INTRODUCTION

The Tennessee River Waterway System consists of 650 miles of main channel and approximately 150 miles of tributary and secondary channels. The waterway is formed by a series of main river locks and dams and two tributary dams, one of which has a lock and the other utilizes a canal. All but one of these facilities were initially constructed by the Tennessee Valley Authority (TVA), which has primary federal responsibility for navigation on the Tennessee River and Tributaries, as charged by an act of Congress on May 18, 1933. TVA operates the reservoir system with navigation as one of the primary objectives in a multipurpose system that includes hydroelectric power generation and flood control. The U.S. Army Corps of Engineers (USACE) operates the locks as it does on the other inland waterways.

Since the dams and locks were initially constructed over 40 years ago, however, changing technologies and increased demands on the waterway have produced a new environment. Larger locks have been added on the lower range of the river, but the three upstream dams (above Chattanooga, Tennessee) still have old small locks. These old locks are now inadequate to handle modern barge and tow sizes and are approaching a situation of rapidly increasing maintenance. Considering the time horizon in the planning and building of new locks, they will be over 50 years old before new locks will likely be built.

To address the deficiencies of the navigation system on the upper range of the Tennessee River, the U.S. Army Corps of Engineers, in partnership with TVA, is presently undertaking a reconnaissance study to investigate the need to rebuild the older locks. These 60 x 360 foot locks were designed for a smaller barge that was standard on the river at the time the locks were constructed. Today, however, these smaller locks are inadequate for the larger barges and tow sizes common on the lower river. Where an eight barge tow (including the towboat) can be locked through in one pass in the lower locks, a time-consuming single lockage would be required for each barge in the upper range of the river. The research presented here describes a modeling methodology which provides the user (in this case TVA and USACE) with a multidimensional planning instrument that can provide the commodity forecast data required by the Water Resources Planning Act (1982) to determine the need for new locks. A waterborne commerce economic simulation model (WCESM) was developed for the Tennessee River in the spirit of the Resources for the Future (RFF) Mississippi River System Model of Howe et al. (1969). The model maps commodity movements with the proper industrial activity linkages so as to realistically simulate river traffic. At the same time, the model provides reasonable forecasts of activity, presently, to the year 2050 for the Upper-Tennessee River project.

The model (WCESM) is a satellite model to the TNVA regional economic simulation model (RESM). National variables enter the model to incorporate trends and factors that are national in scope and as a proxy for economic activity outside the region. Regional characteristics from RESM and resource constraints, however, form the core of the model. The model is unique in the inclusion of a (rail/barge) modal shift factor and a national transportation sector output proxy variable which incorporates inventory cycles among other factors.

The purpose of this paper is to provide the theoretical framework incorporated into WCESM, test the model, and provide a measure of how well the model performs in historical simulation. The paper is organized in the following manner. Section II provides the theoretical framework for the study. In sections III and IV, respectively, the data base and equation specifications are discussed. Section V presents the results of estimating and simulating the model, while section VI concludes the paper.

THEORETICAL FRAMEWORK

The economic environment in which inland waterborne commerce operates dictates that demand factors, as well as resource constraints, determine the tonnage levels that move at any point in time. Thus, the general form of the model we estimate is as follows:

Commodity Terminations = f (Demand factors, Resource Constraints).

In the Mississippi River System Model, Howe et al. identify related economic activity and transportation cost as important considerations in a river traffic model. Specified in this form, the model is incorporating the general form of a derived demand or input demand function.

Such a function was laid out and tested for labor demand by Adams, Brooking, and Glickman (1975) in their study of the Mississippi economy:

\[ \ln L = \alpha_0 + \alpha_1 t + \alpha_2 \ln Q + \alpha_3 (W/P), \]

where

- \( L \) = real output
- \( \alpha_0 \) = labor demand
- \( t \) = time (technology measure)
- \( W/P \) = real wages.

In application of physical inputs, Howe's related economic activity measures \( Q \) and the transportation rates (while not equaling total cost) measure a portion of input cost.

The derived demand function, however, does not fully explain commodity movements. Real output should obviously have a premier role in such a model since it best reflects the demand for the commodities being shipped. In a transportation application, however, the implicit assumption is that output is used instantaneously (in an annual mode in one year) and that output is sold instantaneously are often violated. Input inventories are often accumulated at a rate bearing no relation to present output levels for a variety of reasons, including anticipation of labor contract negotiations and price increases. It is also true that firms may choose to draw inventories down in periods of rapidly increasing output, possibly expecting input unit costs to fall.

