular, speeds of large trucks).

The lateral separation factor accounts for the proximity of pedestrians to motor vehicle traffic. This proximity is affected by the following factors:

- Width of outside lane,
- Width of shoulder, and
- Sidewalk width.

The presence of physical barriers and buffers provides an additional level of safety to the pedestrian and therefore improves pedestrian quality of service. Vertical grade separation (including curb), the width of the buffer, presence of closely spaced barriers (such as trees) and the presence of on-street parking spaces are the significant factors included. The volume of traffic using the lane closest to the pedestrian has a direct impact on the quality of service experienced by the pedestrian. As traffic volumes and speed increase in this outside lane, the pedestrians feeling of safety decreases. The effect of motor vehicle speed in the outside lane is especially significant when those vehicles are trucks or heavy vehicles. Therefore the proportion of heavy vehicles is a significant consideration in this fourth factor.

The frequency of curb cuts was initially considered as a factor in pedestrian level of service determination, but was found to be not significant at the 95th percent confidence interval. This factor was therefore not included in the pedestrian quality of service determination.

A large number of additional factors can be considered to impact pedestrians. These relate to security, safety, convenience and comfort factors. The SCI quality of service construct, at this time, addresses only the pedestrian-motor vehicle interaction safety factor. Examples of other factors that may have significance for pedestrians who access transit are:

- opportunities for crossing,
- percentage of sidewalk coverage,

- sidewalk connection to transit stop, and
- sidewalk condition.

A best fit regression analysis of the five primary factors (lateral separation, physical barriers/buffers, motorized vehicle volumes and types, and speed) results in a Roadside Pedestrian Conditions (RPC) algorithm. The application of this algorithm along any roadway segment gives an RPC score which can be compared against threshold values to assess level of service.

The pedestrian level of service of a roadway segment should be used as one of the primary factors in the transit level of service determination procedure.

DATA AVAILABILITY

Table 3 summarizes the data available from the Gainesville and Orlando MPO's for use in a transit quality of service construct. Gainesville was chosen to represent a small/medium transit system and Orlando was chosen to represent a large transit system. It is assumed that similar data will be available from other MPO's in Florida. Data availability is inventoried so that the transit quality of service construct is based on data that an MPO is likely to have.

Table 3: Data Availability

Performance Measure	**Data Item**	**Available at Route Level?**	
		Gainesville	**Orlando**
Hours of Service and Frequency	Headways or Frequency	8	8
	Service Hours/Span of Service	8	8
	Time Points from Schedule	8	8
	Proposed Frequency	8	8
	Proposed Service Hours	8	8

Table 3 (continued): Data Availability

Performance Measure	**Data Item**	**Available at Route Level?**	
		Gainesville	**Orlando**
Accessibility	Location of Park and Ride Lots and Transit Centers	8	8
	Bus Routes	8	8
	Map of Activity Centers	8	8
	Bicycle and Pedestrian facilities identified	8	8
	Population and Employment by TAZ	8	8
	Presence of Sidewalk	8	8
	Continuity of Sidewalk	8	8
	Width of Sidewalk		8
	Sidewalk Condition		8
	Presence of Bus Stop/Bus Stop Inventory	8	8
	Presence of Sidewalk to Bus Stop Connection	8	8
Reliability	On-Time Performance	8	8
	Headway Adherence	8	8
Travel Speed	Route Length	8	8
	Round Trip Bus Running Time	8	8
Transit/Auto Travel Time	Round Trip Bus Running Time	8	8

Table 3 (continued): Data Availability

Performance Measure	Data Item	Available at Route Level?	
		Gainesville	Orlando
Other	Average Number of Passengers	8	8
	Percent Occupancy on Board Bus	8	8
	Posted Speed	8	8
	Number of Lanes	8	8
	Presence of Median	8	8
	Availability of On-Street Parking	8	8
	Presence of Curb	8	8
	Presence of Bike Lane	8	8
	Presence of Obstacles in Sidewalk		8
	Presence of Crosswalks		8
	Presence of Pedestrian Signal	8	8
	Presence of Trees within ROW and less than or equal to 50 feet apart		8
	Presence of Sidewalk Buffer		8
	Presence of Street Lighting	8	8
	Presence of Bus Shelter	8	8
	Bus Fare Information	8	8
	Average Daily Ridership	8	8

