# A GIS AND TRANSPORTATION OPTIMIZATION MODEL APPROACH TO POLICY EVALUATION

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## Abstract

This paper focuses on a transportation optimization model for wheat flows and blends a Geographic Information System (GIS) with a Generalized Algebraic Modeling System (GAMS) optimization package for allocating shipments on specific highway segments, rail, and barge. Pavement life expectancy, infrastructure maintenance costs, changes in modal use, highway flows, and shipper costs are quantified and displayed in the GIS platform for analytical evaluation.

## INTRODUCTION

A myriad of policy debates involving transportation infrastructure, production agriculture, environmentalism, business and trade, and economic welfare are currently underway in the Pacific Northwest. Among these debates are several of specific interest to residents of Eastern Washington where intense wheat and barley production comprise the predominant land use. In addition to heavy concentration of land allocated to production activities, significant economic activity and transportation demands are generated from the production, harvesting, and marketing of tremendous grain volumes. These immediate and far reaching ties to residents of Eastern Washington, therefore, create sizeable impacts when external or political stimuli alter the manner of grain production, harvesting, and especially, marketing.

Recent national rail mergers and consolidation has targeted several low density rail lines in Eastern Washington for abandonment or sale to shortline operators, creating shipping concerns for producers who rely upon rail transport, highway degradation fears for state transportation officials and highway users, air and noise pollution worries for environmentalists, and traffic safety issues for commuters and passenger vehicle operators. (Casavant and Mack, 1996)

Perhaps less problematic, but significant nonetheless, is the seasonal occurrence of grain rail car shortages. The problem arises from the seasonality associated with grain production, harvest, and transport. Favorable marketing conditions from September through February encourage producers to ship the majority of grain during these time periods, with considerably less grain movement the remaining six months. Consequently, the quantity of rail cars demanded is considerably larger during this time period.

Rail companies, however, invest in equipment (grain cars) with the anticipation of receiving a favorable return on investment, which is difficult if the rail car is not used throughout the year. Thus, to maintain a consistent return on investment, railroad companies attempt to purchase and allocate grain cars on a monthly basis, supplying a base number of rail cars throughout the year rather than supplying cars to meet peak demand. Unfortunately, the demand for grain cars is not evenly distributed throughout the year and a sub-optimal transportation system results as grain is diverted to other, often more costly, modes. (Freight Services Incorporated, 1993)

Environmental choices also impact grain flows, illustrated by recent attempts to save certain species of salmon from extinction. Regional residents involved with, and affected by, salmon recovery efforts in the Northwest realize the complexities involved with debating the competing interests between fish and man. History has favored man, especially in the Pacific Northwest, where the lock and dam system on the Columbia and Snake Rivers has generated an abundance of cheap electricity for businesses and consumers, plentiful water for irrigation in the agricultural sector, and cheap, easy access to ocean ports via river barge navigation from Lewiston, Idaho to the Pacific Ocean.

Certain salmon stocks have continued to decrease, to the point where four Snake River chinook and sockeye species are listed for protection under the federal Endangered Species Act. Since 1980, the Pacific Northwest has spent more than $3 billion trying to save the native fish from extinction, resulting in a multitude of strategies designed to improve salmon survival.

One strategy, known as a "river drawdown," involves lowering the water level, thereby increasing river flow and riverine habitat and hopefully, the salmon's odds of survival. Unfortunately, barge traffic would cease during drawdown periods, causing potentially adverse impacts on grain farmers who rely heavily on barge transportation and on state and local highways as river bound commodities take to the highways.

Paramount with each of these debates is weighing the positive and negative impacts for different constituents and having access to accurate, relevant information. This endeavor works toward that end by constructing a tool that provides information regarding grain producer and transportation infrastructure impacts, for these and other policy discussions. The tool is a transportation optimization model for commodity flows and blends a Geographic Information System (GIS) with a Generalized Algebraic Modeling System (GAMS) optimization package. After describing the model specification and optimization procedure, the model is applied to the salmon river drawdown debate mentioned above.

