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4. Networks

Introduction

2. Transportation Basics made mention of a distribution center as an origin (Mahway NJ) and the customer's address as the destination (Westport CT).[1] Figure 12 Mahway NJ to Westport CT in 2. Transportation Basics on p 10 indicated the route to be followed by the UPS van.

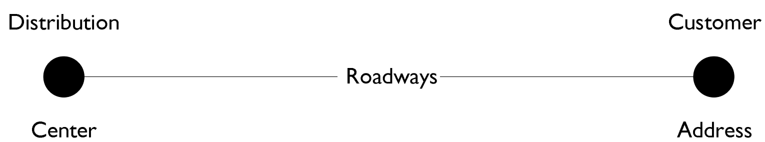

Figure 1 Two Nodes and a Link

In the parlance of networks we have a very simple network comprising two nodes and one link.

There are a number of observations we can make about this simple example.

1. It's doubtful that UPS would have sent the van from Mahwah to Westport with only the single shipment. Thus, when you examine the network in more detail you would likely discover multiple links and nodes. There are hints if this in Figure 15 of 2. Transportation Basics on p 12.
2. Multiple links and nodes imply different speeds on the links and wait (or dwell) times at the nodes. This complicates the issue of provided ETAs (Expected Time of Arrival) to the customers.
3. UPS only makes money when the van is carrying as many shipments as possible and is in motion.
4. There must be some characteristics of Mahwah and Westport that suggests these two points be served by UPS.

Networks, as you might expect, can become extraordinarily complex.

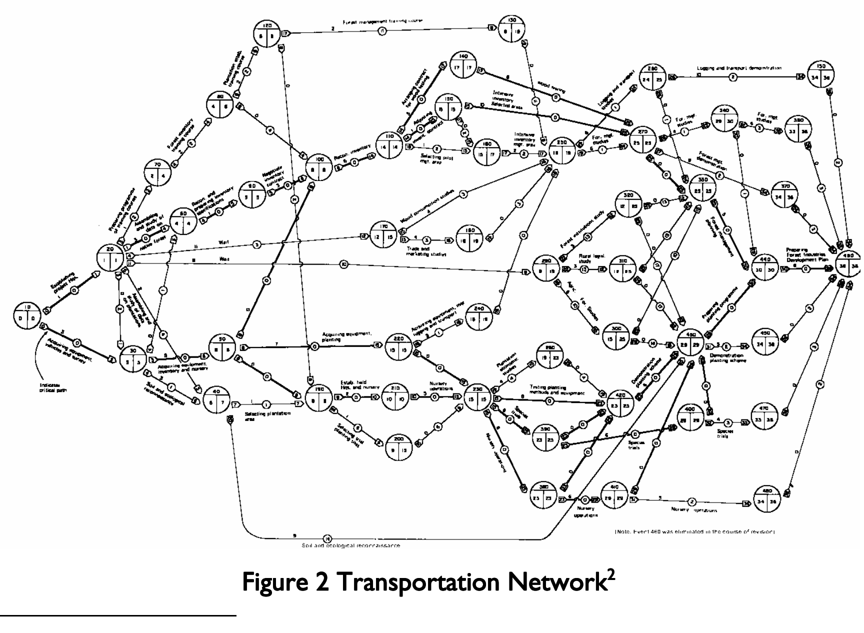

Figure 2 Transportation Network[2]

[1] James Drogan, "2. Transportation Basics," (2007), vol. p 10.

The function of transportation networks is to connect the origins of shipments with the destinations for the shipments. There are multiple origins, destinations, shipments, and paths. There are restrictions as to how paths may be used. For example, shipments of hazardous materials may be banned on a path through a residential area; a path may have a height limitation because of a low bridge; a path may not be able to withstand the weight of a shipment; all origins and destination may not be served by all modes and all paths; paths are dependent upon the mode of transportation and vice-versa.

Services are typically performed at all nodes and all nodes cannot perform all services. For example, a distribution center can transfer a shipment from, say, one truck to another, but it is likely not to transfer a container from a ship to a railroad car.

Congestion forms in the links and the nodes as a function of demand. This then causes further complications to network performance.

Manheim[3] identifies two important basic issues.

1. Each user of the network has a choice of a number of ways through the network. This choice is influenced by the manner in which the user thinks the network will behave.
2. This follows from the first point, users compete for services available in the network. This competition influences network performance.