TRANSIT QUALITY OF SERVICE – "CONCEPTUAL" LEVEL OF ANALYSIS

It is beneficial to have a range of methods to determine quality of service such that a more detailed analysis would require a more definitive method of determining quality of service while a rough estimate would require a simple back of the envelope type of computation or table look- up. The simplest method available to planners for determination of automobile quality of service is the generalized tables in the 1998 Florida Level of Service Handbook. Similarly, for transit quality of service, a simple look-up table is envisioned. For detailed operational level transit quality of service determination, the TLOS method is the appropriate one. A method that will provide a better measure of quality of service than the simple generalized table while not requiring the computational detail of the operational level TLOS method is presented here as a "conceptual" level of analysis method. The conceptual level of analysis requires more information than that required for the generalized table look-up but is simpler to compute (can be implemented through a spreadsheet) than the TLOS method. The "conceptual" level of analysis is envisioned as the preferred analysis tool at the planning level while the TLOS software is the preferred analysis tool at the operational level. This section addresses the proposed conceptual planning level analysis method for determining quality of service.

Bicycle accessibility to transit routes is not considered in this analysis. Transit buses can typically carry not more than two bicycles at any one time. This limitation implies that the number of transit passengers who access the transit vehicle by bicycle is very small when compared to the total number of persons who access transit by walking. Similarly, since most bus stops do not include park-n-ride facilities, automobile access to transit stops is also not considered. Walk access is the primary mode of access to transit stops. Therefore, pedestrian level of service will be used to describe access to transit for the Transit Quality of Service determination.

Consideration of Factors

The Transit Level of Service (TLOS) indicator project completed by the FDOT includes the consideration of the following six factors:

1. Transit Service Coverage - Areawide
2. Transit Service Frequency
3. Hours of Transit Service
4. The Availability of Pedestrian Routes (Sidewalks)
5. Population Density
6. Job (Employment) Density.

The factor “transit service coverage” is more relevant to a system wide assessment of transit level of service. The focus here is on bus route segment level of service. Therefore, the “service coverage” factor is not considered. The proposed methodology for developing generalized tables for transit level of service uses “service frequency” and “presence of sidewalks.” The proposed “conceptual” methodology for a planning level analysis for transit (similar to ART-PLAN for automobiles) includes service frequency, pedestrian access to transit (pedestrian level of service, pedestrian crossing difficulty, and sidewalk connections to transit stop), and also the hours of service factor (for quality of service on a daily basis). The pedestrian access to transit assessment is enhanced beyond that which is used for TLOS by considering pedestrian level of service. The “hours of service” factor will be used for a daily assessment of quality of service.

At this time, the factors related to population and job density will not be considered. In the detailed operational TLOS analysis, density is used only in calculating a system TLOS value by weighting the TLOS of a given area by the number of people/jobs in that area. Population and job density information is data intensive and will likely require a GIS-based assessment. While density can be used where and when GIS is available, and in completing a detailed operational analysis (TLOS), it is omitted from consideration in this initial planning level analysis construct. The omission of the population and job density factor is consistent with the concept that a planning level analysis method is less detailed than the operational level TLOS method.

Additional factors considered in determining transit level of service at a route segment level could include:

- bus stop spacing,
- street density,
- bus stop amenities, and
- ADA compliance.

Both the bus stop spacing factor and street density factor address service accessibility. Access opportunities to transit from the area surrounding the corridor will be the greater of the bus stop spacing or the street spacing. In the case of bus stops, access to bus stops is improved with the provision of additional bus stops. The provision of closely spaced bus stops is however, detrimental to efficient bus service and travel time. Further, if the number of bus stops along a route is considered a factor in determining level of service, one could potentially (or theoretically) improve level of service (albeit to a small extent) through the provision of additional unnecessary bus stops. In order to remove this possibility, the number of bus stops along a route is not used as a factor. Additionally, access to bus service is being measured by the presence and quality of pedestrian routes - pedestrian environment.

In the case of street density, it is possible that a more street dense area provides for greater number of pedestrian routes to get to the bus stop. This assumes that the transit customers are uniformly spread over the street network. It is however, possible that the majority of transit customers are served through a small number of pedestrian corridors independent of the street density. Additionally, the presence of sidewalks and of a pedestrian friendly corridor is likely more significant than street density. Street density is therefore not considered as a factor in the planning-level analysis. The pedestrian environment (instead of street density) which is a significant factor to transit level of service, captures bus accessibility.

