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Multi-state economic contribution and multi-congressional district impact analysis of an inland waterway disruption

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ABSTRACT

In spring 2019, the Oklahoma segment of the McClellan-Kerr Arkansas River Navigation System (OK-MKARNS), a significant in-land water transportation segment in the Central Great Plains region of the United States, was forced to close for months due to an extreme flooding event. The OK-MKARNS supports the economy of multiple states and their connection to domestic and international markets through the Mississippi River. However, the flood's direct, indirect, and induced impacts on Oklahoma's economy and the economies of the surrounding states of Arkansas, Colorado, and Kansas are unknown. The disruption's impacts on the region's economies are evaluated at the congressional district levels of these states using a multi-regional input–output model. Disruption of the waterway transportation resulted in a total loss ranging between 66 and 791 jobs, $15.36 to $175.04 million in output, and $6.08 to $72.98 million in value-added, depending on the duration of the delay experienced by industries. The magnitude of economic loss varied for each congressional district, depending on its economic base's composition and proximity to the OK-MKARNS navigational system. These findings could be helpful to legislators and other decision-makers in allocating scarce resources toward the maintenance of navigable waterway infrastructure. The multi-regional focus of the analysis also suggests a potential role concerning collaborative efforts between legislators across state borders to garner federal spending to support navigable waterway services.

1. Introduction

Transportation infrastructure links the production and distribution of goods and services between industries and regions. A disruption in a supply chain in one location can cause disruptions across multiple businesses and widespread economic impacts across several regions. The interruption of transportation infrastructure hinders access to input and demand markets, decreasing industry productivity (Rietveld and Bruinsma, 2012; Ng et al., 2013; Chen and Li, 2021). Transportation infrastructure that connects regions to international markets plays a crucial role in establishing and maintaining the competitiveness of regional and national economies (Rietveld and Bruinsma, 2012; Bell, 2016). The medium- and long-term effects of disruptions on transportation infrastructure are exacerbated as the duration of a disruption increases (Markolf et al., 2019; Tate et al., 2021; Mahmood and Hamayon, 2021; Williams et al., 2021).

In the United States (US), navigable inland waterways play an essential role in delivering intermediate goods (such as fertilizer) and exporting final products (such as grain and livestock) to local, regional, and international markets (FHWA, 2001; Stommes and Brown, 2002; Casavant et al., 2017). There are more than 40,000 km of navigable inland waterways in the US, with most located in the Mississippi River System (USACE, 2000). Inland waterway transportation is vital for the US rural economy because it provides a cost-competitive alternative for farmers and manufacturers to access international trade markets (Yu et al., 2006; Kruse et al., 2017; USDA, 2019). The value of commodities transported on inland waterways in the US increased from $381 billion in 2007 to $596 billion in 2013, with projected growth in transported value to $973 billion by 2045 (USDOT, 2017).

The McClellan–Kerr Arkansas River Navigation System (MKARNS) is one of the major inland waterway systems linking at least 12 southwestern states to the Mississippi River System (ODOT, 2020). The Oklahoma segment of the MKARNS (OK-MKARNS, thereafter) plays an essential role in the transportation of goods into and out of the Central

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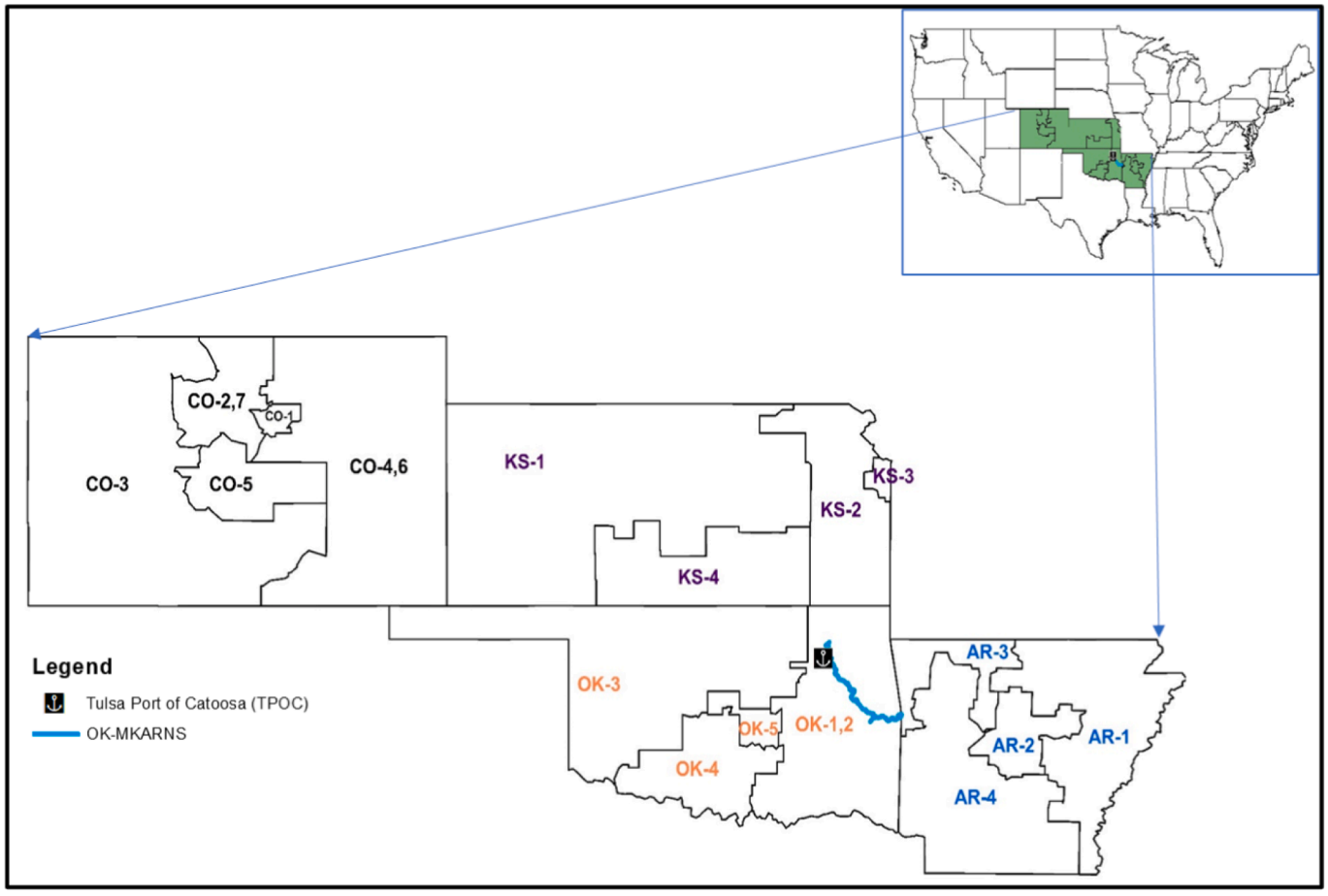

Fig. 1. Study region and congressional districts.

Table 1
Average monthly commodity volumes and reclassification into industries.

Industry	Commodity	Average (Tonnage per month)
Agriculture Inputs	Chemical Fertilizers	162,925
Grain	Grain	70,157
Oilseed	Soybeans	73,492
Other Agriculture and Food Manufacturing	Food and Farm Products	20,042
Manufacturing	Manufacturing Equipment	223
	Other Chemicals	18,189
	Iron and Steel (1)	35,246
Construction	Iron and Steel (2)	14,396
Mining	Coal and Coke	29,875
	Minerals and Building Products	10,940
	Sand, Gravel, and Rock	12,250
Natural Gas and Petroleum	Petroleum Products	8,250

a: This table is derived from Welch et al. (2022).

Table 2
Disruption shocks on industry sectors under different durations of delay (million $).