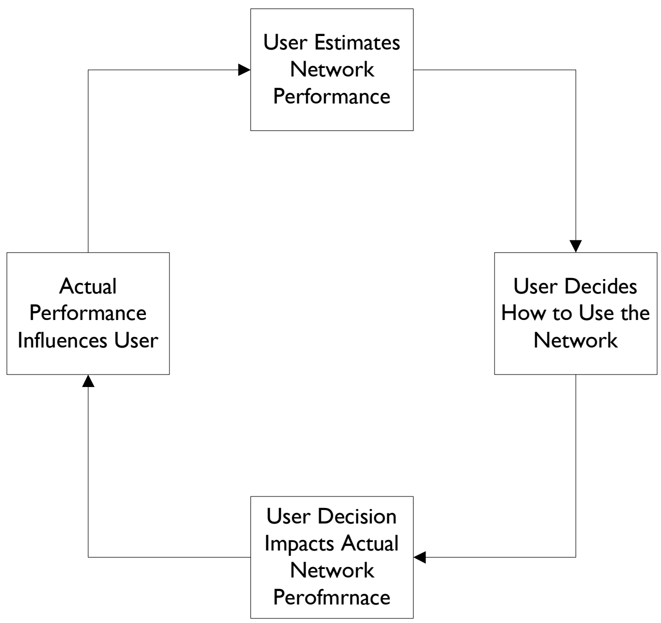

Figure 3 User/Network Influence

Figure 3 can be used to explain the behavior of drivers on a crowded roadway during rush hour, particularly those that change lanes frequently in a vain attempt to wring more performance out of the network than is possible.

This note is not intended to make you an expert in transportation network analysis and design, but rather to acquaint you with the fundamental issues associated with the analysis, design, and operation of transportation networks.

These issues include:

1. Centers of demand for and supply of transportation services.

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2 http://www.fao.org/docrep/a7218e/a7218e03.gif [February 13, 2007]

3 Marvin L. Manheim, Fundamentals of Transportation Systems Analysis, Mit Press Series in Transportation Studies ; 4- (Cambridge, Mass.: MIT Press, 1979). p 466.

2. The nodes, links, and attendant services available from which a network may be built to allow the balancing of demand and supply.
3. The econometric data that allows one to determine the value propositions of various network configurations.
4. The business system necessary to manage the transportation network. Some hint of this has been provided in Figure 11 Transportation Processes and Data on p 9 of 2. Transportation Basics.

Transportation Systems Key Points

Sussman[4] makes 30 key points regarding transportation systems. I provide some additional elaboration for some of these points.

1. People and organizations alter behavior based upon transportation service expectations.

   This point is related to Manheim and to Figure 3 User/Network Influence. In freight transportation, random behavior introduces additional costs in the network that none of the principal parties (shippers, carriers, and consignees) want. Therefore, substantial cooperation between the parties is to be sought in minimizing unpredictable behavior.

2. Transportation service is part of a broader system – economic, social, and political in nature.

   This was taken up in chapter 1 of Coyle[5] and we will return to this issue several times during the course. It's very tempting, and wrong-headed, to isolate transportation from its context.

   This diagram is intended to remind you of the context for transportation.

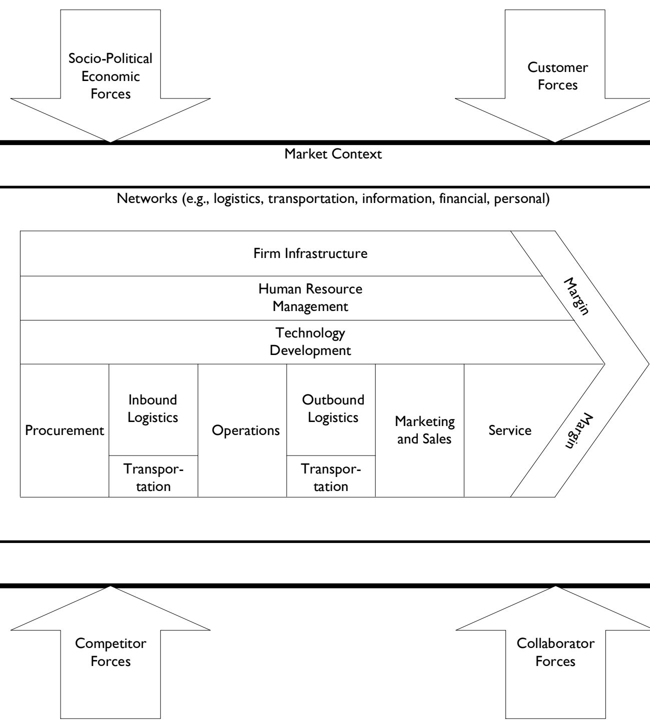

Figure 4 Context of Interest[6]

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[4] Joseph M. Sussman, Introduction to Transportation Systems, Artech House Its Library (Boston: Artech House, 2000). This book is a nice addition to one's library.