Further, while the input demand function theoretically incorporates price competition in the relative price variable \( (W/P) \), price data are usually not available, thus resulting in the need for proxy variables in equation specification. For example, while much of petroleum traffic has been lost from the river due to barge/pipeline rate competition, these data are not available. In periods of intensive utilization of transportation equipment, there is also the possibility that the railroads might move to higher rated (more profitable) goods, and, thus, leave the lower rated goods for waterborne transportation. Again, a railroad rate structure for the study period is not available.

Still other factors include an international crisis such as the Arab oil embargo and changes in government regulation. In the late 1970's, for example, certain petroleum traffic shifted to railroads because the government required double-skinned barges which were not generally available.

THE DATA

Collecting data on the volume of river and lock traffic is the responsibility of USACE. One of their data bases, the data utilized in the present study, is maintained by the Waterborne Commerce Statistical Center (WCSC). These data are a compilation of individual transactions, termed Vessel Operation Reports, which must be reported by the shipper each time a barge is moved. Reported
data include the port and dock of origin and termination, the ship-
ment route, total tons shipped, and a four-digit commodity
classification similar to the Standard Industrial Classification.
These data provide the only measure of river traffic and are the
"official" USACE statistics. The WCSC data are currently avail-
able to TVA for the period 1970-1985.

For the purpose of the present study the data have been
classified into four termination groups: the upper range of the
Tennessee River, the lower range of the Tennessee River, the
Cumberland River, and all other terminations. The data are fur-
ther classified into eight commodity groups: (1) grains and grain
products, (2) logs and pulpwood, (3) chemicals, (4) petro-
leum less coke, (5) metals and ores, (6) stone products, (7) miscella-
nous metals, and (8) coal and coke. In certain instances, equation
estimation is at a more detailed level. Last, coal and coke termina-
tions, accounting for over 50 percent of Tennessee River traffic,
are handled as a case study in the Upper-Tennessee Lock Study
and are therefore not included in the present study.

**MODEL SPECIFICATION**

The model chosen to estimate, as noted, is similar to the Howe
et al. model of waterborne commerce on the Mississippi River
System. It is a linear, model in logarithms such that coefficients are
elasticities, with variables chosen to act as proxies for demand
and resource constraints.

The core of the model is specified with the following variables:

\[ \text{TONS}_{ikt} = \beta_{DMJkt} \times BARGE_t \times EVAL_t \times TRANS_t \times DUMMY_t, \]

where

\[ \text{TONS}_{ikt} \] is tonnage of commodity \( i \) terminating in region \( k \)
and time \( t \).

\[ \text{DMJ}_{ikt} \] is the demand of sector or industry \( j \) in region \( k \)
and time \( t \). As a proxy for demand outside the region, national
product data published by the WEFA Group are used. As a proxy for
demand on the upper and lower ranges of the river, Bureau of
Economic Analysis (BEA) defined earnings data are used in the absence of gross output data. For the upper range, these variables are the county
groups adjacent or proximate to the upper range of the navigable
channel; for the lower range and Cumberland River, these variables are the water-
side counties in the lower channel and the Cumberland River. Other demand variables are
residential oil consumption (RESOIL), U.S. grain
exports (GREX), and the agriculture sector
deflator (DAE).

\[ \text{BARGE}_t \] is the real barge rate from Kansas City, Kansas, to
Chattanooga, Tennessee, in time \( t \).

\[ \text{EVAL}_t \] is the WEFA group's ratio of BTU to value added in
the national transportation sector in time \( t \).

\[ \text{TRANS}_t \] is the WEFA group's constant dollar energy inputs in
the national transportation sector.

\[ \text{DUMMY}_t \] is a dummy (binary) variable used to account for
special circumstances.

The \( \beta_{DMJkt} \) variable is included as a proxy for industrial,
residential, or foreign demand. These variables, as noted, are na-
tional output, regional earnings, oil consumption, grain exports,
and agricultural prices. Based on the input demand relation, it
is expected that industrial earnings or output variables would enter
the regression equations with a positive sign. The oil consump-
tion variable in the model serves as a proxy for regional oil con-
sumption and is expected to enter the petroleum equations with a
positive sign. The grain export variable serves as a proxy for
foreign grain demand and is expected to enter the equation for
terminations off the Tennessee and Cumberland Rivers with a
positive sign. The agricultural price deflator variable serves as a
proxy for expected farm sector price levels and should enter fer-
tilizer equations with a positive sign. The idea is that the expec-
tation of higher farm prices stimulates the demand for all farm
production inputs, including fertilizers.

