6-2015

Development of Public Transit II Course

CUTR

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Development of Public Transit II Course

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16. Abstract

A new course, Public Transit II, was developed and offered spring 2015 as part of NDSU's Transportation and Logistics program. This class expanded upon TL 786, the public transportation class currently offered at NDSU, by going more in-depth in some topics and covering more advanced areas including modeling, economics, and engineering.

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Disclaimer

Acknowledgment

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SYLLABUS

TL 787 Public Transportation II: 3 Credits

Instructors and contact information

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Course description

This course focuses on concepts and modeling procedures used when planning and operating public transportation systems. Topics covered include transit demand analysis, quality of service concepts and estimation, bus and rail capacity, and service planning.

Course objectives

The objective of this course is to provide the student with an understanding of models used when planning and operating public transportation systems. Students will learn methods for estimating transit demand, quality of service, and capacity, as well as tools for designing service. Students will learn the modeling techniques and how to apply them to real-world scenarios.

Prerequisite

TL 786 – Special allowances can be made for those with a background in public transportation who have not taken TL 786.

Evaluation procedures and criteria

Grades will be based on the following:

Homework assignments	25 percent
Online discussions / class participation	10 percent
Exams	30 percent
Final paper / project	35 percent

The following scale will be used to assign letter grades.

Numerical Score	Letter Grade
90 – 100	A
80 – 89	B
70 – 79	C
60 – 69	D
Below 60	F

Homework: Students will be given weekly homework assignments, which will consist of problems or short essay questions. Assignments are due at the start of class on the date indicated, and the solutions will be discussed in class.

Exams: Exams are expected to be a combination of problems and essay questions.

Final paper/project: Students will be assigned a class project to be due by the end of the semester. At the end of the semester, students will make a presentation reporting their project. More details will be given to students early in the semester.

Attendance

According to NDSU Policy 333, attendance in classes is expected. Class attendance is not a direct component of the course grade, but participation in class and online discussion boards accounts for 10% of the grade. Students unable to participate in class are expected to make up for it by participating in the online discussion boards. If you cannot attend a class, it is a courtesy to inform your instructor in advance if possible. Late assignments will have an automatic 10% deducted.

Course schedule / calendar of events

Week	Topic	References
Jan 11-15	Introduction, Mode and Service Concepts	TCQSM Chapters 2
Jan 18-22	Operations Concepts	TCQSM Chapter 3
Jan 25-29	Transit Operations and Service Scheduling	Vuchic Chapter 1
Feb 1-5	Demand Analysis	Balcombe Chapters 3 & 5, Ceder Chapter 11; TCRP 161
Feb 8-12	Quality of Service: Concepts and Methods	TCQSM Chapters 4, 5
Feb 15-19	Bus Transit Capacity	TCQSM Chapter 6
Feb 22-26	Bus Transit Capacity	TCQSM Chapter 6
Feb 29-Mar 4	Demand Response Transit Capacity	TCQSM Chapter 7
Mar 7-9	Mid-term exam (No lecture)	
Mar 14-18	No Class – NDSU Spring Break	
Mar 21-25	Rail Transit Capacity	TCQSM Chapter 8
Mar 28-Apr 1	Railroad Engineering	AREMA Material
Apr 4-8	Service Planning	Vuchic Chapter 4
Apr 11-15	Transit Service Planning Issues	Walker – Human Transit
Apr 18-22	Transit Financing, Transit Surveys	Innovative Funding Sources for Transit, Kockelman et al., TCRP 63
Apr 25-29	Presentations	
May 2-6	No class	
May 9-13	Final exam, class project due	

Required student resources

Students must have access to a computer and the internet. The instructor's lecture notes will be made available. Additional references will be identified on the web.

No textbook is required for this course - handouts will be made available. The following resources are available online or will be provided to students.

- Transit Capacity and Quality of Service Manual (TCQSM), Third Edition. TCRP Report 165. Transit Cooperative Research Program, Washington, DC: Transportation Research Board, 2013. http://www.trb.org/main/blurbs/169437.aspx

- Vuchic, V. Urban Transit: Operations, Planning and Economics. John Wiley and Sons, New Jersey. (2005)

- Balcombe et al. The Demand for Public Transit: A Practical Guide. TRL 2004.

- Innovative Funding Sources for Transit, September 2012.

- TCRP Report 161. Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation: Final Workbook. Transit Cooperative Research Program, Washington, DC: Transportation Research Board, 2013. http://www.trb.org/Main/Blurbs/168758.aspx

- TCRP Synthesis 63. On-Board and Intercept Transit Survey Techniques. Transit Cooperative Research Program, Washington, DC: Transportation Research Board, 2002. http://www.trb.org/Main/Blurbs/156542.aspx

- TCRP Synthesis 69. Web-Based Survey Techniques: A Synthesis of Transit Practice, Transit Cooperative Research Program, Washington, DC: Transportation Research Board, 2006. www.**tcrp**online.org/PDFDocuments/tsyn69.pdf

Optional Reading

- Ceder, A. Public Transit Planning and Operation: Theory, Modeling and Practice (Second Edition) Butterworth-Heinemann. (2014)

- Litman, Todd. 2004. "Transit Price Elasticities and Cross-Elasticities," *Journal of Public Transportation* 7(2):37-58.

- Litman, Todd. (2009). Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Second Edition. Victoria Transport Policy Institute. http://www.vtpi.org/tca/

- Walker, Jarrett. *Human Transit: How Clearer Thinking about Public Transit Can Enrich Our Communities and Our Lives.* Washington, DC: Island Press, 2012

Disability statement

Any students with disabilities or other special needs, who need special accommodations in this course are invited to share these concerns or requests with the instructor and contact the Disability Services Office as soon as possible.

Academic honesty statement

The academic community is operated on the basis of honesty, integrity, and fair play. NDSU Policy 335: Code of Academic Responsibility and Conduct applies to cases in which cheating, plagiarism, or other academic misconduct have occurred in an instructional context. Students found guilty of academic misconduct are subject to penalties, up to and possibly including suspension and/or expulsion. Student academic misconduct records are maintained by the Office of Registration and Records. Informational resources about academic honesty for students and instructional staff members can be found at ***www.ndsu.edu/academichonesty***

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LECTURE NOTES

Topics

Transit Modes → Operating Environments → Service Patterns

Transit Modes

- Bus
  - Most common – accounted for 52% of all U.S. transit trips in 2011

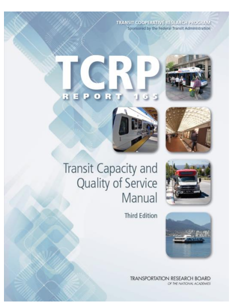
- Demand-Response

- Vanpool

- Rail

- Ferry

MODE AND SERVICE CONCEPTS



Transit Capacity and Quality of Service Manual, 3rd Edition: Chapter 2

Transit Modes

- Bus
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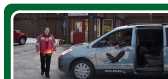
- Demand-Response



- Vanpool

- Rail

- Ferry

Bus Transit

Acceleration characteristics impacted by:
- Vehicle size
- Power source

Number of seats on bus impacted by:
- Low floor (partial or 100%) vs. high floor
- Seat orientation (facing forward, facing aisle, facing each other)
- Seat pitch (distance between seats)
- Number and width of doors
- Accommodations for strollers, bicycles, luggage, etc.

Low-floor buses are predominant type
- Lack of steps speeds up passenger boarding and alighting process
- Low-floor buses have fewer seats than high-floor buses of comparable length

(e) Motor (over-the-road) coach 	• Commuter bus service • Intercity passenger service • Heavier-duty bus for high-speed running • Can carry luggage or bicycles in compartments underneath bus	• Larger, more comfortable seats • May offer internet service, tray tables, overhead storage, and other amenities • Typically no standees allowed • High floor
(f) Special purpose bus 	• Custom designed for a particular application, for example: ○ Doors on both sides for BRT routes with center stations ○ Minimal seats for downtown circulator/distributor routes	• Doors on both sides provide operating flexibility • Replacing seats with standing area provides greater passenger capacity
(g) Double-deck bus 	• Similar capacity/headway reasons as articulated buses • Tall bus stands out • Tourist-oriented or high-volume routes	• Potentially longer boarding/alighting times due to stairs needed to access upper deck • Good views from upper deck • More capacity than a standard bus
(h) Replica trolley 	• Tourist-oriented circulator service • Special event service (e.g., city festival, county fair)	• Distinctive vehicle reassures passengers this is their bus • Increases transit service visibility • Seats may be less comfortable • High floor

Bus Transit

Vehicle types
- Articulated bus (60-foot)
- Standard bus (non-articulated, >35 seats)
- Small bus (25-35 seats)
- Minibus

Power source
- Diesel
- Natural gas
- Biodiesel
- Electric and hybrid
- Gasoline
- Other


Bus Type	Typical Applications	Capacity/Quality of Service Factors
(a) Standard low-floor 	• Typical local bus service	• Faster boarding times, particularly for mobility devices • Fewer seats than comparable high-floor bus • Prefer streets developed with curbs for ramp deployment
(b) Standard high-floor 	• Local bus service on streets without curbs or sidewalks • Routes requiring a little more capacity than what a low-floor bus offers	• Wheelchair lift works better than ramps in areas without curbs and sidewalks • Typically provides 3–5 more seats than a comparable low-floor bus • Longer boarding times (stairs)
(c) Community bus 	• Bus service on lower-volume routes • Bus service that operates on neighborhood streets with tight turning radii	• Can allow bus service to be provided in areas difficult to serve with a standard-size bus • Most or all passengers will be seated
(d) Articulated bus 	• Routes where added capacity is desired without adding more buses • Routes where reduced number of buses, but same capacity, is desired	• 50% more seats and standing capacity than standard bus • High or low floor • Reducing frequency may increase passenger service times and overall travel times

Transit Modes

Bus
- Most common – accounted for 52% of all U.S. transit trips in 2011

Demand-Response

Vanpool

Rail

Ferry

DRT and the ADA

- Americans with Disabilities Act (ADA) of 1990
- All transit vehicles used for fixed-route service must be accessible to people with disabilities
- ADA complementary paratransit is mandated for those who cannot use fixed-route service because of their disability
- Agencies that provide fixed-route service must provide paratransit that complements the fixed routes

Bus Submodes

Electric trolleybus	• Powered by electric current from overhead wires
Commuter bus	• Connects outlying areas to a limited number of central city stops
Bus rapid transit (BRT)	• Operated primarily on fixed guideways or as frequent service with high-quality transit stations, traffic signal priority or pre-emption, and level boarding.
Bus	• All other types of bus transit

Demand-Responsive Transit (DRT)

- Dial-A-Ride
- Flexible transit services
- Defining attributes
  - Trip reservation required
    - Book individual trips
    - Subscription service
  - Flexibility (not fixed-route and not fixed-schedule)
- Service differences between DRT
  - Degree of flexibility
  - Rider groups they serve
  - Operational and performance attributes

Types of DRT

- General public DRT
- Limited eligibility DRT
- ADA paratransit
- Human service transportation
- Jitney

Limited Eligibility DRT

- Operates similar to general public DRT except only defined rider groups are served, such as older adults and people with disabilities – may be referred to as specialized transportation
- May also restrict or prioritize trip purposes

Flexible Transit Services

- Combines attributes of fixed-route, fixed-schedule service and DRT
- Six types (TCRP Synthesis 53)
  - Demand-response connector service (feeder service)
  - Zone routes
  - Point deviation
  - Route deviation (flex route)
  - Flexible-route segments
  - Request stops

General Public DRT

- Flexibly-routed, shared-ride service that responds to requests from the general public
- Routing is typically "many-to-many" or "many-to-few"
- Scheduling policies vary
- Appropriate in low-density communities with geographic dispersion of trip generators or rural communities with limited demand for public transportation

Human Service Transportation

- Shared-ride, advance-scheduled transportation for users and clients of human service programs
- An ancillary service provided by many human service agencies
- Agencies may
  - Purchase transportation services from providers
  - Directly transport their own clients
  - Facilitate their clients’ use of public transportation
- More than 60 different federal programs fund some type of human service transportation

Transit Modes

Bus
- Most common – accounted for 52% of all U.S. transit trips in 2011

Demand-Response

Vanpool

Rail

Ferry

ADA Paratransit

- Predominant form of DRT in urban areas with fixed-route service
- Regulatory requirements
  - Operate in same service area as fixed-route (within ¾ mile of fixed-route system)
  - Have comparable response time as fixed route
  - Have comparable fares as fixed route
  - Meet requests for any trip purpose
  - Operate during same days and hours as fixed-route
  - Operate without capacity constraints
- Premium service: Goes beyond minimum requirements

Jitney

- Demand-response mode open to the general public for which passenger cars or vans are operated on fixed routes without fixed schedules or stops
- Often operated by private owner-operators or small companies
- Banned in many U.S. cities

Transit Modes

- Bus
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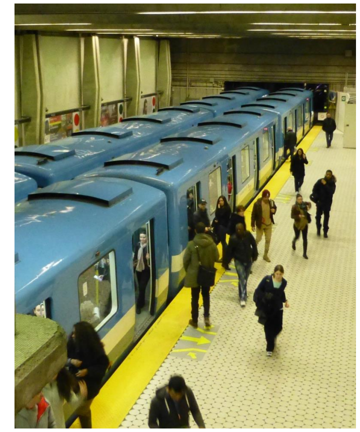
Heavy Rail

- Fully grade-separated rights of way, high-level platforms, and high-speed, electric multiple-unit cars
- Power generally received from a third rail, but can use overhead wires
- Serves high volume of passengers
- Dominant transit mode in the largest metropolitan areas



Vanpool

- Shared rides to a regular destination
- Same group of riders uses the vehicle each day
- Driving duties may be assigned to one of the riders
- Available to the general public
- Vans are typically owned by the public transit agencies, and riders are charged a weekly or monthly fare

Rail Transit Submodes

- Heavy Rail
- Light Rail
- Commuter Rail
- Automated guideway transit
- Others: monorails, funicular railways (inclined planes), aerial ropeways, cable cars

Commuter Rail

- Long-distance transit
- Typically shares track with freight railroads
- Service heavily oriented toward peak commuting hours
- Local trains, limited-stop express trains, and zoned express trains
- Service typically focused to downtown of a major city or between major cities within a region
- Diesel and electric power both used
- High priority on passenger comfort

Other Rail Transit Modes

- Monorail
- Funiculars, Inclines, and Elevators
- Aerial Ropeways
- Cable Car

Light Rail Transit (LRT)

- Can be at grade, above grade, or below grade, and can mix with motor vehicles
- Typically powered by overhead wires
- Three major types:
  - Light rail: relatively frequent along mostly exclusive right-of-way and up to four-car trains
  - Streetcars: mostly shared rights-of-way with one-car trains
  - Vintage trolleys: tourist- or shopper-oriented with low frequencies, using historic or historic-looking vehicles

Automated Guideway Transit

- Completely automated
- Fully grade-separated
- Operate in four-types of environments
  - Airports
  - Institutions (universities, shopping malls, government buildings)
  - Leisure and amusement parks
  - Public transit systems

Ferry Transit

- Provides a water connection where land routes are interrupted by water
- Examples: New York's Staten Island (busiest ferry route in North America), Brooklyn, Manhattan, Vancouver, San Francisco Bay, Puget Sound
- Services: Urban, coastal, rural
- Vessel types: Monohulls, catamarans, and hovercraft

Operating Environments

- ***Mixed traffic*** – shared lane operation with general traffic
  - Bus and streetcar service
- ***Semi-exclusive*** – a lane partially reserved for transit use but also available for other use at certain times or in certain locations
  - Primarily used by bus and streetcar service
  - Examples
    - Freeway managed lanes used by buses and shared with carpools or cars that paid a toll
    - Bus lanes on streets that allow other vehicles to enter to make right turns
    - Parking lanes that transform into bus-only lanes during peak periods
  - Intent is to reduce certain types of interference with traffic that slows transit service

Transit Modes

Bus
- Most common – accounted for 52% of all U.S. transit trips in 2011

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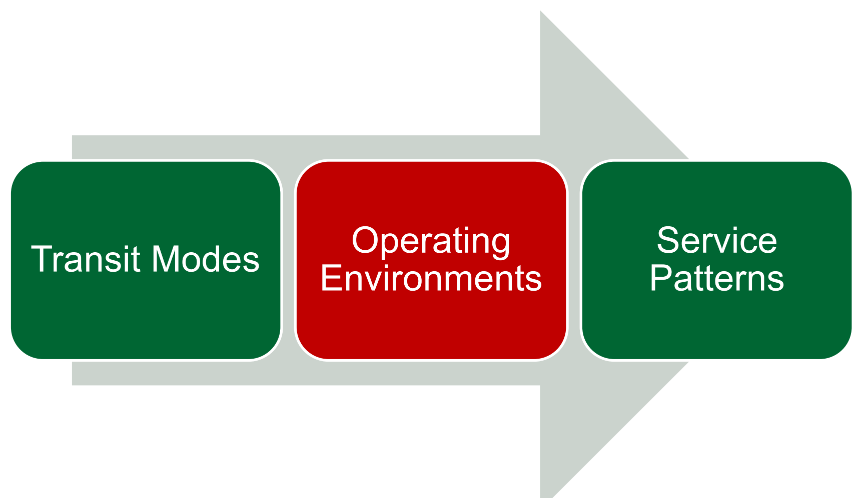
Topics



Operating Environments

- ***Grade separated*** – a facility dedicated to the exclusive use of transit vehicles, without at-grade crossings
  - Delays due to traffic signals and conflicts with other traffic are eliminated
  - Examples
    - Facilities located at grade, where other modes cross over or under
    - Below-grade facilities, such as subways and bus tunnels
    - Elevated facilities

Service Patterns

Fixed route
- Stopping patterns
- Route network designs
- System design

Demand response
- Trip patterns
- Flexible transit services

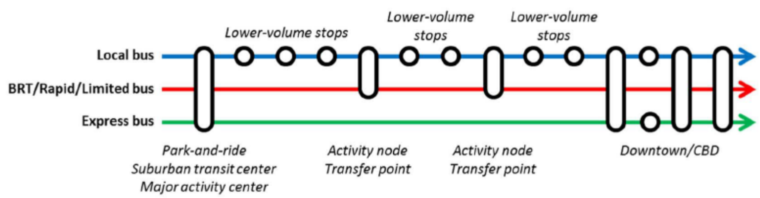
Operating Environments

- ***Exclusive*** – a lane, portion of a roadway, or right-of-way reserved for transit use at all times, but still subject to some external traffic interference (e.g., intersections, grade crossings)
  - Examples
    - On-street lanes reserved for the exclusive use of transit vehicles at all times and locations
    - Bus lanes and light rail tracks in a street median, with vehicle access across the tracks limited to signalized intersections
    - Light rail and commuter rail operating on their own right-of-way, with at-grade crossings where roadways cross the tracks
    - Bus rapid transit operating on its own right-of-way

Topics

Transit Modes → Operating Environments → Service Patterns

Fixed-Route Stopping Patterns



Trunk-and-Branch LRT Route Design, Portland

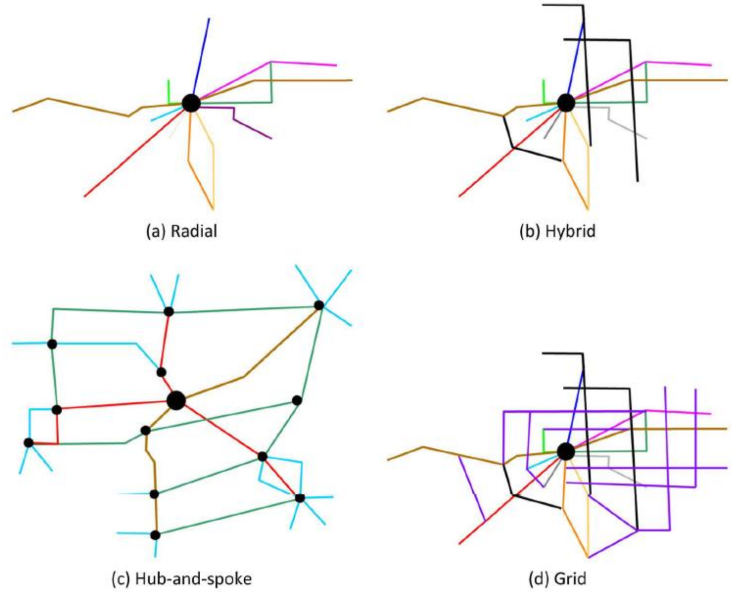
Source: TriMet.

Fixed-Route Stopping Patterns

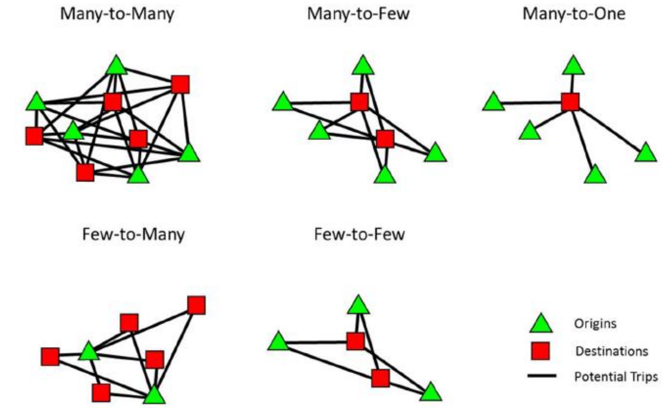
- ***Local*** – Serves all stops along a route, emphasizing access over speed
  - Short stop spacing
  - Flag stops may be used to allow pick up or drop off at any location
- ***Limited stop*** – Serves only high-volume stops
  - Faster trip as a result of fewer stops
- ***Express*** – Provides local service near the end points of the route and operates non-stop over the majority of the route
  - Emphasizes speed over access
  - Used for longer-distance trips

Route Network Design

- Facility-based designs
  - Trunk-and-branch
    - Several transit lines are supported on the inner portion of the facility (trunk)
    - Individual lines branch off from the trunk to serve more localized market areas
  - Feeder service
    - Local transit routes bring passengers to a corridor served by a high-frequency bus or rail line
    - Passengers must transfer to continue their trip along the corridor



DRT Trip Patterns



Fixed-Route System Design

Radial networks

- All routes focus on the downtown area

Hybrid networks

- Overlay key crosstown routes directly connecting major non-downtown origins and destinations

Hub-and-spoke networks

- Timed transfers at transit centers

Grid networks

- Frequent service along major streets covering a large portion of the region

Demand-Response Service Patterns

- Trip Patterns
  - Many origins to many destinations
  - Many origins to few destinations
  - Few origins to many destinations
  - Few origins to few destinations
  - Many origins to one destinations
- Flexible Transit Services
  - Other variations of DRT service have evolved that include elements of traditional fixed-route service with added flexibility

Flexible Transit Services

Point Deviation (also called checkpoint dial-a-ride)

- Operates within a defined area, providing demand response service as well as scheduled service to a limited number of designated stops, without a regular route between the stops

Route Deviation (also called flex-route)

- Less flexible and more similar to fixed-route
- Operates along a regular route and deviates off that route to serve demand-response trips within a zone around the route
- Some limits necessary so that travel times do not become too long

Flexible Transit Services

DRT Connector/Feeder Service

- Provides demand-responsive service within a defined zone that has one or more scheduled transfer points to fixed-route service
- Implemented in low-density areas to connect with fixed-route bus and rail service

Zone Routes

- Combine DRT service within defined zones along a corridor with scheduled departure and arrival times at one or more end points

Flexible Transit Services

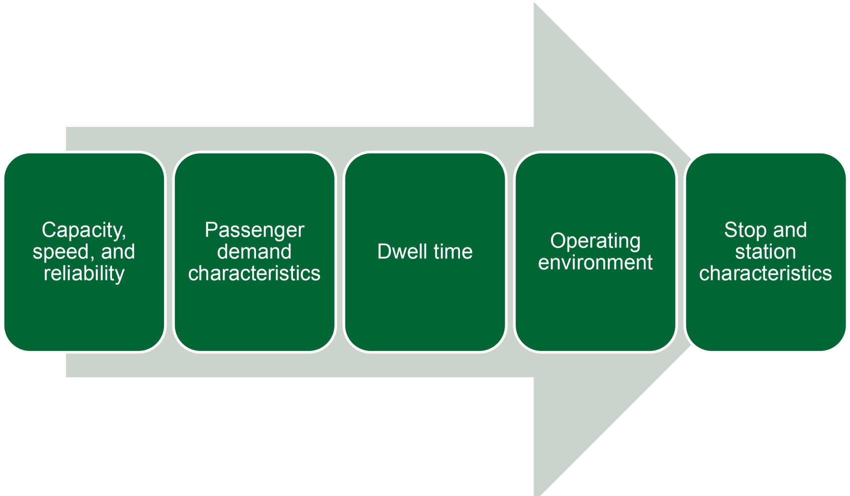
Flexible Route Segments

- Predominately fixed-route but converts to DRT for a limited and defined portion of the route

Request Stop

- Predominately fixed-route but also provides service to a limited number of defined stops close by the route at the request of a passenger

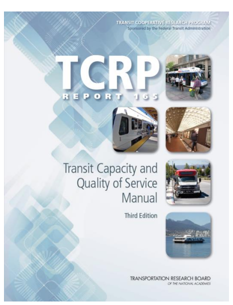
Operations Concepts



Why Transit Capacity is an Issue

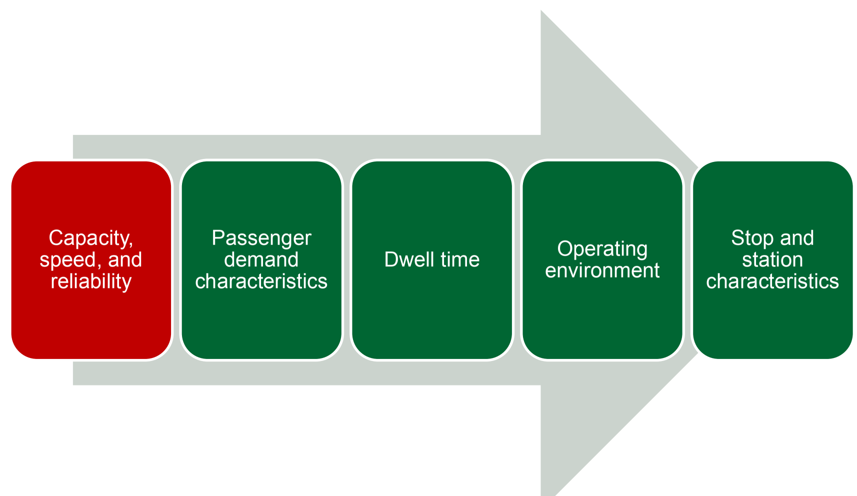
- **Improving speed and reliability**
  - Factors influencing capacity also influence speed and reliability
- **Managing passenger loads**
  - How many buses, trains, or railcars are needed to provide a desired quality of service with respect to passenger loading
- **Forecasting the effects of changes**
  - Fare collection procedures, vehicle types, other agency decisions
- **Planning for the future**
  - Knowledge of the speed and capacity provided by each mode or service type is necessary for planning
- **Analyzing the operation of major bus streets**
- **Special event service**
- **Transportation system management**

OPERATIONS CONCEPTS



Transit Capacity and Quality of Service Manual, 3rd Edition:
Chapter 3

Operations Concepts



Capacity Concepts

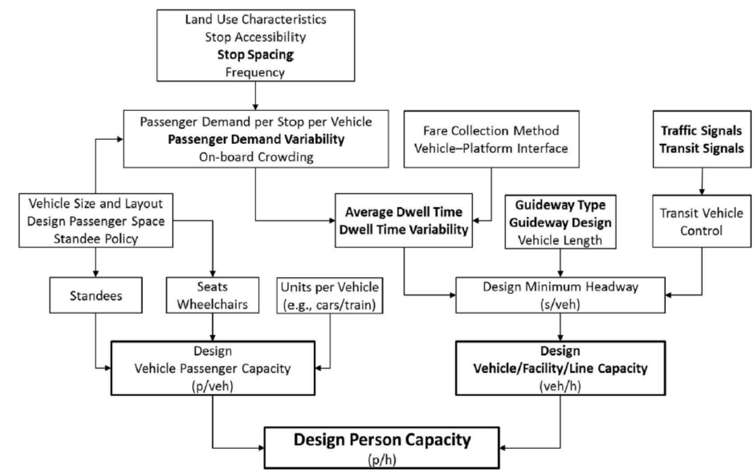
Person capacity

- The maximum number of people that can be carried past a given location during a given time period under specified operating conditions; without reasonable delay, hazard, or restriction; and with reasonable certainty.

Vehicle capacity

- The maximum number of transit vehicles (buses, trains, vessels, etc.) that can pass a given location during a given time period at a specified level of reliability.
- Depends on minimum possible headway between individual vehicles, which is dependent on control systems, passenger boarding and alighting demand at busy stops, the number of transit vehicles that can use a stop or station simultaneously, and interactions with other vehicles
- Operating margin – Specifies desired level of reliability. The operating margin is added to the minimum headway as an allowance for longer-than-average dwell times.

Factors Influencing Person Capacity



Note: Inputs to design person capacity shown in bold also influence transit speed, reliability, or both.

Transit Capacity

- Transit capacity deals with the movement of both people and vehicles
- Transit capacity depends on the agency's operating policies, which specify service frequencies, allowable passenger loading, and the type of vehicle used to carry passenger.
- The traditional concepts applied to highway capacity need to be adapted and broadened.

Design Capacity vs. Maximum Capacity

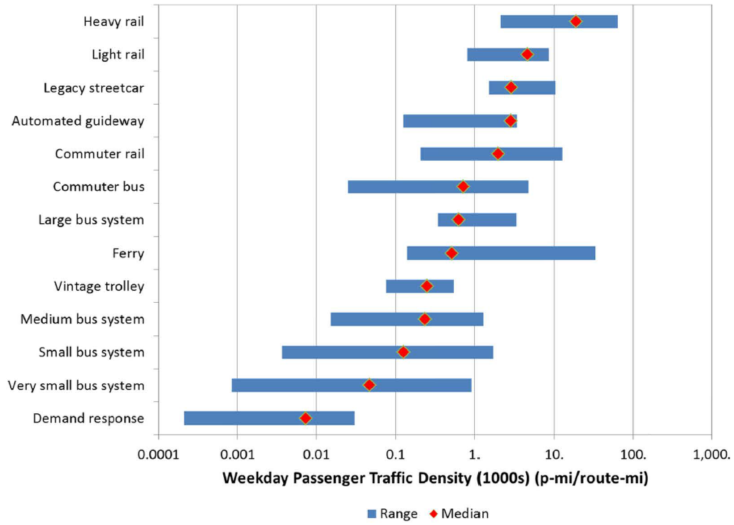
Design capacity

- Capacity that can be sustained day after day, accounting for small irregularities in service and variations in passenger demand and arrival patterns
- The TCQSM refers to design capacities (unless otherwise stated)

Maximum (theoretical) capacity

- Capacity that could be achieved if service was 100% reliable, passenger demand never varied, passengers filled every available space on every trip

Passenger Traffic Density



Components of Transit Speed

- **Running time** – Time spent at constant speed following acceleration
- **Passenger service time** – Boarding and alighting time
- **Delay** – External factors that impede transit vehicles

Passenger Traffic Density

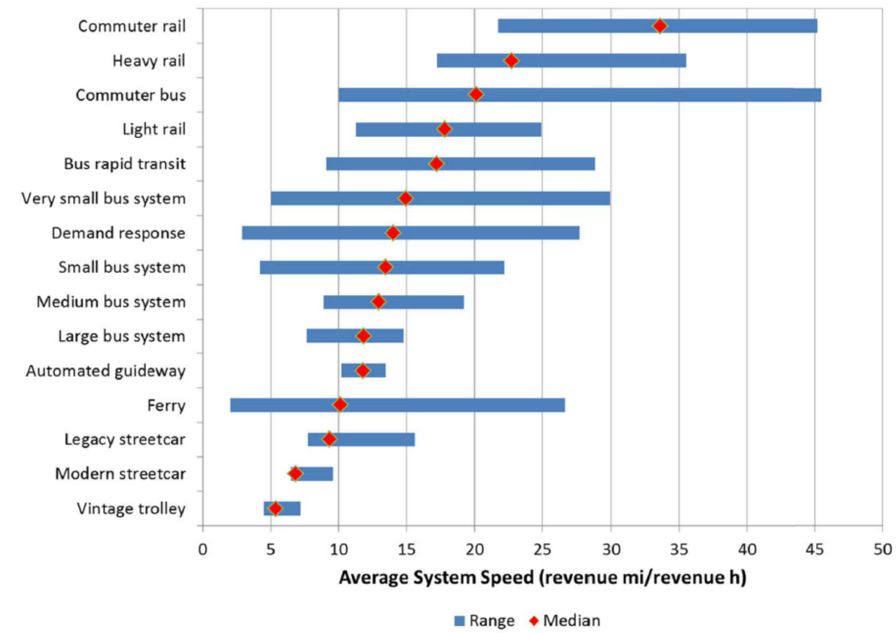
- Passenger miles per directional route mile
- The number of passengers carried on average over a given mile of a route
- Influenced by capacity, demand, and loading levels

Speed Concepts

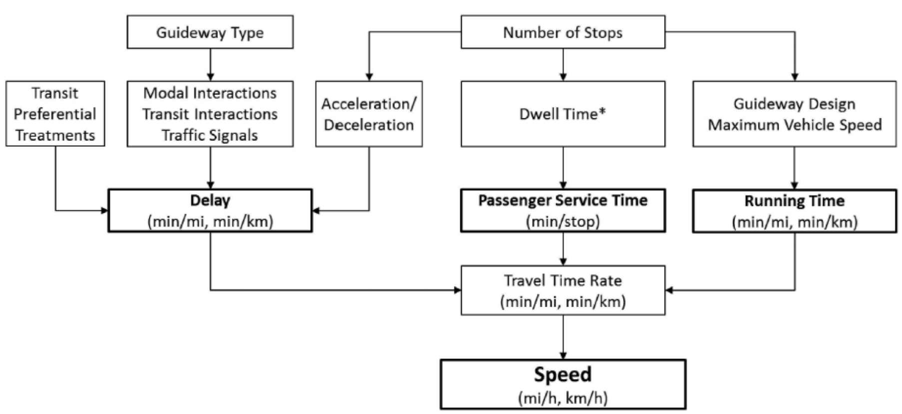
- Why speed matters
  - Important for attracting riders
  - Impacts operating cost
    - The number of vehicles required to operate a service at a given frequency depends on the route’s cycle time.
    - Cycle time divided by headway gives the required number of vehicles to serve a route.

Factors Influencing Transit Speed

- Number of stops influences all three components of transit speed
  - More frequent stops means more time decelerating and accelerating
  - More frequent stops reduces average boarding volume and dwell time at any given stop, but this is more than offset by acceleration and deceleration delays
  - Vehicles may never reach maximum capable speed if stops are frequent
- Running time is constrained by:
  - Guideway design (e.g., maximum allowed operating speed, vehicle passing provisions)
  - Characteristics of the vehicles being operated (e.g., acceleration, maximum vehicle speed)
  - Stopping frequency



Factors Influencing Transit Speed



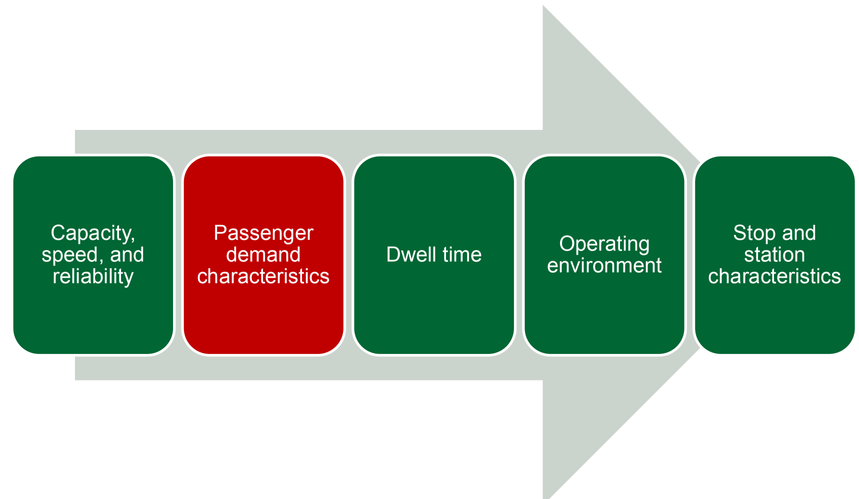
Factors Influencing Transit Speed

- Passenger service time is directly related to
  - Number of stops
  - Average dwell time at each stop
- Delay is related to
  - Type of guideway (e.g., mixed operation vs. exclusive guideway)
  - Number of transit vehicles using a guideway relative to its capacity
  - Traffic signal delays for transit vehicles operating on roadways.

Reliability Concepts

- Reliability is important to both passengers and operators
  - Passenger: Arriving at destination on time and not having to wait long at a stop
  - Operator: Reliability impacts the schedule recovery component of cycle time and can contribute to increased costs when recovery time needs require an extra vehicle to operate on the route at a given frequency
- Factors influencing transit reliability
  - Internal factors (under a transit agency's control)
  - External factors (not under a transit agency's control)

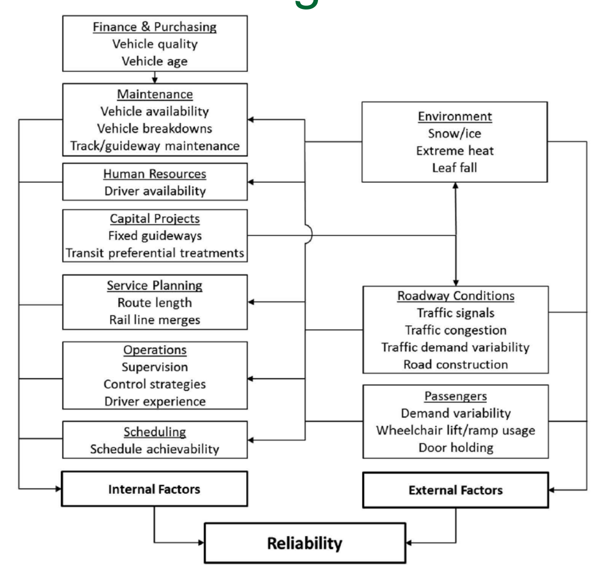
Operations Concepts



Speed Observations

- Higher speeds associated with
  - Long stop spacing
  - Relatively high operating speeds
  - Separation from other traffic
- Wide range of speeds for each mode reflects differences in stop spacing and operating environments
- Larger bus systems have slower average speed than smaller systems because of higher levels of congestion

Factors Influencing Transit Reliability



Time-of-day Demand Variation

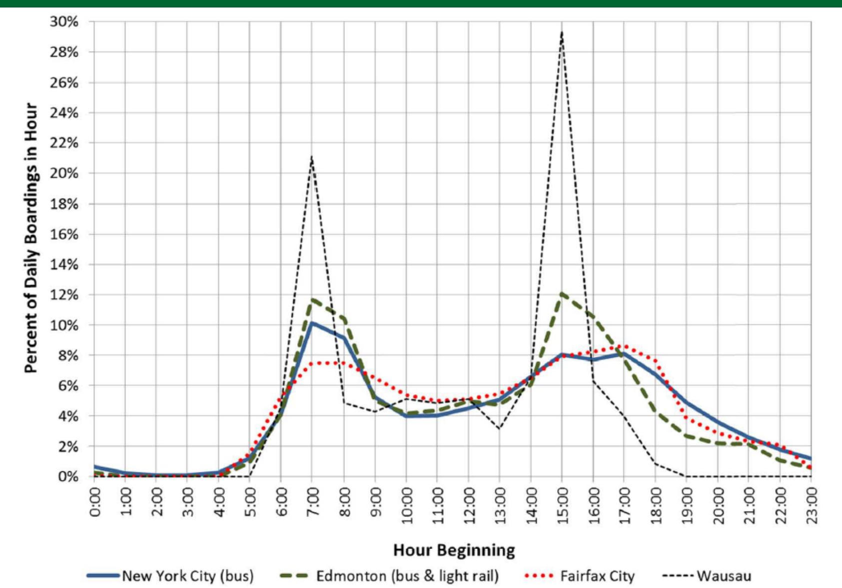
- Transit passenger demand has distinct peaking patterns, often coinciding with peak commuting patterns or school schedules
- Providing extra service during the peak costs more
  - Contractual needs may require providing part-time workers a minimum amount of work or paying drivers who work a split shift at a higher rate
  - Extra vehicles are required, adding capital and maintenance costs
- Transit services in very dense areas or those that serve several different trip purposes have less peaking
- Service between low-density residential areas and major activity centers may only be feasible during peak periods or at a very low frequency during off-peak periods

Peak-Hour Demand Variation

- Passenger demand can also vary within the peak period
- Peak hour factor (PHF) is calculated as demand during the hour divided by 4 times the demand during the peak 15 minutes of the hour
  - $PHF = V/(4 \times V_{15})$
  - PHF of 1.00 indicates even demand
  - PHF of 0.25 indicates all demand occurs in one 15-min period
  - PHFs typically range from 0.60 to 0.95

Passenger Demand Characteristics

- Demand to use transit, and variations in demand, are important factors that influence transit capacity, speed, and reliability
- Transit passenger demand patterns
  - Time-of-day demand variation
  - Peak-hour demand variation
- Demand related to
  - Demographics
  - Land use
  - Transportation demand management strategies



Sources: Lu and Reddy (*9*), City of Edmonton (*10*), Connetics Transportation Group (*11*), and Urbitran Associates and Abrams-Cherwony & Associates (*12*).

Demand Related to Demographics

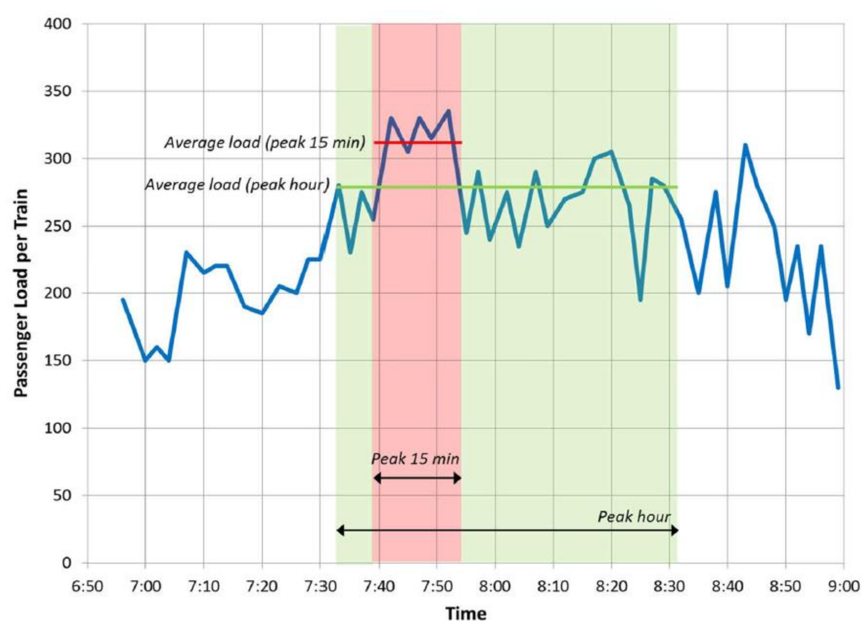
- Gender
- Age
- Employment
- Number of cars in household

Demand Related to Land Use

- Density and transit use relationships
  - People are more likely to use transit when they live in dense areas
  - There are more people within walking distance of transit as density increases

Household Density		Multiplicative Change Relative to Base Condition		
(HH/acre)	(HH/ha)	Households	Likelihood of Using Transit	Overall Transit Demand
2.35	5.8	1.0	1.0	1
4.7	11.6	2.0	2.0	4
10.9	26.9	4.7	5.9	28
26.6	65.7	11.7	15.9	186
46.9	115.9	20.0	24.0	480

Source: Calculated for the TCQSM 3rd Edition from 2009 National Household Travel Survey data (*18*).
Note: HH = households. Base condition is 2.35 HH/acre (5.8 HH/ha). Household densities based on the densities of the census block groups of survey respondents.



Source: Derived from *TCRP Report 13* (*15*).
Note: Vancouver, B.C., Broadway Station inbound, October 27, 1994.

Demand Related to Land Use

- Land use densities supporting various transit service modes and levels
  - More people and more jobs within short distance of transit service means more potential customers

Transit Service	Minimum Residential Density	CBD Commercial/Office Density
Local bus, 1 bus/h	4.5 dwelling units/net acre	5–8 million ft^2
Local bus, 2 bus/h	7 dwelling units/net acre	8–20 million ft^2
Local bus, 6 bus/h	15 dwelling units/net acre	20–50 million ft^2
Light rail, 5-min peak headway	9 dwelling units/net acre in 25–100 mi^2 corridor	35–50 million ft^2 (20 million ft^2 if 100% at-grade)
Rapid transit, 5-min peak headway	12 dwelling units/net acre in 100–150 mi^2 corridor	>50 million ft^2
Commuter rail, 20 trains/day	1–2 dwelling units/net acre	>100 million ft^2

Sources: Pushkarev and Zupan (*20*), Institute of Transportation Engineers (*22*), and Moore et al. (*23*).
Note: Assumes 20 h/weekday service span, 33% farebox recovery.

Demand Related to Transportation Demand Management Strategies

- Transportation demand management (TDM) programs seek to reduce automobile trip making through a variety of means:
  - Incentive to use alternative modes (including transit pass subsidies)
  - Flexible employee work schedules or locations
  - Support infrastructure (pedestrian friendly environments, bicycle lockers, etc.)
  - Support programs (guaranteed ride home, carpool matching, carsharing, etc.)
  - Disincentives for driving (parking charges, reduced parking supply)
  - Marketing programs that raise awareness of transportation options
- Online TDM Encyclopedia from the Victoria Transport Policy Institute: http://www.vtpi.org/tdm/index.php

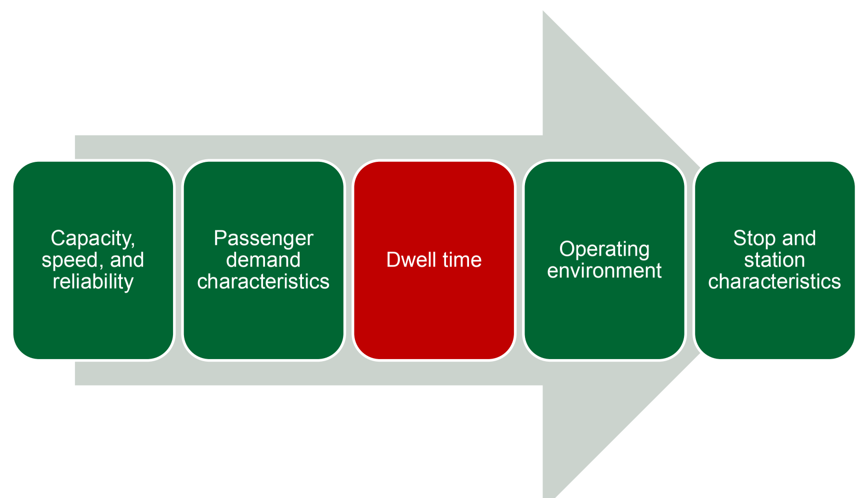
Dwell Time

- Dwell time – Time spent at a stop or station serving passenger movements, including the time required to open and close the doors
- Dwell time components
  - Passenger boarding and alighting volumes
  - Fare payment method
  - Vehicle type and size
  - In-vehicle circulation
- Dwell time is indirectly related to stop spacing (more stops over a given distance decreases number of passengers boarding or alighting at each stop)

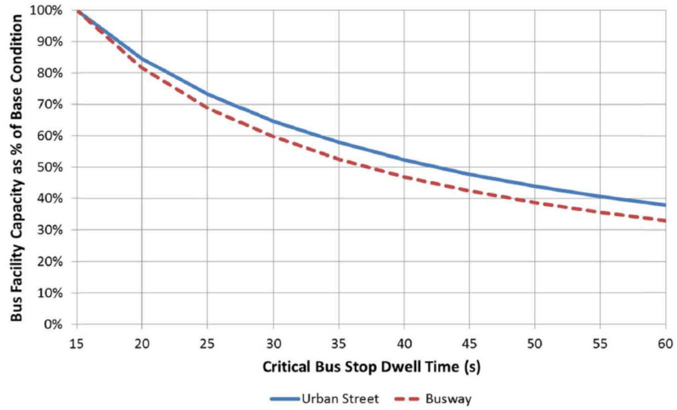
Demand Related to Land Use

- Transit-Oriented Development (TOD)
  - Developments close to high quality transit service, with higher densities, parking management programs, and good walking environments
  - TOD residents are 2-5 times more likely to commute and to make non-work trips by transit as non-TOD residents and are twice as likely to not own a car (could be an element of self-selection involved)

Operations Concepts

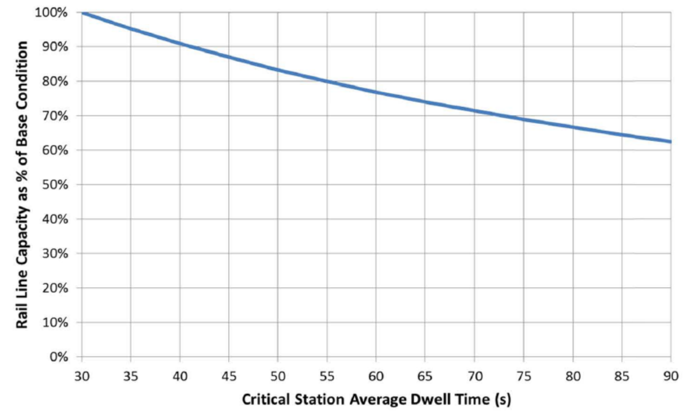


Impact of Dwell Time on Bus Facility Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes 15-s average dwell time, no traffic signals (busway) or 40% traffic signal green time for the bus' direction of travel (urban street), 10-s clearance time, and 60% dwell time variability. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Dwell Time on Rail Line Capacity

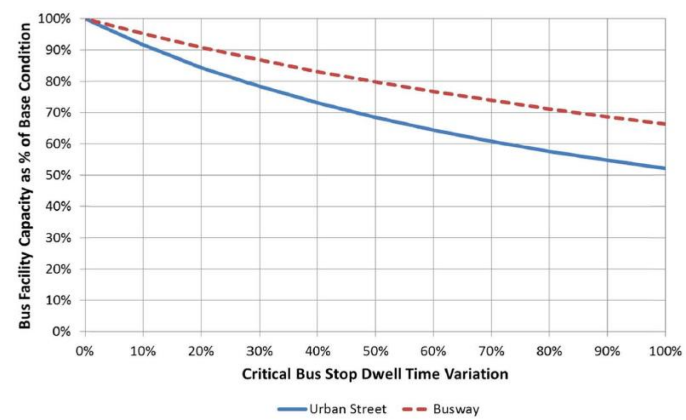


Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 20-s operating margin, and 50-s minimum train separation time. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Dwell Time Variability

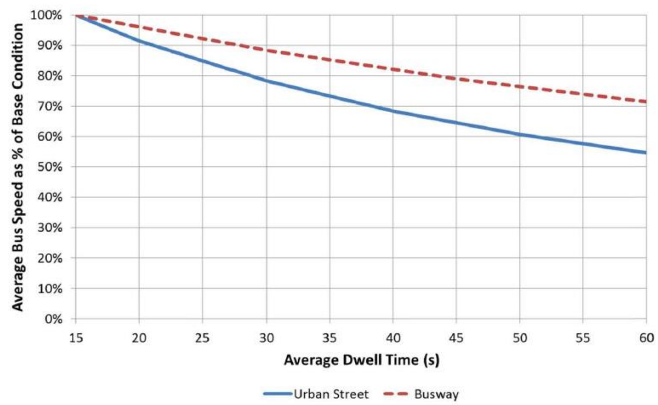
- Important factor affecting transit reliability and capacity
- Reasons for variability:
  - Variations in passenger demand for a particular route over time
  - Variations in passenger demand between different routes sharing the same stop
  - Irregularities in maintaining the planned schedule or headway
  - Crowded conditions on board a vehicle, causing passengers to board and alight more slowly than normal
  - Wheelchair and lift deployment, and bicycle rack usage
  - Driver interactions with passengers
- Variability affects the minimum headway, which controls capacity
  - Operating margin = additional time added to the min headway to account for longer than normal dwell times
  - Greater dwell time variability results in a greater operating margin and lower design capacity

Impact of Bus Dwell Time Variability on Capacity



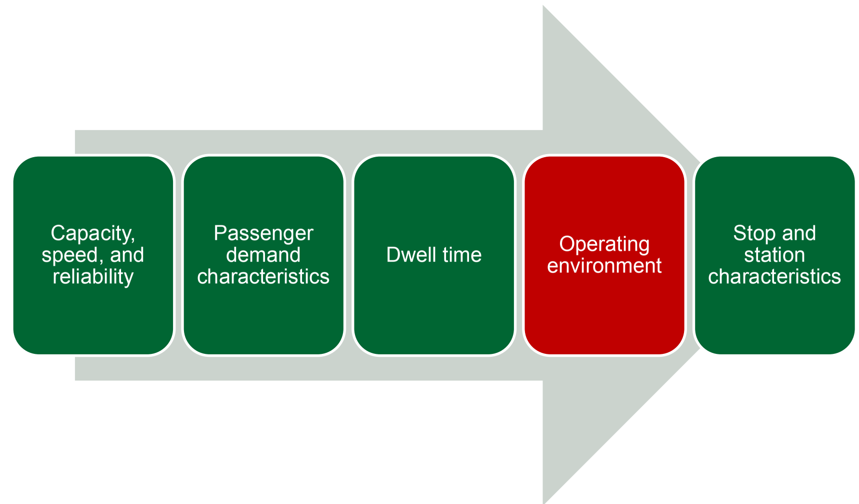
Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, no traffic signals (busway) or 40% traffic signal green time for the bus' direction of travel (urban street), 10-s clearance time, and 0% dwell time variability (i.e., all buses dwell exactly 30 s). See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Dwell Time on Average Bus Speed

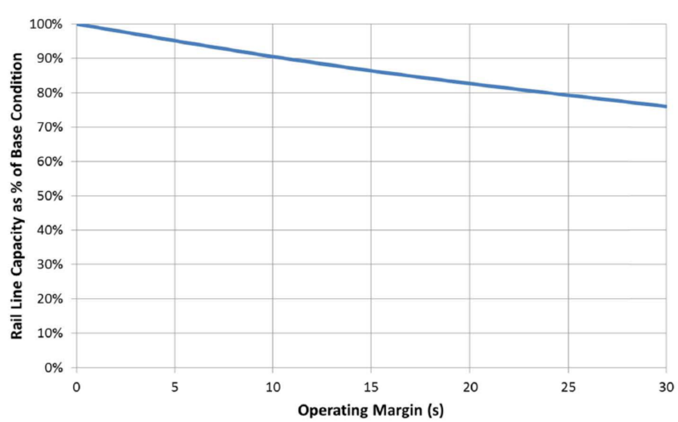


Source: Calculated using TCQSM methods.
Note: Base condition assumes 15-s average dwell time, 1 stop/mi (busway) or 8 stops/mi (urban street), and mixed traffic operation (urban street). See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Operations Concepts

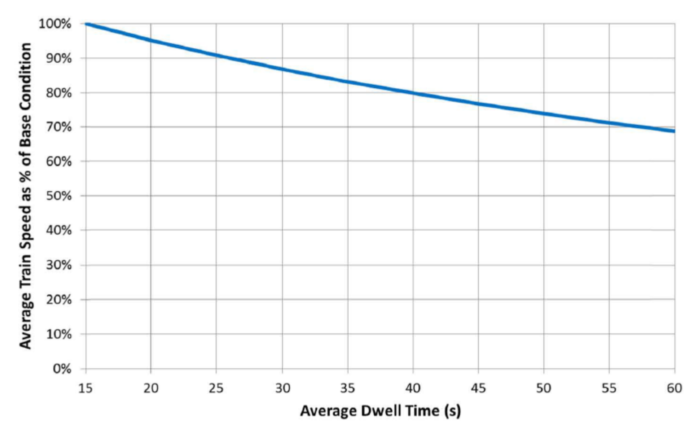


Impact of Operating Margin on Rail Line Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes 45-s average dwell time, 0-s operating margin, and 50-s minimum train separation time. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Impact of Dwell Time on Average Train Speed



Source: Calculated using TCQSM methods.
Note: Base condition assumes 15-s average dwell time, 1 stop/mi, and 55 mi/h maximum train speed.