## OBJECTIVE AND APPROACH

This study's purpose is to empirically investigate shipper and transportation infrastructure usage for current Eastern Washington grain flows and in the presence of a Snake River drawdown. Changes in transportation flows and shipping costs in the 20-county grain production region of Eastern Washington (see Figure 1) are determined and graphically illustrated. A transportation optimization model, implemented through a Geographical Information System (GIS) incorporating grain movements originating from 695 township centers and passing through over 275 grain elevators en route to final destinations, is descriptively and analytically developed. Impacts on the producer's (private) cost of transportation are estimated and transportation flow changes on roads and highways are also presented. Shifts in modal reliance are also provided. Description of the data acquisition and modification procedures are first presented, followed by the transportation optimization model description.

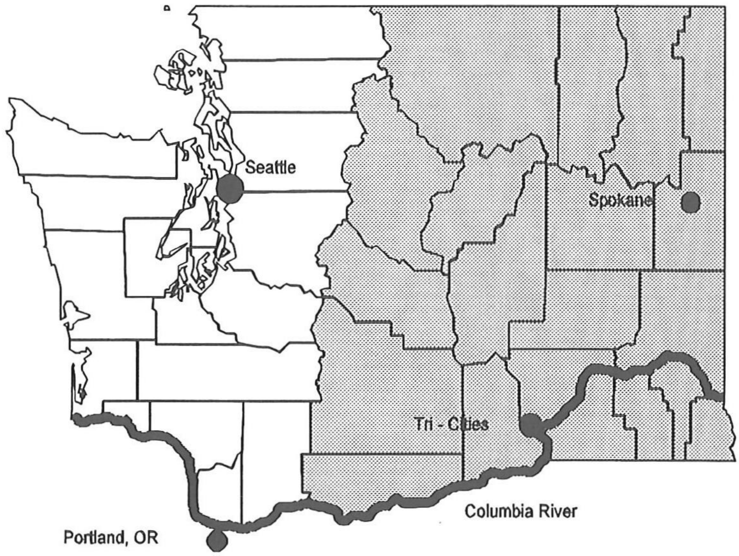



**Figure 1. Eastern Washington Study Area**

## INFORMATION SOURCES

The transportation and marketing system being modeled involves grain movements from production areas in Eastern Washington to feedlots and ocean ports for processing, consumption, and export. Intermediate destinations, such as elevators and river ports, serve as short- (and long-) term storage facilities, transfer stations, and points of consolidation. (Gillis, Jessup, and Casavant, 1995) Hence, information from each component of the system was needed on a common platform to facilitate investigation and analysis. The one common element for each component of the system being modeled is geography. The production areas, elevators, river ports, ocean ports, and transportation infrastructure (roads, highways, rail lines, barges) are all connected through geography, creating an ideal environment for a Geographical Information Systems approach.

The GIS coverages were constructed primarily from four sources, as illustrated in Figure 2. The Washington State Department of Transportation (WSDOT) provided GIS coverages for most county, state, U.S., and Interstate highways, in addition to active rail lines, and navigable waterways. (Jessup and Casavant, 1999) However, these files weren't entirely complete; missing road names and lower density county roads were added from U.S. Bureau of Census Topologically Integrated Geographic Encoding and Referencing (TIGER) files. WSDOT and TIGER file coverages were merged and edited to remove any coinciding arcs or needless road coverages, resulting in a complete and non-duplicative coverage of the road and highway transportation network. (Jessup and Casavant, 1999) The WSDOT no longer differentiates between U.S. and state highways, since both are maintained by the state. However, they are presented separately here, corresponding to the TIGER file classifications.

Additional information relating to the grain production areas and intermediate destinations (elevators and river ports) was obtained from the Agricultural Soil and Conservation Service (ASCS) and from an elevator survey sent to each of the 400 plus grain elevators in the study area. (Newkirk and Eriksen, 1995) Detailed data concerning on-farm storage locations and capacities, in addition to acreage and production estimates within each township, were obtained from the ASCS. (Jessup and Casavant, 1999) Elevator locations, capacities, handling and storage rates, and modal usage were acquired from the brief survey sent to all elevators in the study area. Over 90% of the surveyed elevators (96% of volume) returned completed questionnaires, providing valuable information on grain movements from production locations to final destinations and the modes utilized in the process. Transport rates for truck shipments were also obtained from the elevator survey. Rail rates were collected from Burlington Northern and Union Pacific, the two class I railroad companies operating in the region, and barge rates were collected from barge companies operating on the river.

