CAPACITY, LEVEL OF SERVICE, FUNDAMENTALS OF HIGHWAY CAPACITY ANALYSIS

1. GENERAL

Transportation facilities can be classified into two categories of flow: **uninterrupted and interrupted.**

Uninterrupted-flow facilities have no fixed elements, such as traffic signals, that are external to the traffic stream and might interrupt the traffic flow. Traffic flow conditions result from the interactions among vehicles in the traffic stream and between vehicles and the geometric and environmental characteristics of the roadway.

Interrupted-flow facilities have controlled and uncontrolled access points that can interrupt the traffic flow. These access points include traffic signals, stop signs, yield signs, and other types of control that stop traffic periodically (or slow it significantly), irrespective of the amount of traffic.

Uninterrupted and interrupted flows describe the type of facility, not the quality of the traffic flow at any given time.

Freeways (dálnice) and their components operate under the purest form of uninterrupted flow.

Multilane highways (silnice) and two-lane highways also can operate under uninterrupted flow in long segments between points of fixed interruption (intersections). On these types of communications, it is often necessary to examine points of fixed interruption as well as uninterrupted-flow segments. The analysis of interrupted-flow facilities must account for (doložit, vysvětlit) the impact of fixed interruptions. A traffic signal, for example, limits the time available to various movements in an intersection. Capacity is limited not only by the physical space but by the time available for movements. Transit, pedestrian, and bicycle flows generally are considered to be interrupted.

Capacity analysis defined ability of facilities over a range of defined operational conditions. It provides tools to assess facilities and to plan and design improved facilities.

A principal objective of capacity analysis is to estimate the maximum number of persons or vehicles that a facility can accommodate with reasonable safety during a specified time period. However, facilities generally operate poorly at or near capacity; they are rarely planned to operate in this range. Accordingly, capacity analysis also estimates the maximum amount of traffic that a facility can accommodate while maintaining its prescribed level of operation.

Operational criteria are defined by introducing the concept of level of service. Ranges of operating conditions are defined for each type of facility and are related to the amount of traffic that can be accommodated at each service level.

2. DEFINITION, GLOSSARY

Base condition - The best possible characteristic in terms of capacity for a given type of transportation facility; that is, further improvements would not increase capacity; a condition without hindrances or delays.

Bicycle facility - A road, path, or way specifically designated for bicycle travel, whether exclusively or with other vehicles or pedestrians.

Capacity - The maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour.

Demand - The number of users desiring service on the highway system, usually expressed as vehicles per hour or passenger cars per hour.

Demand to capacity ratio - The ratio of demand flow rate to capacity for a traffic facility.

Density - The number of vehicles on a roadway segment averaged over space, usually expressed as vehicles per km or vehicles per km per lane.

Facility - A length of highway composed of connected sections, segments, and points.

Flow rate - The equivalent hourly rate at which vehicles, bicycles, or persons pass a point on a lane, roadway, or other trafficway; computed as the number of vehicles, bicycles, or persons passing the point, divided by the time interval (usually less than 1 h) in which they pass; expressed as vehicles, bicycles, or persons per hour.

Flow ratio - The ratio of the actual flow rate to the saturation flow rate for a lane group at an intersection.

Free flow - A flow of traffic unaffected by upstream or downstream conditions.

Free-flow speed - (1) The theoretical speed of traffic, in miles per hour, when density is zero, that is, when no vehicles are present; (2) the average speed of vehicles over an urban street segment without signalized intersections, under conditions of low volume; (3) the average speed of passenger cars over a basic freeway or multilane highway segment under conditions of low volume.

Freeway - A multilane, divided highway with a minimum of two lanes for the exclusive use of traffic in each direction and full control of access without traffic interruption.

Freeway facility - An aggregation of sections comprising basic freeway segments, ramp segments, and weaving segments.

Geometric condition - The spatial characteristics of a facility, including approach grade, the number and width of lanes, lane use, and parking lanes.

Interrupted flow - A category of traffic facilities characterized by traffic signals, stop signs, or other fixed causes of periodic delay or interruption to the traffic stream.

Intersection delay - The total additional travel time experienced by drivers, passengers, or pedestrians as a result of control measures and interaction with other users

of the facility, divided by the volume departing from the corresponding cross section of the facility.

Jam density - The density at which congestion stops all movement of persons or vehicles, usually expressed as vehicles per km per lane or pedestrians per square m.