Industry Sector	2-Month[a]	4-Month[a]	6-Month[a]
Agriculture Inputs	−3.67	−16.18	−37.53
Grain	−0.34	−2.14	−5.42
Oilseed	−0.27	−1.48	−3.62
Other Agriculture and Food Manufacturing	−1.30	−5.59	−12.89
Manufacturing	−0.02	−0.06	−0.15
Construction	−0.22	−1.00	−35.47
Mining	−13.06	−28.18	−43.29
Natural Gas and Petroleum	−5.23	−16.67	−28.1

a: Source: Derived and calculated from Robison et al. (2014) and Welch et al. (2022).

Table 3
Economic Contribution of the OK-MKARNS to Oklahoma, Arkansas, Colorado, and Kansas.

States	Employment	TIO($ million)	Value-added($ million)
Oklahoma	38	9.75	2.19
Arkansas	2	0.23	0.12
Colorado	0	0.02	0.01
Kansas	0	0.09	0.04
Total	40	10.76	2.95

Great Plains (CGP) states, including rural and metropolitan areas in Oklahoma, Arkansas, Kansas, and parts of Colorado (Nachtmann and Oztanriseven, 2014) (Fig. 1). In 2017, 6.2 million tons of products, valued at $2.2 billion, were shipped via the OK-MKARNS (ODOT, 2018).

In the spring of 2019, the flooding of the Arkansas River forced the closure of OK-MKARNS ports until late fall of the same year. Two barges broke loose during high water and collided with the Webbers Falls Lock and Dam before eventually sinking. In order to facilitate the recovery of the barges, the water level was intentionally lowered, and additional time was required to repair the damaged lock and dam. The Oklahoma section of the waterway was closed for 140 days in total. OK-MKARNS resumed operations in October 2019 with limited capacity. The closure caused losses in regional transportation capacity. Businesses that relied on waterborne transportation were forced to find short- to

Table 4
Contribution multipliers of the OK-MKARNS for Oklahoma, Arkansas, Colorado, and Kansas.

States	Employment	TIO	Value-added
Oklahoma	3.94	2.24	4.20
Arkansas	1.16	1.05	1.19
Colorado	1.01	1.01	1.02
Kansas	1.05	1.02	1.07

Table 5
Impact on loss in employment at congressional district under different durations of delay (number of supported jobs).

Congressional District[a]	2-Month[b]	4-Month[b]	6-Month[b]
OK-1,2	[−62, −68]	[−287, −312]	[−676, −733]
OK-3	[−1, −1]	[−4, −4]	[−9, −9]
OK-4	[0, 0]	[−1, −1]	[−3, −3]
OK-5	[0, 0]	[−2, −2]	[−5, −6]
Total	[−63, −69]	[−294, −319]	[−692, −750]
AR-1	[0, 0]	[−1, −1]	[−2, −2]
AR-2	[0, 0]	[0, −1]	[−1, −1]
AR-3	[−1, −2]	[−6, −7]	[−15, −16]
AR-4	[0, 0]	[−1, −1]	[−3, −3]
Total	[−2, −2]	[−8, −10]	[−21, −22]
CO-1	[0, 0]	[0, 0]	[0, 0]
CO-2,7	[0, 0]	[0, 0]	[−1, −1]
CO-3	[0, 0]	[0, 0]	[0, 0]
CO-4,6	[0, 0]	[0, 0]	[−1, −1]
CO-5	[0, 0]	[0, 0]	[0, 0]
Total	[0, 0]	[0, 0]	[−2, −2]
KS-1	[0, 0]	[−2, −2]	[−4, −4]
KS-2	[−1, −1]	[−3, −3]	[−7, −7]
KS-3	[0, 0]	[−1, −1]	[−2, −3]
KS-4	[0, 0]	[−1, −2]	[−3, −4]
Total	[−1, −1]	[−7, −8]	[−16, −18]

a: Notation is defined as the state code followed by the congressional district number. For example, OK-3 is Oklahoma congressional district 3.
b: The first entry in the bracket ('[]') is calculated with the RPC equal to zero, and the second entry in the bracket is calculated with the RPC equal to the IMPLAN Social Accounting Matrix (SAM).

medium-term solutions to the supply chain bottleneck caused by the disruption.

This study evaluates the economic impacts the 2019 spring flood disruption of the OK-MKARNS caused over a four-state region, including Oklahoma, Arkansas, Kansas, and Colorado. The states of Arkansas, Kansas, and Colorado border Oklahoma and rely on OK-MKARNS ports for waterway transportation. Although the states of Texas and Missouri also border Oklahoma, these two states have alternative means of accessing inland waterways without relying on the OK-MKARNS. Missouri, for instance, boasts an extensive network of navigable rivers, including 500 miles on the Mississippi River and 550 miles on the Missouri River. These waterways are part of a large inland network that directly connects 15 states (MODOT, 2015). In the case of Texas, its major maritime transportation system is the Gulf Intracoastal Waterway, which provides a crucial link for maritime shipping operations.

The units of analysis are the states and congressional districts of each state. Two specific research objectives are to 1) identify the economic contribution of the OK-MKARNS to each state and 2) estimate the economic impacts of the OK-MKARNS closure on the economies of congressional districts of each state concerning jobs, total industry output, and value-added. A multi-regional input–output (MRIO) modeling approach is used to determine the economic contribution of the OK-MKARNS to each region's economy, in addition to the differential effects of the flood disruption on the scope and magnitude of

Table 6
Impact on loss in Total Industry Output (TIO) at congressional districts under different durations of delay ($ millions).

Congressional District[a]	2-Month[b]	4-Month[b]	6-Month[b]
OK-1,2	[−14.30, −15.50]	[−64.00, −69.30]	[−149.10, −161.50]
OK-3	[−0.10, −0.20]	[−0.70, −0.70]	[−1.60, −1.70]
OK-4	[−0.04, −0.04]	[−0.20, −0.20]	[−0.40, −0.50]
OK-5	[−0.10, −0.10]	[−0.50, −0.50]	[−1.20, −1.30]
Total	[−14.54, −15.84]	[−65.40, −70.70]	[−152.30, −165.00]
AR-1	[−0.04, −0.04]	[−0.20, −0.21]	[−0.49, −0.51]
AR-2	[−0.01, −0.01]	[−0.09, −0.09]	[−0.22, −0.24]
AR-3	[−0.24, −0.26]	[−1.07, −1.16]	[−2.51, −2.72]
AR-4	[−0.05, −0.05]	[−0.25, −0.26]	[−0.60, −0.63]
Total	[−0.34, −0.37]	[−1.61, −1.73]	[−3.82, −4.10]
CO-1	[−0.00, −0.00]	[−0.03, −0.03]	[−0.09, −0.10]
CO-2,7	[−0.02, −0.02]	[−0.10, 0.11]	[−0.25, −0.27]
CO-3	[−0.01, −0.01]	[−0.03, −0.03]	[−0.08, −0.09]
CO-4,6	[−0.01, −0.01]	[−0.08, −0.08]	[−0.21, −0.22]
CO-5	[−0.00, −0.00]	[−0.02, −0.02]	[−0.05, −0.06]
Total	[−0.05, −0.05]	[−0.27, −0.28]	[−0.69, −0.73]
KS-1	[−0.11, −0.11]	[−0.52, −0.53]	[−1.23, −1.27]
KS-2	[−0.19, −0.19]	[−0.88, −0.92]	[−2.08, −2.18]
KS-3	[−0.05, −0.05]	[−0.26, −0.28]	[−0.63, −0.67]
KS-4	[−0.09, −0.09]	[−0.44, −0.46]	[−1.04, −1.09]
Total	[−0.43, −0.45]	[−2.10, −2.20]	[−4.99, −5.21]

a: Notation is defined as the state code followed by the congressional district number. For example, OK-3 is Oklahoma congressional district 3.
b: The first entry in the bracket ('[]') is calculated with the RPC equal to zero, and the second entry in the bracket is calculated with the RPC equal to the IMPLAN Social Accounting Matrix (SAM).

economic impacts. The methodology used here can be extended to other event studies focusing on the duration of transportation infrastructure disruptions in regional economies. The unit of analysis used here also provides immediate, policy-relevant information to local legislators regarding financing the operation and maintenance of the OK-MKARNS or exploration of alternative modes of transportation when access to the OK-MKARNS is limited.

