Modal Capacities and Costs

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US Transit Mode Performance Measures 2013

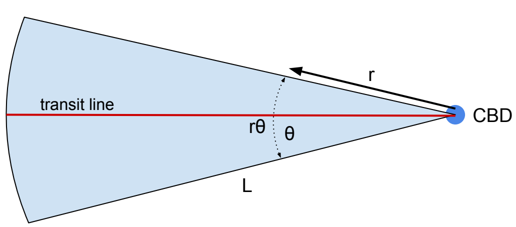
	Bus	Heavy Rail	Light Rail	Commuter Rail	Paratransit
Operating Expenses ($ millions)	20,447.4	8,173.1	1,718.7	5,370.8	5,157.1
Annual Unlinked Passenger Trips (millions)	5,330.0	3,817.0	510.0	480.0	223.0
Annual Passenger Miles (millions)	22,150.0	18,005.0	2,482.0	11,862.0	2,171.0
Annual Revenue Vehicle Miles (RVM) (millions)	2,077.8	654.5	104.0	331.1	1,365.4
Annual Revenue Vehicle Hours (RVH) (millions)	161.1	32.6	7.1	10.2	92.2
Op. Cost/RVH ($)	126.9	250.7	242.1	526.5	55.9
Op. Cost/RVM ($)	9.8	12.5	16.5	16.2	3.8
Op. Cost/Unlinked Pass Trip ($)	3.8	2.1	3.4	11.2	23.1
Op. Cost/Pass Mile ($)	0.9	0.5	0.7	0.5	2.4
Unl. Pass Trips/ RVH	33.1	117.1	71.8	47.1	2.4
Pass Miles/RVH	137.5	552.3	349.6	1162.9	23.5
Mean Trip Length (miles)	4.2	4.7	4.9	24.7	9.7
Mean Pass Load	10.7	27.5	23.9	35.8	1.6
Mean Operating Speed (mph)	12.9	20.1	14.6	32.5	14.8

Source: APTA Fact Book 2015

Simple Capacity Analysis

Question

Given a pie-shaped sector into the CBD served by a single transit line, what will be the peak passenger flow entering the CBD?



Simple Capacity Analysis

Given

P_c = population density at CBD
dP = rate of decrease of population density with distance from CBD
θ = angle served by corridor
r = distance from CBD
L = corridor length
t = number of one-way trips per person per day
c = share of trips inbound to CBD
m = transit market share for CBD-bound trips
p = share of CBD-bound transit trips in peak hour

Then

Population in Corridor = $\int_0^L r\theta\left(P_c - \mathrm{d}Pr\right)\mathrm{d}r$

$$L^2\theta\left(\frac{P_c}{2} - \frac{\mathrm{d}PL}{3}\right)$$

Simple Capacity Analysis

Peak Passenger Flow = $L^2\theta\left(\frac{P_c}{2} - \frac{\mathrm{d}PL}{3}\right)tcmp$

Maximum access distance to transit line = $\frac{L\theta}{2}$

Examples:

P_c	dP	θ	L	t	c	m	p	Required Capacity	Max Access
10,000	800	$2\pi/9$	10	2.5	0.2	0.5	0.25	10,000	3.5
20,000	1,600	$2\pi/9$	10	1.5	0.3	0.8	0.25	30,000	3.5