Guideway Type and Design

- More exclusive right-of-way results in less interaction between transit vehicles and other transportation modes
- Types of interaction
  - Traffic control (e.g., traffic signals, stop signs)
  - Traffic delay
  - Speed restrictions

Traffic and Transit Vehicle Effects

Interaction	Motorized Vehicles	Bicyclists	Pedestrians
Other modes on transit	• Traffic congestion delays transit vehicles operating in mixed traffic • Traffic may delay buses re-entering roadway from bus stops • Day-to-day variation in traffic volumes and delays affects transit travel time and reliability	• May delay buses sharing a lane with bicycles • Bicyclists delay buses re-entering roadway from bus stops • Bicycle environment quality influences ability of transit passengers to bike to transit service	• Traffic signal timing constrained by need to serve pedestrians crossing streets • May directly (crossing street) or indirectly (crossing parallel to street, with turning traffic yielding) delay buses • Pedestrian environment quality influences transit passenger ability to walk to transit service
Transit on other modes	• Buses are equivalent to 2 cars in terms of their effect on roadway capacity • Transit vehicles stopped in travel lane at bus stops reduce available roadway capacity and create delay • Transit signal priority reallocates green time, with potential capacity and delay impacts (both positive and negative)	• Heavy vehicle volume and speed in curb lane (including transit vehicles) negatively impacts bicycle quality of service • Stopped transit vehicles may delay bicyclists or force them to shift lanes • Bicyclists and buses have similar average speeds, creating leapfrog passing patterns when sharing lanes • Bicyclists can use transit to greatly extend the range of a bicycle trip, when bicycles can be brought aboard transit vehicles	• Traffic volume in curb lane (including transit vehicles) negatively impacts pedestrian quality of service • Waiting passengers may block pedestrian flow on sidewalk • Alighting passengers may create cross-flows that disturb pedestrian flow on sidewalk

Source: Derived from *Highway Capacity Manual 2010* (3).

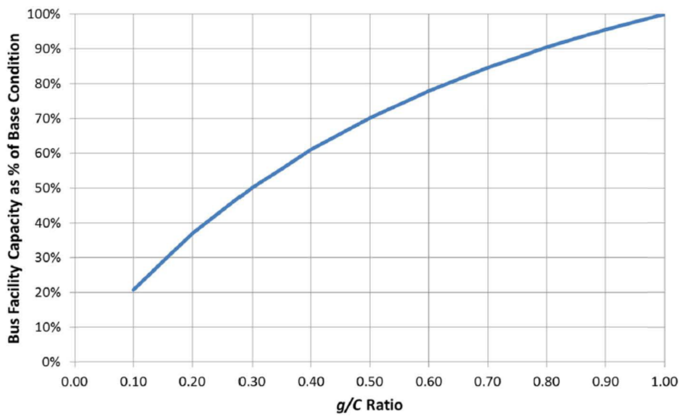
Operating Environment

- Four main types of operating environments
  - Mixed traffic
  - Semi-exclusive
  - Exclusive
  - Grade-separated
- Different operating environments affect transit speed, capacity, and reliability

Guideway Type	Traffic Control	Traffic Delay	Speed Restrictions
Mixed traffic	Transit vehicles regulated by traffic signals [a]	Full exposure to potential traffic delays	Transit vehicle speeds regulated by roadway posted speed
Semi-exclusive	Transit vehicles regulated by traffic signals [a]	Partial exposure to potential traffic delays (typically right turns)	Transit vehicle speeds regulated by roadway posted speed
Exclusive (median)	Transit vehicles regulated by traffic signals [b]	Non-transit traffic prohibited on guideway, pedestrian crossing points may be provided	Transit vehicle speeds regulated by roadway posted speed
Exclusive (off-street)	Buses regulated by traffic signals at street crossings; [c] rail provided with gated crossings, train control signals	Non-transit traffic prohibited on guideway, pedestrian crossing points may be provided	Transit vehicle speeds constrained by vehicle performance and guideway design [c]
Grade-separated	No signal control for busways (unless shared with light rail); train control signals for rail lines	Non-transit traffic prohibited on guideway [d]	Transit vehicle speeds constrained by vehicle performance and guideway design [d]

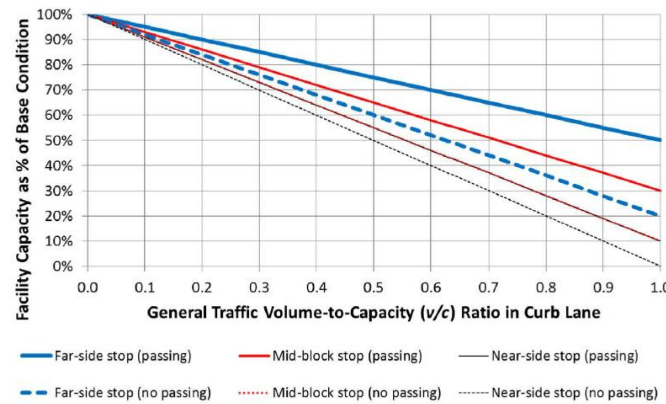
Notes: (a) Transit signal priority may provide some benefit.
(b) Transit vehicles may be provided with signal priority (less feasible with high volumes of transit vehicles). Light rail may be allowed to preempt traffic signals.
(c) Bus signal priority or preemption may be provided. Bus speed restrictions typically imposed at signalized roadway crossings, due to safety issues with cross traffic not observing the traffic signals (*8*).
(d) Some busways allow pedestrian crossings at stations, in conjunction with bus speed restrictions for buses not stopping at the station.

Impact of Traffic Signalization on Bus Facility Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 10-s clearance time, 60% dwell time variability, and no traffic signal (g/C = 1.00). See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Curb Lane Traffic Congestion on Bus and Streetcar Capacity

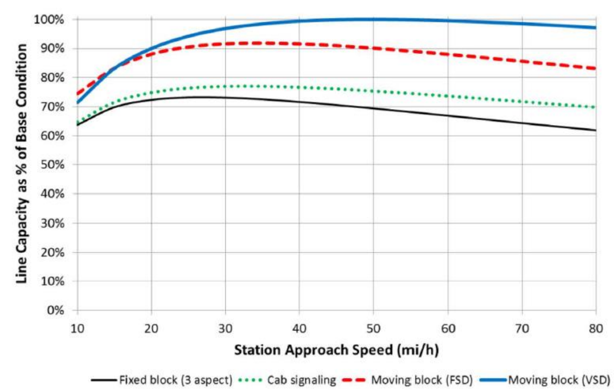


Source: Calculated using TCQSM methods.
Notes: Base condition assumes that only transit vehicles are allowed to use the curb lane.
"Passing" indicates ability of buses to leave the curb lane to pass stopped vehicles.
"Mid-block (no passing)" and "Near side (passing)" have the same characteristics.

Impacts of Operating Environment on Capacity

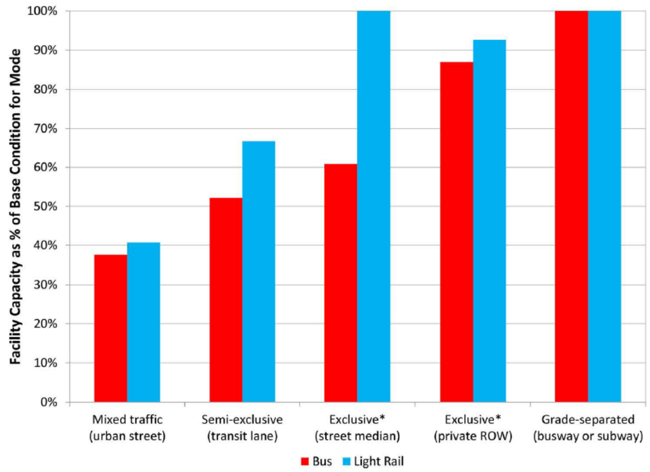
- Traffic control
  - The g/C ratio is the amount of effective green time provided by the traffic signal for the bus' direction of travel g, divided by the traffic signal cycle length C
- Traffic delay
  - High v/c ratios (volume/capacity) result in low capacities, low speeds, and poor reliability
- Speed restrictions
  - Trains take longer to decelerate from line speed when going downhill into a station, increasing safe separation time between trains and decreasing capacity

Impact of Train Signaling System and Station Approach Speed on Line Capacity



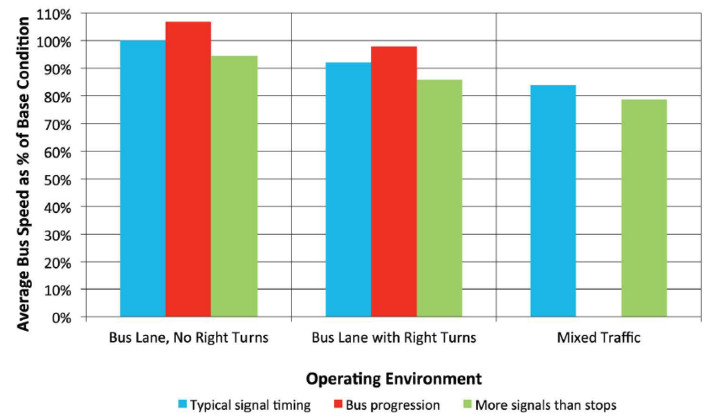
Source: Calculated using TCQSM methods.
Note: FSD = fixed safety distance, VSD = variable safety distance.
Base condition assumes moving block signals with variable safety distances, 45-s average dwell time, and 20-s operating margin, and no grade entering station. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Overall Impact of Operating Environment on Capacity



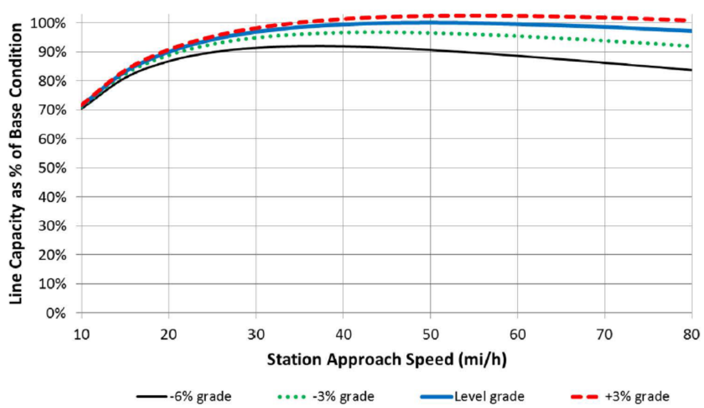
Source: Calculated using TCQSM methods.
Note: *Capacity may be lower when very high cross-street volumes must be accommodated.

Impacts of Traffic Signals on Bus Speeds



Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 8 stops/mi, central business district location, and an exclusive bus lane not allowing general traffic right turns. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Station Approach Grade and Speed on Line Capacity

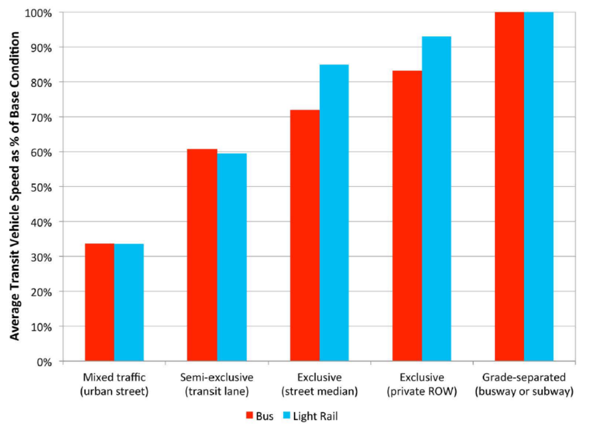


Source: Calculated using TCQSM methods.
Note: Base condition assumes moving block signals with variable safety distances, 45-s average dwell time, 20-s operating margin, and level grade entering station. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Impacts of Operating Environment on Speed

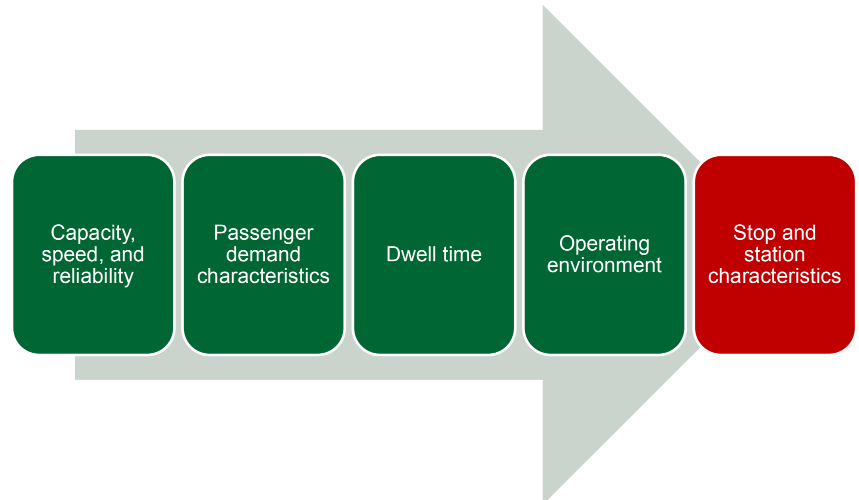
- Traffic control
  - Timing signals to progress buses provides the greater speeds
  - The greater the opportunity for interactions with general traffic, the lower the overall speed
- Transit vehicle interference
  - As the volume of buses on a street increases, the probability increases that one bus will delay another bus, resulting in lower overall speeds

Impact of Operating Environment on Average Transit Speed

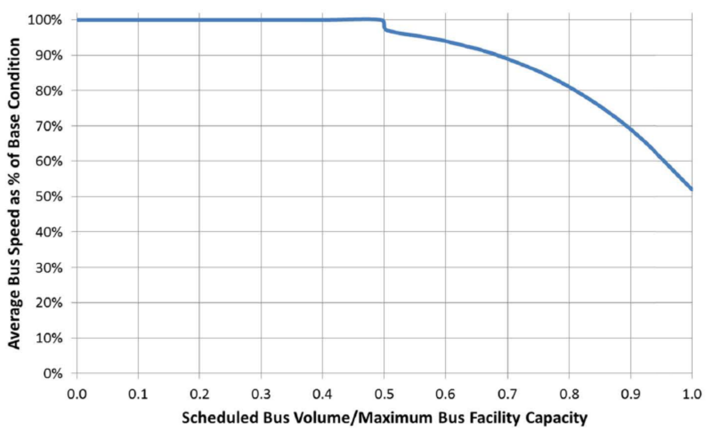


Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 2 stops/mi, and a grade-separated environment. Light rail values assume 55 mi/h maximum speed in private right-of-way (ROW) and grade-separated environments, 35 mi/h in street medians, and 20 mi/h otherwise.

Operations Concepts



Impact of Bus Congestion on Bus Speeds



Source: Calculated using TCQSM methods.
Note: Base condition assumes less than half the facility's maximum capacity in use.

Impact of Operating Environment on Reliability

- With grade-separated facilities, the potential sources of schedule unreliability are generally limited to
  - Things under the transit agency's control, such as schedule achievability, vehicle maintenance, and route length and number of stops
  - Variations in passenger demand
- At-grade crossings introduce potential conflicts with other modes
- On-street facilities introduce traffic signals (with potential randomness), the potential for road construction, and the potential for unauthorized use of the facility
- Semi-exclusive facilities have greater potential for unauthorized use and introduce right-turning traffic delays and parking maneuvers
- Mixed-traffic operations introduce potential travel time variability due to traffic congestion and variability in traffic volumes

Vehicle-Platform Interface

- Factors that affect transit speed and capacity include:
  - Height differential between the vehicle floor and the platform
    - Influences how quickly passengers can board and alight
  - Platform position relative to the guideway
    - On-line stops – Vehicle stops in the guideway to serve passenger movements
      - Allows transit vehicles to proceed as soon as passenger movements are finished, with no delay waiting to re-enter the street
    - Off-line stops – Vehicle stops out of the guideway (e.g., bus pull-out, parking lane, etc.) to serve passengers
      - Allows transit vehicles to pass each other at stations
  - Number of transit vehicles that can stop simultaneously

Fare Collection

- Fare collection affects dwell time in several ways
  - When fares are collected on board, each fare collection method has a passenger service time associated with it
  - The fare collection policy may require all passengers with pre-paid fares or smart cards to interact with the driver, or the policy may allow these passengers to board any door, with smart card holders tagging their cards at one of the rear doors
  - When fares are collected off-board, passengers can use any door to board
    - Proof-of-payment fare collection can significantly reduce dwell time, but it requires the additional cost of fare inspectors

Stop and Station Characteristics

- Vehicle-platform interface
- Vehicle characteristics
- Fare collection
- Stop spacing
- Impacts of stops and stations on capacity and speed

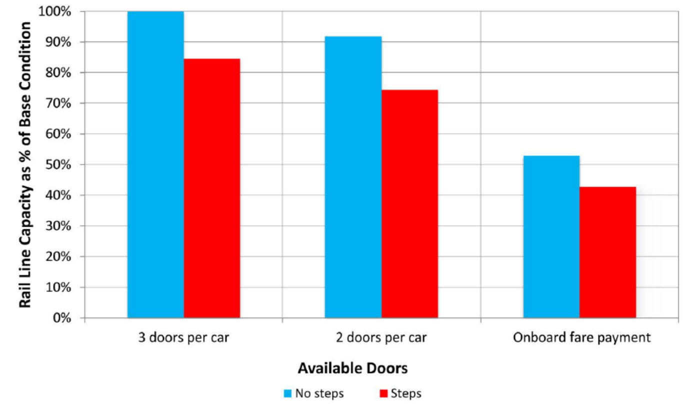
Vehicle Characteristics

- The number and width of doors affects how many passengers can simultaneously board or alight a transit vehicle, which affects dwell time
- The seating arrangement inside the bus influences the width of the aisle and the ease with which passengers can circulate to and from the doors when standees are present

Impacts of Stops and Stations

- Impacts on capacity
  - Passenger service time
  - Type and number of loading areas
- Impacts on speed
  - Fare collection
  - Stop spacing

Impact of Floor Height and Door Availability on Light Rail Line Capacity

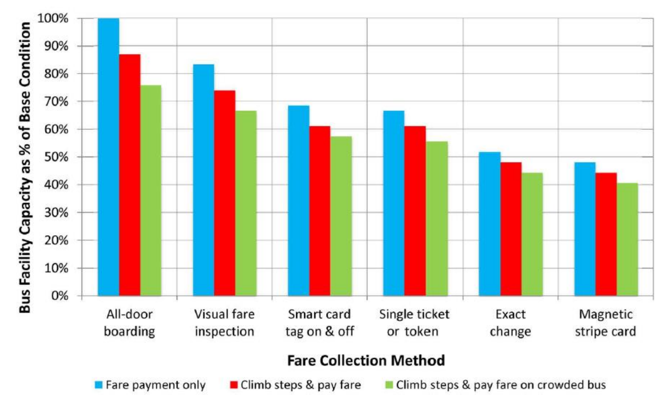


Source: Calculated using TCQSM methods.
Note: Base condition assumes 2-car light rail train with an average of 20 passengers boarding and 20 passengers alighting at the critical stop, level boarding, 20-s operating margin, and 50-s safe train separation time. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Stop Spacing

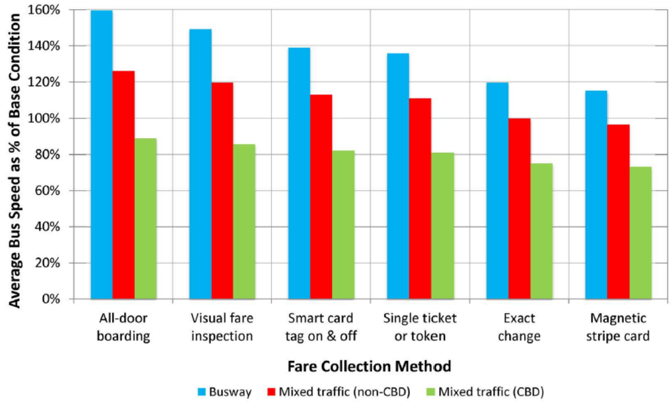
- The more frequently that transit vehicles stop, the more time is lost in decelerating and accelerating
- When operating on the street, each stop carries the risk that the vehicle will fall out of the progression band provided by the street's signal timing and be further delayed at the next traffic light
- When stops are too close together, the transit vehicle cannot reach its maximum allowed speed before it has to decelerate again for the next stop

Impact of Boarding and Fare Collection Method on Bus Capacity



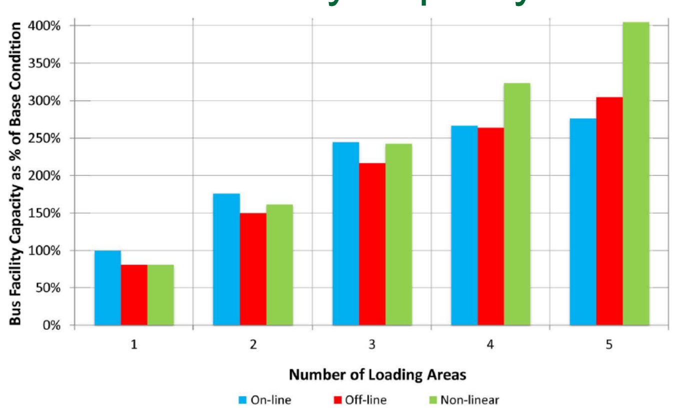
Source: Calculated using TCQSM methods, including default fare collection times from Chapter 6, Bus Transit Capacity.
Note: Base condition assumes 10 passengers boarding and 4 passengers alighting at the critical stop, level boarding, no standees, all-door boarding, 60% dwell time variation, 10-s clearance time, and 0.40 *g/C* ratio. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Fare Collection on Average Bus Speed by Facility Type



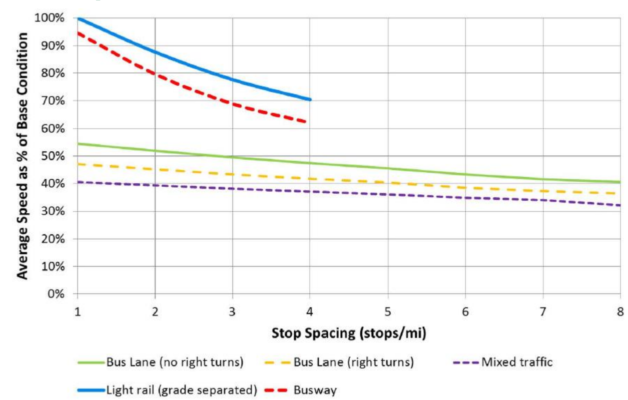
Source: Calculated using TCQSM methods.
Note: Base condition assumes 32-s dwell time, exact change fare payment, non-CBD mixed traffic operation, level boarding, no standees, 35 mi/h maximum speed, and 4 stops/mi. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Number and Type of Loading Areas on Bus Facility Capacity



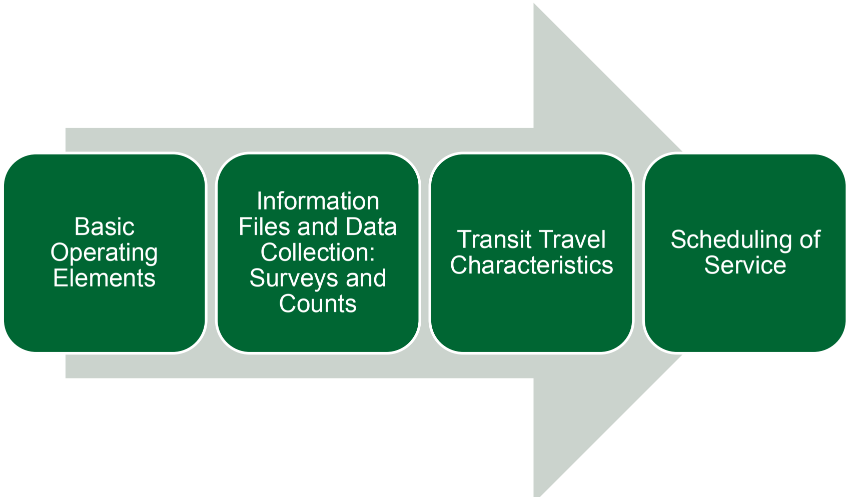
Source: Calculated using TCQSM methods.
Note: Base condition for the critical stop assumes 1 on-line loading area, 30-s average dwell time, 60% dwell time variability, 10-s clearance time, and 0.4 *g/C* ratio. Off-line and non-linear loading areas assume 18-s clearance time. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Impact of Stop Spacing on Average Transit Speed



Source: Calculated using TCQSM methods.
Note: Base condition assumes grade-separated light rail and 1 stop/mi. Assumed dwell time is 15 s at 8 stops/mi (10-s passenger service time and 5-s door opening and closing time), with the passenger service time component increasing proportionately as the number of stops decreases (e.g., 25-s dwell time at 4 stops/mi). Assumed running speed is 55 mi/h for light rail and busway and 25 mi/h otherwise.

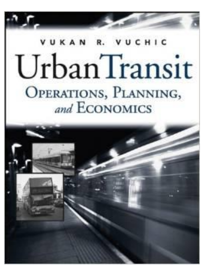
Transit Operations and Service Scheduling



Basic Operating Elements

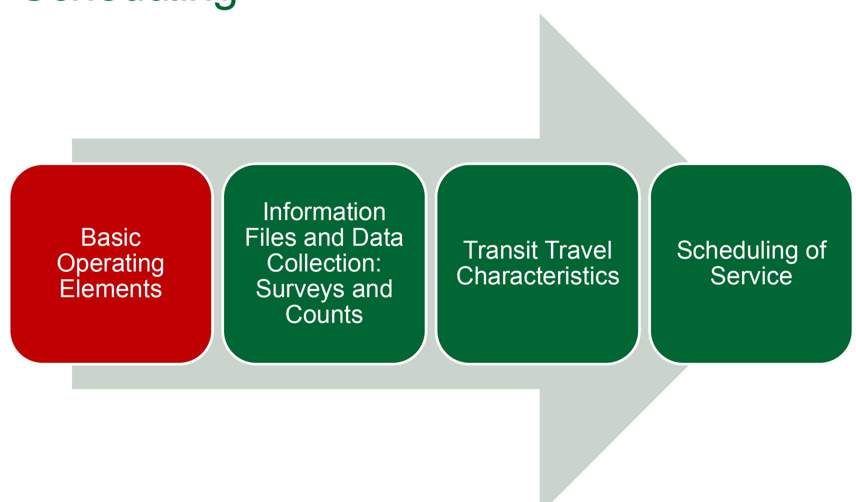
- Line, network, stop, and station
- Vehicles, transit units, and fleet size
- Usage of service: Passenger flow and volume
- Operating elements: Headway and frequency
- Capacity, work, and utilization
- Travel times
- Speeds

TRANSIT OPERATIONS AND SERVICE SCHEDULING



Urban Transit: Operations, Planning and Economics by Vukan Vuchic, Chapter 1

Transit Operations and Service Scheduling



Line, Network, Stop, and Station

- **Line length**
  - One-way distance between the two terminals along the line alignment
- **Network length**
  - Total length of all alignments served by one or more lines
- **Total line length**
  - Sum of all line lengths, whether they operate alone or overlap with other lines

Line, Network, Stop, and Station

- *Transit right-of-way (ROW)* – the strip of land on which a transit line operates, and refers to the facility used exclusively by transit vehicles and also any of the physical forms a transit line may follow (street, elevated structure, tunnel)
  - Three categories
    - Category C: Surface street with mixed traffic
      - No physical separation from other traffic
      - *Street transit*: Buses, trolley-buses, streetcars
    - Category B: Longitudinally physically separated but from other traffic but with at-grade crossings
      - *Semi-rapid transit:* Light rail transit most commonly
    - Category A: Fully controlled, grade separated, exclusive ROW
      - *Rapid transit*: Metro or rail rapid transit

Line, Network, Stop, and Station

- **Transit line**
  - Infrastructure and service provided on a fixed alignment by vehicles or trains operating on a predetermined schedule
- **Transit route**
  - Often synonymous with transit line, but usually designates street transit, often overlapping lines, rather than a major metro or regional rail lines
- **Transit network**
  - Set of transit lines that are connected and coordinated

Line, Network, and Total Line Length

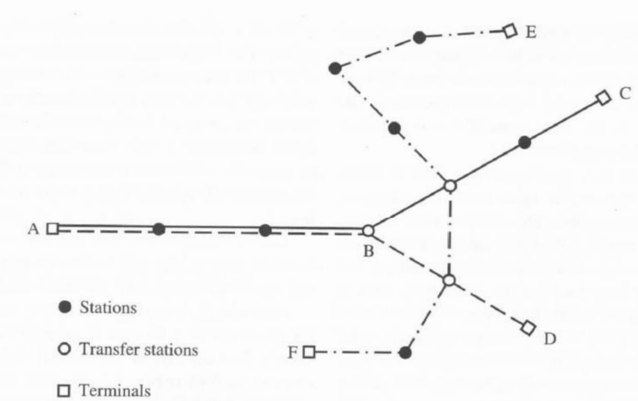


Figure 1.1 Transit line, network, and station concepts. Assuming that each spacing between stations is 1 km long, the values in this network are:

Line, Network, Stop, and Station

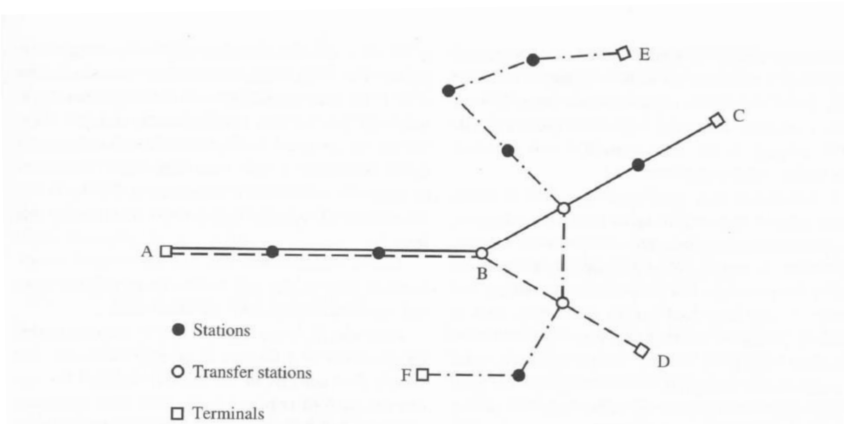


Figure 1.1 Transit line, network, and station concepts. Assuming that each spacing between stations is 1 km long, the values in this network are:

Vehicles, Transit Units, and Fleet Size

The fleet utilization factor, ϕ, is the percentage of fleet available for service:

$$\varphi = \frac{N + N_r}{N_f}$$

Line, Network, Stop, and Station

Transit stop	• Location along a line at which transit vehicles stop to pick up or drop off passengers
Transit station	• Special structure and facility for passenger boarding/alighting, waiting, and transfer
Transfer stations	• Joint stations for two or more lines where passengers can transfer between lines
Terminals	• Stations at the end of a line; sometimes also used to describe major transfer stations

Vehicles, Transit Units, and Fleet Size

- *Transit unit* (TU): A set of n vehicles traveling physically coupled together
  - For buses and single-vehicle operations, $n = 1$
  - For train operation, $n > 1$
- Frequency on a line, f, is TU/h
- $f * n$ = Number of vehicles past a fixed point during one hour
- *Fleet size,* N_f, consists of the vehicles needed for regular service, N (determined by peak hour operation); vehicles needed for reserve, N_r; and vehicles on maintenance and repair, N_m:

$$N_f = N + N_r + N_m$$

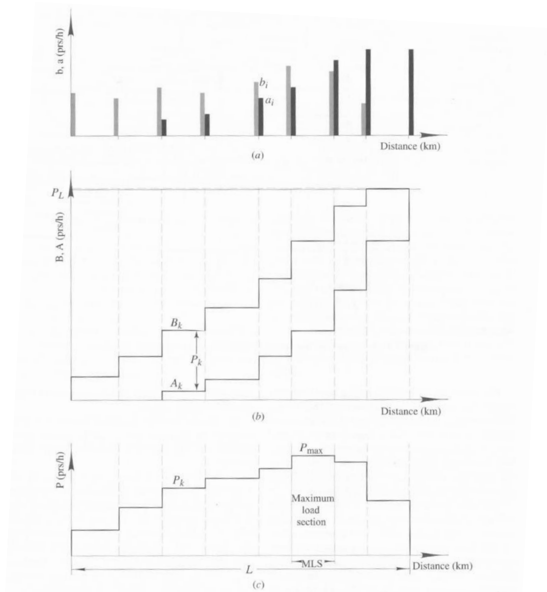


Figure 1.3 Passenger boarding, alighting, and volume diagram for a transit line: (a) boarding and alighting volumes at stations; (b) cumulative boardings and alightings along the line; (c) passenger volumes transported along the line.

Capacity, Work, and Utilization

- ***Vehicle capacity*** C_v is the maximum number of spaces for passengers a vehicle (or TU) can accommodate
  - Static capacity
  - Can be measured three ways
    - Seats plus standing spaces
      - Used for high-volume rail and bus
      - Standard of 0.25 or 0.20 m^2 floor area per standee is used
    - Seats only
      - Used for services designed to provide seats for all passengers
    - Ratio of seats to standing spaces
      - Sometimes used as a goal for comfort
- ***TU capacity***: $C_{TU} = n \times C_v$

Usage of Service: Passenger Flow and Volume

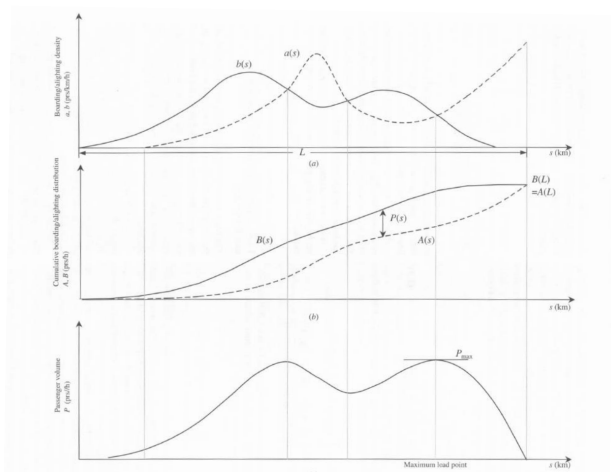


Figure 1.2 Passenger boarding, alighting, and volume along an idealized transit line: (a) boarding and alighting distributions; (b) cumulative functions of boarding and alighting; (c) passenger volume profile.

Operating Elements: Headway and Frequency

- ***Headway*** h is the time interval between the moments two successive TUs pass a fixed point on a transit line in the same direction
- ***Policy headway*** h_p is the longest headway and minimal level of service considered acceptable
- ***Minimum headway*** h_{min} is determined by the physical characteristics of the system and station operations
  - Often determined by minimum headway at station with the heaviest exchange of passengers
- ***Frequency*** is the inverse of the headway. It is the number of TUs passing a point on a transit line in one direction in one hour

$$f = \frac{60}{h}$$

Capacity, Work, and Utilization

Line capacity: The maximum number of spaces that can be transported past a fixed point in one direction during one hour

$$C = C_v * c = C_v * n * f_{max} = \frac{60C_v * n}{h_{min}}$$

Where

- C = line capacity, spaces per hour
- C_v = vehicle capacity
- c = vehicle line capacity, vehicles per hour
- n = number of vehicles per transit unit
- f_{max} = maximum transit unit per hour that can be physically achieved on a line under given conditions (speed, safety, station operations, signal system, etc.)
- h_{min} = minimum headway

Capacity, Work, and Utilization

- ***Transportation work*** *w* performed on a transit line represents its output
  - Offered work w_o can be expressed as vehicle-miles or space-miles. Over entire length *L* of a line, worked performed during one hour is:

    $$w_o = C * L$$

  - Utilized work w_p is represented by passenger-miles; it is computed for one hour as:

    $$w_p = \sum_i p_i * S_i$$

    Where p_i is passenger volume on section *i* of the line and S_i length of that section

Capacity, Work, and Utilization

Table 1.2 Passenger comfort as a function of floor area per standee

Density of Persons prs/m²	Area per Standee m²/prs	Area per Standee ft²/prs	Standing Passengers' Condition
<1	>1.00	>10.8	Independent standing, easy circulation
2–3	0.50–0.33	5.4–3.6	Some body contacts, circulation disturbing others
4	0.25	2.7	Extensive body contacts, difficult movements
5	0.20	2.2	Pressed standing, extremely difficult movements
6.7	0.15	1.6	Crash loads, possible injuries, forced movements

Area conversion: 1 m² = 10.76 ft².

Capacity, Work, and Utilization

- ***Scheduled line capacity*** C_o is the number of spaces transported past a fixed point in one direction during one hour under a given operating schedule
- Ratios of scheduled to absolute capacities represented utilization coefficients of service frequency δ_f, vehicle line capacity δ_v, and schedule line capacity δ

  $\delta_f = f/f_{max}$; $\delta_v = n*f/c$; $\delta = C_o/C$

Capacity, Work, and Utilization

Table 1.1 Capacity, work, and utilization concepts related to transit line operation

Category	Definition	Derivation Formula	Units: Offered	Units: Utilized	Utilization Coefficient
Static capacity	Vehicle capacity (seats only or seats + standing spaces)	C_v (given)	C_v (sps/veh)	P_v (prs)	$\alpha_v = P_v/C_v$
Dynamic capacity	Maximum frequency	f_{max}	f_{max} (TU/h)	f (TU/h)	$\delta_f = f/f_{max}$
	Vehicle line capacity	$f_{max} \cdot n$	c (veh/h)	$f \cdot n$ (veh/h)	$\delta_v = f \cdot n/c$
	Line capacity, min (C_w, C_s)*	$f_{max} \cdot n \cdot C_v$	C (sps/h)	P (prs/h)	$\alpha = P/C$
	Scheduled capacity	$f \cdot n \cdot C_v$	C_o (sps/h)	P (prs/h)	$\alpha = P/C$
					$\delta = C_o/C$
Transportation work	Work on a line during one hour	$f \cdot n \cdot C_v \cdot L$	w (sp-km/h)	w_p (prs-km/h)	$\alpha = w_p/w$
Productive capacity	Product of capacity and speed	$f \cdot n \cdot C_v \cdot V_o$	P_c (sp-km/h²)	(not used)	(not used)

* Way capacity C_w and station capacity C_s are defined in Section 2.1.

Travel Times

- On-line travel times
  - Running time t_r
  - Station standing (dwell) time t_s
  - Station-to-station travel time T_s

$T_{si} = t_{ri} + t_{si}$

If TUs cannot reach max speed:

$$T'_s = t_a + t_b + t_s = \sqrt{\frac{2(\bar{a}+\bar{b})\,S'}{\bar{a}\bar{b}}} + t_s$$

Where t_a and t_b are accelerating and braking intervals; $\bar{a}$ and $\bar{b}$ are average acceleration and deceleration rates, measured in m/s²; and S' is station spacing

If TUs can reach max speed V_{max}:

$$T_s = \frac{3.6S}{V_{max}} + T_\ell$$

Where T_ℓ = incremental time loss per stopping at one station, computed as:

$$T_\ell = \frac{V_{max}}{7.2}\left(\frac{1}{\bar{a}} + \frac{1}{\bar{b}}\right) + t_s$$

Capacity, Work, and Utilization

- ***Work utilization coefficient*** $\bar{\alpha}$ is the ratio of utilized to offered work

$$\bar{\alpha} = \frac{w_p}{w_o}$$

- ***Productive capacity*** P_c is the product of line capacity and its operating speed

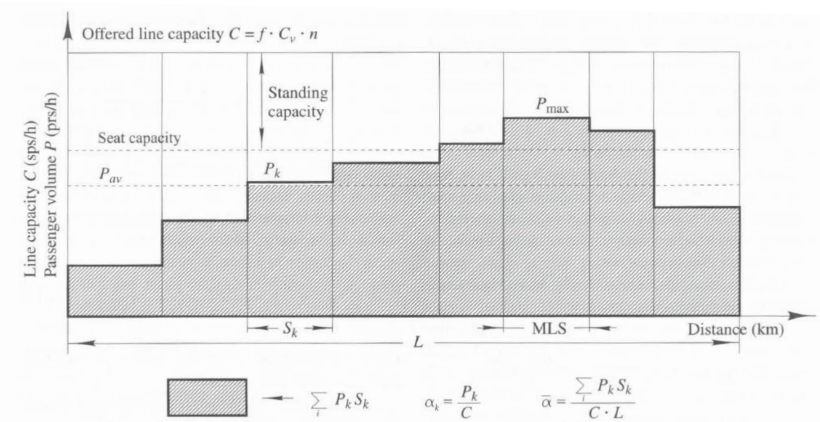


Figure 1.5 Line capacity, passenger volume, and utilization factors.

Travel Times

- Passenger travel times
  - Access time t_a
  - Waiting time t_w
  - On-line travel time t_o
  - Transfer time t_f
  - Origin-destination travel time T_{od}

$$T_{od} = t_a + t_w + t_o + t_f$$

Speeds

Table 1.3 Transit speeds and corresponding travel times

Category	Speed Designation	Symbol	Corresponding Travel Time
Vehicle speed	1. Actual vehicle	V, v	—
	2. Maximum technical	V_{max}	—
Alignment speeds	3. Line design	V_d	—
	4. Legal	V_ℓ	—
	5. Programmed	V_g	—
Vehicle-on-line speeds	6. Running	V_r	t_r
	7. Station-to-station	V_s	T_s
	8. Operating	V_o	T_o
	9. Cycle	V_c	T
	10. Platform	V_p	T_p
Passenger speeds	11. Access	V_a	t_a
	12. Travel on line	V_o	T_o
	13. Origin-destination	V_{od}	T_{od}

Travel Times

- On-line travel times (cont.)
  - Operating (travel) time T_o

$$T_o = \sum_i T_{si}$$

  - Terminal time t_t
    - Vehicle turning, resting of crew, adjustment in schedule, recovery of delays
  - Cycle time T
    - Total round-trip time on a line
    - Basic time unit for scheduling transit service

$$T = T_o' + T_o'' + t_t' + t_t'' = 2(T_o + t_t)$$

  - Deadhead time t_d
  - Platform time T_p

$$T_p = kT + 2t_d$$

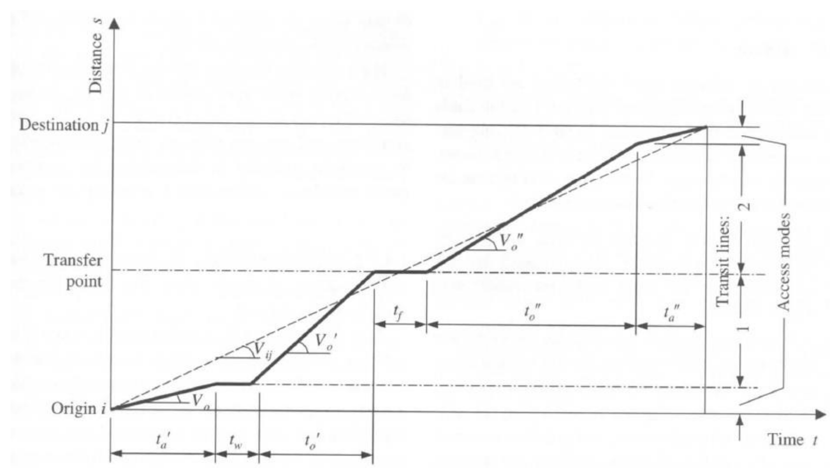
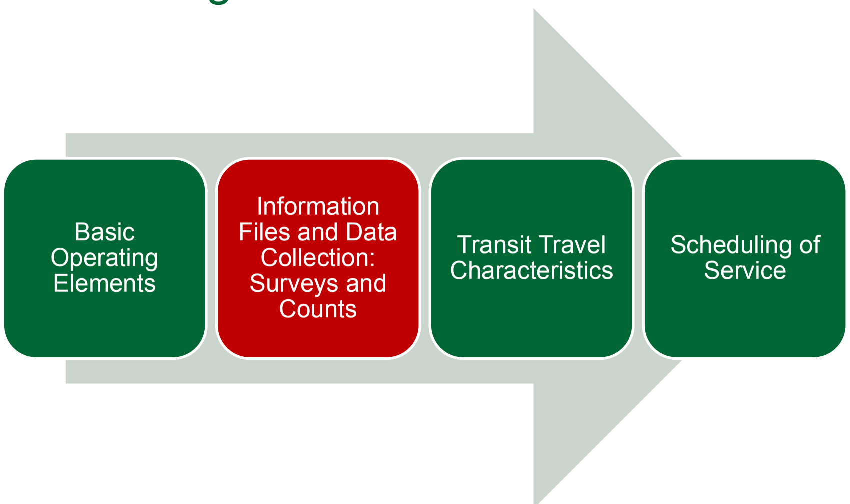


Figure 1.7 *Passenger travel times and speeds.*

Transit Operations and Service Scheduling



Information Files

- Physical inventories of lines and facilities
- Vehicle data
- Operating conditions of lines
- Types of services provided and schedules
- Usage of services
- Miscellaneous information on events in operations, fares, and passenger attitudes

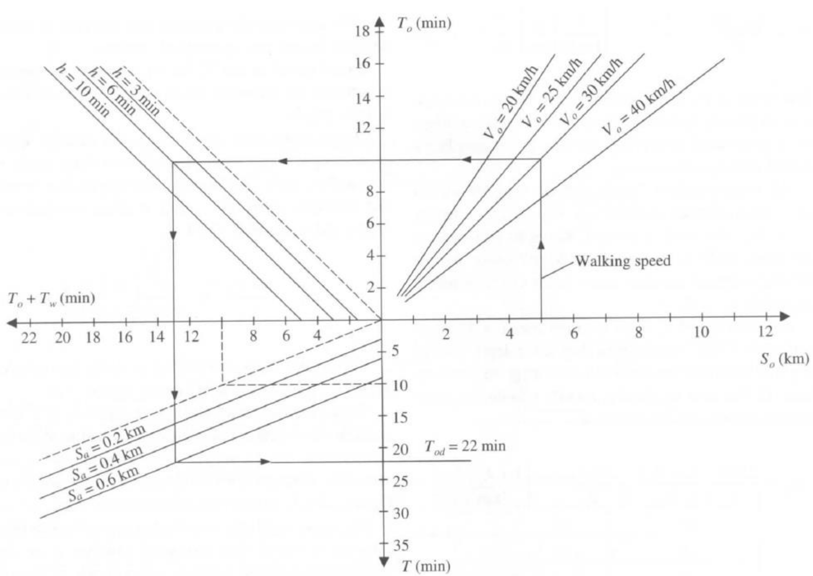


Figure 1.10 Diagram for computation of passenger origin-destination travel time by transit.

Information Files and Data Collection: Surveys and Counts

- Organization of Surveys
- Transit Speed-and-Delay Survey
- Passenger Volume and Load Count
- Passenger Boarding and Alighting Counts
- Other Types of Surveys

Transit Speed-and-Delay Survey

- Finds the distribution of time a TU spends in travel, classified as running, dwells at passenger stops, and several categories of delays
- Records locations, durations, and causes of delays
- Ways to obtain data
  - Rider in front seat of vehicle who observes reasons for slowdowns and stops
    - The observer is given detailed instructions on how to define stopped times and how to classify causes of delay
  - On-board computer connected to the vehicle's power supply, drive shaft, and door-opening mechanism
    - Records locations and times of each vehicle start and stop, as well as door openings
  - Equipment monitoring travel of TUs
    - GPS, automatic vehicle location (AVL)
  - Automated recording systems for systems with automatic driving
- Data are used for analyzing efficiency of operations and are important for planning new routes or operational changes

Passenger Boarding and Alighting Counts

- Counts of boarding and alighting at each stop or station provide most detailed information on passenger volumes
  - Number of passengers using each station
  - TU loads at all points along the line
  - Distribution of passenger trip lengths
  - Passenger miles for each line per day or hour

Organization of Surveys

- Good planning and continuity in data collection are necessary
- Must compromise between need for accurate data and cost of surveys
- A good practice is to organize major, detailed surveys at longer intervals and supplement them with minor ones

Passenger Volume and Load Count

- Purpose of passenger counts is to determine
  - Passenger volumes on TUs over different sections of a line
  - Maximum TU load and the section on which that occurs
  - Variations of volumes in time
  - Analysis of service quality
- Detailed survey should include TU passenger load counts at several points along each line

Other Types of Surveys

- Transfer counts
- Fare usage
- Passenger travel information
  - Actual origins and destinations of entire trips
  - Lengths and modes of access
- Attitudinal and modal split surveys
  - Preferences of passengers with respect to service parameters such as headway length, speed, reliability, fare level, etc., and the relative importance
- Use of timetables

Transit Travel Characteristics

- Transit demand – alternate definitions
  - Number of passengers who want to use a given service and pay its price (same as passenger travel volume)
  - Volume of travel that would take place when service is good and price low enough (potential transit demand)
- Latent demand: unrealized travel
  - The difference between potential transit demand and actual passenger volume

Passenger Boarding and Alighting Counts

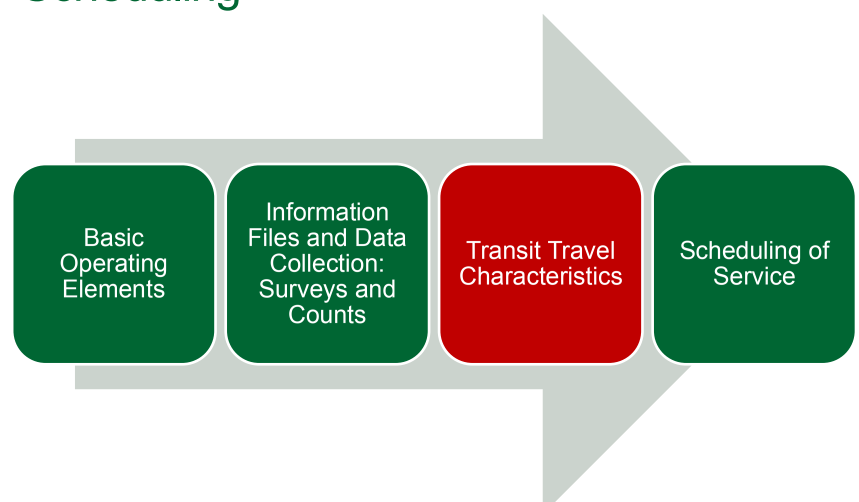
Table 1.4 Summary of passenger counts and computation of person-kilometers

Route no. *41* — Direction *NB* (Departure from South terminal) — Time period *16:30–17:30*

	Number of Passengers				
Transit Stop	*Boarded*	*Alighted*	*On Vehicle*	*Km Between Stops*	*Person-km*
1 (South terminal)	48	—	48	2.2	105.6
2	35	12	71	2.8	198.8
3	54	30	95	3.2	304.0
4	29	13	111	3.4	377.4
5	16	46	81	2.0	162.0
6 (North terminal)	—	81			
Totals	182	182	—	13.6	1147.8

Average trip length: 1147.8 : 182 = 6.3 km
Average boardings/km: 182 : 13.6 = 13.4 prs/km
Average passenger volume/km: 1147.8 : 13.6 = 84 prs-km/km

Transit Operations and Service Scheduling



Spatial Distribution of Transit Travel

- Distribution of travel demand by area and direction is a function of city form and land use
- Highest travel volumes on radial directions toward the area with most intensive activities – the Central Business District
- Regional subcenters in suburban areas are also generators of large travel volumes

Passenger Volume Analysis and Service Capacity Determination

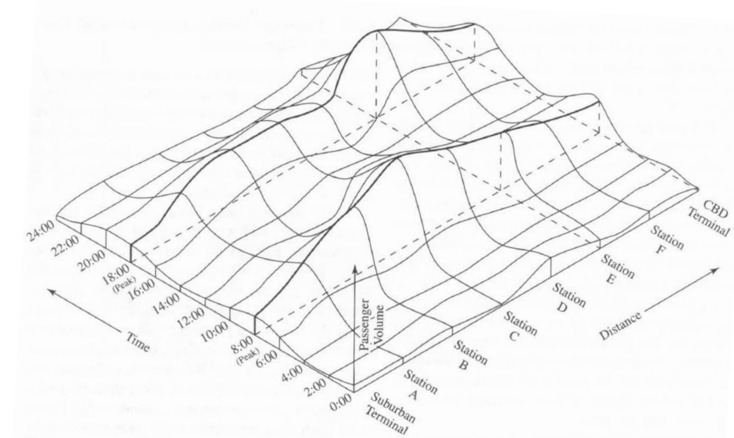


Figure 1.18 Three-dimensional presentation of passenger volume distribution in distance and time along the line from a suburban to the CBD terminal. (Design: Thor Haatveit.)

