Contract Number W912HQ-04-D-007

Delivery Order #24 (6162.001.024)

Statement of Work:

Independent Peer Review: Shippers' Responses to Changes in Transportation Costs and Times: The Mid-America Grain Study

A Summary of Considerations and Recommendations for Incorporating the Results of "Shippers' Responses to Changes in Transportation Costs and Times: The Mid-America Grain Study" into the Army Corps of Engineers ESSENCE Model

by

Donald C. Sweeney II, Ph.D.
Associate Director
The Center for Transportation Studies
University of Missouri - St. Louis
154 University Center
One University Blvd.
St. Louis, MO 63121
(314) 516-7270
dsweeney@umsl.edu

Prepared for the U.S. Army Corps of Engineers
July 2005

Introduction

This report presents a brief summary of the model and results found in "Shippers' Responses to Changes in Transportation Costs and Times: The Mid-America Grain Study" authored by Kenneth Train and Wesley Wilson (2004a). It further provides considerations and recommendations on how their results can be incorporated into the framework of the Army Corps of Engineers ESSENCE model for use in the economic evaluation of potential navigation infrastructure improvements to the Upper Mississippi River and Illinois Waterway. This report is in partial fulfillment of contract number W912HQ-04-D-0007 delivery order #24.

Background

Prior to the pioneering work of the Upper Mississippi River - Illinois Waterway Navigation System Feasibility Study (UMR-IWW), Army Corps of Engineers (ACOE) inland navigation economic models incorporated an unrealistic "all or nothing" shipper's modal choice decision in the model framework. That is, each aggregated water shipper's total annual predicted volume, modal choice, and ultimate destination were insensitive to changes in water transportation rates until the point that the water rate increased to the level of the next best alternative transportation rate to the same destination. Then, at all water transportation rates greater than the alternative rate, the entire shipment was presumed to leave the waterway and move to the exact same ultimate destination using the next least costly mode of transport.

Due to the many obvious and serious shortcomings of this embedded model of shippers' decisions and the large geographic extent of the UMR-IWW study area, the Corps adopted a "spatial equilibrium" framework for a new economic system model for use in the UMR-IWW study. A Microsoft Excel spreadsheet model dubbed "ESSENCE" was developed to begin the transition to a spatial equilibrium based evaluation of shippers' decisions. Microsoft Excel was chosen as the platform for the ESSENCE model because it afforded complete transparency of the model calculations and contained a non-linear optimization solver module capable of identifying a systemic equilibrium. This spreadsheet model recognized for the first time in a ACOE navigation system economic model that individual water shippers could and would respond to changes in water transportation prices by altering the annual quantity of water transportation that they would demand in a less than "all or nothing" manner.

The ESSENCE model specified a flexible functional form to describe the partially aggregated demand curve of movements on the waterway. This demand function included the possibility that shippers might reduce their desired quantities of water transportation at rates less than their next best transportation alternative. The demand curve in the model could be shaped with a movement specific parameter to represent any specified own-price elasticity of each shipper's demand for water transportation that was accurate within the neighborhood of the existing water transportation rate faced by that shipper.

Because no definitive research or study data existed to guide the estimation of these values within the model, a range of hypothetical limiting values were ultimately employed in the UMR-IWW study. For example, to represent the range of unknown own-price elasticities for the demand for water transportation of raw agricultural products the ACOE explicitly used an elasticity of -1.0 as a "lower bound" estimate and an elasticity of -0.5 as an "upper bound" estimate in the ESSENCE model. In a different economic systems model they also employed the "all or nothing" shipper decision which is equivalent to an elasticity of 0.0 near existing water prices. These hypothetical values became the subject of much speculation and controversy because of the lack of any real world data or research to support these hypothetical limits.

The Train and Wilson paper presents a representation of grain transportation demand that is significantly broader and more complex and than the representation of transportation demand in any existing ACOE benefit model including the ESSENCE model. In a related paper (2004b), Train and Wilson suggest a methodology for implementing their modal choice models in ACOE planning models. I focus here on the incorporation of their shipper's modal choice model into the ESSENCE model and present three methods of doing so dependent on the availability of additional data that is not currently contained in the latest version of the ESSENCE model.