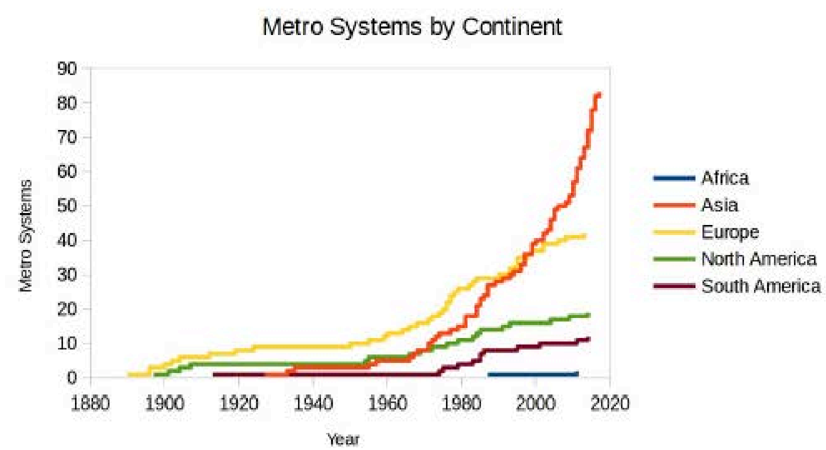
Theoretical Capacities

- Rail
  - 10 car trains
  - 200 pass/car
  - 2-minute headway
  - 60,000 pass/hr
- Bus
  - 70 pass/bus
  - 30-second headways
  - 8,400 pass/hr
- BRT
  - 200 pass/bus
  - 20 second headways
  - 36,000 pass/hr
- Light Rail
  - 2-car trains
  - 150 pass/car
  - 1-minute headway
  - 18,000 pass/hr

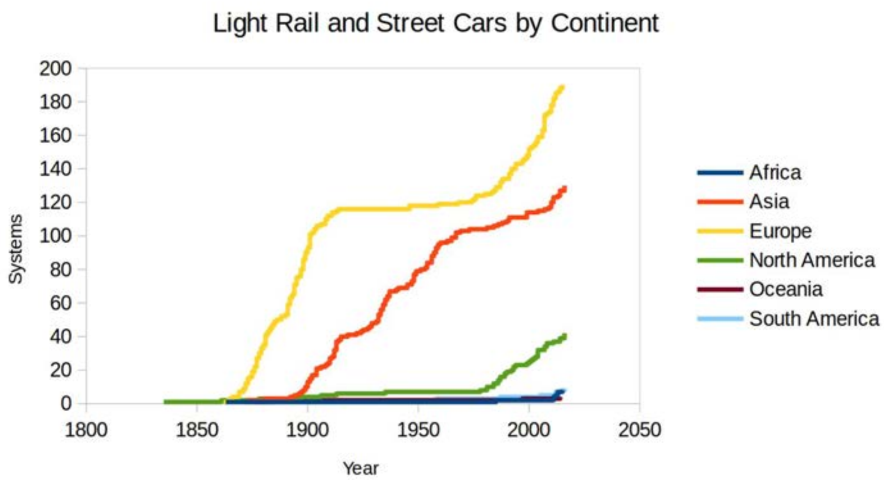
MBTA Rail Lines Peak Hour Volumes

Red Line	Braintree branch	6,700
	Ashmont branch	3,500
	Cambridge	9,700
Orange Line	North	8,300
	Southwest	7,000
Blue Line		6,200
Green Line	B	1,800
	C	1,300
	D	1,800
	E	1,600
	Central Subway	8,000

Worldwide Urban Rail Systems



Worldwide Urban Rail Systems



Capital Costs

In US

- $18.2 billion in capital costs in 2013

By type

- 25% for vehicles
- 59% for infrastructure and facilities
- 16% other

By mode

- 25% for bus projects
- 34% for heavy rail projects
- 17% for commuter rail projects
- 19% for light rail projects
- 5% other (mostly paratransit)

Capital Costs by Type and Mode

	Bus	Heavy Rail	Commuter Rail	Light Rail
Vehicles	52%	10%	17%	7%
Infrastructure, facilities, and other	48%	90%	83%	93%
Total (billion USD)	4.5	6.2	3.0	3.5

- Infrastructure, facilities and systems capital costs dominate for rail modes
- Vehicular capital costs represent about half of all capital costs for non-rail modes

Infrastructure Costs

Key Factors

- Type of construction
  - at grade (least expensive)
  - elevated
  - subway
    - shallow tunnel
    - deep tunnel (most expensive)
- Land acquisition and clearance (relocation)
- Number, size, complexity, and length of stations
- Systems complexity