Factors Influencing Transit Travel

- Total volume of passenger travel in a city
- Transit level of service and price
- Concentration of potential travel demand

Temporal Variations of Transit Travel

- Caused by differences in travel patterns and levels of service of competing modes
- Can vary by time of day, day of week, and time of year
- Peak-to-base ratio: Ratio of highest hourly volume to the average off-peak hourly volume

Passenger Volume Analysis and Service Capacity Determination

- To satisfy variable demand and achieve good utilization of capacity, service can be tailored to cover the demand as closely as possible, by:
  - Changing headways (shorter during peaks)
  - Using different TU sizes/capacities
    - Common in rail transit – additional cars can be added during peak demand
    - Rare for buses (not common to use different buses)
  - Operate TUs on certain sections of the line only (providing additional capacity in peak areas) (short-turn trains)

Characteristics of Travel on a Transit Line

Average passenger volume, P_{av}: total passenger miles on line divided by its length, *L*

$$P_{av} = \frac{\sum_{i=1}^{n} p_i * l_i}{L}$$

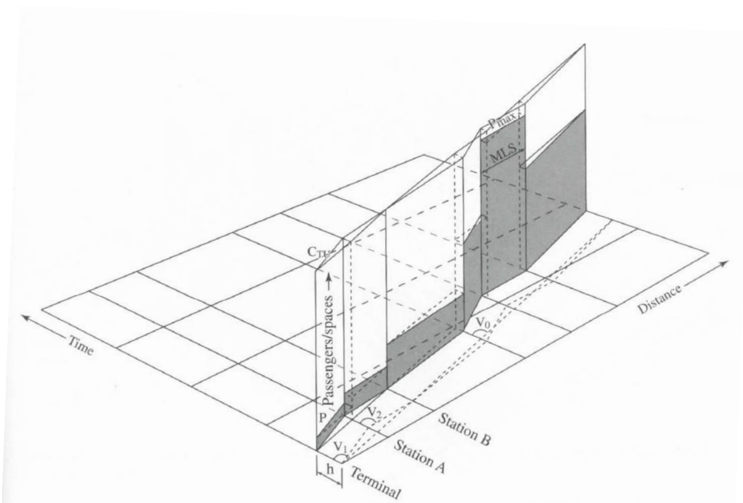


Figure 1.19 Travel of a TU in its passenger load profile along the line.

Characteristics of Travel on a Transit Line

Average passenger trip length, l_{av}: total passenger miles divided by number of passengers

$$l_{av} = \frac{1}{p_t} \sum_{i=1}^{n} p_i * l_i$$

p = number of passengers

l = interstation distance or spacing

Characteristics of Travel on a Transit Line

Coefficient of passenger exchange, η_x, indicates what portion of passengers are exchanged along a line (turnover rate.) It is defined as the ratio of total passengers who board along a line to those who did not replace the alighting passengers

$$\eta_x = \frac{B_L}{B_L - P_x} = \frac{L}{l_{av} * \eta_f}$$

Where P_x is the area of overlap of B_L and A_L

η_x indicates intensity of passenger exchange

Indicators of Transit Usage

- ***Riding habit***: Ratio of annual transit rides to population of area served
  - Generally greater for larger cities
  - Quality of transit is a significant factor
- ***Mode split***, transit travel as a percentage of total travel, shows the relative role that transit plays
  - Analyzed by areas of the city, individual corridors, or travel purposes

Characteristics of Travel on a Transit Line

Coefficient of flow variations, η_f, expresses the degree to which passenger volume peaks along the line, it is the ratio of maximum volume P_{max} and average volume P_{av}

$$\eta_f = \frac{P_{max}}{P_{av}} = \frac{L * P_{max}}{\sum_{i=1}^{n} p_i * l_i}$$

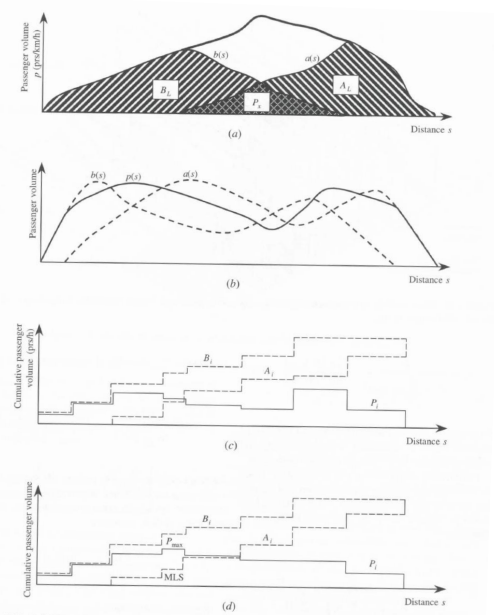


Figure 1.22 Definition of the passenger exchange coefficient η_x: (a) the concept of passenger exchange coefficient; (b) general case of boarding, alighting, and flow functions; (c) discrete boarding and alighting functions; (d) discrete boarding, alighting, and load functions; P_{max} defines the MLS.

Scheduling of Service

- Components of the scheduling process
- Determination of service requirements
- Scheduling procedure
- Graphical presentations of transit operations
- Crew scheduling
- Use of computers in scheduling
- Measures of operating efficiency

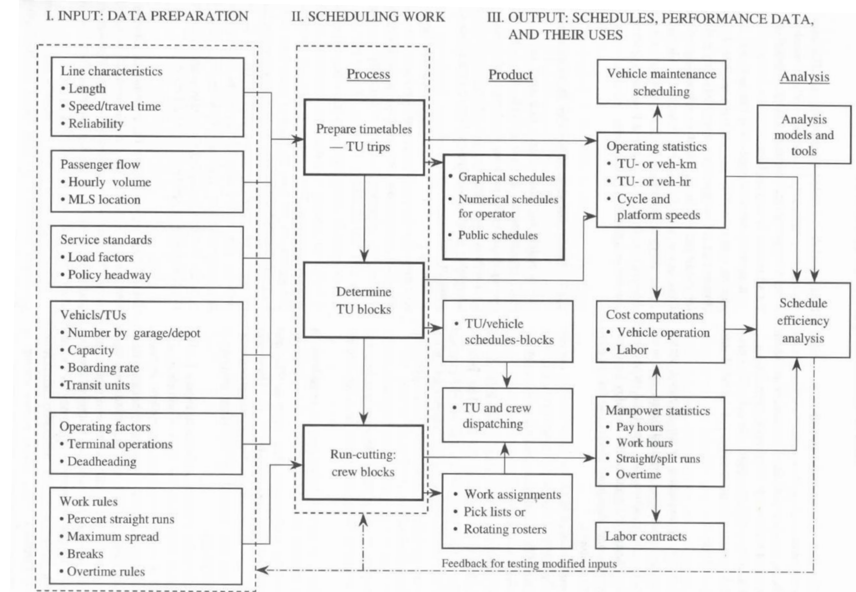
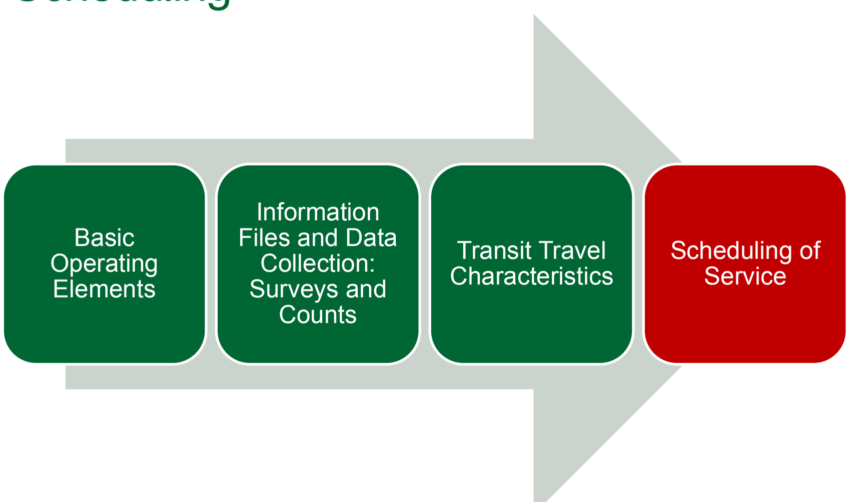
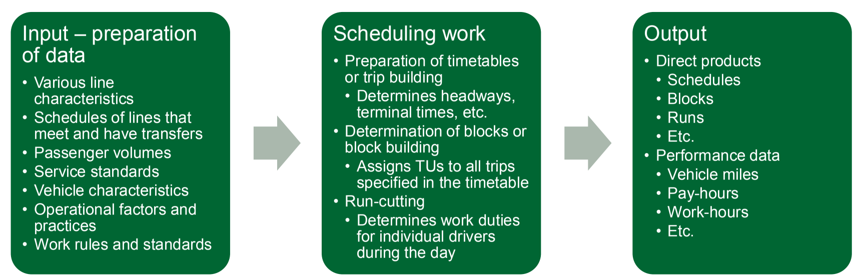


Figure 1.23 Flowchart of transit scheduling.

Transit Operations and Service Scheduling



Components of the Scheduling Process: Three Phases



Passenger Load Profile Diagram

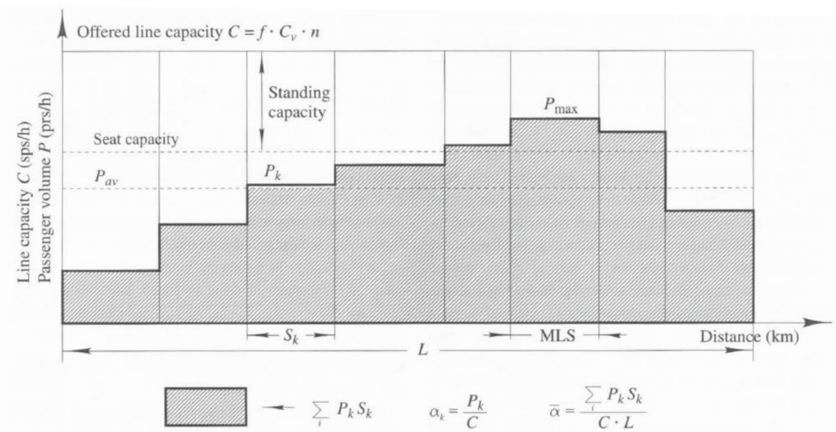


Figure 1.5 Line capacity, passenger volume, and utilization factors.

Temporal Variations Diagram

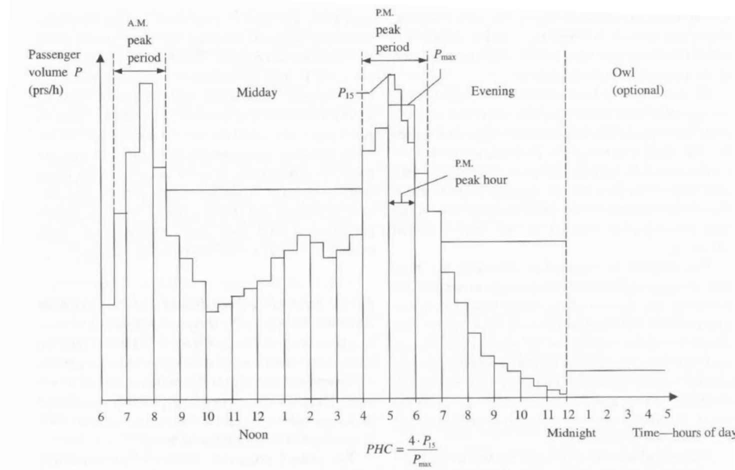


Figure 1.25 Hourly variations of passenger volume on a line and its scheduling periods.

Determination of Service Requirements

- Two basic requirements for schedule
  - It must provide adequate transporting capacity for passenger volume
  - It must offer a certain minimum frequency of service
- Basic information needed
  - Expected volume of passengers
  - Passenger volume distribution in distance and time

Passenger Load Profile Diagram

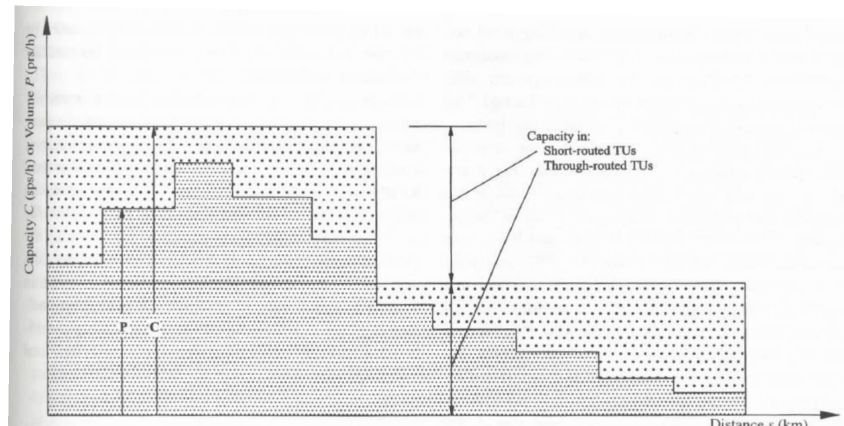


Figure 1.24 Offered capacity and its utilization on a transit line with through- and short-turn TUs.

Scheduling Periods and Design Passenger Volumes

- Design volume, P_d:

$$P_d = P_{max} * PHC$$

- Scheduling done for each scheduling period separately
- Capacity can be increased during peak period by:
  - Shortening headways
  - Increasing the capacity of TUs

Required Capacity: Other considerations for determining load factor, α

Lower values for α	Higher values for α
Uniform passenger distribution along the line	Uneven passenger distribution
High ratio of seated to standing passengers	Higher percentage of standing passengers
Longer average trip length	Shorter average trip length
High percentage of senior citizens or shoppers with packages	High percentage of school children
	Transporting large crowds to special events (max value)

Scheduling Periods and Design Passenger Volumes

- The number and durations of different scheduling periods are determined based on the temporal distribution of passenger volumes
- The maximum load section (MLS) is not always the same during all scheduling periods
- Considerations of detailed variations in time
  - The peak hour coefficient (PHC) is the ratio of the highest 15-minute volume multiplied by four and the total hourly volume on the MLS

$$PHC = \frac{4p_{15}}{P_{max}}$$

Required Capacity

- The level of offered capacity is determined by the selection of the maximum value for the load factor, α, considering the tradeoff:
  - For passenger comfort and convenience, lower values of α result in less crowding, higher availability of seats, and more frequent service
  - Cost of operation is lower when a higher value of α is adopted, because a smaller number of vehicles is required to transport a given passenger volume

Scheduling Procedure

- Design hour volume P_d divided by the average number of passengers a TU will carry on MLS gives the required frequency

$$f = \frac{P_d}{\alpha * n * C_v}$$

- Headway:

$$h = \frac{60}{f} = \frac{60 * \alpha * n * C_v}{P_d}$$

  - If h > 6 min, it should be rounded down to the nearest clock headway (divisible into 60: 6, 7.5, 10, 12, 15, 20, 30, 60)
  - This value of h should be compared to the adopted policy headway, and the smaller of the two should be used

Scheduling Procedures

Cycle time, T: $T = 2(T_o + t_t) = 2T_o(1+\gamma)$

Terminal time coefficient: $\gamma = \frac{t_t' + t_t''}{2T_o}$

Number of TUs, N_{TU}:

$$N_{TU} = \left\lceil \frac{T}{h} \right\rceil \quad \text{(round up)}$$

Adjust T to final cycle time as follows:

$$T = h \cdot N_{TU}$$

Terminal time: $t_t = \frac{T - 2T_o}{2}$

Selection of TU Size, Frequency, and Load Factor

$$C = n * C_v * \alpha * f$$

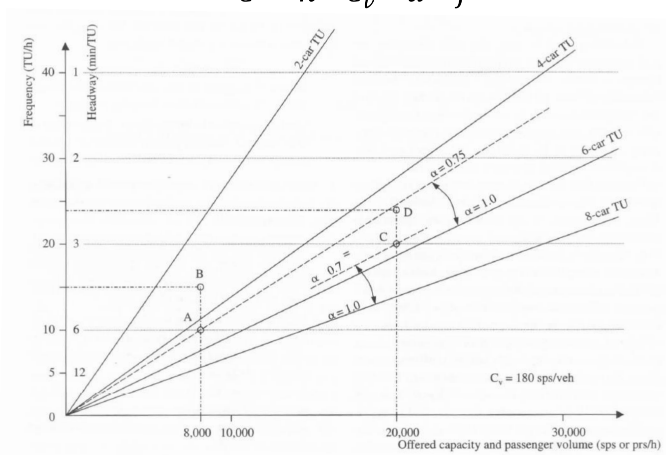


Figure 1.26 Diagram for selection of TU size and headway for different scheduling periods.

Scheduling Procedure

- Actual values of f and α (after rounding h)

$$f = \frac{60}{h}$$

$$\alpha = \frac{P_d * h}{60n * C_v}$$

Procedure Summary

- Step 1: Prepare data and determine factors
  - Line length: L (miles)
  - One-way operating time: T_o (minutes)
  - TU capacity: C_v (spaces/vehicle) and n (veh/TU)
  - Policy headway: h_p (minutes/TU)
  - Load factor (on MLS): α (persons/space)
  - Design volume: P_d (persons/hour) (includes PHC)
  - Minimum terminal time: t_t (minutes) or minimum value of γ
- Step 2: Compute headway and frequency
- Step 3: Determine fleet size
- Step 4: Compute cycle and terminal times
- Step 5: Compute cycle speed

Graphical Presentations of Transit Operations

- Graphical presentations can be used in planning, operations, and analysis
  - Time-distance
  - Time-speed
  - Distance-speed
  - Time-energy consumption

Scheduling Procedures

Cycle speed: $V_c = \frac{120L}{T} = \frac{120L}{h * N_{TU}}$

Operating speed: $V_o = \frac{120L}{T_o' + T_o''}$

Number of TUs: $N_{TU} = \frac{120L}{h * V_c}$

Examples

a. A street transit route operated by 45-seat buses for peak periods
b. The same route for base periods
c. A rapid transit line operated by vehicles with total (seats plus standing) capacity of 140, in trains of up to six cars, for peak hours
d. The same line during base periods, minimum train consisting of a married pair

Crew Scheduling or Run-Cutting

- Assign personnel to a given schedule of TU operations
  - Minimize expenditures for wages
  - Subject to operating and work rules
- Basic concepts
  - Straight run: Continuous work shift (usually 8 hours)
  - Split run: Work shift split between two peaks (with time between)
  - Spread time: Time interval between beginning of work in morning and end of work later in day
  - Extras or trippers: Short time segments

Use of Computers in Scheduling

- Operations research algorithms used to analyze schedule and run-cutting variations
- Total cost and various coefficients of utilization are computed
- Variations in scheduling (changes in initial inputs, work assignments, wage rates, etc.) can be tested
- Numerous local details and procedural peculiarities require the attention of a person familiar with the system

Time-Distance Diagram

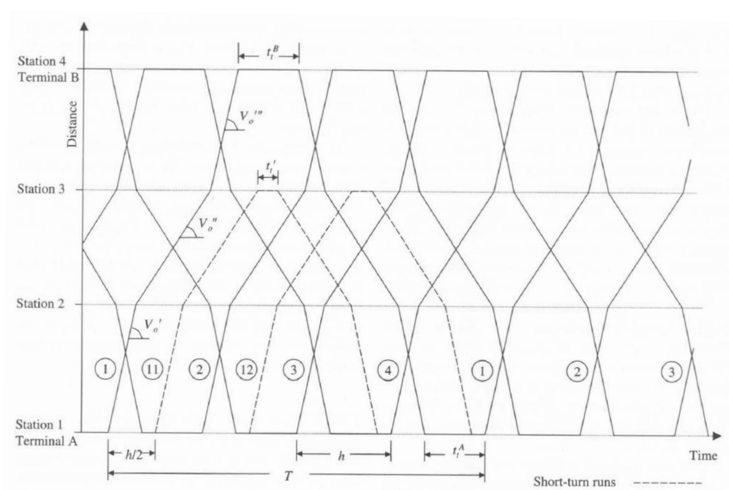


Figure 1.28 Graphical schedule for a transit line with regular and short-turn runs.

Run-Cutting Procedure

- Basic procedure:
  1. Develop as many straight runs as possible
  2. Form split runs within spread time
  3. Divide some straight runs into two or three segments (extras) and combine these segments with the extras left over from step 2 to form additional split runs
  4. Analyze the efficiency (total expenditure) of the obtained solution. If not satisfactory, investigate possibilities for pairing with other routes so that TUs alternate between them

Measures of Operating Efficiency

- Operating Personnel Efficiency
  - Operating personnel efficiency coefficient, η, consists of
    - η_a, attendance coefficient, which represents the ratio of reported hours t^r to paid hours t^p, accounting for losses due to vacation, illness, and other absences
    - η_s, coefficient of run-cutting, is the ratio of hours on transit line t^l to reported hours t^r, including losses caused by split shifts, work preparation, deadheading, etc.
    - η_t, coefficient schedule efficiency

$$\eta = \eta_a \cdot \eta_s \cdot \eta_t = \frac{t^r}{t^p} \cdot \frac{t^l}{t^r} \cdot \frac{2 \cdot T_o}{T} = \frac{t^l}{t^p(1+\gamma)}$$

Measures of Operating Efficiency

- Schedule efficiency
  - η_t reflects terminal time losses

$$\eta_t = \frac{T_o' + T_o''}{T}$$

$$\eta_t = \frac{1}{1+\gamma} = 1 - \gamma'$$

$$\eta_t = \frac{V_c}{V_o}$$

If $T_o' = T_o''$: $\eta_t = \frac{2T_o}{N_{TU} \cdot h} = 1 - \frac{2t_t}{N_{TU} \cdot h}$

Factors Affecting Transit Ridership

Internal factors (within control of transit agency)	External factors (beyond control of transit agency)
• Service adjustments or improvements • Partnerships and coordination • Marketing, promotional and information initiatives • Fare collection and fare structure	• Population characteristics and changes • Economic conditions • Cost and availability of alternative modes • Travel conditions • Public policy and funding initiatives

Elasticity

A measure of the responsiveness of demand to changes in the factors determining the level of demand.

$$e_{x_i} = \frac{\textit{The proportional change in demand}}{\textit{The proportional change in the explanatory variable}}$$

$$e_{x_i} = \frac{\Delta y}{y} \Big/ \frac{\Delta x_i}{x_i}$$

where Δy = change in demand y

Δx_i = change in explanatory variable x_i

DEMAND ANALYSIS

Balcombe et al. (2004) *The Demand for Public Transport: A Practical Guide*, Chapters 3 and 5

Ceder, Avishai (2007) *Public Transit Planning and Operation,* Chapter 11

TCRP Report 161 – Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation: Final Workbook

TCRP Web-Only Document 58 – Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation

Elasticities

- **Elasticities of demand**: The ratio of the proportional change in ridership to the proportional change in a demand factor
  - Elasticity with respect to (w.r.t.) price
  - Elasticity w.r.t. travel time
  - Elasticity w.r.t. waiting time
  - Etc.

Elasticity

- Point elasticity
  - Calculates percentage change based on initial value
  - Generally can only be used for limited changes in the explanatory variables
- Arc elasticity
  - Calculates percentage change based on midpoint
  - Used when larger changes in the explanatory variables are considered
- Log Arc elasticity
  - $e^{arc} = \frac{\Delta\,(\log y)}{\Delta\,(\log x_i)}$

Variations in elasticities

- Short-run vs. long-run
  - Higher (more elastic) in the long run
- Off-peak vs. peak
  - Twice as high for off-peak
- Leisure trips vs. commuting trips
  - Twice as high for leisure

Elasticity

- Own-elasticities: Changes in demand for a particular mode brought about by changes in variables associated with <u>that mode</u>
  - Own-elasticities w.r.t. fares and travel time are expected to be negative
- Cross-elasticities: Changes in demand for a particular mode brought about by changes in variables associated with <u>other modes</u>
  - For example, the demand elasticity of bus travel with respect to rail fares or gas prices
  - Cross-elasticities w.r.t. prices and time are expected to be positive if modes compete with transit or negative if modes are complementary

Elasticity

Shrinkage ratio: $e^s = \left[\frac{y_2 - y_1}{x_{i2} - x_{i1}}\right] * \left[\frac{x_{i1}}{y_1}\right]$

$$y_2 = y_1 + \frac{e^s * y_1(x_{i2} - x_{i1})}{x_{i1}}$$

Elasticity

- Short-run elasticities: demand response within a year or two of a change
- Medium-run elasticities: demand response within five or so years of a change
- Long-run elasticities: demand response within ten years or so of a change

Fare Elasticities

- Fare elasticities are different for different trip purposes
- Fare elasticities may be affected by
  - The magnitude of the fare change
    - Greater fare increases produce higher elasticity values
    - Differences are greatest for long-term elasticities
  - The direction of the fare change
    - Elasticities may not be symmetrical: response to a fare decrease may not be equal and opposite to the response to a fare increase
    - Little evidence regarding possible asymmetry
  - The level of the fare
    - Affected by the current level of the fare relative to people's income
    - Greater when fare levels are high

Short-run vs. Long-run

- Might take some time for all consumers to become aware of new or improved transit service
- Some consumers are slow to change behavior (habit plays a role)
- Some consumers will be constrained by various factors – some factors are fixed in the short run but can change in the long run, such as residential or workplace locations
- Path dependency (the sequence of change is important)
- If changes are rapid, consumer response never settles down

Fare Elasticities

- Bus fare elasticities average
  - -0.4 in the short run
  - -0.56 in the medium run
  - -1.0 in the long run
- Metro rail fare elasticities average
  - -0.3 in the short run
  - -0.6 in the long run
- Local suburban rail elasticities average
  - -0.6 in the short run

Fare Elasticities

- Elasticities for different types of traveler
  - Travelers with access to a car have other options and are more responsive to fare changes – greater elasticities
- Variations by gender and age possible
- Effect of income
  - If higher income
    - More likely to own car and have other options, so could be more responsive to fare levels
    - But, less sensitive to price changes in general and more able to absorb the effects of a fare increase

Fare Direct and Cross Elasticities

Table 11.5 *Adjusted fare (or trip cost) direct and cross-elasticities for commuting trips in Sydney.*

Mode of travel	Train	Bus	Ferry	Car
Train	*−0.156*	0.032	0.003	0.037
Bus	0.063	*−0.070*	0.006	0.046
Ferry	0.039	0.037	*−0.195*	0.003
Car	0.016	0.011	0.000	*−0.024*

Source: Balcombe *et al.* (2004), Table 9.22.

Fare Elasticities

- Variations in different types of areas
  - Urban vs. rural
    - Higher elasticities in rural areas
- Fare elasticities for different trip purposes
  - Peak period trips
    - More work and education trips
    - Less flexibility
    - Inelastic demand
  - Off-peak trips
    - More leisure, shopping, and personal business trips
    - Greater flexibility
    - Higher elasticities (about twice peak values)
  - Work and education trips have lower elasticity values

Fare Elasticities

- Elasticity by distance traveled
  - Very short trips – people have the option of walking, and elasticities tend to be high
  - Long trips – fares are higher and represent a greater portion of incomes, leading to higher elasticities
  - Medium-length trips tend to be less elastic
  - Very long trips may be less elastic due to tapered fare scales
  - For rail, fare elasticities tend to decrease with distance
    - Possibly due to tapered scales – fare per unit distance often decreases with increasing distance

Quality of Service Factors Affecting Demand

- Access time to boarding point and egress time from alighting point
- Service frequency
- Time spent on board the vehicle
- The waiting environment
- Effect of vehicle or rolling stock characteristics
- Transfers
- Reliability
- Information provision
- Marketing and promotion
- Bus specific factors

Service Intervals

- Can be measured in different ways: Vehicle miles, vehicle hours, frequency, headway/service interval, wait time, schedule delay
- Elasticity of demand w.r.t. vehicle miles
  - Bus: about 0.4 in the short run and 0.7 in the long run
    - Much greater on Sundays and in the evenings, when service levels are lower
  - Rail: about 0.75 in the short run, no long-run estimate
  - Tend to be higher in rural areas, where there is less service
- Elasticity of bus demand w.r.t. passenger waiting times
  - Average value: -0.64
  - Tends to be higher for off-peak trips and trips to non-central destinations
- Elasticity of bus demand w.r.t. vehicle hours: 1.0
- Value of waiting time in terms of in-vehicle times
  - Bus: wait time valued at 1.6 times in-vehicle time
  - Rail: wait time valued at 1.2 times in-vehicle time

Elasticities

Table 11.3 *Recommended direct-transit elasticity values*

	Market segment	Short run	Long run
Transit demand in regard to the attribute of fares	Overall	−0.2 to −0.5	−0.6 to −0.9
	Peak hours	−0.15 to −0.3	−0.4 to −0.6
	Off-peak hours	−0.3 to −0.6	−0.8 to −1.0
	Suburban commuters	−0.3 to −0.6	−0.8 to −1.0
Transit demand in regard to the attributes of service quality	Overall	0.5 to 0.7	0.7 to 1.1
Transit demand in regard to the attribute of car operating cost	Overall	0.05 to 0.15	0.2 to 0.4
Car users in regard to transit costs	Overall	0.03 to 0.1	0.15 to 0.3

Source: Litman (2004), Table 11.

Access and Egress Time

- Walking times to and from bus stops and stations has been weighted at a range between 1.4 and 2.0 units of vehicle time
- Access and egress by other modes (including driving, cycling, etc.) has been weighted similarly (1.3 to 2.1)

Generalized costs

- Generalized cost brings together fare, in-vehicle time, walk and wait times
- To estimate generalized costs requires estimates of appropriate values of trip attributes, including values of time
- Estimates of average values of time
  - Value of IVT increases with distance, with a larger increase for the car mode
  - Rail users have higher values of IVT than car users, and bus users have lowest values
  - Value of walk, wait, and headway times vary with user type
    - Car users more averse to walking and waiting, and bus users have the lowest values of walk and wait time
  - For urban trips, value of time is greater for commuting trips than leisure trips
  - Bus users have the lowest value of time

Effect of vehicle or rolling stock characteristics

- Passengers prefer clean, comfortable vehicles that are easy to get on and off, but it is difficult to quantify the relative importance of these factors
- Stated preference (SP) surveys used to value trade-offs
- Perceived values of vehicle attributes are much smaller than the value of in-vehicle time
- Overcrowding can affect demand by increasing the value of in-vehicle time

Time Spent Onboard Vehicle

- Limited evidence on elasticities w.r.t. in-vehicle time (IVT)
  - Urban buses: -0.4 to -0.6
  - Urban or regional rail: -0.4 to -0.9
  - Longer interurban trips: -2.1 for bus, -1.6 for rail

The waiting environment

- Comfort, cleanliness, safety, and protection from the weather are important for passengers who must wait
- Attribute values have been derived for various aspects of bus shelters, seats, lighting, staff presence, closed-circuit TV and bus service information

Reliability

- Problems with poor reliability
  - Long waiting times due to late arrival
  - Excessive in-vehicle times due to traffic or system problem
- Reliability can be expressed in terms of standard deviations in waiting or in-vehicle times
- Limited evidence suggests perceived penalties are equivalent to the standard deviation multiplied by the corresponding value of waiting or in-vehicle time
  - Example: Mean waiting time = 5 min; St. dev = 2.5 min; then effective waiting time = 7.5 min

Marketing and promotion

- Marketing campaigns are often undertaken in conjunction with other service quality or price changes, rather than in isolation, so it is difficult to measure the impact

Transfers

- Passengers dislike transfers
- Average equivalent penalty: 21 minutes IVT on a bus trip, up to 37 minutes IVT on a rail trip
- Considerable variation in transfer penalties between trip purposes and from place to place
  - Transfer penalties smaller in urban areas with high-frequency service

Information provision

- Information about transit services is necessary for riders or potential riders
- Little direct evidence of effects of information systems on demand
- Real-time information provides value to riders

Bus specific factors

- Simplified networks
  - Providing high-frequency routes on a simpler network, while providing lower-frequency service for local access, yields a more attractive service
  - If headways are 10-12 minutes or less, passengers tend to arrive randomly at stops, without needing or bothering to consult a timetable

Effect of income on travel expenditure and distance traveled

- Income has positive effect on amount of travel
- Elasticity of trip length w.r.t. income: 0.09 to 0.21 (higher for car commuting and business trips)

Bus specific factors

- Boarding and alighting
  - Longer boarding and alighting times lead to:
    - Greater average trip times
    - Greater variability in trip times
    - Increase in dwell time at stops, causing additional delays under high-density operating conditions when following buses are unable to enter the stop area
  - A few studies on the ridership impacts of different fare collection systems
  - Low-floor buses have had positive effect on ridership

Demand Interactions

- Effects of fare changes on competing modes
  - Cross-price elasticities: The ratio of the percentage change in ridership on one mode to the percentage change in fares on another mode
    - Normally positive, indicating substitute relationship
    - Dependent on relative market shares and not readily transferable across time and space
    - Transit use is sensitive to car costs, but car use is much less sensitive to transit costs
  - Competition within modes
    - Competition is more effective at generating demand where original service levels are relatively low and can be substantially improved through competition

Effect of car ownership on public transit demand

- Few studies have concentrated solely on car ownership
- Car ownership has negative correlation with both bus trips and rail trips, with a stronger effect for bus travel

Relationships between Land-Use and Public Transit

- Effects of land use on transit demand
- Use of land-use policy to increase the demand for transit
- Effects of transit on economic growth and development
- Transit as an instrument of planning policy

Effect of income on public transit demand

- Elasticity of bus demand w.r.t. income (including car ownership effect): -0.5 to -1.0 in the long run
  - As car ownership approaches saturation, the income elasticity can be expected to become less negative
- Strong correlation between income and car ownership, making it difficult to disentangle the separate effects of each
- Impact of car ownership smaller for rail (but still negative)
- Rail income elasticities are generally positive

Possible variations in income elasticity over time

- As incomes rise and car ownership approaches saturation, it is to be expected that the negative effects of income on bus use with diminish, and that rail income elasticities will increase

Effects of land use on transit demand

- Population location
  - Mixed use development reduces trip lengths and dependence on cars and can (but does not always) encourage transit use
- Employment provision
  - Greater degree of centralization of employment and facilities encourages transit use and reduces car use
  - Peripheral locations are more car dependent
- Urban form

Use of land-use policy to increase the demand for transit

- Zoning and development restrictions
  - Identify areas where land uses can be located with a particular emphasis on accessibility
  - The sites most accessible by transit should be allocated for travel intensive uses, such as offices, retail, and commercial leisure
- Transit-oriented development (TOD)
  - Policies offering incentives for TOD
- Car-free zones, pedestrian zones
  - Improve pedestrian access to shops

Effects of land use on transit demand

- Density and settlement size
  - Higher population densities widen the range of opportunities for consumers, employees, and commercial enterprises
  - With greater density, trip lengths tend to be shorter, influencing the number of trips and mode choice
  - Use of transit is greater in more densely population areas, and there is an inverse relationship between car use and density
  - Due partly to lower levels of income and car ownership and scarcity of parking
- Transit ridership also increases with settlement size

Use of land-use policy to increase the demand for transit

- Land use policies that can affect transit use
  - Location of new residential developments
  - Location of commercial and industrial zones
  - Mixed-use developments
  - Design of locations
  - Car-free development and transit-oriented development
- Density
  - Increasing density increases population within catchment area for transit nodes
- Mixed-use developments and urban villages
  - Can be successful but has limitations

Forecasting demand for new rail services

- Key parameters:
  - Generating potential of the origin station
  - Attracting potential of the destination station
  - Generalized cost of travel between stations

Effects of other transportation policies

- Infrastructure management
  - Partnership between transit operators and public authorities
  - Allocation of road space
    - HOV lanes, bus lanes
- Pricing policies
  - Employer subsidies
  - Congestion charging
  - Route-based tolls
  - Zone-based tolls
  - Parking policy
- Transportation policy integration

New Transit Modes and Services

- Transit demand could be affected by the introduction of new modes of transit or new ways of operating existing modes
- Elasticity values are not applicable when planning new modes of transit or radical developments to existing modes: there is no base level of demand and no historical data to build a model
- Therefore, it is necessary to assess similar developments elsewhere
- Examples
  - Light rail
  - Guided busways
  - Park-and-ride services

Forecasting demand for new rail services

- Four modeling approaches
  - Trip rate models
    - Rail demand is a function of the population surrounding the new station and forecasts are based on ridership at stations in similar areas
  - Trip end models
    - Improves the trip rate model by considering socio-economic characteristics of the population, rail service frequency, and bus service frequency
  - Direct demand models, or gravity models
    - Combines trip generation, distribution, and mode choice into a single direct model
    - Variables include: resident population in the station catchment area, socio-economic characteristics of local population, number of workplaces in area surrounding destination station, trip times by rail, car, bus
  - Mode choice models
    - Variables considered include: in-vehicle time, cost, access and egress time, and service headway for each mode
    - Weakness: inability to account for newly generated trips and need for demand estimates for total travel

Demand Functions

- Explanatory variables include:
  - Monetary costs of the trip
  - Time spent traveling, divided into various components: waiting, walking, in-vehicle
  - Similar variables for competing modes
  - Income

Demand Function

- Values of time in the generalized cost function represent the traveler's willingness to pay to reduce the waiting, walking, or in-vehicle time
- The residual effort component (also measured in monetary units) may represent many different aspects of travel, including comfort and convenience
- The generalized time concept expresses all costs in terms of an equivalent amount of time

$$GT = \frac{a_0 + p}{a_i} + \sum_i \frac{a_i q_i}{a_i}$$

where a_i is the appropriate value of time

Demand Functions

- Travelers choose among alternatives so as to maximize their utility
  - Utility: Total satisfaction derived from consumption of goods or services
- Constraints imposed upon choice
  - Limited amounts of time and money available
- Demand function: Expresses the number of trips demanded during a given time period as a function of a set of explanatory variables

Demand Function

General formulation

$y = f(x_1.....x_n)$

where y is dependent variable (level of demand)

x_i ($i = 1,...,n$) are the explanatory variables

A particular specification of the demand function is expressed in terms of generalized costs

$$GC = a_0 + p + \sum_i a_i q_i$$

Where:

GC =generalized cost of the trip

p = monetary cost of the trip

q_i = time required to complete the trip divided into the various components i of traveling time

a_i = value of time associated with time component i

a_0 = residual component of the cost of making a trip which is not a function of the monetary cost or the time involved but is a cost associated with making use of a particular mode, also referred to as the mode-specific cost or the residual effort component

Guidelines for using elasticities

- Pay attention to the properties of the elasticities
  - Size, direction, and type of change
  - Trip purpose
  - Time period over which demand is measured
  - Characteristics of the individual or population group
  - Transferability in time and space
  - Short-term effect vs. long-term effect
  - Functional form of elasticity used in original study

Shifts in demand curve

- Can be caused by:
  - Marketing
  - Driver training
  - Improved vehicle design
  - Alternative fare structures
  - Etc.
- Less easy to quantify these factors

Demand Function

The demand function can be re-written as:

$$y_j = g(GC_i, \dots GC_j, \dots GC_r)$$

Where y_j = demand for trip type j

Demand for a particular trip type is a function of the generalized cost for that trip as well as the generalized costs of alternative trips, which may refer to trips by a different mode, to a different location, or with a different purpose

The values of parameters of demand functions can be estimated from statistical analysis

Guidelines for using elasticities

- Usually calculated at only one or two values of the explanatory variables
- Elasticities may vary with trip purpose
- An elasticity refers to a response averaged over a given period of time
- Demand functions may refer either to individuals or to groups of individuals
- Elasticities are not necessarily transferable in time or in space
- Pay attention if elasticities reflect long-run or short-run behavior; indirect impacts affect demand at a much later date

Mode Choice Models

- Predict the likelihood of an individual choosing a given mode for a given trip based on individual, mode, and trip characteristics, using a discrete choice modeling technique
- Mode choice influenced by
  - Mode characteristics: monetary cost, travel time (in vehicle, waiting, walking), service frequency, need for transfer, access, comfort, convenience, reliability, security
  - Trip maker characteristics: income, age, car-ownership, ability to drive, household structure, decisions made elsewhere, preferences and attitudes
  - Trip characteristics: trip purpose, trip length, size of party, time of day

Discrete Choice Modeling

- Popular in transportation and marketing research for understanding an individual's stated choice among alternatives
- Multinomial logit model has been traditionally used
- Assumption is that decision makers are utility maximizers

Four-Step Travel Demand Model

- Trip generation
- Trip distribution
- Modal split
  - Price and availability of each mode
  - Quality of service of each mode
  - Trip characteristics for each particular trip
  - Socio and demographic characteristics of the traveler
- Traffic assignment

Stated Preference (SP) Survey

- Have been widely used in transportation and marketing
- Respondents shown a number of choice sets with two or more options described by a set of attributes with varying levels
- Respondent chooses his/her preferred option
- Advantages of SP surveys
  - Identify responses to choice situations that are not revealed in the market
  - Attributes can be varied to levels not yet observed in the market
  - Real-world collection of all the necessary data could be difficult

Multinomial Logit Model

The probability that individual *j* would choose mode *k* among *m* alternatives is as follows:

$$P_{jk} = \frac{\exp(U_{jk})}{\sum_{l=1}^{m} \exp(U_{jl})}$$

$$P_{jk} = \frac{\exp(\beta'_{k} X_j + \gamma'_k Y_j + \theta' Z_{jk})}{\sum_{l=1}^{m} \exp(\beta'_{l} X_j + \gamma'_l Y_j + \theta' Z_{jl})}$$

Example

- Travel times (includes the trip, waiting, walking and transfer times), and fares for each of the three transit modes:

	Travel time (minutes)		
	Z1 to Z2	Z2 to Z1	Fare ($)
Rail	27.1	27.1	7.22
Bus	51.9	51.5	7.91
Ferry	49.2	48.2	5.37

Multinomial Logit Model

$$U_{jk} = V_{jk} + e_{jk}$$

$$V_{jk} = \beta' X_j + \gamma' Y_j + \theta' Z_{jk}$$

where X_j are the characteristics of individual *j*;
Y_j are the trip characteristics for individual *j*;
Z_{jk} are the attributes of alternative *k* for individual *j*;
and β', γ', and θ' are the parameter vectors

Example

- New railway line is introduced in a transit network consisting of rail, bus, and passenger ferry
- Two zones: Z1 and Z2
- Total daily transit demand: 164,000 trips (Z1 to Z2) and 161,000 trips (Z2 to Z1).
- Utility function

$$u(i) = T(t_i - t_{bus}) + C(c_i - c_{bus}) + B_1 + B_2$$

where t_i = the travel time incurred by mode i; c_i = the cost (fare) by mode i; T,C calibrated coefficients; B_1 and B_2 are biases for the mode and movement limitations

Example

$$Modal\ split\ by\ rail = \frac{\exp(0.562)}{\exp(0.562)+\exp(0)+\exp(-0.595)} = 0.53$$

$$Modal\ split\ by\ bus = \frac{\exp(0)}{\exp(0.562)+\exp(0)+\exp(-0.595)} = 0.30$$

$$Modal\ split\ by\ ferry = \frac{\exp(-0.595)}{\exp(0.562)+\exp(0)+\exp(-0.595)} = 0.17$$

Total trips from Z1 to Z2 = 164,000
Trips by mode:
- Rail: 87,026
- Bus: 49,611
- Ferry: 27,363

Rural Transit Demand

TCRP Report 161 – Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation: Final Workbook

TCRP Web-Only Document 58 – Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation

Example

The travel times and fares are inserted into the utility function with the following coefficients:

Mode	T	C	B_1	B_2
Rail	-0.00373	-0.00153	0.202	0.267
Ferry	-0.00373	-0.00153	0.491	-1.1

$u(i) = T(t_i - t_{bus}) + C(c_i - c_{bus}) + B_1 + B_2$

U(Rail) = -0.00373(27.1-51.9)-0.00153(7.22-7.91)+0.202+0.267=0.562

U(Ferry) = -0.00373(49.2-51.9)-0.00153(5.37-7.91)+0.491-1.1=-0.595

Example (2)

- Two market segments and seven zones
- Market segment 1
  - U(Auto) = 2.5 – 0.012t – 0.4 c
  - U(Transit) = -0.01t – 0.5c
- Market segment 2
  - U(Auto) = 3.5 – 0.02t – 0.35 c
  - U(Transit) = -0.015t – 0.35c
- Estimate mode shares based on given travel times and costs between 7 zones

Program-related Trips: Trip Generators

- Developmental services: Adult
- Developmental services: Case management
- Developmental services: Children
- Developmental services: Pre-school
- Group home
- Head start
- Mental health services
- Job training
- Nursing home
- Senior nutrition
- Sheltered workshop
- Substance abuse
- Veteran services
- Native American services

Need Related to Population Characteristics

- Age
- Income
- Vehicle ownership
- Reduced trip making is more strongly related to vehicle availability than to age, at least up to age 80
- Recommendation – Estimates of need for passenger transportation services in rural areas should be presented as:
  - Number of persons resident in households with income below the poverty line, plus
  - Number of persons resident in households owning no vehicle

Four Markets for Rural Transit

- General public rural passenger transportation
- Program related trips – trips that would not occur but for the existence of specific human service program activities
- Fixed-route services in micropolitan areas
- Commuters from rural counties to urban centers

Components of Need

- Number of persons in groups likely to require passenger transportation services
- Rates of trip making for these groups
  - Uses National Household Travel Survey (NHTS) data and compares trip rates of those in households with no vehicles to those in households with one vehicle

Mobility Gap (based on 2009 NHTS)

Census Division	States	Vehicles Available		Mobility Gap (Trips per Day)
		0	1	
National		3.2	4.7	1.5
Division 1:	ME, VT, NH, MA, CT, RI	3.3	5.0	1.7
Division 2: Middle	NJ, NY, PA	3.5	4.8	1.3
Division 3: East North Central	WI, MI, OH, IN, IL	2.7	4.1	1.4
Division 4: West North Central	ND, SD, NE, KS, MO, IA, MN	2.4	4.5	1.7
Division 5: South Atlantic	MD, DE, WV, VA, NC, SC, GA, FL	3.2	4.5	1.2
Division 6: East South Central	KY, TN, AL, MS	2.7	4.1	1.4
Division 7: West South Central	OK, AR, TX, LA	2.9	4.9	2.0
Division 8: Mountain	ID, MT, WY, CO, UT, NE, AZ, NM	5.2	6.0	0.8
Division 9: Pacific	WA, OR, CA, AK, HI	3.8	4.9	1.1

Estimating Demand: General Purpose Rural Passenger Transportation

- Trips per year = (2.20 * Populated age 60 or older) + (5.21 * Mobility Limited Population age 18 to 64) + (1.52 * Residents of Households having No Vehicle)
- Peer data
  - Collect
    - Population of the area served
    - Size in square miles of the area served
    - Annual vehicle-miles and vehicle-hours of service provided
    - Nature of the operation (e.g., fixed-route, route-deviation, demand-response)
    - Number of one-way trips served
    - Degree of coordination with other providers
  - Compute
    - Passenger trips per capita
    - Passenger trips per vehicle mile (by service type)
    - Passenger trips per vehicle hour (by service type)
  - If analyzing effects of service changes, your best peer system is your own operation

Mobility Gap

- Premise that households with a least one vehicle can make trips as needed to satisfy their mobility needs
- Mobility gap can be defined as the difference between trip rates for households with at least one vehicle and trip rates for households with no vehicles
- To estimate annual need, multiply daily mobility gap by 300 days

Need

- Number of persons in need = population residing in households with income below the poverty line + population residing in households having no person vehicle
- Trip need = Households having no personal vehicle x Mobility Gap

Estimating Demand: Program Trips

Program Participants × # Program Events per Week × % of Program Participants Participating on Average Day × % of Program Participants Requiring Transportation × # Weeks per Year that Program is Provided × 2 = Forecast Annual Program Ridership

Estimating Demand: Commuters from Rural Counties to Urban Centers

- Proportion using Transit for Commuter Trips from a Rural County to Urban Place (if service is offered) = 0.024 + (0.0056 * workers commuting from the rural county to the central place) – (0.00029 * distance in miles) + 0.015 if the central place is a state capital
- Demand (trips per day) = Proportion using transit * number of commuters * 2
- Annual demand = Weekday demand * 255

Example

- Demand for general public rural transit demand in Barnes County, ND
- Trips per year = (2.20 * Populated age 60 or older) + (5.21 * Mobility Limited Population age 18 to 64) + (1.52 * Residents of Households having No Vehicle)
- 2014 ACS 5-year data, use American FactFinder to access data

Variable	Table Number
Population 60 +	B01001
Mobility limited population 16-64 (with an independent living difficulty)	S1810
Residents of households with no vehicles	B08201

- Trips per year = 2.2(2943) + 5.21(153) + 1.52*(498) = 8029

Estimating Demand: Small-City Fixed Route

- Annual Unlinked Passenger Trips = 5.77 * Revenue-Hours of Service + 1.07 * Population + 7.12 * College Enrollment
- Population of urban center < 50,000
- Function works best for systems that provide 70 or fewer vehicle-hours per day

Data Sources

- Rural National Transit Database (NTD)
- American Community Survey (ACS)
- Longitudinal Employer-Household Dynamics (LEHD) program
- Metropolitan Planning Organizations (MPOs)

Estimating Demand: Rural Public Transportation (not market specific)

Annual Demand on Rural Public Services = 2.44 * ($Need^{0.028}$) * (Annual Vehicle $Miles^{0.749}$)

Caveats

- Significant variations in demand not captured by the models
- Demand is constantly changing
- Observed demand for a new service is typically significantly less than the mature demand

Quality of Service: Concepts and Methods

Chapter 4 and Chapter 5 of

TCRP Report 165: Transit Capacity Quality of Service Manual 3rd Edition

Chapter 4: Quality of Service Concepts

1. Introduction
2. Quality of Service Factors
3. Quality of Service Framework
4. Quality of Service, Ridership, and Service Costs

1. Introduction

- Quality of Service is passenger's perception of transit performance.
- It is different from financial and output-focused performance measures typically reported by transit agencies to the National Transit Database (NTD)
- Quality of Service: Depends on operations decisions made by transit agencies within their budget constraints. Particularly, where transit should be provided; how often and how long it is provided; and how it is provided.
- Ultimately, quality of service reflects how well transit service meets the needs of its customers, which has ridership implications.

Roles of Transit

Transit plays two major roles in North America.

1. *Accommodate passengers who choose to use transit for their trip making even though they have other means of travel available to them, most likely a motor vehicle (Choice Riders).*
2. *Provide basic mobility for those unable to drive (Transit-dependent Riders).*

Choice Riders: Passengers who have more than one travel option available to them. They choose transit far a variety of reasons, including:

- Saving money (e.g., parking costs, fuel costs, tolls, insurance and registration costs associated with owning a car or multiple cars);
- Potential for a faster or more reliable trip;
- Avoiding the need to drive in congested roadway conditions;
- Being able to use travel time more effectively;
- Helping the environment by not contributing to the negative impacts of automobile travel.

