Assessing User Benefits of Transit System Improvements with Spatially Varying Demands

ALAN J. HOROWITZ

Transit planners recognize that spatially varying demands affect the assessment of transit system alternatives. However, they do not yet possess the tools necessary to properly determine the effects of the variation on estimates of user benefits. An extended measure of user benefits that is consistent with net consumer surplus from classical economic theory is presented. Also presented is the structure of a travel forecasting model that can show the effects of activity allocation, trip distribution, and route choice on net consumer surplus. Individual components of the model have already been extensively tested in practice and are described in the academic literature, but the transit ridership properties of the model, as a whole, have not been established. The model is capable of finding a joint equilibrium solution between activity allocation, mode split, trip distribution, and traffic assignment. Tests of the model on real networks indicate that spatial redistribution of activities resulting from a transit service improvement can be large enough to determine whether the improvement should be implemented.

The measurement of user benefits and its role in transit decision making has recently become a hotly debated subject (*1*). Some of the debate relates to issues of integrity and competence, which cannot be resolved by better measurement methods. However, many remaining issues could be resolved by adopting the best available forecasting techniques, applying them properly, and developing good indicators of user benefits.

Two closely related arguments have attracted considerable attention from planners and researchers. First is the contention that improvements in transportation systems, such as increases in capacity, may not always result in improved user benefits. Some economists argue that demand can become so elastic that an improvement can attract too many users in the long term, causing the whole system to operate less efficiently than before (*2*). That argument is counterintuitive and unlikely to apply to transit system improvements, but it focuses renewed attention on the nature of travel demand and how it affects user benefits. For example, correct assumptions regarding demand elasticity may give lower estimates of benefits than would result if current ways of thinking were applied.

Second, some communities have requested funds for transit system expansion despite poor ridership forecasts. Leaders of the communities have argued that there is an intrinsic relationship between transit supply and the long-term distribution of activities in their region. It is further argued that we do not yet possess the methodology to measure that relationship, so user benefits must be greater than indicated. Although that argument seems plausible, it lacks convincing verification.

Center for Urban Transportation Studies, University of Wisconsin–Milwaukee, EMS Building, Room E 387, P.O. Box 784, Milwaukee, Wis. 53201.

Both arguments could be laid to rest, at least partially, by forecasting models that properly reflect the amount of elasticity found in an actual transportation system. At least such a model must be able to achieve a joint equilibrium solution between mode split, trip distribution, activity allocation, and highway traffic assignment—all with sufficiently realistic relationships. Although the individual components of such a model have been identified for almost two decades, it is only recently that equilibrium solutions satisfying Wardrop's first principle could be obtained.

This paper describes the overall structure of such a model and explains how it might be operated and validated. Tests are then performed to identify the likely "winners" of the two arguments.

NET CONSUMER SURPLUS OF SERVICE CHANGES

User benefits are those that result from increased accessibility when a transit system improves. Benefits accrue to a transit patron because a trip can be made with less cost or greater convenience. Benefits also can accrue to an automobile driver or a passenger, because there might be less congestion on some streets. Furthermore, benefits could accrue to a traveler who chooses to make an additional trip by either mode or to switch modes.

Many benefit studies in the past determined that the greater user benefit resulting from a transportation system improvement is travel time savings. Additional user benefits include user savings from lower costs of fuel, tolls, fares, and vehicle maintenance. In addition, intangible user benefits could include travel comfort and the ability either to make entirely new trips or to satisfy old trip purposes by traveling to a better, but more distant, destination.

In our largest cities, there is increasing interest in transit's impact on traffic congestion. There are two aspects of this impact: (*a*) degradation of traffic flow associated with buses sharing roads with automobiles and (*b*) improvements in traffic flow that might occur if some drivers could be persuaded to take transit. Both of these effects, which are components of user benefits, can be measured with the proper methodology.

Economists tell us that user benefits of any public project can be ascertained by calculating net consumer surplus. Consumer surplus is the difference between the amount an individual is willing to pay for a good and the amount the individual actually pays. Net consumer surplus is the change in consumer surplus caused by the public project.

