Integrated Freight Network Model

A GIS-Based Platform for Transportation Analyses

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Contents

Abstract

The models currently used to examine the behavior transportation systems are usually mode-specific. That is, they focus on a single mode (i.e. railways, highways, or waterways). The lack of integration limits the usefulness of models to analyze the intermodal movement of freight. This project developed a GIS-based model of the three primary surface modes as well as intermodal connections. The resulting Integrated Freight Network Model (IFNM) accommodates highly detailed about shipping costs, transfer costs, traffic volumes (including non-freight auto traffic), and network interconnectivity properties. As a proof of concept, the research team conducted an exploratory analysis that asked what the potential impact would be to Kentucky highways if approximately half of the freight currently transported by barges on the Ohio River were shifted onto trucks. Coal-haul roads in the northeastern and western part of Kentucky would be particularly hard hit by a broad scale modal shift. The IFNM highlighted that roads emanating from the Western Coalfields would experience explosive growth in freight transport, with the proportion of trucks relative to overall traffic significantly increasing. Applying the IFNM to a range of freight-related transportation questions could greatly enhance system efficiencies and positively impact local economies and environments.

Introduction and Problem Statement

Many freight shipments are multimodal – meaning over the course of its journey, freight will move across some combination of highways, railways, and waterways. But the existing transportation system models of freight networks (including GIS-based models) are largely mode-specific. For highways, models are often state-specific; individual states have customized GIS's of their highway systems and associated freight movements. That is, almost all of the freight network models are not integrative, nor are they multimodal. They rely on discrete networks so that freight movements are modeled across a single mode, but they terminate at destinations or intermodal connection points. Rail, highway and waterways movements are thus tracked and evaluated using independent statistiscal and GIS models. This is problematic because we have no way to track movement across transportation modes, which hinders transportation planners' ability to devise the most efficient use of the available modes and determine when the most effective route is multimodal. This may create systematic inefficiencies throuhgout the US freight transportation system.

This research project constucted a national multimodal GIS. While national in scope, there is emphasis on freight movements in the Kentucky portion of the Ohio River Valley. Future research could incorporate more detailed data from other regions into the model. This GIS-based Integrated Frieght Network Model (IFNM) developed by the research team can spatially model mode substitutions across the primary surface freight modes—railways, waterways, and highways—as well as across multiple commodities. It can address questions such as: If, for example, the capacity of the Ohio River were to be severely impaired by a lock and dam failure, how would particular shippers react in the short-, medium- or long-term? What percentage of commodity volumes would no longer move or transition to alternative modes? In turn, what would be the associated impacts of those shifts? If an additional 100 truckloads per day of coal appeared on a portion of the highway network, how would it be distributed across that network? What would the congestion, safety, maintenance or other impacts be? In current practice, such analyses are focused on one mode, with scant attention paid to how substitution beween modes affects overall network dynamics and functioning.

Before starting model development, we addressed some problems with the current data files. For example, the data about the navigable waterways system, which is largely maintained by US Army Corps of Engineers (USACE), consists of GIS files that are spatially fragmented and sometimes lack congruent data fields. We also grappled with the issue of proprietary information. Commodity movement data exists in voluminous raw form, but when it is compiled, its arrangement and display must be customized to protect the confidentiality of private sector firms. Moreover, much end-to-end commodity movement data is incomplete and fragmentary, which poses challenges for validating model accuracy. And, of course, commercial freight data is expensive to acquire and are beset by internal inconsistencies as well.

Project Goals and Tasks

We designed and constructed a detailed an integrated GIS model of the highway, rail and waterway freight networks in the Kentucky portion of the Ohio River Valley. This was nested within in a more generalized national model. During the preliminary phase of research, we identified and acquired the appropriate data to facilitate model development. We focused on data that would let us holistically characterize the operation of the national freight network. Data sources included:

1. Existing state highway GIS files,
2. State truck freight models,
3. USACE waterway GIS files,
4. USACE waterway commodity movement data,
5. Where available, commercial freight movement data,
6. Port survey data,
7. State-based rail files.

Data fell into two broad categories.
A) **The physical characteristics** of the integrated networks, which included alignments, movement speeds and patterns, the location and characteristics of intermodal connections, and transfer capacities and times, among other variables, and
B) **The commodity movements** across the networks, and the data used to characterize those movements—for example, commodity type, volume, speed, cost, and reliability. This second family of data consisted of actual or observed behavior of freight movements. Conversely, the physical characteristics were roughly analogous to LOS data for highways (and in this case could actually include that).

This project built projects we are currently working on for the Kentucky Transportation Cabinet (KYTC) and the U.S. Army Corps of Engineers (USACE). This work attempts to understand the impacts of modal shift within the State of Kentucky. Because the Kentucky data are more readily available, they assist with the preliminaty testing of concepts that could eventually serve as the baseline for future projects that could involve more states, more modes, and more fine-grained data. Current data, however, are adequate for coarse comparisons, which can be made between Freight Analysis Framework (FAF3) data and the customized segment data supplied by USACE to explore the degree of correspondence between the two data sets, and to begin identifying use patterns for the waterways portion of the integrated model.

We addressed three major challenges during the course of this research:

1) We devoted significant effort to rectify and harmonize widely varying and incompatible GIS data files and fields. For example, existing USACE GIS river files were partitioned into multiple spatial segments that lacked harmonized data fields. The USACE's existing database of river ports was badly out of date, it was updated through a coordinated survey jointly conducted by the University of Kentucky and University of Louisville to provide higher quality port data. If this model is eventually extended throughout the Ohio River Basin, future surveys will be necessary to capture new data about ports across the region; once completed, the data obtained from these surveys will provide coherent information an expanded model could be populated with. Another issue to resolve in future work is that each state's highway GIS files will likely have incompatible data fields, both in terms of physical properties and usage.

2) Administration of the shared model was carefully performed so all parties could benefit from it, while leaving the option to protect any data as needed. A multimodal model that represents freight network operations across segments of the transportation regulated by private, state and federal authorities required us to navigate a complex landscape of complex bureaucracies to secure access to the necessary data. This concern for security will let universities cooperate in the development of interlocking portions of the overall model in the future. For example, Marshall University could provide data on the highway and networks of West Virginia, and the University of Louisville could extend the aforementioned port survey to include more ports and more detailed data about them for a broader extent of the Ohio River Valley.

3) Characterizing freight network movements across an integrated network required not just data, but also the expert knowledge of people familiar with waterways operations and truck-based freight movements. Initially, the model was limited to freight movements on highways and waterways. Further refinement and research during future project could pave the way for the collaborative integration of rail models, perhaps with other University Transportation Centers (UTCs) focusing on rail movement.

A Two Phase Work Plan

Project work was divided into two phases. The first phase, which consisted of three tasks, entailed identifying partners, accessing needed data, and formulating strategies to reconcile formatting discrepancies so that information could be integrated into a single model. The second series of tasks focused on creating the GIS model, sharing it with partners for review, and validating its output.

Phase 1
1. Identify potential partners in Ohio River Valley Network Freight Model (e.g., Universities, State DOT's, USACE)
2. Design the administrative form and data sharing properties of model
   a. Compile Meta-data Guidelines
3. Solicit and process data from partners

Phase 2
4. Assemble draft GIS form of model
5. Review with partners
6. Finalize GIS model
7. Identify and solicit freight system data from partners
8. Determine potential modes of application to GIS system
9. Review with partners
10. Conduct modal substitution or other integration pilot test

Collaborators and Activities during Phase 1

The project forged collaborative partnerships between the University of Kentucky and other UTCs, state departments of transportation (DOTs), and the USACE. In each case, collaboration was primarily geared toward acquiring and sharing GIS-based data to understanding how the multi-modal freight network could be best represented and assessed. This collaboration facilitated the successful completion of the three tasks of phase 1.

