1.221J/11.527J/ESD.201J *Transportation Systems*

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LECTURE 5

DISPLAYS

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The Elevator Example

- Elevators are simple compared to some of the more complex transportation systems, but they can be instructive and illustrative.
- With this simple example we can gain insight into overall system behavior that we can apply to more complex systems.

Elevator System

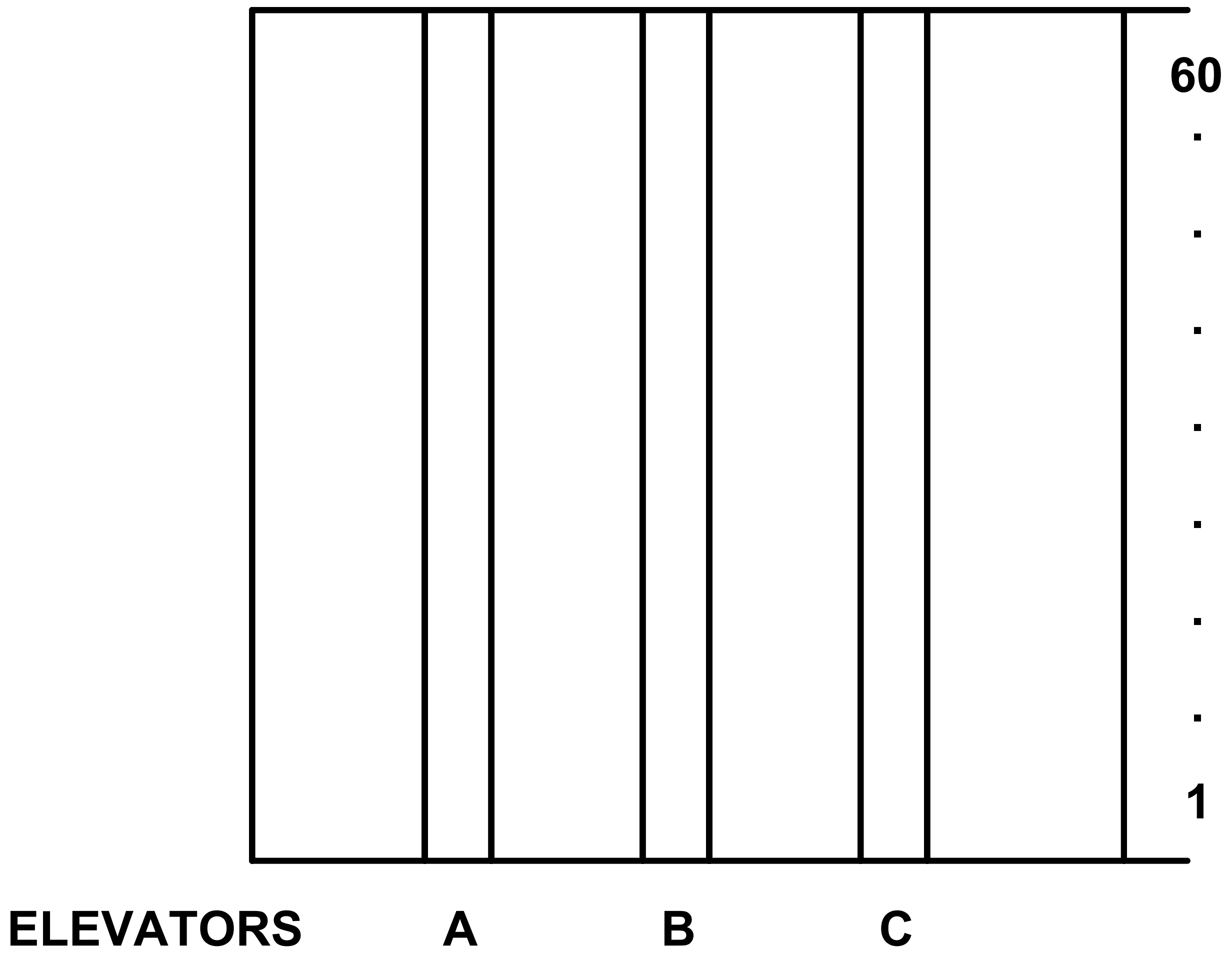


Figure 6.1

Key Point 6: Transfers

Intermodal and intramodal transfers are key determinants of service quality and cost.

Transfers between elements of the transportation system are often inefficient. In the elevator example, a transfer from the walk-mode as one comes into the building, to the elevator-mode, implies some waiting and, hence, some inefficiency.

Key Point 8: Capacity

"Capacity" is a complex, multi-dimensional system characteristic affected by:

- infrastructure
- vehicles
- technology
- labor
- institutional factors
- operating policy
- external factors (e.g., "clean air", safety, regulation)

Key Point 8: Capacity (continued)

In the elevator example,

- We could increase the number of elevators.
- We can also change vehicle technology. For example, we could have larger or faster elevators.
- We could have capacity improvements as a result of control technologies and smarter algorithms for dispatching.

Key Point 9: Supply

Level-of-service = *f* (volume); *Transportation Supply*. As volume approaches capacity, level-of-service deteriorates dramatically -- the "hockey stick" phenomenon.