Transit-dependent Riders (Captive Riders): Mobility for those segments of the population too young, too old, or otherwise unable to drive due to physical, mental, or financial disadvantages.

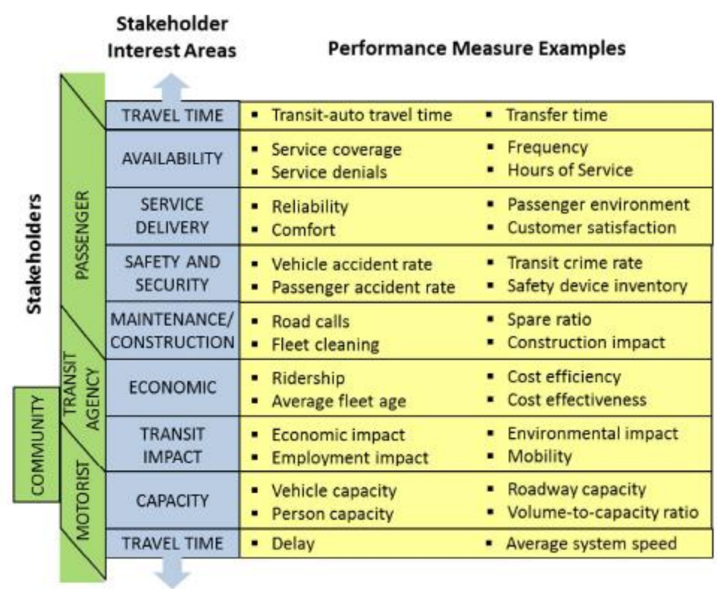
- 2009-31% of US and Canada population did not have drivers license.
- This portion depend on other to transport them, or make walk trips, or bicycling, or use combination of these.

Role of Quality of Service in Attracting and Retaining Ridership

- Although transit may be the best / only travel choice available for many types of trips made by transit-dependent riders, quality of service is still an important consideration for both riders and service providers.
- For riders, a poor quality of service can limit the options available for finding and holding a job, taking classes, or taking care of basic living needs.
- For transit providers, providing a good quality of service can help retain riders once they are no longer transit dependent.
- Land uses along transit routes and around transit stations should help support transit service by providing safe and direct linkages between transit stops and passengers' origins and destinations. This could help develop a more walking- and bicycling-friendly environment.

Stakeholders: Different stakeholders who are interested in transit performance:

- Transit Passengers,
- Transit agency staff and decision makers,
- Motorists, and
- Community members and decision makers



Chapter 4: Quality of Service Concepts

1. Introduction
2. Quality of Service Factors
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2. Quality of Service Factors

Two important ways of identifying the quality of service factors that are most important to existing and potential passengers are:

1) *to ask them directly through customer satisfaction surveys and*
2) *to observe how they react when given actual or hypothetical choices between transit services or travel modes with different characteristics.*

Customer Satisfaction Research:

- TCRP Project B-11, "Customer-Defined Service Quality"
- Florida Department of Transportation
- NCHRP Project 3-70, "Multimodal Level of Service for Urban Streets": *Onboard surveys were conducted on bus routes with varying service characteristics (e.g., frequency, loading, reliability, amenity provision) operated by five different transit agencies around the U.S.*
- *Customers were asked to rate their overall satisfaction with their trip, along with their satisfaction about specific aspects of their trip (e.g., frequency, reliability) [for a list of 17 factors]*

Rank	Route A	Route B	Route C	Route D	Route E
1	*frequency*	*frequency*	*frequency*	*frequency*	frequency
2	*wait time*	*reliability*	*close to home*	*reliability*	wait time
3	*reliability**	*wait time*	*reliability*	*close to home*	close to home
4	*close to home**	close to dest.	*wait time*	close to dest.	reliability
5	service span	close to home	close to dest.	wait time	service span
6	close to dest.	service span		service span	
7	friendly drivers				

Source: Dowling et al. (9).

Exhibit 4-2 Factors Contributing Most to Stated Overall Satisfaction with a Transit Trip

Value of Time Research:

- Passengers also place a value on travel time and journey quality.
- For each available travel option, they will subconsciously make a personal assessment of what is termed the ***generalized cost*** of their trip.
- ***Generalized cost:*** This cost also incorporates transit's quality of service attributes, which affect choice of route and mode. Quality is represented both by the speed of the journey (including potential delays) and the quality of the facilities used during various stages of the journey.
- The higher the perceived cost of a combination of route and mode (*e.g.*, longer travel time, more crowded conditions), the less likely a person would choose it for a given trip.
- The econometric framework is underpinned by in-vehicle value of time (VoT).

In-Vehicle Values of Time:

- Single point estimates for in-vehicle VoT (or value of travel time saved) are often quoted as a dollar-per-hour rate.
- These estimates reflect the average value placed on saving one hour of time within the relevant population.

Exhibit 4-3
Typical Values of Time for Different Types of Travel

Type of Travel	VoT (% of Prevailing Wage Rate)
Personal travel	50%
Commercial (on the clock) travel	100% + benefits
Transit (in vehicle, seated)	25%-35%
Transit (in vehicle, standing)	50%
Transit (in vehicle, crowded)	100%
Waiting (unpleasant conditions)	Up to 175%

Source: Concas and Kolpakov (*10*).

Note: The higher the perceived cost of a combination of route and mode, the less likely a person would choose it for a given trip.

Trip Purpose and Mode:

- Results of a review of over 200 British VoT studies, with values normalized to the commuting car driver valuation, which has been set to 1.0.

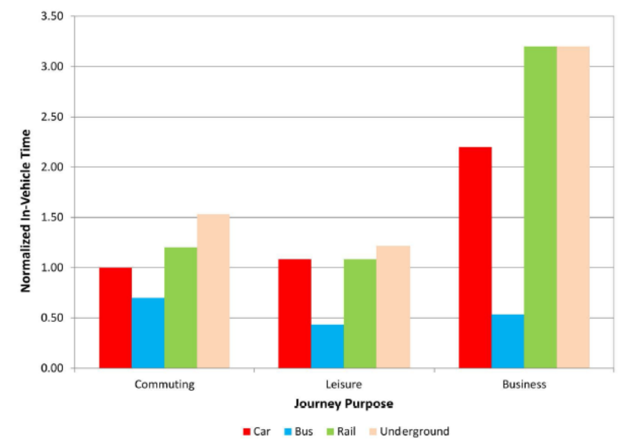


Exhibit 4-4
Relative Urban Travel Values of Time

Trip Duration:

- Longer distance trips are generally agreed to attract a higher unit rate VoT. In other words, the longer the trip to be made, the more value the average passenger will place on reducing the travel time by a single unit of time.

Access, Transfer, and Wait Time:

- When compared to the in-vehicle component of a trip, the access, wait, and transfer elements typically require greater physical effort. Little or no productive use can be made of time during these stages of a trip.
- For these reasons, a unit of time spent during these stages of a transit trip is perceived as more tedious than a unit of in-vehicle time

Exhibit 4-5
Relative Values of Time for Different Stages of a Trip

	In-Vehicle Time	Walk Time	Initial Wait Time	Transfer Time
U.S. average	1.0	2.2	2.1	2.5
U.S. range	1.0	0.8–4.4	0.8–5.1[a]	1.1–4.4
U.K. average	1.0	1.7	1.8	N/A

Sources: *TCRP Report 95, Chapter 10* (*17*) and Wardman (*12*).

Chapter 4: Quality of Service Concepts

3. Quality of Service Framework

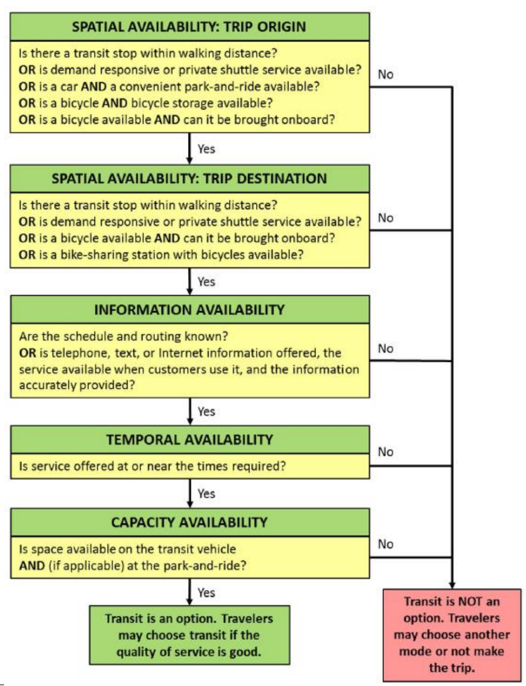
- Transit Trip Decision-Making Process

Transit Trip Decision-Making Process:

Availability:

- *A* key decision is determining whether or not transit service is even an option for a particular trip.
- Transit service is only an option for a trip when:

1. *Service is available at or near the locations and times that one wants to travel, and one can access it* ***(spatial availability)****;*
2. *Service is provided at the times one desires to travel-often including the return trip* ***(temporal availability)****;*
3. *One knows how to use the service* ***(information availability)****; and*
4. *Sufficient space is available on transit vehicles and, potentially, at supporting facilities such as park-and-ride lots* ***(capacity availability)****.*



Transit Trip Decision-Making Process:

Comfort and Convenience:

- If transit service is available as described before, then transit becomes an option for a given trip.
- At this point, passengers weigh the comfort and convenience of transit against competing modes.
- Some of the things that a potential passenger may consider include the following:

1. *Is the service reliable?*
2. *How long is the wait? Is shelter available at the stop while waiting?*
3. *Are there security concerns-walking, waiting, or riding?*
4. *How comfortable is the trip? Will I have to stand? Are there an adequate number of securement spaces? Are the vehicles and transit facilities clean?*
5. *How much will the trip cost?*
6. *Is a transfer required?*
7. *How long will the trip take in total? How long relative to other modes?*

Framework Outline

- The two aspects (availability, and comfort and convenience) can be used for developing quality of service framework (presented below in the picture).
- These frameworks-one for fixed-route service and one for demand-responsive service-focus on key performance measures that transit agencies can use to set service standards and to evaluate the quality of service they provide to their passengers.

Exhibit 4-10 Quality of Service Framework: Fixed-Route Transit

Availability	Comfort and Convenience
Frequency	Passenger Load
Service Span	Reliability
Access	Travel Time

Exhibit 4-11 Quality of Service Framework: Demand-Responsive Transit

Availability	Comfort and Convenience
Response Time	Reliability
Service Span	Travel Time
Service Coverage	No-shows

Chapter 4: Quality of Service Concepts

1. Introduction
2. Quality of Service Factors
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4. Quality of Service, Ridership, and Service Costs

- Improving the quality of service can result in ridership growth, but it may also entail added costs.
- Transit agencies need to consider both issues as they plan service and allocate resources.

Quality of Service and Ridership:

- Improvements in quality of service can result in increases in ridership, which in many cases, can result in an improvement in a transit agency's financial performance.
- The impacts of quality of service on ridership are usually estimated using one of two methods.

1. ***Discrete choice models:*** Estimates the probability that a traveler will use a particular mode choice (e.g., transit) from a variety of mode choice options available.
2. ***Elasticity:*** Elasticity relates the observed percentage change in ridership to the percentage change in some other factor (e.g., fares, headways, etc.).

Quality of Service and Ridership:

Response to Service Frequency Changes:

- Ridership is more responsive to changes in service frequencies when the existing service is infrequent (30-min headways or longer), in middle- and upper-income areas, and when the distances traveled are short enough that walking is an option. Ridership is less responsive when service was already relatively frequent, in lower-income areas, and when most trips are long.
- Observed elasticities generally range from 0.0 (no change in ridership) to+ 1.0 (i.e., a 1% increase in frequency results in a 1% increase in ridership), with an average elasticity in the range of +0.3 to +0.5.

Response to Reliability Changes:

- Reports of passenger responses to decreases in reliability are mostly anecdotal, indicating that ridership is lost when service is perceived to be unreliable.

Quality of Service and Ridership:

Response to Travel Time Changes:

- Bus Rapid Transit Practitioner's Guide suggests a range of elasticities of -0.3 to -0.5 related to travel time, with -0.4 typical.

Response to Service Coverage Changes:

- Average elasticities of service expansions of existing systems (measured in terms of bus miles or bus hours) range from +0.6 to + 1.0, with the higher values occurring in areas where the existing service level is below average, such as in small cities and suburbs, and during off-peak hours.

Quality of Service and Ridership:

Response to Fare Changes:

- Peak-period riders, persons traveling to and from work, and captive riders are significantly less responsive to fare changes than others.
- Passengers in larger cities are less sensitive to fare increases than are passengers in smaller cities.

Response to Package of Improvements:

- Studies of corridor ridership before and after the implementation of BRT service have found up to a 25% increase in ridership in the corridor beyond what would be expected simply from frequency and travel time improvements.

Quality of Service and Service Costs:

Costs Associated with Frequency Changes:

- Operating costs are very sensitive to changes in frequency. All other things being equal (in particular, travel times or speeds), doubling the frequency on a line will result in the operating costs doubling.

Costs Associated with Service Hour Changes:

- Increasing the hours of service increases operating costs, as transit vehicles are in service longer, with the corresponding costs to power them and to drive them.
- All other things being equal, a 20% increase in the hours operated over the course of the week will typically increase operating costs by 20%, whether the added hours come from extending hours of service by 2 hours a day on weekdays, or by providing 10 hours of new service on Saturdays.

Quality of Service and Service Costs:

- Costs Associated with Service Coverage Changes
- Costs Associated with Reducing Crowding
- Costs Associated with Reliability Changes
- Costs Associated with Travel Time Changes

Thank you

Next Lecture: Quality of Service Methods.

Quality of Service Methods

- Chapter 5 of TCRP Report 165: Transit Capacity Quality of Service Manual 3rd Edition
- The report and PowerPoint slides may be accessed online from www.trb.org by typing "TCRP Report 165" in the Search area.
- PPT Slide Credits and Photo Credits: Paul Ryus (Kittelson & Associates, Inc.)

Chapter 5: Quality of Service Methods

1. Fixed-Route Quality of Service
2. Demand-Response Quality of Service

1. Fixed-Route Quality of Service

Availability	Comfort and Convenience
Frequency (Exhibit 5-2)	Passenger Load (Exhibit 5-16 and Exhibit 5-17)
Service Span (Exhibit 5-3)	Reliability (Exhibit 5-21 and Exhibit 5-22)
Access (Exhibit 5-4)	Travel Time (Exhibit 5-24)

Frequency

- Transit service can only be used at discrete times
  - ➢ If service is only offered hourly, there is a very small window of time during the hour when a transit trip can be started immediately
- More-frequent service provides more opportunities for immediate travel
  - ➢ Transit service more closely resembles competing modes (auto, bicycle, pedestrian) in terms of departure time convenience
- Frequency is attractive to passengers
  - ➢ Ridership increases as frequency increases, although a diminishing returns principle applies
- Frequency is a key driver of operating costs
  - ➢ Improvements to speed and reliability can allow better frequency at the same cost

Frequency QOS

- Seven levels

(Average Headway)
  - ≤5 minutes
  - >5 to 10 minutes
  - 11 to 15 minutes
  - 16 to 30 minutes
  - 31 to 59 minutes
  - 60 minutes
  - >60 minutes

Average Headway	Passenger Perspective	Operator Perspective
>5–10 min	• Frequent service, no need for passengers to consult schedules • Bus bunching possible, which can result in longer-than-planned waits for a bus and more variable loads	• Feasible on high-density corridors with bus or rail service, and where routes converge to serve a major activity center • Short headways needed for circulator routes to be able to compete with walking and bicycling (2) • Exclusive right-of-way desirable to reduce external impacts on transit operations and to keep operating speeds high (minimizing operating costs) • Traffic congestion, dwell time variability, and differences in bus operator driving styles may result in bus bunching • Increasing frequency to add capacity usually feasible (budget permitting) when exclusive right-of-way provided in congested areas

- QOS table listing the passenger and operator perspectives fills most of 2 pages, so only an example is shown here

Service Span: Hours of Service

- Service span determines the potential markets that transit serves
  - Starting and ending times of activities
    - Work
    - School
    - Medical appointments
    - Shopping
- Longer service spans serve a greater number of potential passengers
  - Non-traditional work hours
  - Night classes
  - Friday & Saturday night activities
- Longer service spans than needed to serve a particular market give passengers flexibility
  - Ability to stay late
  - Insurance against being stranded

Service Span (Hours of Service) QOS

- Based on number of hours when service offered at least hourly
- Six levels
  - >18 hours
  - 15 to 18 hours
  - 12 to 14 hours
  - 7 to 11 hours
  - 4 to 6 hours
  - <4 hours

Average Headway / Hours of Service	Passenger Perspective	Operator Perspective
>18 h	• A full range of trip purposes can be served • Allows bus travel to replace potentially riskier travel (e.g., crime, drunk driving, poor visibility) by other modes late at night	• Often branded as "night" or "owl" service • May require added driver pay for late-night work • May require increased security measures on transit vehicles and in transit facilities • May only be offered certain days (e.g., Friday and Saturday nights) • May be operated on a different set of routes than operate the rest of the day (e.g., emphasizing coverage over travel time)

Service Coverage

- Mode used to access transit depends on distance to travel and facilities provided along the way and at the transit stop
- Walking is the most common access mode for urban transit service
  - 50-80% of persons walk ¼ mile or less to a local bus stop
  - 50% of persons walk ½ mile or less to rail and BRT service
  - Terrain, street connectivity, street-crossing difficulty, demography are factors
- Bicycling can extend a stop's market area
  - A person can cover 4 times the distance in the same time, compared to walking
- Autos used in lower-density areas to access commuter/express bus and rail transit service when park-and-ride facilities are provided
  - Market area depends on area topography and access road network
  - Typical: 50% of demand comes from within 2.5 miles of lot, 35% of demand comes from upstream up to 10 miles away from lot

Service Coverage QOS

- Five levels
  - >90% of service area population served
  - >90% of transit-supportive area served
  - 75 to 90% of transit-supportive area served
  - 50 to 74% of transit-supportive area served
  - <50% of transit-supportive area served
- ***Transit-supportive area*** defined as an area capable of supporting hourly weekday transit service
  - At least 3 households per gross acre or 4 jobs per gross acre
  - Assumes 33% farebox recovery
- QOS planned for depends very much on transit agency's policy emphasis: coverage vs. cost-efficiency or frequency

Defining Service Coverage Area

- For a planning analysis, the service coverage area of a local bus stop is defined as the air distance within 0.25 mi (400 m) (as shown in figure below) and the service coverage area of a rapid transit (rail or BRT) station is defined as the air distance within 0.5 mi (800 m).
- Because actual walking distances from the edges of these circles will be longer than the air distance, these circles can be assumed to encompass a large majority of the people who will walk to the stop or station.

(a) Air distance–based coverage area

- If a more-detailed analysis is desired, each stop's service coverage area can be reduced in proportion to the additional time required to climb hills, cross busy streets, wind one's way out of a subdivision, and so on. Walking also includes lot of out of direction travel to transit stop.

- Each stop ends up with an individual service radius that, in most cases, is smaller than the 0.25 to 0.5 mi (400 to 800 m) base distance, and therefore serves a smaller number of people and jobs. This can be expressed mathematically as shown in Equation

$$r_s = r_0 f_{sc} f_g f_{pop} f_{px}$$

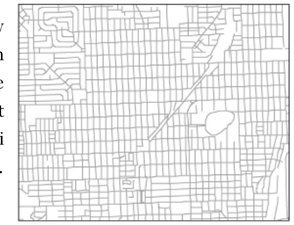
r_s = transit stop service radius (mi, m);
r_0 = ideal transit stop service radius (mi, m),
= 0.25 mi (400 m) for bus stops, and 0.5 mi (800 m) for busway and rai stations;
f_{sc} = street connectivity factor;
f_g = grade factor;
f_{pop} = population factor; and
f_{px} = pedestrian crossing factor.


(a) Air distance–based coverage area


(b) Walk distance–based coverage area

Three types of street patterns

Traditional grid system: Only about 64% of the area within 0.25-mi (400-m) air distance of a transit stop in a grid street pattern lies within 0.25-mi walking distance of the stop.


(a) Type 1—Grid


(b) Type 2—Hybrid

Hybrid Layout: 54% of the area within a 0.25-mi radius of a transit stop in an average hybrid street pattern lies within 0.25-mi walking distance

Cul-de-Sac based street network with limited connectivity.: only 28% of the area in an average cul-de-sac street pattern lies within 0.25-mi walking distance


(c) Type 3—Cul-de-Sac

Passenger Loads

- Passengers perceive travel in crowded conditions as being more burdensome than travel in less-crowded conditions, even when they have a seat
  - Value of time begins to increase when 80% of seats are occupied
  - Standing passengers' perceived value of time considerably higher than seated passengers'
- Cost-effectiveness improves as passenger loads increase
- Passenger throughput generally improves as passenger loads increase
- Passenger boarding & alighting times increase as the number of standing passengers on-board increases

Passenger Load QOS:
Vehicles Designed for Most Passengers Seated

- Nearly all buses, all commuter rail, all ferry, some other rail vehicles with narrow aisles and transverse seating
- Six levels
  - Up to 50% seated load
  - Up to 80% seated load
  - Up to 100% seated load
  - Up to 125% seated load
  - Up to 150% seated load
  - >150% seated load

Up to 125% seated load	• Up to 20% of passengers must stand • Standees may need to shift position within the vehicle at each stop as other passengers board or alight • Perceived travel time up to 1.25x actual travel time for seated passengers and up to 2.1x actual travel time for standees	• Very productive service • Often used as a service standard for off-peak bus service • Time to serve boarding and alighting passengers goes up when standees are present, resulting in longer dwell times and potentially slower travel speeds than at lower loading levels

Passenger Load QOS:
Vehicles Designed for Most Passengers Standing

- Special-purpose buses, most light and heavy rail
- Six levels
  - >1.0 m^2 (10.8 ft^2) per passenger
  - 0.5 to 1.0 m^2 per passenger
  - 0.4 to 0.49 m^2 per passenger
  - 0.3 to 0.39 m^2 per passenger
  - 0.2 to 0.29 m^2 per passenger
  - <0.2 m^2 (2.2 ft^2) per passenger

<2.2 ft^2/p <0.20 m^2/p	• Crush loading conditions	• Moving to and from doorways extremely difficult, increasing dwell time (*13*) • Passengers waiting to board may try to shift to a door in a less-crowded section of the vehicle, increasing dwell time • Passengers waiting to board may choose to wait for the next vehicle, increasing platform crowding

Reliability

- The more unreliable the service, the more extra time passengers have to allow for their trip
  - Arriving at stops earlier than necessary
  - Taking an earlier trip than necessary
- The more unreliable the service, the more recovery time that agencies need to insert into the schedule to compensate
  - Time could be better used in service (operating the route more frequently, operating a longer route)
- Reliability issues depend in part on the scheduled headway
  - Short headways: bus bunching and train stopping/starting
  - Long headways: on-time performance, early departures
- Several different measures of reliability are used by transit operators: on time performance, headway adherence, excess wait time, missed trips, percent of scheduled time in operation, and distance travelled between mechanical breakdowns.

Reliability QOS:
Headway-based Service

- Applicable to service that operates at 10-min headways or better, or to service without fixed departure times
- Based on headway variability (standard deviation of headways divided by the scheduled headway)
  - Described in terms of the probability that a passenger arriving at a stop will experience a vehicle more than ½ headway off the scheduled headway
- Six service levels

c_{vh}	P (abs[h_i-h] > 0.5 h)	Passenger and Operator Perspective
0.00-0.21	≤2%	Service provided like clockwork
0.22-0.30	≤10%	Vehicles slightly off headway
0.31-0.39	≤20%	Vehicles often off headway
0.40-0.52	≤33%	Irregular headways, with some bunching
0.53-0.74	≤50%	Frequent bunching
≥0.75	>50%	Most vehicles bunched

Reliability QOS:
On-time Performance

- Applicable to service that operates to a fixed schedule
- Based on on-time performance
  - Defined as a departure no more than 1 minute early and up to 5 minutes late
- Five service levels
  - 95-100%
  - 90-94%
  - 80-89%
  - 70-79%
  - <70%

80–89%	• Passenger making one round trip per weekday with no transfers experiences up to two not-on-time vehicles every week	• Typical range for commuter rail that shares track with freight rail • Typical range for light rail with some street running • Achievable by bus services in small to mid-sized cities

Travel Time

- Travel time is an important consideration in mode choice
- Travel time impacts operating costs: the slower the route, the more vehicles that are required to be in service to provide a given headway

Travel Time QOS

- Based on the ratio of in-vehicle transit time to in-vehicle auto time
- Six service levels

Transit–Auto Travel Time Ratio	Passenger Perspective	Operator Perspective
≤1	• Faster trip by transit than by auto	• Feasible when transit operates in a separate right-of-way and the roadway network is congested
>1–1.25	• Comparable in-vehicle travel times by transit and auto • For a 40-min commute, transit takes up to 10 min longer	• Feasible with express service • Feasible with limited-stop service in an exclusive lane or right-of-way
>1.25–1.5	• Tolerable for choice riders • For a 40-min commute, transit takes up to 20 min longer	
>1.5–1.75	• Round trip up to 1 h longer by transit for a 40-min one-way trip	
>1.75–2	• A trip takes up to twice as long by transit than by auto	• May be best possible result for mixed traffic operations in congested downtown areas
>2	• Tedious for all riders	• May be best possible result for small city service that emphasizes coverage over direct connections

Chapter 5: Quality of Service Methods

1. Fixed-Route Quality of Service
2. Demand-Response Quality of Service

What Matters to Customers?

- Service availability
  - Is transit an option?
- Comfort and convenience
  - If it is an option, would you want to use it?

- Quality of service (QOS) focuses on the passenger point of view
- Other points of view are also valid and need to be considered

QOS Framework

- The QOS framework presents key performance measures that can be used in setting service standards and evaluating the QOS delivered to passengers
  - Three measures of availability
  - Three measures of comfort and convenience
- Framework and measures intended to be applied to general public and limited eligibility DRT services only
  - ADA stipulates service requirements for ADA paratransit
  - Some measures may be applicable to flexible transit services, but the wide range of these services precludes developing standardized QOS tables

Availability	Comfort and Convenience
Response Time	Reliability
Service Span	Travel Time
Service Coverage	No-shows

Response Time

- Defines how far in advance passengers must schedule a DRT trip
- Measured as the minimum amount of time a rider needs to schedule and access a trip, or the minimum advance reservation time
  - Includes standing-order trips, where passengers are picked up at pre-scheduled times on pre-scheduled days and do not have to call in to reserve each trip
- No data collection required (measure based on service policy)
  - When DRT provider policy stipulates a maximum time for when service will be provided following a request, response time can be determined by logging the call and pick-up times, or by surveying passengers
- Many DRT providers also stipulate a maximum response time
  - Helps to reduce number of cancellations when passenger plans change and no-shows, when the passenger forgets to cancel the reservation

Response Time QOS

- Seven service levels:
  - Guaranteed (standing-order or subscription service)
  - Same-day service
  - Same-day service on a space-available basis
  - Will-call/call when ready
  - Next-day/24-hour advance reservation
  - Two-day/48-hour advance reservation, up to a week
  - More than one week in advance

Same-day service on space available basis	• Provides riders the opportunity to book a same-day trip if space is available • May be adequate service for trips that are last-minute and not time- sensitive • Requires riders to be flexible as to time of travel and open to a trip turn-down if space not available	• Allows DRT provider to use capacity that otherwise might go unused due to same-day cancellations or other day-of-service adjustments • Requires the DRT control center staff to continually monitor service and watch for "slack" time in drivers' schedules when an additional trip could be inserted

Service Span

- Measures the days per week and hours per day that DRT service is available
- Particularly important for the DRT mode because in many small urban communities and rural areas, service is not provided on a full weekly basis or even on every weekday
- Service availability on weekdays allows for more "life-fulfilling trips" to be made, as opposed to "life-sustaining trips"
- As number of days of service decreases, DRT service becomes more of a lifeline service
- As number of hours of service per day decreases, number of trip purposes served decreases and requirement for pre-planning trips increases

Service Span QOS: Days of Service

- Five service levels:
  - 7 days per week
  - 6 days per week
  - 5 days per week
  - 1 to 4 days per week
  - Less than weekly

Days of Service	Passenger Perspective	Transit Agency Perspective
5 days/week	• Allows DRT trips every day of the traditional work week • Permits trips by DRT for full-time, weekday employment and education if combined with appropriate hours per day • Provides access to medical services five days per week	• Provides basic weekday transit service for a community • Requires operating funds for service five days per week • Provides the minimum service that may attract choice riders, depending on hours per day of service

Service Span QOS: Hours of Service

- Five service levels:
  - 16 or more hours per day
  - 12 to 15 hours per day
  - 9 to 11 hours per day
  - 5 to 8 hours per day
  - Less than 5 hours per day

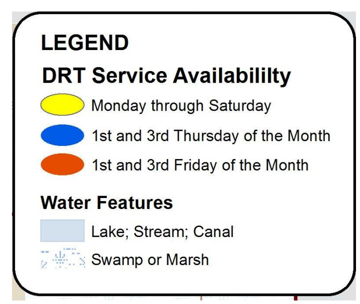
5.0–8.9 h/day	• Allows opportunity for DRT trips for essential shopping, personal business, medical appointments, human or government services, and some part-time jobs and educational programs • Requires pre-planning transit trips to ensure both “going” and return trips are scheduled within service hours	• Provides limited transit service for a community, acceptable if this is the most service a transit agency can provide with available funding

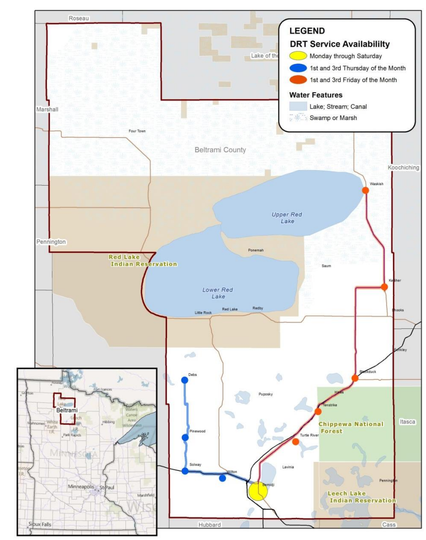
Service Coverage

- Measures the geographic area where DRT service is provided
- Typical for service to be available throughout a jurisdiction, as opposed to fixed-route service
- When service coverage and service span vary within a service area, it may be useful to map the different levels of DRT availability
- No separate QOS table

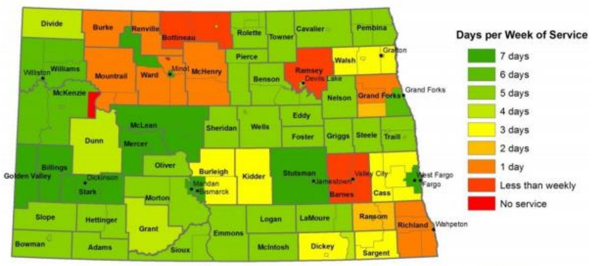
Service Coverage Map Example

- Based on service span provided to different portions of the service area

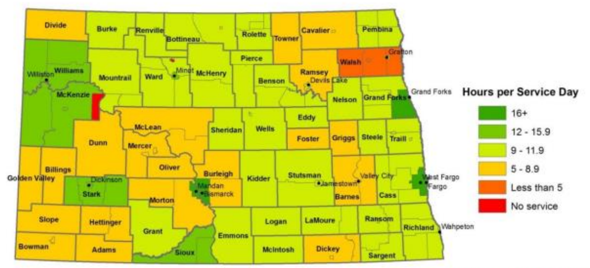




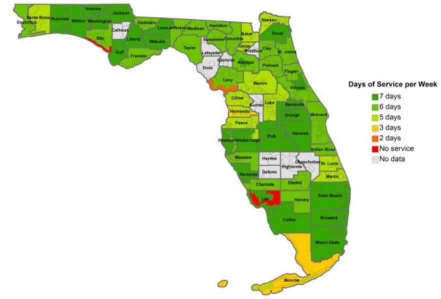
- Our Recent Study: '***Developing a Method for Assessing National Demand-Response Transit Level of Service***'



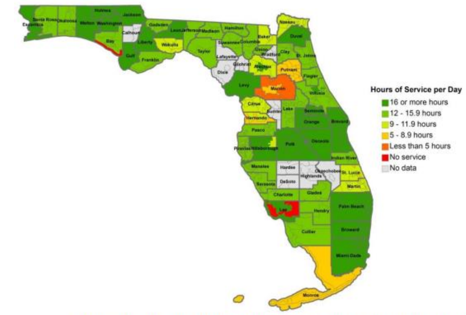
Days per Week of Demand-Response Transit Service in North Dakota



Hours per Service Day for Demand-Response Transit Service in North Dakota



Days of Service per Week for Demand-Response Transit in Florida, Including All Types of Services



Hours of Service per Day for Demand-Response Transit in Florida, Including All Types of Services

Reliability

- A critical measure of service level from the passenger's perspective
  - Will I be able to reserve a ride when I call, or will all the rides be taken?
  - Will the driver get me to my appointment on time?
- Because of the shared-ride nature of DRT service, there is more variability than with fixed route service
  - Available capacity to serve a trip request
  - Window of time when the pick-up will occur
  - Variable travel time to the destination, depending on other passenger pick-ups and traffic conditions
- Two measures used to assess reliability
  - On-time performance
  - Trips turned down

On-time Performance

- Measures the degree to which DRT vehicles arrive at the scheduled times
  - Calculated at the pick-up end of a trip
  - For time-sensitive trips (e.g., work, school, medical appointments), also calculated for the drop-off end
- For pick-ups, any time with the provider's defined pick-up window is considered on-time
- For drop-offs, any time at or before the required time is considered on-time
- Measured by percentage of on-time trips
- Calculate from driver logs
- High levels of on-time performance will negatively impact productivity

On-time Performance QOS

- Five service levels—these assume 30-min "on-time" window:
  - 95% on-time or better
  - 90 to 94% on time
  - 80 to 89% on time
  - 70 to 79% on time
  - <70% on time

On-Time Percentage	Passenger Perspective	Transit Agency Perspective
80.0–89.9%	• Means passengers can usually rely on DRT to be on-time for most scheduled trips, but there will be exceptions • For a frequent rider taking two trips each weekday per month, 80% on-time means 8 late trips per month • Riders with time-sensitive trips (e.g., work, school) will consider DRT unreliable if late pick-ups result in late drop-offs	• Suggests need for more training for scheduling/dispatch staff and drivers or revised policies/procedures to improve on-time performance • Percent on-time performance may fall to low 80% range (or lower) during bad weather and transition periods (new service or new service area, change in service provider, new policies/procedures, fleet maintenance problems, and other major changes). Risks an increase in passenger complaints from riders with time-sensitive trips

Trips Turned Down

- Measures the degree to which passengers can obtain service at their desired time or at a negotiated time that also works for them
- Calculated as the percent of service requests that are turned down due to a lack of capacity at the passenger's desired time(s)
- Most DRT providers turn down trips on an occasional basis
  - Unusual demand
  - Temporary shortage of drivers
- Frequent trip turn-downs signal insufficient capacity
  - May require adjustments to driver schedules
  - May require mix of full-time and part-time driver shifts
  - Might consider passenger incentives to travel at less-busy times
  - May require additional vehicles after operational and policy changes to maximize efficiency have been tried

Trips Turned Down QOS

- Five service levels:
  - 0 to 1%
  - >1 to 3%
  - >3 to 5%
  - >5 to 10%
  - >10%

>5–10%	• Riders may need other options for needed trips when DRT is not available • For a frequent rider taking two trips each weekday per month, 5–10% trips turned down means 2 to 4 trips out of an average 40 DRT requests per month will be refused	• Risks riders with other transportation options may stop using DRT service, particularly for important trips • Calls for an analysis of the number of trips turned down by time of day to analyze patterns and possibly adjust driver scheduling and use of full-time/part-time shifts to ensure driver shifts correspond to ridership patterns • Requires more attention to operational policies/procedures/practices to ensure service is deployed efficiently and capacity is maximized with current resources • Risks an increase in passenger complaints about service availability

Travel Time

- Compares time to an exclusive-ride trip (i.e., no ride-sharing)
  - Ideal from a passenger point-of-view, but shouldn't be expected
  - From the operator point-of-view, travel times that are either too short or too long are undesirable
- Actual travel time can be calculated using a sample of completed trips for different passengers, using automated records from mobile data computers or written records from driver manifests
- Exclusive-ride trip can be calculated from an Internet mapping program
- TCQSM provides guidance on sample size to use, along with other details

Travel Time QOS

- Five service levels:
  - Up to 25% longer than exclusive-ride trip
  - Up to 50% longer than exclusive-ride trip
  - Up to 75% longer than exclusive-ride trip
  - Up to 100% longer than exclusive-ride trip
  - More than 100% longer than exclusive-ride trip

Travel Time	Passenger Perspective	Transit Agency Perspective
Exclusive-ride, direct trip with no ride-sharing (no more than 25% longer than a comparable trip by private taxi or automobile)	• Provides direct service requiring no more than 25% extra time for a DRT trip compared to a trip by taxi or a private vehicle • Requires no delays for other riders to board/alight since no other riders are scheduled on the same trip • Increases a direct, 30-min trip no more than 25%, or 8 min	• Scheduled direct, exclusive-ride DRT trips may happen from time to time but should not be the standard • Indicates the DRT scheduling function may not be grouping passenger trips with similar patterns • Decreases productivity (passenger trips/ revenue hour) • Increases operating cost per passenger trip

No-Shows

- A no-show occurs when a passenger fails to show up for a scheduled trip
- From a passenger perspective, QOS is affected because passengers already on-board the vehicle have wasted time traveling to the pick-up location and waiting for the missing rider
- From a transit agency perspective, no shows reduce productivity and increase operating costs
- Calculated as the sum of passenger no-shows divided by the total number of scheduled trips

No-Show QOS

- Three service levels:
  - <2%
  - 2 to 5%
  - >5%

2 – 5%	• May experience occasional trips where another passenger scheduled on the same vehicle is a no-show • A frequent rider with 40 one-way trips in a month may be inconvenienced 1 or 2 times during an average month due to another passenger who no-shows	• Experiences a percentage of no-shows which may have a negative impact on operations and lower productivity • Requires an effort to mitigate, especially if the trend reflects an increasing number of no-shows • If not already in place, adopt a formal no-show/cancellation policy with appropriate penalties for riders with excessive no-shows • Ensure the riders guide and other passenger information includes the no-show policy, the importance of cancelling unneeded trips, and how to cancel trips • Provide an easy-to-use and well-advertised method for riders to cancel trips (e.g., a dedicated phone line that records messages) • Consider follow-up with riders with frequent no-shows, ensuring their understanding of the policy and consequences of their no-shows on other riders and the DRT service

Potential Applications for DRT Quality of Service

- Developing service standards, balancing the QOS provided with operating cost considerations
- Comparing actual performance to service standards
- Identifying potential problems with excessive cancellations and no-shows
- Identifying the potential need for additional staff training
- Identifying the potential need for additional capacity

Learning Objectives

- Understand why bus capacity is important, even for transit agencies that don't experience capacity problems
- Be able to identify the main factors that influence **bus capacity**, **speed**, and **reliability**
- Understand the process involved in calculating bus capacity and speed
- Become familiar with potential applications for this chapter's material

Why Should We Be Interested in Capacity?

- The same factors that influence capacity also influence speed and reliability
  - Travel time and reliability affects quality of service (and thus ridership)
  - Speed and reliability affects the time required for a bus to make a round trip on a route, including schedule recovery time
    - Affects the number of buses needed to serve the route at a given headway, which directly affects operating costs

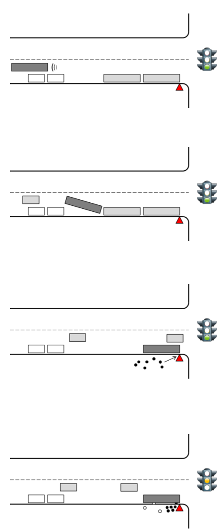
Bus Capacity

- Chapter 6 of TCRP Report 165: Transit Capacity Quality of Service Manual 3rd Edition
- The report and PowerPoint slides may be accessed online from www.trb.org by typing "TCRP Report 165" in the Search area.
- PPT Slide Credits and Photo Credits: Paul Ryus, Justin Jahnke, and Rory Giles.

Bus Capacity Concepts

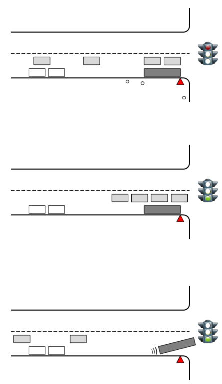
Sources of Bus Delay Associated with Bus Stops

- Deceleration
  - Time spent slowing to serve the stop
- Bus stop failure
  - Waiting for other buses to clear the stop
- Boarding lost time
  - Waiting for passengers to reach the bus
- Passenger service time (dwell time)
  - Opening the doors, boarding and alighting passengers, and closing the doors



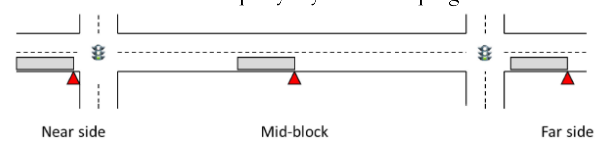
Sources of Bus Delay Associated with Bus Stops (cont'd.)

- Traffic signal (traffic control) delay
  - Waiting for the signal to turn green, or other traffic control delay
- Re-entry delay
  - Waiting for a gap in traffic
- Acceleration
  - Time spent getting back up to speed



Deceleration and Acceleration Delay

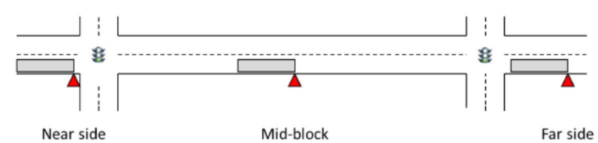
- At urban street speeds, acceleration and deceleration delay amounts to about 10 seconds per stop where the bus would not have had to stop anyway due to traffic control
  - Delay is more significant at higher speeds, as buses accelerate more slowly
  - Different bus sizes and propulsion systems have different acceleration characteristics
- This delay occurs
  - Always, at far-side stops at traffic signals and all other stops where the bus is not required to stop due to traffic control (signs, traffic signals)
  - Sometimes, at near-side stops at traffic signals and roundabouts, where the bus might have had to stop anyway due to the traffic control
    - Traffic control delay includes deceleration and acceleration delay due to the control device—don't want to double-count the delay
  - Never, at near-side stops with stop-sign control
    - The bus would have had to stop anyway for the stop sign



Facility Design

Bus Stop Location:

- On-street bus stops can be located in three places relative to an intersection- near side, far side, and mid-block.
- Bus stop location influences bus speeds and capacity, particularly when other vehicles can make right turns from the curb lane.
- Far-side stops have the least negative impact on speed and capacity.
- Near-side stops are often preferable when curb parking is allowed, since buses may use the intersection area-where cars would not be parking in any event. Far-side stops are desirable where buses make left turns.
- Mid-block stops are typically only used at major passenger generators or where insufficient space exists at adjacent intersections



Boarding Lost Time

- At curbside bus stops with more than one stopping position (loading area), passengers don't know exactly where their bus will stop
- Passengers choose to wait in a location that minimizes their walk to the bus' front door when it arrives
  - For a stop with 3 loading areas, passengers tend to wait around where the second bus' door would be, give or take half a bus length
- It may take a little time for the first passenger to reach the bus and begin boarding after the bus arrives
  - For a stop with 3 loading areas, 4.0 (crowded waiting area) to 4.5 seconds (uncrowded waiting area) are average values
  - Research has not yet determined values for stops with 2, 4, or 5 loading areas; analyst judgment is required
    - 2 loading areas: A value between 0 and 4 seconds
    - 4 and 5 loading areas: Will depend on how often the rear loading areas are used, but could be significantly longer (e.g., individual passengers could need to walk the length of one or two additional buses)

Passenger Service Time

- Fare payment

Situation	Average Passenger Service Time (s/p) Observed Range	Suggested Default
BOARDING		
No fare payment	1.75–2.5	1.75
Visual inspection (paper transfer/flash pass/mobile phone)	1.6–2.6	2.0
Single ticket or token into farebox	2.9–5.1	3.0
Exact change into farebox	3.1–8.4	4.5
Mechanical ticket validator	3.5–4.0	4.0
Magnetic stripe card	3.7–6.5	5.0
Smart card	2.5–3.2	2.75
ALIGHTING		
Front door	1.4–3.6	2.5
Rear door	1.2–2.2	1.75
Rear door with smart card check-out	3.4–4.0	3.5

- Add 0.5 seconds per passenger for steps (1.0 second for steep steps, such as those on motor coaches)
- Add 0.5 seconds per passenger when standees present on-board

Bus Stop Failure

- A situation where a bus arrives at a bus stop to find all loading areas full
  - The bus must wait in the street until space becomes available
  - Slows down the bus and creates schedule reliability issues
  - Delay can range up to the other bus' dwell and traffic control delay times
- Can be measured, but more typically used as a design input when determining capacity
  - Design failure rate, based on transit and traffic operations considerations
  - TCQSM suggestions:
    - Downtown stops: 7.5 to 15% (trade off speed for more capacity)
    - Other stops: 2.5% (preferred) up to 7.5% (minimize transit & traffic delays)

Dwell Time

- Time spent serving passengers, plus the time to open and close the doors
- The most important capacity factor
- Dwell time is affected by
  - Number of passengers to be served
  - Number of doors and door channels available for use
  - Fare payment method(s)
  - Bus floor height relative to platform height
  - On-board crowding
- Dwell time variability is also important
  - Passenger demand variability (generally throughout an hour)
  - Passenger demand variability (between routes sharing a stop)
  - Wheelchair lift/ramp use
  - Bicycle rack use
  - Passenger questions to drivers, fare disputes, etc.

Bus Stop Position

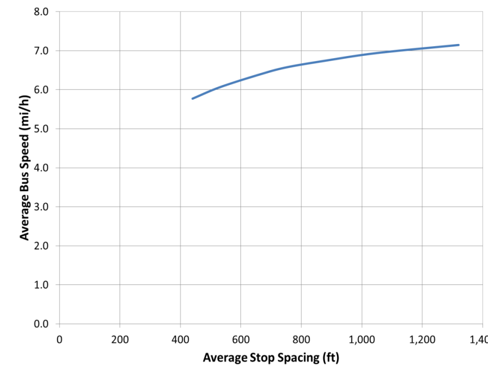
- When buses stop out of the traffic lane ("off-line stops"), they may experience "re-entry delay" waiting for a gap to pull back into traffic
- Buses that stop in the traffic lane ("on-line stops") do not experience this delay
- Yield-to-bus laws may help reduce delay at off-line stops
- All buses require "clearance time" to travel their own length, thus freeing up curb space for the next bus—this time is unusable for serving passengers

On-line (Portland)

Off-line (Albuquerque)

Stop Spacing

- The more frequently a bus stops, the more often certain fixed delays occur
  - Deceleration/acceleration delay (typically 10 seconds per urban street stop)
  - Door opening and closing time (2 to 5 seconds per stop)
- Ability to consolidate stops depends on
  - Local pedestrian environment
  - Passenger characteristics (e.g., seniors, passengers with limited mobility)
  - Neighborhood support or opposition(for losing a stop)
- Consider trade-off of longer walking distances vs. faster on-board trips



Traffic Signal Delay

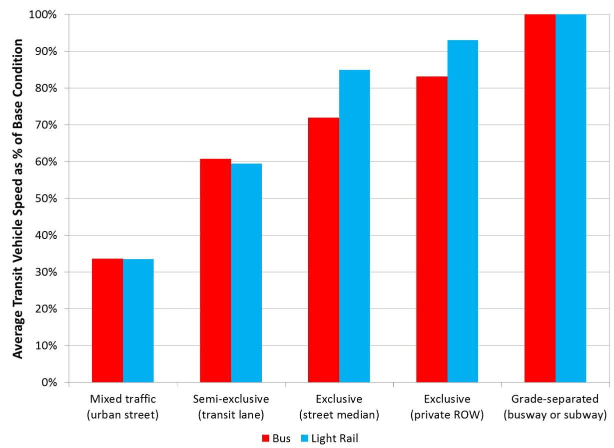
- Potential traffic signal delay is a function of:
  - Traffic signal cycle length (time from start of green to start of next green)
  - Amount of green time given to the street the bus operates on
  - Bus deceleration/acceleration delay (when a bus doesn't need to serve a bus stop at the intersection)
  - In general, shorter traffic signal cycle lengths and more green time for the bus' street reduce bus traffic signal delay
    - Traffic operations policies and requirements (particularly auto operations and pedestrian signal timing requirements) are constraints
    - Regardless of roadway agency policy regarding transit preference or minimum auto level of service, auto operations will affect buses when queues of vehicles prevent buses from getting through the intersection on the first green
- Other types of traffic control also produce delays
  - Yield control (e.g., roundabouts)
  - Stop control

Sources of Bus Delay Associated with Bus Facilities

- Stop spacing
  - How frequently a bus stops to serve passengers
- Exposure to other traffic
  - Delays caused by other traffic using the facility
- Facility design
  - Ability of buses to move around each other and other traffic
- Bus operations
  - Scheduled bus volumes relative to capacity (bus–bus interference)
  - Organization of buses and routes (platooning, skip stops)

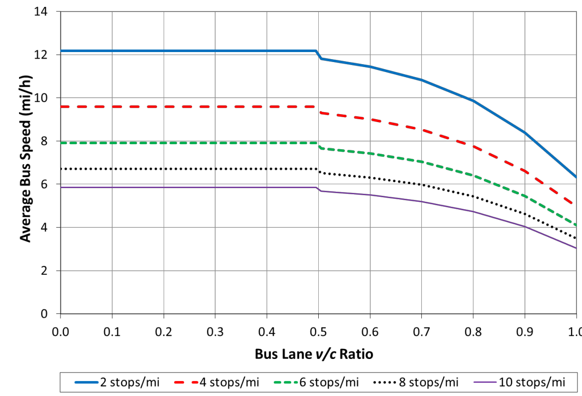
Facility Impact on Speed

- More-exclusive bus facilities cost more but provide faster travel times, along with more capacity and better reliability



Bus Volumes

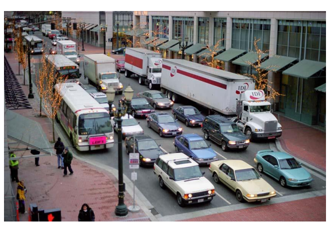
- When bus volumes exceed half of a facility's maximum (i.e., theoretical) capacity, bus speeds begin to drop as buses begin to interfere with each other



Note: v/c ratio = volume-to-capacity ratio. Speeds shown reflect assumptions given in TCQSM Exhibit 6-10.