When dealing exclusively with highway travel, it is sometimes possible to estimate user benefits by adding individual components. However, transit benefits are far more complicated, so it is easiest to estimate directly the net consumer surplus of the system change from a travel forecasting model. If calculated correctly, net consumer surplus will include all of the previously cited benefits, both tangible and intangible.

Classical economic theory deals mainly with changes in price. Clearly, benefits still can accrue to transit users even if fare is constant, such as with improved headways, elimination of transfers, faster speeds, or line extensions. Some service improvements can reduce the duration of trips; other service changes improve the convenience of trips. It is important to include these nonmonetary changes in any estimate of net consumer surplus.

For any given transit trip, it is possible to calculate a comprehensive measure of its costs and inconveniences, that is, the trip's disutility. Disutility is most easily interpreted when it is expressed in units of automobile riding time. A typical disutility function would look like this:

$$\begin{aligned} \text{Disutility} = {} & \text{automobile riding time} \\ & + (\text{transit riding time})(\text{transit riding weight}) \\ & + (\text{walking time})(\text{walking weight}) \\ & + (\text{waiting time})(\text{waiting weight}) \\ & + (\text{transfer time})(\text{transfer weight}) \\ & + \text{initial wait penalty} + \text{first transfer penalty} \\ & + \text{second transfer penalty} \\ & + [\text{fare}/(\text{value of time})] + [(\text{tolls} + \text{parking costs} \\ & + \text{vehicle operating costs})/(\text{value of time})] \\ & + [(\text{vehicle ownership costs})/(\text{value of time})] \qquad (1) \end{aligned}$$

In this equation, the value of time is the rate at which travelers would be willing to trade money for time. Typical values of weights and penalties are given in Table 1. The weights originally were derived through a psychological scaling experiment (*3,4*), but they are consistent with weights observed from the calibration of mode split models and have been adopted widely for travel forecasting.

Equation 1 deals exclusively with cost and convenience issues. Additional terms could be provided for other significant elements of comfort, such as protection from inclement weather and privacy.

The only vehicle ownership costs that should be included in Equation 1 are those that can be attributed to a single trip. Because it has been found that travelers do not correctly perceive the full value of their vehicle ownership costs while making mode choice decisions, this term is often omitted.

Travelers have a willingness-to-pay in units of travel time (*5*). They will choose to ride only if the disutility of travel (in time units) is less than their willingness-to-pay (in time units). Consequently, any traveler must possess a consumer surplus of disutility. That disutility may be expressed mathematically as time savings, or it can be converted to monetary units by multiplying time savings by the value of time. For this research, consumer surplus is left in time units to avoid complications associated with time valuation.

A disutility measure of consumer surplus is shown in Figure 1 for a single trip. A demand curve represents the relationship between numbers of trips and trip disutility, expressed in time units. Point 1 represents the original disutility and number of riders taking the trip. Point 2 indicates a new disutility and the number of riders after a service change, such as shortening the headway. Because of the service improvement, more people have chosen to take the trip. Some new riders switched from the automobile, some new riders have changed their choice of destination, and some new riders are making an entirely new trip. T_1 is the original disutility, and T_2 is the new disutility. All of the old riders receive windfall consumer surplus of $T_1 - T_2$. The windfall is shown as the shaded area A. New riders have a net consumer surplus represented by the shaded area B. The new riders' net consumer surplus is almost a triangular area. Consequently, the total consumer surplus could be found from the roughly trapezoidal, combined area:

$$\text{Net consumer surplus} \approx (T_1 - T_2)(Q_1 + Q_2)/2 \qquad (2)$$

Net consumer surplus may be found by subdividing the shaded area into several flat and wide trapezoids and adding their areas, as shown in Figure 2. The process of finding the area of several smaller trapezoids can be expressed mathematically as:

$$\text{Net consumer surplus} = -\int_{T_1}^{T_2} Q(T)\, dT \qquad (3)$$

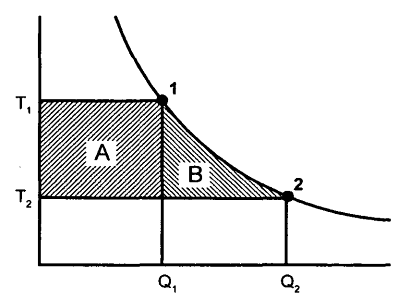

FIGURE 1 Net consumer surplus of trips by a single mode and origin-destination pair.