Review and Discussion of the Train-Wilson Survey Model

The work by Train and Wilson is the first ACOE sponsored study to directly address the issue of the own-price elasticity of the demand for grain transportation in particular or the demand for inland water transportation in general. It employs a rather sophisticated econometric analysis of data compiled from a survey of grain shippers' revealed and stated preferences, which has the advantage of basing the econometric estimations on the input of those actually making day-to-day decisions regarding grain movements. Further, the survey was designed to reduce possible biases often evident in such surveys when the respondents have a stake in the outcome of such a survey.

The authors performed a complex econometric analysis using the survey results as input into a theoretical shipper's modal choice model. In particular, the survey results formed the basis for estimating an econometric model based on current data of grain shippers' revealed best and stated next best preferences which in turn was ultimately used to estimate arc elasticities of shippers' responses to both rate increases and time increases of individual transportation modes. An interesting feature of these estimations is that they result in estimations of the percent of movements that would switch transportation modes or destinations in response to different rate or transit time increases and that the shippers' responses were essentially independent of their existing modal or destination choice.

I offer the following summary comments regarding the Train-Wilson survey:

- They may somewhat under estimate the own-price elasticities since they presume shippers can pass additional transportation costs to an ultimate buyer who may in fact not accept the price or time increase;

- They present an excellent exposition of the time of transit impact (independent of cost) on modal choice;
- They do not address the impact of variability in the time of transit on modal choice;
- Their results seem reasonable and consistent with the literature. Overall, grain shippers in aggregate are found to be fairly elastic (with respect to both transportation rate and transit time) near the existing transportation rate and transit time. As the rate (or time) is increased the arc elasticity decreases at a decreasing rate. This is intuitively reasonable and helps explain the pricing behavior of grain carriers;
- The first arc elasticity presented for a 10% transportation rate increase is -1.38 which is already less than the Corps' "lower bound" for grain elasticity used in the UMR-IWW study;
- When rate and time are considered together the overall arc elasticity (near the existing rate) is close to -3.0, which is significantly less than and more elastic than the Corps' "lower bound"; and
- Using the intrinsic symmetry of the survey, (the revealed preference is always alternative 1) the econometric results should be applicable to cost (or time) decreases as well as cost (or time) increases for small changes in these variables.

Considerations for Implementation in the ESSENCE Model

Any implementation in the ESSENCE model of the modal choice of grain shippers should be in keeping with the fundamental results of the Train and Wilson paper. I summarize their "top-level" findings for grain shippers in the following bullet items.

- Changes in transportation rates and changes in transit times both independently affect the level of shippers' demand for individual transportation modes and/or destinations. The arc elasticity of the probability of making a given modal and destination choice with respect to changes in transportation rates is typically greater than the arc elasticity of making the same modal and destination change with respect to changes in transit times.
- A large share of shippers is insensitive to changes in transportation costs and time.
- Arc elasticities decrease at a decreasing rate with larger percentage increases in both transit times and transportation costs.
- Annual shipping volumes of individual shippers also change in response to changes in transportation rates and times.

Data Requirements for Implementation of the Choice Model

The Train-Wilson model fundamentally operates at the level of individual water shippers. Consequently, to fully implement the Train-Wilson choice model in the ESSENCE model, the following data are required for each existing or potential water shipper.

1. Total water transportation rates including accessorial costs
2. Total transportation rates for the alternative mode and/or destination
3. Total transit time for water transportation including accessorial time

4. Total transit time for the alternative mode and/or destination
5. Total shipment distance for water transportation including accessorial distance
6. Total shipment distance for the alternative mode and/or destination
7. Commodity
8. The transportation mode (rail or truck) utilized to access the water terminal
9. The transportation mode (barge, rail, or truck) utilized for the alternative
10. Water transportation costs including accessorial costs as a share of product value
11. Years the shipper has been at its current location

Only total water and alternative transportation rates averaged by origin pool, destination pool, and commodity group are utilized in the current version of the ESSENCE model. Consequently, most of the data required for implementation of the choice model is not available at all or averaged over many individual water shippers.

