Economic Analysis of Disruptions on the Mississippi River: An Engineering Economy Educational Case Study

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Abstract

Student ability and understanding of engineering economy is promoted through real world application. As engineering and engineering technology educators, we are encouraged to educate our students in contemporary issues related to engineering education. This paper provides engineering economy instructors with a real world educational case study based on maritime logistics. An instructor's solutions manual is available from the authors.

Overview

Real-world application of engineering concepts motivates and engages students in engineering economy coursework. We present an educational case study that has real-world application in the maritime transportation sector. The case study provides detailed background and data for the application area and provides an easy-to-use learning exercise for engineering economics instructors and students. The case study relies on engineering economic concepts including internal rate of return (IRR), Analytic Hierarchy Process (AHP), and simple linear regression.

Maritime transportation is a vital component of the world's logistics system. Natural and man-made events can lead to disruptions of the system including ice, droughts, or floods that can cause non-navigable water levels and earthquakes or terrorist attacks that can destroy the infrastructure of the navigation system. Disruptions to the system can have widespread economic and societal impacts, and their consequences can be significant. Extensive data related to the disrupted inland waterway needs to be collected and economically analyzed to support best disruption recovery practices. A section of the Mississippi River is selected as the study region and supports a realistic case study to put engineering economic tools into practice. Commodity freight, infrastructure, and terminal data within the selected study region are collected to provide a real world information pool to support development of practical engineering economy skills in undergraduate engineering and engineering technology students. An instructor's guide is provided to support efficient adoption in the classroom. Successful completion of the case study will give students an opportunity to utilize engineering economy, decision, and data analysis tools on a real world engineering problem related to the maritime transportation system.

Case Study Introduction

The Mississippi River, including its main channels and tributaries, is a vital component of commodity transport in the United States. It flows 2,350 miles from Minnesota through the center of the United States to the Mississippi River Delta at the Gulf of Mexico[1]. It is estimated that approximately 600 million tons of commodities transported via the Mississippi River each year, including 125 million tons from the Upper Mississippi River (Minneapolis, Minnesota to Cairo, Illinois) and 470 million tons from the Lower Mississippi River (Cairo, Illinois to the Gulf of Mexico)[2]. Multiple river reports use ten major economic sectors to evaluate river contribution to the vicinity areas, which are commercial navigation, harvest of natural resources, water supply, recreation, tourism, mineral resources, agriculture, energy production, manufacturing and ecosystem. The ten economic sectors around the Mississippi River account for approximately $200 billion in revenue to businesses in the corridor and over 1 million jobs are associated with this economic activity[2][3]. The competitiveness of the waterway transportation stems from the efficiency of the waterway system. A standard tow consisting of fifteen barges has the same capacity as 225 rail cars or 900 semi tractor-trailers and can carry roughly 22,500 tons depending on the type and weight of commodity[4]. The average savings of barge transportation over other modes is about $9.00 per ton[3].

Multiple natural and man-made events can lead to the disruptions of the Mississippi River such as ice, droughts, or floods that can cause non-navigable water levels and earthquakes or terrorist attacks that can destroy the infrastructure of the navigation system[5]. Other possible disruption causes include vessel allision or collision and mechanical vessel problems. In 2012, the Mississippi River suffered a record-breaking low water level and was very close to being completely shut down. Disruptions on the inland waterway system can have widespread economic and societal impacts, and their consequences can be significant. For instance, the main lock chamber of Lock 27 on the Mississippi River was closed to navigation traffic for gate repairs between July 26, 2004 and August 10, 2004. The closure resulted in long delays for the carriers. The influence was far-reaching that it aroused concerns from Japan, which was worried if the United States could meet its agriculture needs[6].

Case Study Data

Extensive data related to the inland waterway needs to be collected to analyze the best disruption recovery practice. The selected study region of interest is a 154-mile section on the Upper Mississippi River from Lock & Dam (L/D) 14 north of Davenport, Iowa to L/D 19 at Keokuk, Iowa, as can be seen in Exhibit 1. The cities of Keokuk and Burlington and the Quad Cities metropolitan area (Davenport and Bettendorf in Iowa, and Moline and Rock Island in Illinois) are in this study region[7]. Exhibit 1 shows that there are both railways and highways serving the selected river section. In the event of the waterway disruption, one of the recovery actions considered by the local authorities and private owners is to offload the barge cargoes in the disrupted river section to the nearby terminals and move them to their final destination through land transport methods such as railways or highways. Such practice can prevent the barge cargoes from waiting on the disrupted and turbulent river for a potential long time. The Iowa, Chicago, and Eastern railroad (ICE) connects the terminals on the northern part of the study region to the western areas of the Mississippi River. The Burlington Northern and Santa Fe railroad (BNSF) and Keokuk Junction Railway (KJRY) serve terminals on the southern part of the study region[7].