[5] John J. Coyle, Edward J. Bardi and Robert A. Novack, Transportation, 6e, Sixth ed. (Thomson Southwestern, 2006).

3. Competition (or its absence) for customers by operators is a critical determinant of the availability of quality transportation service.

   Transportation is subject to marketing forces just like any other service. Where there is little competition, there is little incentive to meet customer wants and needs with continuing improvements in quality and price/performance.[7]

   A great example of the importance of competition can be found in examining the change in quality and price/performance in the US transportation before and after deregulation in the late 1980s.

   This is not to argue that competition is always necessary or desirable. For example, in developing countries, the best strategy to support development (and this is related to Sussman's second point) is no competition and constructive government regulation.

4. Analyzing the flow of vehicles on transportation networks, and defining and measuring their cycle, is a basic element of transportation systems analysis.

   This is also critical to making day-to-day operational decisions. This being true, then there should be some level of equivalence between the data gathered to perform transportation system analysis and the data need to manage the transportation system.

5. Queuing for service and for customers and storage for vehicles/freight/travelers are fundamental elements of transportation systems.

   Queuing results in the build-up of inventory, whether this is people or products. Inventory is not necessarily a bad thing, but it can become, if not managed, a bad thing.

					$B
Carrying Costs - $ 1.444 Trillion All Business Inventory					
	Interest				23
	Taxes, Obsolescence, Depreciation, Insuranc				197
	Warehousing				78
				Subtotal	298
Transportation Costs					
	Motor Carriers:				
	Truck - Intercity				300
	Truck - Local				162
				Subtotal	462
	Other Carriers:				
	Railroads				37
	Water (International 21 Domestic 6)				27
	Oil Pipelines				9
	Air (International 7 Domestic 20)				27
	Forwarders				9
				Subtotal	109
Shipper Related Costs					6
Logistics Administration					35
				Total Logistics Costs	910

Figure 5 Total Logistics Costs[8]

[6] The core of this diagram is adapted from Michel E. Porter, Competitive Advantage: Creating and Sustaining Superior Performance (The Free Press, 1985).

[7] Some additional words are in order regarding the phrase "continuing improvements in quality and price/performance." With respect to quality we mean meeting the customer's service requirements (see Figure 5 Transportation Buying Behavior (circa 1994) on p 3 of 2., Transportation Basics). The word "improvements" suggests a rising number. Well, in "price/performance" we clearly don't want a rising number, but a declining number. That is, one should write "performance/price" in order to be consistent. However, no one writes or says "performance/price." We have learning to live with the inconsistency.

In Figure 5 Total Logistics Costs we see that the costs associated with having inventory in the logistics channel was $298B, a fairly large number.[9] Anything that can be done to accelerate the movement of inventory (which is why one mode may be chosen over another) is, in general, good.

While there may be good business reasons for queuing, oft times queuing results from poor transportation system design and operation.

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

    In 3. Modal Consideration we examined the different characteristics of the transportation modes. In many instances, for example global intermodal freight transportation, two or more modes may be used in order to meet the customer service requirements at the lowest possible costs. The handoff of the goods and information from one mode to another is an opportunity for disruption in the overall service. This issue needs to be tended to.

    You may recall that Single Carrier Service was one of the key buying behaviors mentioned in 2. Transportation Basics (p 3).

7. Operating policy affects level of service.

    This should really come as no surprise.

    There are more commuter trains during rush hours than during the middle of the day or late at night. This is policy,

    Our expectations of service (just look at the people staring into the subway tunnel) are different depending upon the policy.

    This was also a matter we took up in 2. Transportation Basics (p 5).

8. Capacity is a complex system characteristic affected by: infrastructure, vehicles, technology, labor, institutional factors, operating policy, external factors (e.g., clean air, safety, regulation).

    Sussman published his book in 2000. The events of 9/11 have substantially added to the complexity of transportation systems analysis, design, and operations.[10]
    Socio-political-economic forces factor into our transportation decisions in new, powerful, and uncertain ways.

9. Level-of-service = f(volume); transportation supply. As volume approaches capacity, level-of-service deteriorates dramatically – the "hockey stick" phenomenon.

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[8] 14th Annual State Of Logistics Report, Cass Information Systems and ProLogis, June 2003; World Trade Organization; World Bank

[9] We will discuss logistics in some detail later in this course.

[10] Yossi Sheffi, "Supply Chain Management under the Threat of International Terrorism," The International Journal of Logistics Management 12.2 (2001).