LOS vs. Volume: The Hockey Stick

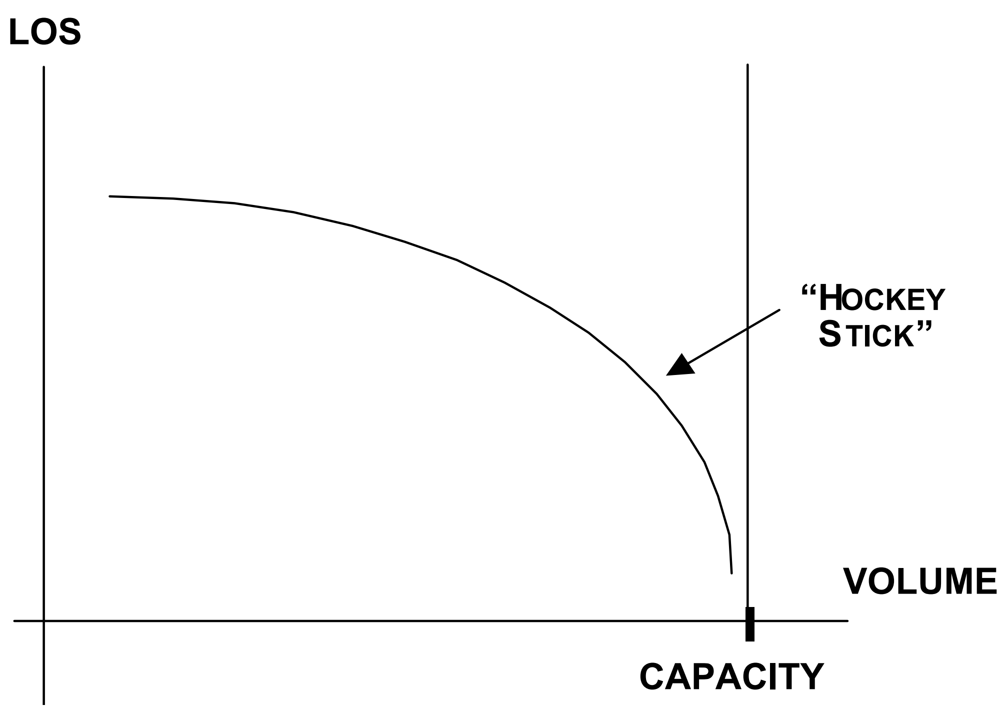


Figure 6.3

Direct Elevator Service

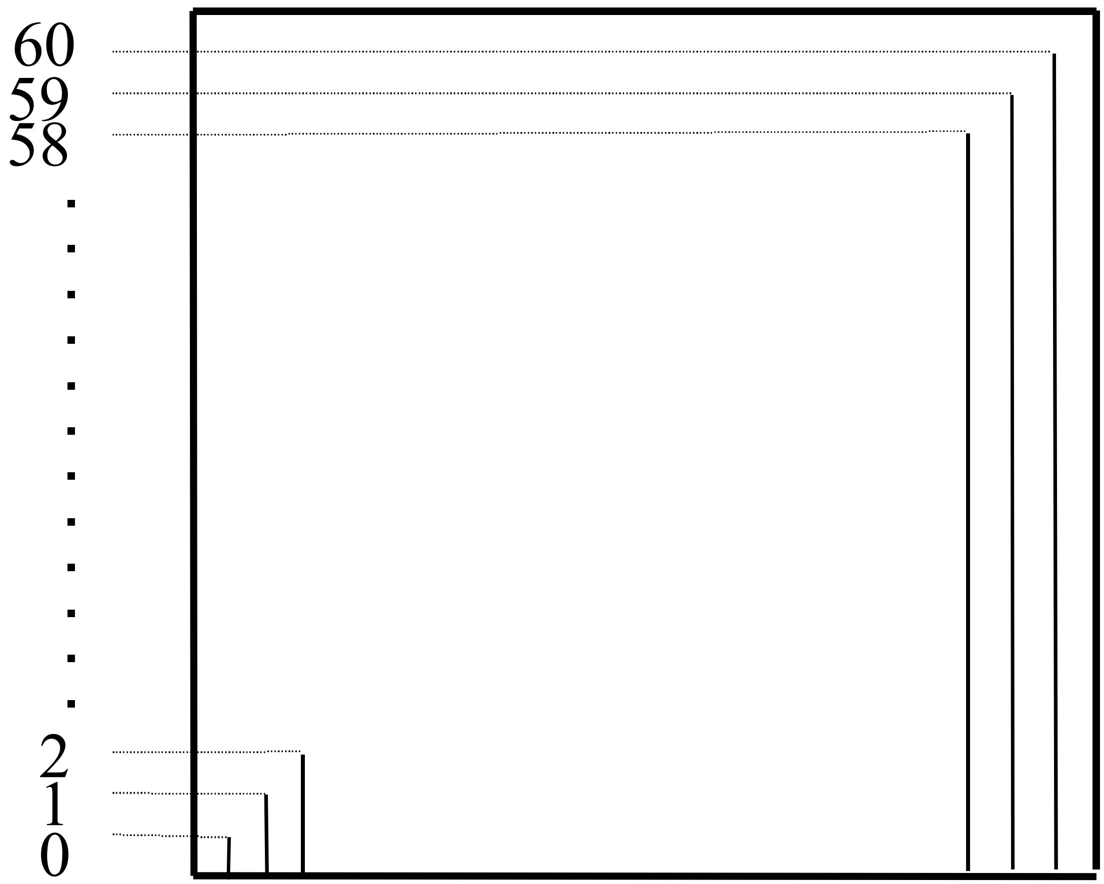


Figure 7.1

Another Elevator Configuration

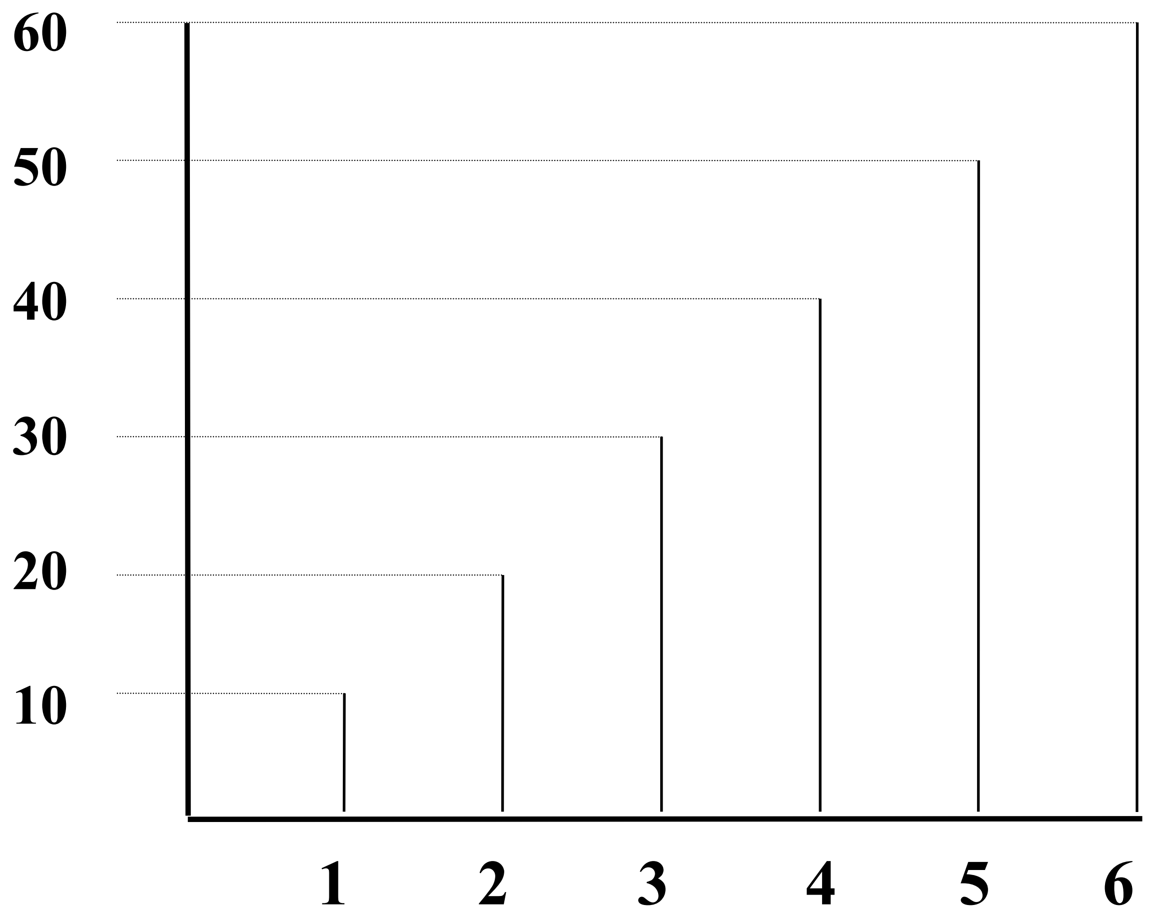


Figure 7.2

What configuration of elevators makes the most sense?

What is the basic trade-off here from the viewpoint of the building owner?

Key Point 11: Infrastructure "Shape"

The "shape" of transportation infrastructure impacts the fabric of "geo-economic" structures.

Key Point 14: Cost/Level-of-Service Trade-offs

Cost/level-of-service trade-offs are a fundamental tension for the transportation provider and for the transportation customer, as well as between them.

Key Point 15: Demand Consolidation

Consolidation of like-demands is often used as a cost-minimizing strategy.

For example, when an airline runs a hub-and-spoke operation, it is consolidating people from different origins who have common destinations into airplanes to lower costs.

Key Point 16: “Lumpy” Investment

Investments in capacity are often lumpy (e.g., infrastructure).