Changes to ESSENCE Required for Implementation

The current ESSENCE model aggregates water shippers' demands by origin pool, destination pool, and commodity group. This aggregation was completed to minimize the size of the constrained non-linear optimization problem solved by the Excel solver module required to identify a systemic equilibrium. Further, the Train-Wilson choice model assumes that the shipper utility coefficients associated with the transit time and cost variables vary over individual shippers with these coefficients distributed over shippers as lognormal random variables. Therefore, a full implementation of the Train-Wilson choice model requires extensive changes to the ESSENCE model as well as substantial disaggregated data not currently directly available in the ESSENCE model.

Alternative Methods for Implementation in ESSENCE

I present two alternative implementations of the Train-Wilson choice model in the ESSENCE system model. The first implementation requires no additional data and only a few changes to the existing model. This simple implementation preserves the top-level results as described by Train and Wilson, but has the unwanted property of making the aggregated pool to pool, commodity specific demand for water transportation functions dependent on the alternatives faced by the shippers surveyed in the Train and Wilson paper rather than the explicit alternatives faced by the water shippers represented in ESSENCE.

The second alternative for implementing the Train-Wilson choice model requires important data not presently contained in the ESSENCE spreadsheet and also requires the addition of a simulation module to ESSENCE to simulate the responses of water shippers to changes in water transportation rates and transit times. The missing data required to fully implement the Train-Wilson choice model are:

- Total transit time for water transportation including accessorial time;
- Total transit time for the alternative mode and/or destination;
- Total shipment distance for water transportation including accessorial distance;
- Total shipment distance for the alternative mode and/or destination;

- The transportation mode (rail or truck) utilized to access the water terminal;
- The transportation mode (barge, rail, or truck) utilized for the alternative;
- Water transportation costs including accessorial costs as a share of product value; and
- The length of time in years the shipper has been at its current location.

The simulation module is required as the responses of shippers to changes in water transportation costs and times vary over individual shippers whose "true" responses are unknown but conditioned on a probability distribution of possible parameter values. Consequently, individual shippers facing identical transportation rates, times, and alternatives may respond differently to identical changes in those variables dependent on an unknown parameter described by a lognormal probability distribution.

A full implementation of the Train-Wilson choice model is clearly the better of the two alternative implementations and in my opinion is worth the required data collection. Only with a full implementation of the choice model will the differential alternatives faced by different water shippers play an important role in estimating shippers' response to changes in water transportation costs and times.

1. Implementation Using Extant ESSENCE Data

Since all the disaggregated data required for implementing the Train-Wilson choice model is not available in the current ESSENCE model, implementing the choice model within the existing model structure and available data necessarily involves some compromises with the full Train-Wilson choice model. I offer an implementation here that preserves the spirit of the Train-Wilson work, requires only minimal changes to the existing ESSENCE model, but has the serious drawback of not incorporating the diverse actual alternatives available to differentially located individual water shippers. This implementation of the Train-Wilson choice model employs the parameterized tabular combined cost and time responses present in Table 11 of Train and Wilson (2004a) and is described in detail in the example implementation section below.

2. Implementation Using Additional Data within the Existing ESSENCE Model Framework

The Train-Wilson choice model may be interpreted as a prediction of the share of shipments that will be sent by any given mode, given the rates, times, and other relevant characteristics for the given and alternative modes that are available from the ultimate origin location to the ultimate destination location. Therefore, their choice model readily aggregates to the level of water shippers who face the same times and costs from an ultimate origin to an ultimate destination and can be used to predict the average change in quantity shipped in response to increases or decreases in water transit times and costs.

Train and Wilson (2004b) offer a method based on appropriately aggregated average water shippers for implementing their choice model in all existing ACOE navigation system models. I have reviewed their suggested methodology and endorse their recommendations for incorporating their choice model into the ESSENCE model. Their implementation offers the distinct advantage of not requiring a complete rewrite of the existing ESSENCE model, but has the disadvantage of requiring additional data not currently available in the model and also requiring the addition of a simulation module in ESSENCE to estimate representative shippers' responses to changes in water transportation costs and times.

A possible alternative to including a simulation module to estimate representative shippers' responses to changes in water transportation costs and times would be to employ the estimated median (or mean) of the distributions of shipper cost and time coefficients as representative coefficients of the underlying lognormal probability distribution..