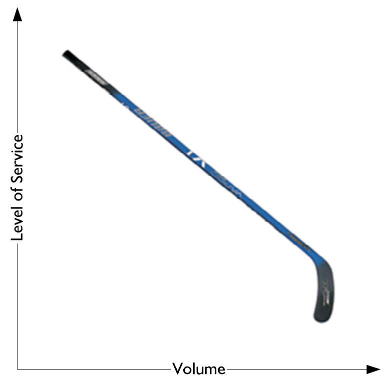

Figure 6 The Hockey Stick Effect

The hockey stick effect can occur anywhere in the transportation system. When it does, its effects tend to ripple upstream and downstream in the transportation network, causing discontinuities requiring a substantial amount of effort to resolve.

10. The availability of information (or lack thereof) drives system operation and investment and customer choices.

    This is perhaps THE (emphasis intended) major issue associated with transportation management.

    Service demand and the subsequent responses of transportation system analysis, design, and operation are dependent upon the availability of information. For example,

Figure 7 Vehicle Message Sign[11]

    Figure 7 represents real-time information to the customer, affecting the way in which the transportation network will be used.

    Information needs should not be decided on an *ad hoc* basis. Three critical questions are involved.

    a. What business decisions must be made and why?

    b. How should these decisions be made and why?

    c. What is the source of the data to support the decisions?

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

[11] http://www.dot.ca.gov/dist3/departments/mtce/graphics/sign.jpg [February 20, 2007]

This is perhaps best brought out when we examine the history of commerce and transportation. First, the waterways, then the roadway, then the railways were used to extend the reach and range of the activities of commerce.

My sense is that the promise of economies in remote geographies called for the development of transportation to reach these geographies and attain the economies. Transportation changed the geography (flattened the mountains, bridged the rivers) thereby opening up the promise of even more economies requiring more transportation – the virtuous cycle.[12]

There are vast expanse in Asia and Africa where this is likely to continue to happen.

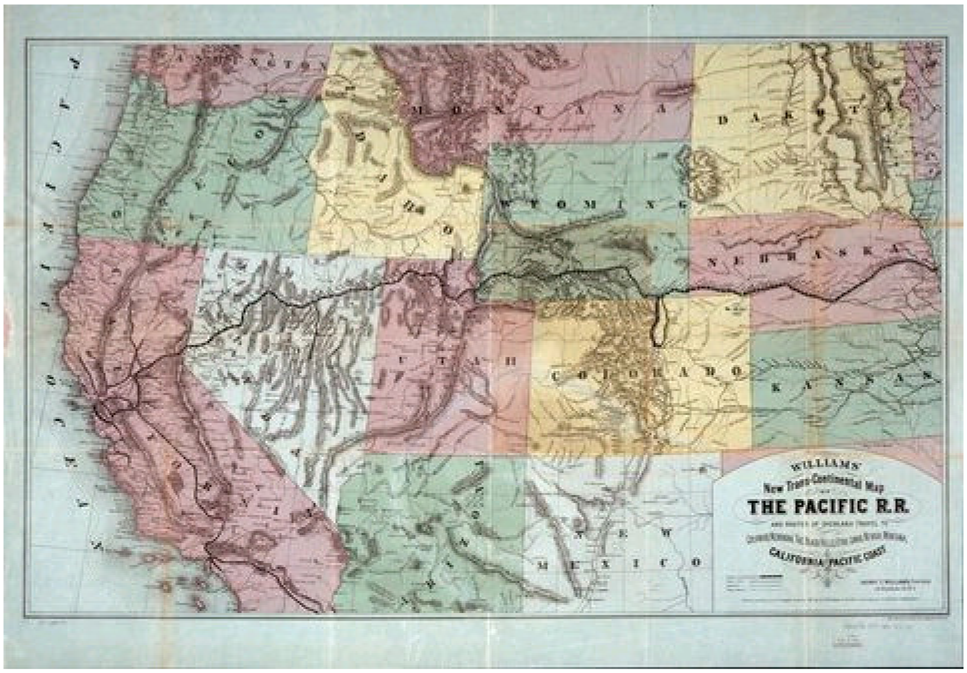

Figure 8 Map, "Williams' New Trans-Continental Map of the Pacific R.R. and Routes of Overland Travel…," 1877[13]

12. The cost of providing a specific service, the price charged for that service, and the level-of-service provided may not be consistent.

There are two example of this.

