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Disruption Response Support For Inland Waterway Transportation

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A dissertation submitted in partial fulfillment
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by

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Abstract

Motivated by the critical role of the inland waterways in the United States' transportation system, this dissertation research focuses on pre- and post- disruption response support when the inland waterway navigation system is disrupted by a natural or manmade event. Following a comprehensive literature review, four research contributions are achieved. The first research contribution formulates and solves a cargo prioritization and terminal allocation problem (CPTAP) that minimizes total value loss of the disrupted barge cargoes on the inland waterway transportation system. It is tailored for maritime transportation stakeholders whose disaster response plans seek to mitigate negative economic and societal impacts. A genetic algorithm (GA)-based heuristic is developed and tested to solve realistically-sized instances of CPTAP. The second research contribution develops and examines a tabu search (TS) heuristic as an improved solution approach to CPTAP. Different from GA's population search approach, the TS heuristic uses the local search to find improved solutions to CPTAP in less computation time. The third research contribution assesses cargo value decreasing rates (CVDRs) through a Value-focused Thinking based methodology. The CVDR is a vital parameter to the general cargo prioritization modeling as well as specifically for the CPTAP model for inland waterways developed here. The fourth research contribution develops a multi-attribute decision model based on the Analytic Hierarchy Process that integrates tangible and intangible factors in prioritizing cargo after an inland waterway disruption. This contribution allows for consideration of subjective, qualitative attributes in addition to the pure quantitative CPTAP approach explored in the first two research contributions.

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1. INTRODUCTION

The research in this dissertation investigates appropriate response support for inland waterway transportation stakeholders when the United States (U.S.) inland navigation system has been disrupted due to a nature or manmade event. The contribution of this research primarily benefits governmental maritime agencies such as the U.S. Coast Guard (USCG), U.S. Army Corps of Engineers (USACE), and other maritime transportation decision makers to mitigate and reduce the negative economic and societal impacts from disruptions to the inland waterway transportation system.

1.1 Research Motivation

The commercially important U.S. inland waterway system is an open system comprised of 12,000 miles of navigable waterways managed by the USACE (Clark et al., 2005). Figure 1 displays the U.S. navigable inland waterway system of which the three largest river components are the Mississippi River, Ohio River, and Illinois River (Henrickson and Wilson, 2007). As a major component of the U.S. transportation system, the inland waterway system serves thirty-eight States and carries one-twelfth of the overall national freight with nearly 200 commercially active lock sites (Stern, 2012; USACE, 2009). Figure 2 presents the waterborne commerce by commodity type from 1993 to 2012. The largest commodities by tonnage moved on the inland waterways are petroleum, coal, food and farm products, crude materials, and chemicals (USACE, 2013). The Nation's inland waterway system plays a vital role in transporting these commodities such that approximately 20% of America's coal, 22% of U.S. petroleum, and 60% of the Nation's farm exports rely on its normal operation (USACE, 2009). The inland waterway system

is also considered as a critical transportation mode for certain geographical regions that rely on long distance transportation of bulk cargoes (Stern, 2012).

Figure 1 U.S. Navigable Inland Waterway System (USDOT, 2008)
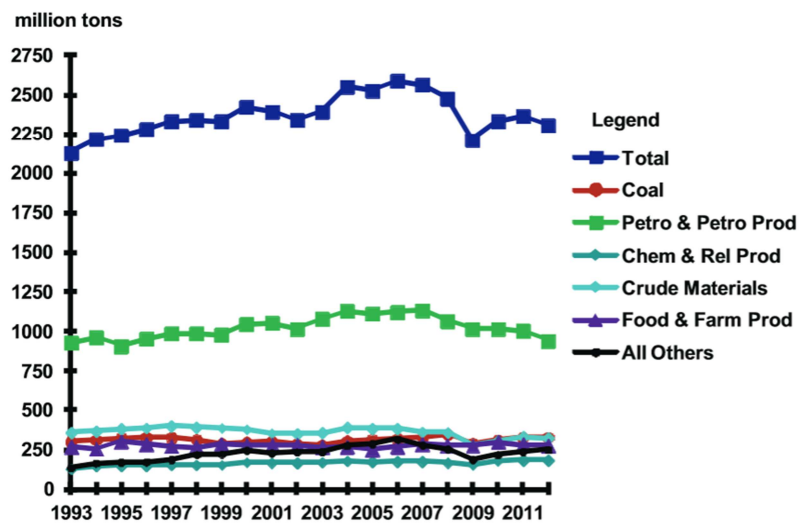
Figure 2 Total Waterborne Commerce by Commodity Group, 1993-2012 (USACE, 2013)

In addition to benefiting the Nation's economy as an important transportation corridor, inland waterways also provide substantial societal benefits. Waterborne transportation reduces land transportation congestion because barges have much larger cargo capacity than alternative modes of land transportation (e.g. the capacity of one barge approximately equals sixty tractor trailers and fifteen railcars). Barge transportation consumes significantly less fuel than rail or truck; one gallon of fuel by barge enables one ton of freight to travel 514 miles, while only 202 miles for rail and 58 miles for truck (Arkansas Waterways Commission, 2013). This energy efficiency makes maritime transportation a "green" sustainable transportation mode such that its wide usage can improve air quality and decrease energy consumption. Other societal benefits of barge transportation include that it contributes low noise pollution and is the safest mode to move hazardous materials (e.g. toxic cargo or chemicals) (Arkansas Waterways Commission, 2013).

Multiple natural and man-made events can lead to inland waterway disruptions such as ice, droughts, or floods that can cause non-navigable water levels and earthquakes that can destroy the infrastructure of the navigation system. In 2012, the Mississippi River, the Nation's critical inland waterway transportation corridor, suffered a record-breaking low water level and was very close to being completely shut down. According to the USACE, drought cycles may last for years and the low river level crisis might appear again in the near future (Schwartz, 2013). Another cause of inland waterway disruptions are maintenance delays associated with the upkeep of the aging infrastructure. Many locks and dams currently in use were built more than 50 years ago and require timely maintenance for continuous future operations. New infrastructure investments and operations and maintenance (O&M) funding have declined in recent decades, which can lead to maintenance and repair postponements and unscheduled closures (Grier, 2009).

Other possible disruption causes include accidents such as vessel allision or collision, mechanical vessel problems, and terrorist attacks (Grier, 2009).

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 the Greenup lock and dam on the Ohio River was closed to navigation traffic for emergency repairs in 2003. The closure lasted more than 52 days, resulting in approximately $41.9 million total cost (USACE, 2005a) that included modal shift expense and delay costs. Another example is the McAlpine Lock and Dam on the Ohio River, which was closed for 10 days to repair extensive cracking in its miter gate. Although early notice was given to the shippers/carriers before the closure, a $9 million total disruption cost was incurred by various stakeholders (USACE, 2005b).

The motivation of this dissertation research is driven by the need to mitigate potentially substantial negative economic and societal impacts from inland waterway transportation disruptions. Key stakeholders, including the USCG and USCAE, need pre- and post-disruption response plans to provide decision support regarding how to respond to disruptive events along the inland navigation system in order to alleviate significant impact to the Nation's freight transportation system and economy. We are interested in developing concrete operational guidelines for these stakeholders to provide them with decision support tools and knowledge to mitigate disruption impacts to inland waterway transportation.

1.2 Research Objective

The overall research goal of this dissertation research is to investigate appropriate response support for inland waterway transportation stakeholders when the inland navigation system has been disrupted due to a natural or manmade event. The primary contribution of this research is to

provide decision support to benefit governmental maritime agencies such as the USCG and

USACE and other maritime transportation decision makers to mitigate and reduce the negative

economic and societal impacts from disruptions to the inland waterway transportation system.