TABLE 1 Typical Weights and Penalties for Travel Disutility

Weight or Penalty	Value
Transit Riding Weight	1 + 2.0 x (fraction of person-time standing)
Walking Weight (good weather)	1.3
Waiting Weight	1.9
Transfer Weight	1.6
Initial Weight Penalty	8.4 minutes
Transfer Penalty (first or second)	23 minutes
Value of Time	0.167 to 0.333 of the average wage of choice riders

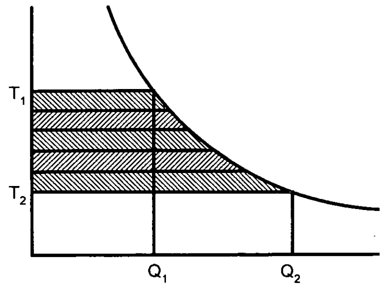

FIGURE 2 Integrating net consumer surplus with trapezoids.

where $Q(T)$ is ridership as a function of disutility (*6*). Because of the integral sign, Equation 3 looks more complicated than it really is. Integral calculus is never actually used to perform such a computation. Instead, one would simply divide the service change into several small increments and compute the net consumer surplus with Equation 2 as each increment is applied.

In a multimodal transportation system it is necessary to sum the net consumer surplus over all possible modes. For example, highway traffic could decline slightly as the result of the service improvement illustrated in Figure 1. Total net consumer surplus for the whole system can be found from the relationship

$$\text{Net consumer surplus} = -\sum_m \sum_i \sum_j \int_{T_{1mij}}^{T_{2mij}} Q_{mij}(T)\, dT \qquad (4)$$

for all modes m, all origins i, and all destinations j. As before, the integral is performed by summing the areas of flat, wide trapezoids (*7*). Unlike the example in Figure 1, Equation 4 also applies to modes that result in losses for users. For example, a highway system can contribute positively to consumer surplus by congestion relief while still giving some of its users to the transit system. Those highway users that remain will realize a windfall consumer surplus equal to the travel time reduction for the trip. Drivers choosing to switch paths are also counted properly by Equation 4.

It is sometimes useful to break net consumer surplus into components to determine the primary sources of the benefits. For example, highway consumer surplus may be differentiated from transit consumer surplus.

FORECASTING TRANSIT RIDERSHIP WITH SPATIALLY VARYING DEMANDS

A travel forecast that can properly measure net consumer surplus is only slightly more difficult than a conventional forecast, provided care is taken to compute the necessary values of disutility and demand for all modes. The model described in the following paragraphs should be considered a reasonable way of doing travel forecasting, but it is certainly not the only way, and it may not even be the best way. The model is an assemblage of tried-and-true components from current planning practice and the academic literature. Techniques that are now considered experimental may later prove to be more accurate. However, it is important for the purposes of this research to adopt only components that have achieved a consensus as to their validity.

The travel forecasting model was custom built for this research, because there are not any commercial forecasting packages that contain all the necessary elements. Nonetheless, each separate component should be considered off-the-shelf technology, even if the entire package seems unusually complex. The activity allocation step was adapted from source code of the Highway Land Use Forecasting Model II, and the traffic and transit forecasting components were taken from the source code of the Quick Response System II. The various pieces were compiled into a single executable module. The pieces are discussed briefly in the following paragraphs.

Activity Allocation Issues

The allocation of activities throughout a region must be sensitive to the quality of transportation services. The most widely researched way of achieving that sensitivity is the Lowry land use model (*8,9*). The Lowry-Garin model, specifically implemented for this paper, is shown in Figure 3. The underlying mathematical relationships have been described elsewhere (*10,11*). Other land use formulations exist that are based on similar principles.