Commodity freight, L/D system, and terminal data within the selected river section are analyzed in order to provide a holistic view and information pool to develop disruption recovery practice. The commodity freight data of the study region significantly influences disruption recovery. Different actions may be taken based on the amount of cargo remaining on the river section that needs to be offloaded when the disruption happens. However, there is no direct cargo data summarized specifically for the study region. The most relevant data available is from the U.S. Army Corps of Engineers (USACE)'s Navigation Data Center, which provides cargo data and vessel trip data for the Mississippi River in general as well as for several major river sections.

Exhibit 1: Study Region on the Mississippi River[7]

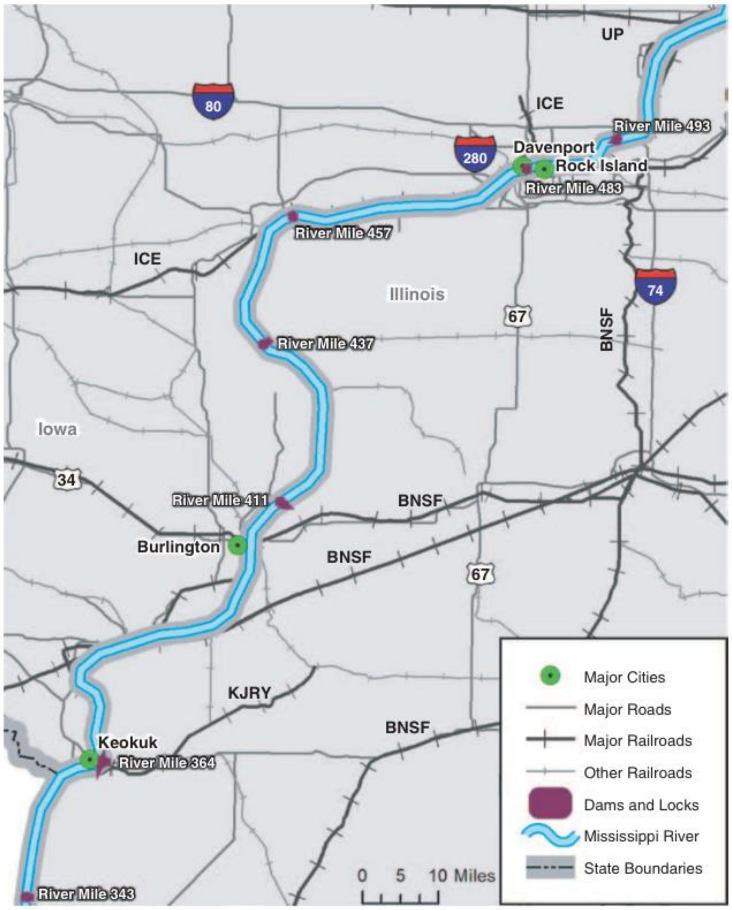


Exhibit 2 and Exhibit 3 display the freight amount by commodity types and the vessel trips by draft size on the Mississippi River from Minneapolis, Minnesota to the Mouth of the Missouri River in 2012[8], which contains the freight data of the study region. A lock is a gate system that allows barges to move smoothly and safely between different water levels on the inland waterway. A dam is a wall-like structure that reserves water for various needs. Together, the lock and dam system is used to control the water levels and provide navigation condition for the waterway throughout the year.[9] Six L/Ds are located within our study region, which are L/Ds 14, 15, 16, 17, 18, and 19. The increasing L/D number indicates a lower water level. For instance, L/D 14 has a higher elevation level than L/D number 19. When an upward bound barge tow enters a lock, the lower doors of the lock are closed, and the lock is filled with water until the water level reaches the upper level. The upper doors are then opened, and the barge tow can safely leave the lock.