Some of the missing data (such as total transit times from ultimate origin to ultimate destinations) may be econometrically estimated using the existing Train-Wilson survey data; however some data (such as years the shippers have been in their current location or the identification of disaggregated ultimate origins and destinations) cannot be estimated from current data.

An Example Implementation in ESSENCE Using Existing Data

The Corps of Engineers supplied documentation of the ESSENCE Model is provided as an attachment. The discussion that follows notes the changes made to that version of ESSENCE to incorporate the Train-Wilson Results.

In order to incorporate the results of the Train-Wilson survey into the existing ESSENCE model results must be formulated such that the Shippers Response can be calculated for each grain movement within an Excel Spreadsheet, in a way compatible with the Solver add-in module. Further, we must be similarly able to calculate the contribution of each grain movement to the total NED benefits estimated by the model.

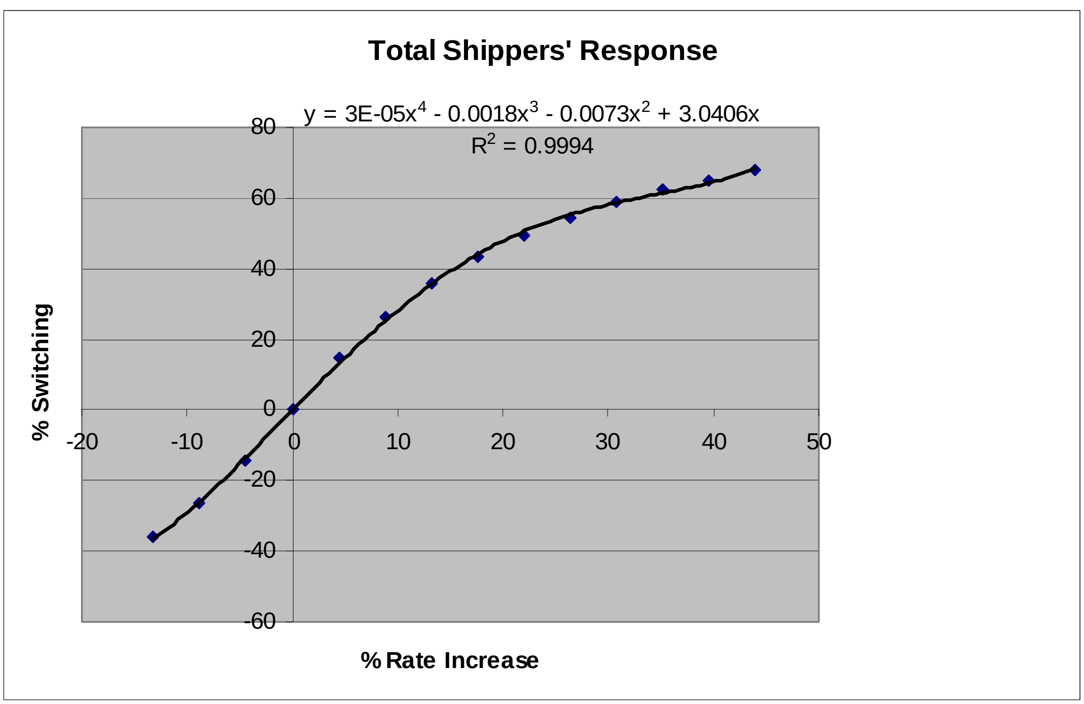
Train-Wilson estimated the shipper' response to both rate and transit time increases. The ESSENCE model, in its current configuration, does not incorporate total trip time. Therefore, it is advantageous to use the result from Train-Wilson that incorporates both the own-rate and own-time response into a single function of rate change alone. Further I assume that, since the Train-Wilson results are independent of which mode is primary and which mode is alternate, the results can (at least for small changes) be reflected across the origin and used to estimate a percentage volume increase for a corresponding percentage rate decrease. These results are displayed in the table below.

In order to incorporate the results into the current ESSENCE spreadsheet it is necessary to find a well behaved function that can used to approximate the tabular data. A well behaved function is required to ensure that the "Solver" add-in tool used in Excel to identify the system equilibrium will have a minimum of difficulties in identifying the equilibrium. After trying several possibilities a 4^{th} degree polynomial was found to provide an excellent fit to the data above.