The project team worked extensively with:
- Representatives of the USACE from Huntington, West Virginia
  o The USACE Data Center in Huntington provided Ohio River Line files to support the creation of the waterways portion of the network
- The University of Tennessee (UT) Center for Transportation Research
  o Staff at UT provided data and technical assistance
- The Kentucky Transportation Cabinet
  o KYTC provided highway lines files and a copy of their latest Freight Network Model for use in the project
- The West Virginia DOT
  o Staff committed to provide its highway line file, as did the Ohio DOT
- The Nu-Rail UTC
  o Dr. Reginald Souleyrette of the University of Kentucky Civil Engineering Department assisted in the provision of rail system data to be incorporated into the IFNM.
- The University of Louisville (U of L)

o   UL furnished the results of its survey of Kentucky River ports

Collaboration and Activities during Phase 2

- Tasks 4, 5 and 6 called for drafting, reviewing and finalizing the GIS Model. Accomplishing this entailed by cleaning up and integrating line data related to waterways, rail, and highway that originated from multiple sources. This resulted in a fully integrated, multimodal GIS network capable of dynamically routing commodities based on route impedance information attached to the network links. Mode impedances were estimated from EIA data and other sources to improve the robustness of routing algorithms.

- During Task 7, we identified and analyzed freight system data. We incorporated the available commodity flow data along the Ohio River Basin system, and then synchronized the GIS network with KYTC's Freight Network Coal Haul Road data. The team solicited Rail Waybill data for Kentucky, with the assistance of the Cabinet. Where available, rate and shipping cost information were updated based on data from the Uniform Rail Costing System (URCS) and the Barge Costing Model (BCM).

- Work during Task 8 centered on determining potential modes of application to the freight network system. We investigated several of these applications, first by coordinating with KYTC to see decide whether the IFNM can support the Cabinet's Freight Planning needs under MAP-21 requirements. Then, we explored a method of supporting the USACE's Huntington Navigation Center through the development of forecasted Coal Routing mapping. As part of Task 8, we assisted in the management of the Supplemental Port Survey conducted by U of L. U of L used industry-sourced data to enhance its survey-based information. These data were augmented that with Google-Earth-based inspection that attempted to improve the accuracy of facility location and material handling estimates for inland navigation ports.

- Task 9 called partners to review our ongoing work. We regularly consulted with partners throughout model development..

- Task 10 involved a pilot test, which the next section describes in detail.

Case Study: Using the Integrated Freight Network Model to Assess the Impacts on the Kentucky Highway Network of a Shutdown of Ohio River Navigation

This section describes our application of the IFNM to determine what consequences would emerge if disturbance completely shut down of barge traffic on the Ohio River in Kentucky. This analysis is exploratory and based entirely on a hypothetical scenario. It represents an initial effort determine the highway network's response if there were to be a sudden influx of freight from the inland waterway system. A number of USACE-funded proprietary studies have looked at this issue, however, our goal here is to use the capabilities of the IFNM to gain some better insights into of the impact inland-waterways-based navigation on the Kentucky highway system.

To do that, our first assumption was that the commodities currently shipped on the river would be transferred to the most appropriate and available highways. The IFNM then predicts changes in patterns of truck traffic on particular highway segments with the aim of identifying areas of the highway network that would be significantly impacted by freight diversions . This kind of analysis is not currently done. Past USACE studies gathered expressed preferences for alternative shipping modes based on interviews with industry officials, however, they did not model actual network effects. These studies evaluated the additional shipping costs industries would incur by switching freight to alternative modes, without estimating the distribution of traffic, and thus the impact, on specific routes on the highway system. Tacking these questions, it should be noted, is beyond the remit of USACE's formally permitted impact analyses process (U.S. Water Resources Council 1982). Consequently, we explored this relationship through use of the IFNM.

This case study provides spatially explicit estimates of potential freight volume changes on Kentucky's highway freight network if a certain proportion of existing inland waterway traffic shifted onto the state's highways. Because two-thirds of the freight originating on the Ohio River System also terminates on it, it provides back-and-forth transportation service more akin to a portion of an integrated transportation system, as compared to the Mississippi River System, which markets much more heavily in commodity exports. Our model relied on a customized Origin-Destination commodity movement summary supplied, upon request, by the USACE Navigation Data Center in Huntington, WV. This Kentucky Origin-Destination Waterway Summary (KODW) consists of a set of origins and destinations. These are defined on each shore of specific reaches of the river systems in or bordering Kentucky, including portions of the Ohio River, Big Sandy, Green, Tennessee, and Cumberland Rivers. These stretches were often, but not always, defined by existing lock and dam pools, and also by the state boundaries of Kentucky. The commodity breakdown used the standard nine categories of river commodities: 1) Coal, 2) Petroleum, 3) Chemicals, 4) Rock/Gravel/Ores, 5) Primary Manufactured Goods, 6) Food and Farm Products, 7) Manufactured Equipment, 8) Waste, and 9) Other. For example,

the requested database could potentially contain information that detailed how much coal entered the river on the Kentucky shore of Reach "2" and that also left the river on the Indiana shore of Reach "4." Similarly, any such combination of the nine commodities and the 17 reaches x 2 shores could be in the final KODW.
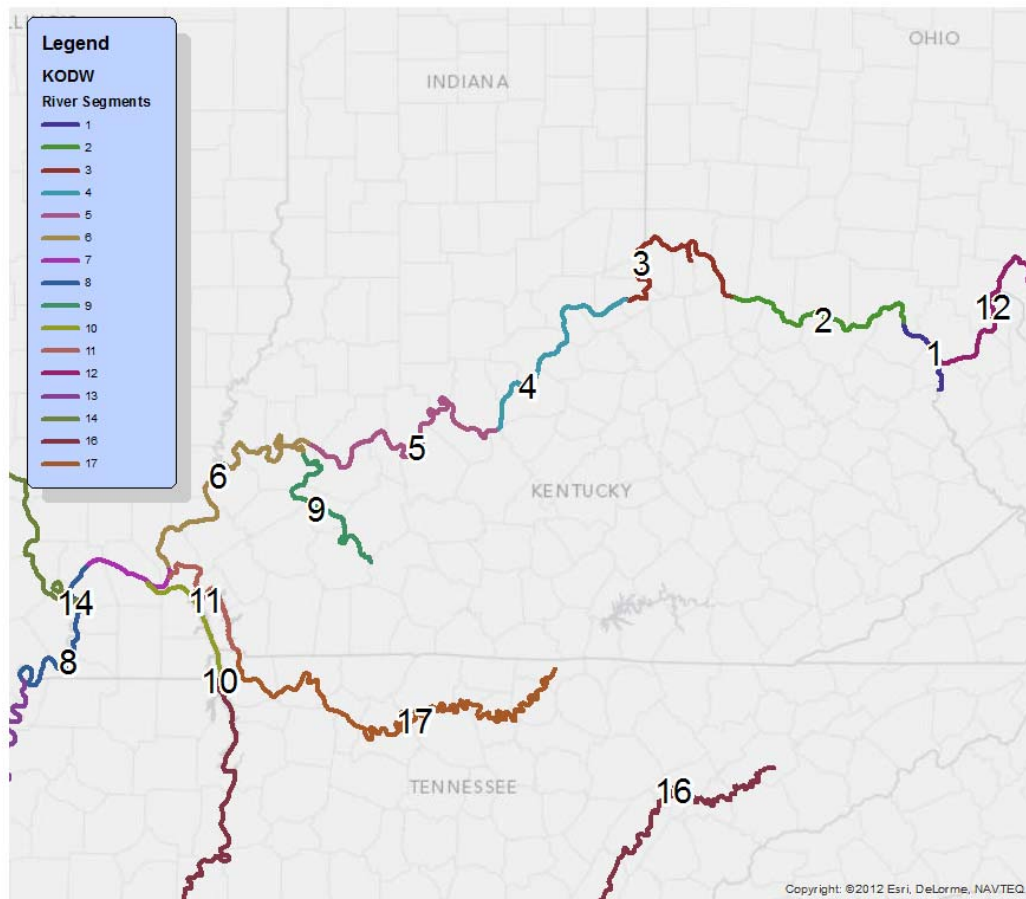