Presence of bus stop amenities such as shelters, benches and transit stop signs are quality of service measures that are more relevant to an assessment of transit stops (where a “point” is the relevant analysis unit). Bus stop amenities are therefore not considered in the route segment level of service determination.

If a bus stop is not served by buses and bus stops that are ADA compliant, it impacts the quality of service assessment for bus stops negatively. This factor, like the amenities factor is not considered for the route segment assessment of level of service as it pertains more to the bus stop than to the route segment.

Bicycle access to transit is not considered in this initial methodology since bicycle access to transit is in smaller numbers than pedestrian access to transit. Most buses carry racks for two bicycles and most bus stops do not have bicycle racks. This limited capability to cater to bicycle access to transit limits the number of transit riders that access transit on bicycles. A future enhancement could include the consideration of bicycle level of service as a factor in transit level of service.

Pedestrian Environment

The “availability of pedestrian routes” factor can be defined in additional detail. This factor can be defined through the all or nothing, “Yes” or “No” (or a percent sidewalk coverage) differentiation proposed in the generalized tables. A more detailed definition of the pedestrian environment is proposed here:

1. What is the pedestrian level of service along the facility?
2. Are there sidewalk connections to the transit stops? (defined by a paved sidewalk connection to the transit stops on the facility), and
3. How easy is it for a pedestrian to cross the facility? (defined by presence of crosswalks and presence of pedestrian signals at signalized intersections or through an index).

The pedestrian level of service along a facility is computed in the pedestrian quality of service module as summarized in Section 3: Pedestrian Mode - Quality of Service Construct. This pedestrian level of service can be directly used as an input to transit quality of service. The pedestrian level of service is the most significant factor (outside of transit specific factors) in transit quality of service.

The presence of a sidewalk and the pedestrian level of service do not tell us if a pedestrian has an adequate paved pathway to access the transit stop from the sidewalk. The sidewalk may be separated from the transit stop by a gully, swale, fence or other feature which prevents the pedestrian from reaching the transit stop easily. The explicit inclusion of this paved connection to the transit stop addresses directly the ease of pedestrian access to transit.

A transit rider may access the transit stop from either side of the street depending on the location of the riders origin or destination. The ease of crossing the street is therefore an important consideration for transit riders. It can be assumed that the easiest location to cross the street is at a signalized intersection with pedestrian features. The spacing of signalized intersections is therefore a factor in crossing difficulty. Additionally, the number of lanes of traffic that one has to cross and the volume of traffic on the facility are considerations in crossing difficulty. A simplistic method to determine crossing difficulty is an important input to transit quality of service.

Pedestrian routes to transit stops along cross streets is not considered a primary focus in transit quality of service along a facility. Consideration of cross-street access is addressed at the operational level in TLOS.

Reliability of Service

Reliability of service is a measure of comfort and convenience of service along a bus route. This measure has a significant effect on choice riders. Choice riders elect to ride transit from among multiple modes of travel available to them. Reliable service attracts choice riders to the transit mode. Reliability encompasses both on-time performance and headway regularity. On-time performance is the most widely used measure of transit reliability. Headway adherence becomes important when vehicles run at frequent intervals and the possibility of vehicles arriving in bunches increases. On-time performance is a measure of reliability for bus routes which have frequencies less than six vehicles per hour. Headway adherence is the service measure for bus routes that have a frequency of six vehicles or greater per hour. A transit vehicle (fixed-route service) can be defined as being late when it is more than five minutes behind schedule. Early departures are not considered on-time. These measures are the TCQSM measures for reliability of service.

Reliability was initially considered as an input to the planning "conceptual" level analysis methodology. It is recommended that reliability be considered as a possible enhancement to the method only after further research is completed to assess the value an average transit rider would give "reliability" in his or her assessment of quality of service.