Facility Type

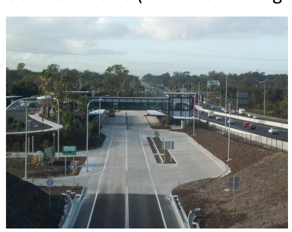
- The more exclusive the bus facility, the less traffic-induced



Mixed traffic

Semi-exclusive (bus lane with right turns allowed)

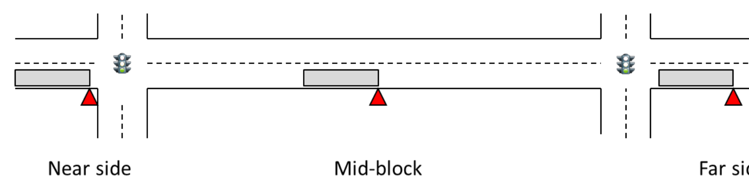
Exclusive (median busway)



Grade-separated (off-street busway)

Bus Stop Location

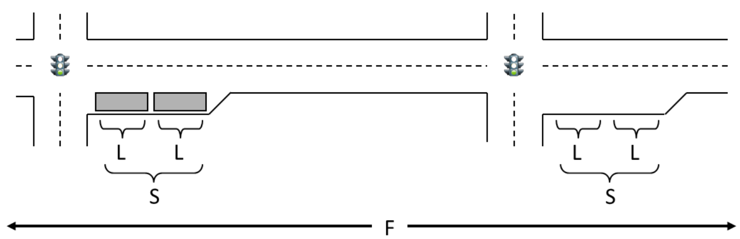
- Far-side stops have the least negative impact on speed and capacity, followed by mid-block stops and near-side stops



- Many other factors must be considered when locating bus stops
  - Vehicle turning volumes, driveways, physical obstructions
  - Transfer opportunities, locations of passenger generators
  - Signal timing, potential for implementing transit preferential measures

Locations Where Capacity Can Be Calculated

- Loading areas (bus berths)
  - Curbside space where a single bus can load and unload passengers
- Bus stops
  - Consist of one or more loading areas
- Bus facilities
  - Consist of one or more (usually many more) consecutive bus stops



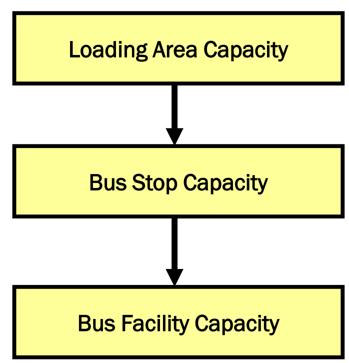
L = loading area, S = bus stop, F = bus facility

Loading Area Vehicle Capacity Factors

$$\text{Capacity} = \frac{\text{Seconds in an hour available for bus movement}}{\text{Seconds that a design bus occupies the stop}}$$

Capacity Calculation Process

Sequence of Calculations



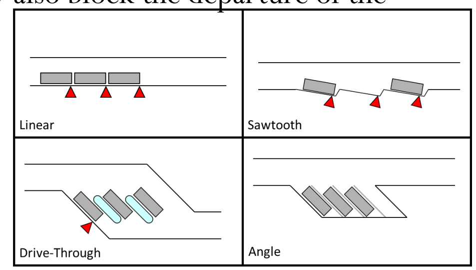
- Person capacity (p/h) = Bus facility capacity (bus/h) Bus passenger capacity (p/bus) × Peak hour factor
- Passenger capacity can be a weighted average when more than one bus type uses a facility
- Peak hour factor reduces person capacity to a design level as an allowance for serving peak-within-the-peak passenger demand

Bus Stop Capacity Factors

Capacity = (loading area capacity) ×
(number of effective loading areas at the stop) ×
(adjustment for traffic blockage)

Loading Area Effectiveness:
Linear and Non-linear Loading Areas

- Buses can move independently in and out of non-linear loading areas
  - Sawtooth, drive-through, and angle berths
  - All loading areas can be used independently of each other, when buses are not assigned to a specific loading area
- The presence of another bus may block access to linear loading areas in front of the bus and may also block the departure of the following bus
  - Each loading area cannot be fully utilized
  - Each additional physical loading area contributes less and less additional capacity



Loading Area Vehicle Capacity Factors

(3,600 s/h) × (% of time traffic control allows bus to enter/leave stop)

↓

Capacity = Seconds in an hour available for bus movement / Seconds that a design bus occupies the stop

↑

(Portion of dwell on green) +
(Time waiting for a gap in traffic to leave loading area) +
(Clearance time while a bus travels its own length when leaving) +
(Allowance for particularly long dwells)

Bus Stop Capacity Factors

(each additional physical loading area may add less than one loading area's worth of capacity)

↓

Capacity = (loading area capacity) ×
(number of effective loading areas at the stop) ×
(adjustment for traffic blockage)

↑

(function of bus stop location [near-side, far-side, mid-block], right-turning auto volumes, conflicting pedestrian volumes, and ability of buses to move around other vehicles)

Bus Stop Placement

Bus Stop Relocation

- On arterial streets, the signals at a series of intersections are timed to turn green as a platoon of vehicles approach the intersection.
- Signal progression for general traffic may work against buses.
- Relocating bus stops can help achieve busses better advantage of the existing signal progression.
- It should be kept in mind that signal timing patterns usually change over the course of the day.
- The potential impact of relocations should be evaluated for peak and off-peak periods prior to implementation

Bus Stopping Patterns

Skip Stop Operation

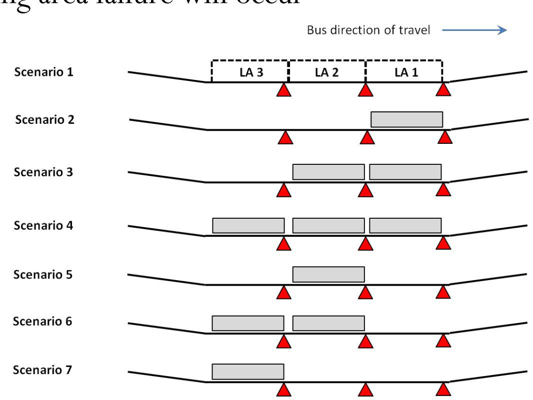
- Spreading out stops among two to four alternating patterns is known as skip stop operation.
- Improves bus speeds and overall facility bus capacity.

Platooning

- Set of busses moving along a street as a group
- Passing activity is minimized.
- High overall speeds, more effective use of bus stop loading areas, higher capacities.
- They can be formed through careful scheduling and field supervision.

Stopping Patterns at Linear Loading Areas

- In Scenario 5, the bus in loading area 2 (LA2) blocks access to the front loading area (LA1) for the next arriving bus—LA1's capacity is unusable
- In Scenarios 6 and 7, if another bus arrives before the rear bus leaves, loading area failure will occur

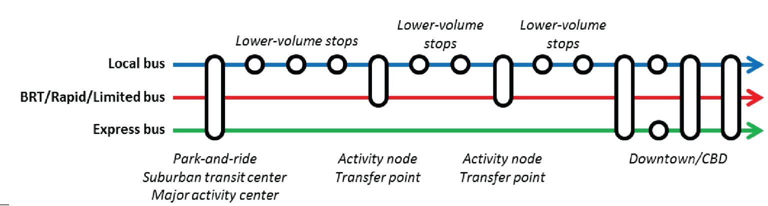


Bus Stop Placement

Bus Stop Consolidation

- Minimizing the number of stops that buses must make will improve overall bus speeds.
- Consolidating bus stops involves trade-offs between the convenience of the passengers using a particular stop, and those passengers already aboard a bus who are delayed each time the bus stops.
- In high passenger volume corridors, an alternative to eliminating stops is providing peak-period or all-day limited-stop or express service in conjunction with local service that serves all stops.

Figure: Bus Stop Spacing Patterns



Yield-To-Bus Laws

- Some agencies have passed laws - Motorists requiring to yield to buses signaling to reenter the street from bus stop.
- Few of the jurisdictions practices: Remind the motorists of the law through stickers, flashing electronic yield sign mounted on back of the bus.

(a) Montréal

(b) Portland

Route Design

Movement Restriction Exemptions

- Due to left turn restrictions, most direct route for bus not possible
- Traffic calming measures such as traffic diverters may create issues for community bus routes.

Parking Restrictions

- Parking restrictions are required near curbside stop to allow buses to pull out of the street and up to the curb to load and unload passengers.

Design Standards

- Design standards needed for: max and min bus stop spacing, route diverting criteria, etc.,

Bus Capacity – Part 2

- Chapter 6 of TCRP Report 165: Transit Capacity Quality of Service Manual 3rd Edition
- The report and PowerPoint slides may be accessed online from www.trb.org by typing "TCRP Report 165" in the Search area.

BUS CAPACITY METHODOLOGY

- Computational Methodology for bus and person capacity of loading areas, stops, and facilities.
- Service Types: Local bus, commuter bus, BRT.
- Stopping Patterns: All stop, limited stop, express.
- Operating Environments: Mixed traffic, semi-exclusive, exclusive, grade seperated.

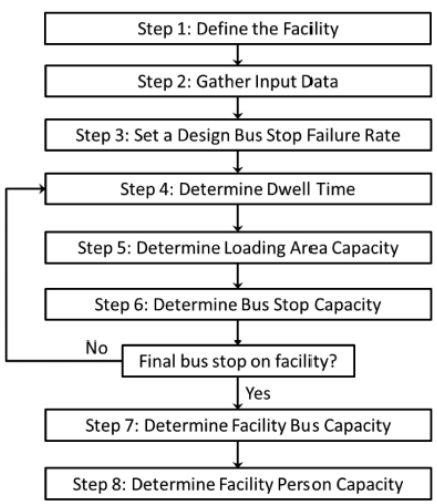


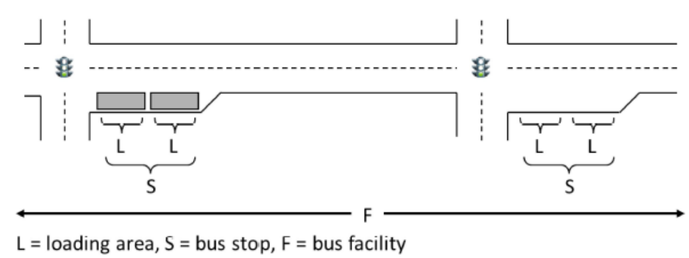
Exhibit 6-53 Bus Capacity Methodology Flowchart

Flowchart: Methodology for Bus Capacity

Step 1: Define the Facility

Bus capacity can be calculated for three locations:

- Bus Loading Areas (curbside spaces where a single bus can stop to load and unload passengers)
- Bus Stops (consisting of one or more adjacent loading areas)
- Bus Facilities (continuous sections of roadways used by buses that include at least one stop, but typically many more)

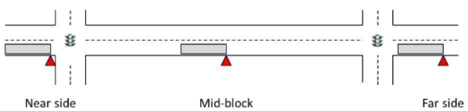


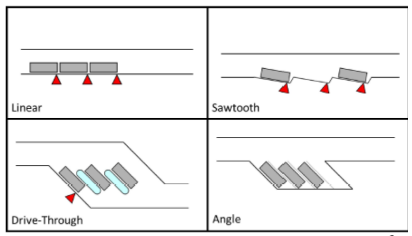
Step 2: Gather Input Data

- Bus Stop Demand Data (Average dwell time, dwell time variability, failure rate, and passenger demand peak-hour factor (PHF).
- Bus Stop Location Data (**Position relative to roadway**, **Position relative to an intersection**, **Bus stop design type**, Number of loading areas, Bus facility type, Traffic signal timing, Curb lane traffic volume, Right turning traffic volume and capacity, and parallel pedestrian crossing volume)
- Skip Stop Operation (Number of stops, bus arrival pattern [random, typical, platooned], traffic volume and capacity of the adjacent lane.


(a) On-line (Portland)


(b) Off-line (Albuquerque)





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- Skip Stop Operation (Number of stops, bus arrival pattern [random, typical, platooned], traffic volume and capacity of the adjacent lane.

Type 1

Type 2

Type 3

Step 3: Set a Design Bus Stop Failure Rate

- Bus capacity analysis incorporates the concept of a *failure rate* that sets how often a bus should arrive at a stop only to find all loading areas occupied.
- The selection of a design failure rate sets the bus stop's *design capacity*
- Design Failure Rates: Downtown areas (7.5 to 15%), Outside downtown areas 2.5% is recommended however up to 7.5% can be accepted.
- Design capacity is maximized at 25% failure rate and termed 'maximum capacity'.

Operating Margin:

- The maximum amount of time that an individual bus dwell time can exceed the average dwell time without creating the likelihood of a bus stop failure, when the number of buses scheduled to use the stop approaches the stop's capacity.

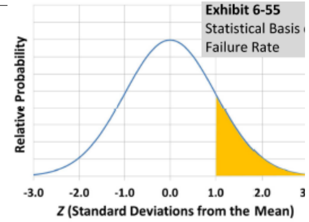
$$t_{om} = t_i - t_d$$

t_{om} = operating margin (s),
t_d = average dwell time (s), and
t_i = dwell time value that will not be exceeded more often than the desired failure rate (s).

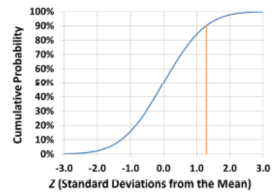
- If a series of dwell time observations were to be plotted, they would form a normal distribution
- The area under and to the right of a given point Z on a normal distribution curve represents the probability that any given bus's dwell time will be longer than that amount.

Example: If desired failure rate is 10%, then it means that there is a 90% probability that any given dwell time will not cause interference with the following bus. Therefore from cumulative probability curve, Z=1.28.

Exhibit 6-55 Statistical Basis of Failure Rate



(a) Standard normal distribution



(b) Probability of bus stop failure associated with Z

$$Z = \frac{t_{om}}{s} = \frac{t_i - t_d}{s}$$ **Equation 6-2**

vhere

Z = standard normal variable corresponding to a desired failure rate,

s = standard deviation of dwell times,

t_{om} = operating margin (s),

t_d = average dwell time (s), and

t_i = dwell time value that will not be exceeded more often than the desired failure rate (s).

$$t_{om} = sZ = c_v t_d Z$$ **Equation 6-3**

Exhibit 6-56 Values of *Z* Associated with Given Failure Rates

Design Failure Rate	Z
1.0%	2.330
2.5%	1.960
5.0%	1.645
7.5%	1.440
10.0%	1.280
15.0%	1.040
20.0%	0.840
25.0%	0.675

Source: *TCRP Report 26* (*21*).

- C_v = coefficient of variation of dwell times

Step 4: Determine Dwell Time

Estimating Dwell Time

Three methods can be used for estimating

1. Field Measurements: Best for existing bus route evaluating

2. Default values: Suitable for future planning when reliable estimates are not available

3. Calculation: Suitable when passenger boarding and alighting counts are available

Method 3: Calculation of Dwell Time

- Determine the average passenger boarding and alighting volumes per bus
- Determine the mix of fare payment methods
- Assign boarding volumes by bus door channel (details on next slide)
- Assign alighting volumes by bus door channel and adjust boarding volumes if necessary (details on next slides)
- Determine average passenger service times for each bus door channel and movement (details on next slide)
- Determine passenger flow time for each bus door channel
- Determine the boarding lost time
- Calculate the dwell time

Assign boarding volumes by bus door channel

- *Single-channel boarding, all fares paid or inspected upon boarding.* Assign all boarding volume to the front door.
- *Double-channel boarding, all fares paid or inspected upon boarding.* Split the boarding volume into (a) those who need to interact with a farebox and (b) those who just need a visual inspection of their fare media (e.g., flash pass, paper transfer, mobile phone). Assign smart card users, if any, to the channel(s) equipped with smart card terminals.
- *All-door boarding ,free or pre-paid fares.* Use Exhibit 6-58 (below table) to determine the boarding volume through the busiest door channel.

Exhibit 6-58 Percent Passengers Using Busiest Bus Door Channel (No Fare Payment)

Available Door Channels	Percent Passengers Through the Busiest Door Channel: Boarding	Alighting
2	60%	75%
3	45%	45%
4	35%	35%
6	25%	25%

Source: Derived from Exhibit 4-3 in TCQSM, 2nd Edition (5).

Note: It can be assumed that boarding passengers are evenly divided among the remaining door channels. With 2 doors available, assume 25% of alightings through the front door and 75% through the rear door. When the front door has 2 door channels, assume that alighting passengers only use the non-farebox door channel. Assume that the remaining alighting passengers are evenly divided among the remaining door channels.

Assign alighting volumes by bus door channel and adjust boarding volumes if necessary

- *Single-channel boarding, all fares paid or inspected upon boarding.* In the absence of local information, it can be assumed that 25% of alightings occur through the front door and that the remainder occur via the rear door
- *Double-channel boarding, all fares paid or inspected upon boarding.* In the absence of local information, it can be assumed that 25% of alightings occur through the non-farebox front door channel and that the remainder occur via the rear door(s).
- *All-door boarding, free or pre-paid fares.* Use Exhibit 6-58 to determine the alighting volume through the busiest door channel.
- *Pay-on-exit*. Assign all alighting volume to the front door and assume only a single passenger can alight at a time, even if two door channels are available, unless (a) the bus interior provides enough circulation space for two passengers to walk side-by-side and *(b)* most fares just need to be visually inspected.

Determine average passenger service times for each bus door channel and movement.

- In the absence of local information, use Exhibit 6-4 (page 6-7) to determine appropriate boarding and alighting service times for the conditions existing at each door channel.

Situation	Average Passenger Service Time (s/p): Observed Range	Average Passenger Service Time (s/p): Suggested Default
BOARDING		
No fare payment	1.75–2.5	1.75
Visual inspection (paper transfer/flash pass/mobile phone)	1.6–2.6	2.0
Single ticket or token into farebox	2.9–5.1	3.0
Exact change into farebox	3.1–8.4	4.5
Mechanical ticket validator	3.5–4.0	4.0
Magnetic stripe card	3.7–6.5	5.0
Smart card	2.5–3.2	2.75
ALIGHTING		
Front door	1.4–3.6	2.5
Rear door	1.2–2.2	1.75
Rear door with smart card check-out	3.4–4.0	3.5

Sources: Jaiswal (2), TCQSM 2nd Edition (5), Milkovits (6), Diaz and Hinebaugh (7), additional research for the TCQSM 2nd and 3rd Editions.

Note: Add 0.5 s/p to boarding times when standees are present. Add 0.5 s/p for non-level boarding (1.0 s/p for motor coaches).

The base values given in Exhibit 6-4 are for level (e.g., boarding from the curb onto a low-floor bus, boarding from a high-level platform onto a high-floor bus) boarding with no standees on the bus and should be adjusted as shown in the exhibit notes to reflect non-level boarding conditions and standees, if present.

Determine passenger flow time for each bus door channel:

- For a given door channel i, the passenger flow time is

$$t_{pf,i} = P_{a,i}t_{a,i} + P_{b,i}t_{b,i}$$ Equation 6-4

where

$t_{pf,i}$ = passenger flow time for door channel *i* (s),
$P_{a,i}$ = alighting passengers through door channel *i* (p),
$t_{a,i}$ = average alighting passenger service time for door channel *i* (s/p),
$P_{b,i}$ = boarding passengers through door channel *i* (p), and
$t_{b,i}$ = average boarding passenger service time for door channel *i* (s/p).

Determine the boarding lost time:

- If a bus stop only consists of one loading area, boarding lost time is zero. From research (1), average boarding lost time for three loading areas is 4 s for more crowded waiting conditions and 4.5 s for less crowded waiting conditions.

Calculate the dwell time.

- The dwell time is the time required to serve passengers at the busiest door, plus the time required to open and close the doors, plus any boarding lost time:

$$t_d = t_{pf,max} + t_{oc} + t_{bl}$$ Equation 6-5

where

t_d = average dwell time (s),
$t_{pf,max}$ = maximum passenger flow time of all door channels (s),
t_{oc} = door opening and closing time (s), 2–5 s typical, and
t_{bl} = boarding lost time (s).

Dwell Time Variability

- The coefficient of variation of dwell times (c_v), the standard deviation of dwell times divided by the average (mean) dwell time, is used to measure dwell time variability
- C_v typically ranges from 0.4 to 0.8, with 0.6 recommended as an appropriate value in the absence of field data

Step 5: Determine Loading Area Capacity

The four factors influence loading area capacity as follows:

- The sum of dwell time and clearance time equals the average time a given bus occupies a loading area.
- The operating margin accounts for longer-than-average dwells to ensure that most buses will be able to immediately use the loading area upon arriving.
- The sum of dwell time, clearance time, and operating margin gives the minimum headway between buses needed to limit bus stop failure to the design level, for a bus stop consisting of one loading area.
- Dividing this headway into 3,600 *s/h* produces the *loading area capacity,* the number of buses per hour that can use a single loading area at a bus stop at the design failure rate.

When the loading area is located at a traffic signal, buses may not be able to leave the loading area immediately after serving passengers (at near-side stops), or enter it immediately (at far-side stops). This requires a few extra considerations:

- The portion of time that the traffic signal permits bus movement is given by the g/C ratio, the ratio of the time the signal is effectively green for buses to the overall length of the traffic signal cycle. Multiplying the g/C ratio by 3,600 gives the number of seconds in an hour that buses are free to enter or leave the stop.

Mathematically, loading area capacity is expressed as (*21*):

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d} \quad \text{Equation 6-6}$$

where

- B_l = loading area bus capacity (bus/h);
- 3,600 = number of seconds in 1 hour;
- g/C = green time ratio (the ratio of effective green time to total traffic signal cycle length, equals 1.0 for unsignalized streets and bus facilities);
- t_c = clearance time (s) = $t_{su} + t_{re}$;
- t_{su} = minimum time for a bus to start up, travel its own length, and the next bus to pull into the loading area (s) (default of 10 s);
- t_{re} = reentry delay (s), from Exhibit 6-59 or field measured;
- t_d = average (mean) dwell time (s);
- t_{om} = operating margin (s);
- Z = standard normal variable corresponding to a desired failure rate, from Exhibit 6-56; and
- c_v = coefficient of variation of dwell times.

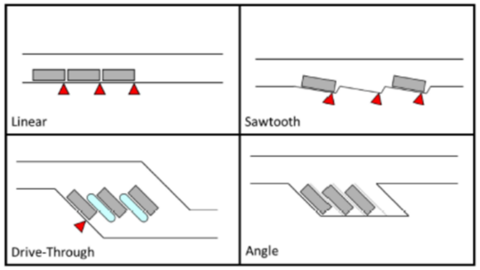
Step 6: Determine Bus Stop Capacity

- *A* bus stop's capacity depends on the capacities of the bus stop's individual loading areas (determined in Step 5), the number of loading areas provided, the design of those loading areas, and the bus stop's position relative to the roadway.
- It is also dependent on traffic congestion that interferes with a bus's access to the stop and on bus stopping patterns.

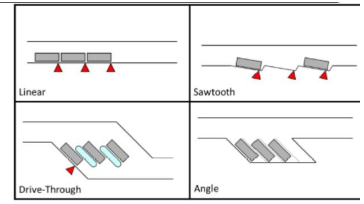
1. *Step 6a: Determine the Number of Effective Loading Areas*
2. *Step 6b: Adjust Capacity for Traffic Blockage at Traffic Signals*
3. *Step 6c: Calculate Bus Stop Capacity*

Step 6a: Determine the Number of Effective Loading Areas

- The more loading areas (linear) that are added, the more likely that some of them will be inaccessible at a given point in time. The concept of *effective loading areas* is used to describe this effect, where the second linear loading area provides less capacity than the first, the third adds even less, and so on.



- Non-linear loading areas are 100% efficient-the number of effective loading areas equals the number of physical loading areas.



- Effective Loading Areas for Linear Loading Areas:

	On-Line Loading Areas				Off-Line Loading Areas	
	Random Arrivals		Platooned Arrivals		All Arrivals	
Loading Area #	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas
1	100	1.00	100	1.00	100	1.00
2	75	1.75	85	1.85	85	1.85
3	70	2.45	80	2.65	75	2.60
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

Sources: *TCRP Report 26* (*21*) and *TCRP Research Results Digest 38* (*37*).
Notes: On-line values assume that buses do not overtake each other.
Values apply only to linear loading areas; non-linear designs are 100% effective.

Exhibit 6-63 Efficiency of Multiple Linear Loading Areas at Bus Stops

Step 6b: Adjust Capacity for Traffic Blockage at Traffic Signals

(a) Los Angeles (right turn)

(b) Portland (left turn)

- Vehicles turning from the bus lane (or across the bus path, at off-line stops) may use up signal green time that would otherwise have been available for bus movement as these vehicles wait for conflicting vehicles and pedestrians to clear before they can complete their turn.
- The impact on bus stop capacity depends on (a) the movement's traffic volume relative to its capacity, (b) the bus stop location (e.g., near side, far side), and (c) the ability or inability of buses to move around turning vehicles.

- The effects of traffic blockage reduce bus capacity in proportion to the following adjustment factor f_{tb}

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right)$$

Equation 6-17

where

f_{tb} = traffic blockage adjustment factor;
f_l = bus stop location factor, from Exhibit 6-66;
v_{cl} = curb lane traffic volume at intersection (veh/h); and
c_{cl} = curb lane capacity at intersection (veh/h).

- Value of f_1:

	Lane Type		
Bus Stop Location	Type 1	Type 2	Type 3
Near side	1.0	0.9	0.0
Mid-block before or after traffic signal	0.9	0.7	0.0
Far side	0.8	0.5	0.0

Source: *TCRP Report 26* (*21*).
Note: f_l = 0.0 for contraflow bus lanes, median busways, and grade-separated busways regardless of bus stop location or lane type, as right turns are either prohibited or do not interfere with bus operations.

Exhibit 6-66 Bus Stop Location Factor f_l

- C_{cl}??

- The curb lane capacity C_{cl}, in vehicles per hour, is the average of the through (C_{th}) and right-turn (C_{rt}) capacities, weighted by their respective volumes.
- The capacity of through movements in the curb lane C_{th} (in vehicles per hour) is the lane's saturation flow rate times the g/C ratio. The saturation flow rate can be calculated from Exhibit 6-60.
- Capacity of right-turn movements C_{rt} based on ranges of conflicting pedestrian volumes and the proportion of effective green time available for traffic.

Exhibit 6-65 Right-Turn Vehicle Capacities c_{rt} for Planning Applications (veh/h)

Conflicting Pedestrian Volume (ped/h)	g/C Ratio for Curb Lane					
	0.35	0.40	0.45	0.50	0.55	0.60
0	510	580	650	730	800	870
100	440	510	580	650	730	800
200	360	440	510	580	650	730
400	220	290	360	440	510	580
600	70	150	220	290	360	440
800	*	*	70	150	220	290
1,000	*	*	*	*	70	150

Source: HCM 2010 (*40*), based on 1,450 × (*g/C*) × (1 – (pedestrian volume/2,000)) with PHF=1.
Note: *Vehicles can only turn at the end of green, assume one or two per traffic signal cycle. Values shown are for CBD locations, multiply by 1.1 for other locations.

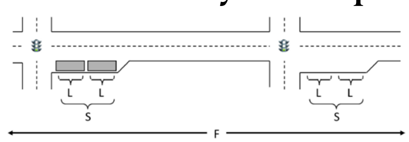
Step 6c: Calculate Bus Stop Capacity

- Bus stop capacity is the capacity of a single loading area multiplied by the number of effective loading areas and the traffic blockage adjustment factor:

$$B_s = N_{el} B_l f_{tb} = N_{el} f_{tb} \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Z c_v t_d}$$ Equation 6-18

- B_s is the bus stop capacity (bus/h), N_{el} is the number of effective loading areas at the bus stop, and all other variables as defined previously.

Step 7: Determine Facility Bus Capacity



L = loading area, S = bus stop, F = bus facility

- Bus facility capacity is greatly dependent on the exclusivity of the facility- the less interference that buses have from other traffic, the greater the capacity.
- When the majority of buses make no stops along a facility (e.g., express services to downtown), and passing lanes are provided at any stops that do exist, a bus facility acts like a pipe that can serve hundreds of buses per hour.
- More typically, even when different service types (e.g., local, limited stop) are operated along a facility, there will be common stops (or groups of stops, with skip-stop operation) served by all buses using the facility. In this case, the facility capacity will be constrained by the capacity of the *critical bus stop* -the bus stop (or group of stops) used by all buses that has the lowest capacity.

Step** 7a: **Non-stop Facility Capacity

- Non-stop facilities include freeway managed lanes and busways where passing lanes are provided at stations.
- Determining the number of buses that can be operated along these facilities requires examining both the facility itself and the facilities and terminals serving it for the constraining location.

Step 7b: Facility Capacity without Skip-Stop Operation

- The facility capacity is equal to the capacity of the ***critical stop*** along the facility.
- When all buses using the facility stop at all stops, the critical stop is the bus stop with the lowest capacity.
- When a mix of service types (e.g., local and limited stop) uses the facility, the critical stop will be the bus stop used by all service types that has the lowest capacity

Step 7c: Facility Capacity with Skip-Stop Operation

- When skip-stop operation is used, the bus facility capacity is equal to the sum of the capacities of the critical bus stops of each skip-stop group, multiplied by an adjustment factor f_k reflecting inefficient arrival patterns and the effects of high vehicular traffic volumes in the adjacent lane

$$B = f_k(B_1 + B_2 + \cdots + B_n)$$ Equation 6-19

where

B = bus facility design capacity (bus/h);

f_k = capacity adjustment factor for skip-stop operations, from Equation 6-20; and

$B_1 \ldots B_n$ = critical bus stop capacity of a given skip-stop pattern (bus/h);

$$f_k = \frac{1 + f_a f_i (N_{ss} - 1)}{N_{ss}}$$ Equation 6-20

where

f_a = arrival-type factor, reflecting the ability to fully utilize the bus stops in a skip-stop operation:
= 0.50 for random arrivals (poor scheduling/poor schedule adherence),
= 0.75 for typical arrivals (imperfect schedule adherence), and
= 1.00 for platooned arrivals (buses travel in groups, like cars of a train);

f_i = adjacent lane impedance factor, from Equation 6-21; and

N_{ss} = number of alternating skip stops in sequence;

and with

$$f_i = 1 - 0.8\left(\frac{v_{al}}{c_{al}}\right)^3$$ Equation 6-21

where

v_{al} = traffic volume in the adjacent lane (veh/h); and

c_{al} = capacity of the adjacent lane (veh/h).

A planning-level estimate of the adjacent lane capacity can be made by multiplying the typical downtown lane vehicle saturation flow rate of 1,7 50 vehicles per lane per hour of green by the g/C ratio of the bus lane. Outside the downtown area, a saturation flow rate of 1,600 vehicles per lane per hour of green may be used.

- Values of the adjustment factor f_k for various lane types, bus arrival types, and bus stopping patterns.

Exhibit 6-67 Typical Values of Adjustment Factor f_k for Availability of Adjacent Lanes

Condition	Adjacent Lane v/c	f_i	N_{ss} - 1	f_a	f_k
TYPE 1 LANE					
Stops every block	0 to 1	0 to 1	0	0.00	1.00
TYPE 2 LANE					
Stops every block	0 to 1	0 to 1	0	0.00	1.00
Alternating 2-block stops, random	0	1	1	0.50	0.75
	1	0.2*	1	0.50	0.55
Alternating 2-block stops, typical	0	1	1	0.75	0.88
	1	0.2*	1	0.75	0.58
Alternating 2-block stops, platooned	0	1	1	1.00	1.00
	1	0.2*	1	1.00	0.60
TYPE 3 LANE					
Alternating 2-block stops, random	0	1	1	0.50	0.75
Alternating 2-block stops, typical	0	1	1	0.75	0.88
Alternating 2-block stops, platooned	0	1	1	1.00	1.00
Alternating 3-block stops, random	0	1	2	0.50	0.67
Alternating 3-block stops, typical	0	1	2	0.75	0.83
Alternating 3-block stops, platooned	0	1	2	1.00	1.00

Source: *TCRP Report 26* (21).
Notes: * approximate
v/c = volume-to-capacity ratio.

- **Step 8: Determine Facility Person Capacity**

- The final step is to determine how many persons can be served by the bus facility over the course of an hour.
- Person capacity is influenced by the following:

1. The facility's bus capacity,
2. Transit agency policy regarding passenger loads,
3. Scheduled headways, and
4. Passenger demand diversity.

Scheduled Person Capacity

- Scheduled person capacity reflects the number of passengers that can be carried through the facility's maximum load section, given the existing schedule and bus model(s) used.
- If a transit agency's policy is that passenger loading should not exceed P_{max} passengers per bus model *on average* during an hour, scheduled person capacity is calculated as follows:

$$P_s = \sum_{i=1}^{N_{bm}} P_{max,i} N_i \qquad \text{Equation 6-22}$$

where

P_s = scheduled person capacity (p/h),
$P_{max,i}$ = maximum schedule load for bus model *i* (p/bus),
N_{bm} = number of different bus models operated on the facility, and
N_i = number of buses of bus model *i* scheduled to use the facility during the hour (bus/h).

- If a transit agency's policy is that passenger loading should *not regularly exceed Pmax* passengers per bus model during an hour, scheduled person capacity is calculated as follows:

$$P_s = \sum_{i=1}^{n} P_{max,i}(PHF)N_i \qquad \text{Equation 6-23}$$

$$PHF = \frac{P_h}{4P_{15}}$$

where

PHF = peak-hour factor;
P_h = passenger volume during the peak hour (p); and
P_{15} = passenger volume during the peak 15 min (p).

Design Person Capacity

- Design person capacity is the number of people that ***could*** be carried through the facility's maximum load section, if buses were scheduled to use the facility at its full capacity, under a specified set of conditions (e.g., design failure rate, vehicle types, fare collection method).
- In this case, Equation 6-22 and Equation 6-23 are replaced with the following, depending on whether the loading standard is an average (Equation 6-25) or is not to be regularly exceeded (Equation 6-26):

$$P = P_{max}B \qquad \text{Equation 6-25}$$

$$P = P_{max}(PHF)B \qquad \text{Equation 6-26}$$

where

P = design person capacity (p/h),
P_{max} = weighted average maximum schedule load for buses using the facility (p/bus), and
B = bus facility design capacity (bus/h).

Calculation Example for Bus Capacity

- Carroll City, the central city in a region of 750,000 people, is examining opportunities to improve transit service through its downtown core as part of a Downtown Circulation Plan. Existing bus service to downtown is concentrated on Carroll Street and George Street, a one-way couplet just *over* one mile in length. Both streets have two through lanes, with on-street parking provided on both sides of the street. The couplet is served by six transit routes operated by Carroll City Transit (CCT), with combined peak-hour frequency of 26 buses per hour. Buses stop *every* block, with average block lengths of 660 ft. On-street parking is removed at bus stops to allow buses access to the curb, and buses must exit the traffic stream to *serve* passengers. Traffic signals are located at each intersection along the downtown couplet.
- What is the potential bus capacity in vehicles per hour.

Step 1. Define the Facility

- The facility consists of the one-way couplet of Carroll Street and George Street through the downtown core.

Step 2. Gather Input Data

- *Coefficient of variation of dwell times* (c_v) = 0.62
- *Passenger demand peak-hour factor (PH F)*= 0.75
- Passenger boarding and alighting volumes are also available
- All stops are *off-line,* as buses exit the travel lane to access the curb
- All stops along the couplet are *far side*
- Bus stop design is *linear*
- Two *loading areas* are provided at bus stops in the central portion of the couplet by removing additional on-street parking at the stop. This reflects the higher passenger demand at these stops. Other stops have only one loading area.

Step 2. Gather Input Data Contd..

- The downtown street network is a one-way grid, with signals on every block. Signals operate on 80-s cycles, with both streets at a given intersection receiving the same amount of green time. Accounting for traffic signal lost time, this results in a g/C ratio of 0.45 for buses on the couplet. The posted speed is 25 mi/h.

	Carroll Street Bus Stops							
	1	2	3	4	5	6	7	8
Number of loading areas	1	1	2	2	2	2	1	1
Curb-lane volume (veh/h)	450	500	500	550	600	650	600	600
Right-turn volume (veh/h)*	75	110	0	160	0	60	80	75
Pedestrian volume (ped/h)	40	70	140	120	280	400	120	80
	George Street Bus Stops							
	1	2	3	4	5	6	7	8
Number of loading areas	1	1	2	2	2	2	1	1
Curb-lane volume (veh/h)	650	600	550	550	550	500	450	450
Right-turn volume (veh/h)*	80	120	60	0	160	0	90	130
Pedestrian volume (ped/h)	110	140	80	300	340	170	130	140

Note: *Included as part of the curb lane volume.

Exhibit 6-76
Calculation Example Summary of Existing Bus Stop Characteristics

Step 3. Set a Design Bus Stop Failure Rate

- The TCQSM recommends a design failure rate of 7.5 to 15% for downtown areas.
- Based on the policies of CCT and the Carroll City Public Works Department, 15% is selected as the design bus stop failure rate for the analysis.

Step 4: Determine Dwell Time

- All bus routes operate using 40-ft low-floor buses that have a wide (two-channel) front door and a narrower (one-channel) rear door.
- Boarding occurs through the front door. Passengers purchasing single-ride or daily fares must use the farebox, but passengers with a monthly pass can bypass the fare box by showing their pass to the operator.
- Agency data show that approximately 55% of passengers use the heavily discounted monthly passes. Therefore remaining 45% will be using farebox.
- Alighting passengers may use either door, but favor the rear door to avoid conflicts with boarding passengers. Standees are not normally present.

	Carroll Street Bus Stops							
	1	2	3	4	5	6	7	8
Boarding passengers	3	5	10	5	12	8	3	6
Alighting passengers	3	2	7	8	7	3	0	0
	George Street Bus Stops							
	1	2	3	4	5	6	7	8
Boarding passengers	2	4	8	10	6	12	4	3
Alighting passengers	2	4	6	6	8	4	2	0

Exhibit 6-77
Calculation Example Average Boardings and Alightings per Bus by Stop

Assign Boarding and Alighting Volume by Door Channel.

- The current boarding scenario reflects *double-channel* boarding, in which 45% of passengers use the farebox (channell) and the remaining 55% use the front door but bypass the fare box (channel 2).
- No alighting passengers will use channell (as it will be occupied by boarders using the farebox) . Assume that 25% of alighting passengers exit from the front door via channel 2 (default value), with the remaining 75% of passengers using the rear door (channel 3).

xhibit 6-78
alculation Example: verage Boardings nd Alightings by oor Channel—xisting Conditions

	Door Channel	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Boardings	1	1.4	2.3	4.5	2.3	5.4	3.6	1.4	2.7
	2	1.7	2.8	5.5	2.8	6.6	4.4	1.7	3.3
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.8	0.5	1.8	2.0	1.8	0.8	0	0
	3	2.3	1.5	5.3	6.0	5.3	2.3	0	0
	Door Channel	**George Street Bus Stops 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boardings	1	0.9	1.8	3.6	4.5	2.7	5.4	1.8	1.4
	2	1.1	2.2	4.4	5.5	3.3	6.6	2.2	1.7
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.5	1.0	1.5	1.5	2.0	1.0	0.5	0
	3	1.5	3.0	4.5	4.5	6.0	3.0	1.5	0

Determine Average Passenger Service Time for Each Bus Door Channel

- Boardings through Channel 1: 4.5 s (exact change into farebox)
- Boardings through Channel 2: 2.0 s (visual fare inspection)
- Alightings through Channel 2: 2.5 s (front door)
- Alightings through Channel3: 1.75 s (rear door)

Exhibit 6-4
Individual Passenger Service Times (Level Boarding)

Situation	Average Passenger Service Time (s/p) Observed Range	Suggested Default
BOARDING		
No fare payment	1.75–2.5	1.75
Visual inspection (paper transfer/flash pass/mobile phone)	1.6–2.6	2.0
Single ticket or token into farebox	2.9–5.1	3.0
Exact change into farebox	3.1–8.4	4.5
Mechanical ticket validator	3.5–4.0	4.0
Magnetic stripe card	3.7–6.5	5.0
Smart card	2.5–3.2	2.75
ALIGHTING		
Front door	1.4–3.6	2.5
Rear door	1.2–2.2	1.75
Rear door with smart card check-out	3.4–4.0	3.5

ources: Jaiswal (*2*), TCQSM 2nd Edition (*5*), Milkovits (*6*), Diaz and Hinebaugh (*7*), additional research for the TCQSM 2nd and 3rd Editions.

lote: Add 0.5 s/p to boarding times when standees are present. Add 0.5 s/p for non-level boarding (1.0 s/p for motor coaches).

- In addition, when minor-direction flow through a door channel is more than 25% of the total flow through the door channel, boarding and alighting times should be increased by 20% to account for the congestion at the door.
- Two-directional flows occur in door channel 2, and minor-direction flow is more than 25% of the total flow at stops 1 and 4 on Carroll Street and at stops 1, 2, 3, and 5 on George Street.

xhibit 6-78
alculation Example: verage Boardings nd Alightings by oor Channel—xisting Conditions

	Door Channel	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Boardings	1	1.4	2.3	4.5	2.3	5.4	3.6	1.4	2.7
	2	1.7	2.8	5.5	2.8	6.6	4.4	1.7	3.3
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.8	0.5	1.8	2.0	1.8	0.8	0	0
	3	2.3	1.5	5.3	6.0	5.3	2.3	0	0
	Door Channel	**George Street Bus Stops 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boardings	1	0.9	1.8	3.6	4.5	2.7	5.4	1.8	1.4
	2	1.1	2.2	4.4	5.5	3.3	6.6	2.2	1.7
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.5	1.0	1.5	1.5	2.0	1.0	0.5	0
	3	1.5	3.0	4.5	4.5	6.0	3.0	1.5	0

Determine Passenger Flow Time for Each Bus Door Channel

Equation 6-4

$$t_{pf,i} = P_{a,i}t_{a,i} + P_{b,i}t_{b,i}$$

$t_{pf,i}$ = passenger flow time for door channel *i* (s),
$P_{a,i}$ = alighting passengers through door channel *i* (p),
$t_{a,i}$ = average alighting passenger service time for door channel *i* (s/p),
$P_{b,i}$ = boarding passengers through door channel *i* (p), and
$t_{b,i}$ = average boarding passenger service time for door channel *i* (s/p).

- Using Equation 6-4, calculate the average passenger flow time for each door channel.

	Door Channel	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Boardings	1	1.4	2.3	4.5	2.3	5.4	3.6	1.4	2.7
	2	1.7	2.8	5.5	2.8	6.6	4.4	1.7	3.3
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.8	0.5	1.8	2.0	1.8	0.8	0	0
	3	2.3	1.5	5.3	6.0	5.3	2.3	0	0
	Door Channel	**George Street Bus Stops 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boardings	1	0.9	1.8	3.6	4.5	2.7	5.4	1.8	1.4
	2	1.1	2.2	4.4	5.5	3.3	6.6	2.2	1.7
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.5	1.0	1.5	1.5	2.0	1.0	0.5	0
	3	1.5	3.0	4.5	4.5	6.0	3.0	1.5	0

- The calculations are shown in their entirety for Stop #1 on Carroll Street below.

$$t_{pf,i} = P_{a,i}t_{a,i} + P_{b,i}t_{b,i}$$

- $t_{pf,1} = 0 + (1.4)x(4.5) = 6.3 = 6s$ (rounded)
- $t_{pf,2} = (0.8)x(2.5 \text{ x } 1.2) + (1.7)x(1.75 \text{ x } 1.2) = 5.97 = 6s$
- $t_{pf,3} = (2.3)x(1.75) + 0 = 4.02 = 4s$

- Exhibit 6-79 shows the average passenger flow time for each door channel resulting from the calculations.

Exhibit 6-79
Calculation Example: Average Passenger Flow Time by Door Channel (s)—Existing Conditions

	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Channel 1 ($t_{pf,1}$)	6	10	20	10	24	16	6	12
Channel 2 ($t_{pf,2}$)	6	7	15	13	18	11	3	7
Channel 3 ($t_{pf,3}$)	4	3	9	11	9	4	0	0
Maximum ($t_{pf,max}$)	6	10	20	13	24	16	6	12
	George Street Bus Stops 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Channel 1 ($t_{pf,1}$)	4	8	16	20	12	24	8	6
Channel 2 ($t_{pf,2}$)	4	8	15	15	14	16	6	3
Channel 3 ($t_{pf,3}$)	3	5	8	8	11	5	3	0
Maximum ($t_{pf,max}$)	4	8	16	20	14	24	8	6

Determine the Boarding Lost Time

- Stops 1, 2, 7, and 8 on both Carroll Street and George Street have only one loading area each, and therefore have no boarding lost time.
- Assume that boarding lost time is equal to 2 s for the remaining stops, each of which have two loading areas.

Calculate the Dwell Time

- Calculate the average dwell time for each bus stop.
- The calculation is shown for Stop #1 on Carroll Street.

$$t_d = t_{pf,max} + t_{oc} + t_{bl}$$

- $t_d = 6 + 4 + 0 = 10s$

	Bus Stop 1	2	3	4	5	6	7	8
Carroll Street	10	14	26	19	30	22	10	16
George Street	8	12	22	26	20	30	12	10

Exhibit 6-80
Calculation Example: Average Dwell Time by Stop (s)—Existing Conditions

Step 5: Determine Loading Area Capacity

Determine the Clearance Time

- Because the stops on the corridor are off-line, the clearance time is equal to 10 s (the minimum time for a standard bus to start up and travel its own length, and for the next bus to pull in) plus reentry delay.
- The calculation of reentry delay varies depending on the bus stop location relative to traffic signals; since all bus stops in the corridor are located at signalized intersections, Case 2 applies to all stops.
- The clearance time t_c is the reentry delay (4.5 s) plus the minimum bus startup and movement time (10 s), or 14.5 s. Exhibit 6-81 provides reentry and clearance times for all stops in the corridor.

Exhibit 6-81
Calculation Example: Reentry and Clearance Times by Stop (s)—Existing Conditions

	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Reentry time t_{re} (s)	5	6	6	7	9	12	9	9
Clearance time t_c (s)	15	16	16	17	19	22	19	19
	George Street Bus Stops 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Reentry time t_{re} (s)	12	10	8	8	8	6	5	5
Clearance time t_c (s)	22	20	18	18	18	16	15	15

Calculate the Loading Area Capacity

- The standard normal variable Z associated with the design failure rate of 15% is 1.04.

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{14.5 + 10(0.45) + (1.04)(0.60)(10)}$$

$$B_l = \frac{1{,}620}{25.24} = 64 \text{ bus/h}$$

Exhibit 6-56
Values of Z
Associated with Given
Failure Rates

Design Failure Rate	Z
1.0%	2.330
2.5%	1.960
5.0%	1.645
7.5%	1.440
10.0%	1.280
15.0%	1.040
20.0%	0.840
25.0%	0.675

Source: *TCRP Report 26* (*21*).

Exhibit 6-82
Calculation Example:
Loading Area Capacit
by Stop (bus/h)—
Existing Conditions

	Bus Stop							
	1	2	3	4	5	6	7	8
Carroll Street	64	53	37	48	31	36	54	44
George Street	53	50	40	36	42	34	59	64

Step 6: Determine Bus Stop Capacity

Determine the Number of Effective Loading Areas

- Use Exhibit 6-63 to estimate the number of effective loading areas N_{el} at each stop. Stops with one loading area will be 1.00 effective loading areas, while stops with two loading areas will have 1.85 effective loading areas (as the stops are off-line).

Adjust Capacity for Traffic Blockage

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right)$$ **Equation 6-17**

- Use Equation 6-17 to calculate the traffic blockage adjustment factor f_{tb}☐
- The bus stop location factor *fi* is 0.5 because stops are located far side and buses are able to move into the adjacent travel lane as needed.

Exhibit 6-66
Bus Stop Location
Factor f_l

Bus Stop Location	Lane Type: Type 1	Type 2	Type 3
Near side	1.0	0.9	0.0
Mid-block before or after traffic signal	0.9	0.7	0.0
Far side	0.8	0.5	0.0

- The capacity of the curb lane through movement *Cth* is estimated as 1,625 x *(g/C)*, or 731, based on the saturation flow values in Exhibit 6-60.
- The capacity of the right-turn movement *Crt* is estimated as 1,450 x *(g/C)* x (1-(pedestrian volume/2,000)), using the equation accompanying Exhibit 6-65.
- The curb lane capacity (C_{cl}) is the volume-weighted average of the through and right-turn capacities:

$$c_{cl} = 731\frac{(450-75)}{450} + 639\frac{75}{450} = 716 \text{ veh/h}$$

Adjust Capacity for Traffic Blockage

- The traffic blockage adjustment factor calculation for Stop #1 on Carroll Street is as follows :

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right)$$

- $f_{tb} = 1 - 0.5(450/716) = 0.69$

Calculate Bus Stop Capacity

$$B_s = N_{el} B_l f_{tb} = (1.0)(64)(0.69) = 44 \text{ bus/h}$$

Exhibit 6-83
Calculation Example:
Bus Stop Capacity—
Existing Conditions

	Carroll Street Bus Stops							
	1	2	3	4	5	6	7	8
Loading area capacity B_l (bus/h)	64	53	37	48	31	36	54	44
Effective loading areas N_{el}	1.00	1.00	1.85	1.85	1.85	1.85	1.00	1.00
Blockage factor f_{tb}	0.69	0.65	0.66	0.61	0.59	0.54	0.58	0.58
Bus stop capacity B_s	44	33	44	53	34	35	31	25
	George Street Bus Stops							
	1	2	3	4	5	6	7	8
Loading area capacity B_l (bus/h)	53	50	40	36	42	34	59	64
Effective loading areas N_{el}	1.00	1.00	1.85	1.85	1.85	1.85	1.00	1.00
Blockage factor f_{tb}	0.55	0.58	0.62	0.62	0.59	0.66	0.68	0.68
Bus stop capacity B_s	29	28	45	41	45	41	40	43

Step 7: Determine Facility Bus Capacity

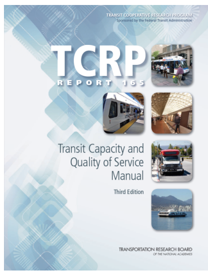
- As skip-stop operations are not used on this facility, the facility bus capacity is simply equal to the capacity of the critical bus stop (i.e., the bus stop with the lowest capacity).
- The critical bus stop on Carroll Street is Stop #8, with a capacity of 25 buses per hour, and the critical bus stop on George Street is Stop #2, with a capacity of 28 buses per hour.

	Carroll Street Bus Stops							
	1	2	3	4	5	6	7	8
Loading area capacity B_l (bus/h)	64	53	37	48	31	36	54	44
Effective loading areas N_{el}	1.00	1.00	1.85	1.85	1.85	1.85	1.00	1.00
Blockage factor f_{tb}	0.69	0.65	0.66	0.61	0.59	0.54	0.58	0.58
Bus stop capacity B_s	44	33	44	53	34	35	31	25
	George Street Bus Stops							
	1	2	3	4	5	6	7	8
Loading area capacity B_l (bus/h)	53	50	40	36	42	34	59	64
Effective loading areas N_{el}	1.00	1.00	1.85	1.85	1.85	1.85	1.00	1.00
Blockage factor f_{tb}	0.55	0.58	0.62	0.62	0.59	0.66	0.68	0.68
Bus stop capacity B_s	29	28	45	41	45	41	40	43

Thank You

- Next Topic: Rail Transit Capacity

DEMAND-RESPONSIVE TRANSIT CAPACITY



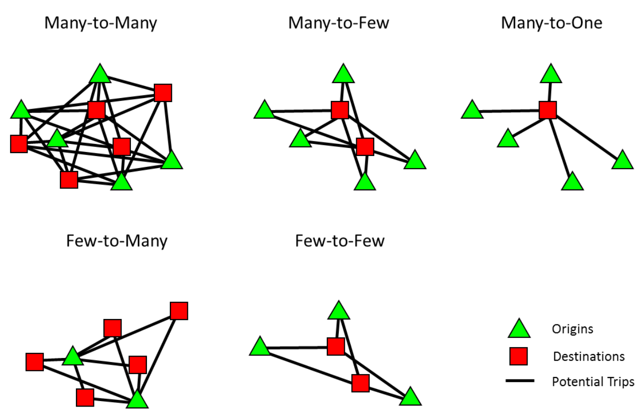
Transit Capacity and Quality of Service Manual, 3rd Edition:

Chapter 7

Definition and Overview

- DRT is a form of public transportation characterized by flexible routing and scheduling of small- to medium-size vehicles operating in a shared-ride mode between pick-up and drop-off locations according to passengers' needs
- Historically, DRT has been referred to as "dial-a-ride" service
- More recently, DRT has evolved to include a range of services—flexible transit services—that share attributes of pure DRT and fixed-route service
  - Share a common element of trip reservation
  - Services vary in their degree of flexibility, rider groups served, and operational and performance attributes

Service Pattern Types



Types of DRT Service

- General Public
- Limited Eligibility
- ADA Paratransit
- Human Service Transportation
- Jitney
- Flexible Transit Services

What Matters to Customers?

- Service availability
  - Is transit an option?
- Comfort and convenience
  - If it is an option, would you want to use it?
- Quality of service (QOS) focuses on the passenger point of view
- Other points of view are also valid and need to be considered
  - May have conflicting objectives (e.g., passenger comfort vs. agency resources)
  - Best-quality passenger service may not be feasible or desirable
  - ADA requirements must always be met
- See the Quality of Service presentation for a more in-depth presentation of QOS concepts

QOS Framework

- The QOS framework presents key performance measures that can be used in setting service standards and evaluating the QOS delivered to passengers
  - Three measures of availability
  - Three measures of comfort and convenience
- Framework and measures intended to be applied to general public and limited eligibility DRT services only
  - ADA stipulates service requirements for ADA paratransit
  - Some measures may be applicable to flexible transit services, but the wide range of these services precludes developing standardized QOS tables

Availability	Comfort and Convenience
Response Time	Reliability
Service Span	Travel Time
Service Coverage	No-shows

DRT Capacity

Capacity Issues

- How many vehicles and vehicle service hours are required to accommodate a given passenger demand and service area?
- DRT capacity depends on vehicle size and the operating policies

Capacity Factors

- Ridership demand
- Passenger characteristics
- Peak period demand
- Service area size
- Service area characteristics
- Trip pattern type
- Operating policies

Capacity Factors

- Ridership demand
  - Key factor for the calculation of needed capacity
  - Demand should be determined on an average weekday basis as well as a peak-period basis
- Passenger characteristics
  - Is service for general public or a specialized group?
  - ADA paratransit cannot limit its capacity for eligible riders
  - Differences in passenger characteristics can impact wait times or dwell times, affecting capacity
    - Services designed for people with disabilities will have longer wait times and longer dwell times

Capacity Factors

- Peak period demand
  - If DRT systems have peaked ridership demand, additional capacity is required at those peak times
  - A DRT vehicle generally does not carry more passengers during peak times (unlike fixed-route buses), so DRT providers may need to provide more service during peak demand periods
  - Ways to provide additional service
    - Deploy additional vehicles
    - Supplement DRT service with non-dedicated service such as taxis
    - Improve DRT vehicle schedules to ensure adequate capacity
  - Whether a DRT provider can manage demand during peak periods will affect capacity needs

Capacity Factors

- Service area size
  - A large service area results in longer passenger trips, lowering productivity and increasing need for additional capacity
  - Service area may be divided into zones, which offer connections to the fixed-route network and also serve neighborhoods with short trips to local destinations
  - Number of vehicles needed for each zone depends on number of passengers from that area
- Service area characteristics
  - Locations of major bridges, railroad crossings, geographic features, and other characteristics of the service area can increase travel time and impact capacity
- DRT trip pattern type
  - If a DRT service can group more riders (many-to-one, many-to-few, few-to-few), it will have a higher productivity
  - Many-to-many results in fewer passenger trips per vehicle because of greater dispersion of origins and destinations, resulting in a need for additional capacity

Capacity Factors

- Operating policies
  - A policy with a short on-time window (e.g., 15 or 20 min) that requires high on-time performance standards will result in less grouping of passenger trips, limiting productivity and requiring additional capacity
  - A policy that increases the time to serve each passenger trip (the wait time for riders at pick-up location) will increase rider travel times, which also lowers productivity and requires additional capacity

Summary of Factors Affecting DRT Capacity

- ***Demand for DRT service*** - estimated in terms of one-way passenger trips
- ***DRT provider policies*** - particularly the amount of capacity to be deployed, which may be affected by available funding or other local issues
- ***Passenger characteristics*** - whether the service is provided for the general public or specialized rider groups
- ***Peak-period demand*** - when demand during peak periods is significantly greater than off-peak, additional capacity may be needed
- ***Service area size and characteristics*** - in particular, a large service area results in longer passenger trips, lowering productivity with additional capacity needed to serve the demand
- ***Trip pattern type*** - many-to-few, many-to-one and few-to-few DRT services can group passenger trips, achieving higher productivities and requiring fewer vehicles than a service that operates many-to-many
- ***Service policies***, such as the size of the on-time window - the shorter the window, the more the window constrains scheduling, with a resulting need for additional vehicles.