Figure 1: Kentucky Origin-Destination Waterway Segments

Critically, we defined the reaches to understand freight flows and diversions in Kentucky, particularly; our goal was not to develop a comprehensive understanding of all movements relative to the inland waterways system. Also, USACE compiled the request to maintain the confidentiality of carriers, which resulted in the redaction of some origin-destination (O-D) volumes. Comparing FAF summary data with the specific values contained in the KODW summary suggests that the data values received represent between 40-50% of the total freight volume moving on the Ohio River System. Thus, it can be used to begin an assessment of the transportation value, or impact, of inland river movements in the Ohio River Basin. This preliminary assessment does not attempt to impute shipping cost savings as are typically done to assess lock outages. Our interest is in the pattern of potential state and/or regional public

sector transportation impacts that would result from the loss or diminution of inland river transportation.

We converted KODW movement data into equivalent truckloads and introduced this onto the Kentucky Freight Focus Network (KFFN) (Fig. 2). In freight network terms, each O-D reach was treated as a freight generator, with the actual loads introduced and distributed across the relevant portions of the truck network in proportion to their existing traffic. These simplifying assumptions could be modified as better data about each port clarifies the exact nature of the intermodal commodity connections available on the combined network becomes available, and thus where specific kinds of commodities could in fact move.
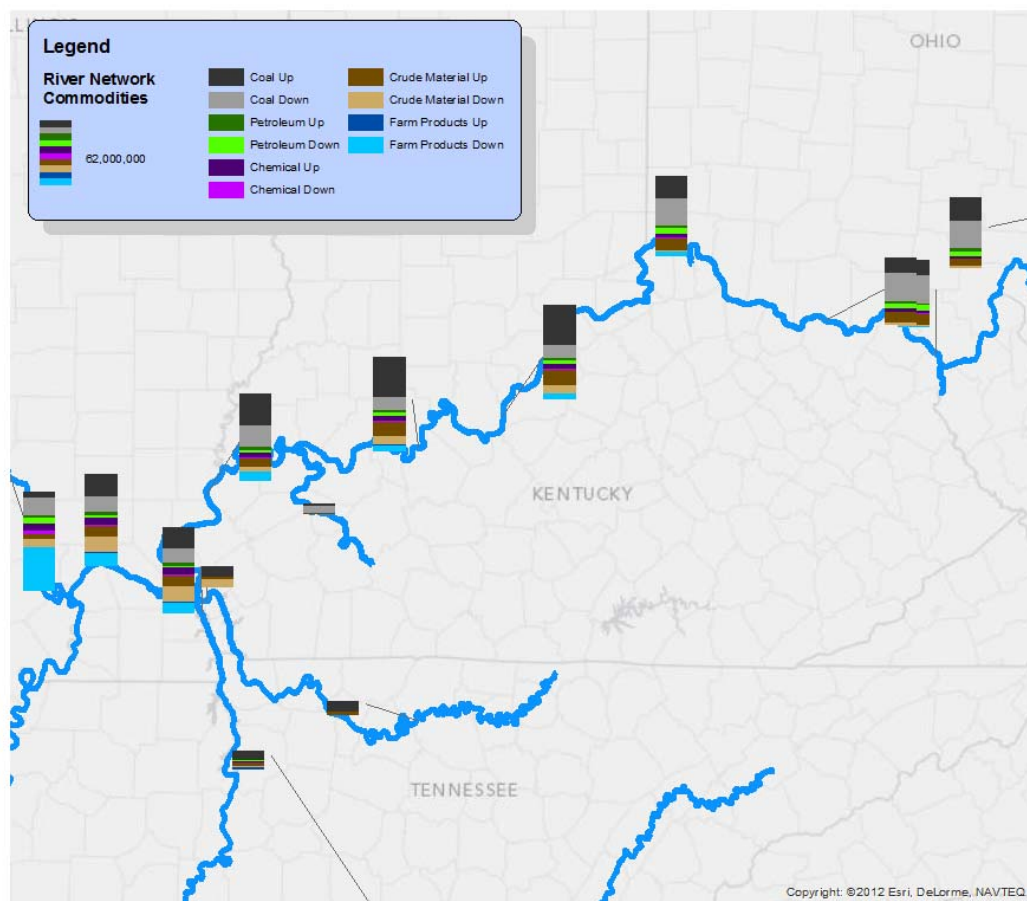
Figure 2: Ohio Basin Commodity Flows Based on the KODW data.

This KODW data is not exactly a subset of FAF data, however. Whereas FAF data reports O-D freight movements at a regional scale, the KODW Summary reports only the movements along the waterways. Thus, a portion of these freight movements represents only one segment of a larger movement. This difference reveals interesting outcomes. For example, the 2002 FAF

data indicates ≈ 3 million tons (about 2% of all freight by weight in Kentucky) of waterborne freight moving each year in Kentucky, whereas the KODW Summary indicates the 'Kentucky shore-to-Kentucky shore' waterborne freight is nearly matched (2.9 Million Tons) merely by the volumes incoming to reaches "4" and "5", a 150-mile stretch between the Markland and Newburgh Locks and Dams. This segment is located between Cincinnati and Owensboro, with its center located near Louisville. If movements within the same reach are included (e.g., Reach 4 to Reach 4 then the reported quantities portion of the KODW Summary totals over 5 million tons for 'Kentucky shore-to-Kentucky shore' (KYTC, 2007, p. 8). Even this is not the total, because as mentioned, a certain portion of the total flows is redacted. Apparently, including the Ohio River Basin as a part of an integrated freight network undercounts movements that transit across the region using these waterways.

On the other hand, the KODW Summary directly quantifies about two-thirds of the FAF-reported volumes for freight moving in and out of Kentucky. The KODW Summary reports 19.2 million tons of outbound freight, vs. a total of 29.9 million suggested in FAF, and 16.5 million inbound tons of freight, vs. a total of 27.7 million reported in FAF. Again, due to the redactions in the KODW Summary, these numbers are not unexpected.

The finer-grained spatial data provided by the KODW Summary clarified the relationship between waterborne and non-waterborne freight in specific portions of Kentucky and along specific stretches of the highway network. Each of the O-D movements quantified in the KODW, if transferred to the KFFN, impacts a specific set of links. Combining all the quantified movements on the network should reveal which network segments would shoulder the largest proportions of the movements, and which of them have the least capacity to do so. It should better illustrate which portions of the highway network are most reliant on complementary waterways freight movement to maintain their serviceability as freight carriers.