This is fulfilled through four research contributions. The first research contribution introduces

and models the cargo prioritization and terminal allocation problem (CPTAP) that minimizes

total value loss of the barge cargoes due to disruption on the inland waterway transportation

system and develops and tests a GA-based heuristic to solve realistically-sized problem instances.

The second research contribution provides solution improvements to the CPTAP model through

the development of a TS heuristic approach. The third research contribution provides a

methodology to determine cargo value decreasing rates (CVDRs) for transportation in general.

The fourth research contribution develops a multi-attribute decision model based on the Analytic

Hierarchy Process that integrates tangible and intangible factors to address the cargo

prioritization decision for inland waterway disruptions.

1.3 Research Contributions

This dissertation research provides practical decision support for transportation stakeholders

regarding inland waterway disruption response, which is primarily intended to assist

governmental maritime agencies. The work described in Chapter 2-3 contributes a current

knowledge base obtained through a comprehensive literature review that supports the research

contributions in Chapter 4-7.

The contribution in the Chapter 4 contains a thorough description of CPTAP as a novel research

problem to inland waterway disruption response, a mathematical model of CPTAP, and a GA-

based heuristic as an effective solution approach to CPTAP. The model output indicates the

terminal that each disrupted barge is assigned to for offloading and the prioritized turn each barge takes at its assigned terminal while considering the availability and capacity of nearby terminals and land-based freight infrastructure to receive and transport these cargoes. It assists responsible parties in responding promptly to the disruption with system-level efficient barge-terminal assignments that can consider both economic and societal impacts. In addition to providing tactical disaster response for redirecting disrupted barges to alternative terminals, the CPTAP model in Chapter 4 can be used to evaluate the resiliency of the inland waterway system to handle hazardous and high volume cargo and guide investment towards increasing capacity at key terminals.

The contribution of Chapter 5 is an improved CPTAP solution approach based on TS. The TS heuristic obtains the best solutions found for all tested instances and results in lower total value loss and computation time. Moreover, the CPTAP model is systematically evaluated through comparison of the three cargo prioritization strategies (GA, TS, and a naïve minimize distance approach).

The contribution of Chapter 6 is a step-by-step methodology to determine a cargo value decreasing rate (CVDR) to measure the total value loss of the disrupted cargo as the component of cargo prioritization models. This contribution provides a Value-focused Thinking (VFT) based approach to support transportation decision makers in prioritizing cargo with a well-constructed model parameter. The CVDR delivered by the developed methodology is applicable to the CPTAP model as well as other cargo prioritization models designed for other transportation modes.

The contribution of the Chapter 7 is a multi-attribute decision approach based on the Analytic Hierarchy Process (AHP) that integrates qualitative and quantitative factors to assess the prioritized ordering of the barge cargoes for maritime governmental agencies. The model output in Chapter 7 indicates the priorities assigned to all the barge cargoes. Different from Chapters 4 and 5 that involve terminal selection as part of the decision making, Chapter 7 provides decision support that informs the decision maker of the most important cargoes in terms of societal and economic aspects but does not handle the rerouting decision.

1.4 Organization of Dissertation

Chapter 1 presents the motivation of conducting research on the disruption response for inland waterway transportation, describes the four research objectives of the study, and summarizes the resulting research contributions. Chapter 2-3 include a comprehensive literature review, specifically, Chapter 3 is a conference paper published in the *Proceedings of the 2012 Industrial Engineering Research Conference* titled "A Review of Cargo Prioritization Techniques within Inland Waterway Transportation (Tong and Nachtmann, 2012)." Chapter 4 is a manuscript entitled "Cargo Prioritization and Terminal Allocation Problem for Inland Waterway Disruptions" that employs a mathematical model and a GA-based heuristic solution approach for the cargo prioritization and terminal allocation problem. Chapter 5 provides a manuscript titled "A Tabu Search Approach to the Cargo Prioritization and Terminal Allocation Problem" that contains a TS heuristic to solve the CPTAP model. Chapter 6 presents a manuscript to be submitted to the *Engineering Management Journal* titled "Value-Focused Assessment of Cargo Value Decreasing Rate" aimed at providing a methodology to determine the value decreasing rate of the disrupted cargo to support the first two chapters. It is an extension of a conference paper published at the

Proceedings of the American Society for Engineering Management 2013 International Annual

Conference (Tong et al., 2013). Chapter 7 is a conference paper published in the *Proceedings of*

the 2013 Industrial Engineering Research Conference titled "Multi-attribute Decision Model for

Cargo Prioritization within Inland Waterway Transportation" that involves subjective factors to

provide decision support for maritime transportation stakeholders (Tong and Nachtmann, 2013).

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2. LITERATURE REVIEW

This literature review describes the motivation and background of our dissertation research and is organized as follows: Section 2.1 investigates the literature related to inland waterway disruption response, Section 2.2 reviews cargo prioritization techniques, Section 2.3 presents an overview of cargo prioritization factors, Sections 2.4-2.7 describe the berth allocation problem, tabu search heuristic, value-focused thinking, and analytic hierarchy analysis.

2.1 Literature Review on Inland Waterway Disruption Response

Nine publications most closely related to inland waterway disruption response are reviewed to reveal the most current research in this area. The authors investigate disruptive scenarios from many angles and provide recommendations and insights to improve pre-disaster preparation and after-disaster response in order to mitigate the disruption impacts. Our review does not consider the literature that strictly focuses on disruption due to one type of disruptive event such as the work related to oil spill management (e.g. Camp et al., 2010) or flood management (e.g. Du Plessis, 2004). Our review is focusing on all-hazard literature that provides decision support that is applicable to disruptions caused by any type of event, manmade or natural disaster.

Tables 1 and 2 present two matrices to summarize these papers. Table 1 provides general information of the select publications including publication year, publication type, cause of the disruption, pre- or post-disaster focus, type of the study, and whether or not rerouting is considered. Table 2 provides brief descriptions of the core model(s) and objective(s) of each study.

Table 1 Publication Comparison Matrix

Authors	Year	Publication	Cause of Disruption	Pre/Post Disaster	Type of Study	Rerouting Considered
Dobbins	2001	Dissertation	Manmade	Post	Case Study	No
Wang et al.	2006	Journal	Manmade	Pre	Experimental Design	Yes
GAO	2007	Government Report	Natural	Pre/Post	Review	No
Folga et al.	2009	Journal	N/A	Post	Case Study	Yes
Channell et al.	2009	Government Report	Natural	Post	Review	No
Zaloom & Subhedar	2009	Working Paper	Manmade/ Natural	Pre	Theory	No
Almaz	2012	Dissertation	Manmade/ Natural	Post	Case Study	Yes
Mackenzie	2012	Dissertation	Manmade/ Natural	Post	Case Study	No
Bemley et al.	2013	Journal	Natural	Pre	Experimental Design	No

Table 2 Model(s) and Objective(s) Comparison Matrix

Model(s)	Objective(s)	Author(s)
Risk management information system	• Provide the Vessel Traffic Service (VTS) and U.S. Coast Guard (USCG) personnel with critical information related to the barges carrying hazardous materials, especially in the event of an accident • Identify cargoes and vulnerable receptors before responders arrive at the accident scene	Dobbins (2001)
Waterway demand models	• Analyze changes in waterway traffic patterns due to lock service interruptions • Suggest additional warning time to barges	Want et al. (2006)
Review of port preparation and mitigation methods	• Examine port disaster preparedness measures and the federal role in helping ports plan and recover from natural disaster impacts • Make recommendations for utilizing existing forums to discuss the planning actions and developing communication strategies	GAO (2007)
System-level economic analysis methodology	• Rerouting analysis for disrupted commodity flow including waterway shipments	Folga et al. (2009)
Review of current debris management practice	• Develop recommendations based on the research gaps with the goal of improving disaster response	Channell et al. (2009)
Delphi method	• Identify accidents that most likely occur in maritime domain and explore relevant recovery plans to alleviate the risks	Zaloom & Subhedar (2009)
Simulation based risk model	• Determine prioritization order to guide the vessels entering and leaving the disrupted river in order to achieve the optimum balance between security and resiliency	Almaz (2012)
Dynamic multiregional interdependency model	• Model and quantify actions of moving commodities by alternate modes of transportation during inland waterway port closures	Mackenzie (2012)
Stochastic facility location model	• Explore effectiveness of pre-positioning strategies for port recovery	Bemley et al. (2013)