2. Previous studies

Previous literature on the effects of natural hazard-induced transportation disruptions has focused on people, businesses, and regional economies (for example, Muriel-Villegas et al., 2016; Toma-Danila et al., 2020; Li et al., 2020; Boakye et al., 2022). The increased frequency of extreme weather events, such as floods or drought, highlights the urgency for this type of research (Chang, 2016). Research on hazard-induced transportation disruptions and their effects on supply chains has mainly focused on urban areas where major transportation networks are located (Dong et al., 2020; Rebally et al., 2021). Protecting waterway transportation infrastructure from natural hazards requires public and private investment (Jonkeren and Rietveld, 2016). Assessment of the direct, indirect, and induced economic impacts from disruptions at different spatial scales could support stakeholder decision-making regarding prioritizing infrastructure projects that could prevent or mitigate future hazard impacts on transportation capacity (de Moel et al., 2015).

Natural hazards and climate change present significant risks to inland waterway transportation (Wiegmans and Knoings, 2017; Jonkeren et al., 2007, 2014). According to the US Environmental Protection Agency (EPA, 2016), floods have become more frequent and extensive in the US Northeast and Midwestern rivers and streams. Smaller waterway

Table 7
Impact on loss in value-added at congressional districts under different durations of delay ($ millions).

Congressional District[a]	2-Month[b]	4-Month[b]	6-Month[b]
OK-1,2	[−5.60, −6.20]	[−26.20, −28.50]	[−61.60, −67.00]
OK-3	[−0.07, −0.07]	[−0.30, −0.40]	[−0.80, −0.80]
OK-4	[−0.01, −0.02]	[−0.08, −0.09]	[−0.20, −0.20]
OK-5	[−0.05, −0.06]	[−0.30, −0.30]	[−0.60, −0.70]
Total	[−5.73, −6.35]	[−26.90, −29.30]	[−63.20, −68.70]
AR-1	[−0.01, −0.01]	[−0.07, −0.07]	[−0.16, −0.17]
AR-2	[−0.01, −0.01]	[−0.04, −0.04]	[−0.10, −0.11]
AR-3	[−0.12, −0.13]	[−0.55, −0.60]	[−1.29, −1.40]
AR-4	[−0.02, −0.02]	[−0.09, −0.09]	[−0.21, −0.23]
Total	[−0.16, −0.17]	[−0.75, −0.81]	[−1.77, −1.91]
CO-1	[−0.00, −0.00]	[−0.02, −0.02]	[−0.05, −0.06]
CO-2,7	[−0.00, −0.01]	[−0.05, −0.05]	[−0.12, −0.13]
CO-3	[−0.00, −0.00]	[−0.01, −0.02]	[−0.04, −0.04]
CO-4,6	[−0.01, −0.01]	[−0.03, −0.04]	[−0.09, −0.10]
CO-5	[−0.00, −0.00]	[−0.01, −0.01]	[−0.02, −0.03]
Total	[−0.02, −0.02]	[−0.12, −0.13]	[−0.33, −0.35]
KS-1	[−0.03, −0.04]	[−0.17, −0.17]	[−0.40, −0.41]
KS-2	[−0.08, −0.08]	[−0.37, −0.39]	[−0.88, −0.92]
KS-3	[−0.02, −0.03]	[−0.12, −0.13]	[−0.30, −0.32]
KS-4	[−0.03, −0.03]	[−0.15, −0.16]	[−0.36, −0.38]
Total	[−0.17, −0.17]	[−0.81, −0.85]	[−1.93, −2.02]

a: Notation is defined as the state code followed by the congressional district number. For example, OK-3 is Oklahoma congressional district 3.
b: The first entry in the bracket ('[]') is calculated with the RPC equal to zero, and the second entry in the bracket is calculated with the RPC equal to the IMPLAN Social Accounting Matrix (SAM).

systems are generally more susceptible to water-level change disruptions (Schweighofer, 2013). During high water level events, delays are sometimes caused by outdated lock and dam infrastructure failure. These failures have become increasingly prevalent due to the accumulation of maintenance backlogs. The frequency of flooding has also risen, leading to more barge and boating collisions and increasing damage to waterway structures. Inland waterway transportation prices rise substantially during low water level periods due to backlogs, and higher costs could result in loss of transportation volume to other transportation modes, according to research by Jonkeren et al. (2011) and Jonkeren et al. (2007) in specific ports of the river Rhine. Understanding the economic effects of delays and limited or eliminated access to waterway transportation is required to assist decision-makers in reconciling the costs of maintaining navigable waterways with other spending priorities (TRB, 2015). For example, when prioritizing the lock and dam infrastructure repair needs, the US Army Corps of Engineers (USACE) uses regional economic impact analysis method to gauge the effects of waterway transportation failure on economies and to communicate these findings to taxpayers on the social and economic benefits of inland waterways (Litz, 2017; McGinnis, 2016; TRB, 2015).

Several approaches are used to estimate the effects of natural disasters on transportation systems, in addition to various social and economic indicators used to quantify impacts. Yu et al. (2006) applied a regional spatial equilibrium model to estimate the economic benefits of improving the efficiency of inland waterway transportation. Jonkeren et al. (2007) estimated the welfare effects of having navigable inland waterways based on the demand for waterborne transportation for the river of Rhine. Jonkeren and Rietveld (2016) reviewed the government and market failure in investing inland water transportation facility protection. Their findings suggested that regional collaboration and cost-sharing initiatives would be required to address inadequate infrastructure maintenance investment.

However, research on waterway transportation impacts on regional economies frequently uses input–output (IO) modeling due to its ability to link the transportation sector to other sectors and capture economic sector interdependencies (Yu, 2018). Previous studies on the economic impacts of inland waterways used IO to calculate the direct, indirect, and induced effects for a single region or multiple regional economies following a waterway disruption (for example, Richardson and Heidelberg, 2012; Pant et al., 2015; Thekdi and Santos, 2016). Hamilton (2001) developed an IO procedure to measure the economic contributions of existing rural inland waterway ports and terminals. MacKenzie et al. (2012) used an MRIO model to measure the economic impacts of closing an inland port. Oztanriseven and Nachtmann (2017) focused their impact analysis of waterway distributions on the strategic solutions local decision-makers could adopt to minimize economic losses. This study uses a multi-regional input–output model to quantify the effects of the 2019 flooding of the OK-MKARNs and its effect on the region's economies.

Waterway transportation creates significant indirect and induced value-added to the manufacturing and agricultural sectors. Previous research on Oklahoma and Arkansas MKARNS segments found that the waterway is a significant component of the nation's business sales, especially in providing industries access to agricultural and manufacturing input and output markets (Mackenzie et al., 2012; Caneday and Soltani, 2014; Oztanriseven and Nachtmann, 2020). Robinson et al. (2014) concluded that the complete closure of the MKARNS would result in a loss of $4.1 billion in the nation's business sales. Economic losses also stem from lost revenue from decreased recreational use (Folga et al., 2009). Welch et al. (2022) estimated that the economic contribution of OK-MKARNS segment for Oklahoma was 38 jobs, $9.6 million in total industrial output, and $2.2 million in value-added. The temporary closure of OK-MKARN has a broader economic impact beyond Oklahoma, as enterprises in states neighboring Oklahoma may also be affected if their businesses use the waterway to ship and receive goods. For example, some economic sectors inland states, such as Kansas, Colorado, and Arkansas, depend on the OK-MKARN as a low-cost transportation option. However, it is unknown what the specific economic contribution of OK-MKARNS is to surrounding states and the potential economic consequences the economies of these states experienced during the Spring 2019 closure. To better understand the importance of maintaining a functional and reliable waterway infrastructure, especially when state and federal funding is involved, it is essential to measure the economic impact of OK-MKARNS on these neighboring states' economies. This study fills these gaps. The study is also among the limited research to evaluate the economic contribution of the OK-MKARNS waterway in the study region of Oklahoma, Kansas, Arkansas, and Colorado, in addition to the impact of the 2019 flooding event on these economies.