Exhibit 2: 2012 Freight Data on the Upper Mississippi River, Minneapolis, MN to Mouth of Missouri River (tons)[8]

	All Traffic Directions	Receipts	Shipments	Intra-waterway	Through
All Commodities	61,706,845	7,955,338	21,061,711	4,312,680	28,377,116
1000 Total Coal, Lignite and Coal Coke	3,729,663	1,390,756	96,456	1,660,484	581,967
2000 Total Petroleum and Petroleum Products	11,026,568	251,543	5,662,666	37,389	5,074,970
2100 Subtotal Crude Petroleum	4,892,995	6,000	4,401,153	0	485,842
2200-2900 Subtotal Petroleum Products	6,133,573	245,543	1,261,513	37,389	4,589,128
3000 Total Chemicals and Related Products	8,762,445	3,169,652	456,970	115,164	5,020,659
3100 Subtotal Fertilizers	4,746,871	2,816,399	219,059	96,621	1,614,792
3200 Subtotal Other Chemicals	4,015,574	353,253	237,911	18,543	3,405,867
4000 Total Crude Materials	7,075,691	1,611,596	1,003,340	1,616,698	2,844,057
4100 Subtotal Forest Products	223,912	6,455	0	0	217,457
4200 Subtotal Pulp and Waste Paper	0	0	0	0	0
4300 Subtotal Soil, Sand, Gravel	3,503,057	562,977	668,109	1,565,350	706,621
4400 Subtotal Iron Ore and Scrap	1,061,661	36,841	333,622	25,958	665,240
4500 Subtotal Marine Shells	2,794	2,794	0	0	0
4600 Subtotal Non-Ferrous Ores and Scrap	189,330	105,327	0	0	84,003
4700 Subtotal Sulphur, Clay and Salt	138,409	8,256	0	0	130,153
4800 Subtotal Slag	225,931	117,988	0	18,908	89,035
4900 Subtotal Other Non-Metal. Min.	1,730,597	770,958	1,609	6,482	951,548
5000 Total Primary Manufactured Goods	5,351,565	1,110,102	507,370	481,917	3,252,176
5100 Subtotal Paper Products	18,257	0	0	0	18,257
5200 Subtotal Lime, Cement and Glass	2,613,441	821,656	495,208	480,362	816,215
5300 Subtotal Primary Iron and Steel Products	2,594,288	277,480	12,162	1,555	2,303,091
5400 Subtotal Primary Non-Ferrous Metal	125,579	10,966	0	0	114,613
5500 Subtotal Primary Wood Products	0	0	0	0	0
6000 Total Food and Farm Products	25,450,885	203,199	13,318,880	401,028	11,527,778
6100 Subtotal Fish	0	0	0	0	0
6200-6400 Subtotal Grain	12,084,092	60,829	6,272,289	29,069	5,721,905
6500 Subtotal Oilseeds	10,923,477	33,821	6,286,267	371,959	4,231,430
6600 Subtotal Vegetable Products	539,158	76,448	351,924	0	110,786
6700 Subtotal Processed Grain	1,731,165	6,814	405,137	0	1,319,214
6800 Subtotal Other Agricultural Products	172,993	25,287	3,263	0	144,443
7000 Total All Manufactured Equipment	310,028	218,490	16,029	0	75,509
8000 Total Waste Material; Garbage, Landfill	0	0	0	0	0
9000 Total Unknown	0	0	0	0	0

Exhibit 3: 2012 Vessel Trip Data on the Upper Mississippi River, Minneapolis, MN to Mouth of Missouri River (trips)[8]

	All Vessel Types			Self-Propelled Dry Cargo			Self-Propelled Towboat			Non-Self Propelled Dry Cargo			Non-Self Propelled Tanker barge		
	All Traffic Directions	Up-bound	Down-bound	All Traffic Directions	Up-bound	Down-bound	All Traffic Directions	Up-bound	Down-bound	All Traffic Directions	Up-bound	Down-bound	All Traffic Directions	Up-bound	Down-bound
All drafts	77,341	38,657	38,684	5,740	2,870	2,870	16,498	8,244	8,254	45,446	22,715	22,731	9,657	4,828	4,829
0-5 ft.	26,168	17,419	8,749	2,892	1,446	1,446	3,636	1,939	1,697	16,089	11,956	4,133	3,551	2,078	1,473
6-9 ft.	45,528	18,766	26,762	2,848	1,424	1,424	12,377	6,095	6,282	25,335	9,217	16,118	4,968	2,030	2,938
10-12 ft.	4,957	1,911	3,046	0	0	0	485	210	275	3,842	1,489	2,353	630	212	418
13-14 ft.	688	561	127	0	0	0	0	0	0	180	53	127	508	508	0

Exhibit 4: 2014 Freight Data for L/D 14 to 19 on the Mississippi River (tonnage)[10]