Already, significant portions of the KFFN carry high proportions of truck traffic. Many of these segments run parallel to the Ohio River System. For example, Kentucky State Highway 9 is a two-lane road which links the Eastern Kentucky coalfields with the Cincinnati Metro area, and the proportion of truck freight in relation to total traffic exceeds 30%, with a volume-to-capacity Ratio (V/C) over 1. Similarly, on much of the Kentucky four-lane Parkway network, which is embedded near the Western Kentucky coalfields over 40% of movements are truck-related and V/C ratios are typically below 0.5. This region is bounded on the north by the Ohio River, the west and southwest by the Cumberland and Tennessee Rivers, with the Green River running through it (Fig. 3). In situations like this, it is possible that a much of the diverted waterways freight would be concentrated in a limited area.
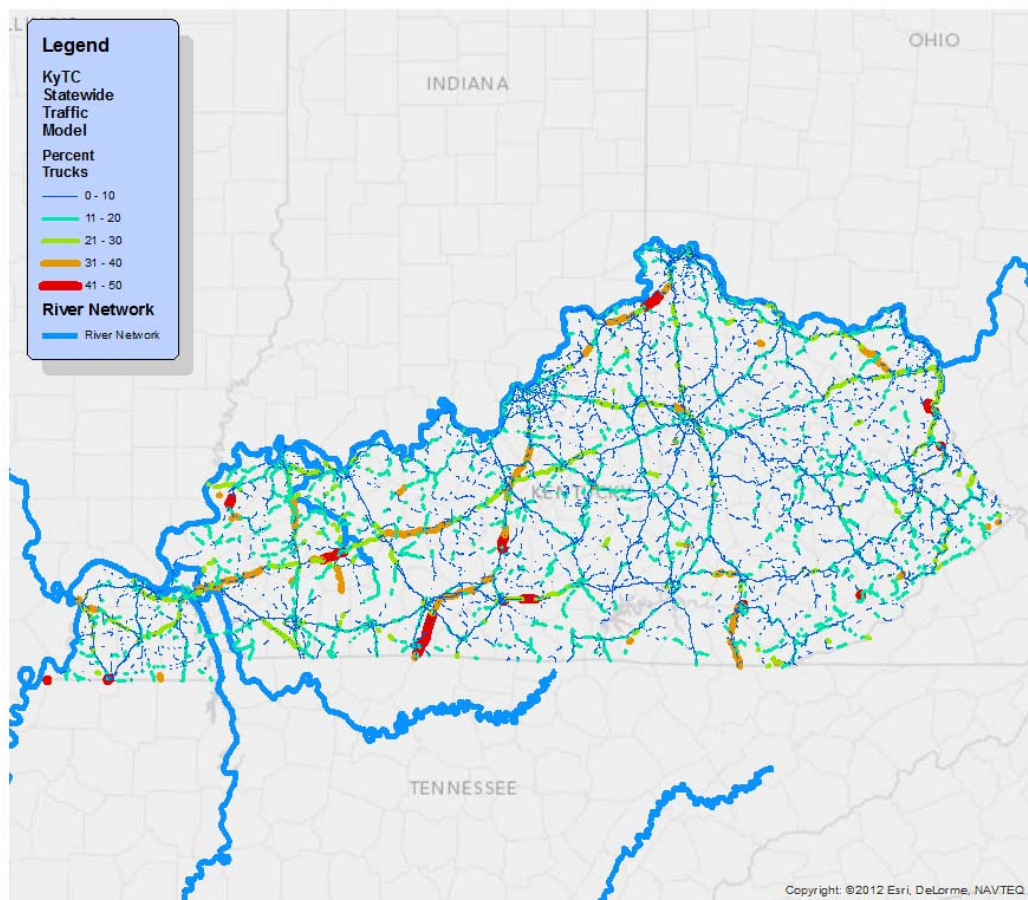
Figure 3: Percent Trucks on the Statewide Traffic Model

Data Sources and Analysis

Waterway Network

As noted, we developed a GIS-based representation of the inland waterway network (Fig. 1) by updating the National Waterway Network developed by Oak Ridge National Laboratory and Vanderbilt University. The segmentation was based on a mixture of metropolitan areas, state boundaries, locks, river ports, major highways, freight generators and power plants.

We derived commodity flow data from the KODW, which included Waterway Network Link Commodity Data available from the USACE Navigation Data Center (Fig.2). We located highway network endpoints by distributing them across each river segment proportionally according to the number of ports, the amount of coal burned at each power plant, and the number of trucks currently on the system. The data source for the river ports was the National Transportation

Atlas Database augmented by the U of L port survey. The current truck traffic was derived from the KFFN.

Highway Network

We created representations of the highway network using the Kentucky Statewide Traffic Model (KySTM), which incorporates the KFFN as indicated by the attribute TRUCKNET = 1. The KySTM includes useful attributes such as Annual Daily Truck Traffic (ADTT) as TRK_CNT, Volume to Capacity Ration (VC Ratio) as S_VOC_DAY, and Percent Trucks as TRUCKPCT.

Information on the existing truck traffic information came from the Area Development Districts (ADD) in Kentucky, and was designated for use in the Major Freight Users Inventory (MFUI). ADDs gather this data by conducting a survey in each region and review the statewide model to ensure proper coverage on the modeled networks within the KFFN. Part of the process of the MFUI involves the review of the National Highway System (NHS) Intermodal Connector Listing; therefore routes, traffic, locations, and modes are reviewed by each area (Fig. 3).
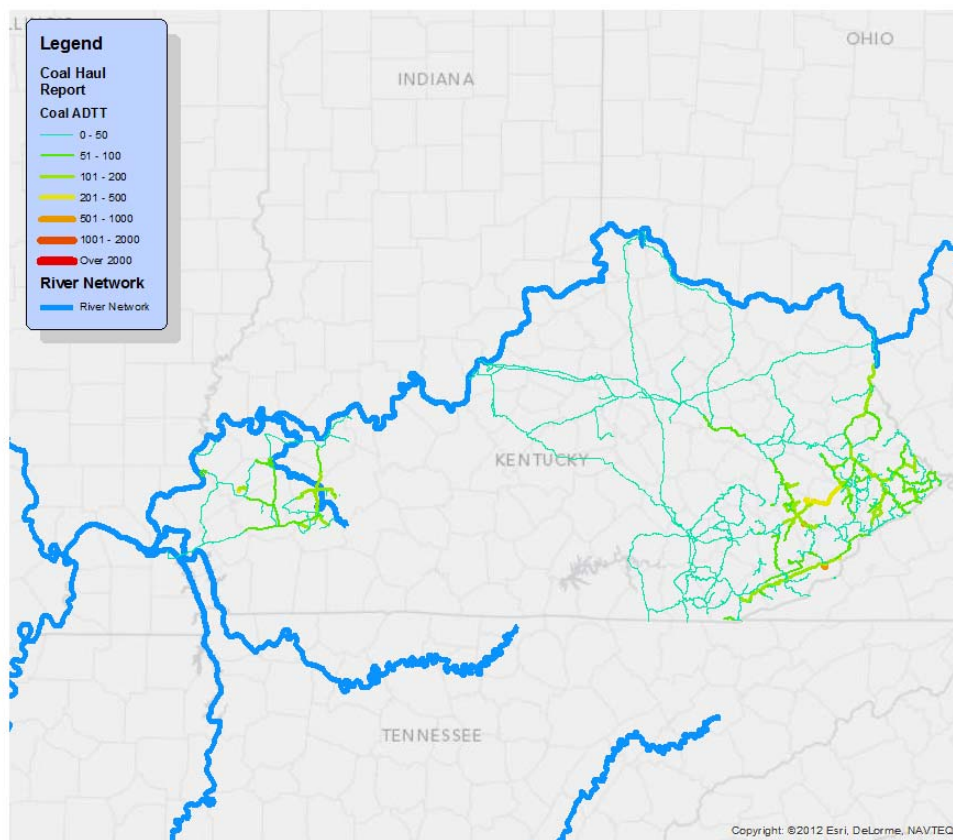

Figure 4: Coal Haul Report – ADTT

Preliminary analysis indicated that a large percentage of commodity movements involve coal. Therefore we added into the analysis the truck traffic relating directly to coal trucks. Kentucky maintains a listing of public highways that coal is hauled on; coal transporters are responsible for reporting these data. To prepare these data for analysis, we digitized the paper report, converted it to a spreadsheet, and applied to it the state Linear Referencing System (LRS) using the AllRds_M shapefile available from the state (Fig. 4).