Table 8
Impact on loss in employment by industry sectors at selected congressional district under a 6-month delay (number of supported jobs).

Industry Sectors	AR-3[a]	CO-2,7[a]	KS-1[a]	KS-2[a]	OK-1,2[a]	OK-3[a]	OK-4[a]	OK-5[a]
Oilseed	–	–	–	–	[−42, −42]	–	–	–
Grain	–	–	[−1, −1]	[−1, −1]	[−127, −130]	[−1, −1]	–	–
Fruit and vegetable	–	–	–	–	–	–	–	–
Tree nut	–	–	–	–	–	–	–	–
Greenhouse	–	–	–	–	–	–	–	–
Cotton	–	–	–	–	–	–	–	–
Beef cattle	–	–	–	–	[−1, −1]	–	–	–
Dairy cattle and milk	–	–	–	–	–	–	–	–
Poultry and egg	–	–	–	–	–	–	–	–
Other animal production	–	–	–	–	[−1, −1]	–	–	–
Primary forestry	–	–	–	–	–	–	–	–
Commercial fishing and hunting	–	–	–	–	–	–	–	–
Natural gas petroleum	–	–	–	–	[−2, −7]	–	–	–
Mining	–	–	–	–	[−35, −37]	–	–	–
Services	[−7, −7]	–	–	[−1, −1]	[−92, −101]	[−2, −2]	[−1, −1]	[−1, −2]
Utilities	–	–	–	[−1, −1]	[−4, −4]	–	–	–
Construction	–	–	–	–	[−29, −37]	–	–	–
Textiles	–	–	–	–	–	–	–	–
Milling	–	–	–	–	–	–	–	–
Food manufacturing	–	–	–	–	[−10, −11]	–	–	–
Dairy processing	–	–	–	–	–	–	–	–
Animal processing	–	–	–	–	–	–	–	–
Breweries, wineries, distilleries	–	–	–	–	–	–	–	–
Secondary forestry	–	–	–	–	–	–	–	–
Agriculture inputs	–	–	–	–	[−90, −92]	–	–	–
Other agriculture	–	–	–	–	[−9, −17]	–	–	–
Wholesale	[−1, −1]	–	–	–	[−21, −23]	[−1, −1]	–	[−1, −1]
Retail trade	[−1, −1]	–	–	–	[−35, −39]	[−1, −1]	–	–
Rail transportation	–	–	–	–	[−1, −1]	–	–	–
Water transportation	–	–	–	–	[−5, −5]	–	–	–
Truck transportation	[−1, −1]	–	–	–	[−10, −11]	–	–	–
Other transportation	–	–	–	–	[−2, −3]	–	–	–
Warehousing and Storage	–	–	–	–	[−5, −5]	–	–	–
F.I.R.E.	[−1, −1]	–	–	[−1, −1]	[−46, −49]	[−1, −1]	–	[−1, −1]
Miscellaneous	[−2, −2]	–	–	[−1, −1]	[−42, −46]	[−1, −1]	–	[−1, −1]
Government	–	–	–	[−1, −1]	[−32, −34]	[−1, −1]	–	[−1, −1]
Manufacturing	–	–	–	–	[−32, −35]	–	–	–

a: The first entry in the bracket ('[]') is calculated with the RPC equal to zero, and the second entry in the bracket is calculated with the RPC equal to the IMPLAN Social Accounting Matrix (SAM). "-" refers to no impact.

3. Research design and data

The objective of this case study is to 1) estimate the OK-MKARNS economic contribution to Oklahoma, Arkansas, Colorado, and Kansas (Section 3.2) and 2) determine the direct, indirect, and induced economic impacts from the closure of OK-MKARNS on the congressional district of these states, given different durations of waterway shutdowns (Section 3.3). The 2020 Economic Impact Analysis for Planning (IMPLAN) data and its software package were used to conduct the analysis (Lindall et al., 2006; MIG, 2020). All monetary values are in 2020 US dollars.

IMPLAN was created by the United States Forest Service (USFS) in response to the National Forest Management Act of 1976 to determine the socioeconomic effects of forest management plans. The Minnesota IMPLAN Group (MIG, Inc.) partnered with the University of Minnesota to further develop the Input-Output modeling database and software in 1985. IMPLAN was used outside of the federal government for the first time in 1988. Since then, the platform has expanded to include national-level production tables, state- and county-level data on employment and business establishments, and Multiregional Input-Output (MRIO) capabilities. The county is the basic geographic unit of analysis in IMPLAN. Details in the county-level database facilitate aggregating county economic data to tailor research regions, such as US congressional districts. This research used congressional districts as the unit of analysis because of their political significance and role in representative democracy.

IMPLAN's industry production functions use fixed proportions technology. This assumption implies that one input cannot be substituted with another even though the relative prices of both inputs favor the alternative input. One also assumes that all resources are used at full capacity and that changes in final demand solely drive changes in industry output. This last assumption implies that industry supply is perfectly elastic. For these reasons, IMPLAN results are more applicable to short-term study periods. For example, in the short term, it takes time for businesses to substitute one mode of transportation for another as they adapt to supply chain disruptions. In the medium- or longer-term, competitive modes of transportation will be used after enterprises adapt to new conditions. These caveats, and a short-term outlook, are maintained in this research.

3.1. Industry aggregation and multiregional input-output modeling

There are 546 industry sectors defined in the IMPLAN data tables. This research aggregates these sectors into 37 industries most representative of the region's core economic sectors (Appendix A, Table A1). Aggregation also facilitates the interpretation of the findings. The economic impact of a shock is measured in terms of direct, indirect, and induced effects. Direct effects are the initial impact of a shock on the region's economic activity, such as the closure of a navigable waterway. Indirect effects are changes in business-to-business purchases resulting from the initial impact, such as inter-industry transactions between the water transportation sector and other economic sectors. Induced effects are changes in household spending of labor income following the shock.

The OK-MKARNS Tulsa port classifies the goods most often transported on the waterway into 12 categories: chemical fertilizers, coal and coke, food and farm products, iron and steel, manufacturing equipment, minerals and building, miscellaneous products, other chemicals,

Table 9
Impact on loss in TIO by industry sectors at selected congressional district under a 6-month delay (thousand $).