“TOTAL RESPONSE” as a Function of Rate Only

SOURCE	Percent rate increase	Percent switching
Extension of results	-13.2	-35.85
Extension of results	-8.81	-26.37
Extension of results	-4.40	14.54
TRAIN-WILSON	0	0
TRAIN-WILSON	4.40	14.54
TRAIN-WILSON	8.81	26.37
TRAIN-WILSON	13.2	35.85
TRAIN-WILSON	17.6	43.45
TRAIN-WILSON	22.0	49.59
TRAIN-WILSON	26.4	54.61
TRAIN-WILSON	30.8	58.76
TRAIN-WILSON	35.2	62.24
TRAIN-WILSON	39.6	65.19
TRAIN-WILSON	44.0	67.71

The 4th degree polynomial approximation is displayed below.



Note that the percent of shippers switching modes or destinations is calculated based on the percent increase in the total water transportation rate which facilitates its incorporation into the existing ESSENCE model. It should be noted that the defined domain of this function is from a rate decrease of 13.2% to a rate increase of 44%, yielding a defined range of a 35.85% increase in traffic to a 67.71% decrease in traffic. This is a sufficient range for evaluating the economic impacts of the group of navigation alternatives considered in the Upper-Mississippi River-Illinois Waterway Navigation System Feasibility Study. The introduction of this formulation into ESSENCE is done as follows:

(1) The coefficients of the above polynomial are entered into the "inputs" worksheet as follows:

	A	B
	percent of traffic diverted polynomial coefficients	
43	b0	0.0000000000
44	b1	3.0405912849
45	b2	-0.0073435652
46	b3	-0.0017896126
47	b4	0.0000270465

(2) On the "equilibrium" worksheet of the ESSENCE Model a calculation is added into cells BB48:BB447 to compute the percentage rate change for the grain movements. This calculation is accomplished using existing ESSENCE model cells AX48:AX447 and AW48:AW447, the rate increase and the total (base) rate respectively. The calculation in cell BB48 is provided as an example:

	BB
	Percentage Water Increase
48	=(AX48/AW48)*100

(3) Another calculation is added to the "equilibrium" worksheet in cells BC48:BC447. This calculation uses the percentage rate increases in the BB column along with the polynomial coefficients discussed above to calculate, for each grain movement, the percentage of traffic decrease. The calculation in cell BC48 is shown as an example:

Note that the calculated value is multiplied by -1 indicating traffic declines with increasing rate.

	BC Percentage Traffic **Change**
48	=-1*(BB48*Inputs!$B$44+BB48^2*Inputs!$B$45+BB48^3*Inputs!$B$46+BB48^4*Inputs!$B$47)

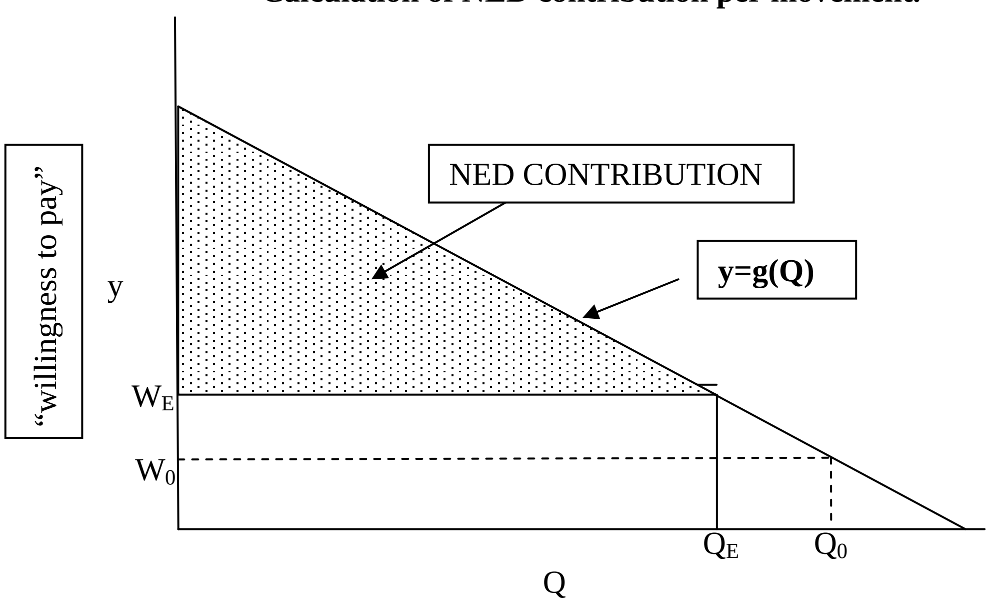
(4) The calculation of traffic in the cells G48:G447 is now accomplished using the baseline forecasts from cells E48:E447 in conjunction with the percentage of traffic chance from cells BC48:BC447. The example calculation from cell G48 is shown below:

	G
48	=MAX(0,E48*(1+BC48/100))

Note that this calculation of traffic replaces the calculation of traffic using the "N-value" formulation of the Corps' existing ESSENCE Model. The calculation of traffic for the non-grain movements are left in their original formulation. The above alterations are sufficient to allow the essence model to find an equilibrium condition. This is where the Excel Solver add-in is used to find the balance between traffic estimated by willingness to pay for additional units of output and the additional costs of lock delay caused by this same traffic transiting the navigation locks.

In order to use this altered model to estimate project benefits some further calculations must be completed. To do this we remember from the original ESSENCE documentation that the added National Economic Development (NED) benefits from a particular movement can be illustrated as follows:

Calculation of NED contribution per movement.



Where:

Quantity

W_E = Equilibrium Water Rate;
Q_E = Quantity Moved at Equilibrium Water Rate;
W_0 = Baseline Rate; and
Q_0 = Quantity Moved at Baseline Rate.

As illustrated above the per-ton contribution to system benefits from a movement may be expressed as:

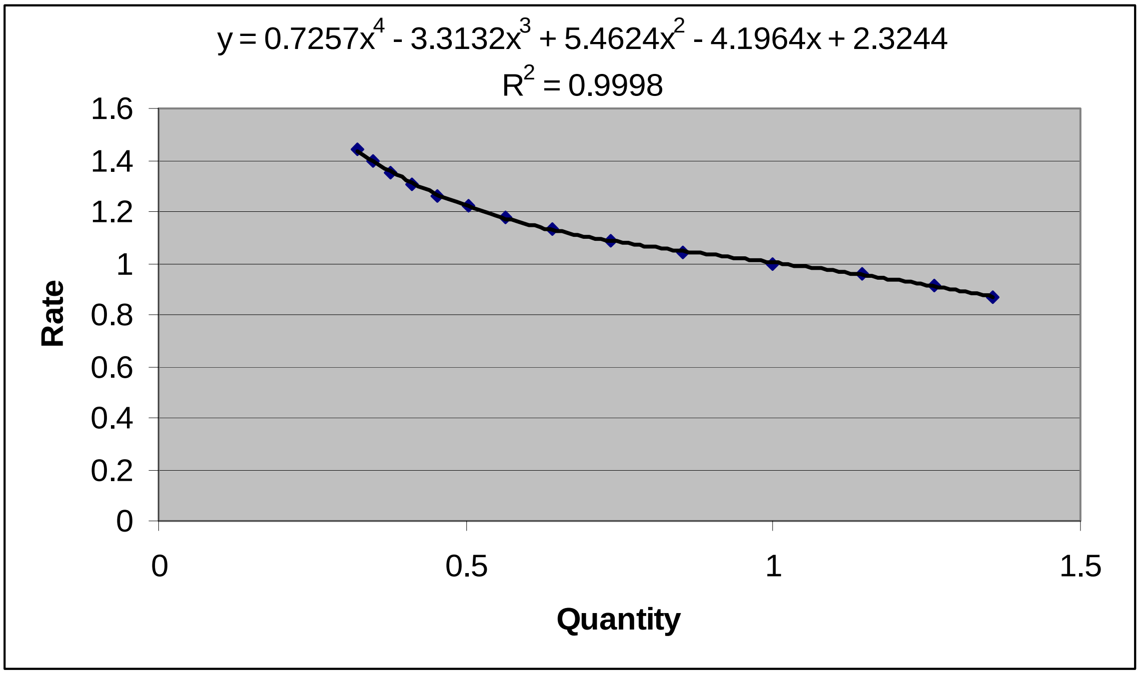
$$\textbf{NED} = \frac{1}{Q_E}\int_0^{Q_E}(y - W_E)dQ$$

Where y=g(Q) gives the total water transportation rate as a function of quantity.