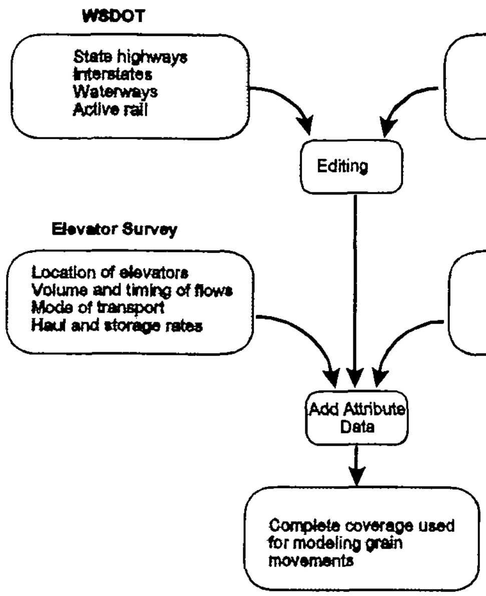



**Figure 2. Data and Information Services**

## OPTIMIZATION/MODELING PROCEDURE

Several GIS software packages designed for transportation modeling and analysis do provide some limited internal optimization features. However, the approach implemented in this analysis utilizes, for flexibility and robustness, an optimization package which is external to the GIS software. The process being modeled consists of two products (wheat and barley), utilizing multiple modal options and passing through multiple intermediate destinations along several route options to different final destinations. The complexity associated with this transportation system necessitates a modeling procedure with tremendous flexibility at each phase of the transport process. Therefore, the optimization software used to allocate grain shipments on various modes and routes is called GAMS, an acronym for Generalized Algebraic Modeling System, and is external to the GIS software, Arc Info.

The method used to combine the GIS with the minimum cost transportation model is presented in Figure 3. Arc Info is used to generate a collection of minimum distance node combination tables from township centers to elevators, township centers to ports, elevators to elevators, and elevators to river ports. These distance tables are then exported to an intermediate program, such as Quattro Pro and Fox Pro, to generate cost coefficients which are used as an input file in the GAMS optimization model. At each phase of the transportation process, multiple shipment alternatives are incorporated into the optimization model to provide maximum flexibility. Hence, should an optimization run, examining an alternative policy, preclude use of one route, the model still has several routing alternatives from which to choose. Once the set of minimum distance routes are compiled in Arc Info, and associated cost components incorporated in Quattro Pro, the GAMS optimization software is used to determine the least cost set of shipping routes.

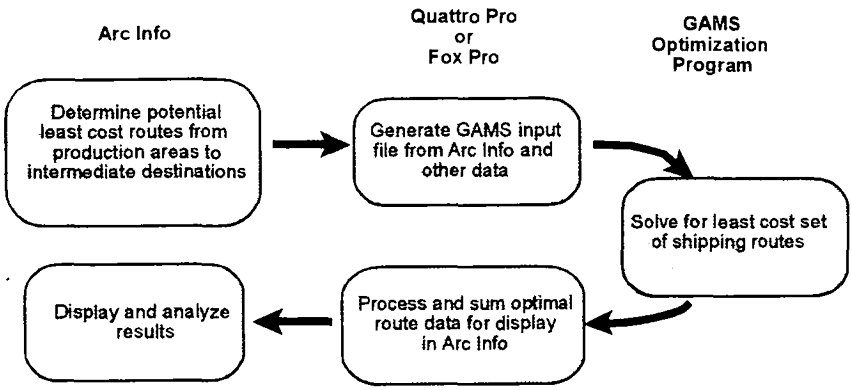



**Figure 3. Optilzation Methodology using GIS and external optimization program, GAMS**

Truck transportation cost coefficients were calculated by estimating a regression equation from elevator survey responses concerning truck transport cost per bushel/mile. Cost per bushel/mile decreases as distance increased initially, but then reaches a point where costs bottom out and then increases with subsequent increases in distance. This reflects the fixed cost of owning a truck and how that amount decreases per bushel/mile as it is spread across more miles. But as distance increases, truck operating expenses increase, causing truck transportation costs per bushel/mile to increase as well.