Typical Capital Costs: Heavy Rail

	System cost (includes stations and vehicles) ($ billion)*	Cost/km ($ million)
Tren Urbano: new system (2002) Phase I: 17 km, 16 stations 50% at grade, 40% elevated, 10% subway	2.0	118
MBTA Red Line Alewife Station Extension (1984) 5 km, 4 stations: 100% subway	0.6	120
LA MTA: new system (late 1980s) 7 km: subway	1.2	180
WMATA: new system (late 1970s-early 1990s) Multiple phases 100 km, 70 stations (partial system) Mix of subway, elevated, and at grade	6.4	60

* Costs are expressed in current USD, not adjusted for inflation
Kain (mid-1990s) estimate of average heavy rail capital costs: $80 million/km

Typical Capital Costs: Light Rail

	System cost (includes stations and vehicles) ($ million)*	Cost/km ($ million)
LA MTA (late 1980s) 30 km, at grade	690	23
Buffalo (late 1980s) 10 km, subway	529	53
Santa Clara (late 1980s) 30 km, at grade	498	16
Portland (mid 1980s) 24 km, at grade	214	9

* Costs are expressed in current USD, not adjusted for inflation
Kain (mid-1990s) estimate of average LRT capital costs: $25 million/km

Typical Capital Costs: Busways

	System cost (includes stations) ($ million)	Cost/km ($ million)
MBTA South Boston Transitway (2002) 2 km, bus tunnel	606 **	303
Bogotá Transmilenio (2001) 36 km, at grade	200	5
Seattle (mid 1980s) 2 km, bus tunnel	319	160
Pittsburgh (mid 1980s) 10 km, at grade	113	11
Houston (early 1980s) 35 km, at grade	290	8

* Costs are expressed in current USD, not adjusted for inflation
** Also includes vehicle cost

Vehicle Capital Costs: Rail

- Generic Cost: $2.0-2.5 million per car
- Recent MBTA orders
  - CNR (2014): $2.0 million per car, 284 cars for Orange and Red Line
  - Siemens (2010): $2.3 million per car, 94 Blue Line cars
  - Hyundai Rotem (2008): $2.3 million per car, 75 commuter rail cars
  - Breda (2004): $2.0 million per car, 95 light rail cars
  - Motive Power (2010): $5.7 million per locomotive, 20 locomotives

Vehicle Capital Costs: Bus

	Generic Cost (million USD)	MBTA Recent Orders
Standard 40 ft. bus (CNG)	0.30-0.35	NABI $0.32 M, 300 vehicles, 2004
Standard 40 ft. trolley	1.0	Neoplan $0.943 M, 28 vehicles, 2004
Articulated 60 ft. bus (CNG)	0.5-0.7	Neoplan $0.614 M, 44 vehicles, 2003
Articulated dual-mode 60 ft. bus		Neoplan $1.6 M, 32 vehicles, 2004

Typical Capital Costs per Passenger Mile

For all modes

- Vehicle cost per passenger mile: $0.05-0.10
- Infrastructure cost per passenger mile: $0.01-1.00

Operating Costs

- In US
  - $42.2 billion in operating costs in 2013
- By type
  - 44% for vehicle operations
  - 16% for vehicle maintenance
  - 11% for non-vehicle maintenance
  - 16% for administration
  - 14% for purchased transportation
- By mode
  - 49% for buses
  - 19% for heavy rail
  - 13% for commuter rail
  - 4% for light rail
  - 12% for paratransit
  - 3% for other modes

Productivity

Employees per Revenue Vehicle (U.S., Industry-wide, 2013)

Paratransit	Bus	Commuter Rail	Heavy Rail	Light Rail	Total
1.6	3.5	4.7	5.5	6.8	2.7

Bus/rail comparison for NYCT (Pushkarev and Zupan in 1970s), employees/veh

	Veh. Ops.	Veh. Maint.	Manage & Control	Fare Coll.	Way Maint.	Total
Bus	2.2	0.8	0.5			3.5
Rail	1.0	0.8	0.8	0.6	1.2	4.4

Metro productivity is 3-4 times bus productivity measured in passenger-miles per revenue vehicle hour.

1.258J / 11.541J Public Transportation Systems
Spring 2017