Diversion Routes

Using the origin/destination (O/D) matrix from the USACE data request for the KODW, we generated diversion routes for each O/D pair using ArcGIS Desktop's Find Route tool. The routes were constrained to the KFFN (TRUCKNET = 1), with the impedance factors being time, distance, and VC Ratio. The routes and the corresponding commodity flows were merged into one layer (Diversion Routes) to represent all diverted traffic (Fig 5). No coal traffic routes emerge directly from the coal regions of eastern Kentucky.

An initial analysis of US 23 near the Big Sandy River, which borders the eastern and northern portions of Kentucky's coal region, shows a very high percentage of truck traffic, a VC Ratio over 1 and a moderately high number of coal trucks (Fig. 6). As such, we hypothesize that US 23 is a connector that links coal mines of eastern Kentucky to the inland waterway system. If the waterway system links were compromised, the routes for coal would be diverted directly into the state where needed. For the purposes of this study, any coal volumes reported in the KODW for the Big Sandy segment would originate and be diverted from the same Big Sandy area. Further study could potentially analyze the consequences of diverting traffic at the coal mines.
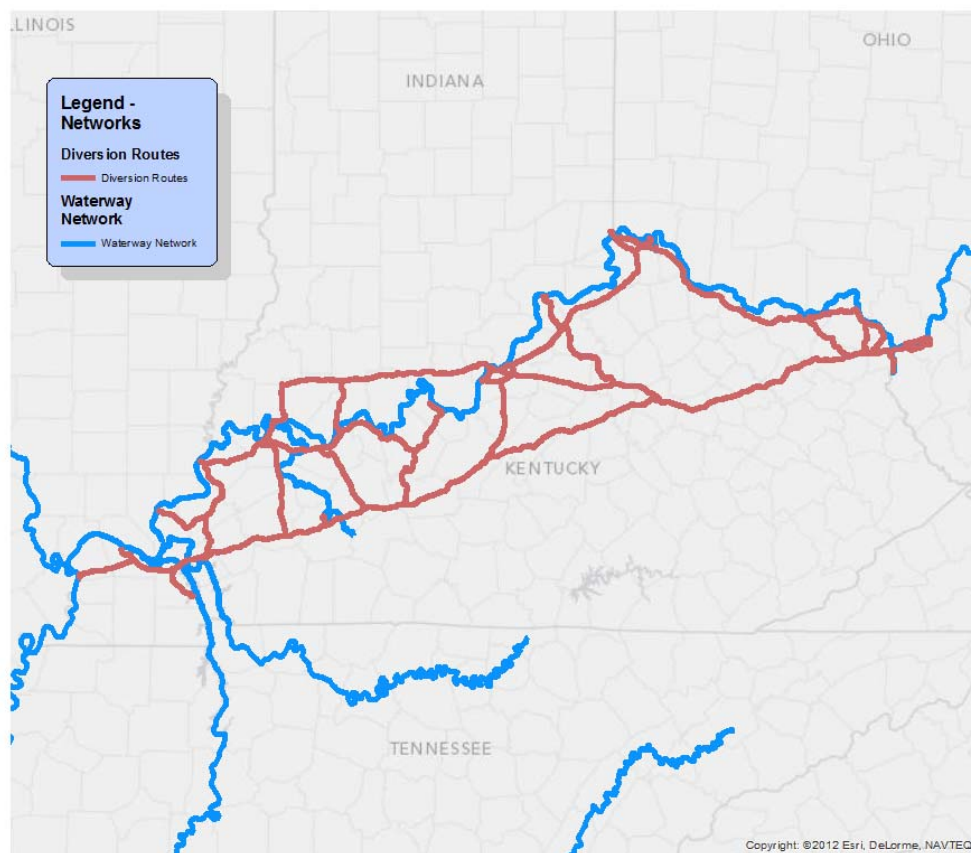
Figure 5: Diversion Routes
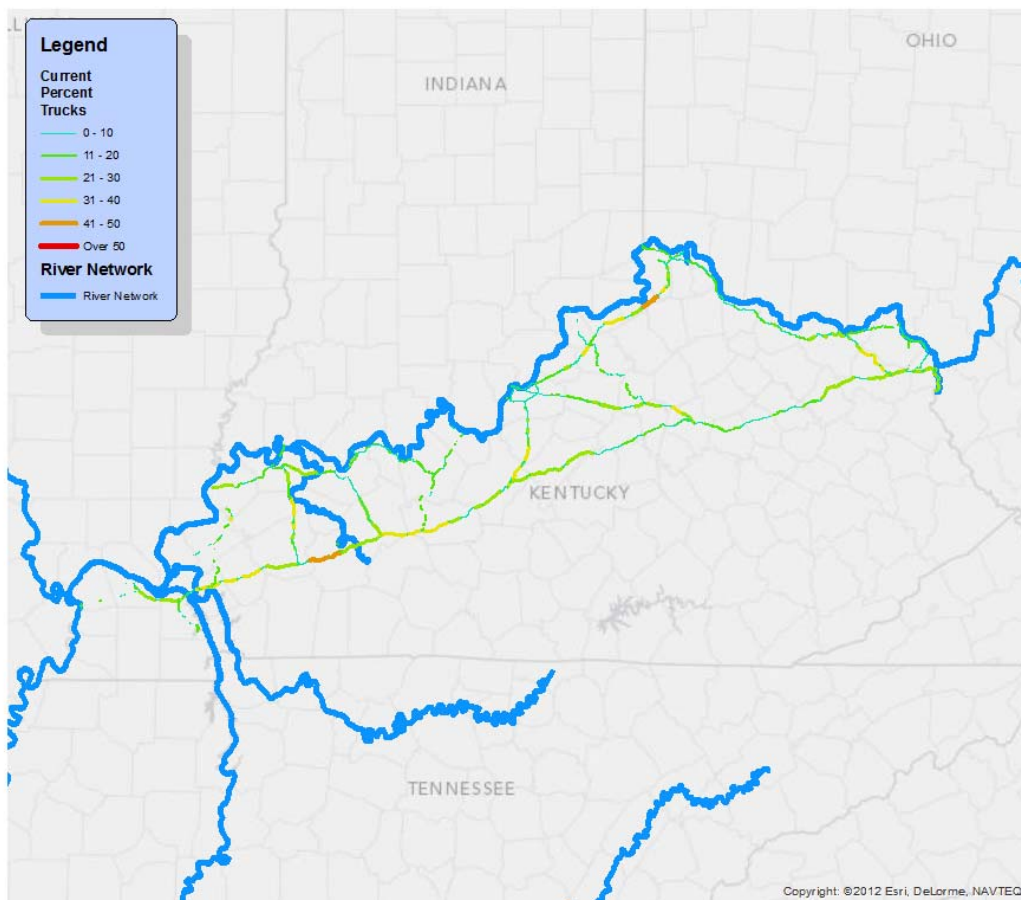
Figure 6: Percent Trucks before Diversion