$$\textit{Wheat Truck Cost per Bushel Mile} = .001911 * miles + .036018 + .151866/miles \quad \textbf{Eqn. (1)}$$

The GAMS model is a linear programming model where the objective is to ship known quantities of grain from production points (township centers) to predefined destinations, while minimizing total transportation cost. The volume of grain supply (and demand) at each township (and final destination) is known. However, the volume of shipments on given routes and modes to reach the final destination is not known. The complexity increases with the introduction of intermediate destinations (elevators and river ports). The movement from production areas is predominately confined to truck shipments which generally haul directly to either river ports for barge transport or to elevators. Once the grain reaches the elevator, several possibilities exist for where and how it may move. If the elevator has rail access, the grain may be loaded onto rail for shipment to final destinations. If the elevator doesn't have rail access, then grain may be transhipped to another elevator with rail access or trucked to a river port for barge transport. The GAMS optimization model incorporates each of these modal shipment and route options at each stage of the grain marketing process, with the decision criteria at each juncture being cost minimization.

The optimization model also includes a variety of constraints which are constructed to maintain realism in the modeling process. A true optimization system would identify the origin points and the quantities to be shipped, the collection of possible routes on various modes, the cost associated with each route option, and the final destinations and then allow the linear program to solve for the least cost optimal solution. However, there are capacity constraints at the intermediate destinations which limit the amount of grain which can be handled at each location. There are also capacity constraints associated with usage of certain modes of transport, particularly for rail shipments. Therefore, to insure that these capacities and others relating to the origins and destinations are not exceeded, the following constraints are included in the optimization model.

## SUPPLY BALANCE EQUATION

$$\sum_{i=1}^{n} s_{ij} \le S_j \quad \forall\ j \qquad \textbf{\textit{Eqn (2)}}$$

Where $s_{ij}$ is the $i$th grain shipment from township $j$ and $S_j$ is the available grain supply produced in township $j$. Thus, the supply balance equation prevents the total amount of shipments from any township from exceeding the available supply produced within that township.

## NODE BALANCE EQUATION

$$\sum_{i=1}^{n} x_{ij} = \sum_{i=1}^{n} y_{ij} \quad \forall\ j \qquad \textbf{\textit{Eqn (3)}}$$

Here $x_{ij}$ is the $i$th grain shipment into the $j$th intermediate location (river ports and elevators) and $y_{ij}$ is the $i$th shipment leaving the $j$th intermediate location. Therefore, the total volume of grain flowing into intermediate locations must equal the amount flowing out of each location. This constraint abstracts from reality somewhat by preventing any grain storage. However, the analysis utilizes grain production and consumption volumes for the year and the majority of grain produced in a given year is marketed before the next harvest period.

## DESTINATION BALANCE EQUATION

$$\sum_{i=1}^{n} d_{ij} \ge D_j \quad \forall\ j \qquad \textbf{\textit{Eqn (4)}}$$

This constraint verifies that the sum of all shipments ($d_{ij}$) to the $j$th final destination is greater than or equal to the grain demanded at each final destination.

## ELEVATOR CAPACITY EQUATION

$$\sum_{i=1}^{n} x_{ij} \leq C_j \quad \forall\ j \qquad \textbf{\textit{Eqn (5)}}$$

This constraint assures that elevator capacity is not exceeded at any individual elevator. Here $x_{ij}$ is the $i$th shipment into the $j$th elevator and $C_j$ is the grain capacity at elevator $j$. Therefore, the sum of all shipments into a given elevator cannot exceed the capacity of the elevator.

Once the optimal shipping routes have been determined for the entire transport of grain from production locations to final destinations, truck shipments are assigned to individual highways for each segment throughout the transport chain. Traffic volumes are then summed for each individual highway arc, since truck shipments starting at different origin points, and traveling to different destinations may at times utilize common roads and highways. The truck traffic volumes on roads and highways can then be displayed geographically using either Arc Info or Arcview. Identification of highway segments with heavy concentrations of truck traffic are then easily identified in addition to illustrating changes in highway truck traffic flows from different policy scenarios.

## RESULTS

This portion of the paper presents results from the transportation optimization model concerning modal usage, highway grain flows, and transportation costs for wheat shipments. Two different scenarios are provided including (1) a base scenario depicting current grain flows and (2) a no-barge scenario where barge traffic is eliminated above the Tri-Cities. The total volume of one year's grain production (1994) is modeled, assuming no extended grain storage.