The \( \beta_{BARGE_t} \) variable is included as a proxy for barge cost on
the river. While it is well known that barge rates vary widely, be-
ing higher on the upper range of the river than the lower, it is a
fact that temporal variation in all barge rates has followed ap-
proximately the same pattern, especially given the recent drastic
rate decline. Furthermore, it is well known that barge rates vary
for different commodities; however, it is a fact that "... as go grain
rates, so go all rates." Thus, it is expected that the barge variable
is representative of the variation in all rates on the river and, given
the input demand function, the expected regression coefficient
of the barge variable is negative.

The \( \beta_{EVAL_t} \) variable is included as a proxy for the shift in the
national transportation modal mix that occurs as transportation
output rises and declines. Viewed in terms of \( \text{EVAL} \) (the ratio of
BTU consumption per dollar of real value added), barge transpor-
tation shares the least efficiency.

Unlike other transportation modes, the fuel cost of a barge tow
can be up to 50 percent of total cost, resulting in a high BTU level.
Value added per unit of volume, conversely, is very low due to the
primary commodities presently barged. The combination of a high BTU content and low value added results in a high BTU/Value added ratio for the barge component. Thus, when \( \text{EVAL} \) rises; the shift is toward the least efficient modes.

Conversely, a fall in \( \beta_{EVAL_t} \) would indicate a shift toward the
more efficient modes. The suspected interpretation of the upward
shift in \( \beta_{EVAL} \) is that, the more efficient modes have either ex-
perienced constraints in capacity or moved after higher rated
goods. [Railroads, for example, would much prefer to have the
high rated automobile cargo than primary commodities.] The ex-
pected sign of the regression is, therefore, positive.

The \( \beta_{TRANS_t} \) variable, real value of fuel consumption in the
transportation sector, is a proxy for output in that portion of the
transportation sector that actually moves goods and thus avoids
warehousing and services incidental to transportation. While this
variable would be expected to be, to a degree, redundant with
respect to industrial output, the transportation sector often moves
goods without respect to current demand. The \( \beta_{TRANS} \) variable
thus adds the dimension of inventory adjustments and would be
expected to enter the regressions with a positive sign.

The \( \beta_{DUMMY_t} \) variable serves as a proxy for a variety of
miscellaneous factors. Depending on the commodity, the \( \beta_{DUMMY_t} \) variable incorporates the following effects:

- entry of new firms along the waterway
- Arab oil embargo
- large construction projects
- regulation changes
- new movements
- pipeline competition.

**RESULTS OF THE ESTIMATION AND SIMULATION**

A summary of the model estimation utilizing Tennessee River
data for the period 1970-1984 is reported in Table 1. For each
commodity group modeled, the table reports the adjusted coef-
ficient of determination (\( R^2 \)), the equation "F" statistic, and the
significance level of the equation (\( PROB > F \)). As for providing
empirical support for the model of waterborne commerce, the
results are quite strong but not perfect. The "\( PROB > F \)" statistic,
a statistic which is the level of significance in which the data re-
ject the null hypothesis of no relation between the dependent and
independent variables, suggests that all regression equations are
statistically significant at least at the five percent confidence level.

Thus, the model variables are significantly associated with com-
modity terminations. The coefficient of determination (adjusted
for degrees of freedom) values reported in the table range from
This statistic, which indicates the proportion of the variation in the dependent variable explained by the independent variables, provides some evidence to indicate that the data are not adequate to test the model for certain commodity movements.