2.2 A Review of Cargo Prioritization Techniques within Inland Waterway Transportation[1]

2.3 Cargo Prioritization Factors

From the literature we know that most cargo prioritization methods include one or more factors to prioritize the commodities. In order to develop an integrated and effective approach for determining which cargo should be prioritized to alternative modes if an inland waterway transportation is disrupted, we look into each cargo prioritization method contained in the selected literature, extract the factors considered in the method and establish a factor matrix that describes and categorizes all these factors (see Table 3). The literature-based factor matrix suggests the aspects one should recognize and contemplate in developing the cargo prioritization model in an inland waterway transportation context. These factors were divided into nine groups based on the type of criteria they evaluate.

2.3.1 "Value/Cost/Revenue" Factors

This group covers the prioritization factors that relate to pecuniary aspects of the commodities, including the value of the commodity (Aragon, 2000), the revenue of transporting the commodity (Lau et al., 2009), the profit of marketing the commodity (Bennett, 2002), the efficiency index associated to the benefits of investing a commodity research program (Nagy & Quddus, 1998), the marginal revenue costs of the commodity (Madden, 1995) and an implicit standard of the benefit of the product which possibly refers to profit (EPA, 1999). Factors in this group more frequently take the commodity's inherent characteristics as the prioritization criteria, e.g. the valuable products receive high priorities and the heavy products that receive more revenue are usually prioritized.

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[1] See *Chapter 3* for the published review article

2.3.2 "Time" Factors

Four factors are included in the group of time, which uses specific dates as the prioritization criteria. They are the earliest due date (EDD) (Armstrong et al., 1983; Sinclair & Dyk, 1987; Schank et al., 1991), latest arrival date (LAD) (Schank et al., 1991), ready to load date (RLD) (Schank et al., 1991) and available to load date (ALD) (Schank et al., 1991). EDD is one of the most popular prioritization criteria among the literature and three papers have referred to EDD. The reason of EDD's widely usage lies in its connection to the customer service level. Prioritization based on EDD guarantees that the cargoes are sequenced and delivered to the customers with the objective of minimizing the due date violation, which increases the total customer satisfaction level. The remaining three factors within the time category come from the same paper as one of the tasks of the strategic mobility model.

2.3.3 "Risk" Factors

The group of risk contains four factors focusing on risk and security. Human risk (Ibrahim and Ayyub, 1992) and security risk (Ibrahim & Ayyub, 1992) are two example criteria mentioned in prioritizing components for inspection purpose. The prioritization order should be decided in order to decrease the risk related to the commodities. On the contrary, another two factors in this group, the health and/ or safety function served by the product (EPA, 1999) and the security status of the vessel (USDHS, 2007), prioritize the cargoes for the purpose of increasing the security level associated with the commodity. All four factors covered in this group do not provide detailed prioritization steps but propose that risk/security needs to be considered when prioritizing the commodities.

2.3.4 "Weight" Factors

Two papers use cargo's weight to determine the prioritization order. One paper employs the cargo draft (MAR Inc., 1987) as the criterion which has not been defined explicitly but should relate to cargo's weight to some extent according to the definition of the vessel draft. Smallest weight (SWT) (Armstrong et al., 1983) and largest weight (LWT) (Armstrong et al., 1983) prioritize the commodities on the basis of their weight in increasing or decreasing order. The author has not indicated when and why to adopt the increasing or decreasing order, however, we reckon that this factor is necessary when the weight of commodity becomes a constraint of the facility capacity to load/transport the commodity.

2.3.5 "Quantity" Factor

The weighted average of the percentage of the amount of cargoes transported in different direction is the exclusive factor contained in this group (Ahanotu et al., 2007) indicating that researchers usually do not take account of amount as an important factor to prioritize cargo. Within this prioritization group, commodities are sequenced solely according to their amounts rather than their characteristics. Thus the commodity type becomes insignificant in prioritization process.

2.3.6 "Environmental" Factors

Among the four factors in this group, product's loss of resources (Hansen & Cowi, 2003) and the energy consumption (Hansen & Cowi, 2003) concentrate on the general consumption of resources and energy. The remaining two factors (EPA, 1999) prioritize the commodities with consideration of the environmental effects of the volatile organic compounds (VOC).

2.3.7 "Urgency" Factors

Three factors are included in the urgency group, among which, the urgency of need designator (UND) (Grandjean & Newbury, 2001) and the force activity designator (FAD) (Grandjean & Newbury, 2001) are the two factors constituting a priority system to prioritize materials. The criterion of Emergency needs (USDHS, 2007) is one of the factors to assess the national commodity priorities and it mainly refers to the emergency in saving human lives. The factors in the group of urgency are defined from military or public perspective instead of private or customer perspective. It is appropriate to have the urgency factors in mind in prioritizing the military and strategic commodities.

2.3.8 "Importance" Factors

Six factors are sorted into this category. The factors of important for food security (Bennett, 2002) and traditionally important (Bennett, 2002) are the two example criteria to prioritize commodities for marketing purpose. It reminds us that the traditional important cargoes in various prioritization contexts should be assigned additional concern. Another four factors come from the same paper: The factor of commodity needs for local prioritization (USDHS, 2007) synthesizes the priorities on the national, regional and local levels; the remaining three factors (USDHS, 2007) that relate to the national commodity priorities (response needs/community needs/national security) identify and prioritize the essential cargoes for the various prioritization objectives. For instance, the fire boats are necessary in response operations if a big fire breaks out at an incident site and thus they are prioritized for the factor of response needs. Similarly, cargoes that are important to community survival such as heating oil and national security such as escort ships should be prioritized in accordance with the factor of the community needs.

2.3.9 "Others" Factors

This group includes the factors contained in the selected papers but cannot be classified into the previous categories. It lists the supplemental aspects we need to consider in addition to the discussed factors: whether to give extra priorities due to seasonal reason (seasonal advantage (Bennett, 2002)); the availability of substitute commodities decreases the ranking position of the commodity (the availability of substitute materials (EPA, 1999)); export or refrigerated cargoes should be given priority in some cases (Sinclair & Dyk, 1987); commander's determination should be given priority in some cases (commander in chief (Schank et al., 1991)); the capabilities of berth and port infrastructure should be taken into account if the commodities require sea transportation (USDHS, 2007); priorities should be given to fuel oil in winter (USDHS, 2006), and to gas, perishable cargo and assembly line components in both winter and summer (USDHS, 2006).