The total volume of wheat shipped via different modes for the base and no-barge scenarios is 132,836,124 bushels, as depicted in Table 1. Approximately 60 percent of this volume is shipped from production areas to elevators and the remaining 40 percent shipped directly to river ports via truck. This proportion is practically the same for both scenarios, indicating that sizeable amounts of grain would still be trucked directly from production locations to river ports at/or below the Tri-Cities in the absence of river navigation above the Tri-Cities. The largest change in modal usage for wheat shipment in the presence of a river drawdown would be the elevator to river port shipments which would switch to rail. Elevator to river port shipments decrease 21 percent while elevator to Portland via rail shipments increase by roughly the same percentage. In terms of absolute change, 28.3 million bushels of wheat would switch from barge to rail.

Total transportation costs for all wheat shipments is $65,901,176 and $67,205,885 for the base and no-barge scenarios, respectively, as illustrated in Table 2. The $1.3 million increase in shipper transportation costs amounts to slightly less than 1 cent/bushel, illustrating very little change in region-wide shipping charges. However, this represents somewhat of an "averaged" cost per bushel shipping charge indicating that certain shippers (especially those that switched to rail) would be more adversely impacted than others.

Separating the total wheat transportation cost into the different origin-destination type components helps illuminate which shippers are most dramatically impacted with Snake River access, as illustrated in Table 3. Per bushel shipping costs increase slightly for farm to elevator shipments, illustrating the slightly longer distance shippers must travel to reach elevators with rail access. Farmers whose least cost shipping alternative continues to be directly from farms to river ports experience the largest increase in transportation costs with more than a 6 cent increase. Elevator to elevator transportation costs increase 2 cents per bushel, as transhipments are forced to travel further to reach elevators with rail access. However, transportation cost for elevator to river port shipments decreases 2.7 cents per bushel, since those elevators which continue to ship to river ports (below the Tri-Cities) are the ones which are relatively close to the Tri-Cities. Transportation costs for rail shipments from elevators to Portland also decrease slightly. This is likely due to a larger proportion of wheat being shipped to elevators with larger rail loading capacity, and therefore, lower rail rates. The 1.4 cent per bushel decrease in transportation cost for river port to Portland barge shipments is due to the shorter distances barges travel when the ports above the Tri-Cities are accessed.

Base scenario flows for wheat shipments are also concentrated on key roads and highways heading to river ports along the Snake/Columbia River (Figure 4). Wheat highway flows are substantially altered with a river drawdown as more truck shipments head for the Tri-Cities, as illustrated in Figure 5. Without barge access above the Tri-Cities, wheat flows funnel into State Route 395, the primary corridor into the Tri-Cities and the accessible river ports.

## CONCLUSION

The primary focus of this research study has been the development of a tool for evaluating impacts to different constituents regarding transportation infrastructure, production agricultural, economic, and environmental policy issues currently confronting Eastern Washington residents. The transportation optimization model (tool) uniquely blends a Geographical Information System with an external GAMS optimization capability, resulting in a modeling approach that offers improved flexibility and robustness to commodity flow and transportation infrastructure analysis. Visual identification of traffic flow changes in addition to enhanced data detail capabilities through the use of a GIS provides an appealing argument for this type of modeling approach.

Applying this model to the Snake River drawdown issue provides timely information regarding impacts to producers (in terms of changes in transportation cost) and transportation planners (in terms of altered truck traffic flows). Total transportation cost for transporting wheat from production locations to final market increases $1.3 million without barge access above Pasco. When spread across the 132 million bushels produced in Eastern Washington, this amounts to about 1 cent/bushel. Truck traffic flows no longer concentrate on several corridors to river ports as they do with the base scenario, but instead become concentrated on a few routes to Pasco, Washington.

Other policy issues can readily be addressed with this tool, including rail car shortages for grain shipments, road closures during selective time periods, rail line abandonment, and changes in truck (vehicle) size and weight configurations for commodity shipments.