**Equation Estimation and Simulation Properties**

<table>
<thead>
<tr>
<th>Destination/Commodity</th>
<th>$R^2$</th>
<th>$F$</th>
<th>Prob $&gt; F$</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Grain</td>
<td>0.58</td>
<td>10.65</td>
<td>0.0022</td>
<td>29</td>
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<tr>
<td>Petroleum</td>
<td>0.84</td>
<td>25.22</td>
<td>0.0001</td>
<td>11</td>
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<td>Wood</td>
<td>0.89</td>
<td>37.38</td>
<td>0.0001</td>
<td>6</td>
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<tr>
<td>Other</td>
<td>0.60</td>
<td>7.91</td>
<td>0.0044</td>
<td>15</td>
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<tr>
<td>Lower Chemicals</td>
<td>0.79</td>
<td>18.12</td>
<td>0.0001</td>
<td>11</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>0.66</td>
<td>10.12</td>
<td>0.0017</td>
<td>15</td>
</tr>
<tr>
<td>Grain</td>
<td>0.83</td>
<td>21.49</td>
<td>0.0001</td>
<td>6</td>
</tr>
<tr>
<td>Stone Products</td>
<td>0.74</td>
<td>20.82</td>
<td>0.0001</td>
<td>7</td>
</tr>
<tr>
<td>Metals and Ores</td>
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<td>0.0011</td>
<td>9</td>
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<tr>
<td>Petroleum</td>
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<td>15.36</td>
<td>0.0003</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
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<td>22.04</td>
<td>0.0001</td>
<td>6</td>
</tr>
<tr>
<td>Cumberland Chemicals</td>
<td>0.38</td>
<td>3.67</td>
<td>0.0514</td>
<td>14</td>
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<tr>
<td>Metals and Ores</td>
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<td>14.10</td>
<td>0.0007</td>
<td>13</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.82</td>
<td>22.54</td>
<td>0.0001</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>0.96</td>
<td>103.13</td>
<td>0.0001</td>
<td>12</td>
</tr>
<tr>
<td>Off River Grain</td>
<td>0.88</td>
<td>26.30</td>
<td>0.0001</td>
<td>25</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>0.79</td>
<td>28.10</td>
<td>0.0001</td>
<td>12</td>
</tr>
<tr>
<td>Metals and Ores</td>
<td>0.62</td>
<td>8.46</td>
<td>0.0034</td>
<td>15</td>
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<tr>
<td>Stone</td>
<td>0.72</td>
<td>13.18</td>
<td>0.0006</td>
<td>27</td>
</tr>
<tr>
<td>Chemicals</td>
<td>0.87</td>
<td>32.25</td>
<td>0.0001</td>
<td>5</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0.67</td>
<td>10.44</td>
<td>0.0015</td>
<td>26</td>
</tr>
</tbody>
</table>

### a. Mean Absolute Percentage Error.

Probably the strongest finding in the regression analysis is confirmation of the idea that an input demand function forms a firm theoretical basis for modeling waterborne commerce. This relationship is especially strong in the upper range of Tennessee River where the majority of waterborne commerce terminates. Elasticities of the earnings and residential oil consumption variables in this termination range are statistically significant in five of the seven equations. Support, however, is also found in the other terminations groups. On the upper range of the river, for example, barged wood chips are related to pulp and paper earnings; and petroleum shipments, principally asphalt, are related to contract construction earnings. Another example is in the off-river group where foreign grain purchases are significant. In summary, 13 of the 21 estimated equations contain input demand elasticities which are significantly different from zero at least at the five percent confidence level. Several less significant elasticities were also estimated in the study.

The transportation sector output proxy variable (TRANS) enters six equations, with estimated elasticities being highly significant in four equations and marginally significant in two equations. Interestingly, TRANS seems to be related to metals and ores terminations on all ranges of the river except the upper range which had no appreciable terminations in this group. The variable also appears in the chemicals equations estimated for the lower and off river ranges and in the Cumberland river asphalt equation. As noted, the TRANS variable could be capturing inventory adjustments, or possibly, serving as a proxy variable for waterborne transportation to industrial terminations not represented in the regression equations. This latter explanation might be particularly applicable to waterborne chemicals traffic which is diverse and has a potentially wide industrial distribution.

In the theoretical framework it was postulated that transportation costs enter the model in two manners: directly through the barge rate and indirectly through the shift by railroads to/from higher rated goods. Concerning the latter, it was argued that during periods of increased demand on the transportation system, railroads would move to higher-rated manufactured goods and away from primary goods. Barge transportation would take up the slack, but would lose this traffic during periods of declining aggregate demand.

In the regression analysis, the BARGE and EVAL variables enter the estimated equations with significant (at five percent) elasticities in six cases and in another case at a 14 percent confidence level. The barge variable enters the lower range grain and fertilizer equations and the off-river iron and chemicals equations. Interestingly, in two of three cases the EVAL variable enters equations where the BARGE variable is included—lower range fertilizer and off-river chemicals.