Perhaps the most well known is public transportation. For example,

"This bill requires the Maryland Transit Administration (MTA) to continue to recover at least 40% of the operating costs for its bus, light rail, and metro services in the Baltimore region until June 30, 2008 and establish a goal of 50% farebox recovery. Under current law, the mandated operating cost recovery rate will revert to 50% on June 30, 2004. The bill also extends several other reporting and auditing requirements related to transit services."[14]

[12] A condition in which a favorable circumstance or result gives rise to another that subsequently supports the first. Answers.com [February 20, 2007]

[13] http://americanhistory.si.edu/ONTHEMOVE/collection/object_372.html [February 20, 2007]

[14] http://mlis.state.md.us/2004rs/fnotes/bil_0002/sb0282.doc [February 20, 2007]

However, this also finds its way into for-hire transportation where some judge the prices paid are not justified. This has been called the captive shipper phenomenon associated with the railway industry.[15]

13. The computation of cost for providing specific services is complex and often ambiguous.

    This is particularly true in a transportation mode, such as railways, requiring high capital costs. How does on allocate the several billion dollars in costs for railway infrastructure development and maintenance to a particular service?

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.

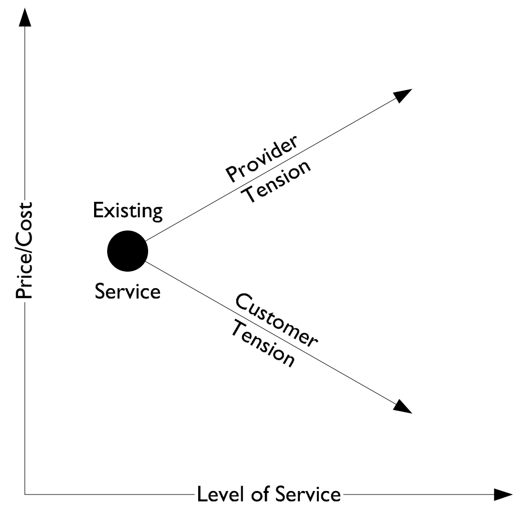

Figure 9 Provider/Customer Tension

    The transportation provider, particularly the for-profit firm, is looking to meet its responsibilities to its investors. The transportation customer, particularly the for-profit firm, is also looking to meet its responsibilities to its investors.

    Resolving these tensions is not simply a mechanical matter. Much depends upon the degree to which there is congruency between the agendas of the parties. For example, if the customer and provider can make changes to their respective business in a mutual effort to reduce costs, then perhaps both parties can win. Toyota is often cited as the model for provider-customer cooperation.[16]

    The traditional zero-sum game in transportation is changing to win-win strategies. This means that the knowledge, skills, and experience required of the participants must also change.

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

    The premier example of this is quite likely ocean container service.

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

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[15] http://www.findarticles.com/p/articles/mi_m1215/is_3_207/ai_n16133573 [February 20, 2007]

[16] Cooperation with Business Partners, https://www.toyota.co.jp/en/environmental_rep/05/download/pdf/so_03.pdf [February 20, 2007]

As implied under Sussman's Key Point 13, investment for a transportation provider can be substantial. For example, Burlington Northern Railroad announced a planned $2.75 billion capital commitment program for 2007.[17]

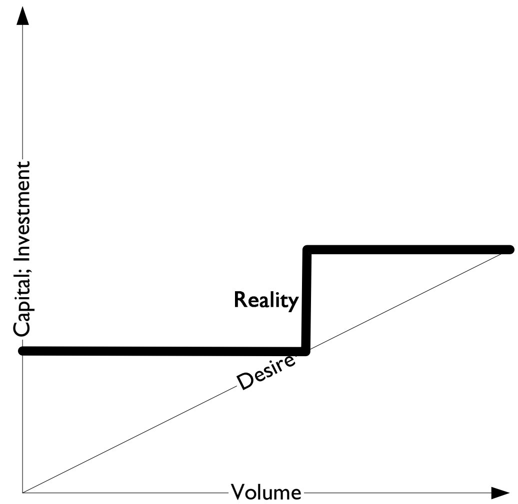

Figure 10 The Lumpiness of Investment

One would like to smoothly ramp up the investment in as a function of demand, but in modes such as railways and container lines (e.g., the Emma Maersk, estimated to carry 15,000 TEUs and cost $145M) capacity must be added in large chunks. This means that there is more risk associated with these large investments.

This is to be contrasted with a trucking company that can add capacity in much smaller increments (see Figure 3.5 on p 105 of Coyle).

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.

    There is also, I think, a timing issue here. In general, demand can change much more rapidly than supply. In fact, one might argue that supply might only go up. One can't easily cut back on supply as demand falls. One might, of course, tie-up ships and railroad cars, but the investments in these assets has been made and depreciation will continue to be carried on the books.

    It is this fluctuation between supply and demand that has given rise to the ship chartering industry.

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

    It is very costly to meet all the demand all the time (e.g., this is why rush hour trains exist). One needs to decide what level of service (e.g., meet 80 percent of the demand) one is willing to provide. Along with this one must decide how to act when the 20 percent of the demand is not being met and customer become dissatisfied. Fundamental to this issue is the question of whom do you choose to serve and why?