Capacity Calculation Procedures

- Analogy method
- DRT resource estimation model
- Analytical model
- Non-dedicated DRT service
- Rural DRT

Analogy Method

- Estimates number of vehicles and vehicle service hours needed using data from similar DRT systems (comparable communities or areas)

DRT Resource Estimation Model

- Developed in *TCRP Report 98: Resource Requirements for Demand-Responsive Transportation Services*
- The model estimates the number of vehicles needed
- Trade-off between high service quality and cost – the model shows the trade-off between fleet size and share of market served at a given level of service quality
- Model inputs: definition of service area, type of riders to be served, vehicle capacity, hours of service, pick-up and drop-off windows, expected number of trip requests per day
- Model estimates fleet size, vehicle miles, vehicle hours

Analytical Model

- Developed by L. Fu and presented in *Transportation Research Record 1841*
- Estimates fleet requirements, system capacity, and quality of service measures for specific operating conditions
- The minimum number of vehicles needed
  - directly related to trip demand and service area
  - inversely related to acceptable passenger ride times, average travel speed, dwell times, and the on-time window
- Incorporates peak-period demand – fleet size depends on peak period demand

Non-dedicated DRT Service

- Non-dedicated services included vehicles that serve both DRT riders and other riders not affiliated with the DRT service (e.g., taxis)
- Using non-dedicated vehicles can be an effective strategy for dealing with capacity issues, such as excess peak-period demand, and long, out-of-the-way trips

Non-dedicated DRT Service

- *TCRP Report 121: Toolkit for Integrating Non-Dedicated Vehicles in Paratransit Service*
  - Guidance and a software tool for how to provide capacity with taxis or other transportation resources not solely serving the provider's passengers
  - Determine optimum split between dedicated and non-dedicated service
  - Two component models
    - 1) Driver/run optimization model to determine the most cost-effective schedules for the DRT-dedicated vehicles
    - 2) DRT capacity estimation model, incorporating service supplied, non-dedicated vehicles available for DRT use, operating costs, ridership demand, and service area characteristics

Rural DRT

- Method presented in a paper by Sandlin and Anderson in *Journal of Public Transportation,* Vol. 5, No. 3
- Rural DRT model determines the total area that can be served with a given budget, for a particular set of demand characteristics
- Basis is the economic notion of diminishing returns
- Variables needed: operational costs (per mile), transit need (likely users), the charge for the service, distance to each stop

Ridership Estimation Tools

- DRT ridership demand is an important input for determining DRT capacity needs
- The TCQSM is not a ridership estimation guidebook, but provides references to other tools:
  - *TCRP Report 119: Improving ADA Complementary Paratransit Demand Estimation*
  - *TCRP Web-only Document 58 and Report 161*: Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation
  - *TCRP Report 158: Improving ADA Paratransit Demand Estimation: Regional Modeling*
  - *TCRP Report 95: Traveler Response to Transportation System Changes,* Chapter 6—Demand Responsive/ADA

Rail Transit Capacity

- Chapter 8 of TCRP Report 165: Transit Capacity Quality of Service Manual 3rd Edition
- The report and PowerPoint slides may be accessed online from www.trb.org by typing "TCRP Report 165" in the Search area.
- PPT Slide Credits and Photo Credits: Foster Nichols (Parsons Brinkerhoff, Quade & Douglass), based on an earlier presentation by Paul Ryus (Kittelson & Associates, Inc.), and Dorret Oosterhoff.

Rail Capacity Factors

Paris Metro

Capacity Defined

- Line capacity definition
  - The maximum number of trains that can pass a given location during a given time period at a specified level of reliability
- Person capacity definition
  - The maximum number of people that can be carried past a given location during a given time period under specified operating conditions; without unreasonable delay, hazard, or restriction; and with reasonable certainty

- Unless otherwise specified, whenever the TCQSM uses the term "capacity", a design (practical, achievable) capacity is meant
  - Maximum capacity is only achievable when service is 100% reliable, passenger demand never varies, passengers fill every available space on every trip, etc.
  - Scheduling for maximum, instead of design, capacity results in unstable, unreliable service

Line Capacity Factors

- Dwell time
- Signal system
- Operating margin
- Minimum headway
- Junctions
- Turnbacks
- Power supply

New York City

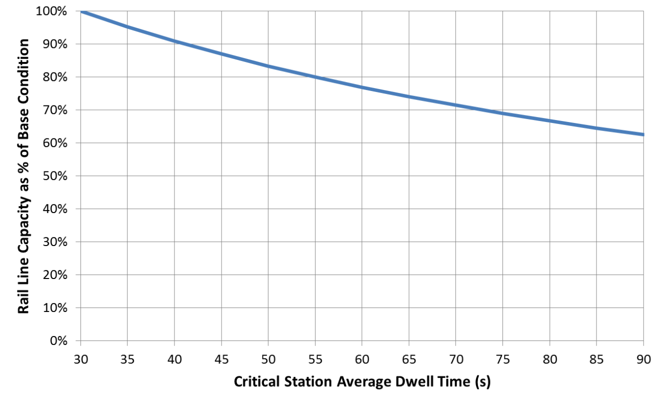
Dwell Time

- How long a train is stopped to serve passengers at a station
- Dwell Time – Dominant factor in determining the minimum train headway and, thus, the line capacity.
- Three main components of dwell time: 1. door open and close time, and waiting to depart after being closed, 2. passenger flow time, and 3. Time the doors remain open after passenger flow ceases.

Contributing factors for passenger flow:
Passenger volumes at stations, Distribution of passengers along platform, Number and width of train doors, Vehicle height, Wheelchair lift/ramp deployment, On-board crowding, Passenger behavior (stepping aside, holding doors), On-board fare collection (if used), Unused time with doors open, Waiting-to-depart time with doors closed.

San Diego Trolley

Illustrative Impact of Dwell Time on Line Capacity



Base condition assumes 30-second dwell times, 20-second operating margin, 50-second minimum train separation

Train Signaling System

- Determines the minimum safe spacing between trains
- The more accurately a train's position is known, the closer together that trains can operate, resulting in higher train throughput
- All urban rail transit train control systems are based on dividing the track into sections known as 'blocks' and ensuring that trains are separated by a suitable and safe number of blocks.
- Other possible elements:
  - Positive train control (commuter rail)
  - Automatic train operation
  - Automatic train supervision

Basic Train Signal Operation

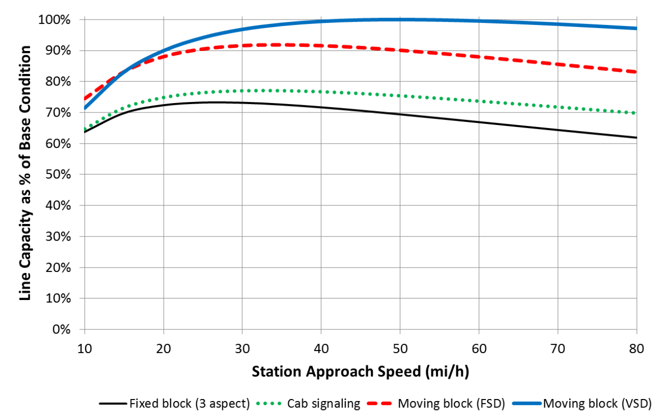
Signal System Types

- Fixed block
  - Trains detected by wheels and axles sending a low voltage current into rails.
  - Provides a coarse indication of train location
  - Two-aspect system (red/green) requires two empty blocks between trains.
  - Three-aspect system (red/yellow/green) requires one empty block between trains

- Cab signaling
  - Antenna on each train detects the electronic codes inserted into each track circuit.
  - Cab signaling sets authorized, safe train speeds
  - Authorized speeds displayed in driver's cab
  - Problems with signal visibility reduced or eliminated
  - A typical selection of reference speeds would be 50, 40, 30, 20, and 0 mph

- Moving block
  - Also called *transmission-based* or *communication-based* signaling systems
  - Requires continuous or frequent two-way communication with each train, and precise knowledge of a train's location, speed, and length, and of fixed details of the line—curves, grades, interlockings, and stations
  - Computer calculates the next stopping point of each train and commands the train to brake, accelerate, or coast accordingly

Illustrative Impact of Signaling and Station Approach Speed on Line Capacity



Base condition assumes moving block signals with variable safety distances, 45-second average dwell time, 20-second operating margin, and no grade entering station.
FSD = fixed safety distance, VSD = variable safety distance

Hybrid Systems:

- When an urban rail transit system shares tracks with other services, such as long-distance passenger trains, whose equipment is impractical or uneconomic to equip with the moving-block signaling system.
- Hybrid or overlay systems are available that allow use by unequipped trains-with longer separation.

Automatic Train Operation

- Relays, and more recently microprocessors, control the rate of acceleration of train smoothly from the initial start to maximum speed.
- The driver or attendant's role is typically limited to closing the doors, pressing a train start button, and observing the line ahead.

Automatic Train Supervision

- It does little more than display the location of trains on a mimic board or video screen in the central control or dispatcher's office.
- In more advanced systems where there is Automatic Train Operation, computer algorithms are used to attempt to automatically correct lateness. These are rare in North America and are generally associated with the newer moving-block signaling systems.

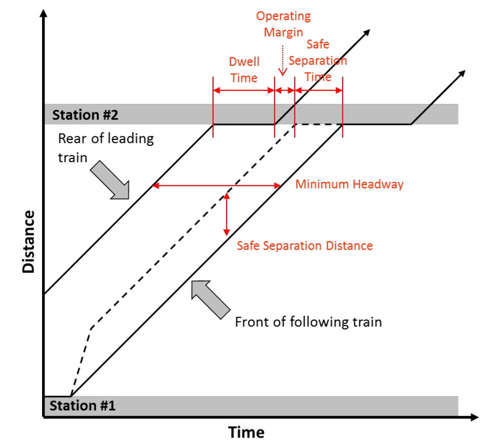
Operating Margin

- When a rail system is operating close to its capacity, small irregularities in service can lead to delays.
- These irregularities can be caused by variations in station dwell times, variations in train performance, and-on manually driven systems-variations between operators.
- To compensate for these variations, when creating a minimum headway, most rail systems add an operating margin to the combination of the signal system's minimum train separation time and the critical station dwell time.

Non-interference Headway

- The combination of the safe separation time imposed by the train control and signaling system, the longest (or *critical)* average dwell time along the line, and the operating margin will determine the minimum headway that can be operated along the route.
- This minimum headway is known as the *non-interference headway*, because as long as it can be maintained, following trains will be able to proceed from one station to the next without stopping or slowing for preceding trains.

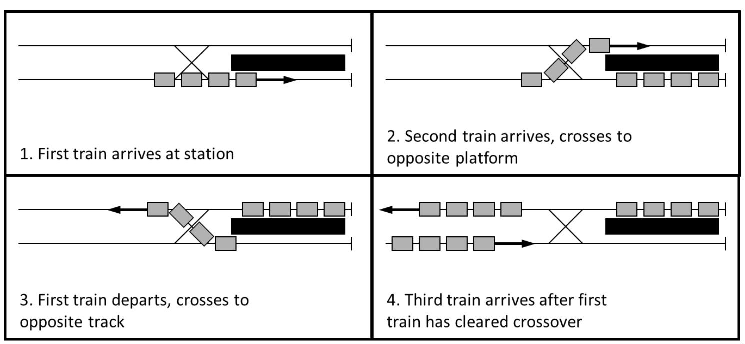
Distance–Time Plot of Two Successive Trains



Source: TCRP Report 13: Rail Transit Capacity
Braking and acceleration curves omitted for clarity

Turnbacks

- Typically handle two trains at once in high-capacity situations



- Time in turnback includes:
  - Passenger service time
  - Time for driver to switch ends of the train and perform inspections (can occur during passenger service time)
  - Time to clear crossover in advance of turnback
  - Operating margin

Hatfield Government Center Station, Hillsboro, Oregon

Junctions

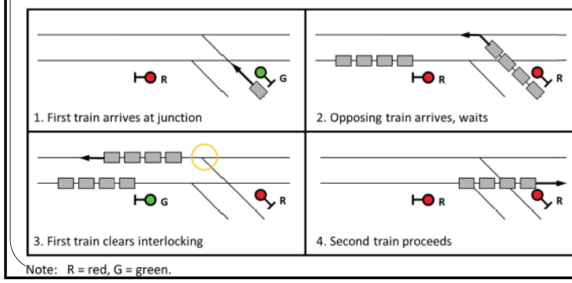
- Locations where lines merge, diverge, or cross at-grade can constrain capacity, or introduce the likelihood of interference, when scheduled head ways approach 2 to 2.5 min.
- Two trains may need to use the space where the tracks cross, but only one train can occupy that space at a time.
- It is not desirable for one train to have to wait for another. When more capacity is required, grade-separated ("flying") junctions are typically used.

Flat junction, Pittsburgh

Flying junction, Paris

The minimum interval between trains on a given line at an at-grade ("flat") junction is a combination of:

1. The time required for an opposing train to move through the junction,
2. The time required to move ("throw") and lock the switches,
3. The delay incurred in decelerating from and accelerating to line speed, and
4. The minimum headway imposed by the signaling system on the line.



Operation of a flat junction

Rail Capacity Methods

Chicago

Rail Capacity

- Many variables involved: train characteristics, speed limits, train and siding lengths, signal system characteristics, etc.
- Formulas that estimate minimum headways and capacities based on operational performance measures provide useful surrogates that can be used to estimate the capacity of a line or system for planning purposes.
- However, complex networks, terminals, and systems with complicated train operating patterns are difficult to analyze.
- Four subsections for rail capacity analysis purposes: 1) a general methodology suitable to many types of rail transit operations (e.g., heavy rail, light rail, and commuter rail not sharing trackage with non-commuter trains); 2)Commuter rail when tracks are shared 3) General methodology for AGT 4) Ropeway capacity

General Methodology

Identify the weakest link along the rail line that will ultimately control train throughput by setting the minimum headway that can be operated between trains. Potential weak links:

- Dwell time at the controlling station along the line;
- Minimum train separation allowed by the train control system;
- Right-of-way characteristics (e.g., single-track operation);
- Turnbacks;
- Junctions;
- Power supply constraints;
- Train length limitations; and
- Track configuration within terminals

On a new system, the sum of the controlling dwell time, the minimum train separation, and the operating margin will typically control the line capacity.

Step 1: Determine the Non-interference Headway

- 1a. Determine the maximum load point (critical) station
- 1b. Determine the control system's minimum train separation
- 1c. Determine the average dwell time at the critical station
- 1d. Select an operating margin
- 1e. Non-inteference headway =
  Critical station average dwell time +
  Minimum train separation +
  Operating margin

Step Ib: Determine the Control System's Minimum Train Separation

- Minimum train separation associated with three types of train control systems.
- 1. Three-aspect fixed-block signaling system,

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a + a_g G_o}} + \frac{L_t}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$ **Equation 8-1**

- 2. Multiple-command cab signaling, and

$$t_{cs} = \frac{L_t + S_{mb}}{v_a} + \frac{1}{f_{br}}\left(\frac{v_a}{2d}\right) + t_{jl} + t_{br}$$ **Equation 8-2**

- 3. Moving-block signaling system.

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$ **Equation 8-3**

Exhibit 8-28
Minimum Train Control Separation Parameters

Default Value	Term	Description
Calculated	t_{cs}	train control separation (s)
650 ft, 200 m	L_t	longest train length (ft, m)
35 ft, 10 m	d_{eb}	distance from the front of stopped train to start of station exit block (ft, m)
Calculated	v_a	station approach speed (ft/s, m/s)
88 ft/s, 27.8 m/s	v_{max}	maximum line speed (88 ft/s = 60 mi/h, 27.8 m/s = 100 km/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75% (decimal)
2.4–three-aspect, 1.2–cab, 1.0—moving block	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—to be replaced with driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
4.3 ft/s², 1.3 m/s²	a	initial service acceleration rate (ft/s², m/s²)
4.3 ft/s², 1.3 m/s²	d	service deceleration rate (ft/s², m/s²)
32 ft/s², 10 m/s²	a_g	acceleration due to gravity (ft/s², m/s²)
0%	G_i	grade into station, downgrade = negative (decimal)
0%	G_o	grade out of station, downgrade = negative (decimal)
90%	l_v	line voltage as percentage of specification (decimal)
20.5 ft, 6.25 m	P_e	positioning error—moving block only (ft, m)
165 ft, 50 m	S_{mb}	moving-block safety distance—moving block only (ft

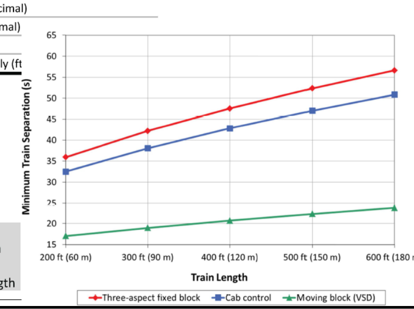


Exhibit 8-29
Typical Minimum Train Separation Versus Train Length

1c. Determine the average dwell time at the critical station

The main constituents of dwell time are as follows:

- Passenger flow time at the busiest door,
- Remaining (unused) door-open time, and
- Waiting to depart time (with doors closed)

First Method: Assigning a dwell time: 15 to 20 s for minor stations and 30 to 45 s for major stations

1d. Select an operating margin

- Operating margin should be added to the minimum train separation and dwell time to create the closest sustainable headway without interference.
- The recommended procedure is to aim for 25 sand back down to 20 or even to 15 s if necessary.
- When a line already exists, the operating margin can be selected to accommodate 95% of dwells that occur at the critical station.

1e. Non-inteference headway

$$h_{ni} = t_{cs} + t_{d,crit} + t_{om}$$

Equation 8-4

where

h_{ni} = non-interference headway (s),

t_{cs} = train control separation (s),

$t_{d,crit}$ = average dwell time at the controlling station (s), and

t_{om} = operating margin (s).

Step 2: Determine the Minimum Headway Based on ROW

- This step is skipped for grade-separated rail
- Right-of-way (ROW) types considered:
  - Single-track, two-way operation headway
    - Two times (time for a train to traverse the section + operating margin + average station dwell time in section, if any)
  - On-street operation headway
    - Greater of (twice the traffic signal cycle length) or (headway based on average dwell time at critical station)
  - Station departures adjacent to grade crossings
    - May need to increase dwell time to account for gate-lowering time, when the gates are manually activated to minimize delay to cross-street traffic
- Minimum headway is the highest of the applicable ROW headways

Step 3: Determine the Limiting Junction Headway

- This step is skipped when there are no at-grade (flat) junctions
- Major factors influencing junction headways:
  - Train control separation
  - Train length
  - Maximum line speed
  - Switch angle (influences speed of trains switching to new track)
  - Operating margin

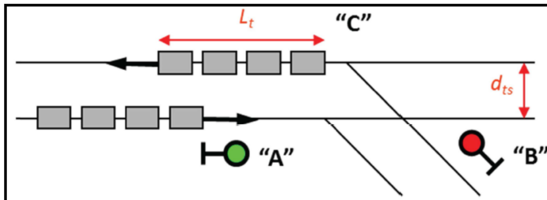


Exhibit 8-41
Flat Junction Dimensions

$$h_j = t_{cs} + \sqrt{\frac{2(L_t + 2f_{sa}d_{ts})}{a}} + \frac{v_{max}}{a+d} + t_s + t_{om}$$

where *[typical heavy rail values shown in brackets]*

- h_j = limiting headway at junction (s);
- t_{cs} = train control separation time (s); *[32 s]*
- L_t = train length (ft, m); *[650 ft, 200 m]*
- d_{ts} = track separation (ft, m); *[33 ft, 10 m]*
- f_{sa} = switch angle factor (see also Exhibit 8-43):
  - —5.77 for #6 turnout,
  - —6.41 for #8 turnout, and
  - —9.62 for #10 turnout;
- a = initial service acceleration rate (ft/s², m/s²); *[4.3 ft/s², 1.3 m/s²]*
- d = service deceleration rate (ft/s², m/s²); *[4.3 ft/s², 1.3 m/s²]*
- v_{max} = maximum line speed (mi/h, km/h); *[60 mi/h = 91 ft/s, 100 km/h = 27.8 m/s]*
- t_s = switch throw and lock time (s); and *[6 s]*
- t_{om} = operating margin time (s).

Step 4: Check Power Supply Limitations

- The power supply for a new rail line will presumably be designed to accommodate the number of trains planned to be operated.
- However, the power supply for an existing line that is being considered for improved headways may not be capable of supporting the additional number of trains without being upgraded.
- The average headway imposed by a given substation will be a function of the number of trains the substation can power at a time and the time required for a train to traverse the track section powered by the substation, including station stops.

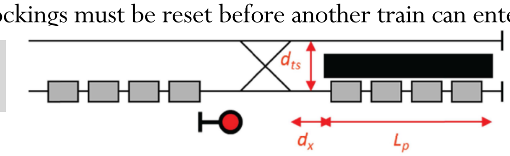
Step 5: Determine the Controlling Headway

- Controlling headway is the highest of the headways determined from
  - Step 1 (train control system)
  - Step 2 (right-of-way type)
  - Step 3 (limiting junction)
  - Step 4 (power supply)

Step 6: Check Terminal Layover (Turnback) Time

- Correctly designed and operated turn backs should not be a constraint on capacity.
- The worst case is based on the arriving train (lower left) being held at the crossover approach signal while a train departs. It must, moving from a stop, traverse the crossover and be fully berthed in the station before the next exiting train (lower right) can leave. The exiting train must then clear the crossover and the interlockings must be reset before another train can enter the station.

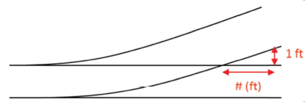
Exhibit 8-42
Key Turnback Dimensions



- The difference between the scheduled headway and the time required to make these maneuvers, doubled for a two-berth station such as the one illustrated, is available for terminal layover. The terminal layover time must be sufficient to accommodate passenger movements, and allow time for the driver to change ends, inspect the train, and check train integrity and braking.

- The maximum time available per track for terminal layover is given by

$$t_{tl} \le 2\left(h - t_s - \sqrt{\frac{2(L_p + d_x + f_{sa}d_{ts})}{a+d}} - \sqrt{\frac{L_p + d_x + f_{sa}d_{ts}}{2a}}\right)$$



where [typical heavy rail values shown in brackets]

t_{tl}	=	terminal layover time (s);	
h	=	train headway (s);	[120 s]
t_s	=	switch throw and lock time (s);	[6 s]
L_p	=	platform length (ft, m);	[660 ft, 200 m]
d_x	=	distance from cross-over to platform (ft, m);	[65 ft, 20 m]
d_{ts}	=	track separation (ft, m),	
	=	platform width + 5.25 ft (1.6 m);	[33 ft, 10 m]
f_{sa}	=	switch angle factor (see also Exhibit 8-43): —5.77 for #6 turnout, —6.41 for #8 turnout, and —9.62 for #10 turnout;	
a	=	initial service acceleration rate (ft/s², m/s²); and	[4.3 ft/s², 1.3 m/s²]
d	=	service deceleration rate (ft/s², m/s²).	[4.3 ft/s², 1.3 m/s²]

Step 7: Determine Train Throughput (Line Capacity)

- Line capacity = (3,600 / controlling headway), rounded down

$$T = \frac{3{,}600}{h_c}$$

where

T = line capacity (trains/h),

3,600 = number of seconds in an hour, and

h_c = controlling headway (s/train).

Step 8: Determine Person Capacity

- Person capacity (persons per hour) =
  Line capacity (trains per hour) ×
  Train length (cars per train) ×
  Car passenger capacity (persons per car) ×
  Peak hour factor (decimal)

$$P = TN_cP_c(PHF)$$

$$PHF = \frac{P_h}{4P_{15}}$$

where

P = design person capacity (p/h),

T = line capacity (trains/h),

N_c = number of cars per train (cars/train),

P_c = maximum schedule load per car (p/car), and

PHF = peak-hour factor,

P_h = passenger volume during the peak hour (p), and

P_{15} = passenger volume during the peak 15 minutes (p).

CALCULATION EXAMPLE: HIGH-CAPACITY HEAVY RAIL

- A transit agency is planning to build a heavy rail transit line and wants to determine the minimum train separation possible with a cab signaling system and with a variable safety distance moving-block signaling system.

1. What is the minimum train separation (ignoring station dwell time and operating margin effects) with each type of signaling system?
2. What is the non-interference headway with typical dwells and operating margins?
3. What is the resultant line capacity for a new system with higher-quality loading standards?

- The transit agency is planning to use trains consisting of a maximum of eight 75-ft cars. Trains will operate at a maximum of 60 mi/h (88 ft/s) and will be traveling at 32 mi/h (47 ft/ s) when entering stations if the cab signaling system is chosen, and at 34 mi/h (50 ft/s) if a moving-block system is selected.

Calculation Example: Input Data

Value	Term	Description
calculated	t_{cs}	train control separation
600 ft	L_t	length of the longest train
35 ft	d_{eb}	distance from front of stopped train to start of station exit block in meters
47 ft/s (cab) 50 ft/s (moving block)	v_a	station approach speed
88 ft/s	v_{max}	maximum line speed (88 ft/s = 60 mi/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75%
1.2 (cab) 1 (moving block)	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
4.3 ft/s^2	a	initial service acceleration rate
4.3 ft/s^2	d	service deceleration rate
20.5 ft	P_e	positioning error—moving block only

Step Ia: Determine the Maximum Load Point Station

- Because this example addresses a rail line that does not yet exist, the dwell time selected in Step 1c (*Average Dwell Time at the Critical Station)* should reflect conditions at a maximum load point station.

- *Step Ib: Determine the Control System's Minimum Train Separation*
- *1. Cab Signaling*

Equation 8-1

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a + a_g G_o}} + \frac{L_t}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a}} + \frac{L_t}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{a t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

Equation modified for the current situation

$$t_{cs} = \sqrt{\frac{2(600 + 35)}{4.3}} + \frac{600}{47} + \left(\frac{1}{0.75} + 1.2\right)\left(\frac{47}{2 \times 4.3}\right) + \frac{(4.3)(3)^2}{2 \times 47}\left(1 - \frac{47}{88}\right) + 3 + 0.5 + 1.5$$

$$t_{cs} = 17.2 + 12.8 + (2.53)(5.47) + (0.412)(0.534) + 3 + 0.5 + 1.5$$

$$t_{cs} = 49.1\ s$$

- Moving-Block Signaling

Equation 8-3

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{100}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{a t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

Equation modified for the current situation

$$t_{cs} = \frac{600 + 20.5}{50} + \left(\frac{100}{75} + 1\right)\left(\frac{50}{2 \times 4.3}\right) + \frac{(4.3)(3)^2}{2 \times 50}\left(1 - \frac{50}{88}\right) + 3 + 0.5 + 1.5$$

$$t_{cs} = 12.4 + 13.6 + (0.387)(0.432) + 3 + 0.5 + 1.5$$

$$t_{cs} = 31.2\ s$$

The minimum train separation at stations (ignoring the effects of station dwells and an operating margin at this point) would be 49.1 s with a cab signaling system or 31.2 s with a variable safety distance moving-block system

Step 1c: Determine the Average Dwell Time at the Critical Station

- Four possible methods for determining the controlling dwells available.
- Method 2, *Using Existing Dwell Time Data,* is not applicable to a new system.
- The simplest option is to use Method 1, which recommends a range of dwell values from 35 to 45 s.
- If there are no indications of any single, very high-volume stations (where the more complicated dwell calculations should be used) then a median value of 40 s can be selected.

Step 1d: Select an Operating Margin

- 20 to 25 s suggested as the best guide.
- Here, 25 s is selected to provide better reliability.

Step 2: Determine the Minimum Headway Associated with the Right-of-Way Type

- Step 2 primarily applies to light rail lines and therefore can be skipped for this heavy analysis.

Step 3: Determine the Limiting Junction Headway

- As this will be a new line, it is assumed that it will be designed so that any junctions will not constrain capacity.

Step 4: Check Power Supply Constraints

- As this will be a new line, it is assumed that the power system will be designed to accommodate the desired headway.

Step 5: Determine the Controlling Headway

- In the absence of other constraints, the controlling headway is the sum of the minimum train separation time (Step 1b), average dwell time at the critical station (Step1c), and the operating margin (Step 1d).
- Cab Signaling: 49.1+40+25 = 114.1 s
- Moving-block Signaling: 31.2+40+25 = 96.2 s

Step 6: Determine Terminal Layover Time

- As this will be a new line, it is assumed that the terminals will be designed so as not to constrain capacity.

Step 7: Determine Train Throughput

- *3600/controlling headway.*
- *Cab signaling: 31 trains per hour*
- *Moving-block signaling: 37 trains per hour*

Step 8: Determine Person Capacity

- In the absence of a specific vehicle, the text accompanying Step 8 in TCQSM indicates that a recommended comfortable heavy rail car loading for a new system is 1.8 passengers per linear foot of train length, inclusive of diversity allowances.
- At this loading level, each specified train of eight 75-ft-long cars can carry 8x1.8x75 = 1,080 passengers.
- Passengers per peak hour direction per track = passengers per train number of trains per hour. 33,480 p/h/dir for cab signaling and 39,960 p/h/dir for moving-block signaling.

Thank you.

Next Topic: Rail Road Engineering Introduction and Concepts

Transit Service Planning: Transit Lines and Networks

Chapter 4 of *Urban Transit: Operations Planning, and Economics* by Vukan Vuchin

Basic Transit Operational Elements

- **Transit Line:** *Infrastructure and service provided along fixed lines.*
- **Transit Route:** *Similar to transit line but is usually for street transit.*
- **Transit Network:** *Set of transit lines that connect with or cross each other*

Transit Line, and network.

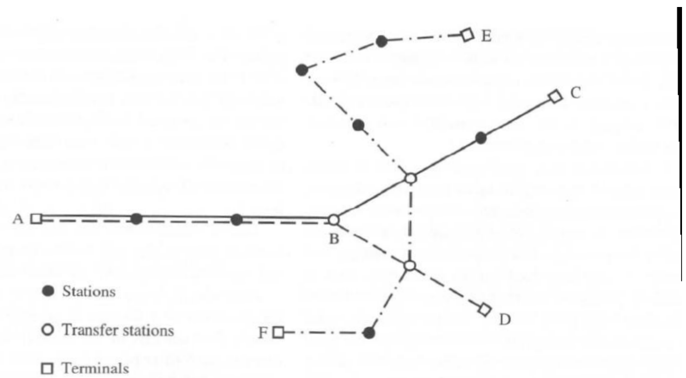


Figure 1.1 *Transit line, network, and station concepts. Assuming that each spacing between stations is 1 km long, the values in this network are:*

Basic Transit Operational Elements

- **Line length:** *One-way distance between the two terminals.*
- **Network length:** *Length of all alignments served by one or more lines.*
- **Total line (route) length:** *Sum of all line lengths, regardless of whether they operate alone or overlap with other lines.*

- **Transit Stop:** *Location along a line at which transit vehicles stop to pickup or drop off passengers.*
- **Transit Station:** *Special Structure and facility for passenger boarding/alighting, waiting, and transfer.*
- **Transfer Stations:** *Joint stations for two or more lines at which passengers can transfer between lines.*
- **Terminals:** *End stations on transit line. Some times this term is also used for major transfer stations.*

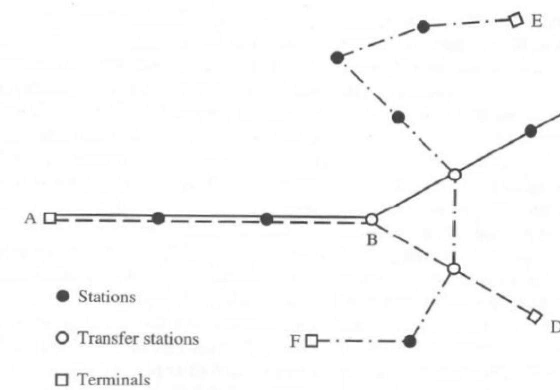


Figure 1.1 Transit line, network, and station concepts. Assuming that each spacing between stations is 1 km long the values in this network are:

Transit right-of-way (ROW)

- Facility used exclusively by transit vehicles.
- Degree of separation from other vehicles and pedestrians – most important for transit operations, performance, and cost characteristics.
- Transit ROW Classification: C, B, and A

Transit ROW

- Category C: Surface street with mixed traffic.
- Category B: Transit is longitudinally physically separated from other traffic, but not at intersections.
- Category A: Transit has fully controlled ROW without grade crossings or any legal access by other vehicles or persons.

ROW category A has highly reliable performance. However for ROW B and C, reliability is dependent on traffic conditions along the line.

Transit Lines and Networks

1. Planning Objectives, Principles, and Considerations
2. Geometry of Transit Lines
3. Types of Transit Lines and Their Characteristics
4. Transfers in Transit Network

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1 Planning Objectives, Principles, and Considerations

Objectives in Planning a Transit Network:

- **Perform Maximum Transportation Work:** *Provision of high travel speed, passenger convenience, and other elements that attracts passengers.*
- **Achieve maximum operation efficiency:** *Minimum total system cost for a required performance level.*
- **Create Positive Impacts:** *Short-range goal: Reduction of highway congestion; Long-range goal: achievement of high population mobility, desirable land use patterns, sustainability, and high quality of life.*

1.1 Passenger Attraction

Features that affect transit service quality and influence passenger attraction:

- Average Coverage
- Operating Speed
- Travel Desire Lines
- Directness of Travel
- Simplicity, connectivity, and easy transfers must be considered.

Average Coverage: Percent of total coverage area that is within 5-minute (primary) and 10-minute (secondary) walking distance of transit stations

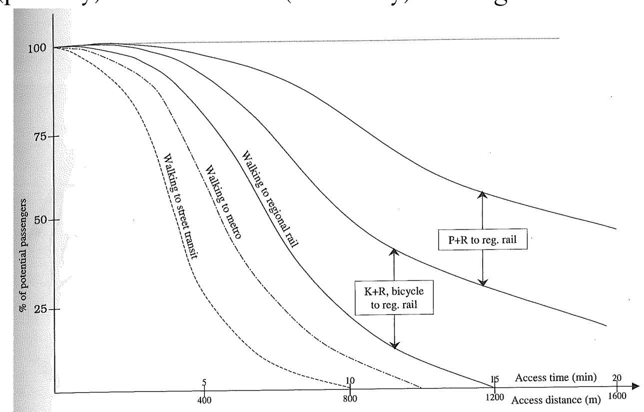


Figure 4.1 Acceptance of access distances for different transit services by mode of access. Note: *Walking distance curves are approximately scaled; K+R and P+R vary greatly with local conditions.*

- It can be observed from Figure that decrease in ridership with access distance is more rapid for Street Transit than for Metro and Regional Rail, due to higher level of service the later modes offer.

- In small and medium-sized cities, the goal should be to achieve high coverage (80-100%).
- In large cities, trip lengths are greater and therefore metro systems are basic carriers. High area coverage should be one of the primary planning goals.

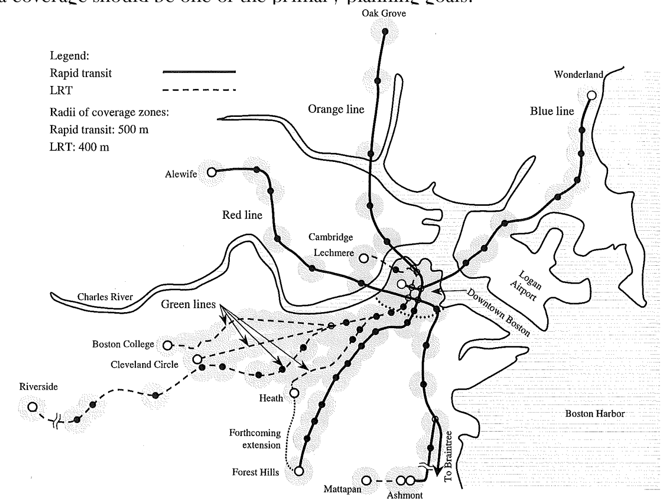


Figure 4.2 Area coverage by rapid transit and LRT networks in Boston.

Operating Speed: *It is a function of right-of-way category and station spacing.*

- Street Operations (ROW C): Speed depends on street and traffic conditions.
- Rapid Transit (ROW A): Station spacing is a major element influencing travel speeds.

Travel Desire Lines: Transit lines should be designed closely to major origin-destination patterns to attract and serve efficiently to maximum number of passengers.

Simplicity, connectivity, and easy transfers: These features has to be considered in design as they are important for passenger convenience and attraction.

- Greatest Operational Simplicity is achieved by operating lines independently of each other with easy passenger transfers among them. Some Examples are Paris Metro (Figure) and Tokyo Subway.

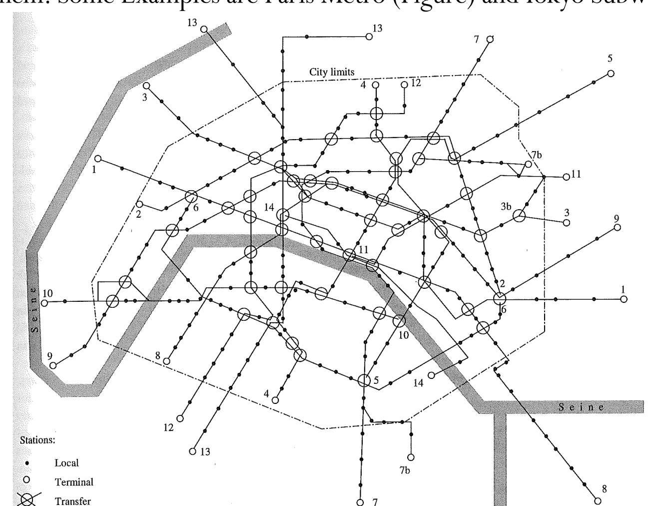


Figure 4.3 The Paris Metro network: 14 independent lines.

- Networks with integrated (overlapping) lines, such as New York City Subway and Washington Metro are more convenient for passengers because they allow more trips to be made without transferring.

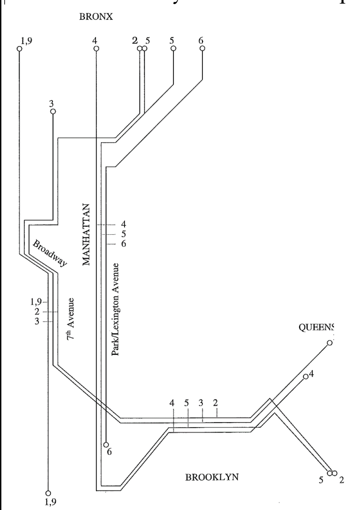


Figure 4.8 Schematic layout of the contiguous Division A network in New York City.

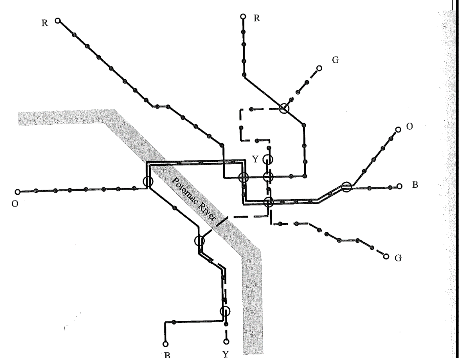


Figure 4.38 Washington Metro network, highlighting the Green and Yellow Lines. (This 2003 network has a few minor line and station modifications from the 1980 network used in the analysis.)

1.2 Network Operating Efficiency

- Operating efficiency represents performance and cost of operations.
- It is the major concern of second interested party – operator/transit agency.

Major Determinants of Efficiency:

- Continuity and balancing of lines or provision of direct services among areas with heavy travel demand
- Operating flexibility to provide connections between lines
- Integration with other modes
- Proper location of terminals, depots, and yards
- Cost of the system

1.3 Network-City Interactions

To ensure that transit system have positive impact and minimum undesirable effects, the following major factors are considered.

- Land use: major factor
- Topography and environment

Transit Lines and Networks

1. Planning Objectives, Principles, and Considerations
2. Geometry of Transit Lines
3. Types of Transit Lines and Their Characteristics
4. Transfers in Transit Network

2. Geometry of Transit Lines

- Passengers tend to prefer frequent, fast services over infrequent, slower ones and accept longer walking access to such lines.
- Transit networks designed by contemporary principles have fewer lines.
- The spacing's among the transit lines are greater, but more of them have higher types of ROW A, B, or preferential treatment. Therefore higher speeds and reliability.

Different geometric elements of transit lines will be discussed in detail. 1.Spacing 2. Length 3. Alignment 4. Interconnections among lines

2.1 Spacing of Parallel Lines

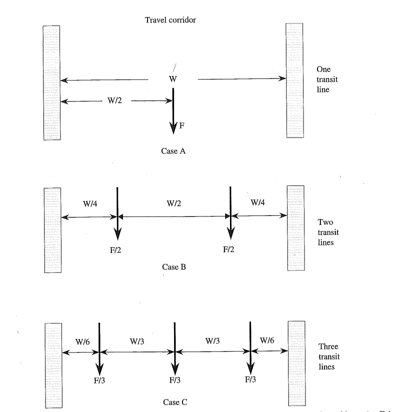


Figure 4.4 Relationship between line spacing and frequency of service for a fixed total number of bus trips F in a corridor.

- If the required service is provided by n lines, their optimum locations for minimum access distance is shown in figure.
- The distance of each ith line from left boundary (W_i) is calculated using…

$$W_i = \frac{W}{2n}(2i - 1)$$

- *Therefore, for 2 lines, the second line is at a distance of 3W/4.*
- *For n=3, the third line i=3, is 5W/6 from the left boundary.*

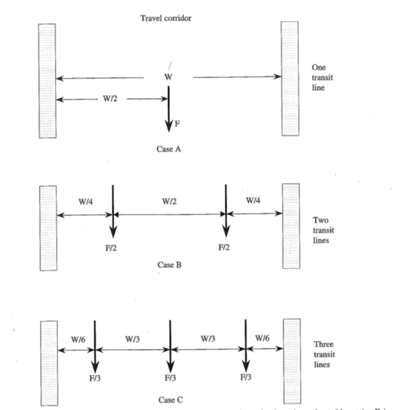


Figure 4.4 Relationship between line spacing and frequency of service for a fixed total number of bus trips F in a corridor.

- Frequency of service on each line is f = F/n.
- Average and maximum access distance to the lines L_a and $L_{a\,max}$, respectively are:

$$L_a = \frac{W}{4n} \quad \text{and} \quad L_{a\,max} = \frac{W}{2n}$$

- Problem: If a corridor width is W=1200m, required total service frequency is F=12TU/h, what are the line designs for 1, 2 and 3 number of transit lines.

Table 4.1 Relationship between access distances and service frequency

Case	Number of lines n	Access distance (m) Average $\bar{L}_a$	Maximum $L_{a\,max}$	Frequency f(TU/h)	Headway h(min/TU)
A	1	300	600	12	5
B	2	150	300	6	10
C	3	100	200	4	15

2.2 Line Lengths

- **Long lines advantages:**

1) They serve more trips than short lines. A line with K stations offers direct service to K(K-1)/2 stations-to-station two way links; if it is extended by one station, K additional links are served; another station adds K+1 links.

Example: a line with 10 stations serves 10(10-1)/2 = 45 bidirectional links. If it is extended by one station, it serves 10 more bidirectional links. If a line with 20 stations is extended by one station, its number of links increases from 190 to 210, or 20 more.

2) They have smaller portion of terminal time (changing ends of train, or turning vehicles or trains around a loop).

- **Long Lines Disadvantages:** Less efficient scheduling. Long cycle times are difficult to fit into shifts. They may also have a problem of major delay propagation.

Planning a radial metro lines from center city:

- Typically radial rail lines are complemented by feeder bus routes and/or P+R facilities.
- Short metro line: large portion of riders must transfer to less efficient feeder bus routes.
- Line extend far into suburb: no need for feeder lines.

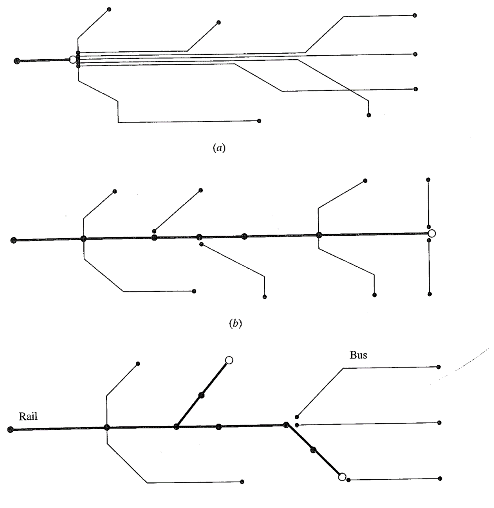


Figure 4.5 Alternative radial line lengths in suburbs: (a) minimum length trunk with extensive feeders; (b) maximum length trunk with lateral feeders; (c) trunk incorporates two branches; feeders complement them.

2.3 Line Alignments

- Circuitous routing for collecting/distributing passengers in low density suburbs: Acceptable at only end sections of lines (a).
- However it should not be used at midroute as they may create delays for passengers from outer areas (b).
- When passenger volume is substantial, this service should be provided by two separate lines (c).

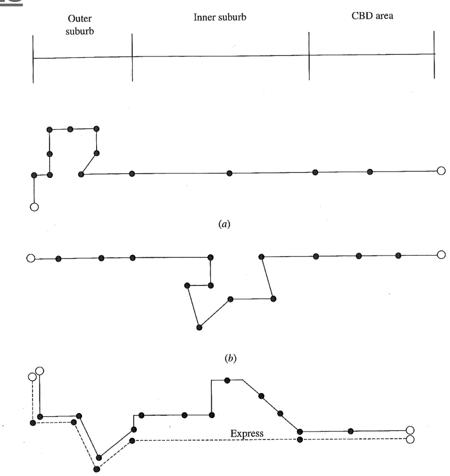


Figure 4.6 Types of bus routings: (a) circuitous routing at the end of the route: acceptable; (b) circuitous routing at midroute: unacceptable; (c) express complementing local route.

2.4 Independent versus Integrated Lines

- There are two basic types of transit lines 1)independent lines and 2)integrated lines.
- They are different with respect to networks they form, the service they provide, and the operations they perform.
- Their use can be applied in modes: bus, LRT, metro, and regional rail.

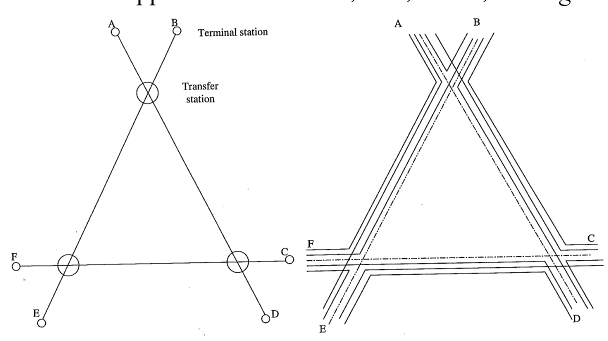
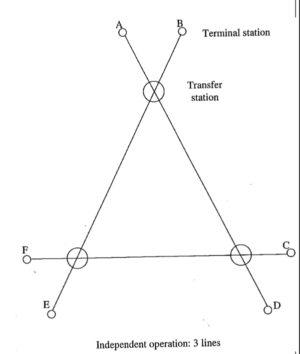


Figure 4.7 A theoretical transit network with independent and with integrated line operations.

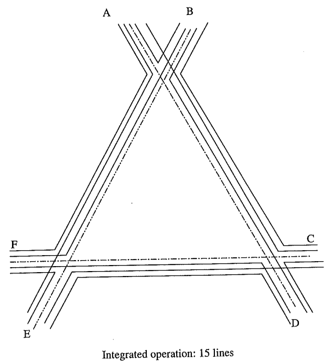
Independent Lines

- They have independent alignments, without overlap with other lines.
- Simple to operate, but their utilization of offered capacity is low because all Tus operate the entire length, while their load factor may decrease as passenger volume drop towards the end.
- *Example: Assume frequency on each line=15TU/h (4 min headway [h]). Assume passengers can travel between any two stations of the network with at most one transfer. Then total average waiting time is 4 minutes (h/2 at origin and h/2 at transfer station).*



Integrated Lines

- They have branches, converge, diverge, and mutually overlap on portions of their alignments.
- These lines can be scheduled to fit the passenger volumes better than independent lines.
- More station-to-station service, and number of passenger transfers is lower.
- *Example: Here 15 lines are operated instead of 3. Since there are direct lines, no need for transfer. However 15TU/h is distributed on 5 lines. Therefore frequency of service on each line is 3TU/h. Headway =20 min. Avg waiting time=h/2=10min.*



Integrated operation: 15 lines

- Networks with n terminals and line frequencies f operated with independent and integrated lines.

Table 4.2 Characteristics of networks connecting *n* terminals with independent and with integrated lines

Type of Operation / *Characteristics*	*Independent*		*Integrated*	
	General	*Example*	*General*	*Example*
Number of lines/routes	$n/2$	3	$n(n-1)/2$	15
Frequency on each route	f	15	$f/(n-1)$	3
Transfers	Many		None	
Network operation	Simple		Complex	
Rolling stock utilization	Independent among lines		Good network-wide	

Independent Lines or Integrated Lines?

- Independent lines are used mostly on very heavily used metro networks.
- Some planner and operators think independent line operation is optimum for rail transit networks.
- While it may be true for some cities, it is not for many others.
- Examples of integrated line operations: Chicago, New York, San Francisco BART, and Washington Metro.

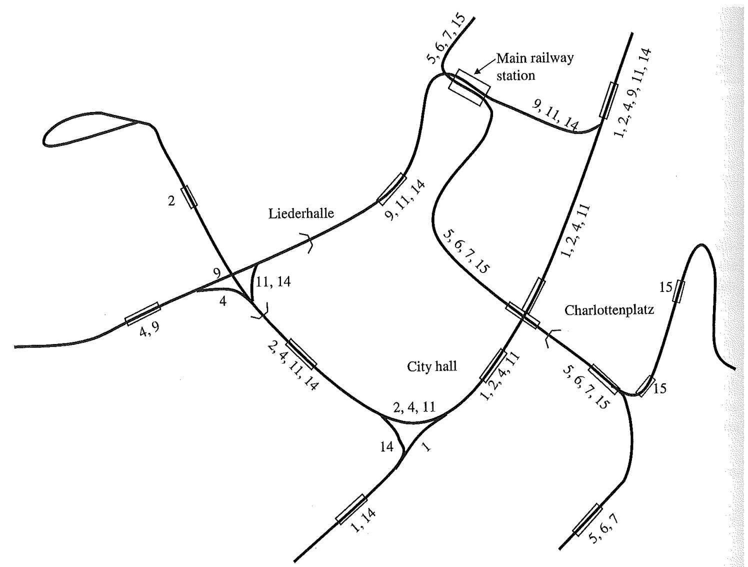


Figure 4.9 *Typical light rail transit integrated network in center city: Stuttgart.*

NYC Integrated Metro Network Features:

- Three parallel lines with multiple sections at all three outward sections.
- Two of the trunk lines (lines 1-3, 9, and 4-6) with converging branches on both sides.
- Multiple tracks on many sections of the lines, with different lines using separate pairs.
- Skip-stop operations on some sections (north end of lines 1 and 9)
- Local express operations on several long line sections.

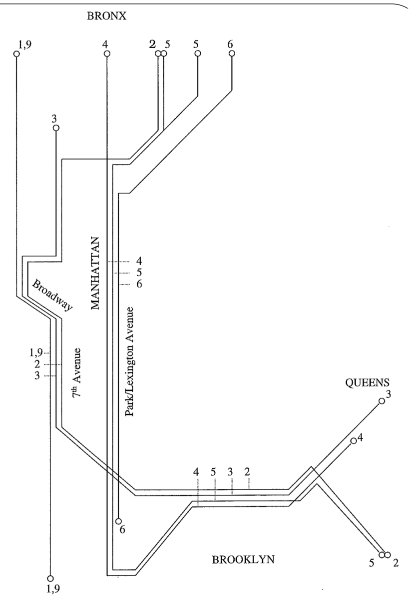


Figure 4.8 Schematic layout of the contiguous Division A network in New York City.