Mountainous terrain - A combination of horizontal and vertical alignments causing heavy vehicles to operate at crawl speeds for significant distances or at frequent intervals.

Multilane highway - A highway with at least two lanes for the exclusive use of traffic in each direction, with no control or partial control of access, but that may have periodic interruptions to flow at signalized intersections no closer than 3 km

Pedestrian flow rate - The number of pedestrians passing a point per unit of time, usually expressed as pedestrians per 15 min or pedestrians per minute.

Potential capacity - The capacity of a specific movement at a stop-controlled intersection approach, assuming that it is unimpeded by other movements and has exclusive use of a separate lane, in vehicles per hour.

Quality of service - A performance indicator of a traveler's perceived satisfaction with the trip.

Quantity of service - A measure of the utilization of the transportation system.

Roadway characteristic - A geometric characteristic of a street or highway, including the type of facility, number and width of lanes (by direction), shoulder widths and lateral clearances, design speed, and horizontal and vertical alignments.

Rural - An area with widely scattered development and a low density of housing and employment.

Service flow rate - The maximum hourly rate at which vehicles, bicycles, or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a given time period (usually 15 min) under prevailing roadway, traffic, environmental, and control conditions, while maintaining a designated level of service; expressed as vehicles per hour or vehicles per hour per lane.

System level of service - The quality of service provided by the transportation system.

Traffic condition - A characteristic of traffic flow, including distribution of vehicle types in the traffic stream, directional distribution of traffic, lane use distribution of traffic, and type of driver population on a given facility.

Two-lane highway - A roadway with a two-lane cross section, one lane for each direction of flow, on which passing maneuvers must be made in the opposing lane.

Uninterrupted flow - A category of facilities that have no fixed causes of delay or interruption external to the traffic stream; examples include freeways and unsignalized sections of multilane and two-lane rural highways.

Urban - An area typified by high densities of development or concentrations of population, drawing people from several areas within a region.

Volume - The number of persons or vehicles passing a point on a lane, roadway, or other traffic-way during some time interval, often 1 h, expressed in vehicles, bicycles, or persons per hour.

Volume to capacity ratio - The ratio of flow rate to capacity for a transportation facility.

3. CAPACITY, LEVEL OF SERVICE

CAPACITY

Capacity – Maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway in one direction during a given time period under prevailing roadway and traffic conditions.

Prevailing (převládající) roadway, traffic, and control conditions define capacity; these conditions should be reasonably uniform for any section of facility analyzed. Any change in the prevailing conditions changes the capacity of the facility.

LEVEL OF SERVICE

Quality of service requires quantitative measures (rozsah) to characterize operational conditions within a traffic stream. Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Six LOS are defined for each type of facility that has analysis procedures available. Letters designate each level, from A to F, with LOS A representing the best operating conditions and LOS F the worst.

Level A:

Level D:

Level F:

Each level of service represents a range of operating conditions and the driver's perception of those conditions. Safety is not included in the measures that establish service levels.

LOS A describes free-flow operations. Free-flow speeds prevail. Vehicles are almost completely unimpeded in their ability to maneuver within the traffic stream. The effects of incidents or point breakdowns are easily absorbed at this level.

LOS B represents reasonably free flow, and free-flow speeds are maintained. The ability to maneuver within the traffic stream is only slightly restricted, and the general level of physical and psychological comfort provided to drivers is still high. The effects of minor incidents and point breakdowns are still easily absorbed.

LOS C provides for flow with speeds at or near the FFS of the freeway. Freedom to maneuver within the traffic stream is noticeably restricted, and lane changes require more care and vigilance on the part of the driver. Minor incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage.

LOS D is the level at which speeds begin to decline slightly with increasing flows and density begins to increase somewhat more quickly. Freedom to maneuver within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort levels. Even minor incidents can be expected to create queuing, because the traffic stream has little space to absorb disruptions.

At its highest density value, ***LOS E* describes operation at capacity**. Operations at this level are volatile (nestálý), because there are virtually no usable gaps in the traffic stream. Vehicles are closely spaced, leaving little room to maneuver within the traffic stream at higher speeds. Any disruption of the traffic stream, such as vehicles entering from a ramp or a vehicle changing lanes, can establish a disruption wave that propagates throughout the upstream traffic flow. At capacity, the traffic stream has no ability to dissipate even the most minor disruption, and any incident can be expected to produce a serious breakdown with extensive queuing. Maneuverability within the traffic stream is extremely limited, and the level of physical and psychological comfort afforded the driver is poor.