Capacity of
Single vs. Double Track
Rail Line

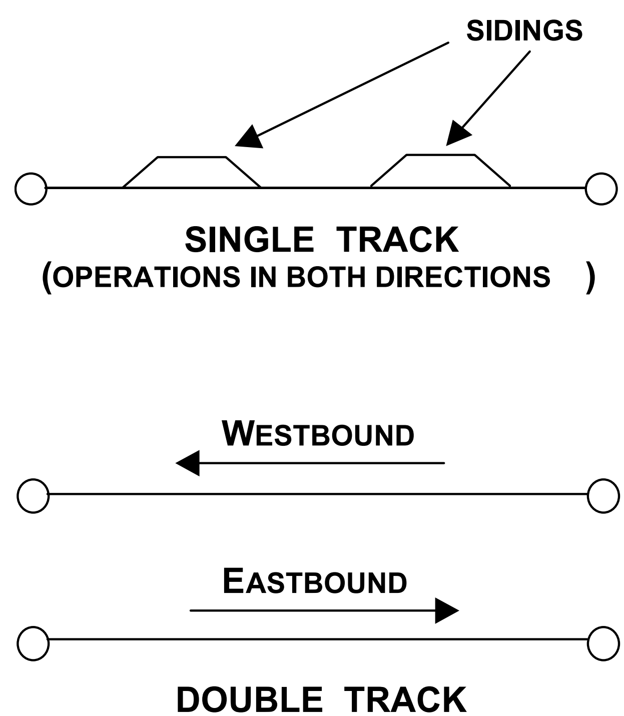


Figure 7.7

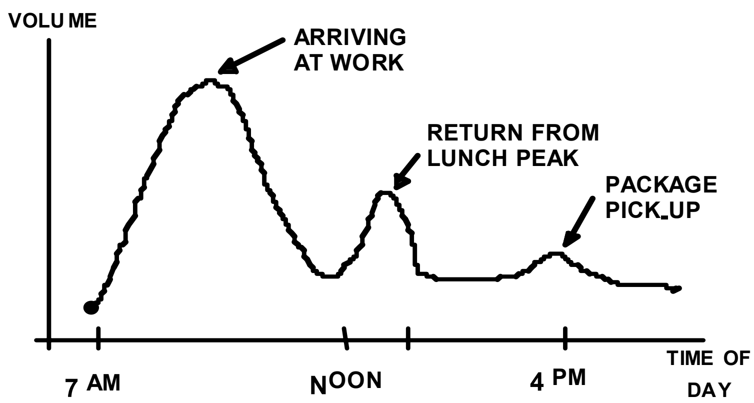
Key Point 17: Capacity, Cost and Level-of-Service

The linkages between capacity, cost and level-of-service -- the lumpiness of investment juxtaposed with the “hockey stick” level-of-service function as volume approaches capacity -- is the central challenge of transportation systems design.

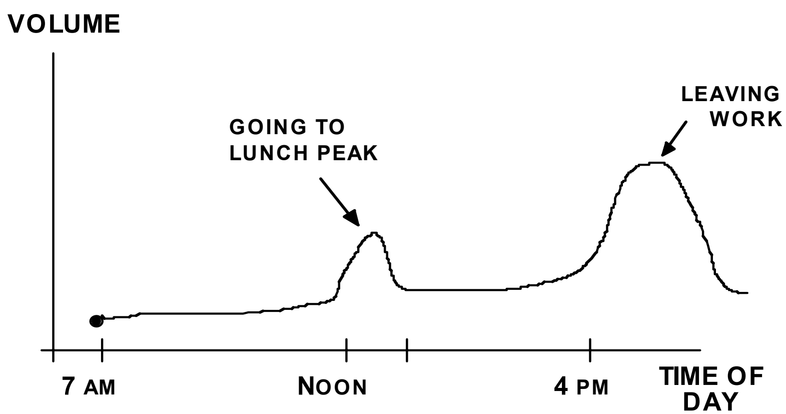
If we underinvest in capacity, our level-of-service may be uncompetitive. If we overinvest, level-of-service may be fine, but costs will be high and our prices may not be competitive. Making this decision, faced with *lumpy investments* and the “hockey stick” LOS/volume relation, is difficult indeed. This leads to the central challenge of transportation system design.

Our Next Concept -- Peaking

Volume vs. Time of Day



UP DIRECTION

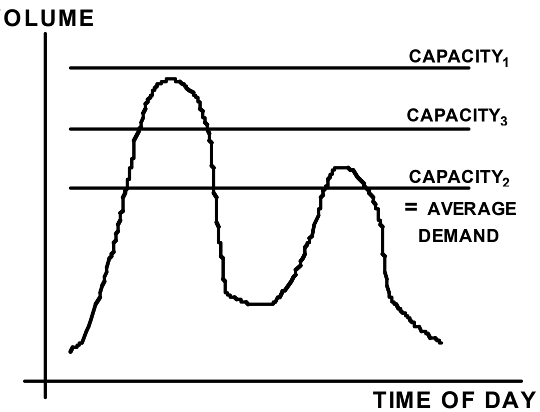


DOWN DIRECTION

Figure 8.1

How much capacity should we provide?

Different Capacity Decisions



So what do we do? We cannot choose such a low capacity that customer levels-of-service during peak periods are unacceptable. At the same time, however, we cannot provide a level-of-service such that nobody ever has to wait
-- it's not economical. So, $capacity_3$ may be a good compromise. The question of design capacity and how we accommodate temporal peaks in demand is Key Point 18.

Figure 8.2

Key Point 18: Peaking

Temporal peaking in demand:
a fundamental issue is design capacity -- how often do we not satisfy demand?

Our Next Concept

- The volume that a transportation service attracts is a function of the level-of-service provided to customers. If the level-of-service deteriorates, less people will want to use the service.
- This is simply a micro-economic concept. For example, if a movie theater doubles its price, therefore making its service less attractive -- in this case, more expensive -- fewer people will go to that movie theater. If a movie theater halves its price, more people will go.