Transit Lines and Networks

1. Planning Objectives, Principles, and Considerations
2. Geometry of Transit Lines
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3. Types of Transit Lines and Their Characteristics

- Geometric form and alignment in the city give transit lines certain operational and functional characteristics.
- Although some lines have irregular forms, many can be classified into several basic types.

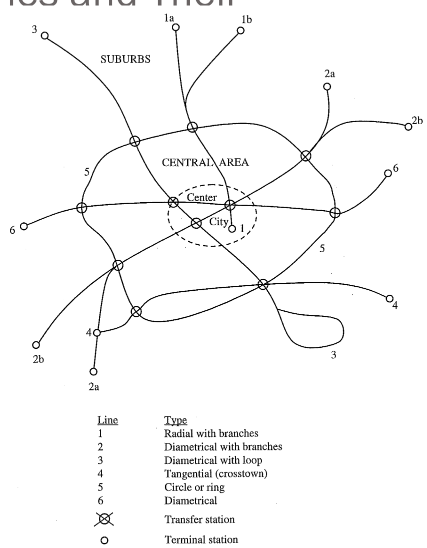


Figure 4.10 Geometric forms of transit lines.

- Radial: 11;
- Diametrical: 1, 3, 4, 7, 8, 9, 12, and 14
- Tangential: 5 and 10
- Circumferential: 2 and 6
- Trunk with branches: 13
- Trunk with feeder: 3/3b, 7/7b
- Loops: on lines 7b and 10

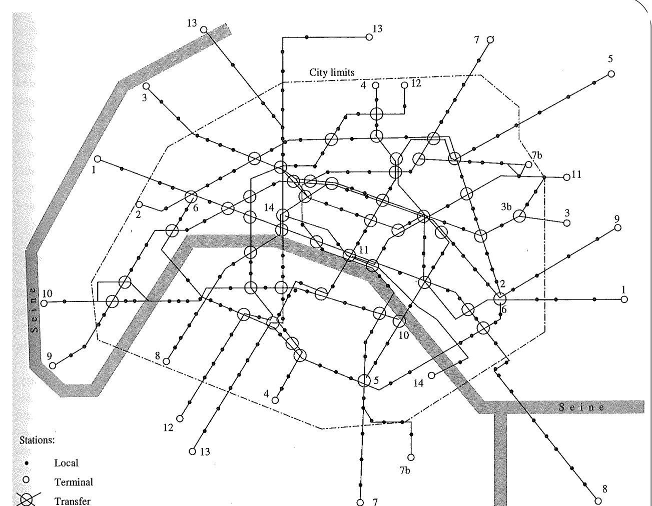


Figure 4.3 The Paris Metro network: 14 independent lines.

- Circle line, as well as many diametrical lines are found on the Moscow network.

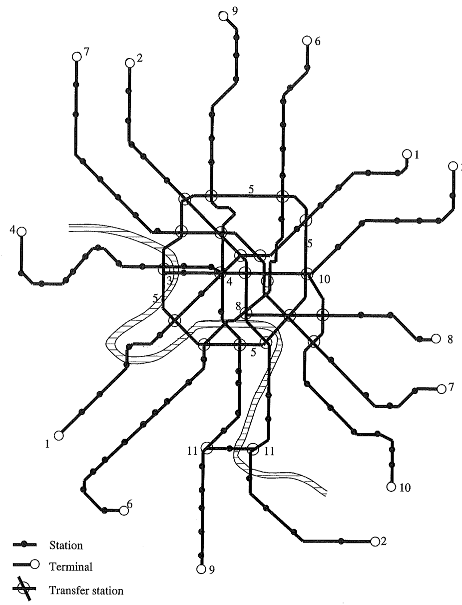


Figure 4.11 *The Moscow Metropolitan network.*

Trunk Lines with Branches and Feeders

- Radial transit lines have the highest passenger volumes.
- Starting as heavily travelled trunk lines from the city center outward, they divide into great number of lines with low loads serving large areas which are often low density suburban areas.
- By the design and operation, these distributed lines may be of two types 1. those that provide direct service from the trunk are branches 2. others, which operate independently from trunk line stations in outward directions which are called feeders

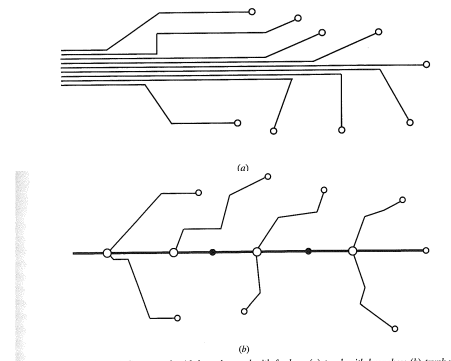
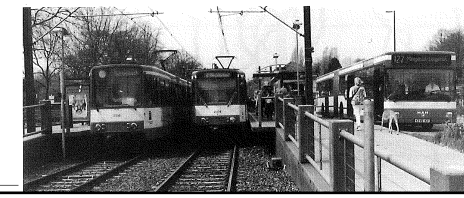


Figure 4.14 *Radial transit lines: trunk with branches and with feeders: (a) trunk with branches; (b) trunk with feeders.*



Branches Vs. Feeders

Branches, compared to feeders, have the following advantages:

+ Provide for passengers a continuous service without transfers and delays between center city and suburban areas.
+ Being longer lines, trunk and branches have smaller percentage of cycle time as terminal times than trunk with feeders.
+ Transfer stations are not needed.

Feeders, on the other hand, have the following advantages over branches:

+ Each line section can be optimized with respect to mode and vehicle type (or TU) used, schedule, etc.; load factors are higher, fleet size smaller, and operating costs lower.
+ Use of higher-performance vehicles or mode (usually rail) on the trunk provides superior service at lower operating cost than smaller vehicles from branches (buses) can provide.
+ Regular headways can be operated on the trunk and on each feeder line.
+ More reliable service: delays are less likely to transfer between trunk and feeders.
+ Suburban terminals for trunks offer not only trunk/feeder transfers, but also transfers among feeder lines, providing greater network connectivity.

Example:

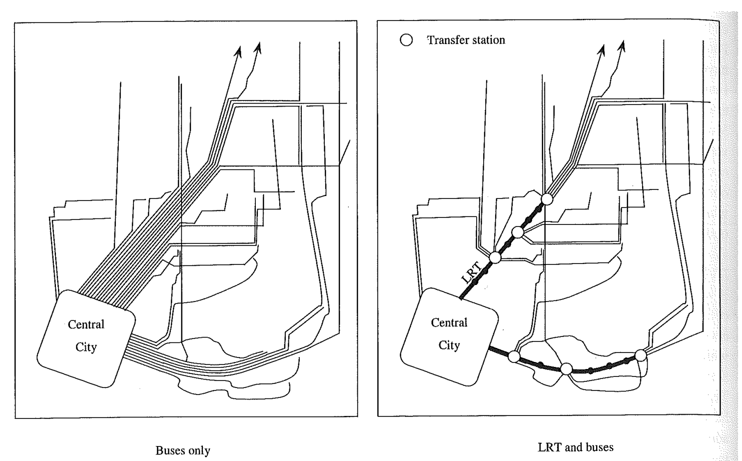


Figure 4.15 *Change from an extensive bus network into an intensive, more efficient and attractive LRT-bus network (Sacramento, CA).*

Transit Lines and Networks

1. Planning Objectives, Principles, and Considerations
2. Geometry of Transit Lines
3. Types of Transit Lines and Their Characteristics
4. Transfers in Transit Network

4. Transfers in Transit Network

- Transfers: To achieve intermodal integration of different lines, as well as intermodal integration.
- Transfers involved certain passenger resistance because they interrupt travel. Some delay is also caused.
- Transit network with many transfer opportunities offer passengers much greater selection of travel paths when compared to transit networks that involve little or no transferring.

Classification of Transfers by Headway Length

- For the classification purpose, transit lines are classified into those with shorter headways (generally < or equal to 10 minutes) and transit lines with long headways (>10 minutes).
- Transfers between these transit lines can now be classified by the headways of originating and destination lines into four cases, A through D.

Table 4.3 Transfer times between lines with short and long headways

Origin Line \ Destination Line	Short Headway	Long Headway
Short headway	*Case A* Always short, convenient	*Case C* Varies greatly Information about connecting runs required
Long headway	*Case B* Always short, convenient	*Case D* Variable depending on headways: 1. Equal and simultaneous—all transfers convenient (TTS) 2. Equal but not simultaneous—convenient in one direction 3. Different—impossible to coordinate; long transfer times

- ***Case A (Short-to-short headway) and B (long-to-short headway):*** Transferring from any line, with short or long headway, to a line with short headway involves short transfer times.
- ***Case C: Short-to-long headway:*** This is reverse of case B. Such transfers may involve waiting times that vary from very short ones to those close to the long headway on the line to which the passenger is transferring. Therefore, the delay varies randomly.
- ***Case D: Long-to-long headway:*** Further classified into 3 subcases.

Case D_1: Long-to-long equal headways synchronized: TUs from the connecting lines arrive at the same times, in constant intervals and dwell for a few minutes to exchange passengers among all TU's. This is called timed transfer system.

Case D_2: Long-to-long, equal headways: No overlapping. TU arrives on different connecting lines are always in the same time sequence., It is possible to make convenient transfers from one line to another(e.g., M line to N), but not in the opposite direction (N to M). For example, if line M arrives at 07, 27, and 47 minutes after each hour and line N arrives at 10, 30, and 50 minutes after each hour, M to N transfer involves only 3-minute wait, but N to M transfer requires 17-minutes wait.

Case D_3: Long-to-long, different headways: No co-ordination is possible. Transfer times are random and they can approach the headway length on the destination line.

Classification of Transfers by Type of Line

- The number of transfers and character of transfers are influenced considerably by two aspects of lines among which transfers take place.
- 1. Relationship of line to the transfer point: whether it terminates or passes through it. In this respect, lines are referred as terminating (t_e) and through (t_t) lines.
- 2. Whether all lines are of similar nature (frequency, capacity, and transit mode) or one of them is a dominant or trunk line with considerably higher performance than any other line, while the others, with low frequency, capacity, etc. represent its feeders with collection/distribution function. This aspect of line type, similar of different, influences transferring patterns of passengers (i.e., many-to-many among similar lines, or many many-to-one and one-to-many between different line categories, such as trunk and feeders.

Table 4.4 Classification of transfers by types of lines

Case Number	Number of Lines: Terminating	Number of Lines: Through	Transfer Permutations	Similar Lines/Routes: Sketch	Similar Lines/Routes: Typical Case	Similar Lines/Routes: Comment	Trunk with Feeders: Sketch	Trunk with Feeders: Typical Case	Trunk with Feeders: Comment
1	N_e	0	$N_e(N_e-1)$		Many suburban lines terminating	Coordination between lines needed. TTS can be applied successfully		Trunk line terminating with many feeders	Requires coordination in case of transfers among feeders (TTS)
2	0	N_t	$4N_t(N_t-1)$		Any point with several intersecting transit lines	TTS desirable, but causes delay of through passengers		Trunk line station where feeders intersect and/or terminate	TTS possible. Feeders' arrivals and departures around trunk's stopping
3	N_e	N_t	$(N_e+2N_t)^2-(N_e+4N_t)$		Many transit lines terminate or pass through	TTS desirable; easier to achieve than with case 2		Trunk line passes through where feeders intersect and or terminate	
4	2	0	2		Terminal point of two suburban lines			Trunk line terminal with one feeder	
5	0	2	8		Intersecting point of any two transit lines			Trunk line station where a feeder intersects	
6	1	1	4		Point where one line terminates another passes through			Trunk line passes through and feeder terminates	

Metro Station Layouts and Schedules for Simultaneous Transfers

- Most stations in metro have two or more lines crossing themselves at different levels.
- Since passengers must negotiate one or two flights of stairs, schedules of trains in different lines cannot be coordinated for simultaneous transfers.
- However, whenever geometry of line alignments allows, and particularly when large passenger volumes make fast and convenient transfers highly desirable, station layouts that provide for across-platform simultaneous two-way transfers between trains should be planned.

Simultaneous Transfers between Weaving

- When the alignments of two metro lines can be brought to intersect under a flat angle, tracks should be woven as shown in the figure.
- The two trains in each direction are then scheduled to operate with equal and simultaneous headways. The passengers are thus given the ultimate type of transfer: across platform between two standing trains, thus requiring minimum distance and no waiting.

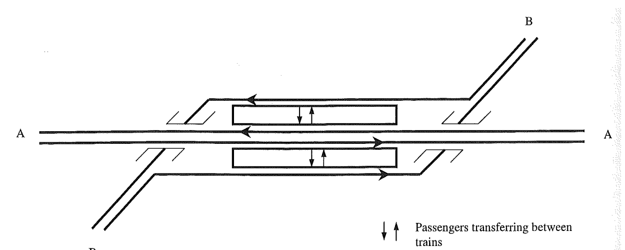


Figure 4.16 *Metro station for simultaneous transfers between trains on two weaving lines.*

Station Design for Transfers at Y Junctions

- Y-shaped radial network is operated with one trunk and one feeder line. The four directional transfers, E-N, N-E, E-S, and S-E are possible and divided into two stations, Prince Edward and Mong Kok. The lines run parallel between the two stations and have two platforms at different levels at each of the two station.

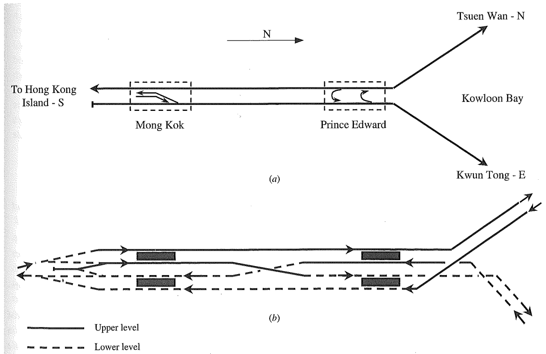


Figure 4.17 Two-station Y junction with across-platform transfers for all movements (Hong Kong MTR—left-hand driving): (a) distribution of transfers; (b) layout of tracks and platforms.

Transfers between Local and Express Trains

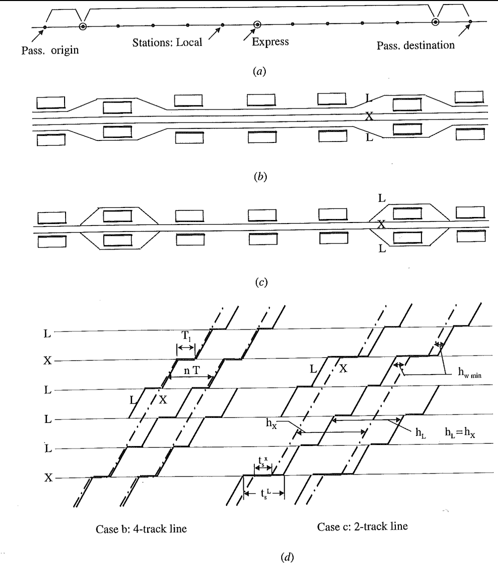
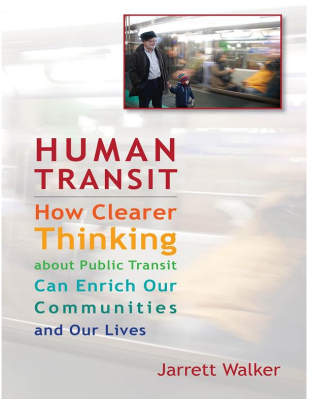


Figure 4.18 Station layout and schedule for local/express services with simultaneous transfers: (a) line layout and travel pattern for a typical passenger's trip; (b) four-track with local (L) and express (X) operations; (c) two-track line with local (L) and express (X) operations; (d) graphical schedule of synchronized local/express operations.

- Thank You



Transit Service Planning Issues

Notes from *Human Transit: How Clearer Thinking about Public Transit Can Enrich Our Communities and Our Lives*
by Jarrett Walker

Fixed or Flexible?

- Trips need to be predictable
  - Fixed services follow the same path, at the same time, day after day, so customers can plan around the pattern
- Fixed service are more efficient – they can carry more passengers per vehicle service hour
- Flexible route service can be innovative but are limited because they are less efficient
- Flexible routes tend to be useful where the overall demand is low or for specific populations whose needs aren't met by fixed services

Seven Demands of Public Transit

1) It takes me *where* I want to go.
2) It takes me *when* I want to go.
3) It is a good use of my *time*.
4) It is a good use of my *money*.
5) It *respects* me in the level of safety, comfort, and amenity it provides.
6) I can *trust* it.
7) It gives me *freedom* to change my plans.

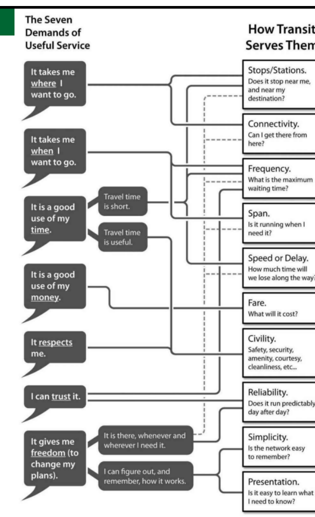


Figure 2-1 Seven desires for useful transit, and how transit serves them. Credit: Eric Orozco

The Seven Phases of a Trip

1) Understanding
   - You need a sufficient understanding of the service, frequency, and fare to know how to make the trip
   - *What transit agency can do*: Make it easier to understand the service
2) Accessing (at the origin)
   - Walk, drive, or ride bicycle to the stop where you will board the service
   - *What transit agency can do*: Locate stop in logical place, make it a civilized place to wait, provide parking options to car or bike (where appropriate)
3) Waiting
   - Least favorite phase of trip
   - *What transit agency can do*: Improve frequency and reliability, use technology such as real-time information that tells you how long you have to wait

The Seven Phases of a Trip

4) Paying
   - Costs money to user but also costs time
   - *What transit agency can do*: Use forms of fare collection that require you to buy a ticket before you board
5) Riding
   - Time spent on board vehicle is determined by average speed (or delay) and reliability
   - Quality of time is determined by the quality of the vehicle and your ability to make use of the time
   - *What transit agency can due*: Attempt to minimize delay
6) Connecting
   - Repeat steps 2 through 5 if you trip requires a transfer
   - *What transit agency can do*: Minimize the hassle of these steps. For example, offer free transfers.
7) Accessing (at the destination)
   - Traveling by some means from the transit stop to your actual destination
   - *What transit agency can do*: Logical location of stops. (Design of area is also very important but beyond the control of the transit agency).

Relative Values of Time for Different Stages of a Trip

	In-Vehicle Time	Walk Time	Initial Wait Time	Transfer Time
U.S. average	1.0	2.2	2.1	2.5
U.S. range	1.0	0.8–4.4	0.8–5.1[a]	1.1–4.4
U.K. average	1.0	1.7	1.8	N/A

Sources: *TCRP Report 95, Chapter 10* (*17*) and Wardman (*12*).

Note: N/A = not available. Values shown are multiples of the value of a unit of in-vehicle time.
(a) Two studies showed a sharp decrease in these values after the first 7–7.5 min of wait time.

Five Paths to Confusion

- Map-Reading Errors
  - Perceiving map area as though it were population
  - Transit planning requires looking at maps of data about populations
  - Maps that show the paths that transit runs on but not how frequently it runs tend to conceal the patterns of good service.
- Motorist’s Errors
  - Mistake that arises from unconsciously thinking about transit as though it works like cars and roads.
  - Someone who have never tried to walk along a busy street may not realize how unsafe or intolerable it is or what needs to be done to fix it.
  - Overvaluing speed and undervaluing frequency

Five Paths to Confusion

- Box Errors and False Dichotomies
  - Associating buses with poor people
  - Discretionary (choice) riders vs. transit-dependent (captive) riders
- Polarization Errors
  - Taking a stance of "you're either with us or against us."
- Unfortunate Connotations
  - Most words used in transit have a more common meaning outside that context
  - Examples: captive, route vs. line

Network Design

Imagine a city made up of nine major points ...

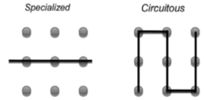
This configuration would be good for minimizing total travel distances, which is why towns on open plains tend to grow this way ...

But the ideal geography for transit would be like this, so that just one line could serve them:

(Strings of towns along a coastline, for example, are easy for transit to serve.)

Given the first kind of city, what are transit's basic choices for fitting a line to a grid of dots?

We can deploy just one line, by either *specializing* (only serving certain areas) or by running a *circuitous* service



Or we can deploy *multiple* lines. It will take lots of lines to link all nine centers directly. We need fewer lines if we rely on *connections* (Chapter CXNS).

Remember! Our budget for service must be spread across the miles of line that we need to run. So fewer miles of line means more service (more frequency, longer span) on each line!

Barriers and Chokepoints

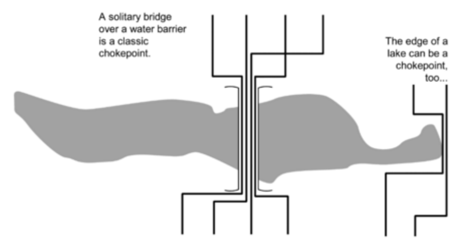
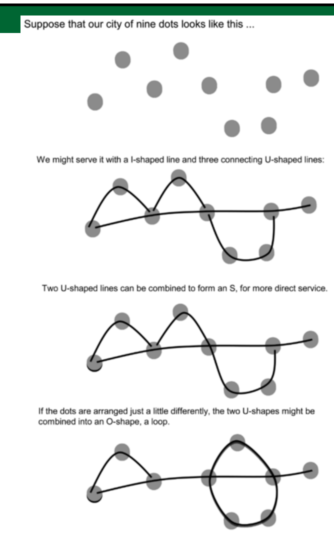


Figure 4-3 Chokepoints bring parallel lines together, permitting connections and increasing the impact of any transit priority. *Credit:* Erin Walsh

Basic Route Shapes

- *I-shape*: Optimal direct line
- *U-shape*: Reasonably direct between any two of its points, except the end points (end points must be connected by a more direct I-shaped line). They exist to serve their midpoints, not their endpoints. Signage should provide two important pieces of information: the "to" (final endpoint of the line) and the "via" (major intermediate stop).
- *S-shape*: Two (or more) U-shaped lines combined. These lines are not intended to be ridden long distances but provide a series of short-distance links
- *O-shape*: Continuous loop



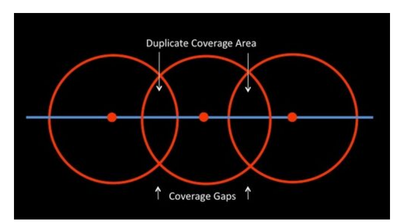
Loops

- Appealing image
- Problem: Very few people want to travel in circles
- Unlike I-shapes, loops are never a reasonably direct link between all of their stops
- Worse if loop is one-way (you may have to ride more than half-way around the loop to get where you're going)
- One-way loops work only in two settings
  - Very low-ridership areas, where it is cheapest way to cover a lot of area (goal is to provide basic lifeline service, so directness is sacrificed to cover as large an area as possible)
  - Very small circulation networks, such as an airport or downtown
- Cannot be extended
- No breaks for the driver

The Spacing of Stops and Stations

http://humantransit.org/2010/11/san-francisco-a-rational-stop-spacing-plan.html

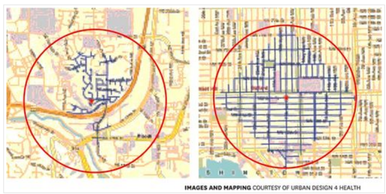
- Every stop or station has a walk radius, the area from which most people would be willing to walk to a stop. (Different people are comfortable walking different distances, so the outline of these circles would be fuzzy.)



- Generally, transit planers assume a tolerable walking distance of 400 meters (1/4 mile) for a local stop service and about 1,000 meters (about 3/5 mile) for very fast, frequent, and reliable rapid transit service

The Spacing of Stops and Stations
http://humantransit.org/2010/11/san-francisco-a-rational-stop-spacing-plan.html

- The walk circle is not an actual circle, because we must walk along the networks of streets and paths.
- The network design is a crucial element of walking distance.



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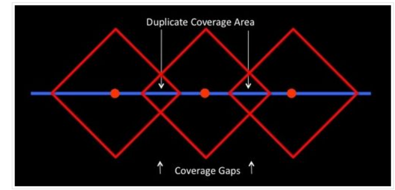


Duplicate coverage area: Area that has more than one stop within walking distance (waste)
Coverage gap: Area that is within walking distance of the line but not of a stop

Goal is to minimize both duplicate coverage area and coverage gap.
- Close stop spacing means smaller coverage gaps but larger duplicate coverage area
- Wide stop spacing means smaller duplicate coverage area but larger coverage gaps

The Spacing of Stops and Stations
http://humantransit.org/2010/11/san-francisco-a-rational-stop-spacing-plan.html

- Tradeoff of duplicate coverage area vs. coverage gap
  - If you care mostly about designing for coverage (to meet social service needs), you care more about minimizing the coverage gap
  - If you want to maximize ridership, you care more about minimizing the duplicate coverage gap, because closer stop spacing means slower operations
- In most urban areas, there will be more stuff close to the transit line than far from it, which means there is more stuff in the duplicate coverage area than in the coverage gaps. When looking at a map, don't just consider areas equally, consider where stuff is located.
- Variations in terrain could change the calculation.
- If demand is low, you can place closely spaced stops knowing that the bus usually won't have to stop at all of them

Frequency

- Direct role in meeting four of the seven transit demands
- Dominates three of the seven phases of a trip
- The essence of the distinction between routes (sites of occasional transportation events) and lines (transit that is there whenever you need it)

Frequency and Span

- Critical for getting people to choose transit
  - They provide freedom for a transit passenger
  - High-frequency, long-span service is there whenever you want to use it
- But they are expensive
  - Doubling frequency doubles operating cost
  - Increasing length of service day has corresponding increase in operating cost
- They are invisible
  - You see maps of networks or certain transit proposals
  - You read descriptions of transit proposals emphasizing where the proposed service will operate
  - You see transit vehicles moving around your city and signs indicating where service goes
  - You see people waiting at stops
  - You see images in the media that generalize about the quality of service or its users
  - Nothing shows the impact of frequency or span
- To be useful, transit must exist in both space and time (it must run not just where we need it but also when we need it)

Frequency Map

http://humantransit.org/2010/08/basics-the-case-for-frequency-mapping.html

- Consider the hierarchy of the street map
- Many transit maps make all lines look alike, but
  - Some of these lines have frequent all-day service
  - Some of these lines have infrequent all-day service
  - Some of these lines are peak-only
  - One of these lines is a nighttime-only route
- Transit agencies should make their systems look as simple as possible

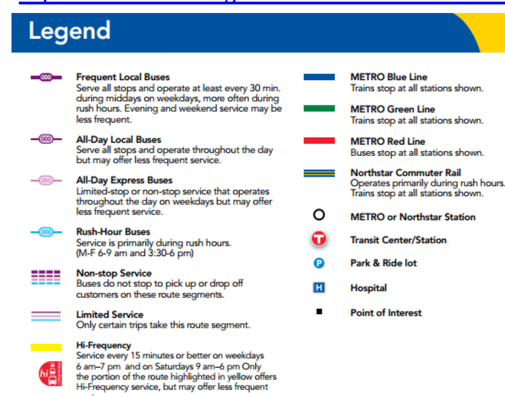
Frequency Map

http://humantransit.org/2010/08/basics-the-case-for-frequency-mapping.html

- Determinants of "major" routes
  - Frequency
  - Span of service
  - Speed
  - Reliability
  - Ease of access
- Three categories of usefulness
  - The Frequent Network
  - Infrequent All-Day Services
  - Peak-Only Service
- Recommendation for bus network: The three categories should be represented by three kinds of lines
  - Visually strong line for the Frequent Network (stands out)
  - Lesser solid line for infrequent all-day service
  - Dashed line for peak-only
- Emphasizing speed over frequency is a motorist's error

Frequency Map

http://humantransit.org/2010/08/basics-the-case-for-frequency-mapping.html

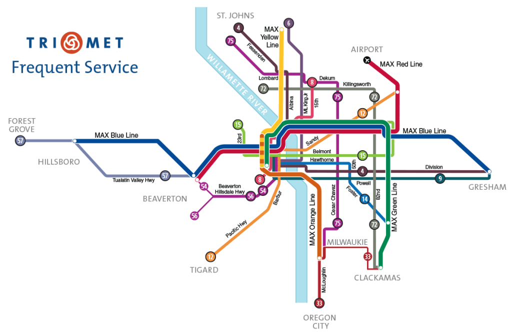


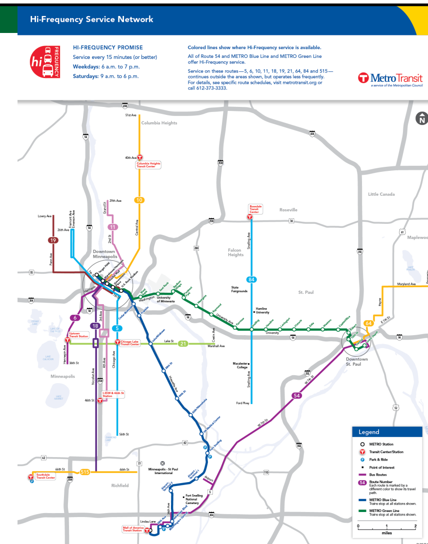
- Example: Minneapolis-St. Paul
  - https://www.metrotransit.org/Data/Sites/1/media/pdfs/sysmap/map_system.pdf

Frequency Map

http://humantransit.org/2010/08/basics-the-case-for-frequency-mapping.html

- One option: separate maps of just the Frequent Network





Minneapolis-St. Paul High frequency Network

https://www.metrotransit.org/high-frequency-network-map.aspx

Frequency Map

http://humantransit.org/2010/08/basics-the-case-for-frequency-mapping.html

- The Frequent Network is potentially useful to land use planners anyone deciding where to live, where to shop, or where to start a business.
- Potential problems
  - Finances are uncertain and transit agency may not be able to keep to a 15 minute headway
  - Difficulties on finding consensus on what the definition of "Frequent Network" should be

Speed, Delay, and Reliability

- Delay is the main problem for speed and reliability
  - To speed up transit, we focus on removing delays
  - Delay is the main source of reliability problems
- Urban transit is different than longer-distance travel
  - Stops more frequently (top speed is less important)
  - More situations with restrictions on speed, including congestion
- Three sources of routine delay
  - Traffic delay
  - Signal delay
  - Passenger-stop delay
- Routine delay is influenced by operating environment, right-of-way characteristics (mixed traffic, semi-exclusive, exclusive, separated)

Seven Types of Delays

- Traffic delay
  - Congestion – Exclusive or separated ROW protects from congestion.
  - Friction – Delay cause by individual vehicles. Putting transit lanes in the center of busy streets eliminates most friction.
- Signal delay
  - Only separated ROW eliminates signal delay
  - Signal priority tools can reduce delay
- Passenger-stop delay
  - Dwell due to boarding/alighting
  - Dwell due to fare collection
  - Acceleration/deceleration
  - Stop spacing

How to Reduce Delay

- Rapid transit systems/subways (separated ROW)
  - Automatic Train Control systems make it possible to run trains much closer together
  - These systems are very sensitive to dwell times at stations
  - Strategies to speed up boarding and alighting allows trains to run closer together and increase potential capacity
- Mixed traffic
  - Signal delay – traffic signal priority (can be tricky)
  - Move toward BRT to reduce traffic and passenger-stop delay
    - Median bus lane to protect from friction
    - Off-board fare payment to reduce dwell due to fare collection
    - Widen stop spacing to reduce passenger stop delays

The Case for Transit Lanes

- What percentage of the people who are already traveling down the street's traffic lanes are on transit instead of a car?
- How much faster will transit be if it has an exclusive lane?

Density

- Average density of metro area can be misleading
- More important to look at
  - Density within walking distance of transit stops
  - Percentage of citizens who live at high density

Ridership or Coverage?

- How should transit agencies divide up its resources among the communities it serves?
- Why are you providing transit at all?
- Transit faces a contradictory mission
  - Serve all parts of our community (Coverage Goal)
  - Maximize ridership with our fixed service budget (Ridership Goal)
- Reasons for Coverage Goal
  - Equity
  - Social service objective – focus on meeting the needs of people reliant on transit
  - Not just about how many people need it but the severity of the need

Ridership or Coverage?

- Ridership goal
  - Calls for deploying service the way private business would, with goal of highest possible ridership for given budget
  - Measures such as farebox recovery, trips per vehicle hour
  - Intense service where demand is high and no service where demand is low
  - Serves two major public interests
    - Compete successfully with cars to achieve environmental benefits
    - Maximize fare revenue
- Coverage goals and Ridership goals are both popular
- Transit agencies will often adopt both goals but not resolve the conflict between them

Denseville and Sparseville: Unavoidable Choices

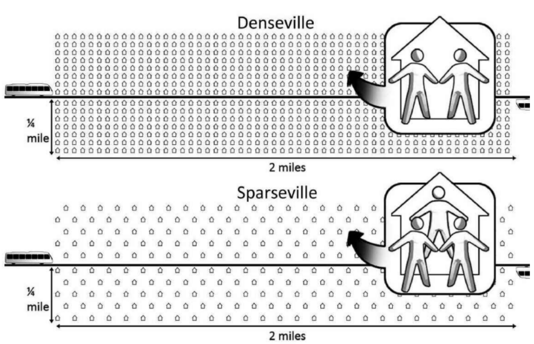


Figure 10-1 Denseville and Sparseville. Credit: Erin Walsh

Denseville	Sparseville
15,000 people	7,500 people
1,500 daily boardings*	750 daily boardings*

*Assume 5% of people in each neighborhood make one two-way trip each day.

Ridership per unit of operating cost will be twice as high in Denseville.

Denseville has more riders because it has more people, and more activities, in the fixed area within walking distance of any transit stop.

Denseville's Intensification Effects

- Differences in density imply other important differences
  - Easier to own and park cars in Sparseville
  - Denseville residents have less need to drive (can walk or bike to more places)
  - Denseville residents have lower rates of car ownership
  - The rate of transit use per person will be higher in Denseville
- Ridership = Population × Rate of Transit User per Person
- Ridership often varies with the square of the density
- If you double the density, transit demand goes up by more than double

Household Density (HH/acre)	Household Density (HH/ha)	Multiplicative Change Relative to Base Condition: Households	Likelihood of Using Transit	Overall Transit Demand
2.35	5.8	1.0	1.0	1
4.7	11.6	2.0	2.0	4
10.9	26.9	4.7	5.9	28
26.6	65.7	11.7	15.9	186
46.9	115.9	20.0	24.0	480

Source: Calculated for the TCQSM 3rd Edition from 2009 National Household Travel Survey data (*18*).
Note: HH = households. Base condition is 2.35 HH/acre (5.8 HH/ha). Household densities based on the densities of the census block groups of survey respondents.

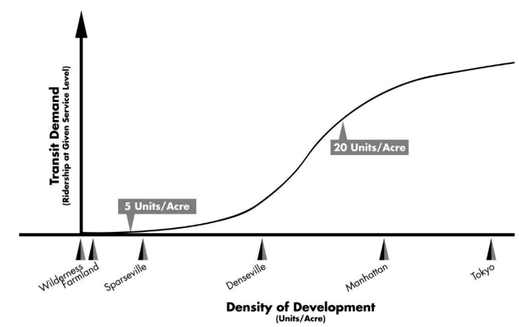


Figure 10-2 *How residential density affects transit demand. Credit: David Jones; adapted from Spillar and Rutherford, 1998*

Job/Activity Density

- Effective service allocation policy will count both residential density and the density of activities people need to travel to
- The concentration of jobs may affect ridership more than the concentration of residents
- Trip generation – how often does someone in this zone want to go somewhere
- Trip attraction – how often does somebody want to go to somewhere in this zone

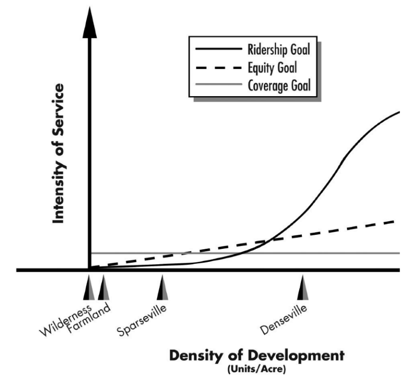
Policy: How would you deploy service?

- Coverage Goal: Serve all parts of our community
  - Same amount of service everywhere
  - Common in smaller cities transit is more of a lifeline service for transit dependent
  - Allocates service in proportion to area, not in proportion to population
- Equity Goal: Service shall be allocated proportional to population
  - Denseville's transit service runs twice as frequently as Sparseville's
  - Denseville buses will still be more crowded
    - Greater propensity to use transit in denser areas
    - Increased frequency will attract more riders
  - Seems fair but will still draw complaints

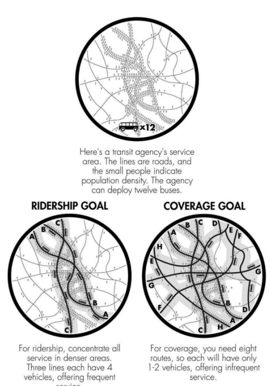
Policy: How would you deploy service?

- Ridership Goal: Maximize ridership with our fixed service budget
  - Environmentalists wanting to reduce vehicle miles
  - Fiscal conservatives wanting transit to run a profit
  - Both ask: Are we allocating transit resources to carry as many riders as possible within our budget?
  - With ridership goal, we should cut service further in Sparseville and add service in Denseville
  - Deploy service wherever it will carry the most people
- The Coverage Goal apportions service regardless of density
- The Equity Goal apportions service proportional to density
- The Ridership Goal apportions service in response to the observed pattern on demand

Policy: How would you deploy service?



From Policy to Network



Service Allocation Policy

- Percentage split of resources between the different goals
  - Example, allocate 55% of resources according to the Ridership Goal and 45% according to the Coverage Goal
- Services justified by the Ridership Goal would be assessed based on ridership
- Services justified by the Coverage Goal would be assessed based on the percentage of the population that they cover and the efficiency with which they do that

The Feedback Loop

- High quality transit in Denseville can make more people want to locate there, and it will get even denser.
- Density, service, and ridership are all feeding off of each other

Connections or Complexity?

- Many-to-one network
  - One example where connection-free networks work well
  - Everyone is going to the same destination
  - Radial network
- Many-to-many demand patterns
  - More typical
  - Choice between connections or complexity: If you try to avoid connections, you will create a very complex network with lower frequencies

Connections and Frequency

A Simple City

Figure 12-1 A simple city: three residential areas, three activity centers. Credit: Alfred Twu

- Direct Service Option
  - Direct service from each residential area to each activity center
  - Nine transit lines
  - Headway 30 minutes
- Connective Option
  - Direct line from each residential area to *one* activity center
  - All lines connect at a strategic point
  - Three transit lines
  - Headway 10 minutes
    - Don't need to worry about timetables
    - Total trip time could actually be faster

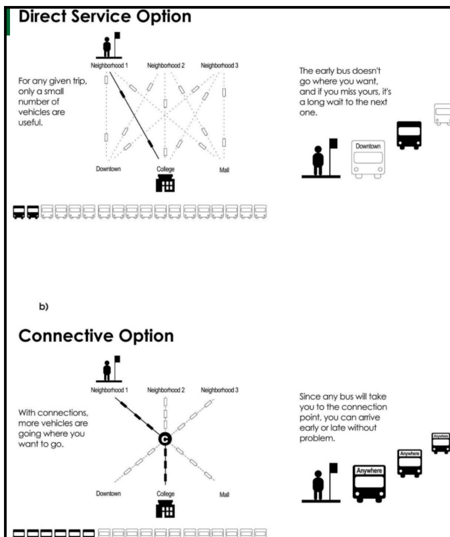


Table 12-1 Total Average Travel Time, Neighborhood 1 to College (per figure 12-2)

Direct Service Option		Connective Option	
Wait	15 min	Wait	5 mi
Ride	20 min	Ride	10 mi
		Connection Wait	5 mi
		Ride	10 mi
Total Trip Time	35 min	Total Trip Time	30 mi

- Total trip time is shorter with Connective option due to higher frequency and shorter wait time
- Frequency is less important if you organize your schedule around the transit schedule
- The advantages of the Connective option increase as the city grows
- The Connective network is simpler, with fewer transit lines, which makes it easier to learn

Benefits of Connections

- A Connective network covers the same area with far fewer routes
- Because of greater route distance, frequency or span must be lower
- Low frequency and shorter span mean:
  - More waiting
  - Constraining your schedule to the transit schedule
  - Higher risk of trip being disrupted by a reliability problem with a single vehicle
- A Direct Service network has more overlapping lines and more complexity
  - More difficult to understand the system
- To avoid connections we must sacrifice frequency, span, and simplicity

Designing a Connective Network

- Aspects of each connection point are important
  - *Timing*: Is the connection point's position in the network conducive to fast connections?
  - *Environment*
    - Is it a safe and pleasant place to wait? Or walk?
    - Does the site lend itself to reliable operations, keeping transit vehicles out of congestion or other causes of delay?
    - Does it offer additional ridership potential?

Pulse Network

- Timed transfers among multiple vehicles
- Common in smaller cities or suburban areas with less frequent service
- Schedules coordinated so that buses from each route come together at a central point
- Provides fast connections

Pulse Network

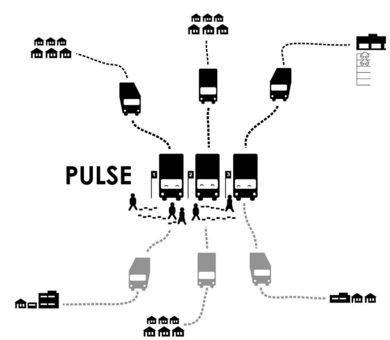


Figure 13-1 Typical pulse of local buses. Credit: Alfred Twu

Pulse networks can be more sophisticated with multiple pulse points where buses meet.

Can also be used for trains or ferries.

Grid Network

- You're designing a transit system for the following:
  - Fairly dense city that has many activity centers
  - You want people to be able to travel from anywhere to anywhere else by a reasonably direct path, at a high frequency
  - Then, the grid pattern is most efficient
- Services have to be frequent so riders do not have to wait long for the connection
- Spacing between lines in an ideal system is exactly twice our maximum walking distance

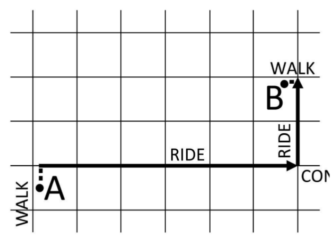


Figure 13-3 High-frequency grid with an "anywhere to anywhere" trip. Credit: Erin Walsh

Grid Network

- Types of grid network
  - Rectangular: Ideal for large areas of continuous density with many scattered activity centers
  - Spiderweb: Makes sense when you have a single, dominant center of demand. Radiating lines are called radials, and circular lines are called orbitals or crosstowns
- Most cities need hybrids of the two grid types

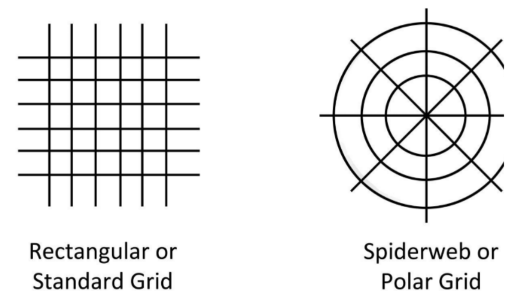


Figure 13-5 Basic grid types. Credit: Erin Walsh

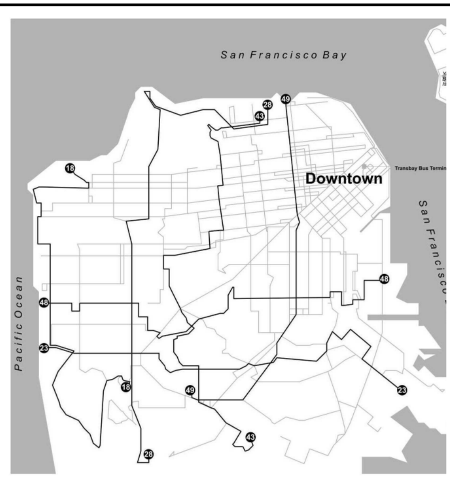


Figure 13-6 Rectangular or "straight line" elements of San Francisco's all-day grid, excluding lines into downtown (northeast corner). Credit: Daniel Howard

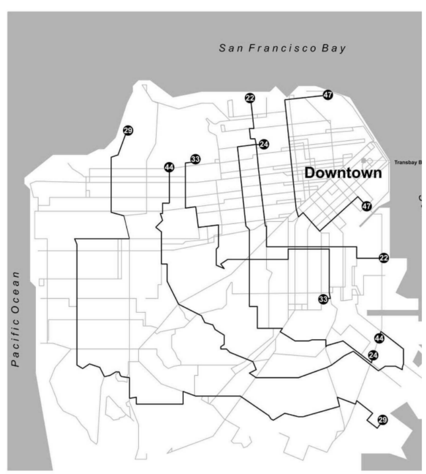


Figure 13-7 Spiderweb elements of San Francisco's all-day grid. Credit: Daniel Howard

Grid Network

- Attempt to connect any two points in a city with good transit service, rather than selecting preferred destinations
- Require high frequency because you cannot time every connection
- Optimal grid is rectangular, but most cities have high-demand destinations where lines should converge
  - Evolve elements of a spiderweb grid, or
  - Retain a rectangular grid but converge a bit around the major destinations

Reasons for a Connection

- Geometrically required connections
  - Changing directions within a grid
  - Connecting between lines in a pulse network
  - Connecting between services of dramatically different speed (between rapid transit and a local service, between airplanes and trains)
- Politically required connections
  - Occur at government boundaries where you connect from one agency's service to another
  - Political problem
- Technologically required connections
  - Changing from one kind of transit vehicle to another, even to continue in the same general direction and the same general speed
  - Interrupts a logical, linear pattern of transit

Be on the Way! Transit Implications of Location Choice

- An efficient transit line connects multiple points but is also reasonable direct
- Good transit geography is any geography in which high-demand transit destinations are on a direct and operable path between other high-demand transit destinations

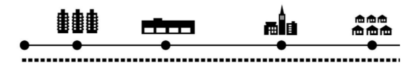


Figure 14-1a *Ideal geometry for transit. Credit: Alfred Twu*

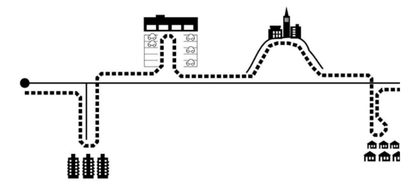


Figure 14-1b *Terrible geometry for transit. Credit: Alfred Twu*

Types of Cul-de-Sacs

- A person who lives at the end of a mile-long dead-end road complains that the bus doesn't go by their house.
- A small shopping center or grocery store sets itself too far back from its street, even though the street is where the transit service is.
- A university, hospital, business park, or other campus-style development positions itself on a hill or promontory, often at the end of a road leading only to it, or on a road at the edge of the city where there is nothing farther beyond it.
- A new community or suburb is located in such a way that no cost-effective transit line will ever get to its town center.

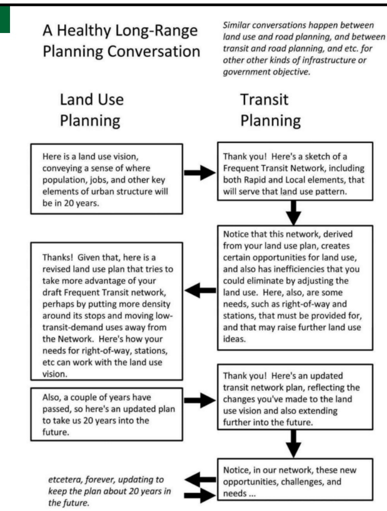
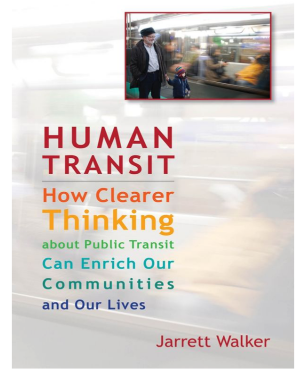


Figure 16-1 *Ideal interaction of transit and land use planning on the long-term scale. Source: Erin Walsh*

Choices

- Ridership or Coverage?
- Connections or direct service, which implies low frequency and complexity?
- Peak-first or base-first? Is peak service the primary product or is it a supplement to a consistent all-day product?
- Exclusive right-of-way vs. compromised right-of-way?

"Live where you want to live. Build whatever kind of community you want. Nobody is coercing you. But understand the costs, and don't expect transit to be both high quality and cost-effective if you live in a place where that's geometrically impossible."



Credit:

Walker, Jarrett (2012). Human Transit: How Clearer Thinking about Public Transit Can Enrich Our Communities and Our Lives. Island Press.

TRANSIT FINANCING

The Economics of Transportation Systems: A Reference for Practitioners by Kockelman et al., Chapter 5

Innovative Funding Sources for Transit, OmniTrans, UTA, Parsons Brinkerhoff, Lochner, RTD, 2012

Revenue Sources

- Federal Funding
  - Federal Highway Trust Fund funded from motor fuel taxes, truck tire excise, truck and trailer sales, and heavy vehicle use taxes
- Bond Proceeds
  - State and local governments issue bonds to raise money for transportation projects
- Tolls
- State Motor Fuel Tax
- State Motor Vehicle Tax
- Other State Funding
  - Property taxes and motor vehicle operator license fees
- Local Funding
  - Local motor fuel taxes, local motor vehicle registration fees, local option sales taxes, value capture, property taxes, tolls

Innovative Financing

- Section 129 loans
- State infrastructure banks (SIB)
- The Transportation Infrastructure Finance and Innovation Act (TIFIA)
- TIGER grants - https://www.transportation.gov/tiger
- Tax Increment Financing (TIF)
- Public-private partnerships (PPP)

Innovative Financing

- Special tax assessment districts
- In-kind private sector funding/developer contributions
- Joint development
- Intellectual property rights
- Energy cost savings and development
- Naming rights
- Toll revenues

Tax Increment Financing (TIF)

- Mechanism for capturing all or part of the increased property tax paid by a subset of properties within a designated area
- Not an additional tax
- Part of, or all of, future property taxes above the set base level (resulting from increased property values or new development) are dedicated to paying for the public improvement
- TIF districts can be implemented in a targeted geographical area

Tax Increment Financing (TIF)

- Disadvantage: Incremental revenues may grow slowly over time, while the capital investment is needed upfront
- The timing of future TIF revenues are speculative
- Example: Dallas
  - 558-acre TIF district around Dallas Area Rapid Transit stations
  - Revenue used to financing improvements and developments where needed

Special Tax Assessment Districts

- Additional taxes paid within defined geographic areas where parcels receive a direct and unique improvement from a public improvement
- Examples
  - Dulles Corridor Metrorail Project, Fairfax County, VA
    - Special assessment districts contributing $400 million
  - New York Ave/Gallaudet University station in DC
    - Landowners in vicinity of station agreed to pay special assessment over period of 30 years
    - Bonds repaid using funds collected through the special assessment

Developer Contributions

- Local governments may obtain contributions from landowners or developers to help fund transit improvements
- Types of contributions
  - Property dedications
  - One-time payments
  - Development impact fees
- Example: San Francisco authorizes the use the Transit Impact Development Fee for providing service to a new development.

Joint Development

- Arrangements between the public sector and private developers to develop assets, such as land
- Often used by transit agencies to construct stations, enhance station access, or build parking facilities
- Private investor enters the joint development agreement to enhance the property in partnership with the transit agency
- Potential benefits
  - Revenues can be used for the capital cost of a new project, or if lease revenues are provided to the agency on a annual basis, they can be used to fund operating costs
  - Transit agencies can leverage their property to generate revenue from private development
  - Can lead to increased revenue, ridership, or both
  - Often enhances financial viability of a project through the involvement of multiple uses
  - Transit agency can benefit from private sector expertise

Joint Development

- Challenge: Deals are complex, with many state and federal laws
- Example: Denver Union Station
  - Union Station being extensively renovated and expanded to connect light rail, commuter rail, intercity rail, and local, regional, and intercity buses
  - Plans call for private developer to build brand new neighborhood of housing, retail, restaurants, and offices on 20 acres of currently vacant land owned by the Regional Transit District (RTD)

Intellectual Property

- Common types of intellectual property rights: copyrights, trademarks, patents, industrial design rights, and trade secrets
- Some agencies have developed (using in-house resources and staff) technological solutions for operations, communications, or security issues that are faced by a wide range of agencies.
- These agencies could potentially sell the rights to these services or technologies or act as consultants to other agencies.
- Challenges: Estimating the value of the intellectual property and navigating property patent rights.