Commodity Type	L/D 14	L/D 15	L/D 16	L/D 17	L/D 18	L/D 19
10 - All Coal, Lignite, and Coal Coke	1,845,800.00	1,845,900.00	1,838,300.00	2,212,500.00	2,244,200.00	758,200.00
20 - All Petroleum and Petroleum Products	441,165.00	446,553.00	408,987.00	415,387.00	404,487.00	410,587.00
30 - All Chemicals and Related Products	3,557,169.00	3,565,369.00	3,750,269.00	3,979,727.00	3,938,161.00	4,101,960.00
40 - All Crude Materials, Inedible, Except Fuels	3,138,582.00	3,104,132.00	2,871,872.00	2,832,372.00	2,835,778.00	2,862,178.00
50 - All Primary Manufactured Goods	1,356,408.00	1,595,458.00	1,517,258.00	1,523,458.00	1,523,358.00	1,515,958.00
60 - All Food and Farm Products	5,732,112.00	5,855,712.00	6,390,435.00	6,649,187.00	7,598,703.00	8,786,937.00
70 - All Manufactured Equipment & Machinery	27,102.00	34,302.00	50,552.00	34,500.00	34,385.00	53,990.00
80 - All Waste Material	3,000.00	4,500.00	3,005.00	3,005.00	3,005.00	3,005.00
90 - All Unknown or Not Elsewhere Classified	1,500.00	1,500.00	1,500.00	1,500.00	1,600.00	4,800.00

The L/D system is investigated because of its vulnerable position during the inland waterway transportation. The L/D infrastructure can be damaged by man-made events or rendered dysfunctional through natural occurrences, both of which can lead directly to the waterway closure. The risk is amplified for the study region by the presence of the six important L/Ds located within the area. In addition, the available freight data at L/D provides a reliable data source to estimate the actual commodity freight on the study region. The data containing annual tonnage by commodity group (coal, petroleum, chemicals, etc.) for each L/D in the study region is available through the Navigation Data Center operated by U.S. Army Corps of Engineers. Currently, historical data is provided from 1993 to 2014. Exhibit 4 shows the waterborne freight by commodity type for the L/Ds 14 to 19 in 2014[10]. Food and farm products, chemicals, and crude materials are the three primary commodity types moved through the L/D systems in the selected river section.

There are seventy-four terminals located within the study region, among which sixty-five are active terminals. For the active terminals, fifty-six terminals have handling facilities to accept at least one type of cargo that is carried on the disrupted barges[7]. Terminals are designed to receive cargoes of certain types, ship cargoes of certain types, or conduct both functions. Depending on the handling facilities, terminals usually cannot accept all types of cargoes. The cargo that is disrupted on the waterway needs to be offloaded at the terminal that has the handling facility to support it. Therefore, the data related to terminal conditions within the study region is also of interest. Exhibits 5 & 6 reveal the locations of the seventy-four terminals in the study region as well as the terminal accessibility of offloading the major cargo types moved along the study region. According to Exhibit 5, terminals are scatted along the river section in the study area with river miles 460-490 containing the highest number of terminals. Based on Exhibit 6, agriculture products and coal are accepted by quite a number of terminals within the study region. Chemicals have a moderate number of terminals to support them and petroleum products have the least terminal accessibility. In general, when the disruption happens, the cargo has a higher chance to be smoothly and safely offloaded to the land transportation mode if its location has multiple nearby terminals and the terminals accept its cargo type.

Exhibit 5: Terminal Locations within Study Region[7]