General Imputed Pattern of Diverted Waterways Freight in Kentucky

Percent Trucks

Two major areas stand out as being significantly impacted by diverted truck traffic: 1) Kentucky State Highway 9, which runs along the Ohio River on the northern border of Kentucky that services the Big Sandy area to the Cincinnati, OH metropolitan area, and 2) the routes around the western Kentucky coal fields. The proportion of truck traffic that consists of vehicles hauling coal has the greatest effect on the diverted routes (Fig 7). Based on the current traffic (derived from the coal haul report), any traffic diverted from the western Kentucky coal fields is likely to significantly impact all nearby highway links because these fields are surrounded by the highway transportation system. As these routes are already in use, we can assume that traffic volume would necessarily increase along them.
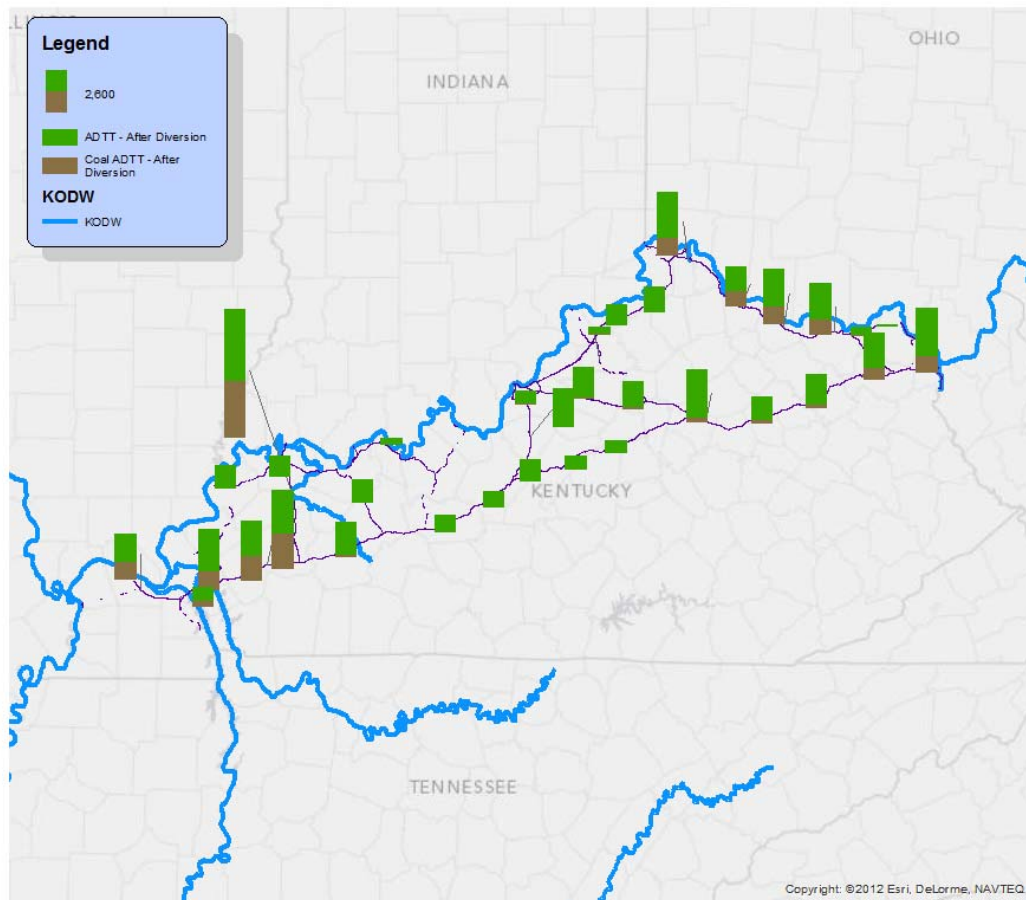
Figure 7: ADTT and Coal ADTT with Diverted Traffic

The proportional increase in truck traffic is most pronounced along the state's northern border and in the western Kentucky coalfields (Figs 6 and 8). Most of the traffic near the Cincinnati, OH metropolitan area converges on the city from the east and west – this works to compound the problem of increased congestion. However, Highway 9 in northeast Kentucky is primarily one-way traffic towards Mayfield, KY and Cincinnati, OH from the coalfields in Eastern Kentucky.

A large portion of the traffic around the coalfields of western Kentucky heads north and northeast along the Kentucky Parkway system to the power plants along the Ohio River. The number of cars that travel on the western Kentucky Parkway system is low compared to the rest of the state, but certainly, if trucks, which now comprise 10% of all traffic, increase to the point where they make up 50% of all traffic there is a high likelihood this will noticeably accelerate the deterioration of pavement and other infrastructure. The blip in Central Kentucky on Highway 421 (Fig 8) results from a segment along the system for which there is no reported

data on the number of automobiles. The reported proportion of truck traffic to all vehicle traffic is 100%, but this is obviously erroneous.
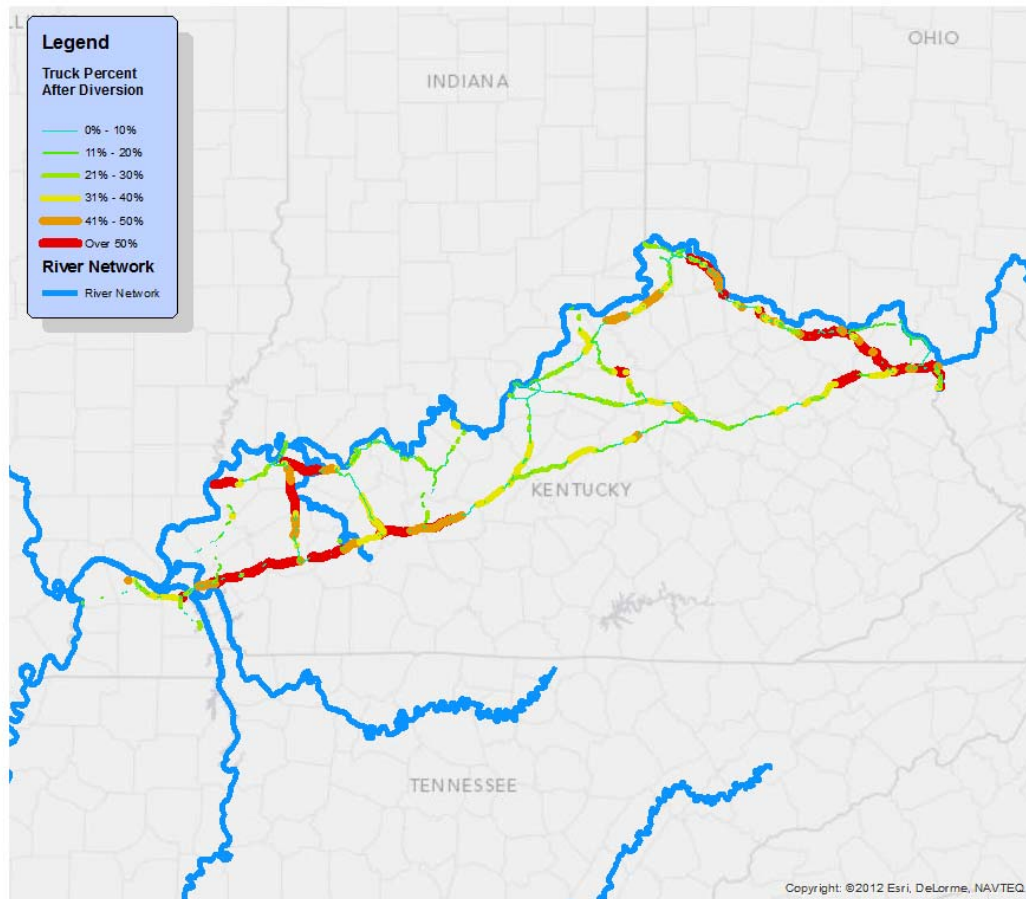

