results are subject to independent verification and not simply taken at face value.

Main Point 5: Technology Transfer

The bottom line for any innovative idea is its eventual dissemination and implementation. Timely and responsive dissemination of information takes multiple forms. Many state universities, by virtue of their land-grant mission, already have technical assistance programs in place. The recently formed National Center of Excellence in Aviation Operations Research (NEXTOR) launches a potentially excellent model for rapid implementation of basic university research by industrial partners. Can you think of other effective means for information exchange? Specifically, are there more innovative means beyond traditional seminars and discussion forums?

Questions and Responses

Any other examples similar to NEXTOR?

- Many other consortiums exist; working groups are less formal analogues of FAA's Centers of Excellence.

As convenient as the Internet is for sharing information, what are some of the drawbacks?

- Search among Web sites often leads to superfluous information; perhaps a better linkage among sites, including a "smart" search engine, is in order.

What do you think of the three examples of technology transfer mentioned earlier under Main Point 2 through Main Point 4?

- They all prove to be excellent models for technology transfer. Main Point 2 illustrates how basic research can play a part in cooperative decisionmaking. Main Point 3 illustrates the synergy possible among the military, civilian and local aviation entities. Main Point 4 again shows the usefulness of information technology from DOD.

It remains to be seen how successful Centers of Excellence will be at rapid implementation of research findings. The Internet is already the fastest and probably the most readily available forum for information dissemination in the near future. Use of E-mail notification of newly posted information (which already exists on sites equipped with "push" technology), password-protected Web sites, scheduled Internet Rewrite Chat (IRC) rooms (with prearranged schedules), and 24-hour bulletin boards (monitored daily) can all be used to achieve the desired results. It should be remembered that information exchange is only one part of technology transfer. The more difficult part is developing the research result (or prototype technology) into an implementable product. This requires a further and substantial commitment of resources. For a number of years, the Federal Highway Administration has supported a large technology transfer program that might provide some useful ideas.

PERSPECTIVES ON TECHNOLOGY TRANSFER

Aside from questions and responses, selected panelists have provided individual statements on technology transfer. Following are the statements directly supplied by the identified contributor, with minimal editing.

Technology Transfer Between Transportation Modes (J. Morrison)

The purpose of my remarks is to highlight differences between modeling and analysis requirements for different modes of transportation as well as significant differences between commercial and military air transport systems. Transportation system throughput estimates such as travel time and ton-miles-per-day are influenced by a range of phenomena. Some of these phenomena are mode-specific, some are influenced by the network control system, and some are associated with specific classes of transportation activities. It is important that transportation models accurately reflect the effects of these unique interactions in order to produce realistic predictions.

Characteristics of Route (Link) Travel Times

Consider the four basic modes of military and commercial transportation: surface (roadway), rail, maritime, and air. Each of these network systems has unique characteristics that affect the rate of travel and predictions associated with travel planning. To a large extent, these differences reflect the relationship between the transportation performance of a particular platform (vehicle type) and the activity of other platforms. More specifically, some transportation phenomena are relatively independent, and some are not. Examples of relatively independent phenomena are air and sea, port-to-port travel times. Because the capacity of air and sea lanes are practically infinite, the presence of even a relatively large change in their use is not likely to produce platform-to-platform interactions that would

TABLE 1 RELATIONSHIP BETWEEN CAPACITY, CONTROL, AND THROUGHPUT VARIABILITY

Mode	Capacity	Control	Travel Time
Air	Unlimited	Centralized	Independent
Sea	Unlimited	Centralized	Independent
Rail	Unlimited	Centralized	Independent
Surface	Limited	Autonomous	Dependent

measurably reduce travel time. For this reason, representations of these processes that assume statistical independence or linearity are not likely to contribute to significant modeling error.

Surface travel on roadways, however, is highly sensitive to vehicle-to-vehicle interactions. Gridlock is the most well-understood example of this phenomena. However, traffic engineers have understood for years that there is a significant, nonlinear relationship between vehicle density (cars per mile of roadway) and the rate of flow on that roadway (cars traversing per unit of time). While the specific characteristics of this relationship are sensitive to each roadway, the characteristic shape is so common as to be a domain standard. It is referred to by traffic engineers as the fundamental diagram reflecting the consistent nonlinear relationship between vehicle density and expected travel speed and rate of flow.