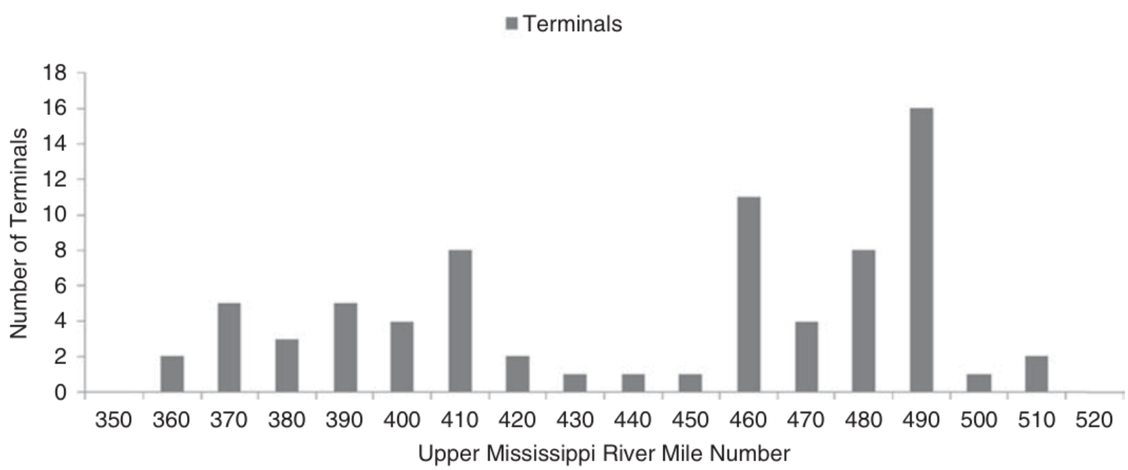


Exhibit 6: Terminal Accessibility by Cargo Types within Study Region

Category	Commodity	Terminals
Agriculture Products	Grains, Rice	19
	Vegetable Products	3
	Animal Feed, Grain Mill Products, Flour, Processed Grain	2
	Forest Products, Lumber, Logs, Woodchips	1
	Other Agricultural Products; Food and Kindred Products	1
Coal	Coal, Lignite and Coal Coke	14
	Sand, Gravel, Stone, Rock, Limestone, Soil, Dredged Mate	9
	Primary Iron and Steel Products (Ingots, Bars, Rods, etc.)	5
	Sulfur (Dry), Clay & Salt	2
Chemicals	Chemical Products	1
	Fertilizers	9
	Other Chemicals and Related Products	4
Petroleum	Petroleum Products	1
	Petroleum Pitches, Coke, Asphalt, Naphtha and Solvents	2
Others	Unknown or Not Elsewhere Classified*	8

*Typically specific dry bulk or resource commodities

Case Study Questions

Question 1: Use simple linear regression method to analyze how the terminal accessibility relates to the disruption recovery. The percentage of the disrupted cargo that is rescued from the inland waterway is used as the indicator of the level of disruption recovery. A high percentage means more cargo is successfully offloaded at a terminal. Experts provide the percentage data based on historic disruption cases on the study region in Exhibit 7.

Exhibit 7: Study Region Cargo Recovery Rate (Composed data for student practice)

Category	Commodity	Cargo Recovery Rate
Agriculture Products	Grains, Rice	80%
	Vegetable Products	10%
	Animal Feed, Grain Mill Products, Flour, Processed Grain	10%
	Forest Products, Lumber, Logs, Woodchips	5%
	Other Agricultural Products; Food and Kindred Products	6%
Coal	Coal, Lignite and Coal Coke	45%
	Sand, Gravel, Stone, Rock, Limestone, Soil, Dredged Mate	41%
	Primary Iron and Steel Products (Ingots, Bars, Rods, etc.)	13%
	Sulfur (Dry), Clay & Salt	12%
Chemicals	Chemical Products	3%
	Fertilizers	39%
	Other Chemicals and Related Products	11%
Petroleum	Petroleum Products	3%
	Petroleum Pitches, Coke, Asphalt, Naphtha and Solvents	3%
Others	Unknown or Not Elsewhere Classified	35%

Question 2: There are six L/D systems (L/Ds 14 to 19) located in the study region. Apply the Analytic Hierarchy Process (AHP) to determine which L/D is the most challenging one for the waterway authority to conduct the cargo recovery actions if it is disrupted due to a man-made disruption event. Assume the three major influencing factors are the commodity tonnage passing through the L/D, the number of available terminals nearby, and the railway accessibility. Exhibits 8 and 9 provide the relevant data. The weights of the three factors are given as 0.4, 0.4, and 0.2 respectively.

Exhibit 8: Locations of Active Terminal-handling Capabilities by Commodity Classification[7]