[17] http://www.bnsf.com/media/news/articles/2007/01/2007-01-23b.html [February 20, 2007]

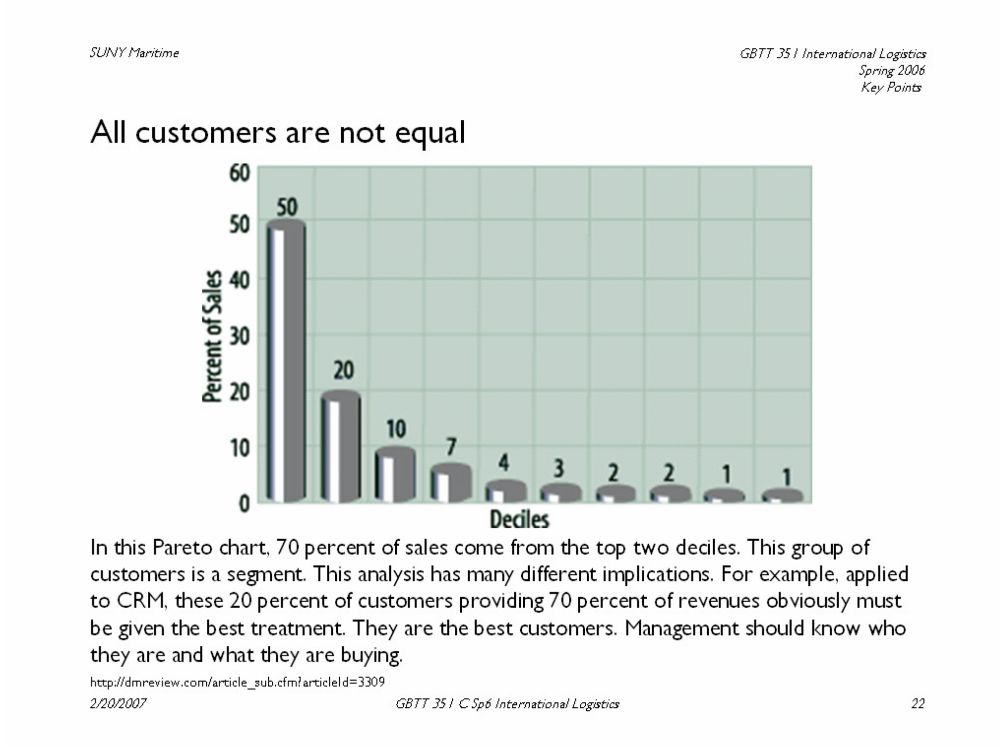

Figure 11 All Customer are Not Equal

In Figure 11, for example, one might chose a strategy that provides levels of service as a function of the decile in which the customer falls. I'm not just talking about demand here, but also the notion of the lifetime value of the customer to the provider.

19. Volume = f(level-of-service); transportation demand.

There is a balance to be wrought here. Review of Figure 3 User/Network Influence on page 2 ought to make this clear.

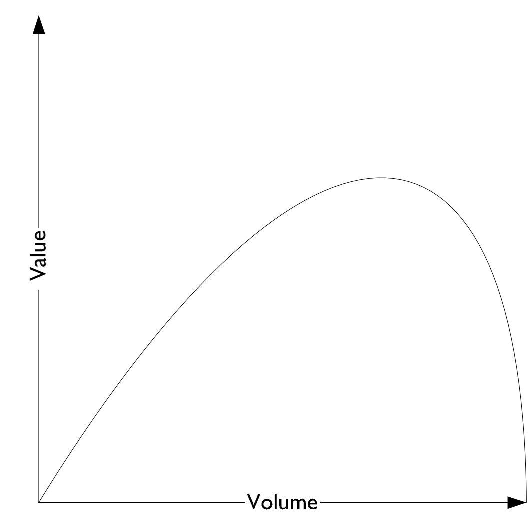

Figure 12 Value versus Volume

There is a point in Figure 12 where providing higher levels of service and attracting more demand will decrease the value of the transportation systems to its owner. Transportation system analysis and design will help find that point to which one manages on a day-to-day basis.

20. Level-of-service is usually multidimensional. For analysis purposes, we often need to reduce it to a single dimension, which we will call utility.

    Sussman refers to the place/time utility to which you were introduced in 2. Transportation Basics. He is suggesting, I think, that not all dimensions of level of service are equally important. The trick is to understand the key aspects of the customer's buying behavior (a topic we took up in 2. Transportation Basics) and use these to illuminate the critical dimensions of the transportation network problem.

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).

    I alluded to this a bit under Sussman's Key Point 16.