Key Point 19: Volume = f(level-of-service); *Transportation Demand*

Transportation Demand: LOS vs. Volume

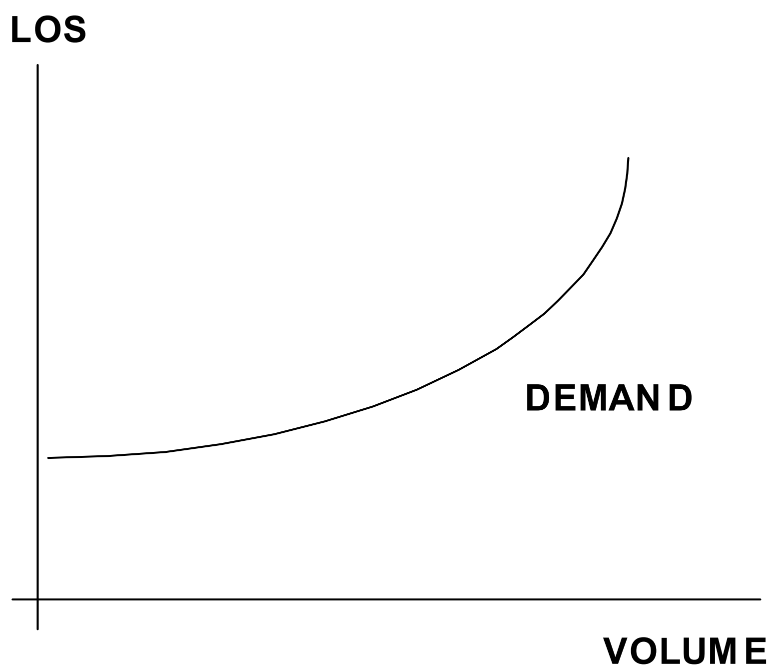


Figure 8.3

Key Point 21: Different Time Scales

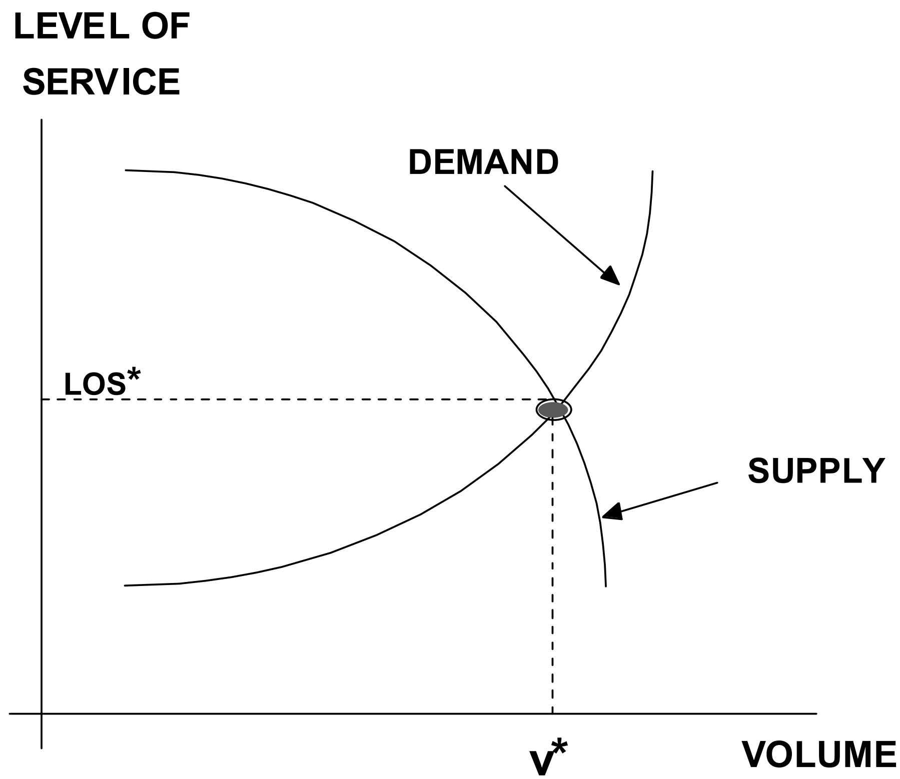
Different transportation system components and relevant external systems operate and change at different time scales, e.g.,

- ◆Short run -- operating policy
- ◆Medium run -- auto ownership
- ◆Long run -- infrastructure, land use.

Equilibrium between Supply and Demand

- Level-of-service is a function of volume. As a facility gets congested, the level-of-service for customers deteriorates, as discussed in Key Point 9.
- But, as level-of-service changes, demand changes as well. Demand increases as level-of-service improves and decreases as level-of-service deteriorates.