To find a suitable form for y we return to the Train-Wilson results, but for convenience I now work in proportions rather than percentages, and rather than consider the proportion of shippers switching to their next best alternative I look at the proportion of shippers that do not switch. The results in this form are displayed below:

SOURCE	Proportion of Rate	Proportion of Shipments
Extension of results	.8680	1.3585
Extension of results	.9119	1.2637
Extension of results	.9560	1.1454
TRAIN-WILSON	1.0000	1.0000
TRAIN-WILSON	1.0440	.8546
TRAIN-WILSON	1.0881	.7363
TRAIN-WILSON	1.1320	.6415
TRAIN-WILSON	1.1760	.5655
TRAIN-WILSON	1.2200	.5041
TRAIN-WILSON	1.2640	.4539
TRAIN-WILSON	1.3080	.4124
TRAIN-WILSON	1.3520	.3776
TRAIN-WILSON	1.3960	.3481
TRAIN-WILSON	1.4400	.3229

Total Shipper Response (time & rate increase) as an (inverse) function of rate only



Note that since this calculation is expressed in proportions the actual water rate is given by $y*W_0$. As illustrated above an excellent fit to the Train-Wilson survey data results can be obtained using a fourth degree polynomial approximation. The polynomial can then be substituted into the integral above and integrated to yield the following solution for the per-ton contribution to NED benefits of each movement:

$[(b_4/5*Q_E^4 + b_3/4*Q_E^3 + b_2/3*Q_E^2 + b_1/2*Q_E + b_0)*W_0 – W_E]$; or equivalently

$[W_0*((b_4/5*Q_E^4 + b_3/4*Q_E^3 + b_2/3*Q_E^2 + b_1/2*Q_E + b_0) – W_E/W_0)]$,

where the coefficients (b4, b3, …,b0) are as defined above.

From a mathematical perspective the function is only defined over the domain of quantity proportions from approximately 0.32 to 1.40 so (as long as the model stays within the defined range discussed above) the integral will be incorrect by some constant value. This is not a problem for computing the benefits of a particular action, since the constant terms cancel in subtraction.

As previously noted the ESSENCE model will solve for the equilibrium water rate and associated tonnage. The necessary coefficients to evaluate the above are place in ESSENCE in the inputs sheet in cells B51 thru B55 as illustrated below.

	A	B
	consumers' surplus	
	integration coefficients	
51	b1	2.3244000000
52	b2	-2.0982000000
53	b3	1.8208000000
54	b4	-0.8283000000
55	b5	0.1451400000

The per-ton (unscaled) contribution to NED is then computed on the "equilibrium" worksheet of the ESSENCE in cells BE48:BE447. The calculation is illustrated below.

	BE
	Total Un-scaled Surplus per Water <u>Ton</u>
48	=((Inputs!$B$55*(BD48^5)+Inputs!$B$54*(BD48^4)+Inputs!$B$53*(BD48^3)+Inputs!$B$52*(BD48^2)+Inputs!$B$51*BD48)/BD48)-(1+BB48/100)

Finally this result is scaled by multiplying by the base water rate W_0 to provide the per-ton contribution to NED. This then replaces the previously calculated per-ton contribution to NED in cells H48 to H447. This is illustrated to for cell H48 below:

	H
	NED
48	=AW48*BE48

At this point the ESSENCE has successfully incorporated the spirit of the Train-Wilson results and can be used to evaluate waterway actions in exactly the same manner as the earlier version of the model as previously documented in USACE (2004).

References

U. S. Army Corps of Engineers (2004), Integrated Feasibility Report and Programmatic Environmental Impact Statement for the UMR-IWW System Navigation Feasibility Study, U.S. Army Corps of Engineers, Rock Island District, September, 2004.

Train, K. and Wilson W. (2004a), Shippers' Responses to Changes in Transportation Rates and Times: The Mid-American Grain Study, Institute for Water Resources, U.S. Army Corps of Engineers November, 2004.

Train, K. and Wilson W. (2004b), Implementation of Choice Models into ACE Planning Models, Institute for Water Resources, U.S. Army Corps of Engineers November, 2004.