PUBLIC TRANSPORT
MODAL CAPACITIES AND COSTS

Outline

1. Modal Characteristics (cont'd) -- Simple Capacity Analysis
2. World-Wide Status of Urban Rail Systems
3. Capital Costs
4. Operating Costs

Simple Capacity Analysis

Question: Given a pie-shaped sector corridor serving a CBD served by a single transit line, what will be the peak passenger flow at 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 out from CBD
L	=	corridor length
t	=	number of one-way trips per person per day
c	=	share of trips inbound to CB
m	=	transit market share for CBD-bound trips
p	=	share of CBD-bound transit trips in peak hour

Then:

Population in corridor=

$$\int_0^L r\theta\left(P_c - d\,\mathrm{Pr}\right)dr$$

$$= L^2\theta\left(\frac{P_c}{2} - \frac{dPL}{3}\right)$$

Simple Capacity Analysis

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

Maximum access distance to transit line = $L\theta/2$

Examples:

P_c	dP	θ	L	t	c	m	p	Req. 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: 150 pass/car, 2-car trains, 1-minute headway ≡ **18,000 pass/hr**

MBTA Rail Lines Peak Hour Volumes

Red Line:	**Braintree branch**	**6,100**
	Ashmont branch	**3,700**
	Cambridge	**8,200**
Orange Line:	**North**	**8,100**
	Southwest	**7,400**
Blue Line:		**6,000**
Green Line:	**B**	**2,000**
	C	**1,900**
	D	**2,200**
	E	**900**
	Central Subway	**6,500**

Worldwide Urban Rail Systems

A. Full Heavy Rail Standards

Started system operation	N. America	Europe	Rest of World	Total Starts	Cumulative Starts
Pre 1901	2	4	--	6	6
1901-1920	2	3	1	6	12
1921-1940	--	2	2	4	16
1941-1960	2	6	1	9	25
1961-1980	5	16	10	31	56
1981-2000	4	9	18	31	87
Post-2000 or	1	3	5	9	96
In Construction	1	1	3	5	101
TOTALS	17	44	40	101	

B. Light Rail Systems: total in operation

	N. America	Europe	Rest of World	Total
Total Systems	29	60	16	105

Capital Costs

In US:

- **$14.5 billion in capital costs in 2007**

By type:

- **27% for vehicles**
- **61% for infrastructure and facilities**
- **12% other**

By mode:

- **23% for bus projects**
- **32% for heavy rail projects**
- **17% for commuter rail projects**
- **21% for light rail projects**
- **7% other**

Capital Costs by Type and by Mode

	Bus	Heavy Rail	Commuter Rail	Light Rail	Other
Vehicles	52%	27%	18%	11%	58%
Infrastructure, facilities, and other	48%	83%	82%	89%	42%
Total ($ bill)	3.3	4.7	2.4	3.0	1.1

- 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 in current $, not constant $.*

Kain (mid-1990s) estimate of average heavy rail capital costs: $80 million/km

Typical Capital Costs (cont'd)

LRT:

	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: 22 km, at grade	214	10

* *Costs are in current $, not constant $.*

Kain (mid-1990s) estimate of average LRT capital costs: $25 million/km

Typical Capital Costs (cont'd)

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

* also includes vehicle cost

Vehicle Capital Costs

	Generic Cost	MBTA most recent order
Rail Car (Heavy Rail or LRV)	$1.5-2.5 mill	Breda $1.985 mill 100 vehicles (LRT)
Standard 40’ bus - CNG	$0.3-0.35 mill	NABI $0.31, $0.32 mill 300 vehicles
Standard 40’ trolley	$1 mill	Neoplan $0.943 mill 28 vehicles
Articulated 60’ bus - CNG	$0.5-0.7 mill	Neoplan $0.614 mill 44 vehicles
Articulated dual-mode 60’ bus	---	Neoplan $1.6 mill 32 vehicles

Typical Capital Costs on Per Passenger Mile Basis

Vehicle cost per passenger mile: $0.05-0.10 for all modes

Infrastructure cost per passenger mile: $0.01-1.00

Operating Costs

In US:

- **$33.9 billion in operating costs in 2007**

By type:

- **46% for vehicle operations**
- **18% for vehicle maintenance**
- **9% for non-vehicle maintenance**
- **14% for administration**
- **13% for purchased transportation**

By mode:

- **51% for buses**
- **17% for heavy rail**
- **12% for commuter rail**
- **4% for light rail**
- **13% for paratransit**
- **3% for other modes**

Productivity

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

Paratransit	Bus	Commuter Rail	Heavy Rail	Light Rail	Total
1.4	2.9	4.5	4.9	5.5	2.3

- Bus/rail comparison for NYCT (from Pushkarev and Zupan in 1970s) (employees/vehicle):

	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 average bus productivity measured in pass. miles/RVH

1.258J / 11.541J / ESD.226J Public Transportation Systems

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