A Lowry-Garin model allocates residences proximately to workplaces and allocates services proximately to their markets. Within a Lowry-type model, services are defined as those employers who derive their income from within the region and who are sensitive to the locations of their customers. Services are further subdivided into two classes: (*a*) those that serve people and tend to locate proximately to concentrations of population and (*b*) those that serve businesses and tend to locate proximately to concentrations of employees.

Population is allocated to zones with a residential location model on the basis of the residential attractiveness of the zone (typically, net developable area) and on the basis of the disutility of travel between the zone of residence and all zones of employment. Services are allocated to zones in much the same way as residences are allocated to zones, considering both service attractiveness and the disutility of travel.

A Lowry-type model cannot allocate "basic" industries (businesses that derive their income from outside the region), so their locations must be provided as input.

Lowry-type models become computationally messy because services themselves must be served and because services have employees needing residences. Consequently, Lowry-type models simultaneously solve for the number of people and the number of service employees in every zone. Such a solution requires a large amount of computation, especially if the model must also resolve conflicts over land, satisfy hard constraints on population or on service employment, or introduce agglomeration effects.

Once population and services have been allocated, it is possible to perform a traffic forecast in the usual way. The traffic forecast may reveal unanticipated congestion effects, so the activity allocation step may have to be repeated.

Equilibrium Assignment Issues

When computing consumer surplus, it is important that automobile disutility be consistent with the amount of traffic along the path from origin to destination. In addition, the amount of traffic should be sensitive to possible variations in activity allocation, mode split, and the distribution of trips, all of which depend on automobile disutility. This consistency is sometimes referred to as an elastic demand-equilibrium assignment.

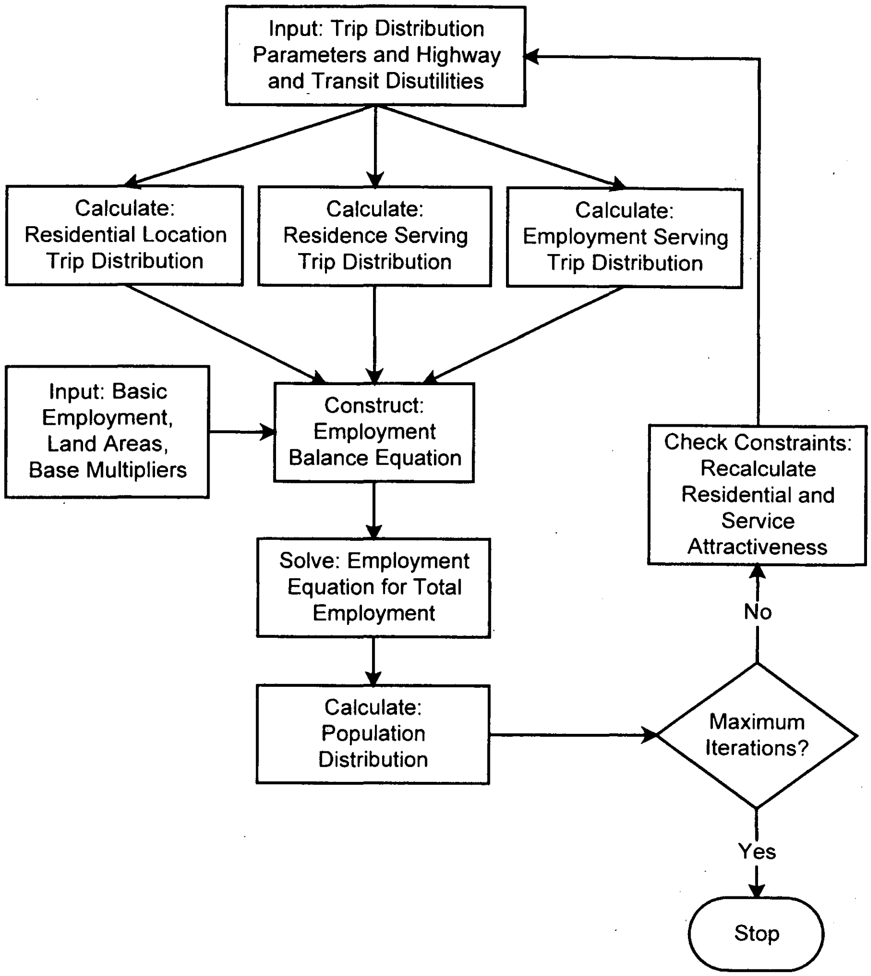

FIGURE 3 Activity allocation step of the travel forecast.