Table 3 Factor Matrix for Cargo Prioritization Methods

Classification	Ranking Factor	Source
Value/Cost/ Revenue	Profitability: One of the example criteria to prioritize commodities that will get greater attention in the market scoping process	Bennett, 2002
	Revenue: The cargoes are sorted on the basis of descending order of cargo revenue. When a customer wants to transfer their cargoes to a foreign country, they employ the services of a freight forwarder who will charge the customer for the cargo shipping cost (revenue) if the cargo is scheduled to be loaded. This charge is based on the chargeable weight (i.e. the volume weight or actual weight) of each cargo, whichever is the larger. The revenue for loading the cargo with respect to its volume: $$r_{l\_y} = \frac{w_l \cdot l_l \cdot h_l}{6000} \cdot P_{C_l} \quad \forall l \in C$$ The revenue for loading the cargo with respect to its weight: $r_{l\_wt} = t_l \cdot P_{C_l} \quad \forall l \in C$ h_l Height of the cargo l l_l Length of the cargo l w_l Width of the cargo l t_l Weight of the cargo l P_{C_l} Cargo forwarding price	Lau et al., 2009
	Efficiency Index: Net present value divided by the present value of research expenditure. It's used to identify a new research agenda with agricultural research priority setting.	Nagy & Quddus, 1998
	The use, benefit, and commercial demand for the product: Identify the products that contribute to ozone formation	EPA, 1999
	Marginal Revenue Costs (MRC): Prioritize the goods in the context of the Ahmad-Stern model of indirect tax reform including labor supply	Madden, 1995
	Value of production: One of the selected statistical parameters to prioritize commodities	Aragon, 2000
Time	Earliest due date (EDD): Due date in non-decreasing order	Armstrong et al., 1983; Sinclair and Dyk, 1987; Schank et al., 1991
	Latest arrival date (LAD): One of the factors to prioritize cargoes in a step of the strategic mobility model	Schank et al., 1991
	Ready to load date (RLD): One of the factors to prioritize cargoes in a step of the strategic mobility model	Schank et al., 1991
	Available to load date (ALD): One of the factors to prioritize cargoes in a step of the strategic mobility model	Schank et al., 1991

Table 3 Factor Matrix for Cargo Prioritization Methods (Cont.)

Classification	Ranking Factor	Source
Risk	Economic risk: One of the example criteria for prioritizing the components for inspection purposes	Ibrahim & Ayyub, 1992
	Human risk: One of the example criteria for prioritizing the components for inspection purposes	Ibrahim & Ayyub, 1992
	The health and/or safety function served by the product: Identify the products that contribute to ozone formation	EPA, 1999
	Local Prioritization for Commodity Movement-The security status of the vessel: -Is the vessel cleared for entry into a United States seaport based on established or incident specific screening procedures? -Are resources available to inspect or otherwise clear the vessel for entry, if necessary? -Is any of the cargo on the vessel suspect, or deemed 'high risk' by CBP's ATS using any new revised risk scoring based upon the incident? -Are resources available to implement required security measures on the vessel's inbound and outbound transit? -Is the vessel operated by a trusted partner, such as a validated participant in the C-TPAT program?	USDHS, 2007
Weight	Cargo draft: No specific description & might be the distance from waterline to the bottom of cargo if it's placed in the sea. Cargoes are sequenced for loading and offloading on the basis of the cargo draft, e.g. the deep draft cargo is loaded prior to the shallow draft cargo.	MAR Inc., 1987
	Smallest weight (SWT): Weight in non-decreasing order. It's one of the cargo priority dispatch rules.	Armstrong et al., 1983
	Largest weight (SWT): Weight in non-increasing order. It's one of the cargo priority dispatch rules.	Armstrong et al., 1983
Quantity	Weighted average of the percentage of the amount of commodity transported in different directions: It is used to prioritize which commodities should be included in the commodity database for the region of concern.	Ahanotu et al., 2007
Environment	Product's loss of resources: The quantity of materials in a commodity group that is not recycled, because the materials end up as waste that is disposed of or incinerated, or because the materials during their use are spread diffusely to the surroundings as a result of wear or corrosion.	Hansen & Cowi, 2003
	The energy consumption: The energy consumption used for extraction, manufacture and processing of the materials in the commodity group, plus the energy latent in these materials (if relevant), plus the energy consumption during the use phase (if relevant), minus the amount of energy recovered by incineration of the loss of resources.	Hansen & Cowi, 2003
	Whether the product emits highly reactive volatile organic compounds (VOCs): Identify the products that contribute to ozone formation	EPA, 1999
	The cost-effectiveness of VOC emission controls for the product: Identify the products that contribute to ozone formation	EPA, 1999

Table 3 Factor Matrix for Cargo Prioritization Methods (Cont.)

Classification	Ranking Factor	Source
Urgency	Urgency of Need Designator: The urgency of the material needed. It's classified into three levels and it's one of the two factors that form the UMMIPS (Uniform Material Movement and Issue Priority System).	Grandjean & Newbury, 2001
	Force Activity Designator: The military necessity of the force or activity. It's a Roman numeral designator with five levels that depend on activity or unit relative importance to national objectives. It's one of the two factors that form the UMMIPS (Uniform Material Movement and Issue Priority System).	Grandjean & Newbury, 2001
	National Commodity Priorities: Emergency Needs (Goods necessary for the saving and continuation of life)	USDHS, 2007
Importance	Important for food security: One of the example criteria to prioritize commodities that will get greater attention in the market scoping process	Bennett, 2002
	Traditionally important: One of the example criteria to prioritize commodities that will get greater attention in the market scoping process	Bennett, 2002
	Local Prioritization for Commodity Movement-Commodity needs: -What are the national priorities? -What are the regional priorities? -What are the local priorities (seasonal, etc.)?	USDHS, 2007
	National Commodity Priorities: Response Needs (Personnel and equipment necessary to conduct response operations at the incident site, i.e. fire boats)	USDHS, 2007
	National Commodity Priorities: Community Needs (Examples are crude oil, heating oil and chemicals necessary for industrial continuity, and drinking water.)	USDHS, 2007
	National Commodity Priorities: National Security (Specific coordination or prioritization of support assets, e.g. small vessels to conduct escort duties)	USDHS, 2007
Others	Seasonal advantages: One of the example criteria to prioritize commodities that will get greater attention in the market scoping process.	Bennett, 2002
	The availability of substitute materials, considering utility, cost, safety, health, and environmental issues: Identify the products that contribute to ozone formation	EPA, 1999
	One of the criteria of assigning priority to movement: Export movements have higher priorities than import movements	Sinclair & Dyk, 1987
	One of the criteria of assigning priority to movement: Refrigerated containers have the higher priority	Sinclair & Dyk, 1987
	Commander in chief (CINC): Priority is determined by the commander	Schank et al., 1991

Table 3 Factor Matrix for Cargo Prioritization Methods (Cont.)

Classification	Ranking Factor	Source
Others (Cont.)	Local Prioritization for Commodity Movement-The capacity of the port infrastructure to offload the cargo or commodity and move it from the port: -Are there labor issues? -Are there inter-modal issues? -Are there space or facility issues? -Is there CBP resource availability to clear cargo or commodities once landed?	USDHS, 2007
	Local Prioritization for Commodity Movement-The ability of vessels to transit to and from its berth: -Are there berthing/space/facility issues? -Are there waterway functionality issues (no obstructions, operating Aids to Navigation (ATON), etc.)?	USDHS, 2007
	Local Cargo Priority: Vessels with fuel oil in winter	USDHS, 2006
	Local Cargo Priority: Vessels with gas & diesel in winter and summer	USDHS, 2006
	Local Cargo Priority: Vessels with perishable cargo in winter and summer	USDHS, 2006
	Local Cargo Priority: Vessels with assembly line components in winter and summer	USDHS, 2006