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

    See my comment under Sussman's Key Point 19. There is a need to clearly define the objectives one is striving for in the business. Mathematicians would call this defining the objective function. For example, in Figure 12 Value versus Volume on page 10 I have implied that this point may not be where the supply and demand are in balance.

23. Pricing of transportation services to entice different behavior is a mechanism for lowering the negative externalities caused by transportation users on other transportation users and society-at-large.

    Level-of-service pricing (e.g., first class seats on airlines), congestion pricing (e.g., Westport to Grand Central Terminal peak-hour price is $13.54; off-peak is $10.21), HOV (High Occupancy Vehicle) and bus lanes are examples of pricing of the services to change behavior.

    This could, of course, work the other way around. The customer could offer you different volumes if you are willing to charge a different price. The user is intending to induce a different level of behavior from the transportation system.

    This is further inducement to have a clear understanding of the user's buying behavior.

24. Geographical and temporal imbalances of flow are characteristic in transportation systems.

    Ocean shipping container rates are probably the best surrogate for illustrating this point. For example,

    "Base Ocean Rates to Europe in the local market currently have been hovering between US$700-750 per TEU (twenty-foot equivalent), way below rates of US$1,200 - 1,300 per TEU during the heydays of 2004/05 period."[18]

    The reasons for this was lack of demand for service.

25. Network behavior and network capacity, derived from link and node capacities and readjustment of flows on redundant paths, are important elements in transportation system analysis.

    Sussman and I have previously mentioned the relationship between behavior and capacity. The criticality of the key point is also underscored by the difference in modal characteristics. For example, if the Emma Maersk pulls into the Port of New York to unload 15,000 TEUs whose ultimate destination is inland US, then a substantial number of trucks, each hauling a single TEU, will be required to achieve this outcome. And a substantial amount of highway capacity will be required to achieve this outcome.

[18] http://eaglespeak.blogspot.com/2006/07/container-shipping-rates-fall-law-of.html [February 20, 2007]

Indeed, capacity mismatches in the transportation network is one of the more significant issues to be resolved.

26. Stochasticity – in supply and demand – is characteristic of transportation systems.

    Stochasticity is a fancy word for randomness. This means that supply and demand is determined by random behavior. Of course, through pricing (see Sussman's Key Point 23) and an understanding of the context the provider tries to dampen this randomness as much as possible, but it always remains, at least on the supply side or the demand side.

    Randomness leads to the building of queues and inventory which, in turn, means that it becomes more costly to provide the desired service levels.

27. The relationship among transportation, economic development, and location of activities – the transportation/land-use connection – is fundamental.

    This is, in many ways, similar to Sussman's Key Point 11.

28. Performance measures shape transportation operations and investment.

    This is probably evident. Systems respond to expectations and incentives. Management of this response is based upon one's understanding of how the system is behaving and the actions that can be taken to change its behavior. This understanding comes from the performance measures.

    One should keep in mind that "Systems aligned with human motivational factors will sometimes work. Systems opposing such vectors will work poorly or not at all."[19]

29. Balancing centralized control with decisions made by managers of system components (e.g., terminals) is an important operating challenge.

    The transportation network should be considered as complex with decisions being made at the level of individual links and nodes. For example, a state police department may choose to aggressively enforce speed limits on a highway, thereby slowing throughput on that link, resulting in the development of queues elsewhere in the network; or a port terminal might be so congested with containers because of inappropriate decisions regarding resource assignment that movement in and out is severely limited.

    Performance measures (see Sussman Key Point 28) may motivate management to make decisions to improve performance at the local level without consideration of the system impact.

    This operating challenge becomes more daunting when centralized control is impossible because various parties own and operate different parts of the network.

30. The integrality of vehicle/infrastructure/control systems investment, design, and operating decisions is basic to transportation systems design.

    A system is a group of interacting, interrelated, or interdependent elements forming a complex whole.[20]

    For example, the Hales Road Bridge in Westport CT is rated at five tons. Vehicles heavier than five tons must use either the South Compo underpass with a height limitation, or the Hillspoint Road Bridge.

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[19] John Gall, General Systemantics : An Essay on How Systems Work, and Especially How They Fail, Together with the Very First Annotated Compendium of Basic Systems Axioms : A Handbook and Ready Reference for Scientists, Engineers, Laboratory Workers, Administrators, Public Officials, Systems Analysts, Etc., Etc., Etc., and the General Public, 1st ed. (Ann Arbor, Mich.: General Systemantics Press, 1975).

[20] Answers.com [February 21, 2007]

Another example is high and wide loads carried on railways. One of the characteristics of a railway route is called a clearance diagram. Here is a clearance diagram for New Jersey Transit.