Representations of vehicle travel in traffic models that do not incorporate this significant nonlinear relationship can contribute to significant error in travel time predictions. This fundamental system characteristic drives the relationship between traffic count studies (data collection in the domain) and system characterization in regional traffic models.

Railroads are somewhat unique in that, although they are capacity-constrained like roadways, they do not typically reflect the same uncertainty in estimated travel time. This is almost certainly due to the fact that, as a highly regulated utility, the set of commercial carriers behave as though they were centrally controlled. Therefore, although travel is practically constrained by a finite infrastructure, it is believed that in practice, current demand for rail utilization (combined with strong centralized control) reflects a system in which capacity is not stressed. This system, under current capacity/demand relationships should produce travel times for individual trips that are statistically independent of the behavior of other carriers in the system.

Table 1 summarizes the relationship between capacity, control, and throughput variability.

The implication of the previous observation is that estimates or calculations of point-to-point travel times for individual air, sea, and rail platforms can probably be conducted independently without a significant effect on the predictive qualities of the model. For this reason, expected value treatment of travel time in models for these modes are probably adequate. However, traffic models that fail to explicitly treat either the underlying cause or the effect (fundamental relationship) of these vehicle-to-vehicle interactions are vulnerable to producing inaccurate predictions of system throughput and vehicle travel times.

Characteristics of Port (Node) Service Times

Transportation nodes are of two general classes: those that require a service cost (time) penalty and those that do not. Examples of the latter include transportation way-points that affect direction or speed only. This discussion focuses on nodes that provide services to carriers that require an explicit time penalty. Examples of these services are staging (waiting for a transportation mission), onloading and offloading of cargo, and carrier service (vehicle and crew).

As with travel time on links, when capacity is constrained, total time for service (time waiting for service plus service time) can be affected by the activity of other carriers. More specifically, when the purpose of the stop is to acquire services for which there is some practical limit, the carrier will, typically, queue for service. Because military and commercial carriers typically require special facilities to onload and offload cargo, this service is vulnerable to "queuing behavior." The same is true for carrier services such as fueling, maintenance, etc. Although staging time is not typically sensitive to the effects of queuing behavior, it can be sensitive to the effects of variability in arrival times of cargo to be transshipped. This general phenomena in which delays in one carrier's schedule contribute to subsequent delays in other carriers' schedules is referred to as "cascading."

TABLE 2 IMPLICATIONS OF CAPACITY CONSTRAINTS

Mode	Capacity	Control	Service Time
Air	Limited	Centralized	Dependent
Sea	Limited	Centralized	Dependent
Rail	Limited	Centralized	Dependent
Surface	Unlimited	Autonomous	Independent

It can be shown that the effects of delay in the arrival of inbound traffic as well as the characteristic behavior of queues contributes to nonlinear relationships for service times at nodes. These nonlinear relationships are the result of carrier-to-carrier interactions. Cascading phenomena reflect the fact that when transportation activities are not independent, random early arrivals for one element do not, typically, offset the effects of random delays caused by other, related, elements. For this reason, expected value representations of travel time contribute to an optimistic bias. When there is significant variability in transit times or service times or both for the objective system, this bias can cause the model to overestimate the throughput of the system. The degree to which the prediction overestimates the true value is compounded by the extent to which cargos are transloaded and by the relationship between service demand and service capacity. More simply, a transportation system with relatively unlimited service capacity supporting a plan without staging and transloading will be relatively insensitive to this bias when modeled. However, complex, multimodal transportation plans that stress the system's service capacity (such as executing a deployment plan for a major defense contingency) are likely to be significantly impacted by this bias. To the extent that the system controller effectively accounts for this uncertainty and bias in the schedule, then it is realized implicitly.

Queuing theory shows that relatively modest amounts of variability can contribute to significantly greater delays in total service time than would be predicted by deterministic methods. As with the fundamental relationship that characterizes the nonlinear relationship between vehicles for surface transportation, it is likely that the vehicle-to-vehicle relationships that affect service activities for airports/bases are equally nonlinear. For this reason, deterministic relationships at these transportation nodes are likely to produce throughput estimates that significantly overestimate true system capacity.