Key Point 22: Equilibrium

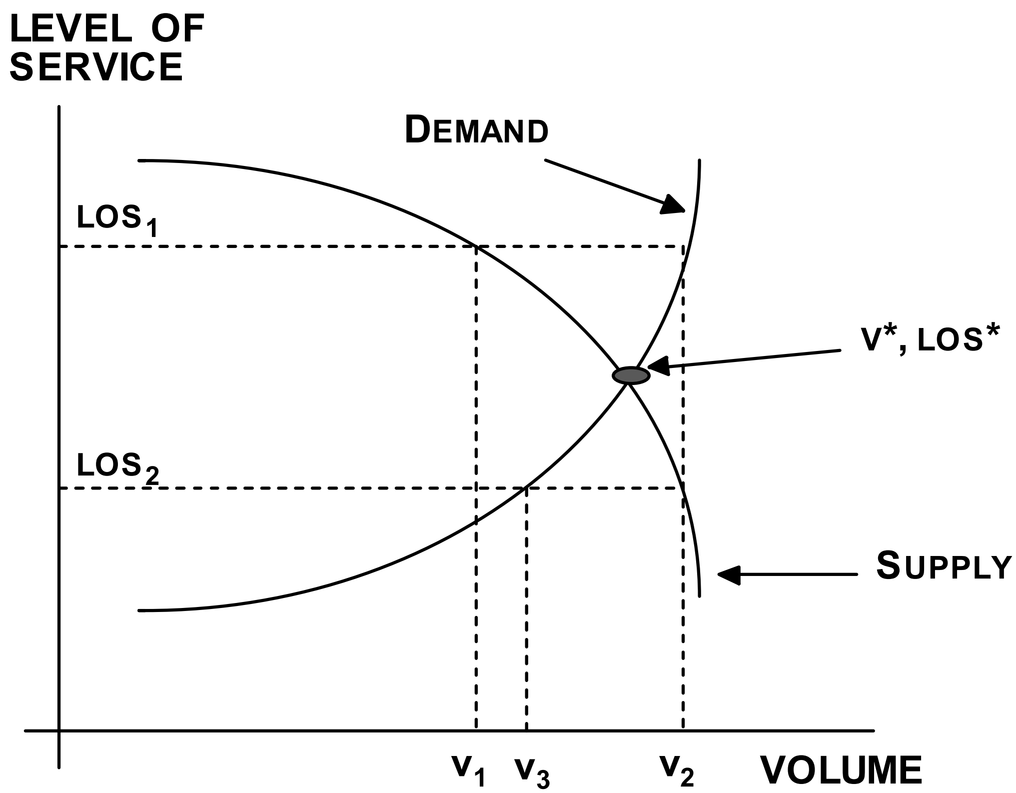


Equilibration of transportation supply and demand for transportation service to predict volume is a fundamental network analysis methodology.

Figure 8.4

The Mechanics of Supply/Demand Equilibrium

Iteration to Find Equilibrium



v_1 -- first guess at volume

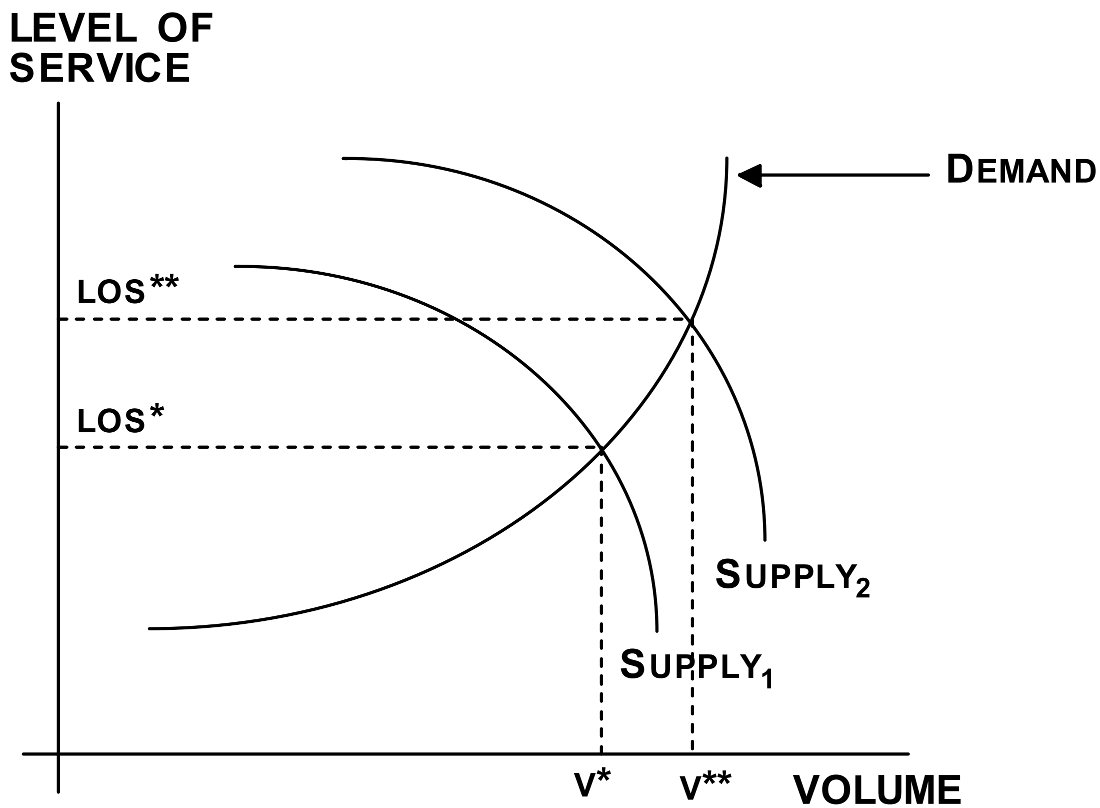
LOS_1 implies demand v_2

v_2 implies LOS_2

LOS_2 implies v_3 , etc., until v*, LOS* are found.