2.4 Berth Allocation Problem (BAP)[2]

We identified that the proposed CPTAP model in Chapter 4 has similar structure to the berth allocation problem (BAP). Imai et al. (1997) pioneered the static berth allocation problem formulated as a bi-objective nonlinear integer program which minimizes total vessel staying time and dissatisfaction with berthing order. Imai et al. (2001) later considered a dynamic berth allocation problem (DBAP) where vessels may arrive to a single berth location during the planning horizon, which they formulated as a mixed integer program and solved problems of realistic size through Lagrangian relaxation. Nishimura et al. (2001) expanded DBAP to allow each berth to accept multiple vessels within quay capacity limitations by employing a GA approach. Imai et al. (2003) further extended DBAP to consider vessel size and cargo volume service priority (referred to as PBAP), which they attempted to use Lagrangian relaxation initially but the computational burden led them to adopt a GA approach. Cordeau et al. (2005) proposed a new BAP formulation – the multi-depot vehicle routing problem with time windows (MDVRPTW) which considers the weighted sum of the service times and time windows of the berthing times. They employed a Tabu search heuristic which is capable of obtaining optimal solutions for small size problems and improved solutions for large size problems over a truncated branch-and-bound algorithm. Boile et al. (2006) reformulated the Imai et al. (2003) mixed integer nonlinear program for PBAP as a mixed integer program and developed a heuristic to solve the problem. Their linear reformulation is further considered in terms of its solution approach by Theofanis et al. (2007). Imai's group (2007) continued their work on BAP and developed the bi-objective BAP which minimizes both delay time and service time and found that a GA approach achieves better solutions than a subgradient optimization approach. The

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[2] Excerpted from *Section 2 of Chapter 4*

multi-objective BAP is further investigated by Golias et al. (2009) by employing a GA to optimize conflicting objectives of minimizing service time for various vessel groups and minimizing service time for all the vessels at the terminal. Other recent BAP extensions handle uncertainty (Zhen and Chang, 2012), integrate quay crane allocation (Han et al., 2010; Raa et al., 2011), consider water depth and tidal conditions (Xu et al., 2012), and address bulk cargo ports (Umang et al., 2013) and environmental concerns (Golias et al., 2010; Du et al., 2011; Wang et al., 2013).

2.5 Tabu Search (TS) Heuristic[3]

Tabu search (TS) heuristic is applied to solve CPTAP in Chapter 5. We investigated papers that employ a TS heuristic to solve the Berth Allocation Problem (BAP) and Vehicle Routing Problem (VRP). The BAP TS literature was most valuable in developing our TS heuristic since it has the similar framework with CTPAP. However, since a limited number of BAP papers focus on the TS heuristic, we extended our literature review to include the VRP literature because considerable papers have investigated TS implementation in VRP.

TS in BAP

Cordeau et al. (2005) proposed a new formulation approach for the discrete berth allocation problem (BAP) – the multi-depot VRP with time windows (MDVRPTW) formulation which handles the weighted sum of the service times and the time windows of the berthing times. They employed a TS heuristic to solve the discrete case with an extension for the continuous BAP, which is capable of obtaining optimal solutions for small size instances and better solutions for large size instances when compared to a truncated branch-and-bound algorithm. Meisel and

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[3] Excerpted from *Section 3 of Chapter 5*

Bierwirth (2009) integrated the BAP and crane assignment problem (BACAP) to provide an integer linear program model that incorporates the practical impact of the crane resources on the handling time. Both squeaky wheel optimization and TS heuristic are employed and compared in solving a set of benchmark problems. Giallombardo et al. (2010) studied the BACAP as a mixed integer linear program formulation where TS is used to solve their BAP decision (adapted from Cordeau et al., 2005) and obtains good solutions within a satisfactory amount of time.

TS in VRP

A steady, thorough, and extensive evolution of VRP heuristics has been observed in the last forty years, among which the TS heuristic is identified as one of the best metaheuristics for the VRP (Cordeau and Laporte, 2005; Taillard et al., 2001). More than fifty papers have been published on this topic since the first TS implementation to the VRP in 1989 (Laporte, 2009). Multiple survey papers have summarized the TS literature in VRP (Eksioglu et al., 2009; Laporte, 2009; Braysy and Gendreau, 2005; Cordeau, et al., 2002; Cordeau and Laporte, 2005) and identified TS as a competitive metaheuristic method to solve VRP. Some researchers consider TS to be the best metaheuristic method for solving the VRP (Cordeau, et al., 2002). Nine papers were found to be the most informative to our work and are summarized in Table 4. Among these TS heuristics, the Unified TS is chosen as the most suitable TS method for CPTAP due to its proved efficiency, robustness (small number of parameters to be determined), and compatibility to our CPTAP structure.

Table 4 Comparison of Select TS VRP Literature

TS Approach	Author(s)	Year	VRP Type(s)	Unique Feature(s)
Unified TS	Cordeau et al.	1997	Periodic VRP & Multi-depot VRP	• Generate one initial solution irrespective of feasibility • Employ the penalized function with self-adjusting coefficients • Use limited user-controlled parameters
	Cordeau et al.	2001	Multi-depot VRP with Time Windows (VRPTW)	• Apply a very simple exchange procedure for a predetermined number of iterations
	Cote and Potvin	2009	VRP with Private Fleet and Common Carrier (VRPPC)	• Use a union of two neighborhoods as the neighborhood structure
Taburoute TS	Gendreau et al.	1994	VRP	• Include a generalized insertion routine procedure to periodically improve the tours of the solution in order to decrease the chance of being trapped in a local optimum
	Gendreau et al.	2008	Capacitated VRP with Two-dimensional Weighted Item (2L-CVRP)	• Use constraints to express the two-dimensional loading feature of the items • Accept moves that cause the infeasibility of either weight constraints or loading constraints
TS with Adaptive Memory Procedure	Rochat and Taillard	1995	Capacitated VRP (CVRP)	• Generate multiple initial solutions to form a solution pool which produces a number of tours • Extract tours according to a probabilistic technique to form a new solution
	Tarantilis	2005	Capacitated VRP (CVRP)	• Utilize the sequence of nodes to create the new solution instead of extracting and combining routes • Select the elite parts according to deterministic selection criteria rather than the probabilistic routes selection
Other TS	Wassan et al.	2008	VRP with Pickups and Deliveries (VRPPD)	• Create an innovative procedure to check the feasibility of the insertions without increasing the computational complexity of the neighborhood search
	Bolduc et al.	2010	VRP with Production and Demand Calendars (VRPPDC)	• Employ two new neighbor reduction strategies • Include an improvement phase after the tabu iterations are completed

2.6 Value-focused Thinking (VFT)[4]

In Chapter 6, we use value-focused thinking (VFT) methodology to develop the cargo value decreasing rate (CVDR). Our previous work has investigated the related literature to provide a sufficient knowledge base in the VFT application area (Tong et al., 2013). Since the appearance of VFT by Ralph Keeney in 1992, a large number of papers have discussed or applied this unique methodology in various decision making scenarios. According to the recently published VFT survey (Parnell et al., 2013), there are eighty-nine journal papers that implemented VFT in their analysis from 1992 to 2010. The number of studies is even larger if VFT books and thesis/dissertations are included. In our review, we selected the literature whose application context is closely related to our problem domain – the VFT papers that study transportation, logistics, and supply chain (TLSC).

2.6.1 Literature Summary

The seven VFT papers within the TLSC field are reviewed, and a brief summary of each paper is presented.

Supply Chain Risk Identification with Value-focused Process Engineering (Neiger et al., 2009). This article proposes a novel supply chain risk identification methodology on the basis of value-focused process engineering (VFPE), which integrates the principles from VFT and extended-event-driven process chain (e-EPC). The contribution of VFT in this article is to provide a unique perspective in which the supply chain is composed of multiple interconnected value-adding processes and risk objectives (defined as "minimizing the chance of an adverse event") which are considered as the mean objectives that can fit into the VFT framework. Together with e-EPC methodology, VFT aids the researchers to model the process-based risks

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[4] Excerpted from *Section 2 of Chapter 6*

with a thorough consideration of processes, objectives, and risk sources. Figure 1 displays the

first three steps of the VFPE-based risk identification process, which illustrate how VFT

functions in the scheme and how it interacts with other components. In Step One, functional risk

objectives are identified by providing each supply chain activity with a generic risk objective,

while in Step Two, VFT is used to generate value risk objectives through decomposing the

higher-level process objective of minimizing process failure risk. Based on the delivery from the

first two steps, a completely decomposed risk objectives structure is developed in Step Three.