Figure 8: Percent Trucks after Diversion

Volume to Capacity Ratio

Generally speaking, under our modeling scenario, there are no major impacts on the VC Ratio (Figs 9 and 10). However, if we calculate the change in the VC Ratio as a proportion of overall change (Fig 11), northeastern Kentucky and the western Kentucky coalfields are identified as trouble spots. The impacts of freight diversion on the direction of commodity flow is clear when it is visualized. River segments with the most significant commodity flows are located near the largest metropolitan areas in the study region: Louisville, KY and Cincinnati, OH (Fig. 12). This is particularly noticeable for coal.
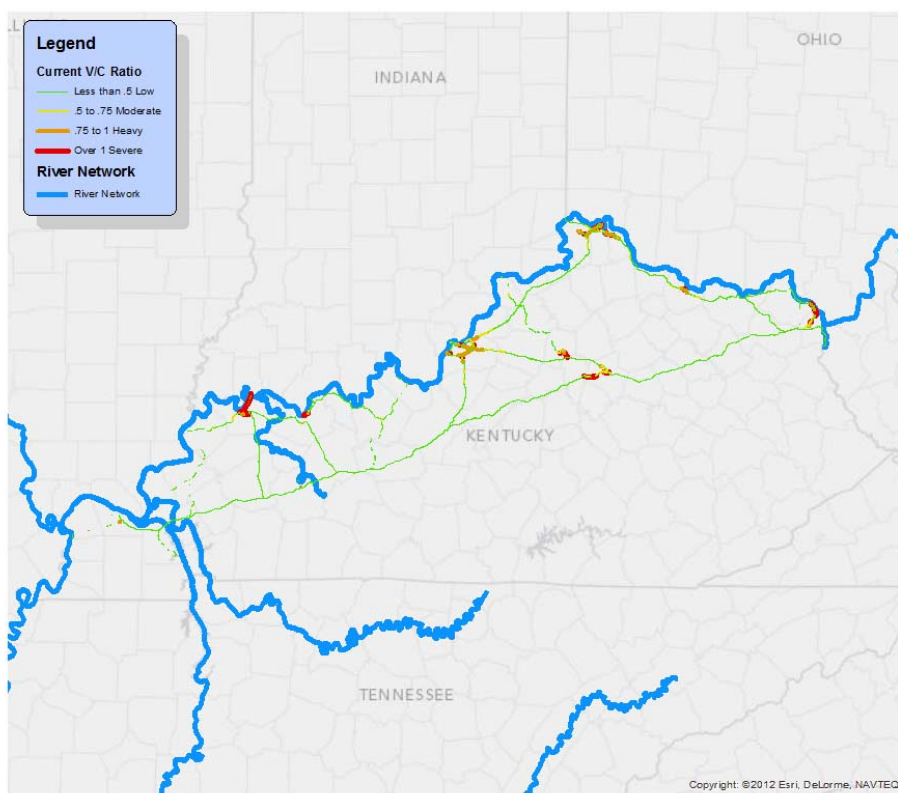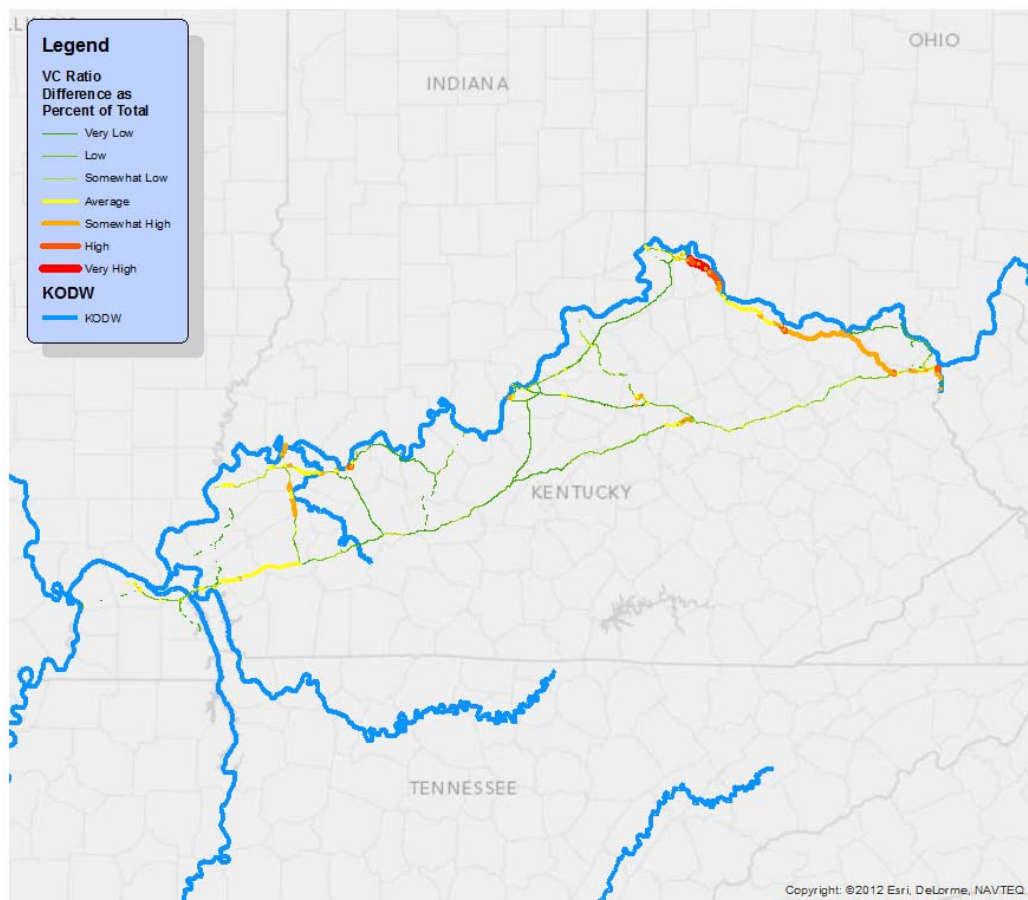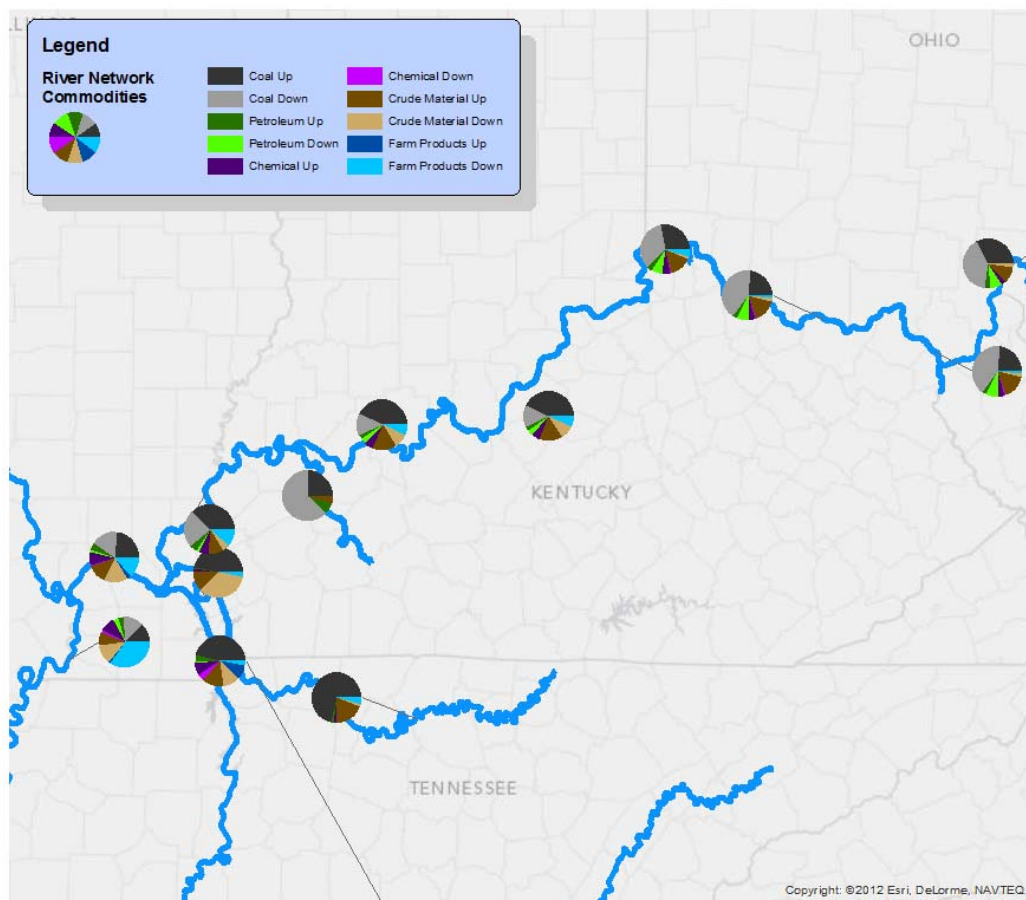
Figure 9: VC Ratio before Diversion
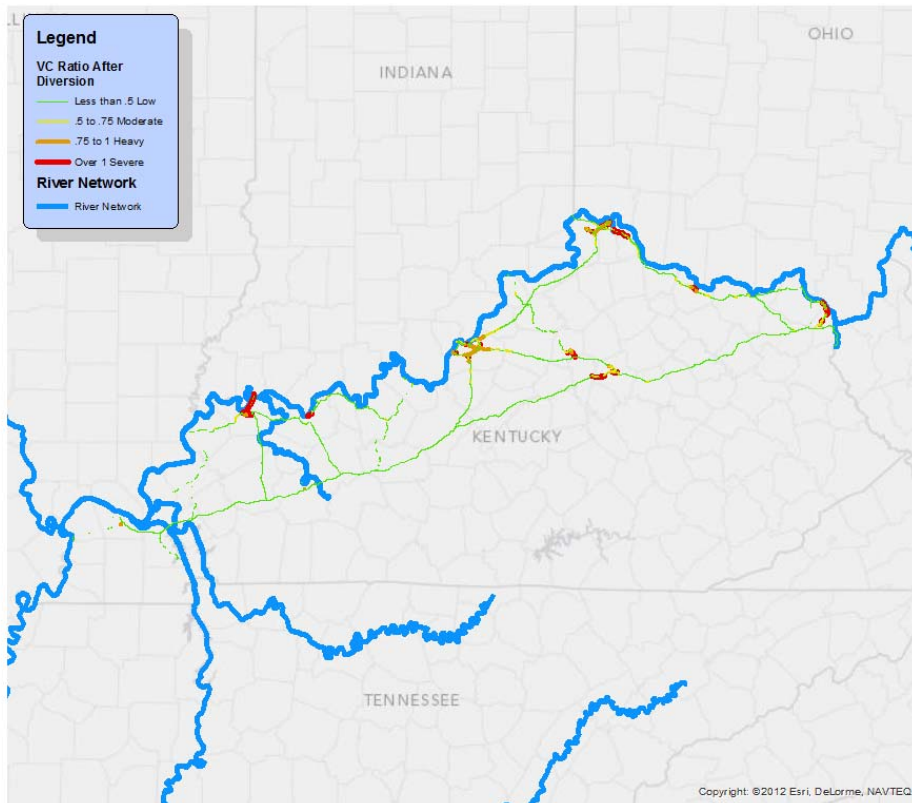
Figure 10: VC Ratio after Diversion