Figure 8.5

Changing Supply



People respond to incentives. If highway transportation becomes cheaper, people buy more.

Figure 8.6

Equilibrium: A Second Look

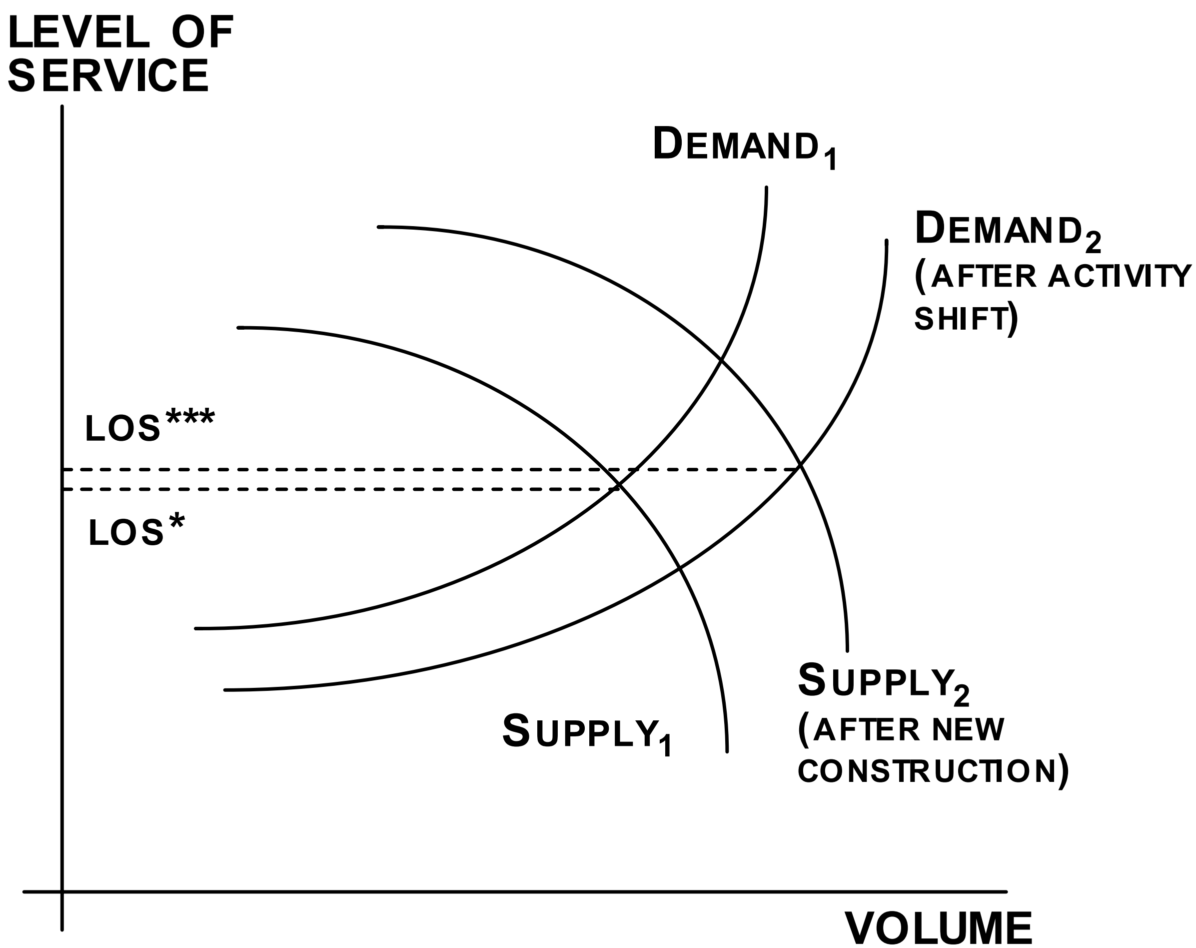


Figure 8.9

Increased Volume: Better or Worse?

- So, at a higher volume, the customers are seeing the same level-of-service. Are we worse or better off than we were before we started?

CLASS DISCUSSION

Key Point 26: Stochasticity

Stochasticity -- in supply and demand -- is characteristic of transportation systems.

Stochasticity

Stochasticity in traffic volume is *different* than peaking.