***LOS F* describes breakdowns in vehicular flow**. Such conditions generally exist within queues (fronty) forming behind breakdown points. Breakdowns occur for a number of reasons:

Traffic incidents can cause a temporary reduction in the capacity of a short segment, so that the number of vehicles arriving at the point is greater than the number of vehicles that can move through it.

Points of recurring congestion, such as merge or weaving segments and lane drops, experience very high demand in which the number of vehicles arriving is greater than the number of vehicles discharged.

In forecasting situations, the projected peak-hour (or other) flow rate can exceed the estimated capacity of the location.

SERVICE FLOW RATES

The analytical methods in this manual attempt to establish or predict the maximum flow rate for various facilities at each level of service except for LOS F, for which the flows are unstable or the vehicle delay is high. Thus (čili, tudíž), each facility has five service flow rates, one for each level of service (A through E). For LOS F, it is difficult to predict flow due to stop-and-start conditions.

The service flow rate is the maximum hourly rate at which persons or vehicles Service flow rate defined reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a given period under prevailing roadway, traffic, and control conditions while maintaining a designated level of service.

Note that service flow rates are discrete values, whereas levels of service represent a range of conditions. Because the service flow rates are the maximums for each level of service, they effectively define the flow boundaries between levels of service. Most design or planning efforts typically use service flow rates at LOS C or D, to ensure an acceptable operating service for facility users.

Example service volumes for multilane highways from HCM 2000

FFS (mi/h)	Number of Lanes	Terrain	Service Volumes (veh/h)				
			A	B	C	D	E
60	2	Level	1120	1840	2650	3400	3770
		Rolling	1070	1760	2520	3240	3590
		Mountainous	980	1610	2310	2960	3290
	3	Level	1690	2770	3970	5100	5660
		Rolling	1610	2640	3790	4860	5390
		Mountainous	1470	2410	3460	4450	4930
50	2	Level	940	1540	2220	2910	3430
		Rolling	890	1460	2120	2780	3260
		Mountainous	820	1340	1940	2540	2990
	3	Level	1410	2310	3340	4370	5140
		Rolling	1340	2200	3180	4170	4900
		Mountainous	1230	2010	2910	3810	4480

Example service volumes for basic freeway segments from HCM 2000

	Number of Lanes	FFS (mi/h)	Service Volumes (veh/h) for LOS				
			A	B	C	D	E
Urban	2	63	1230	2030	2930	3840	4560
	3	65	1900	3110	4500	5850	6930
	4	66	2590	4250	6130	7930	9360
	5	68	3320	5430	7820	10,070	11,850
Rural	2	75	1410	2310	3340	4500	5790
	3	75	2110	3460	5010	6750	8680
	4	75	2820	4620	6680	9000	11,580
	5	75	3520	5780	8350	11,250	14,470

FFS - Free-flow speed is the speed of traffic at low volume and low density. It is the speed at which drivers feel comfortable traveling under the physical, environmental, and traffic-control conditions on an uncongested section of multilane highway.

Example service volumes for basic urban communications ČSN 736110

Category	Main traffic precint	LOS (czech – level of traffic quality) / lane		
		C	D	E
MS2 18/8,5/50	8,50 m	1 100	1 300	1 500
MS2p 17/12/50*)	12,00 m	1 100	1 200	1 400
MS4 25/15,5/50**)	15,50 m	1 000	1 200	1 400
MS4dp 33/21,5/50*)	21,50 m	1 000	1 100	1 300
MS6d 35,5/26/50	26,00 m	950	1 000	1 200
MS6dp 39,5/28/50*)	28,00 m	900	1 000	1 100

4. FACTORS AFFECTING CAPACITY AND LOS

BASE CONDITIONS

Base conditions assume (předpokládají) good weather, good pavement conditions, users familiar with the facility, and no impediments (překážky) to traffic flow.

In most capacity analyses, prevailing conditions differ from the base conditions, and computations of capacity, service flow rate, and level of service must include adjustments. Prevailing conditions are generally categorized as roadway, traffic, or control.

ROADWAY CONDITIONS

Roadway conditions include geometric and other elements. In some cases, these influence the capacity of a road; in others, they can affect a performance measure such as speed, but not the capacity or maximum flow rate of the facility.

Roadway factors include the following:

Number of lanes,

The type of facility and its development environment,

Lane widths,

Shoulder widths and lateral clearances,

Design speed,

Horizontal and vertical alignments

Availability of exclusive turn lanes at intersections

The horizontal and vertical alignment of a highway depend on the design speed and the topography of the land on which it is constructed.