RECOMMENDED METHODOLOGY - "BUS-LOS"

The relevant time period for the transit quality of service assessment on a bus route segment is an hour, frequently a peak hour. Additionally, the relevant unit under analysis is defined as a segment of a street, which accommodates one or more bus routes, within which the frequency of bus service is the same. As an example, say State Road 7 between Sheridan Street and Miramar Parkway (in Broward County, Florida and approximately 3 miles in length) is taken for analysis. On this corridor, bus routes 18, 3, 7 and 5 operate during the peak hour. The route segments under analysis are depicted in Table 4:

Table 4: Example of Transit Segment Definition

End points	Bus Routes	Frequency of Bus Service during peak hour
Sheridan St. to Taft St.	18	3 per hour
Taft St. to Hollywood Blvd.	18 and 3	4 per hour
Hollywood Blvd. to Pembroke Rd.	18, 5 and 7	7 per hour
Pembroke Rd. to Miramar Pkwy.	18 and 7	6 per hour

Example Application of the Methodology

The methodology for determining transit LOS for each route segment on an hourly basis would be:

1. Identify location and length of the facility for analysis.

   As an example, Main Street in Gainesville, Florida; between North 8th Avenue and N 23rd Avenue is identified as a facility of interest. The length of this facility is 1.07 miles.

2. Divide the facility into route segments (consistent with the segments used for the automobile mode in ART-PLAN).

   Our example of Main Street in Gainesville is divided into three route segments defined by the locations of signalized intersections. The route segments on Main Street are:

   Route Segment 1: N 8th Avenue to N 10th Avenue
   Route Segment 2: N 10th Avenue to N 16th Avenue, and
   Route Segment 3: N 16th Avenue to N 23rd Avenue.

   It should be noted that defining route segments to be between signalized intersections is consistent with the definition of roadway segments when determining automobile level of service in ART-PLAN.

3. Determine transit frequency for each route segment.

   In the case of our example facility, Main Street is served by one transit route - transit route number 15 on all three route segments. Transit Route 15 provides service on all three route segments of Main Street at <u>one bus per hour</u> frequency.

4. Determine impact of pedestrian environment.

- Pedestrian LOS

  The pedestrian LOS is available from the PED_LOS computation and should be used as an input. For <u>illustrative</u> purposes, the following pedestrian levels of service are assumed.

  Route Segment 1: (N 8th Avenue to N 10th Avenue) Pedestrian LOS = B
  Route Segment 2: (N 10th Avenue to N 16th Avenue) Pedestrian LOS = E, and Route Segment 3: (N 16th Avenue to N 23rd Avenue)Pedestrian LOS = A.

  Table 5 provides the impact of pedestrian LOS on transit frequency by providing an adjustment factors for given pedestrian LOS.

Table 5: Pedestrian Environment Impact on Transit Quality of Service

Pedestrian LOS:

Pedestrian LOS A	=	1.15
Pedestrian LOS B	=	1.10
Pedestrian LOS C	=	1.00
Pedestrian LOS D	=	0.90
Pedestrian LOS E	=	0.75
Pedestrian LOS F	=	0.55

The adjustment factor for pedestrian level of service would be:
Route Segment 1: Adjustment factor for Pedestrian LOS B = 1.10
Route Segment 2: Adjustment factor for Pedestrian LOS E = 0.75, and
Route Segment 3: Adjustment factor for Pedestrian LOS A = 1.15.

The "adjusted" frequency of bus service on all three route segments of Main Street is:
Route Segment 1: Adjusted frequency = 1 * 1.10 = 1.10
Route Segment 2: Adjusted frequency = 1 * 0.75 = 0.75, and
Route Segment 3: Adjusted frequency = 1 * 1.15 = 1.15 buses per hour.

- Connections to transit stop (paved connection from sidewalk to transit stop)

  In our example Main Street facility in Gainesville, Florida; paved connections from the sidewalk to the transit stop can (in general or more than half the time) be found on route segment 3 - between N 16th Avenue and N 23rd Avenue. Paved sidewalk connections can not be (in general) found between N 8th Avenue and N 16th Avenue. The adjustment factors for sidewalk connections to the transit stop are:

  Paved connection provided between sidewalk and bus stop = **1.05**
  No paved connection exists between sidewalk and bus stop = **0.90**
  Default value (if information is not available or unknown) = 1.00

Route segments between N 8th Avenue and N 16th Avenue are therefore adjusted by 0.90 while the third route segment between N 16th Avenue and N 13th Avenue is adjusted by 1.05.

The frequency of service previously adjusted for pedestrian level of service is now adjusted for sidewalk connections to the transit stop. The "adjusted" frequency of bus service is therefore:

Route Segment 1: Adjusted frequency = 1.10 * 0.90 = 0.99
Route Segment 2: Adjusted frequency = 0.75 * 0.90 = 0.675, and
Route Segment 3: Adjusted frequency = 1.15 * 1.05 = 1.2075 buses per hour.