Table 2 summarizes the implications of capacity constraints, and to some extent control methods, on modeling service cost (time) of alternative transportation systems. The assumption here is that, for transportation modes in which service capacity is constrained, models that treat carrier service times independently are likely to produce inaccurate predictions. Additionally, because of the sensitivity of system throughput to the effects of cascading, the characteristics of the scheduler play a significant role in the overall performance of the system. More specifically, the objective of the scheduler is to produce a demand schedule that minimizes the effects of cascading in the presence of uncertainty.

It is our observation that air transportation systems are the most sensitive to the nonlinear affects of travel and service time variability. For this reason, representation of service activities exert a considerable influence on the predictive qualities of air transport simulations.

Modeling Summary

The preceding discussion and examples were provided to show that some transportation phenomena, under some operating conditions, are highly sensitive to vehicle-to-vehicle interactions. When these conditions exist, simplistic model representations can lead to predictions about system performance that are not valid. However, the world of practical modeling and simulation is constrained by real limits on the complexity of the code and the time required to exercise the analysis tool. There will be conditions under which a deterministic representation of surface travel time satisfies the prediction requirements of a given decision, and there will be conditions and occasions when it does not. One of our ongoing research projects is motivated by a desire to find disciplined methods for making intelligent choices about the relationship between alternative model representations (levels of complexity) and the validity of a model's output with respect to the questions being asked. We propose methods that will allow model developers to stipulate, with confidence, what these conditions are.

TABLE 3 CHARACTERISTICS OF COMMERCIAL AND MILITARY AIR TRANSPORTATION SYSTEMS

System Characteristic	Commercial	Military
Operational Performance Data	Substantial	Uncertain
Demand	Stable	Dynamic
Load Relationships	Independent	Dependent
Delay Tolerance	Hours	Days

Differences Between Commercial and Military Air Transportation Systems

For both systems, performance is typically based on some function of arrival times (travel and service time). We believe that, although the problems are quite similar, there are aspects of the two systems that can affect modeling. These system characteristics include the characteristics of the demand for system capacity, load relationships, delay tolerance, and the availability of operational performance data (Table 3).

With respect to demand, commercial air transport systems are relatively stable within the time frame of practical scheduling. Military demand for system services during operational contingencies is highly dynamic. This contributes to a significant level of prediction uncertainty on a daily and weekly basis. This phenomena is compounded by the fact that, unlike most commercial cargo loads, military loads are typically not independent. By this we mean that the system goal is to have all of a unit's cargo arriving within some specific time frame. Because unit cargos are typically spread over many missions, a delay or schedule change may impact many missions. This is less often the case for commercial systems.

Two additional factors create differences in control activity for commercial and military systems. First, the relatively stable route structures and travel activity for commercial systems supports a relatively stable and substantial source of operational performance data for the system. The unique characteristics of military contingencies contributes to a relatively sparse database for the expected performance of the operational system. This compounds the prediction requirements for the system scheduler. The good news is that unlike commercial customers who measure delay in minutes or hours, realistic military schedules are not particularly sensitive to delays of this duration. For strategic deployment, the system customer is rarely sensitive to delays that do not exceed a day.

Summary

The purpose of this brief discussion was to motivate discussion about differences between the modeling and analysis requirements of alternative transportation modes and of military and commercial travel. Our observation is that air transportation models and analysis will be particularly sensitive to the complex carrier-to-carrier relationships that affect service cost. Differences between military and commercial system goals will likely contribute to different control logic in their schedulers.

Comments Concerning ITS

The concept of Free Flight for commercial air routes has a number of potential implications with respect to these observations. First, to the extent that variation in flight paths produces variation in arrival times for aircraft at airports, it provides a source of uncertainty that can measurably affect system throughput. This effect can be realized either through the direct impact of variation on service-queuing activities at airports, or implicitly through a requirement to incorporate more "slack time" in the schedule to offset the potential impacts of this variability. Either way, this potential source of variability can create a reduction in system throughput. Second, to the extent that one pilot's "planning freedom" is a source of planning uncertainty for other aircraft flight plans, it might provide a source of aircraft-to-aircraft interaction that could cause air traffic models to become more complex in order to produce accurate predictions.

Technology Transfer from Basic Research (N. Glassman)

The Air Force Office of Scientific Research (AFOSR) is the basic research agency for the Air Force—it controls all of the funds spent by the U.S. Air Force on basic research.