Industry Sectors	AR-3[a]	CO-2,7 [a]	KS-1 [a]	KS-2 [a]	OK-1,2 [a]	OK-3 [a]	OK-4 [a]	OK-5 [a]
Oilseed	[−3, −3]	–	[−55, −56]	[−138, −140]	[−13,399, −13,423]	[−17, −17]	–	–
Grain	–	–	[−445, −456]	[−242, −248]	[−12, 791, −13,081]	[−115, −118]	[−2, −2]	–
Fruit and vegetable	–	–	–	–	[−5, −6]	–	–	–
Tree nut	–	–	–	–	[−3, −4]	–	–	–
Greenhouse	–	–	–	–	[−17, −19]	[0, −1]	–	–
Cotton	–	–	–	–	–	[−3, −3]	[−1, −1]	–
Beef cattle	[−1, −1]	–	[−23, −23]	[−5, −6]	[−38, −39]	[−6, −6]	[−2, −2]	–
Dairy cattle and milk	–	–	[−1, −1]	–	[−6, −6]	[−1, −1]	–	–
Poultry and egg	[−27, −28]	–	–	–	[−32, −33]	–	–	–
Other animal production	–	–	[−2, −2]	[−3, −3]	[−29, −30]	[−2, −2]	[−1, −1]	–
Primary forestry	[−4, −4]	–	–	[−1, −1]	[−21, −22]	[−1, −1]	–	[−2, −2]
Commercial fishing and hunting	–	–	–	–	[−1, −1]	–	–	–
Natural gas petroleum	[−8, −10]	[−1, −1]	[−28, −30]	[−34, −37]	[−1,716, −5,280]	[−32, −36]	[−68, −84]	[−24, −27]
Mining	[−9, −9]	[−9, −9]	[−2, −2]	[−14, −15]	[−7,840, −8,315]	[−1, −1]	–	[−37, −39]
Services	[−815, −902]	[−31, −33]	[−41, −43]	[−142, −152]	[−10, 469, −11,527]	[−172, −187]	[−53, −59]	[−179, −194]
Utilities	[−35, −38]	[−2, −2]	[−81, −85]	[−586, −613]	[−3, 762, −3,943]	[−108, −114]	[−24, −25]	[−208, −218]
Construction	[−22, −23]	[−1, −1]	[−6, −6]	[−11, −12]	[−3, 687, −4,761]	[−15, −16]	[−4, −5]	[−6, −7]
Textiles	[0, −1]	–	–	–	[−1, −1]	–	–	–
Milling	[−37, −38]	–	[−54, −56]	[−35, −36]	[−888, −912]	[−42, −43]	[−5, −5]	[−40, −41]
Food manufacturing	[−38, −41]	[−2, −3]	[−6, −6]	[−9, −9]	[−3,247, −3,454]	[−5, −5]	[−5, −5]	[−11, −12]
Dairy processing	[−7, −8]	–	[−2, −2]	–	[−29, −30]	[−6, −6]	[−1, −1]	[−2, −2]
Animal processing	[−103, −107]	–	[−49, −50]	[−12, −12]	[−89, −93]	[−25, −26]	[−3, −3]	[−7, −7]
Breweries, wineries, distilleries	[−14, −14]	[−55, −57]	[−1, −1]	–	[−28, −29]	[−2, −2]	–	[−5, −5]
Secondary forestry	[−44, −48]	[−1, −1]	[−2, −2]	[−8, −9]	[−133, −146]	[−3, −3]	[−1, −2]	[−6, −6]
Agriculture inputs	[−81, −83]	[−27, −27]	[−114, −116]	[−151, −155]	[−36, 921, −37,821]	[−84, −87]	[−32, −33]	[−26, −27]
Other agriculture	[−8, −9]	[0, 1]	[−2, −2]	[−3, −3]	[−321, −593]	[−7, −8]	[−1, −1]	[−2, −2]
Wholesale	[−314, −335]	[−12, −13]	[−46, −47]	[−91, −95]	[−6, 445, −6,866]	[−274, −292]	[−28, −30]	[−156, −166]
Retail trade	[−61, −67]	[−4, −4]	[−19, −19]	[−30, −31]	[−2, 932, −3,203]	[−88, −95]	[−13, −14]	[−25, −27]
Rail transportation	[−2, −2]	–	[−4, −5]	[−42, −44]	[−1,045, −1,094]	[−7, −8]	[−3, −3]	[−5, −5]
Water transportation	–	–	–	–	[−2,127, −2,136]	–	–	–
Truck transportation	[−165, −174]	[−1, −1]	[−10, −10]	[−13, −14]	[−1, 937, −2,057]	[−34, −36]	[−16, −17]	[−12, −13]
Other transportation	[−21, −23]	[−1, −1]	[−6, −6]	[−16, −17]	[−1,714, −1,856]	[−15, −16]	[−7, −8]	[−18, −19]
Warehousing and Storage	[−39, −42]	–	[−2, −2]	[−4, −4]	[−499, −531]	[−3, −3]	[−10, −10]	[−11, −12]
F.I.R.E.	[−283, −307]	[−22, −24]	[−109, −112]	[−182, −190]	[−12,759, −13,692]	[−274, −295]	[−50, −55]	[−160, −172]
Miscellaneous	[−168, −184]	[−30, −32]	[−31, −32]	[−64, −67]	[−5,037, −5,485]	[−113, −123]	[−36, −39]	[−103, −111]
Government	[−29, −32]	[−2, −2]	[−12, −13]	[−78, −82]	[−3,662, −3,899]	[−74, −79]	[−33, −35]	[−55, −58]
Manufacturing	[−105, −116]	[−43, −47]	[−36, −40]	[−94, −103]	[−12,982, −14,334]	[−80, −88]	[−43, −47]	[−101, −112]

a: The first entry in the bracket ('[]') is calculated with the RPC equal to zero, and the second entry in the bracket is calculated with the RPC equal to the IMPLAN Social Accounting Matrix (SAM). "–" refers to no impact.

petroleum products, and sand, gravel, and rock (Table 1, second column). These definitions were apportioned across the 37-industry aggregation into aggregate subsets (Table 1, first column). For example, the commodity "Iron and Steel" was appropriated into more than one sector due to overlapping definitions. Apportionment was accomplished using weights determined as value shares. Apportionment weights were calculated as the ratio of the total industry output of the industry (valued in dollars). Total industry output (TIO, dollars) for construction was $18 billion, and the TIO for manufacturing was $45 billion. The $18 billion was divided by the combined TIO of construction and manufacturing ($63 billion), which resulted in a construction weight of 0.29. This process was also repeated for manufacturing. The total value of the "Iron and Steel" tonnage reported by port operators was multiplied by their respective weights, thereby allocating the share-weighted values for "Iron and Steel" to the manufacturing and construction industries, respectively (Table 1).

A multi-regional input–output (MRIO) was used to link the economies of each region spatially to the congressional districts where the OK-MKARNS resides (Fig. 1). The MRIO model extends Leontief's single region IO model (Leontief, 1936) to one that allows for transactions between regions and the economic sectors in those locations. MRIO linkages permit economic shocks occurring in a sector of a given region to impact sectors in linked regions through market-based transactions. All regions included in an MRIO experience these effects through changes in trade between regions and local household spending within regions (Miller and Blair, 2009). An MRIO model was built for the congressional districts of all four states to estimate the economic impact of port closure length on each district.

The OK-MKARNS flows through Congressional District 1 (OK-1, the Tulsa metropolitan statistical area) and Congressional District 2 (OK-2) before it reaches Arkansas. OK-2 includes counties in the state's eastern region spanning from the northern state line with Kansas to the southern state border with Texas and extending to the Oklahoma City metroplex. Port closures have direct impacts on the OK-1 and OK-2's economies. These districts were combined into one region (OK-1,2 hereafter). The indirect and induced effects experienced in the other three districts in Oklahoma (OK-3, OK-4, and OK-5), the five congressional districts in Arkansas (AR-1, AR-2, AR-3, AR-4, and AR-5), the four congressional districts in Kansas (KS-1, KS-2, KS-3, and KS-4), and the seven congressional districts in Colorado (CO-1, CO-2, CO-3, CO-4, CO-5, CO-6, and CO-7) through feedback paths. In Colorado, districts 2 and 7 (CO-2,7 hereafter) and districts 4 and 6 (CO-4,6 hereafter) had to be combined because these congressional districts' border lines did not match the county border lines. Table A2 in Appendix A presents a comprehensive list of county names and their respective grouping into congressional districts.

3.2. Contribution analysis

A contribution analysis is a counterfactual exercise. A contribution analysis quantifies the direct, indirect, and induced effects of the removal of Oklahoma's water transportation sector on the jobs, TIO, and value-added for each of the four states. To estimate the economic contribution of the OK-MKARNS to the economies of the four states analyzed, we removed the water transportation sector from Oklahoma's economy.

Table 10
Impact on loss in value-added by industry sectors at selected congressional district under a 6-month delay (Thousand Dollars).