- Crossing Difficulty (based on Arterial Class, number of lanes to be crossed, and automobile level of service)
- Crossing difficulty is proportional to traffic volumes and crossing length; and indirectly proportional to the number of signalized intersections per mile.

Traffic Volumes: Crossing difficulty is understood to be directly proportional to traffic volumes on the street but the specific relationship between crossing difficulty and traffic volumes is not defined. It is more difficult to cross a busy street as against a street that has low traffic volumes. A surrogate for traffic volumes could be automobile level of service. As traffic volumes increase on a road, the quality of service perceived by a motorist on that road becomes worse. (See Section 1 discussion on page 2). Automobile level of service can then be used as a measure of how busy or congested a given roadway is, and as a surrogate for traffic volumes in the determination of crossing difficulty. While the relationship between arterial quality of service and crossing difficulty is also not defined, the relationship is easier to comprehend and define. As an example, it is easy to understand that a road that operates at automobile level of service A usually has lower volumes and will therefore be easier to cross than the same road if it operates at automobile level of service E, and is therefore more difficult to cross.

Crossing Length: A road that has more number of lanes is more intimidating to cross than one that has a fewer number of lanes. Crossing of a six or eight lane road is substantially more difficult than crossing a two lane (or even a four lane divided) road. Crossing difficulty is therefore directly proportional to crossing length (defined by number of lanes). The specific relationship however, is not defined.

Signalized Intersections per mile: Signalized intersections provide pedestrians the opportunity to cross a road at a defined spot with conflicting vehicular traffic at a standstill. The fewer the number of signalized intersections, more difficult it is to cross a road. Arterial classification provides a method to group roads based on signal density (signalized intersections per mile) and area type. It will be easier to cross a road that is a Class III or Class IV road (more than 4.5 signals per mile) than it will be to cross a Class I road (less than 2 signals per mile).

It should be noted that all three variables used in the determination of the crossing difficulty are available from ART-PLAN. Arterial class and number of lanes are roadway characteristics input used in ART-PLAN. Automobile level of service is an output from ART-PLAN. Since automobile level of service, an output from ART-PLAN, is a required input to crossing difficulty in BUS-LOS, ART-PLAN will have to be completed before BUS-LOS can be determined. The following are the recommended crossing difficulty factors based on Arterial Class, number of lanes to be crossed, and automobile level of service

Table 6: Crossing Difficulty Factors

Conditions that must be met:				Crossing Difficulty Factor
Arterial Class	Median Type	Number of through Lanes	Automobile LOS	
I	R, NR, None	2	A or B	1.05
II	R, NR, None	2	A, B or C	
III	R, NR, None	[4	A or B	
IV	R, NR, None	[4	All levels of service	
I	NR and None	m 4	B, C, D, E or F	0.80
	Restrictive	m 8	All levels of service	
II	NR and None	m 4	C, D, E or F	
	Restrictive	m 8	All levels of service	
III	NR and None	m 4	D, E, or F	
	Restrictive	m 8	All levels of service	
All cases not included in conditions for factor 1.05 and 0.80 =				1

Note: Median type; R = Restrictive, NR = Non-Restrictive, None = No median

For the example facility of Main Street:

Arterial class can be determined from signal density. There are three traffic signals along a length of 1.07 miles; a signal density of 2.8 signals per mile. Main Street is therefore a Arterial Class II facility between North 8th Avenue and North 23rd Avenue.

Main Street is a four lane undivided facility on all three route segments. There is no median.

Automobile level of service for the facility is assumed (for illustrative purposes) to be LOS "D".

From Table 6, for the above listed conditions, the crossing difficulty factor for Main Street between North 8th Avenue and North 23rd Avenue is found to be 0.80.

The frequency of service previously adjusted for pedestrian level of service and sidewalk connections is further adjusted for crossing difficulty. The “adjusted” frequency of bus service is therefore:
Route Segment 1: Adjusted frequency = 0.99 * 0.80 = 0.792
Route Segment 2: Adjusted frequency = 0.675 * 0.80 = 0.54, and
Route Segment 3: Adjusted frequency = 1.2075 * 0.80 = 0.966 buses per hour.

5. Assess transit level of service.

Transit level of service for a given hour of analysis is assessed by comparing the adjusted frequency of service to the values in Table 7.

Route Segment 1: Adjusted frequency of 0.792 = LOS F
Route Segment 2: Adjusted frequency of 0.54 = LOS F, and
Route Segment 3: Adjusted frequency of 0.966 = LOS F (see Table 7).