The chosen method of obtaining an equilibrium assignment is shown in Figure 4 and contains many of the same steps as a traditional travel forecast. However, the model shown in Figure 4 differs from traditional travel forecasting by routing the feedback loop so that the trip distribution, mode split, and activity allocation steps can be based on the highway disutilities that are appropriate for the amount of traffic congestion. Critical to the feedback loop is an averaging step (*12*). At this step, traffic volumes from all previous all-or-nothing traffic assignments are averaged together. Then new disutilities on each link are obtained. It has been previously shown that equilibrium solutions can be consistently obtained in this manner. An unweighted average works consistently well, although convergence is slow (*13,14*).

Assignment Convergence Issues

Given the complexity of the model and the method chosen for obtaining an equilibrium solution, we lack standard means to determine when convergence has been reached. The accepted method of monitoring an objective function of a nonlinear program is not available in this case. The surest method of determining whether an equilibrium solution has been reached is to compare the final total assigned travel time with the travel time obtained by loading the final trip table on to the network with all-or-nothing assignment. The two total travel times must be equal for the network to be in equilibrium. Less precise, but almost as effective, is to monitor assigned volumes on successive iterations. In either case, the uniqueness of the equilibrium solution cannot be established.

Location Models within Activity Allocation Step

All three location models are singly constrained, entropy-maximizing gravity models.

Composite Disutilities

Most travel forecasts find the distribution of trips throughout the community with a model step that excludes information about the quality of transit service. Consequently, such a forecast will not be properly sensitive to changes in transit service. Forecasters have

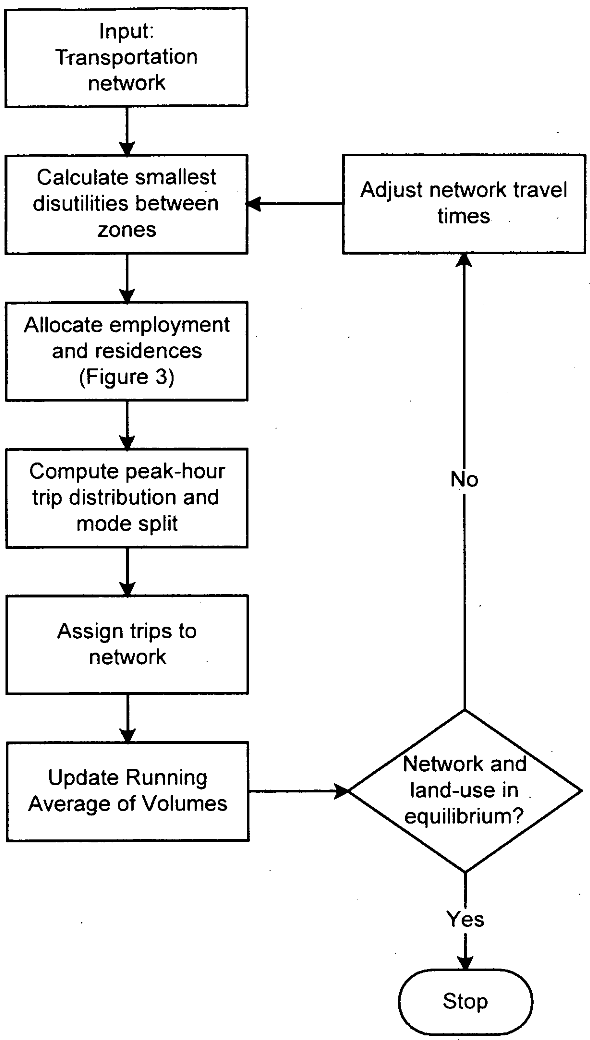

FIGURE 4 Combined-steps method of travel forecasting.

sometimes included transit service in the trip distribution step by computing composite disutilities between origins and destinations that account for both highway and transit service. The following composite disutility function has been found to provide the correct degree of sensitivity:

$$T^c_{ij} = \ln[\exp(-\alpha\, T^b_{ij}) + \exp(-\alpha\, T^a_{ij})] \,/\, (-\alpha) \qquad (5)$$

where

T^c_{ij} = composite disutility from origin i to destination j,
T^b_{ij} = disutility by transit,
T^a_{ij} = disutility by automobile, and
α = coefficient for an unweighted minute of travel time in a mode split model (*15*).