Industry Sectors	AR-3 [a]	CO-2,7 [a]	KS-1 [a]	KS-2 [a]	OK-1,2 [a]	OK-3 [a]	OK-4 [a]	OK-5 [a]
Oilseed	[−2, −2]	–	[−22, −23]	[−56, −56]	[−8,955, −8,971]	[−11, −11]	–	–
Grain	–	–	[−112, −115]	[−61, −62]	[−4,739, −4,847]	[−42, −44]	[−1, −1]	–
Fruit and vegetable	–	–	–	–	[−2, −2]	–	–	–
Tree nut	–	–	–	–	[−2, −2]	–	–	–
Greenhouse	–	–	–	–	[−6, −7]	–	–	–
Cotton	–	–	–	–	–	[−1, −1]	–	–
Beef cattle	–	–	[−4, −4]	[−1, −1]	[−11, −11]	[−2, −2]	[−1, −1]	–
Dairy cattle and milk	–	–	–	–	[−1, −1]	–	–	–
Poultry and egg	[−2, −2]	–	–	–	[−2, −2]	–	–	–
Other animal production	–	–	[−1, −1]	[−2, −2]	[−22, −23]	[−2, −2]	–	–
Primary forestry	[−2, −2]	–	–	[−1, −1]	[−10, −11]	–	–	[−1, −1]
Commercial fishing and hunting	–	–	–	–	[−1, −1]	–	–	–
Natural gas petroleum	[−2, −3]	–	[−5, −5]	[−6, −7]	[−696, −2,140]	[−11, −13]	[−15, −18]	[−13, −14]
Mining	[−3, −4]	[−4, −5]	[−1, −1]	[−5, −5]	[−2,491, −2,641]	[−3,−3]	[−2, −2]	[−32, −33]
Services	[−506, −561]	[−19, −21]	[−21, −22]	[−79, −85]	[−6,011, −6,618]	[−85, −92]	[−27, −30]	[−108, −117]
Utilities	[−15, −16]	[−1, −1]	[−32, −34]	[−244, −255]	[−1,398, −1,465]	[−33, −35]	[−6, −7]	[−73, −76]
Construction	[−10, −10]	[−1, −1]	[−3, −3]	[−5, −6]	[−1,634, −2,111]	[−7, −7]	[−2, −2]	[−3, −3]
Textiles	–	–	–	–	–	–	–	–
Milling	[−4, −4]	–	[−6, −6]	[−9, −9]	[−100, −102]	[−6, −6]	[−1, −1]	[−5, −5]
Food manufacturing	[−10, −11]	[−1, −1]	[−1, −2]	[−2, −2]	[−951, −1,011]	[−1, −1]	[−1, −1]	[−3, −3]
Dairy processing	[−1, −1]	–	–	–	[−5, −5]	[−1, −1]	–	–
Animal processing	[−21, −21]	–	[−6, −7]	[−1, −1]	[−14, −15]	[−3, −3]	–	[−1, −1]
Breweries, wineries, distilleries	[−7, −7]	[−24, −25]	–	–	[−7, −7]	[−1, −1]	–	[−2, −2]
Secondary forestry	[−12, −13]	–	[−1, −1]	[−3, −3]	[−45, −50]	[−1, −1]	[0, −1]	[−2, −2]
Agriculture inputs	[−19, −20]	[−8, −8]	[−31, −31]	[−34, −34]	[−9,212, −9,437]	[−25, −26]	[−10, −10]	[−8, −8]
Other agriculture	[−4, −4]	–	[−1, −1]	[−2, −2]	[−165, −305]	[−3, −3]	–	[−1, −1]
Wholesale	[−193, −205]	[−7, −7]	[−24, −25]	[−49, −51]	[−3,745, −3,990]	[−175, −186]	[−16, −17]	[−88, −94]
Retail trade	[−37, −40]	[−2, −3]	[−11, −11]	[−17, −18]	[−1,678, −1,833]	[−47, −51]	[−7, −8]	[−15, −16]
Rail transportation	[−1, −1]	–	[−3, −3]	[−24, −25]	[−701, −734]	[−5, −5]	[−2, −2]	[−3, −4]
Water transportation	–	–	–	–	–	–	–	–
Truck transportation	[−78, −83]	–	[−4, −4]	[−6, −6]	[−1,019, −1,082]	[−15, −16]	[−6, −7]	[−6, −6]
Other transportation	[−11, −11]	–	[−4, −5]	[−11, −12]	[−1,548, −1,676]	[−9, −10]	[−4, −5]	[−14, −14]
Warehousing and Storage	[−20, −21]	–	[−1, −1]	[−2, −2]	[−201, −214]	[−2, −2]	[−5, −5]	[−6, −6]
F.I.R.E.	[−154, −167]	[−11, −12]	[−53, −54]	[−96, −100]	[−6,613, −7,097]	[−137, −147]	[−26, −28]	[−81, −87]
Miscellaneous	[−85, −93]	[−17, −18]	[−16, −17]	[−34, −36]	[−2,495, −2,718]	[−57, −62]	[−16, −17]	[−57, −61]
Government	[−27, −29]	[−2, −2]	[−12, −12]	[−72, −76]	[−2,663, −2,835]	[−61, −65]	[−26, −28]	[−51, −54]
Manufacturing	[−31, −34]	[−18, −20]	[−10, −11]	[−27, −29]	[−3,824, −4,223]	[−21, −23]	[−12, −13]	[−31, −34]

a: The first entry in the bracket ('[]') is calculated with the RPC equal to zero, and the second entry in the bracket is calculated with the RPC equal to the IMPLAN Social Accounting Matrix (SAM). "–" refers to no impact.

The process of conducting a contribution analysis eliminates the forward (downstream) and backward (upstream) linkages between the water transportation sector in Oklahoma to all other sectors in each of the other three states as well as Oklahoma's economy (Henderson, 1982; Miller and Blair, 2009; Parajuli et al., 2018). Levels of TIO, jobs, and value-added, absent a water transportation sector, are re-estimated and compared to the status quo levels of these economic indicators. The contribution analysis is reported as a multiplier. For an additional 1$ increase in final demand, the sector's contribution to the economy in dollar terms is the multiplier less the initial dollar spent. We expect that the further away a state is from the OK-MKARNs, the smaller the economic contribution will be.

3.3. Economic impacts and waterway transportation delays

An economic impact analysis differs from a contribution analysis in that the effects of a specific disruption, measured in terms of value lost due to the waterway's disruption, on TIO, jobs, and value-added are quantified. This study examines the impacts of a 2-Month, 4-Month, and 6-Month waterway closure on the OK-MKARNS section of the navigation system. Again, this specific shock is only applied to Oklahoma congressional districts '1' and '2' (OK-1,2).

Delayed disruption shocks by each industry sector are presented in Table 2. Disruption shocks were calculated using the delay costs per tonnage by commodity and the term of delay multiplied by the average tonnage delayed per month (Robinson et al., 2014; Welch et al., 2022). The top three industries that experienced the most economic disruption from the shock are "*Agricultural Inputs*, *Mining*", "*Natural Gas and Petroleum*", and "*Grain*, *Oilseed*, and *Construction*". These shocks were applied to the MRIO model to estimate the economic impacts of each delay scenario. We expect the disruption's economic impacts on congressional districts will be lower than those of congressional districts near the OK-MKARNS waterway.

3.4. Regional purchasing coefficient (RPC)

We evaluated the MRIO under two scenarios. The scenarios vary the extent to which a sector in a congressional district depends on transactions with other sectors in neighboring districts. The key parameters changed inside the MRIO model are the regional purchasing coefficients (RPC). RPC, which range between '0' and '1', determine how much the total demand of a commodity or service in a region is met with its supply (Miller and Blair, 2009). We first set the RPC to '0' in the directly affected regions of OK-1,2. This RPC assumption maintains that when the water transportation sector is removed or disrupted, the industry is forced to source all demand for navigable waterway services outside the directly affected region.

The second RPC scenario uses information in the social accounting matrix to make proportional weights, which determine the amount of local industry demand supplied locally as a weighted average, with the remainder outsourced outside the region. Therefore, the economic contribution or impact estimated using 'RPC = 0' will be smaller than those generated when RPC is larger than zero. These two scenarios provide lower and upper ranges in the contribution and impact analyses.

Table A1
Industry sector aggregation.