The impact of pedestrian access to transit has resulted in a different level of service determination on all three segments as compared to that which would have been reached if no adjustments were made. If no adjustments were made for pedestrian access, the TCQSM based level of service would result in LOS E since service frequency is one bus per hour on all three route segments.

Table 7: Level of Service for Transit Users - Hourly Analysis

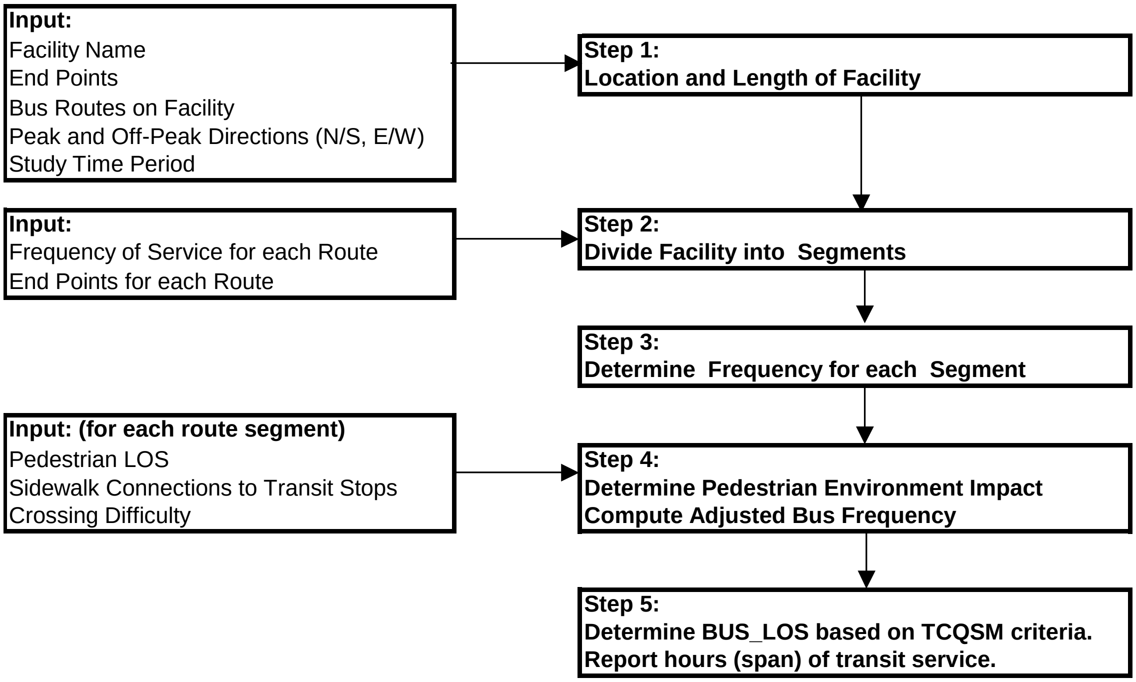
Level of Service	Adjusted Service Frequency (Vehicles/hour)	Headway (minutes)	Comments
A	**>6.0**	**<10**	**Passengers don’t need schedules**
B	**4.01 to 6.0**	**10 to 14**	**Frequent service, passengers consult schedules**
C	**3.0 to 4.0**	**15 to 20**	**Maximum desirable time to wait if transit vehicle missed.**
D	**2.0 to 2.99**	**21 to 30**	**Service unattractive to choice riders**
E	**1.0 to 1.99**	**31 to 60**	**Service available during hour**
F	**<1.0**	**>60**	**Service unattractive to all riders**

6. Note span of service for facility.

The span of service on Main Street during the weekday is 7:00 to 18:00 in the northbound direction and 6:30 to 18:30 in the southbound direction. The span of service information informs the reader about the time duration within which some transit service is available on the facility. The span of service should be noted in the report of an hourly level of service.

The flow chart depicted in Figure 2 summarizes the methodology to be used in the transit level of service determination. The quality of service during any hour can be ascertained through this methodology. For multi-modal comparison purposes, a common hour should be used for all modes.

Figure 2: Transit LOS Methodology Flow Chart



ASSESSMENT OF TRANSIT LOS ON A DAILY BASIS

For a daily level of service determination the procedure is similar except that span of service is also a determinant of the quality of service a user experiences along the facility. The methodology, therefore, introduces an adjustment factor to account for span of service. These adjustment factors are tabulated in Table 8.