Figure 1 Step 1-3 of VFPE-based Supply Chain Risk Identification (Neiger et al., 2009)

Value-focused Supply Chain Risk Analysis-Book Chapter (Olson & Wu, 2010). This research investigates the plant location decision for the supply chain participant with consideration of supply chain risk. VFT is mainly used to establish the value hierarchy for the supply chain and to create the alternatives. The SMART technique is applied to conduct the remaining multi-attribute decision analysis. The authors strengthen the importance of values in structuring the value hierarchy – VFT aims to develop a hierarchy that gains a wide spectrum of values. Beginning with searching for the overall values, the authors develop a three-level value hierarchy for the supply chain risk and point out that every element in the hierarchy is able to be used to locate the risks for any specific supply chain situation. It is also suggested that alternatives should be generated in the hierarchical development process. In terms of the number of alternatives that should be created, two to seven alternatives are recommended for multiple attribute decision analysis.

A Value Focused Thinking Tutorial for Supply Chain Application (Jordan, 2012). This research discusses the VFT application in supply chain decision making. According to the author, various multi-criteria approaches are widely used to model supply chain and logistics problems. However VFT is rarely considered in this field; thus the author presents a detailed VFT tutorial and conducts VFT analysis on a common logistics problem – the supplier selection. The bottom-up method is used to construct the supplier selection hierarchy, followed by a complete analysis directed by the VFT methodology. Important strengths of VFT for supply chain problems are that a VFT approach can reveal the true value that an alternative has for the decision and alert the decision maker to derive better alternatives if the existing alternatives do not have a satisfying value to the decision. It is a powerful feature for the supply chain problem which regularly has a

large number of alternatives. The new alternatives can be quickly valued and compared with the others.

Transportation Readiness Assessment and Valuation for Emergency Logistics (Nachtmann & Pohl, 2013). This article examines the readiness level of transportation considered by local and state operation planners in their emergency preparedness plans. The transportation readiness assessment and valuation for emergency logistics (TRAVEL) scorecard is developed to help the operation planners identify the deficient areas in their emergency operations plans (EOP) and improve them through evaluating the EOP quality with regards to transportation readiness. VFT framework is applied in developing the TRAVEL tool and spreadsheet is used to provide software platform for TRAVEL. Figure 2 shows the eight-step VFT processes that create TRAVEL. The top-down method is employed to develop the value hierarchy in Step Two. Under the fundamental problem of assessing transportation readiness of EOP, four supporting objectives are placed at the second level, each of which further splits into several measurable attributes. Three county-level EOPs are assessed by the authors to validate the TRAVEL scorecard. The analysis results show that TRVEL can quickly identify the shortcomings of the EOP with respect to transportation and enables the operation planners to revise the EOP promptly.

Figure 2 TRAVEL Development Process (Nachtmann & Pohl, 2013)

Value Focused Thinking Analysis of the Pacific Theater's Future Air Mobility En Route System (Axtell, 2011). This study provides the decision makers in the Air Mobility Command

(AMC) with a validated decision tool to evaluate the locations in the future en route system in the Pacific Theater. VFT methodology is used to analyze whether the proposed en route locations have appropriate level of access in the Pacific Theater. A six-level value hierarchy with twenty-seven attributes termed "En Route Base Selection Tactical Sub-model" developed by previous researchers has been utilized as part of the overall value hierarchy (see Figure 3) in this study. As can be seen in Figure 3, the tactical sub-model is included as one of the three supporting objectives under the fundamental objective "Operational Value Score." The case study includes twenty current and eight future en route locations and evaluates each location based on the operational value hierarchy. The author points out that the proposed VFT decision analysis tool advocates replacing the existing en route linear system with a more integrated one.

Figure 3 Operational Value Hierarchy (Axtell, 2011)

Decision Analysis with Value-focused Thinking as a Methodology in Structuring the Civil Engineering Operations Flight (Katzer, 2002). This study investigates how to help the operations flight commander select the best organizational structure of the civil engineer operations flight. The author believes that VFT methodology is one of the most ideally suited approaches that can answer the two-fold questions regarding the selection decision – what values are important to the decision and how the ranking of the alternatives changes with various situations. Figure 4 displays operations flight value hierarchy. As described by the author, the first-level fundamental objective is identified, followed by the brainstorming sessions of asking

"what does that mean" which further identifies four supporting values that are placed at the second level. This question is asked repeatedly until the lowest level values are measurable. The final alternative ranking reveals the extent to which the alternative meets the values from the operations flight commander's perspective in order to reach the fundamental objective.

Figure 4 Operations Flight Value Hierarchy (Katzer, 2002)

Technology Selection for the Air Force Research Laboratory Air Vehicles Directorate: An Analysis Using Value Focused Thinking (Winthrop, 1999). This paper focuses on exploring the technology direction that is most supportive to the U.S. Air Force values, which should be given more consideration by the air vehicles directorate (VA) when they have sufficient funds. Both VFT and optimization approaches are used in this analysis. Research and development (R&D) literature are first reviewed to help identify the fundamental objective and supporting objectives in the value hierarchy. In order to assure the value hierarchy represents the core values of VA, a number of VA experts and leaders are involved in developing and confirming the value definitions and the final hierarchy. Among over one hundred identified VA R&D programs, a couple of them are selected in the case study. An additive value model is employed to evaluate the overall score for each alternative, and sensitivity analysis is conducted at last.

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2.6.2 Literature Assessment

To gain further insights from these VFT studies within TLSC domain, we continue examining the select literature in the form of answering research questions with respect to these studies. We use the research questions developed in a recent survey paper (Parnell et al., 2013) and create a matrix to present the answers to these questions based on the contents of each study. Table 5 displays the literature assessment matrix.

Table 5 Literature Assessment Matrix

Research Questions	Neiger et al., 2009	Olson & Wu, 2010	Jordan, 2012	Nachtmann & Pohl, 2013	Axtell, 2011	Katzer, 2002	Winthrop, 1999
Publication	Journal	Book Chapter	Dissertation	Journal	Thesis	Thesis	Thesis
Authors	Australia	U.S.	U.S.	U.S.	U.S.	U.S.	U.S.
Year of Publication	2009	2010	2012	2012	2011	2002	1999
Type of Study	Theory	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study
Problem Domain	Supply chain	Supply chain	Supply chain	Transport	Transport	Transport	Transport
Clients	Corporate leaders	Corporate leaders	Corporate leaders	Government policy makers	Military leaders	Military leaders	Military leaders
Alternatives by VFT	N/A	Previously known	Previously known	Previously known	Previously known	Previously known	Previously known
Value/Utility Model	N/A	Value model	Value model	Value model	Value model	Value model	Value model
Number of Measures	N/A	12 (Case study)	8 (Case study)	8 (Model)	29 (Model)	10 (Model)	31 (Model)
Other OR/MS Technique	e-EPC	SMART	None	None	GERBIL	None	LP

As is shown in Table 5, ten research questions are selected (with slight revision from Parnell et al., 2013) as the criteria to investigate and compare the literature. Based on the seven TLSC VFT studies, answers to the research questions are summarized as follows:

- *Publication*. Among the seven studies, we found that one is published as a book chapter, two as journal articles, and four as a thesis or dissertation.