The composite disutility is always smaller than the smallest value of its components. Composite disutilities should not be used for trips that are captive to any particular mode.

Any forecast can be performed either with or without Equation 5. The differences in the two forecasts can be interpreted as transit's impact on the spatial distribution of activities.

Application of Composite Disutility Function

The composite disutility function was used for the distribution of all trip purposes, except for employment-serving trips in the activity allocation step. Employment-serving trips are rarely made by transit and are assumed to be captive to the automobile.

Other Distribution Issues

The full trip distributions from the activity allocation step are discarded before the trip distribution step of the traffic and transit forecast. Somewhat inefficiently, the procedure retains only the estimates of activity levels in each zone. The trip distribution step in Figure 4 uses a doubly constrained gravity model, which satisfies both attraction and production end constraints. Consequently, trip distribution is less sensitive to variations in disutility than the location models of the activity allocation step (Figure 3).

Mode Split

Mode split was handled with a binary logit model (automobile, generalize transit) with two market segments (captive, choice). Transit trips were loaded with a stochastic, multipath assignment algorithm.

ISSUES OF MEASURING CONSUMER SURPLUS

Approximating Net Consumer Surplus Integral with Trapezoids

Transit service changes can be either discrete or continuous. An example of a discrete service change would be the addition of a new rail station. An example of a relatively continuous service change would be an improvement in headways. It would make sense to compute the net consumer surplus of only part of a headway improvement, but it would make little sense to compute the net consumer surplus of only part of a new station. For discrete service changes, there can be only two possible valid forecasts—with and without the change. Consequently, net consumer surplus must be computed by Equation 2, recognizing that an overestimate in benefits is possible.

For continuous service changes, the calculation of net consumer surplus can be more precise. The service change can be divided arbitrarily into several increments and the net consumer surplus computed for each increment. The sum of the net consumer surpluses for each increment is the total net consumer surplus. The major drawback to subdividing service changes in this manner is the added computation time necessary to evaluate each amount of intermediate service.

Double Counting

When benefits are calculated for a project, it is important to avoid double counting. Because consumer surplus as defined here is such a broad measure, it encompasses effects, such as land value changes, that can be measured separately. Environmentally related benefits, such as land preservation, are not included in consumer surplus.

Need for Realistic Null Alternative

Net consumer surplus is always calculated between a before case and an after case. The most relevant before case is the null alternative, that is, the most likely state of the community without the service change. The null alternative is not necessarily the current state of affairs. The null alternative should include growth or decline, redistribution of activities, or natural changes in the character of the community. Good null alternatives are difficult to construct, but they are essential to a valid calculation of consumer surplus.

CASE STUDY NETWORKS AND SCENARIOS

The case study region selected for this study was Wausau, Wisconsin, because its networks have been extensively used for testing both travel forecasting models and land use models. Its networks are known to behave similarly to those from much larger cities. The Wausau network has the advantage of computational speed, because it has only 36 highway zones and 9 external stations. Calibration runs were made to ensure that the forecasting model produced reasonable highway volumes and transit loads.

Separate networks were created for the highway and transit systems. The transit system had only five bus routes, operating on 30-min headways. Highway zones were subdivided into 60 transit zones for the purposes of transit trip assignment. All highway links were given a capacity (Level of Service C, design capacity), and delay was calculated exclusively with the BPR speed and volume function.

Wausau does not have much traffic. To determine how activity levels influence the net consumer surplus of a service change, two different states of the city were created:

- Scenario 1: current activity levels, basic employment at existing conditions; and
- Scenario 2: twice current activity, basic employment doubled in each zone.