Table 1. Wheat Flow Modal Distribution (bushels)

| Scenario | Truck | | | | Rail | Barge | Total |
|---|---|---|---|---|---|---|---|
| | Township to Elevator | Township to River Port | Elevator to Elevator | Elevator to River Port | Elevator to Portland | River Port to Portland | |
| Base | 78,098,753 | 54,737,371 | 40,276 | 51,102,369 | 26,996,384 | 105,839,740 | 132,836,124 |
| (Percent of Total)* | 59% | 41% | .03% | 38% | 20% | 80% | |
| No-Barge | 78,288,953 | 54,547,171 | 595,817 | 22,921,729 | 55,367,224 | 77,468,900 | 132,836,124 |
| (Percent of Total) | 59% | 41% | .4% | 17% | 42% | 58% | |
| Absolute Change | + 190,200 | - 190,200 | + 555,541 | - 28,180,640 | + 28,370,840 | - 28,370,840 | |

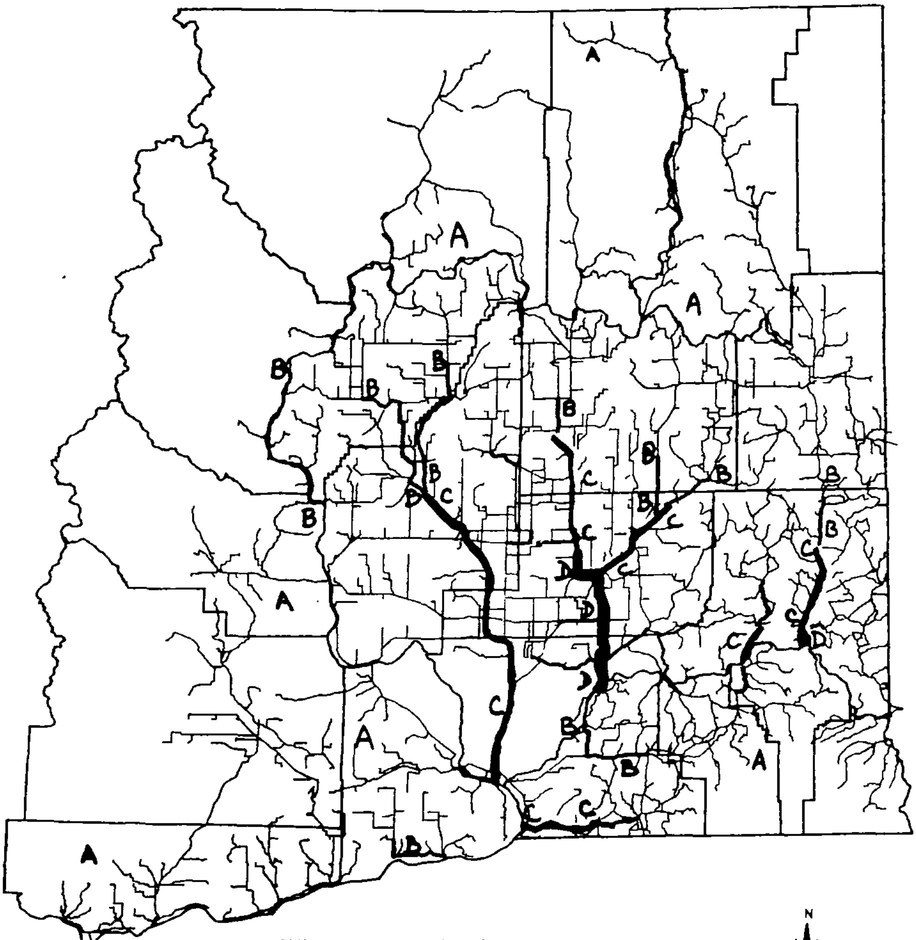
* Does not sum to 100% due to double counting.