Aggregated Industry Sectors	Industry in Aggregation
Oilseed	Oilseed farming
Grain	Grain farming
Fruit and vegetable	Vegetable and melon, and other fruit farming
Tree nut	Tree nut farming
Greenhouse	Greenhouse, nursery, and floriculture production
Cotton	Cotton farming
Beef cattle	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming
Dairy cattle and milk	Dairy cattle and milk production
Poultry and egg	Poultry and egg production
Other animal production	Animal production, except cattle and poultry and eggs
Primary forestry	Forestry, forest products, and timber tract production; Commercial logging
Commercial fishing and hunting	Commercial fishing, hunting, and trapping
Natural gas and petroleum	Oil and gas extraction; drilling oil and gas wells; support activities for oil and gas operations; petroleum refineries; industrial gas manufacturing
Mining	All commercial mining and other nonmetallic minerals; drilling oil and gas wells; supportive activities for oil and gas operation
Services	All services
Utilities	Electric power generation, transmission, and distribution; natural gas distribution; water, sewage, and other systems
Construction	All constructions, maintenance, and repair
Textiles	All textiles
Milling	Flour and rice milling, malt manufacturing; wet corn milling; soybean and other oilseed processing; fats and oils refining and blending; sugar cane mills and refining
Food manufacturing	All food manufacturing
Dairy processing	Cheese and dairy production
Animal processing	Poultry processing; animal, except poultry, slaughtering; meat processed from carcasses; rendering and meat byproduct processing; seafood product preparation and packaging; leather and hide tanning and finishing
Breweries, wineries, distilleries	Breweries; wineries; distilleries
Secondary forestry	Furniture, woodwork manufacturing; and all other converted paper product manufacturing
Agriculture inputs	Support activities for agriculture and forestry; other animal food, fertilizer, pesticide, and other agricultural chemical manufacturing; farm machinery and equipment, lawn and garden equipment manufacturing
Other agriculture	Tobacco, sugarcane, and sugar beet farming; all other crop farming; Landscape and horticultural services
Wholesale	Wholesale
Retail trade	Dealers; retail stores
Rail transportation	Rail transportation
Water transportation	Water transportation
Truck transportation	Truck transportation
Other transportation	Air transportation; transit, ground passenger, pipeline, scenic and sightseeing transportation; support activities for transportation; couriers and messengers;
Warehousing	Warehousing and storage
F.I.R.E.	Depository and non-depository credit intermediation; brokerage; financial vehicles; insurance carriers, agencies, brokerage, and related activities; Real estate and owner-occupied dwellings
Government	Schools, local and federal electric utilities; transit, state, and local government enterprises; local and federal employment and payroll of state and federal government, rest of the world adjustment
Manufacturing	Non-food manufacturing (not including agricultural and forestry input- or output-related manufacturing)
Miscellaneous	All other industries (used goods, scrap, religious, business, and social organizations)

Table A2
Counties included in each congressional district.

Congressional District	Counties
AR-1	Phillips, Independence, Prairie, Chicot, Fulton, Cleburne, Cross, St. Francis, Mississippi, Woodruff, Jackson, Izard, Monroe, Craighead, Lee, Stone, Arkansas, Greene, Lonoke, Desha, Searcy, Poinsett, Baxter, Clay, Crittenden, Lincoln, Sharp, Lawrence, Randolph
AR-2	White, Conway, Faulkner, Saline, Van Buren, Pulaski, Perry
AR-3	Pope, Carroll, Boone, Sebastian, Marion, Benton, Crawford, Washington
AR-4	Howard, Garland, Hempstead, Pike, Ashley, Bradley, Scott, Lafayette, Miller, Grant, Montgomery, Newton, Nevada, Union, Franklin, Columbia, Yell, Cleveland, Madison, Jefferson, Polk, Sevier, Calhoun, Ouachita, Clark, Logan, Hot Spring, Little River, Johnson, Drew, Dallas
CO-1	Denver
CO-2,7	Grand, Broomfield, Summit, Clear Creek, Larimer, Boulder, Gilpin, Jefferson
CO-3	San Juan, Jackson, Dolores, Huerfano, San Miguel, Lake, Rio Blanco, Gunnison, Archuleta, La Plata, Routt, Ouray, Mineral, Rio Grande, Custer, Mesa, Pitkin, Delta, Montezuma, Conejos, Costilla, Saguache, Moffat, Alamosa, Garfield, Hinsdale, Pueblo, Eagle, Montrose
CO-4,6	Elbert, Sedgwick, Kiowa, Cheyenne, Crowley, Phillips, Las Animas, Weld, Bent, Lincoln, Otero, Washington, Morgan, Logan, Baca, Adams, Yuma, Arapahoe, Prowers, Kit Carson, Douglas
CO-5	Chaffee, Fremont, Teller, El Paso, Park
KS-2	Shawnee, Jackson, Miami, Woodson, Montgomery, Neosho, Anderson, Jefferson, Brown, Wilson, Douglas, Franklin, Marshall, Bourbon, Nemaha, Crawford, Cherokee, Linn, Leavenworth, Coffey, Atchison, Allen, Labette, Doniphan, Osage
KS-3	Wyandotte, Johnson
KS-4	Sumner, Cowley, Chautauqua, Barber, Kiowa, Harvey, Stafford, Edwards, Sedgwick, Pratt, Butler, Kingman, Harper, Comanche, Greenwood, Elk
OK-1,2	Mayes, Rogers, Tulsa, Pittsburg, Delaware, Ottawa, Coal, Craig, Atoka, Okmulgee, Hughes, Nowata, McCurtain, Johnston, Le Flore, McIntosh, Adair, Haskell, Bryan, Cherokee, Marshall, Pushmataha, Muskogee, Washington, Choctaw, Latimer, Okfuskee, Wagoner, Sequoyah
OK-3	Caddo, Roger Mills, Washita, Kiowa, Ellis, Osage, Canadian, Grant, Payne, Major, Woods, Blaine, Kingfisher, Dewey, Alfalfa, Custer, Kay, Beckham, Garfield, Logan, Greer, Harmon, Woodward, Texas, Jackson, Lincoln, Pawnee, Noble, Cimarron, Creek, Harper, Beaver
OK-4	Comanche, Murray, Stephens, Tillman, Love, Carter, Jefferson, Pontotoc, Grady, Cotton, McClain, Garvin, Cleveland
OK-5	Seminole, Pottawatomie, Oklahoma

4. Results

4.1. OK-MKARNS economic contribution to each state

The total contribution of the OK-MKARNS to the economy of all four states (Oklahoma, Arkansas, Colorado, and Kansas) is estimated to be 40 jobs, $10.76 million in TIO, and $2.95 million in value-added (Table 3). However, unsurprisingly, the main contribution is to Oklahoma, with 38 jobs, $9.75 million in TIO, and $2.19 million in value-added, since all the direct impacts of the contribution analysis are within Oklahoma. The contribution of the OK-MKARNS is much smaller in the other states because only indirect and induced impacts are experienced in Arkansas, Colorado, and Kansas. Arkansas includes a significant portion of MKARNS. Shipment from OK-MKARNS must go through the Arkansas portion of MKARNS before reaching the Mississippi River. Therefore, the OK-MKARNS economic contribution to Arkansas is the largest among the three states excluding Oklahoma, with two jobs, $0.23 million in TIO, and $0.12 million in value-added.

The importance of the OK-MKARNS contribution to Oklahoma's economy is evident in the employment, TIO, and value-added multipliers (Table 4). An additional job employed by OK-MKARNS ports brings an estimated 2.94 (=3.94–1) indirect and induced jobs to other industries in Oklahoma (Table 4). The TIO multiplier of 1.24 (=2.24–1) in Oklahoma indicates that for every dollar of activity supported by the

OK-MKARNS, an additional $1.24 is generated in other industries of Oklahoma's economy. Employment, TIO, and value-added multipliers in other states are just over one job and $1, and are relatively small compared to the effects observed in Oklahoma. This finding is unsurprising, given that enterprises in these congressional districts likely use a variety of other modes of transportation and that they are located further away from the waterway.