Doubling the basic employment in the Lowry-Garin model has the effect of doubling both population and service employment in the region as a whole. Scenario 2 is quite congested, and drivers have ample incentive to choose transit.

It is possible that a forecasting model can take on a much different character when evaluating large service changes instead of small ones. To determine whether the magnitude of the service change had interesting effects, two different service changes were created:

- Service Change A: a reduction of headways from 30 to 15 min (mild), and
- Service Change B: a reduction of headways from 30 to 5 min and elimination of the $0.50 fare (aggressive).

CASE STUDY MEASUREMENT OF NET CONSUMER SURPLUS

Except as noted, calculations were conducted with sufficient precision for routine regionwide travel forecasting. Of special concern were errors associated with insufficient equilibrium iterations (Figure 4) and the method of integration. A good equilibrium solution is essential to accurate estimates of consumer surplus.

Convergence Error

An earlier study indicated that approximately 20 iterations of the equilibrium loop of Figure 4 would usually be sufficient for travel forecasting purposes (*11*). However, the number of iterations necessary for precise calculation of net consumer surplus was not determined. Because net consumer surplus is found by comparing two different forecasts, convergence errors in each forecast can combine unpredictably.

Table 2 gives the values of net consumer surplus for 10, 20, 40, and 100 equilibrium iterations for Scenario 2 and Service Change B. It appears that net consumer surplus stabilizes at about 20 iterations for this network. Assuming that a 100-iteration forecast contains essentially no convergence error, the error at 20 iterations is an acceptable 0.13 percent.

All remaining simulations described in this paper were still nicely converging to an equilibrium solution at 20 iterations.

Integration Slices

Simulations are time consuming, so it is tempting to use a single slice when integrating the net consumer surplus. A single slice will cause an overestimate, which becomes worse as the difference between the alternatives becomes larger. Table 3 compares the net consumer surplus with a single slice to that with five slices for Scenario 2 and Service Change B. Because the combination of scenario and service change produces a large net consumer surplus, the integration error is also large. The overall integration error for a single slice is at least 20.4 percent.

TABLE 2 Variation in Net Consumer Surplus with Equilibrium Iterations*

	Net Consumer Surplus		
Number of Iterations	Highway	Transit	Total
10	19957	349679	369636
20	23703	348872	372575
40	22817	349531	372348
100	23200	348901	372101

*Twice current activity levels (Scenario 2), with composite disutilities. Before: 50 cent fare; 30 minute headways. After: 0 fare; 5 minute headways (Service Change B). Units are minutes of riding time.

TABLE 3 Comparison Between a One-Slice and a Five-Slice Integration*

Number of Slices	Net Consumer Surplus Highway	Transit	Total
5	26002	283370	309372
1	23703	348872	372575
Percent Difference	-8.8%	23.1%	20.4%

*Twice current activity levels (Scenario 2), 20 iterations, with composite disutilities. Before: 50 cent fare; 30 minute headways. After: 0 fare; 5 minute headways (Service Change B). Units are minutes of riding time.

Because the conclusions are unaffected by this type of systematic error, the remaining analysis in this paper uses a single integration slice. However, it would be a mistake to rely exclusively on single slices in practical applications. User benefits can be seriously overestimated with big system changes, making them seem more cost-effective than they really are.

Computational Considerations for Lowry-Garin Model

The solution of the employment balance equations within the Lowry-Garin model is always exact, but the need to resolve conflicts over available land required repeated solutions of these equations. The number of needed land use iterations (the loop of Figure 3) during any given equilibrium iteration (Figure 4) was reduced by capturing the attractiveness values from the previous equilibrium iteration. Thus, it was possible to reduce the number of land use iterations to just three, achieving a significant reduction in computation time. Because of capturing, the resolution of land conflicts becomes increasingly better with each equilibrium iteration.

RESULTS

Transit Ridership

Not all of Wausau is served by transit. When transit service is improved, the model tends to concentrate activities in zones served by transit. Some zones pick up additional services, whereas other zones pick up population. In either case, the concentration has a positive effect on ridership. Table 4 compares gains in forecast transit ridership with and without the composite disutility function. Without the composite disutility function, transit can influence the distribution of activities only by relieving highway congestion, a relatively minor effect.