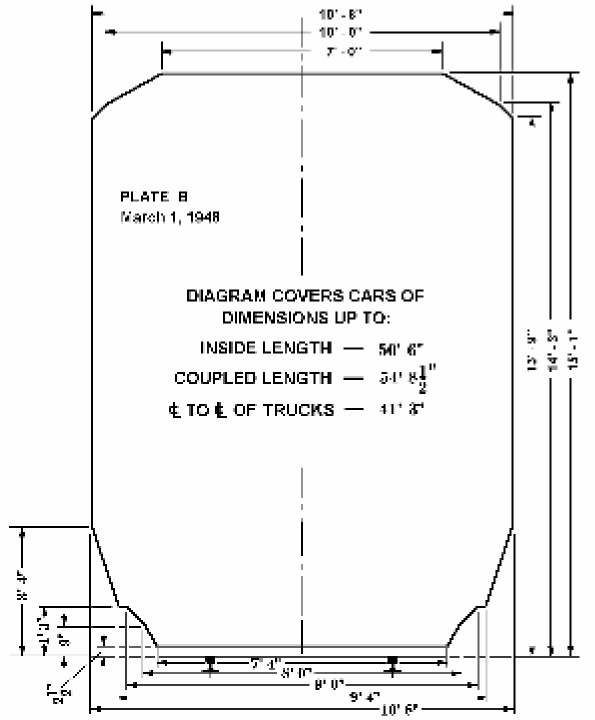

Figure 13 NJT Clearance Diagram[21]

Any railway equipment, including load, to run over the NJT must fit within this plate.

Nodes

Nodes join links and at these nodes some sort of transformation takes place.

For example, at a bus station (an example of a node) one transfer to and from a bus and some other mode of transportation. Services (e.g., purchase a bus ticket) are often performed at nodes. In the following table are examples of nodes, their purpose, and the links they may connect.

[21] http://www.transportation.njit.edu/NCTIP/final_report/RailFreightSurvey_files/image052.gif [February 21, 2007]

The reader may wish to refer to other material for discussions of the services performed at these nodes.

Node	Purpose	Links
Destination	End point for the shipment	Highway Railway
Distribution Center	Intermodal and intramodal transfer of goods	Highway – highway Highway – railway
Maritime Port	Intermodal and intramodal transfer of goods	Maritime – maritime Maritime – highway Maritime – railway
Origin	beginning point for the shipment	Highway Railway
Railway Terminal	Intermodal and intramodal transfer of goods	Railway – railway Railway – highway

Table 1 Nodes

Nodes have associated capacities, throughput rates, and, as the result of a combination of these two factors, dwell time (how much time goods spend in the node).

Links

Links join nodes. Typically, links provide only for the movement of goods.

Link	Purpose	Nodes Served
Highway	Infrastructure for the movement of goods via truck	Destination Distribution Center Maritime Port Origin Railway Terminal
Maritime (i.e., deep ocean, rivers, canals, lakes)	Infrastructure for the maritime movement of goods	Destination Maritime Port
Railway Terminal	Infrastructure for the movement of goods via rail	Destination Distribution Center Maritime Port Origin Railway Terminal

Table 2 Links

Links have associated capacities, throughput rates, and, as the result of a combination of these two factors, dwell time (how much time goods spend on the link).

I do not wish to trivialize nodes and links through simple explanations I have offered above. On the other hand, this is not a transportation network analysis and design course. Therefore, the limitation on detail seems appropriate. The reader is referred to Manheim and Sussman for further detail.

Summary

Scott and Beckner refer to five systems flows – people, goods, conveyances, money, and information – in their paper on global intermodal freight transportation.[22] They treat the network, which this note is about, somewhat lightly. I mention Scott and Beckner because their paper is currently the basis for the project associated with this course. Scott and Beckner's research is also closely linked with Figure 3 Transportation Management Themes on page 5 of 2. Transportation Basics.

It is the networks that provide the substrate upon which Scott and Beckner's systems flows depend. We might usefully examine whether the lack of focus on networks is a weakness in their report.

Transportation networks are complex assemblies of nodes and links, each with different service levels, each with management with different incentives, each subject to external forces (e.g., Hurricane Katrina). Networks are, however, somewhat static.

Networks are shaped by and shape the dynamics of the demand for and the supply of transportation services, and the complex interaction of equipment (conveyances to Scott and Beckner), and personal and firm relationships.

Manheim and Sussman remind us of the issues and key points associated with transportation network analysis, design, and operations.

James Drogan
February 21, 2007

[22] W. Scott Gould and Christian Beckner, Global Movement Management: Securing the Global Economy (IBM Business Consulting Services, 2005).

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