The methodology for determining transit LOS for each route segment on a daily basis is presented below. This methodology is the same as that for an hourly with the additional step to account for span of service. The additional step is italicized:

1. Identify location and length of the facility for analysis.
2. Divide the facility into route segments (consistent with the segments used for the automobile mode in ART-PLAN).
3. Determine transit frequency for each route segment.
4. Determine the impact of span of service (Table 8)
5. Determine impact of pedestrian environment.
   - Pedestrian LOS
   - Sidewalk connections to transit stop (paved connection from sidewalk to transit stop)
   - Crossing Difficulty
6. Assess transit level of service.

Table 8: Impact of Span of Service - Daily Analysis

Hours of Service per Day	Service Frequency Adjustment Factor	Comments
19-24	1.15	Night or owl service provided
17-18	1.05	Late evening service provided
14-16	1	Early evening service provided
12-13	0.9	Daytime service provided

4-11	0.75	Peak hour service/limited mid-day service
0-3	0.55	Very limited or no service

In the example of Main Street in Gainesville; the determination of a daily level-of-service would be as follows:

1. Location Main Street, Gainesville between N 8th Avenue and N 23rd Avenue
   Length = 1.07 miles

2. Route segments:
   Route Segment 1: N 8th Avenue to N 10th Avenue
   Route Segment 2: N 10th Avenue to N 16th Avenue, and
   Route Segment 3: N 16th Avenue to N 23rd Avenue.

3. Transit Frequency for each Route Segment:
   Route Segment 1: N 8th Avenue to N 10th Avenue = 1 bus per hour
   Route Segment 2: N 10th Avenue to N 16th Avenue, = 1 bus per hour, and
   Route Segment 3: N 16th Avenue to N 23rd Avenue = 1 bus per hour.

4. Impact of Hours of Service:
   Span of Service = 11 hours in northbound direction
   = 12 hours in southbound direction
   From Table 8: Adjustment factor = 0.75 in northbound direction, and
   = 0.90 in southbound direction.
   Frequency adjusted for span of service = 0.75 in northbound direction,

   = 0.90 in southbound direction.

5. Adjustment for pedestrian environment:

   Pedestrian LOS: Route Segment 1 (Pedestrian LOS B) = 1.10
   Route Segment 2 (Pedestrian LOS E) = 0.75
   Route Segment 3 (Pedestrian LOS A) = 1.15

   Paved connection to bus stop: Route Segment 1 = 0.90
   Route Segment 2 = 0.90
   Route Segment 3 = 1.05

   Crossing Difficulty factor: = 0.80

Therefore, frequency adjusted for pedestrian environment:

Route Segment 1 Northbound = 0.75 * 1.10 * 0.90 * 0.80 = 0.59
Route Segment 1 Southbound = 0.90 * 1.10 * 0.90 * 0.80 = 0.71

Route Segment 2 Northbound = 0.75 * 0.75 * 0.90 * 0.80 = 0.40
Route Segment 2 Southbound = 0.90 * 0.75 * 0.90 * 0.80 = 0.49

Route Segment 3 Northbound = 0.75 * 1.15 * 1.05 * 0.80 = 0.72
Route Segment 3 Southbound = 0.90 * 1.15 * 1.05 * 0.80 = 0.87

6. Assess Level of Service:
From Table 7: Level of service for all analyzed segments of Main Street
Route Segment 1: Northbound adjusted service frequency of 0.59 = LOS F
Southbound adjusted service frequency of 0.71 = LOS F

Route Segment 2: Northbound adjusted service frequency of 0.40 = LOS F
Southbound adjusted service frequency of 0.49 = LOS F

Route Segment 3: Northbound adjusted service frequency of 0.90 = LOS F
Southbound adjusted service frequency of 1.09 = LOS F

SUMMARY

The methodology described in Section 5 of this memorandum provides a recommended planning method for the determination of quality of service for scheduled bus service on route segments. The methodology is a tool that will assist planners in Florida complete multi-modal quality of service evaluations. Table 9 summarizes the variables used in the determination of the transit level of service.

Following additional research regarding user sensitivity to each of the variables, the adjustment factors should be updated to make the results of the method more meaningful (or relevant) to transit users. As an example, the crossing difficulty adjustment factor can be replaced by a continuous function in the future after appropriate research has been completed.