Table 4 indicates that redistribution of activities causes a ridership increase of 3 to 14 percent. Although such increases are not dramatic, they would lead one to favor the more aggressive alternatives for transit service improvement. A particularly good transit system can induce some of its own demand.

Table 4 also indicates, as expected, that transit ridership increases substantially faster than the activity level. The composite disutility function does not appear to interact with the level of activity in the region.

Consumer Surplus

Not surprisingly, the effect on net consumer surplus of activity redistribution is similar to the effect on ridership gains. Table 5 presents net consumer surplus for both highway and transit users. Net consumer surplus increases from 3 to 12 percent with the composite disutilities.

The values of net consumer surplus indicated in Table 5 are uncorrected for integration errors, which would be especially pronounced for all cases of Service Change B.

TABLE 4 Forecast Transit Ridership Gains due to Service Changes*

With Composite Disutilities:

Scenario	Service Change Mild (A)	Aggressive (B)
Current Activity (1)	2122	9185
Twice Current (2)	5212	20877

Without Composite Disutilities:

Scenario	Service Change Mild (A)	Aggressive (B)
Current Activity (1)	2021	8069
Twice Current (2)	5045	19499

Percent Difference:

Scenario	Service Change Mild (A)	Aggressive (B)
Current Activity (1)	5.0%	13.8%
Twice Current (2)	3.3%	7.1%

*Units are system riders.

TABLE 5 Effect of Composite Disutilities on Net Consumer Surplus*

Scenario	Service Change Mild (A)	Service Change Aggressive (B)
Current Activity (1)	45450	154275
Twice Current (2)	112138	372575

Without Composite Disutilities:

Scenario	Service Change Mild (A)	Service Change Aggressive (B)
Current Activity (1)	44219	138214
Twice Current (2)	104458	339537

Percent Differences:

Scenario	Service Change Mild (A)	Service Change Aggressive (B)
Current Activity (1)	2.8%	11.6%
Twice Current (2)	7.4%	9.7%

*Units are minutes of riding time.

Highway-Related Consumer Surplus

Referring to Table 3 (Scenario 2, Service Change B), one observes that the net consumer surplus from highway users is positive and is about 10 percent of the net consumer surplus from transit users. This component of net consumer surplus is almost entirely the result of congestion relief. The highway net consumer surpluses for both service changes for Scenario 1, with little congestion, are negligible.

Discussion of Findings

The tested service changes applied to the whole transit system, so shifts in activity levels occurred, essentially, between nonserved and served areas. A major transit alternative that upgrades service in a single corridor could prompt a relatively larger redistribution. The effects of the redistribution on net consumer surplus could be substantial.

The model is sensitive only to service changes that affect the disutility function (Equation 1). For activity redistribution to occur, there must be measurable advantages for a traveler. For example, the model will not redistribute activity when a bus line is replaced by a light rail line that operates at the same speeds and headways.

Wausau, the test city, is small but exhibits many of the same characteristics as larger cities. It would not be possible to extrapolate specific numbers to larger cities; however, the general trends discussed would still hold.

CONCLUSIONS

It is possible to build a travel forecasting model that finds a joint equilibrium solution between activity allocation, mode split, trip distribution, and traffic assignment. It is possible for such a model to include all major aspects of spatial variations in travel and still find an internally consistent solution.

When measuring net consumer surplus of transit alternatives, it is important to observe computational requirements. There should be sufficient equilibrium iterations to eliminate biases from convergence error. Furthermore, for big service changes, there should be sufficient slices in the integration of net consumer surplus to avoid a substantial overestimate of net consumer surplus.

Given the assumptions of the forecasting model, which represent a consensus of the transportation planning literature, activity redistribution increases net consumer surplus of transit service changes. The increase can be large enough to affect decisions regarding aggressive service improvements, especially those in well-defined corridors.

There is no evidence, either for highway users or transit users, that net consumer surplus would be negative (or even significantly retarded) for any reasonable service change.

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