- *Authors*. All authors are from the U.S. except for one group of authors who are from Australia.

- *Year of Publication*. Five out of seven studies are published within the past five years. The other two studies are published in 2002 and 1999 respectively.

- *Type of study*. One research focuses mainly on building a theoretical model while the others include both a theoretical methodology and a case study.

- *Problem domain*. Within TLSC, four studies are related to transportation, and three focus on the supply chain.

- *Clients*. Corporate and military leaders are the two largest groups for which the select VFT studies serve (each is involved in three papers). Only one study is conducted for government policy makers.

- *Alternatives by VFT*. None of them actually use a VFT concept to design or improve the alternatives. Alternatives are generated based on collected data/information.

- *Value/Utility model*. Not surprisingly, the value model dominates the utility model among the literature. Six studies employ the additive value model.

- *Number of measures*. The number of measures in the value model range from eight to thirty-one. Four papers determine the measures when the VFT framework is constructed. Two publications identify the measures only in the case study.

- *Other operations research or management science (OR/MS) technique*. Four studies integrate VFT and other OR/MS techniques in developing the methodology framework. The techniques referred in these studies include extended-event-driven process chain (e-

EPC), simple multi-attribute rating theory (SMART), global en route basing

infrastructure location model (GERBIL), and linear programming (LP).

2.7 Analytic Hierarchy Process (AHP)[5]

Analytic Hierarchy Process (AHP) approach is employed to construct the multi-attribute decision

model in Chapter 7. AHP is widely used by decision makers and researchers to solve different

problems, and a large number of papers have been published relating to the AHP application.

Vaidya and Kumar (2006) classified the AHP papers according to the theme such as "selection,

evaluation, benefit-cost analysis, allocations, planning and development, priority and ranking,

and decision-making." We primarily focus on the papers that fall into the "priority and ranking"

category which is more similar to our proposed cargo prioritization problem. Bandeira et al.

(2009) applied AHP technique to prioritize the maritime booking confirmations in the event of

the scarcity of the transportation supply. Financial, managerial and organizational factors are

incorporated in the evaluation process of the clients, which is on the consensus of both the sales

team and the top executives. Farhan and Fwa (2009) explored the AHP application on the

prioritization of the pavement maintenance activities with the objective of reflecting the

engineering opinions of a group of highway agencies and engineers. Three AHP forms are

considered and compared in terms of their suitability and effectiveness in the priority

assessments according to a direct assessment method. Modarres and Zarei (2002) examined the

city vehicle transport network for the earthquake crisis preparation, using an AHP model to

determine the trip priorities and the shortest path theory to identify the fastest and safest routes.

Hafeez et al. (2002) looked into how to determine a firm's key capabilities in order to improve

its core competencies and adopted AHP to construct the evaluation framework. Contributions of

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[5] Excerpted from *Section 2 of Chapter 7*

firm capabilities are assessed for both financial and non-financial performances. An interesting field in which AHP approach is also widely employed as the decision method is the sports management. One example is Bodin and Epstein (2000)'s paper of using AHP to rank the players in the professional baseball team for the expansion draft. Braglia (2000) explored the effectiveness of AHP by proposing the multi-attribute failure mode analysis (MAFMA). It uses an AHP-based method to prioritize failures identified in the reliability research in order to determine the most appropriate corrective actions.

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3. A REVIEW OF CARGO PRIORITIZATION TECHNIQUES WITHIN INLAND WATERWAY TRANSPORTATION[6]

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Abstract

In order to support the development of a cargo prioritization model for inland waterway transportation and as part of ongoing research funded by the U.S. Department of Homeland Security, the paper provides a vital knowledge base of existing cargo prioritization models by reviewing twenty selected papers from governmental agencies and academic institutions. A methodology comparison matrix is constructed based on three criteria that summarize features of the cargo prioritization methods.

Key Words: Inland Waterways; Cargo Prioritization; Literature Review

1. Introduction

Inland waterways play an important role in the Nation's transportation system. Disruption of the inland waterway transportation system can have widespread economic and societal impacts. In order to mitigate these impacts, ongoing research funded by the U.S. Department of Homeland Security is developing a prototype decision support system to provide timely knowledge of what barge cargoes should be prioritized for offloading in the event of a disruption while considering the availability and capacity of nearby ports and land-based freight infrastructure to receive and

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transport these cargoes. This paper establishes a knowledge base of exiting prioritization methods to support cargo prioritization model development in our future research. A total of twenty papers that include prioritization methods across a diverse set of application contexts are selected for review.

2. Review of Selected Papers

2.1 "Market scoping: Methods to help people understand their marketing environment" (Bennet, 2002)

Bennet (2002) develops multiple techniques to examine the marketing environment of rural communities. One method prioritizes products based on their economic and social importance in order to identify the products that should receive more attention in the analysis of market scoping. Three steps are involved in Bennet's prioritization process:

- Identify products that have been marketed before or have value to be marketed.

- Identify criteria by which to prioritize the products.

- Score each product for each criterion on a scale of one to three and calculate the total score of the product.

2.2 "Multi-criteria ranking of components according to their priority for inspection" (Ibrahim and Ayyub, 1992)

The authors propose a fuzzy multi-criterion risk-based prioritization method to determine the order in which the critical components of the system are inspected in order to enhance the inspection effectiveness. For the alternatives X_i , $C = \{C_i : i = 1,2, \dots, m\}$ represents a fuzzy set of criteria and $C_i (X_i) \in [0,1]$ indicates the extent to which the alternative satisfies the corresponding criterion. Decision function R is shown as follows:

$$R = C_1 \cap C_2 \cap ... \cap C_m \qquad (1)$$

The *m* fuzzy sets of criteria are transformed into the decision fuzzy set by selecting the minimum score assigned to the alternative among all the criteria. The alternative with the maximum score in the decision fuzzy set is selected as the best candidate. In addition, through attaching a scalar number α to each criterion, the authors address the issue of the different importance levels of the criteria. The improvement is shown as follows:

$$R = C_1^{\alpha_1} \cap C_2^{\alpha_2} \cap ... \cap C_m^{\alpha_m} \qquad (2)$$

A number of criteria for prioritizing components are used in this paper, among which economic and human risks are the factors that have potential to be used in cargo prioritization for inland waterway transportation.

2.3 "Danish environmental protection agency environmental project No.839: Ranking of industrial products" (Hansen and Cowi, 2003)

This report focuses on prioritizing industrial products in Denmark based on losses of resources and energy consumption in order to identify the commodity groups that have the most negative impact on the environment and should be considered first when the associated cleaner technology is developed. The prioritization method is illustrated through the following formula:

$$P = P_R + P_E \qquad (3)$$

P_R represents the prioritization criterion associated with loss of resources, which is the amount of the non-recycled materials. P_E represents the prioritization criterion associated with energy consumption, which is defined as the amount of energy consumed in production phase minus the amount of energy that is recycled from incinerating the materials that end up as waste. The prioritization method is based on the integration of both criteria. The prioritized products

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correspond to those with greater loss of resources and more energy consumption and their negative environmental impacts are further intensified if they have higher demand in the market.

2.4 "An assessment of the worldwide express program and its effects on customer wait time (CWT) and readiness" (Grandjean and Newbury, 2001)

The Navy's logistics system employs a Uniform Material Movement and Issue Priority System (UMMIPS) to prioritize the materials according to the importance of movement. Two factors, the Urgency of Need Designator (UND) and the Force Activity Designator (FAD), constitute the UMMIPS. UND is the priority level assigned to materials based on their urgency level for the mission (see Table 1). FAD is the priority level assigned to the mission based on its relative importance (see Table 2). The UMMIPS prioritization matrix is then established based on UND and FAD with fifteen priority levels (see Table 3), which are further categorized into three priority groups as shown in Table 4.