Table 9: Transit Level of Service Variables

Type	Variable	Comments
Transit Availability	Service Frequency	Required input in buses per hour.
	Hours of Service	Required input for a daily analysis of a facility.
Pedestrian Accessibility	Pedestrian LOS	From pedestrian LOS module.
	Sidewalk Connection to Transit Stop	Required input.
	Crossing Difficulty	Computed from information provided in automobile LOS module.
Roadway Impacts	Presence of Bus Bays	This input impacts automobile LOS but not transit LOS.

Notes: Hours of service is used in a daily analysis of transit level of service but is not required in an hourly analysis.
Roadway impacts refer to the impact that the presence of bus bays would have on automobile level of service.

Impact of Bus Bays on Automobile LOS:

The provision of bus bays at bus stops allows passengers to enter and exit transit vehicles (buses) outside of the stream of traffic on the roadway. If a bus bay is not provided, the curb lane is not available for use by traffic while passengers are boarding and alighting the stopped transit vehicle. When bus bays are provided, Florida law requires vehicles in the curb lane to stop and yield to buses pulling out of the bus bay. This disruption of traffic however, will be shorter than the disruption caused when there is no bus bay. The provision of bus bays therefore, has a positive effect on traffic as it removes the stopped vehicle from the stream of traffic. The absence of bus bays results in decreased roadway saturation flow rate when a bus is stopped at a bus stop.

The impact of the absence of a bus bay is similar to the provision of a traffic control device (such as a traffic signal) for the curb lane of traffic. The traffic signal analogy can be considered in quantifying the impact. The cycle length of the signal would be the headway between buses that use the facility. The curb lane has the green indication when no buses are stopped at the bus stop. When a bus stops at the bus stop, the curb lane has the red indication and one lane of the roadway is effectively unavailable to traffic (and traffic will queue behind the bus). The indication turns green when the bus leaves the bus stop.

The impact of bus bays is determined as follows:

Assume ten (10) minutes bus headway along the facility, and time taken to decelerate/stop/alight/board passengers and accelerate (clearance) is 15 seconds. This accounts for an average of two persons who board or alight the bus at a stop.

Cycle length is 600 seconds.

Assuming an additional lost time of two seconds;

Green time to Cycle length ratio (g/C) for curb lane is 583/600 = 0.972 OR

curb lane is not available to traffic for 2.8 percent of the time.

For a two lane roadway with a single lane in each direction; the roadway saturation flow rate is reduced by 2.8 percent. For a four lane roadway with two lanes in each direction the reduction in saturation flow rate would be 1.4 percent, and for three lanes in each direction the reduction would be 0.9 percent.

The following table provides a matrix of bus bay impact on roadway saturation flow rate.

Table 10: Reduction in Saturation Flow Rate due to absence of Bus Bays

No. of lanes in each direction of travel (unadjusted sat. flow rate)	Adjusted Saturation Flow Rate as a percent reduction and the resulting adjusted saturation flow rate in vphpl.					
	Headway 8 min.	Headway 10 min.	Headway 15 min.	Headway 20 min.	Headway 30 min.	Headway 60 min.
One lane (1850)	-3.5% 1785	-2.8% 1798	-1.9% 1815	-1.4 % 1824	-0.9% 1832	-0.5% 1841
Two lanes (1850)	-1.8% 1817	-1.4% 1824	-0.9% 1833	-0.7% 1837	-0.5% 1841	-0.2% 1846
Three lanes (1850)	-1.2% 1828	-0.9% 1834	-0.6% 1839	-0.5% 1841	-0.3% 1844	-0.2% 1847
Four lanes (1700)	-0.9% 1685	-0.7% 1689	-0.5% 1692	-0.4% 1694	-0.2% 1696	-0.1% 1698

Note: Saturation flow rate adjusted for bus bays is based on an unadjusted saturation flow rate of 1850vphpl for up to (and including) three lanes in each direction and a saturation flow rate of 1700vphpl for four lanes in each direction.

As is evident from Table 10, the impact of the absence of bus bays on a facility is minimal in most cases. At a planning level, the impact of bus bays is not significant. In cases where bus bay impact may be of concern; where bus frequency is at least one bus every 10 minutes and number of lanes in each direction is two or less, an operational level Highway Capacity Analysis should be completed. It is recommended that the impact of bus bays is not included in the ART-PLAN methodology due to its minor impact.

SECTION 6

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