Figure 11: Change in VC Ratio as percent of Total Change

Figure 12: Percent of commodities flowing up or down stream

Categories of Potential Impacts (Future Analysis)

Congestion

As the total proportion of Kentucky freight carried by waterways in Kentucky is at or below 10%, it is unlikely there will be broad-based severe impacts on the highway network from these imputed volumes of waterways freight. However, there could be significant local impacts given the linkages that hold the network together. Also, the assumptions regarding backhaul loading would increase the total expected volumes above a 1-to-1-conversion ratio of waterway traffic to truck traffic. Backhaul rates of 75%, for example, would add 25% to the total truck volumes.

Further, increased congestion delays can be partitioned into a) recurring delays related to ongoing traffic congestion, and b) incident-related delays stemming from crashes. These costs of these can be estimated using rates established by Weisbrod and Weisbrod (1997).

Safety

The relative safety of transporting freight on trucks as opposed to waterways has been estimated by developing ratios of fatalities and injuries to billion ton-miles. At the national level for truck freight, in 2006 this ratio was 4.4 fatalities and 99 injuries per billion ton-miles. This compares to .028 fatalities and .045 injuries per billion ton-miles for inland waterways freight at the same scale (USDOT 2009, p. 43-44).

In Kentucky, on four-lane rural Interstates, there are 50 crashes per 100 Million Vehicle Miles (MVM), and of those, about 25% involve an injury or fatality. However, the commercial vehicle crash rate varies across capacity categories. As Volume-to-Capacity ratios rise from less than .4 to greater than .8, the truck crash rate for all (rural + urban) 4-lane Interstates rises from 54 per MVM to 67 per MVM (Kirk et al, 2005, pp. 33 and 38). However, the same study did not find a significant relationship between the proportion of truck traffic and crash rates on Interstate Highways in Kentucky (Kirk et al, 2005, p 41). Kentucky data also indicates that a truck crash is nearly twice as likely to involve fatalities as non-truck crash (Green, Pigman, and Agent 2011, p. 17).

Extrapolations of additional crashes can be assessed using the NHSTA's "Economic Impact of Motor Vehicle Crashes," which is based on national data and includes specific values assigned to different types of crashes (Blincoe et al. 2002).

Air Quality

An appropriate method for estimating potential air quality impacts has not been developed by the authors. Certain urban areas along the Ohio River Valley have historically been classified as non-attainment areas, so there is potential that additional truck traffic could have an impact in those areas.

Summary of Case Study

While this study provides a broad exploratory analysis of an entire system, there are areas of localized effects that warrant greater scrutiny. The VC Ratio in any area is not likely to be an issue even in the case of total system failure, however, the overall truck traffic and percentage of trucks on the highway system will be noticeable higher if even one link in the waterway system becomes non-operational.

Report Conclusion

As the case study illustrates, the IFNM can model freight movements when they shift from one mode to another. It can thus be of immense value in forecasting changes to multimodal freight network dynamics when conditions in the intermodal freight system are altered by internal or external constraints. Applied judiciously, the IFNM will improve our understanding of modal

substitution effects. Planners can use IFNM predictions to more efficiently move freight—especially in urban areas where all three modes tend to converge.

The IFNM can also be used to model various decision-making scenarios shippers engage in when deliberating on which transportation mode to utilize. These choices affect how freight volume is distributed across the freight system, and the attendant secondary impacts, both positive and negative. Further refinement and use of the IFNM can aid us in our efforts to realize greater overall efficiency within the freight system. Greater efficiency, in turn, will yield monetary and non-monetary benefits, including fuel and air quality improvements, congestion reduction, lower cost of goods, a better business climate, lower public sector costs, and improved transportation network safety. Dramatically shifting the amount of freight moved on each mode could ameliorate infrastructure bottlenecks, air quality, fuel efficiency, and safety, all of which are objectives of the planning professions.

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