4.2. Congressional district economic impacts and delay duration

Port closure due to disruption of the OK-MKARNS has either no impact or a negative impact on jobs, TIO, and value-added across all congressional districts. Tables 5–7 summarize the results of a short-term delay (2-month), a medium-term delay (4-month), and a relatively long-term delay (6-month) in each congressional district. Overall, the longer the closure duration is, the more negative the impacts on employment, TIO, and value-added are.

Economic losses due to port closures were largest for Oklahoma congressional districts 1 and 2 (OK-1,2) because the OK-MKARNS is located in these districts. OK-1,2 are the only districts to experience direct economic losses for this reason. The losses attributable to closure in the other states are only experienced as indirect and induced losses. A 2-month delay in waterway transportation services resulted in 62 to 67 jobs lost in OK-1,2. In comparison, the other districts lost less than two jobs (Table 5). As the delay increases, the impact of the closure on jobs also increases, most notably for AR-3 and KS-2 (up to 16 jobs for AR-3 and seven jobs in KS-2 when the delay extended to 6 months). Interestingly, job losses are higher in AR-3 than in other Oklahoma congressional districts (OK-3, OK-4, and OK-5). This difference in magnitude happens because of AR-3's proximity to the OK-MKARNS portion of the waterway.

The top five congressional districts experiencing a loss in TIO are $14 to $16 million for OK-1,2, $0.24-$0.26 million for AR-3, $0.19 million for KS-2, $0.11 million for KS-1, and $0.1 million for OK-3 under the 2-month port closure scenario (Table 6). The closure impacts on value-added were quatitatively similar to those observed for TIO. In addition, across the three delay lengths, AR-3, CO-2,7, and KS-2 experienced the most considerable value-added losses apart from Oklahoma congressional districts (Table 7). AR-3 and KS-2 value-added decreased by over $2 million under 6-month delay. Disruption in OK-MKARNS operations likely reduced the volume of goods and services transacted between OK-1,2, and AR-3. Congressional districts KS-1 and KS-2 are prominent grain and oilseed exporting regions, and congressional district KS-2 is just above the OK-1,2 districts.

The direct and indirect impacts on industry sector performance due to port delays differ among the affected congressional districts. Tables 8–10 summarize the impacts on employment, TIO, and value-added by industry sectors for selected congressional districts, considering a relatively long-term disruption. This scenario aligns closely with the actual closure of OK-MKARNS, which lasted for 140 days and experienced reduced capacity after reopening because of unfinished dredging of the channel. These selected congressional districts include AR-3, CO-2,7, KS-1, KS-2, OK-1,2, OK-3, OK-4, and OK-5. The results show that congressional district OK-1,2 losses jobs mainly in the sectors of "*Oilseed*", "*Grain*", "*Mining*", "*Service*", "*Construction*", and "*Agricultural inputs*" (Table 8). For AR-3, about seven jobs are lost in *Service* sector, while there was no employment impact in CO-2,7 and only one or two job losses in KS-1, KS-2, OK-1,2, and OK-3. The industry sectors' TIO and value-added most affected are "*Oilseed*", "*Grain*", "*Agriculture inputs*", "*Services*", and "*Financial, Insurance, and Real Estate* (*F.I.R.E.*)" (Tables 9 and 10). The closure directly impacted "*Oilseed*", "*Grain*", *and* "*Agriculture inputs*" because they are industries that normally use the OK-MKARNS to receive fertilizer and ship grains and oilseed products. Agricultural industries are important to the OK-1,2, OK-3, KS-1, and KS-2's economies, with Kansas ranking second in the US wheat exports and Oklahoma seventh (USDA-ERS, 2020). "*Services*" and "*F.I.R.E.*" industries incurred indirect and induced impacts in AR-3 compared with other congressional districts outside Oklahoma.

Although CO-2,7 is furthest from OK-MKARNS ports, long port service delays could affect TIO and value-added in CO-2,7's industry sectors, including "*Breweries, wineries and distilleries*", "*Service*", "*Manufacturing*", and "*Agriculture inputs*". For example, the results show that the estimated loss in TIO under 6-month delay is $55 to $57 thousand in the "*Breweries, wineries and distilleriesI*" sector and $43 to 47 thousand in the *Manufacturing* sector. CO-2,7's *Service* and *Agriculture inputs* sectors could lose $27 to $33 thousand in TIO and $19 to $21 thousand in value-added. Although these losses are relatively small compared to those experienced in other congressional districts much closer to OK-MKARNS ports, the ripple effects are noticeable.

5. Conclusions

Inland ports and waterway systems are essential to US domestic and international transportation networks. Disruption of one port or waterway segment due to natural disasters could put undue pressure on other transportation modes in the supply chain. It is therefore important to have practical information on the resilience of the disrupted port and its waterway transportation concerning the changes in shipment throughput and what volume of the shipment switch to other modes of transportation at the regional level.

The unprecedented flooding events of 2019 shut down the OK-MKARNS, a gateway for the Central Great Plain states to the Mississippi River and international markets. The purpose of this research was to 1) determine the economic contribution of the OK-MKARNS navigable waterway system to the economics of four states (Colorado, Oklahoma, Kansas, and Arkansas) and 2) document the regional economic impacts of the 2019 flood and the ensuing closure of the OK-MKARNS on these economies. For the second objective, the analysis focused on the inter-regional linkages between Oklahoma's congressional districts with congressional districts in Colorado, Arkansas, and Kansas. The application used a multi-regional input–output model to achieve both objectives.

The scientific challenge was to answer the question: what is the economic contribution of a navigable waterway system on the economics of four states located in the Central Great Plains? The null hypothesis was that 1) the economic contribution of the OK-MKARNs was zero and 2) that the 2019 flood disruption of the OK-MKARNS had no impact on the region's economies. The MRIO model is not a statistical model, which precludes formal hypothesis testing using typical statistical assumptions. This is a limitation of input–output modeling approaches and, more generally, math programming approaches. On the other hand, we are unaware of any statical models capable of examining the effects of the flood's dustup on the region's only navigable inland waterway in the details afforded by the multi-regional input–output model used here.

Nonetheless, results show that OK-MKARNS contributes to Oklahoma's economy as the only inland waterway transportation system available and significantly to its neighboring states. The results show that the economic contribution of the OK-MKARNS, and the economic impacts of OK-MKARNS closure, are larger and is integrated to the region's supply chain. The analysis estimated that disruption of the OK-MKARNS will cause negative economic impacts on Oklahoma's congressional districts, especially on agricultural industries, mining, construction, and manufacturing sectors in Oklahoma congressional districts 1, 2, and 3, as these sectors depend either directly or indirectly on OK-MKARNS waterborne transportation services to ship out and receiving goods. Oklahoma congressional district 3 is a central agricultural production region. The disruption of OK-MKARNS port indirectly affects this district's farming communities to delay receiving fertilizer and shipping their wheat and corn products. Therefore, allocating sufficient funds to maintain the OK-MKARNS waterway would likely benefit Oklahoma's agricultural producers by keeping transportation

costs low.

Congressional districts in other states who are close to OK-MKARNS ports, such as Arkansas congressional district 3 and Kansas congressional districts 1 and 2, should also consider the loss of TIO and value-added in agricultural and service sectors if the length of OK-MKARNS disruption extends over a longer period (i.e., six months of delay in this study). The loss of TIO and value-added in these districts are mainly incurred by the oilseed and grain farming, services, and agricultural inputs, indicating the OK-MKARNS economic importance to these congressional districts. Colorado congressional districts 2 and 7 also experience considerable economic loss in services and breweries, wineries, and distilleries with a six-month delay scenario. However, these two districts are the furthest from the OK-MKARNS. This finding could be helpful to state transportation authorities and congressional leaders as they balance fiscal responsibilities with the funds needed to maintain the waterway.

CRediT authorship contribution statement

Katherine L. Welch: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Lixia H. Lambert:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Dayton M. Lambert:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Dave Shideler:** Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

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