The special circumstances variables were utilized frequently in the regression analysis. These variables allowed the incorporation of prior information into the estimated equations such as the impact on petroleum traffic of barge/pipeline price competition. A good example of the application of these dummy variables is in the modeling of sand and gravel terminations in the lower range of the river. This traffic dropped markedly in 1974 due to the use of manufactured limestone as a replacement for dredged river sand in construction application. The dummy variable incorporates this information into the equation.

For simulation of the model, problems were encountered concerning the input demand variables, such as insignificant regression coefficients, coefficients of the wrong sign, and one equation with an elasticity value that was too large. Since it was critical that each equation incorporate this element of the theoretical structure, our mode operandi was as follows. If the input demand elasticity was of the correct sign, insignificant, but of a reasonable magnitude, it was left in the equation. Those values that were less than 0.0 or (in one case) greater than 3.0 were constrained to 1.0. The utilization of this constraint allows the incorporation into the model a crude approximation of reality that will cause the model to replicate data somewhat like the real world would. Although somewhat arbitrary, the confidence intervals of unconstrained input demand elasticities for these commodity groups on different ranges of the river either included or were proximate to the unity elasticity.

Like the regression results, the simulation analysis of WCESM was encouraging. Even though certain of the individual commodity MAPE values were high as would be expected in a microeconomic analysis that incorporates inventory adjustments and other factors, the aggregate (or macroeconomic MAPE values) were very low. Included in Table 1 are the mean absolute percentage error (MAPE) values for each of the 21 estimated equations. These values, calculated for the period 1972-1984, range from a high of 29 in grain terminations on the Upper Tennessee River to a low of five both for lower-Tennessee River petroleum terminations and off-river chemicals terminations. While several of the MAPE values are very high when compared with those of regional models of employment and earnings, the general lumpiness of waterborne traffic and the often lack of the inertia in waterborne commerce (as compared to that found in aggregate economic measures) contribute to the higher MAPE values. Additionally, in the Tennessee River application high MAPE values could be related to commodity movements by single firms or small groups of firms. Still, though, low aggregate MAPE values in the study are due to many individual MAPE values being low and prediction errors cancelling out.

<table>
<thead>
<tr>
<th>Destination</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>upper range</td>
<td>5.6%</td>
</tr>
<tr>
<td>lower range</td>
<td>4.6%</td>
</tr>
<tr>
<td>Cumberland River</td>
<td>9.3%</td>
</tr>
<tr>
<td>Off River</td>
<td>8.5%</td>
</tr>
<tr>
<td>Total</td>
<td>4.0%</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSIONS

The purpose of this research was to provide a modeling methodology that can be utilized to provide input into the planning for inland waterway system navigation projects. The framework for the analysis followed Howe's 1969 RFF model, but included additional variables for a more complete equation specification. For example, a national transportation output proxy variable was included in the equations in an attempt to explain waterborne commerce movements related to inventory expansion or contraction.

The results of estimating and simulating the model generally supported the framework, especially in the confirmation of the idea that an input demand function provides a firm framework for modeling waterborne commerce. In the estimation, 13 of the 21 equations contained input demand elasticities which were significantly different from zero at the five percent confidence level.

For certain of the equations, however, the estimated input demand coefficients did not enter as expected. The value was either negative, positive but insignificant, or too large. For simulation purposes, the input demand elasticity was constrained to unity in these equations, a value that was either proximate to or included in the confidence intervals for the input demand elasticity in related equations. Having the input demand variable in every equation causes the model to realistically replicate data, given that the input demand variable is the model's link to the regional and national "driver" models.

Evidence was also presented in the analysis to support other elements of the theoretical framework. Statistical significance of the national transportation output proxy variable is supportive of the proposition that inventory adjustments are a factor in certain inland waterborne commerce movements. The impact of transportation cost was also captured in the regression analysis. Barge rates entered the model directly and, indirectly, through the modal shift variable. Thus, some support was given to the proposition that during periods of increased demand railroads move to higher rated goods and away from primary goods.

Last, the model appears to provide good simulations of historical data and good forecasts. Through the period 1972-1984, the equations have predicted traffic with a 4.0 percent error rate. Through the period 1984-2050, the model is providing reasonable data in preliminary tests.