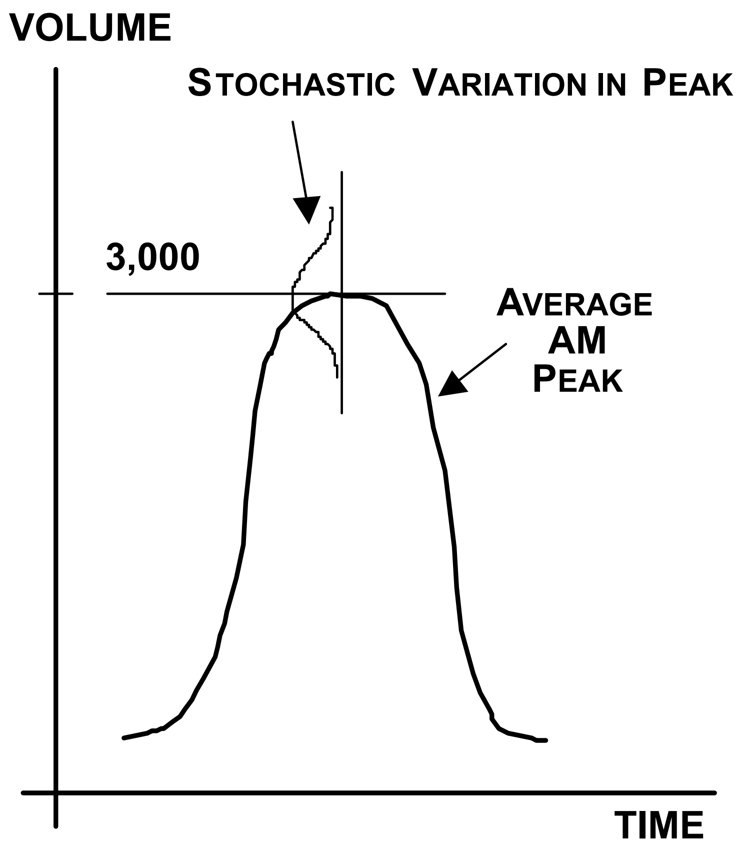


Figure 9.1

Measuring Transportation System Performance

What do your customers perceive?

- *Our ways of measuring performance have to relate to the ways in which our customers make decisions about whether to use us or our competitors*.

Performance Measures and Cost

- A second concept is that performance measures have to relate to costs of operations and revenues derived from operations of those systems.
- The customer cares about system performance (e.g., overall travel time), but
- A third concept: System vs. Component Performance. The operation is often managed on a component basis.
- The hope is, if we do a good job of operating the components, the system as a whole will operate well. Usually, it is a *necessary* condition that component operation be effective for system operation to be effective, but it is very often not a *sufficient* condition. We can have a poorly meshed system in which the components are operating well, but the system performance is still poor.

Key Point 28: Performance Measures

Performance measures shape transportation operations and investment.

CLASS DISCUSSION

Some examples from transportation systems you are familiar with.

Key Points -- Summary (1)

1. People and organizations alter behavior based on transportation service expectations.
2. Transportation service is part of a broader system -- economic, social and political in nature.
3. Competition (or its absence) for customers by operators is a critical determinant of the availability of quality transportation service.
4. Analyzing the flow of vehicles on transportation networks, and defining and measuring their cycle, is a basic element of transportation systems analysis.
5. Queuing for service and for customers and storage for vehicles/freight/travelers, etc., are fundamental elements of transportation systems.

Key Points -- Summary (2)

6. Intermodal and intramodal transfers are key determinants of service quality and cost.
7. Operating policy affects level-of-service.
8. "Capacity" is a complex, multi-dimensional system characteristic affected by:
   - infrastructure
   - vehicles
   - technology
   - labor
   - institutional factors
   - operating policy
   - external factors (e.g., "clean air", safety, regulation)
9. Level-of-service = f(volume); *Transportation Supply*. As volume approaches capacity, level-of-service deteriorates dramatically -- the "hockey stick" phenomenon.
10. The availability of *information* (or the lack) drives system operations and investment and customer choices.

Key Points -- Summary (3)

11. The “shape” of transportation infrastructure impacts the fabric of “geo-economic” structures.
12. The cost of providing a specific service, the price charged for that service, and the level-of-service provided may not be consistent.
13. The computation of cost for providing specific services is complex and often ambiguous.
14. Cost/level-of-service trade-offs are a fundamental tension for the transportation provider and for the transportation customer, as well as between them.
15. Consolidation of like-demands is often used as a cost-minimizing strategy.

Key Points -- Summary (4)

16. Investments in capacity are often lumpy (e.g., infrastructure).
17. The linkages between capacity, cost and level-of-service -- the lumpiness of investment juxtaposed with the "hockey stick" level-of-service function as volume approaches capacity -- is the central challenge of transportation systems design.
18. Temporal peaking in demand: a fundamental issue is design capacity -- how often do we not satisfy demand?
19. Volume = f (level-of-service); *Transportation Demand*.
20. Level-of-service is usually multi-dimensional. For analysis purposes, we often need to reduce it to a single dimension, which we call utility.

Key Points -- Summary (5)

21. Different transportation system components and relevant external systems operate and change at different time scales, e.g.,
    - Short run -- operating policy
    - Medium run -- auto ownership
    - Long run -- infrastructure, land use
22. Equilibration of transportation supply and demand for transportation service to predict volume is a fundamental network analysis methodology.
23. Pricing of transportation services to entice different behavior is a mechanism for lowering the negative externalities caused by transportation users on other users and society-at-large.
24. Geographical and temporal imbalances of flow are characteristic in transportation systems.
25. Network behavior and network capacity, derived from link and node capacities and readjustment of flows on redundant paths, are important elements in transportation systems analysis.

Key Points -- Summary (6)

26. Stochasticity -- in supply and demand -- is characteristic of transportation systems.
27. The relationship among transportation, economic development, and location of activities -- the transportation/land-use connection -- is fundamental.
28. Performance measures shape transportation operations and investment.
29. Balancing centralized control with decisions made by managers of system components (e.g., terminals) is an important operating challenge.
30. The integrality of vehicle/infrastructure/ control systems investment, design and operating decisions is basic to transportation systems design.