Table 2. Wheat Transportation Cost

| Scenario | Total Transportation Cost ($) | Total Transportation Cost/bu. (cents/bushel) |
|---|---|---|
| Base | 65,901,176 | .4961 |
| No-Barge | 67,205,885 | .5059 |

Table 3. Wheat Transportation Cost by Origin-Destination Shipment Type

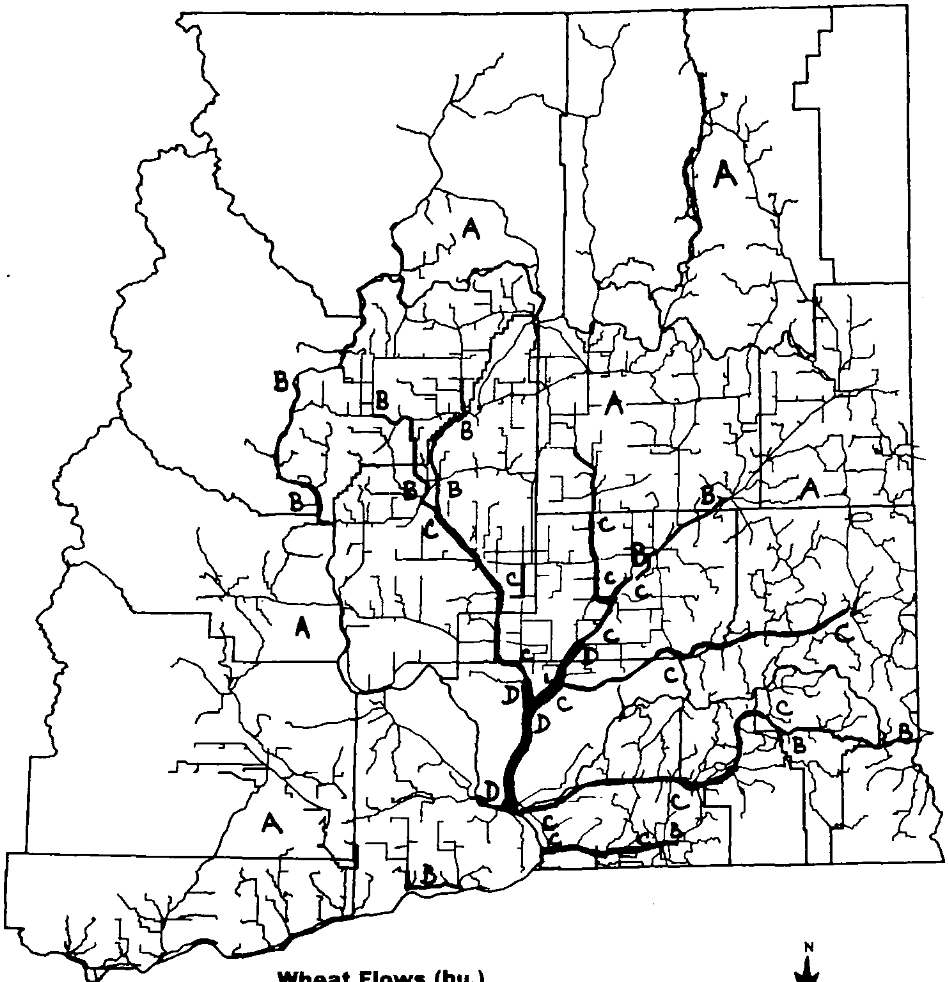
| O-D Shipment Type | Base Transportation Cost (cents/bushel) | No-Barge Transportation Cost (cents/bushel) | Change (cents/bushel) |
|---|---|---|---|
| Farm to Elevator | 22.8 | 23.1 | 0.3 increase |
| Farm to River Port | 14.1 | 20.3 | 6.2 increase |
| Elevator to Elevator | 15.2 | 17.2 | 2.0 increase |
| Elevator to River Port | 20.7 | 18.0 | 2.7 decrease |
| Elevator to Portland | 33.7 | 33.3 | 0.4 decrease |
| River Port to Portland | 19.5 | 18.1 | 1.4 decrease |



**Wheat Flows (bu.)**

| | |
|---|---|
| **A** | **1 - 2,000,000** |
| **B** | **2,000,001 - 5,000,000** |
| **C** | **5,000,001 - 15,000,000** |
| **D** | **15,000,001 - 40,737,357** |

**Figure 4. Optimized Wheat Flows on Eastern Washington Highways (Base Scenario)**




**Wheat Flows (bu.)**

| | |
|---|---|
| **A** | **1 - 2,000,000** |
| **B** | **2,000,001 - 5,000,000** |
| **C** | **5,000,001 - 15,000,000** |
| **D** | **15,000,001 - 40,737,357** |

**Figure 5. Optimized Wheat Flows on Eastern Washington Highways (No-Barge Scenario)**

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