Energy Cost Savings

- Opportunities to generate revenue through implementation of alternative energy technologies
  - Selling energy that the agency produces
  - Entering into joint development agreements for energy facilities using publicly-owned land

Sale of Naming Rights

- Transit agencies could sell or lease the ability for private companies to add their names or logos to transit stations, for a defined period of time
- Benefits to transit agencies
  - Ability to generate revenue using existing facilities
  - Obtaining a recurring source or revenues for operations
  - Establishing a “sense of place” for a neighborhood surrounding a transit station
  - Developing positive economic development relationships within the community

Sale of Naming Rights

- Challenges
  - Potential perception of unfair commercial benefits
  - Aesthetic concerns
  - Conflicts with local regulations
  - Brand dilution for the transit agency
  - Multi-year commitments required
  - Difficulty in valuing the benefit of the rights to name a station
  - Potential negative associations with the company or entity involved
  - Need to reproduce maps and announcements if businesses change

Toll Revenues

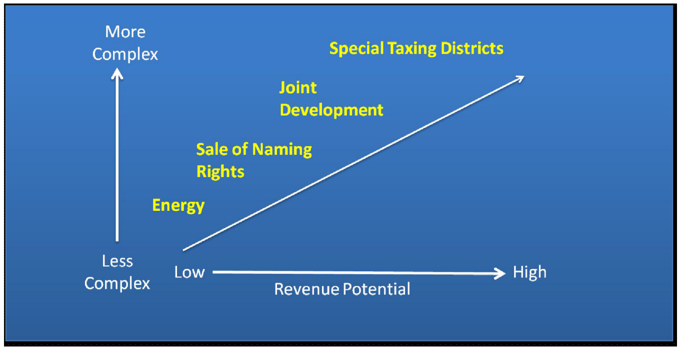
- Multi-modal authorities may fund transit operations with toll revenues
- Many state and local agencies are using toll revenues to cross-subsidize transit projects
- Benefits
  - May keep the fees charged to drivers within a common multi-modal highway and transit corridor
  - Provides a steady, continuous revenue stream
  - May help manage the overall transportation demand in a corridor and encourage more commuters to use transit
- Challenges
  - Regions must have existing toll facilities or the ability to begin charging tolls on an existing roadway;
  - FHWA / State DOT approval processes for converting existing highways to toll facilities, and requirements to apply toll revenues to transportation projects in the same corridor;
  - Resistance from toll road users to new or higher fees; and
  - Diversion of revenues from roadway funding needs.

Innovative Partnerships

- Local government
  - Agreements to provide a portion of funding for capital projects
  - Taxing type structures set up for ongoing operations funding
- Healthcare
  - Negotiations for transit passes for employees
  - Naming rights with large health facilities
- Retail businesses
  - Bulk pass sales
  - Leasing space to retail businesses in facilities owned by the transit agency
- Utility companies
  - Installing common utility line needs
  - Selling power back through solar or other generation by the transit agency
  - Negotiations for utility pricing based on bulk use
- State government
  - Authorizations from the state for the transit agency to operate
  - Funding through authorizations for using property or sales taxes
- Schools
  - Bulk sale or distribution of transit passes

Key Findings

- Tradeoff between revenue potential and complexity



Key Findings

- Innovative funding sources used for both capital and operating budgets
- Agencies of varying sizes and resource capabilities use innovative funding strategies, though larger agencies are more likely to pursue multiple innovative practices
- Partnerships provide both tangible and intangible benefits
  - Increase level of professional expertise and efficiency of projects
  - Create buy in from the public, by adding the credibility of the private sector
- Innovative funding will be very important in the future

Lessons Learned from Survey

- Most U.S. transit agencies, especially true of smaller agencies, are researching innovative funding methods but have not implemented them.
- The most beneficial funding types require long lead times and are complex requiring more expertise, resources and preparations. This requires agencies to be willing to dedicate the necessary effort and possible resources to achieve the goal.
- There is a difficulty in valuing public assets (e.g. right of way, advertising space) as part of deals with private sector partners. A correct assessment of the value both near and long term is often the source of program/project delay.
- Leaders have been largely successful in identifying substantial and sustainable innovative funding by leveraging existing assets for increased long term benefits, investing current worth in real property and land improvements for a greater future value.

ON-BOARD AND INTERCEPT TRANSIT SURVEY TECHNIQUES

TCRP Synthesis 63

Onboard and Intercept Surveys

- **Onboard survey**: Survey conducted on buses, subway cars, light rail cars, commuter trains, paratransit vehicles
- **Intercept survey**: Surveys conducted in person

Onboard and Intercept Surveys

- Onboard and intercept surveys are highly valuable to transit agencies as a means of obtaining important information
- Onboard and intercept surveys used to collect data for:
  - Customer trip characteristics
  - Travel behavior
  - Demographic characteristics
  - Customer attitudes about service
- Survey results used for:
  - Travel modeling
  - Long-range and area-wide planning
  - Route planning and scheduling
  - Service design
  - Marketing
  - Customer communications

Onboard and Intercept Surveys

- Large agencies conduct 5 or more surveys annually
- Small agencies conduct surveys every 1-3 years
- Surveys generally address 2-4 of the following:
  - Where and when do customers use transit?
  - Who uses transit?
  - How satisfied are customers?
  - Why do customers use transit?
  - How could the agency attract increased ridership?
  - How effective are the agency communications and information?

Important issues in planning and conducting these surveys

- What is the most effective way of obtaining a representative sample of the target rider group?
- What is the clearest way to word questions and elicit accurate responses?
- What are the effective ways of eliciting meaningful responses on service quality issues?
- What response rates have been achieved?
- What techniques have transit agencies used to increase response rates?
- How long can surveys be without discouraging participation?
- How often are survey results updated?

Planning Survey

- Defining project goals
- Choosing where and how to conduct the survey
- Identifying the study population and sampling frame
- Deciding what degree of precision is needed in the results

Project Goals

- What information does the survey need to collect?
- Major areas:
  - Travel modeling
  - Long-range and area-wide planning
  - Route planning and scheduling
  - Marketing
  - Customer communications
- Surveys can cover multiple areas (but rarely all of them)
  - Origin-destination surveys are used in route planning, long-range planning, and scheduling and modeling
  - Customer attitude and demographic surveys are used in area-wide and route planning, marketing, and customer communications

Where and how to conduct surveys

- Self-administered or personal interviews?
- On-board or in-station?
- Distribution and collection of self-administered surveys
- Prior notice to riders
- Incentives

Self-Administered vs. Personal Interview

- Self-administered surveys
  - Respondents complete survey form themselves and return form to transit agency
  - More common than personal interviews
  - Distributed by survey workers or bus operators or made available in a convenient location (such as onboard the bus for riders to pick up)
- Personal interview
  - Trained interviewer guides respondents through the survey
  - Important when some respondents don't have the literacy or English language skills to complete a survey

TABLE 7
CHARACTERISTICS OF SELF-ADMINISTERED SURVEYS AND PERSONAL INTERVIEWS

	Self-Administered	Personal Interview
Strengths	• Need fewer surveyors to obtain a given number of completed surveys because multiple respondents can complete the survey simultaneously • Can potentially survey all riders boarding a bus or train; no need to select a sample from among those boarding	• Higher level of respondent understanding of questions • Ensures that all questions are answered • Obtains responses from persons with limited literacy skills
Weaknesses	• Respondents may misinterpret questions (measurement error) • Respondents may not complete the entire questionnaire (item nonresponse) • May result in lower response rate than personal interviews • Depends on ability of respondent to read questionnaire • Difficult to use branching and skip patterns	• Can be time-intensive for surveyors; may need larger number of surveyors • Possible bias from nonrandom selection of riders interviewed • Cost
Situations likely to be used	• Projects needing large number of respondents • Same questions asked of all respondents • Relatively long questionnaires	• Short questionnaires • Need relatively smaller number of completed surveys • Respondents unable to complete survey due to language, literacy, and/or disability • Use as adjunct to self-administration at choice of respondent
Implications for survey planning	• Survey instrument must be well designed, with clearly worded questions and clear navigation	• Length of survey may need to be minimized • Need to interview riders where they will take the time needed to complete the interview

Onboard vs. In-Station Surveying

- More common onboard
- Reasons for onboard survey
  - Steady flow of riders
  - Adequate time to complete survey
  - Surveys can be returned on the spot
  - Relatively safe environment for surveyors
  - Facilitates obtaining a representative sample of riders
- Reasons for in-station survey
  - Circumstances particular to the survey or transit property (such as if most riders pass through a few transfer points)

Distribution and Collection of Self-Administered Surveys

- Often distributed and collected by survey staff assigned for this purpose (1 or 2 survey workers assigned to each bus or train car)
- Surveyors offer questionnaire and pen or pencil to passengers as they board
- Passengers return questionnaire when completed
- Return by mail is often provided as an option
- Some surveys distributed by bus operators (more common at smaller agencies) or left onboard for riders to pick up

Prior Notice

- Some agencies notify passengers about the survey in advance through media, onboard announcements, or other means
- May help boost response rates

Incentives

- Incentives may increase response rates, though there is little evidence to document or quantify the size of the effect for transit surveys
- Research on mail surveys suggest incentives increase response rates and that small incentives sent with questionnaires have greater impact than prizes awarded afterwards

Identifying Study Population and Drawing the Sample

- Theoretical population: The population to which researchers wish to generalize.
  - For transit survey, theoretical population may be all riders or a subset such as riders on a particular route or traveling in a particular area or at a particular time of day
- Study population: The population to which the researcher can gain access.
  - The study population for onboard/intercept surveys could be the same as the theoretical population because all riders could, in theory, be reached onboard transit vehicles
  - Riders vs. trips as study population
    - Focus on riders for customer satisfaction, attitudinal, demographic questions
    - Focus on trips for origin-destination surveys, trip purposes

Identifying Study Population and Drawing the Sample

- Sample frame: The listing of the study population from which the sample will be drawn.
  - Telephone survey – sample frame might be all residential phone numbers
  - Onboard surveys – sample frame is customers on the listed routes or vehicle trips
  - Surveys at stations or stops – sample frame is customers passing through those locations
  - Sample frame could be further defined by time of day, days of week, and direction of travel

Identifying Study Population and Drawing the Sample

- Sample: Group of people selected to be surveyed (not the group of people that actually complete the survey but the group the researcher attempted to contact)
  - May consist of entire sample frame or a randomly selected subset of the sample frame
    - Random selection of routes, etc.
    - Personal interviewers may select every *n*th person

Identifying Study Population and Drawing the Sample

- Stratified sampling: The sample frame is divided into mutually exclusive and exhaustive subsets, and a random sample is chosen from each subset
  - Objective is to ensure that key subgroups of the population are represented
  - Can be stratified by time of day and route
  - Proportionate or disproportionate random sample
    - Disproportionate random sample can be used to obtain statistically significant results for small subgroups
  - Weights used for each group (strata) based on ridership for that group and number of surveys collected

Minimizing Errors in Survey

- Sampling error
- Nonresponse error
- Coverage error
- Measurement error

Sampling Error

- Arises from surveying a sample of the study population rather than the entire population
- The difference between the true (but unknown value) and observed values
- Expressed with confidence interval and confidence level
  - Example: +/- 3 percentage points with a 95% confidence level
    - The confidence interval (+/- 3 percentage points) is the degree of precision and reflects the spread of observed values if the survey were repeated numerous times
    - The confidence level (95%) is how often the observed rate would be within the confidence interval (within 3 percentage points) of the true rate if the survey were repeated numerous times

Sampling Error

- Sample size needed depends on the population size and the level of precision needed
  - With stratified sampling, sample size needs to be computed for each subgroup

TABLE 8
SAMPLE SIZES NEEDED FOR VARIOUS POPULATION SIZES AT VARIOUS LEVELS OF PRECISION

	Sampling Error for 95% Confidence Level		
Population	±10%	±5%	±3%
200	65	132	169
400	78	196	291
1,000	88	278	517
6,000	95	361	906
20,000	96	377	1,013
1,000,000	96	384	1,066

Note: Sample size needed for each sampling error; responses with frequency of 50%.

Nonresponse Error

- Failure to obtain completed surveys from some portion of the population selected in the sample
- Unit nonresponse error: Over- or under-representation of groups within sampling frame when members of sample do not respond to survey request
- Item nonresponse error: Respondents skip questions or fail to complete survey
- No standardized way to compute the error
- Compare characteristics of respondents with those of entire population or sampling frame

Coverage Error

- Occurs when a portion of the respondent population cannot be reached by the survey method being used
  - A web-based survey cannot reach members of the population without access to the internet or those who have not provided an email address
  - A landline phone survey cannot reach those without a landline phone
- Coverage error varies depending on the respondents being targeted and the survey method

Measurement Error

- Results when respondents misunderstand questions and give inaccurate responses
- Measurement error and item nonresponse error are minimized with well-written questions, appropriate answer choices, and an easy-to-follow survey design

Developing Questionnaires

- Properly designed questionnaire will minimize nonresponse and measurement error
- Aspects of survey design
  - Introduction – Short explanation of purpose, focused on motivating response
  - Topics and question wording
    - Questions need to serve the goals and objectives

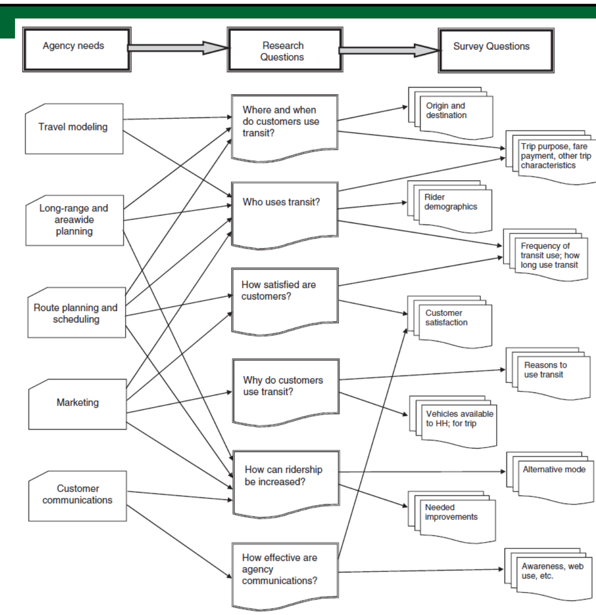


FIGURE 1 Translating agency needs into research questions and survey questions.

Developing Questionnaire

- Aspects of survey design
  - Questionnaire design and layout
    - Question ordering
    - Navigation guides
    - Answer choices: One, two, or three columns?
    - Matrix formats
    - Branching and skips
    - Use of other languages
    - Surveying respondents who cannot read
  - Pretest questionnaire

Question Ordering

- Key aspect of survey design
- First question should be:
  - Easy to answer
  - Apply to all respondents
  - Interesting
  - Clearly connected to the purposes of the survey
- Questions on the same topic are grouped together
- The ordering of attitudinal questions may introduce bias
  - Ask about overall satisfaction with service before asking about satisfaction for reliability, speed, routing, or other specifics (the more general question first)

Navigation Guides

- Visual clues to guide respondents in navigating from one question to the next
- Use simple, clean-looking layouts
- Simple formatting devices to aid navigation
  - Questions begin in the upper left corner
  - Vertical one or two-column formats
  - Sequential questionnaire numbering from beginning to end
  - Bold questions and light answer choices to clearly distinguish questions from answers
  - Check-off boxes to indicate answer choices
  - Minimal use of lines between columns or sections of the survey, avoiding visual clutter

Response Rates

- A higher response rate reduces nonresponse error and cost per completed survey
- Ideally measured as number of surveys returned and usable as a percentage of the number of riders asked to participate
- Response rates found to vary from 13% to 90% and were typically 33%-67%
- Factors affecting response rates
  - Enthusiasm and diligence of survey workers who distribute surveys or conduct interviews
  - Level of rider interest
  - Self administered vs. personal interviews
  - Length and complexity of survey
  - Use of incentives
  - Frequency of surveys being conducted
  - Demographic factors

Credit:

Schaller, Bruce. *On-Board and Intercept Transit Survey Techniques: A Synthesis of Transit Practice.* TCRP Synthesis 63. Transit Cooperative Research Program, Transportation Research Board, 2005.

ASSIGNMENTS

TL 787
Homework 1
Due: January 22

1. *What is your background knowledge, interest, and experience with transit, and what do you hope to learn from this course?*

2. *Describe the transit system in your home community. (If none exists, describe the transit system of another city.) Describe the modes available, types of vehicles, operating environments, system design, etc.*

TL 787
Homework 2[1]
Due: February 1

The objective of this assignment is to make use of the expertise of transit planning, design and operations experts from around the world from the Transportation Research Board annual meeting.

You should choose a paper written for a recent TRB annual meeting to write an approximately one page summary. The essay should be organized in the following five paragraph structure:

1. Introduction (including thesis statement)
2. Body Paragraph One (strongest argument/piece of evidence/theme)
3. Body Paragraph Two (additional argument/piece of evidence/theme)
4. Body Paragraph Three (additional argument/piece of evidence/theme)
5. Conclusion (ties together, summarizes, broader perspective)

You can search for papers at http://amonline.trb.org/. If you do not have free access to the full papers, you may email the instructor with the requested paper number and it will be emailed to you.

You should choose a paper with a focus on topics related to public transportation. In general, this would be sessions sponsored by:

- AL020 Transit and Intermodal Transportation Law
- AP010 Transit Management and Performance
- AP015 Transit Capacity and Quality of Service
- AP020 Emerging and Innovative Public Transport and Technologies
- AP025 Public Transportation Planning and Development
- AP030 Public Transportation Marketing and Fare Policy
- AP040 Major Activity Center Circulation Systems
- AP045 Intermodal Transfer Facilities
- AP050 Bus Transit Systems
- AP055 Rural Public and Intercity Bus Transportation
- AP060 Paratransit
- AP065 Rail Transit Systems
- AP070 Commuter Rail Transportation
- AP075 Light Rail Transit
- AP085 Ferry Transportation
- AR055 Rail Transit Infrastructure
- Some papers in ABE30 Transportation Issues in Major U.S. Cities
- Some papers in ABE60 Accessible Transportation and Mobility

[1] This assignment was developed by the Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE). STRIDE's Public Transportation Course Modules and associated assignments are available at https://stride.ce.ufl.edu/2017/04/public-transportation-course-modules/

TL 787
Homework 3[1]
Due: February 8

1. (7 points) A heavily traveled bus line has a length of 12 km. It has stops every intersection and there are 5 blocks per kilometer (a bus stop every 200 meters). The running speed of the buses is 34 km/h. Terminal time is 9 minutes at each end. Assume that the buses stop at every stop, losing 20 seconds for deceleration and acceleration plus dwell time of 15 seconds every stop. The average passenger trip length on the line is 4.8 km. Service headway is 5 minutes.

   You want to propose a reduction of stop density to one stop per two blocks. In that case, time loss for deceleration/acceleration per stop would not change, but dwell times would increase to 25 seconds per stop due to an increased number of passengers boarding and alighting per stop. The company management believes that the existing operation is desirable for passengers (short access) and that the changes would not make much of a difference in operating costs anyway. To convince management that the change would be useful, compute and systematically present the following consequences of the change in stop density, assuming uniform distribution of origins-destinations along the whole line:

   a. Additional average walking distance per passenger along the line, which includes access and egress (in meters per person)
   b. Additional average access and egress time (in minutes per person) if the speed of walking is 75 meters per minute.
   c. Reduction of the average passenger travel time on buses (in minutes per person).
   d. Change in passenger total travel time.
   e. How many buses can be saved due to higher operating speed? HINT: calculate round-trip cycle time under current and proposed scenario and calculate number of buses needed based on cycle time and headway.

2. (7 points) A 14-km (one-way) long trolleybus line has an operating speed V_o = 12km/h; terminal time at each end t_t is at least 6 minutes.
   a. How many trolleybuses are required for operation with a 10-minute headway? What will be the cycle speed V_c for the line with that schedule?
   b. What new operating speed V'_o should be achieved in order to reduce the number of trolleybuses by two, while maintaining the same headway and increasing the minimum required terminal time at one terminal to 8 minutes.
   c. What will be the offered line capacity if C_v = 80 spaces? Compute α_{max} if the line carries 300 persons per hour on its maximum load segment?

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[1] Source of homework problems: Vuchic, Vukan R. (2005) *Urban Transit Operations, Planning, and Economics.* Hoboken, New Jersey: John Wiley & Sons, Inc.

3. (6 points) A rapid transit line is 14.2 km long (one way) and has the following passenger volumes boarding and alighting at individual stations in the peak direction during the peak hour.

Station	A	B	C	D	E	F	G	H	I	J	K
Boardings (prs/h)	3300	1700	1900	3200	2900	1300	1600	600	400	700	0
Alightings (prs/h)	0	0	500	700	2100	700	4000	2700	2200	1700	3000

Capacity of each train is 590 spaces, α_{max} is selected to be 0.9, travel speed on the line is V_o = 36 km/h. Terminal time is 5 minutes at each terminal.

a. Compute the maximum load segment (MLS)
b. Compute the headway, frequency, number of trains required for the service, actual load factor, cycle time, and cycle speed.

TL 787
Homework 4
Due: February 15

1. (5 points) Describe the concept of elasticities, including different types of elasticities, and how elasticities can vary.

2. (5 points) Given a calibrated utility function, u = b – 0.04*C* – 0.02*t*, where *C* is the cost of travel (in cents) and *t* is the travel time (in minutes).

    a. What will be the modal split (percentage demand traveling by each mode) for the data given below?
    b. Given rising gasoline prices, if *C* for a car increases by $1.20 (from 110 cents to 230 cents), what impact will this change have on the modal split?

Mode	*b*	*C*	*t*
Bus	-0.30	85	30
Light rail	-0.35	100	50
Car	-0.25	110	35

3. (5 points) Pick a rural county (a county with no metro area) located in your home state. Estimate demand for general purpose rural public transit in the county. Use the equation from TCRP 161:

    Trips per year = (2.20 * Populated age 60 or older) + (5.21 * Mobility Limited Population age 18 to 64) + (1.52 * Residents of Households having No Vehicle)

    Use 2014 ACS 5-year data, which can be accessed through the American FactFinder. Use table numbers indicated in the lecture.

4. (5 points) Find a news article about ridership for a particular transit agency. (It doesn't have to be a recent article, but you should be able to find several articles if you do a Google news search.) Post the article on the discussion board in the Demand Analysis thread, and then give a one paragraph summary on the discussion board. In your summary, you should 1) briefly describe changes in ridership, 2) summarize the factor(s) believed to be contributing to the ridership changes, 3) identify if these factors are internal factors or external factors, and 4) discuss whether you think the given explanations for ridership changes are reasonable.

TL 787
Homework 5
Due: February 26

1. In week 4 lecture, we have learned about transit trip decision making process from availability, and comfort and convenience stand point. In this context, please explain what mode you mostly chose to travel while making your regular weekday trips to work/school. Do you use public transit in making your every day trips? Please provide your explanation about your trip decision making process about why you do/do not choose transit for your regular trips. You can explain your answer from availability, and comfort and convenience stand point.

2. The objective of this task is to get a better understanding about park-and-ride services that are common on transit networks in urban areas. In Transit Capacity and Quality of Service Manual (TRCP Report 164) Chapter 4, please review the material in pages 4-24 through 4-28, and write a 1-page summary to explain park-and-ride service, park and ride facilities, characteristics of park and ride users, and park and ride market areas.

   Instead, if you want to review a technical report, journal article, or couple of news articles and then wanted to write a 1-page summary on any particular aspect relating to park-and-ride services; that should also be acceptable. In such situation, please provide the reference of materials you reviewed. This option may be a potential option for students who already have a good working knowledge about park-and-ride services. You don't need to do both. Just pick one option.

TL 787
Homework 6
Due: April 10th 2019

1. (15 points) A bus stop is located at a midblock on a two-way street having two through lanes in each direction. There is no parking on either sides of the roadway. The design of the bus stop is linear with three loading areas and the bus stop position is offline relative to the road and therefore the buses must exit the traffic stream to serve the passengers. The average number of boarding passengers is 10 passengers per bus and average number of alighting passengers is 12 passengers per bus. All the buses that stop in the bus stop are 40-foot low floor buses (that will facilitate level boarding at bus stop) that have a narrow front door (one channel) and a narrow rear door (one channel). Standees are not normally present on the bus. All boarding occurs through the front door and 60% of the passengers use monthly passes which needs visual inspection and the remaining 40% of passengers who purchase single ride or daily fares should use farebox with exact change. For percentage of passengers alighting through front door and rear door, use the recommendation provided from the bus capacity methodology in chapter 6. Assume that the passengers waiting at the loading area is in crowded condition. Assume coefficient of variation of dwell times (c_v) as 0.6. Assume the bus door opening and close time as 4 seconds.

Assume a re-entry delay of 3 seconds for each bus to pull back into the traffic stream after serving the passengers. Using the design bus stop failure rate of 10%, calculate the dwell time and loading area capacity for the bus stop. Follow and illustrate all the steps from steps 1-5 while solving dwell time and loading area capacity. When any needed data is not given, use the recommended values from Week 7 lecture notes or in the bus capacity methodology section of Chapter 6 in TCQSM 3rd edition (pages 6-60 to 6-85).

2. (5 points) For the above situation, calculate the bus stop capacity. Assume that all the buses at the bus stop arrive at a random pattern. Also the bus stop is located far enough from a traffic signal that there is no influence for the bus stop from the queue of the stopped vehicles generated by the traffic signal.

TL 787
Homework 7
Due: April 6th

1. (10 points) This is a reading assignment. The objective of this task is to get knowledge about some of the topics/concepts relating to rail transit capacity that were not covered in the lecture. Study Chapter 8 of Transit Capacity and Quality of Service Manual (TRCP Report 164) and write a brief summary (at least 4 sentences) for each of the following concepts.

a. Traffic Signal Priority for Transit Vehicles

b. Skip-Stop and Express Operation

c. Passenger-Actuated Doors

d. Fare Payment

e. Wheelchair Accommodations

2. (10 points) For the calculation example that is solved in the Week 11 recorded lecture, calculate the controlling headway and train throughput when there is a slope of 1.5% downgrade into the station and a 1.5% upgrade out of the station. There is no need to consider the effect of line voltage and hence the assume the value of l_v as 1 (meaning 100%). Assume an average dwell time at the critical station as 35 seconds and operating margin as 40 seconds.

TL 787
Homework 8[1]
Due: April 15th

1. (5 points) A transit network is being designed to serve a 1500-m-wide corridor. There should be two lines parallel to the corridor axis, and it is possible to locate them at any location.

    a. What would be the optimal locations of the two lines to minimize access distances perpendicular to the lines, measuring from the left-hand boundary of the corridor?

    b. What will be the average and maximum access distances, assuming that the population distribution in the corridor is uniform?

2. (5 points) List and define the advantages and disadvantages of trunk lines with feeders as compared to trunk lines with branches.

3. (5 points) How many transfer possibilities are there at a joint station with the following numbers of transit lines:

    a. Three lines intersecting each other

    b. Eight terminating lines

    c. Three intersecting and two terminating lines.

4. (5 points) Define and briefly describe the three major objectives that should be considered in planning transit networks. Which three major parties are affected by the three major objectives?

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[1] Source of homework problems: Vuchic, Vukan R. (2005) *Urban Transit Operations, Planning, and Economics.* Hoboken, New Jersey: John Wiley & Sons, Inc.

TL 787 Public Transportation II
Term Project: Write a Transit-Related Paper
Assigned: January 28, 2016
Final Report Due: May 10, 2016

Instructions

For the term project, you should write a research paper on a public transportation topic. This project could be a qualitative analysis of a transit issue, a quantitative analysis of a transit-related data source, or a synthesis of previous research regarding a specific transit-related topic. Potential topics can include any transit-related topic. Search previous literature for ideas before selecting a topic. A list of potential topics can be provided by the instructor. The types of projects that can be conducted are described below.

Qualitative analysis: This could include a case study analysis, the creation and application of a framework, or some other type of qualitative analysis. This type of paper should also include references to at least four other research studies related to the chosen topic.

Quantitative analysis: This includes an analysis of a transit-related data source. Data could be obtained from the National Transit Database (http://www.ntdprogram.gov/ntdprogram/), a local transit agency, or some other source, or it could be collected yourself. This type of paper should also include references to at least four other research studies related to the chosen topic.

Synthesis report: A synthesis report is a summary of previous research conducted regarding a specific topic. In a synthesis report, you should summarize methods and key findings, compare and contrast the studies, identify and analyze key themes, and draw some conclusions. This type of paper should include references to at least ten research studies, though you do not need to go into an in-depth analysis of each study. Include at least 5-7 studies that you analyze in greater detail, while the other studies could be referenced for minor points or supporting arguments.

Literature Review

Each type of research project will require some type of literature review. You can search for literature through the TRID database (http://trid.trb.org/) or Google Scholar (scholar.google.com), though you are not limited to these options. You can also try the World Transit Research site at http://www.worldtransitresearch.info/. At least half of your articles should include journal articles or TCRP reports, as these are generally of higher quality. If you find an article online that you do not have access to, email one of the instructors, and we may be able to access the article for you.

Due Dates

The following are important due dates for the term project:

- Project Proposal Due: February 16
  - The project proposal should be about 1-2 pages and it should provide a description of the topic you plan to write about and how you plan to complete the project.
- Draft Report Due: April 18
  - Rough draft or detailed outline of complete paper
- Presentations: April 25-29
  - 15 minute PowerPoint presentation
- Final Report Due: May 10

Manuscript Format

Basic formatting guidelines are as follows:

- **Overall Length:** The length of the paper – including the abstract and references – should be a minimum of 3,500 words.
- **Cover Page:** The paper title, the author's name, the class name, and the date submitted should be included on the title page.
- **Abstract:** Following the cover page should be an abstract. The abstract must be no longer than 250 words, it must be self-contained, and it must not require reference to the paper to be understood.
- **Page Setup:** Students can use the font of their choice, but font size for the body of the text should be 10-12 points. Page numbers should be included. Page margins should be 1 inch.
- **Tables & Figures:** Tables and figures should be embedded in the body of the report.
- **References**: The reference list should contain only references that are cited in the text, listed alphabetically. Denote a reference at the appropriate place in the text by citing the author name and year of publication.

Other formatting details are up to the student.

Presentation Format

Presentations should be about 15 minutes in length. Presentations will be followed by a brief question and answer session that will be moderated by the instructor. Tips for presentations can be found at the following link: http://onlinepubs.trb.org/onlinepubs/am/2015/AVTips.pdf

Grading

The paper will be evaluated on the following criteria:

- Depth of coverage and completeness
- Clarity and organization
- Correctness (logical, computational, technical, grammatical)
- Findings/conclusions and lessons learned
- Neatness and professionalism

The overall grade for the project will be determined as follows:

- Project Proposal 5%
- Draft Paper 10%
- Presentation 30%
- Final Paper 55%

EXAMS

TL 787
Mid-Term Exam
Due: March 11, 2016

1. (10 points) Describe the four main types of operating environments and how they affect transit speed, capacity, and reliability.

2. [1]Operating speed on an 8-km-long line is V_o = 16 km/hr. The headway is 12 minutes, and terminal time at each end is 6 minutes. Bus preferential treatments are being considered to improve the operation, but they would require a certain level of investment. The transit operator will make the investment if it can reduce the number of buses by one due to these improvements.
   a. (10 points) What is the current number of buses needed for this bus line?
   b. (10 points) What is the minimum operating speed that would allow saving one bus, assuming the headway remains at 12 minutes?

3. (10 points) Summarize the factors influencing transit ridership.

4. (10 points) Describe how elasticities and mode choice models can be used to predict changes in ridership following changes in service characteristics or external factors.

5. (7 points) Availability and Comfort and Convenience are the two important aspects in the transit trip decision making process. What are the key performance measures that are available in each aspect to evaluate the quality of service for fixed-route service and demand-response service?

6. a. (2.5 points) What is service coverage area?
   b. (2.5 points) What are the values that are generally used for service coverage area for local bus stop and for rapid transit station?
   c. (2.5 points) Explain walk distance based service coverage area and how it is different from air distance based coverage area?
   d. (2.5 points) Explain the various street patterns and how walk distance based service areas varies for each type of street pattern.

7. (8 points) What are various sources of bus delay associated with bus stops? Briefly describe each source of bus delay.

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[1] Source of problem: Vuchic, Vukan R. (2005) *Urban Transit Operations, Planning, and Economics.* Hoboken, New Jersey: John Wiley & Sons, Inc.

8. (25 Points) A bus facility in a non-CBD area of a metropolitan city consists of a series of five bus stops on a straight stretch of the road and is served by five transit routes with a combination peak hour frequency of 35 buses per hour. The straight stretch of the roadway is a three-lane one-way street and all the bus stops are linear and on-line design and located at the near side of an intersection with g/C ratio of 0.5 for all traffic signals. Determine the bus stop capacity for all the bus stops and bus facility capacity for a design failure rate of 7.5%. Illustrate all the steps in the capacity calculation process.

Input Data for 5 bus stops on the bus facility:

	Bus Stops on Bus Facility				
	1	2	3	4	5
Number of loading areas	2	2	1	1	2
Curb-lane volume (veh/h)	350	450	300	400	500
Right-turn volume (v/h)	60	70	45	65	60
Pedestrian volume (v/h)	35	45	50	40	55
Capacity of through movement (C_{th}) (v/h)	900	900	900	900	900
Reentry Delay (seconds)	5	6	3	2	8
Boarding Passengers	8	10	4	5	9
Alighting Passengers	7	6	3	4	10

All the buses that stop in the bus stop are 40-foot low-floor buses (that will facilitate level boarding at bus stop) that have a wide front door (two channel) and a narrow rear door (one channel). Standees are not normally present on the bus. All boarding occurs through the front door and 55% of the passengers use monthly passes which need visual inspection, and the remaining 45% of passengers who purchase single-ride or daily fares should use the farebox with exact change. For percentage of passengers alighting through front door and rear door, use the recommendations provided from the bus capacity methodology in chapter 6 of TCQSM.

Assume coefficient of variation of dwell times (c_v) as 0.6.

Assume the bus door opening and close time as 4 seconds.

Assume a boarding lost time as 3 seconds for bus stops with two loading areas. Also assume buses arrive in platoons at all bus stops.

When any needed data is not given, use the recommended values from Week 7 lecture notes or in the bus capacity methodology section of Chapter 6 in TCQSM 3rd edition (pages 6-60 to 6-85).

TL 787
Final Exam
Due: May 13, 2016

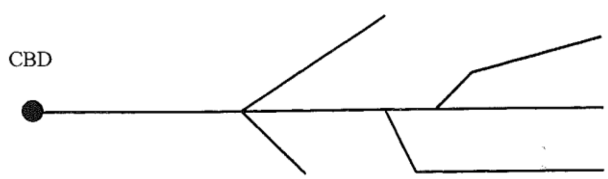
1. (15 points) Discuss demand-response transit capacity issues and the factors you need to examine to determine needed capacity (e.g., number of vehicles and vehicle-hours needed).

2. (15 points) Discuss the differences between ridership and coverage goals, including the reasons for each goal, the tradeoffs, implications for service deployment, and performance measurement.

3. (12 points) Describe the types of errors that can arise when conducting transit surveys and how to minimize each.

4. (13 points) List and describe major factors of transit network design that mostly affect passenger attraction.

5. [1]An urban sector has a transit network consisting of a trunk line and a number of branches, as shown below. This network is served by buses that come from the branches and continue on the trunk to the CBD.



Discuss the advantages and disadvantages of changing the present operation into each one of the following alternatives:

a. (3 points) The same buses, but branches made to terminate at transfer points and the trunk line operate independently.
b. (3 points) The same as (a), but it is possible to obtain different types of buses for different lines; for example, articulated buses for the trunk, regular buses and minibuses for different feeders.
c. (3 points) The same as (a), but introduce a rail system (light rail transit [LRT] or rail rapid transit [RRT]) on the trunk.

(3 points) Which major factors would influence among the selection among the three alternatives?

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[1] Source of problem: Vuchic, Vukan R. (2005) *Urban Transit Operations, Planning, and Economics.* Hoboken, New Jersey: John Wiley & Sons, Inc.

6. (13 points) List and describe the various rail track types. Discuss the construction materials/elements used for each track type, and locations where each track type is commonly used.

7. (20 points) Determine the control system's minimum train separation for both cab signaling system and moving block signaling system for the below situation.

   For a heavy rail transit line, trains are planned to operate at a maximum speed of 65 mi/h and while entering the stations, a speed of 35 mi/h is maintained. Service is provided by ten-car trains with each car being 75 ft long. Consider a slope of 1.5% downgrade into the station and a 1.5% upgrade out of the station. There is no need to consider the effect of line voltage and hence the assume the value of lv as 1 (meaning 100%). For all other variables, use the default values suggested from the TCQSM 3rd Edition Chapter 8.

COURSE EVALUATIONS

TL 787: Public Transportation II

Evaluation of Spring 2016 Semester

TL 787 Public Transportation II was offered for the first time in the Spring 2016 semester. The course was conducted strictly online. Originally 13 students registered, though one dropped within a couple weeks, another dropped shortly thereafter, and a third dropped in the middle of the semester. Among the ten remaining students, seven were actively involved in the class. The three other students took an incomplete for the course. Six of the actively involved students received an A for the course, and the other received a B.

The class schedule closely followed the schedule outlined in the syllabus. The actual schedule of topics and the reference material from which the lectures were derived are shown in the Table below.

Week	Topic	References	Instructor
Jan 11-15	Introduction, Mode and Service Concepts	TCQSM Chapters 2	Jeremy
Jan 18-22	Operations Concepts	TCQSM Chapter 3	Jeremy
Jan 25-29	Transit Operations and Service Scheduling	Vuchic Chapter 1	Jeremy
Feb 1-5	Demand Analysis	Balcombe Chapters 3 & 5, Ceder Chapter 11; TCRP 161	Jeremy
Feb 8-12	Quality of Service: Concepts and Methods	TCQSM Chapters 4, 5	Ranjit
Feb 15-19	Bus Transit Capacity	TCQSM Chapter 6	Ranjit
Feb 22-26	Bus Transit Capacity	TCQSM Chapter 6	Ranjit
Feb 29-Mar 4	Demand Response Transit Capacity	TCQSM Chapter 7	Jeremy
Mar 7-9	Mid-term exam (No lecture)		
Mar 14-18	No Class – NDSU Spring Break		
Mar 21-25	Rail Transit Capacity	TCQSM Chapter 8	Ranjit
Mar 28-Apr 1	Railroad Engineering	AREMA Material	Ranjit
Apr 4-8	Service Planning	Vuchic Chapter 4	Ranjit
Apr 11-15	Transit Service Planning Issues	Walker – Human Transit	Jeremy
Apr 18-22	Transit Financing, Transit Surveys	Innovative Funding Sources for Transit, Kockelman et al., TCRP 63	Jeremy
Apr 25-29	Presentations		
May 2-6	No class		
May 9-13	Final exam, class project due		

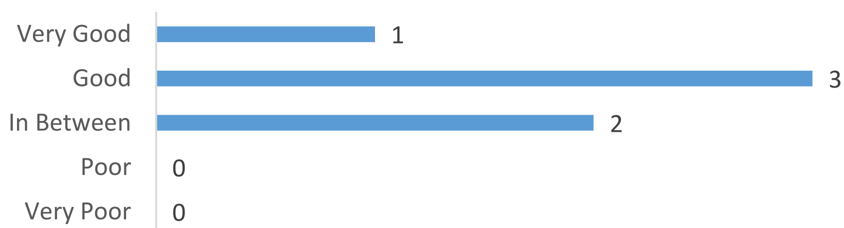
In most weeks, recorded lectures were provided in Blackboard using Tegrity. The length of the recorded lectures each week typically ranged from 1 hour to 1 hour 45 minutes (though they were sometimes broken into more than one part). Two live lectures were conducted. The first was on Railroad Engineering during the week of March 28 – April 1, and the second was on transit service planning issues during the week of April 11-15. The first was conducted on Blackboard using Collaborate and suffered from poor audio. The second was conducted with Adobe Connect and had much better audio, as well as better class attendance. The first live lecture only had three students attend (and only two for the entire lecture), while the second had five students attend.

Students were given eight homework assignments throughout the course of the class, and they typically had 1-2 weeks to complete each assignment. They were given a mid-term exam and final exam, both being take home exams, and a class project that required a final paper and class presentation. The students recorded their presentations using Tegrity. Class participation, which included use of the discussion board, counted for 10% of the final grade.

Student Feedback

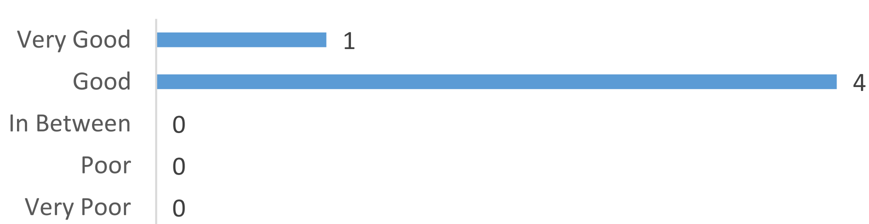
At the end of the semester, students were asked to complete a standard course evaluation. In addition to this evaluation, we provided an additional survey to gather further student feedback regarding the content of the material covered in the class. Six students completed the course evaluation, and three completed the course content survey. Responses to the course evaluation are shown below.

Please rate your satisfaction with the instruction in this course.

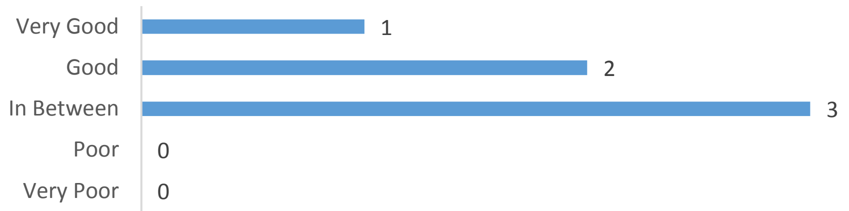


Please rate the instructor as a teacher.

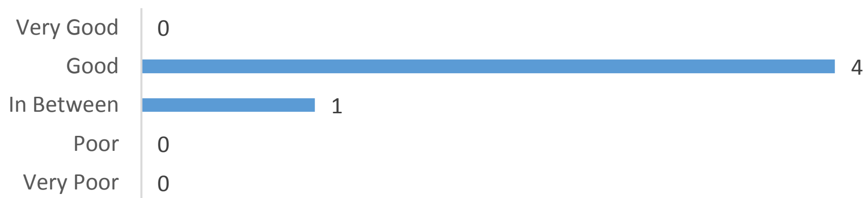
Please rate the ability of the instructor to communicate effectively.



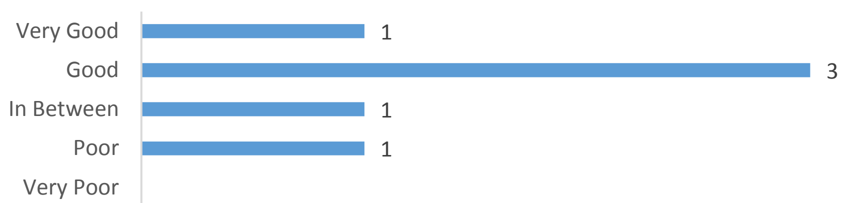
Please rate the quality of this course.



Please rate the fairness of procedures for grading this course.

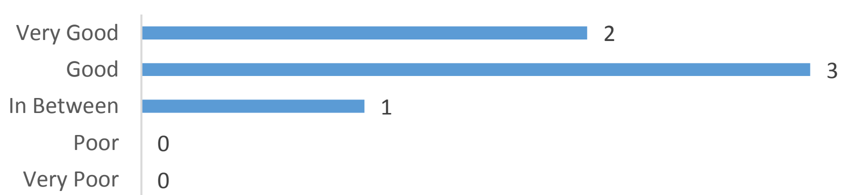


Please rate your understanding of the course content.

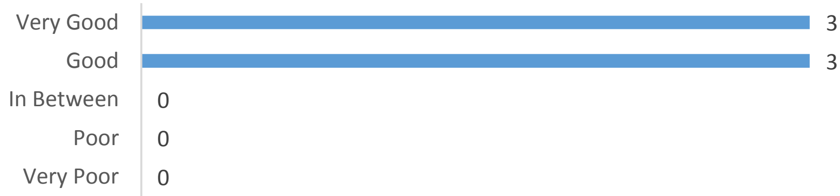


The course objectives were clearly stated.

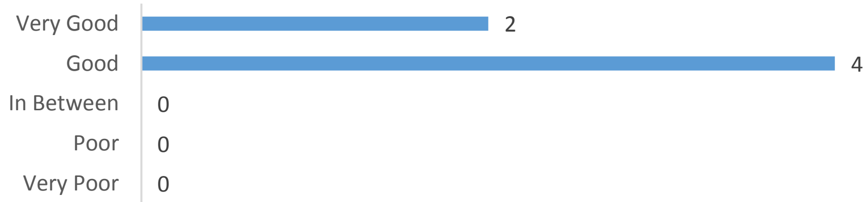
The coursework covered was pertinent to the course objectives.



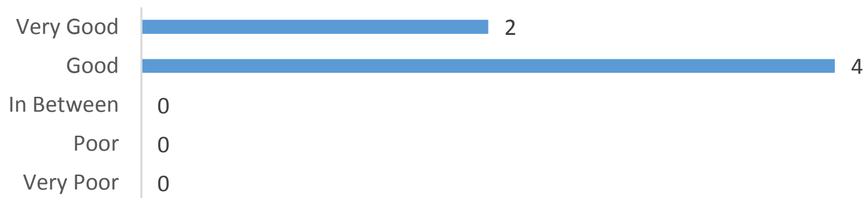
The examinations reflected class materials.



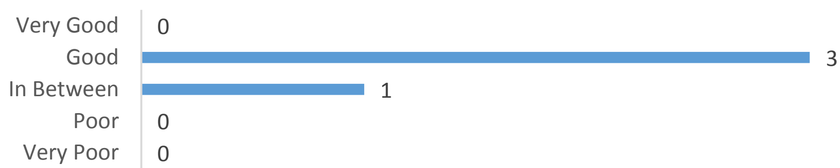
The instructor demonstrated a command of the subject matter.



The instructor presented material at an appropriate intellectual level and was enthusiastic about the subject matter.

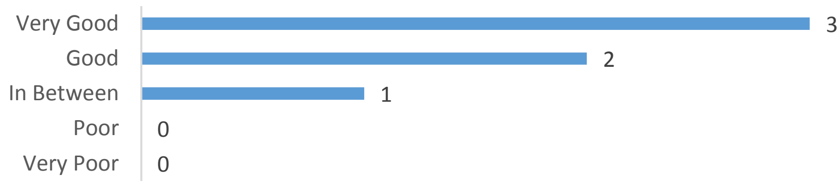


The instructor encouraged students' participation.



The instructor answered questions clearly.

The instructor was available for students.



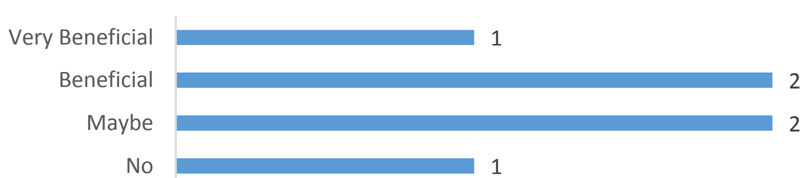
Please list at least ONE outstanding characteristic of this course.

- I liked that the instructors attempted to have live lectures.
- Provided the recorded lectures for future references and reviews for the homework assignments, papers, exams, and such. Provided assistant in a timely manner.
- This course contained significant analytical content that is not present in other courses.
- Tegrity presentations were easily digested.
- The course materials were good and relevant to what i want to know about transportation planning

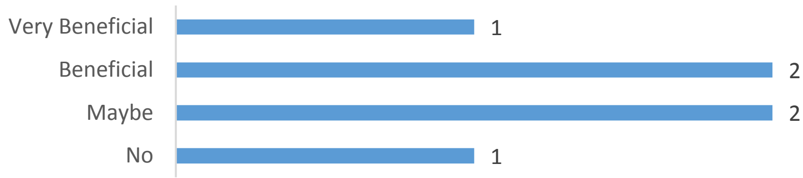
Please list at least ONE aspect about this course that needs improvement and suggest a strategy for improvement.

- Sometimes the technology (Tegrity) seemed to not be working correctly.
- High frequency of the homework assignments that require decent amount of time. Recommend increasing the time of the due dates for the assignments.
- There should be a more content that relates to the theme of the course beyond purely mathematical approaches to public transportation. The course title may need to be changed to reflect an emphasis on engineering analysis and modeling.
- This course has heavy assignments in total, we have final projects, presentation, final exams and homeworks. Some of the homework questions are so difficult that takes too much time. Personally, I think the instructor should balance the homework, projects, and exams with class participations.
- I wish the discussions had the ability to send daily digests or notifications.
- good to me so far

Was this course beneficial to you and your future career moves within the military, Department of Defense, or in the civilian sector.



Was the content of this course relevant to your future positions and the future of military logistics around the world.



Responses to the course content survey are shown below. Only four students completed this survey, and one of the student's responses were not useful.

Which topic(s) covered in this class did you find most beneficial or interesting?

- none
- all the topics
- I found the topics on transit passenger volume analysis calculations and transit planning and investments to be the most beneficial to me.
- Bus Capacity and Demand Analysis

Were there any topics covered in this course that you would have liked to have seen covered in greater detail?

- no
- no
- I think more detail on transit planning topics would have been relevant to this course.
- Transit Operations and Service Scheduling

Were there any topics not covered in this course that you would have liked to have seen covered?

- no
- aviation planning
- I would like to see the more information on transit finances as they relate to real world practices that would have been helpful.
- Use of Advanced Technologies

Which topic(s) covered in this course did you find the least interesting or beneficial?

- no
- none
- It was the least beneficial for me going over the data collection methods, that might be better served in another class.
- Transit Financing

Provide any other comments about the content or structure of the course:

- no
- air transport planning should be introduced
- I think that some participation is helpful in encouraging communication between students.
- Overall, the course was conducted successfully.

Recommendations

Based on the experience of the instructors and student feedback, we developed a number of recommendations for improving the course.

Increase student interaction and use of the discussion board

The discussion board can be used to a greater extent to encourage interaction between students, as well as between students and the instructors. The discussion board was used in the class but was not used very extensively until near the end of the semester. After giving class presentations, students were required to provide comments and questions to other students about their presentation on the discussion board. This proved to be very successful in encouraging interaction between the students. Similar exercises like this should be conducted throughout the semester. Homework assignments could be given that require use of the discussion board.

Conduct more live classes

The recorded lectures work well, but providing live classes allow students the opportunity to interact with the instructor or other students. When polled, most students answered that they were somewhat interested in having live classes, indicating that it may not be most important but they see some benefit to it. Finding a time that most students could attend the class was difficult, as they all had full-time jobs and other commitments, but students who could not attend were able to view a recording of the lecture.

Rearrange the order of topics covered

The lecture near the end of the semester on transit service planning issues was a less technical lecture that would have worked well as more of an introductory lecture earlier in the semester. We should consider if we should do any further rearranging, such as moving service planning from Vuchic up earlier in the semester, though I think the order worked generally well.

Cover service planning more, and possibly demand analysis

We were not able to cover all of chapter 4 from Vuchic on service planning, though I think this is an important topic. We could spend an additional week on this topic and cover the entire chapter. We could also consider adding another week on demand analysis. One student mentioned that the transit planning and demand analysis topics were the most beneficial, and the class could benefit from providing greater coverage of these topics.

Consider adding more material on transit finances and investments

One student recommended additional coverage of transit finances and investments. One brief lecture was given on this topic. This is an important topic, and the class would benefit from covering it in greater detail. Unfortunately, this is a difficult subject to cover and is not an area of expertise for either instructor. However, we can study this issue more and investigate how it could be covered better in the class.

Cut lecture on transit surveys and data collection

While conducting transit surveys and collecting data is important, this topic may not fit as well in this class and could be cut if we plan to extend coverage of other topics. The lecture on railroad engineering could also be cut if needed because some of this material is covered in another course.

Consider renaming course to provide greater detail

One student commented that “the course title may need to be changed to reflect an emphasis on engineering analysis and modeling.” This course is much more analytical and quantitative than the preceding course, TL 786 Public Transportation I. Although the more quantitative nature of the course is noted in the course description, some students may have expected the class to be more like TL 786 and were not expecting the more analytical and quantitative material. The course title could be changed to something more descriptive to ensure more accurate expectations. Alternatively, the course description could be edited to more clearly describe the analytical and quantitative nature. A possible alternative course name would be something like Public Transportation Engineering and Analysis or Public Transportation: Planning, Analysis, and Design. The course title, though, needs to be inclusive of all topics covered, and if we add more material on finances, it may not fit under a new course title such as these.

Evaluate assignments

The workload for the course seems appropriate, compared to other courses in the program, though a couple students did comment on the heavy workload. The workload is heavier than that for some other courses in the program, but other courses in the program have a similar or even greater workload. The workload consisted of eight homework assignments, two take-home exams, and a class project that required a final paper and class presentation. This may be fine, but we could consider alternative approaches, such as fewer homework assignments with more time to work on them but with more questions. The class projects worked well and allowed students to explore different topics and share their work with other students. However, there was somewhat of a disconnect between the class project and the material covered in the class. That’s not necessarily bad, as it broadened the range of topics studied, and the projects were mostly well done, but the class project seemed like it did not fit quite as well with the theme for the rest of the class. Options are to adjust the class project so that it focuses more on the topics covered in class, drop the class project and increase the workload for other assignments, or keep it as is.