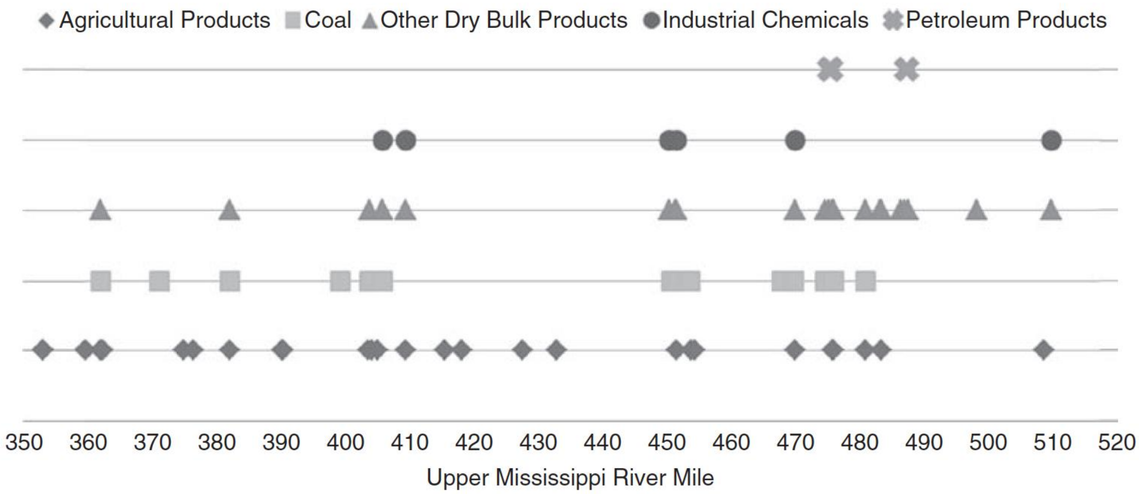
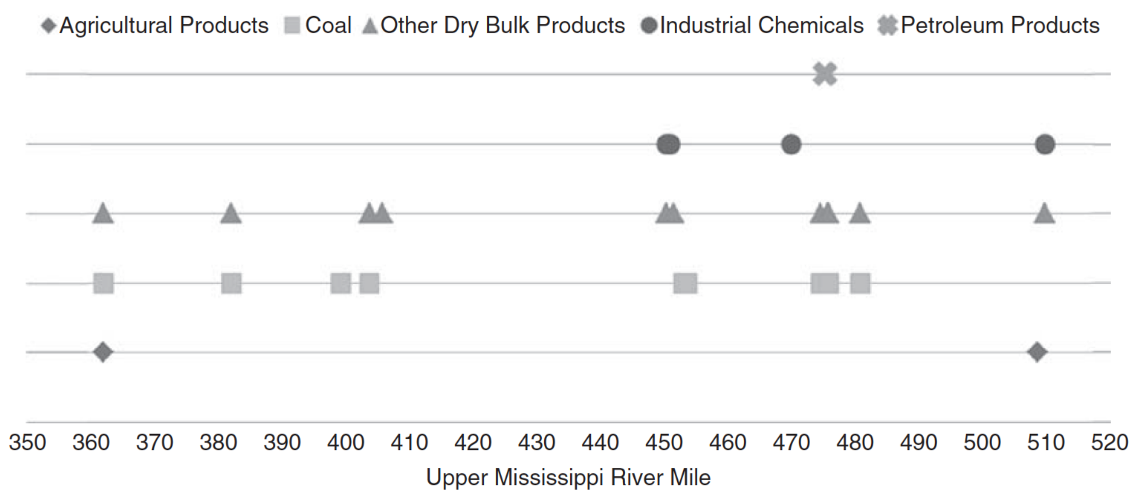


Exhibit 9: Locations of Active Terminals with Off-loading Capabilities and Rail Access by Commodity Classification[7]



Question 3: Assume the U.S. Army Corps of Engineers has received $5 million funding, the agency is considering investing the funding on maintenance and repair of the six L/D systems in this river section. It is estimated that the investment will reduce the waterway disruptions caused by L/D maintenance delays substantially. The investment benefit is represented in dollars as the cash inflows over several years after the investment, which is shown as follows:

N	Net Cash Flow
0	-$5,000,000
1	$1,000,000
2	$1,600,000
3	$2,000,000
4	$2,200,000
5	$3,000,000

(a) Computer the IRR for this investment using trial and error method.
(b) Would you accept this investment at MARR = 20% (Show your work for why)?

Conclusions

The educational case study presented in this paper is designed to highly replicate a real-world inland waterway disruption scenario. A solutions manual is available to engineering educators by submitting an email request to the authors. The significance of this developed case study is twofold. First, it provides the students with a real-world engineering problem to apply and practice their engineering economy and decision analysis skills. Students will be able to practice identifying and analyzing the data sets, selecting the appropriate analysis tool, conducting numerical analysis, and summarizing results and conclusions. Second, it provides students with the opportunity to learn the maritime transportation system. The case study has detailed and easy-to-understand explanations of basic maritime transportation facts. It opens a window for engineering students who may be interested in but not familiar with the subject. Similar case studies based on different subjects could be developed and compiled into a pool of engineering economy educational case studies for students to select and practice.

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