In general, the severity (prudkost) of the terrain reduces capacity and service flow rates. This is significant for two-lane rural highways, where the severity of terrain not only can affect the operating capabilities of individual vehicles in the traffic stream, but also can restrict opportunities for passing slow-moving vehicles.

TRAFFIC CONDITIONS

Traffic conditions that influence capacities and service levels include vehicle type and lane or directional distribution.

Vehicle Type:

The entry of heavy vehicles into the traffic stream affects the number of vehicles that can be served. Heavy vehicles are vehicles that have more than four tires touching the pavement.

Heavy vehicles adversely affect traffic in two ways:

- They are larger than passenger cars and occupy more roadway space;
- They have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades.

  (The second impact is more critical. The inability of heavy vehicles to keep pace with passenger cars in many situations creates large gaps in the traffic stream, which are difficult to fill by passing maneuvers)

Heavy vehicles also can affect downgrade operations, particularly when downgrades are steep enough to require operation in a low gear. In these cases, heavy vehicles must operate at speeds slower than passenger cars, forming gaps in the traffic stream.

Trucks cover a wide range of vehicles, from lightly loaded vans and panel trucks to the most heavily loaded coal, timber, and gravel haulers. An individual truck's operational characteristics vary based on the weight of its load and its engine performance.

Directional and Lane Distribution:

Directional distribution is a characteristic of traffic, that volume may be greater in one direction than in the other during any particular hour on a highway.

Directional distribution has a dramatic impact on two-lane rural highway operation, which achieves optimal conditions when the amount of traffic is about the same in each direction. Capacity analysis for multilane highways focuses on a single direction of flow. Nevertheless, each direction of the facility usually is designed to accommodate the peak flow rate in the peak direction. Typically, morning peak traffic occurs in one direction and evening peak traffic occurs in the opposite direction. Lane distribution also is a factor on multilane facilities.

CONTROL CONDITIONS

Control conditions are mainly the traffic controls and regulations in effect for a segment of street or highway, including the type, phasing, and timing of traffic signals; stop signs; lane use and turn controls; and similar measures.

For interrupted-flow facilities, the control of the time for movement of specific traffic flows is critical to capacity, service flow rates, and level of service. The most critical type of control is the traffic signal. The type of control in use, signal phasing, allocation of green time, cycle length, and the relationship with adjacent control measures affect operations.

Stop signs and yield signs also affect capacity, but in a less deterministic way. A traffic signal designates times when each movement is permitted; however, a stop sign at a two-way stop-controlled intersection only designates the right-of-way to the major street. Motorists traveling on the minor street must stop and then find gaps in the major traffic flow to maneuver. The capacity of minor approaches, therefore, depends on traffic conditions on the major street. An all-way stop

control forces drivers to stop and enter the intersection in rotation. Capacity and operational characteristics can vary widely, depending on the traffic demands on the various approaches.

Other types of controls and regulations can affect capacity, service flow rates, and LOS significantly. Restriction of curb parking can increase the number of lanes available on a street or highway. Turn restrictions can eliminate conflicts at intersections, increasing capacity. Lane use controls can allocate roadway space to component movements and can create reversible lanes. One-way street routings can eliminate conflicts between left turns and opposing traffic.

TECHNOLOGY

Emerging transportation technologies, also known as intelligent transportation systems (ITS), will enhance the safety and efficiency of vehicles and roadway systems. ITS strategies aim to increase the safety and performance of roadway facilities. ITS may includes any technology that allows drivers and traffic control system operators to gather and use real-time information to improve vehicle navigation, roadway system control, or both.

Current ITS programs might have the following impacts on specific capacity analyses:

- *For freeway and other uninterrupted-flow highways, ITS might achieve some decrease in headways, which would increase the capacity of these facilities. In addition, even with no decrease in headways, level of service might improve if vehicle guidance systems offered drivers a greater level of comfort than they currently experience in conditions with close spacing between vehicles.*
- *For signal and arterial operations, the major benefits of ITS would be a more efficient allocation of green time and an increase in capacity. ITS features likely will have a less pronounced impact on interrupted flow than on uninterrupted-flow facilities.*
- *At unsignalized intersections, capacity improvements might result if ITS assisted drivers in judging gaps in opposing traffic streams or if it somehow controlled gaps in flow on the major street.*