Table 1 Three Levels of UND

A	B	C
Cannot Perform Mission	Mission Capability Impaired	Requirements and Stock Replenishment

Table 2 Five Levels of FAD

I	II	III	IV	V
Combat	Combat Readiness	Deployment Readiness	Active Reserve	Other

Table 3 UMMIPS Priority Matrix

FAD/UND	A	B	C
I	1	4	11
II	2	5	12
III	3	6	13
IV	7	9	14
V	8	10	15

Table 4 Priority Groups of UMMIPS

Priorities 1-3	Group 1
Priorities 4-8	Group 2
Priorities 9-15	Group 3

2.5 "Preferences for distributing goods in times of shortage" (Kemp, 1996)

This paper adopts a questionnaire method to prioritize commodity for revealing people's preference regarding how to allocate a scarce commodity. The study considers shortages of champagne, heating fuel, sports fields, and a medical drug in both two month and infinite time horizons (eight scenarios in total) and questionnaires were distributed to students to rate each scenario. The rating scale is from 0 (prefer governmental committee to regulate commodity allocation) to 9 (prefer market itself to regulate commodity allocation). The results of the study show that champagne receives the highest score and should be allocated by market, which is followed by sports fields, heating fuel, and the medical drug.

2.6 "National agricultural commodity research priorities for Pakistan" (Nagy and Quddus, 1998)

This paper includes a commodity prioritization process to support the research funding decision. The approach employed prioritizes commodities based on an efficiency index – the Net Present Value (NPV) divided by the present value of the research expenditure. Compared to NPV and

Internal Rate of Return (IRR), which are both conventional approaches for assessing return, the efficiency index is stated to be more appropriate to prioritize commodities for the purpose of determining research budget due to its focus on estimating marginal rate of return.

2.7 "Deployable waterfront transportability study using heavy lift submersible ships" (Mar Inc., 1987)

This paper refers to a decision process of cargo sequence in loading and offloading cargoes. The cargo is prioritized according to the cargo draft: Deepest-draft cargo is loaded first and shallowest-draft cargo is unloaded first. Characteristics of the cargo such as weight and volume and the environmental condition such as water density and wind speed may all influence the cargo draft.

2.8 "Regulatory schedule for VOC-emitting consumer and commercial products revised" (EPA, 1999) and "Study of Volatile Organic Compounds from consumer and commercial products—report to congress" (EPA, 1995)

Excessive exposure to ground-level ozone can pose significant negative effects to human health, crop growth and even the ecosystem. The US Environmental Protection Agency (EPA) prioritizes consumer and commercial commodity on the basis of emission of the Volatile Organic Compounds (VOCs), the major reactants that produce ground-level ozone, in order to establish regulation plans in successive years. The prioritized commodity is regulated in the most recent regulation year due to its considerable contribution to the ground-level ozone formation. Five factors are considered in commodity prioritization: "The use, benefit, and commercial demand for the product (Factor 1); the health and/or safety function served by the product (Factor 2); whether the product emits highly reactive VOCs (Factor 3); availability of substitute materials considering utility, cost, safety, health, and environmental issues (Factor 4); and the

cost-effectiveness of VOC emission controls for the product (Factor 5)". EPA further extends the five factors into eight criteria to establish regulation priorities (see Table 5). The prioritized commodities are categorized into four groups with different regulation priority levels.

Table 5 EPA Factors and Criteria of VOC Regulation

Factor 1	• Criterion 1 – Utility
	• Criterion 2 – Commercial demand
Factor 2	• Criterion 3 – Health or safety functions
Factor 3	• Criterion 4 – Emissions of "highly reactive" compounds
Factor 4	• Criterion 5 – Availability of alternatives
Factor 5	• Criterion 6 – Cost-effectiveness of controls
Additional Considerations	• Criterion 7 – Magnitude of annual VOC emissions
	• Criterion 8 – Regulatory efficiency

2.9 "An AI approach for optimizing multi-pallet loading operations" (Lau et al., 2009)

The paper develops a hybrid approach of heuristics and Genetic Algorithms (GAs) to solve the multi-pallet loading problem. One step of the Profit-based Loading (PL) heuristic is to sort the cargoes according to revenue – the shipping cost paid by cargo owners. This cost is determined by the chargeable weight of the cargo – the volume weight or the actual weight. The cost is estimated based on the larger amount of these two weights. The volume weight and the actual weight are defined as follows:

$$Volume\ weight = \frac{w_l l_l h_l}{6000}\ \forall l \in C \tag{4}$$

$$Actual\ weight = t_l\ \forall l \in C \tag{5}$$

C is the index set of cargoes, $C = \{1, 2 \ldots N\}$;

w_l, l_l, h_l are the width, length and height of the cargo l respectively;

6000 is the factor utilized in air transport to convert the volume to volume weight;

t_l is the weight of the cargo l.

Revenue is calculated by multiplying the cargo forwarding price and the larger chargeable weight. The cargo is prioritized according to its revenue.

2.10 "Priority dispatch and aircraft scheduling: A study of strategic airlift scheduling" (Armstrong et al., 1983)

This paper put forth a methodology to evaluate algorithms for allocating strategic airlift resources and rules for cargo priority dispatch. In order to assess the effectiveness of the proposed methodology, five rules for prioritizing cargo for dispatch purposes are selected as the test cases:

- Aircraft preference: Cargoes of the same type are assigned to an aircraft that has preference on that type of cargoes.

- Earliest Due Date (EDD): Cargoes are prioritized by their due dates in increasing order.

- Smallest Weight (SWT): Cargoes are prioritized by their weights in increasing order.

- Largest Weight (LWT): Cargoes are prioritized by their weights in decreasing order.

- Slack per operation: It represents the remaining days before the due date divided by the operation quantity.

A description of how to systematically prioritize cargo once the above factors are determined is not provided in the paper.

2.11 "The International Institute of Tropical Agriculture's (IITA) experience in priority assessment of agricultural research" (Manyong et al., 2009)

This paper consists of two prioritization approaches for identifying agricultural research programs that should be carried out with high priority. The quantitative approach – Priority Assessment Exercise (PAE) – determines which commodities should be researched first to best contribute to decreasing poverty levels in Nigeria. In PAE, two sub-approaches are used. An

efficiency-based approach adopts the factors of Net Present Value (NPV) and Internal Rates of Return (IRR) to assign priorities to the commodity research programs. An equity-based approach allocates priorities to the commodities that can obtain the largest poverty decreases using a function of poverty estimation.

2.12 "Developing a commodity flow database from transearch data" (Ahanotu et al., 2007)

This paper includes a commodity prioritization method to identify important non-manufactured goods that should be filed in the Transearch database to modify the Transearch's incompleteness. The commodities are prioritized by the weighted average of the amount percentage of commodity transported in different directions. The first four prioritized commodities will be added to the database.

2.13 "Combined routing and scheduling for the transportation of containerized cargo" (Sinclair and Dyk, 1987)

This paper develops an algorithm to solve a combined routing and scheduling tractor-trailer problem. One aspect of the decision of movement priorities provides general qualitative principles for cargo prioritization:

- Priority should be given to export movement as compared to the import movement since the export cargoes must be loaded onto overseas vessels in time for departure.
- Priority should be given to movements that require execution time in commodity export.
- The highest priority should be given to the refrigerated containers in commodity import.

2.14 "Labor supply, commodity demand and marginal tax reform" (Madden, 1995)

This article employs labor supply to estimate the marginal revenue cost (MRC) for indirect and direct taxation. There are three versions with respect to the calculation of the MRC: LESo1,

LESo2, and LESo3. Commodities are prioritized based on the MRC with varied LES systems. The prioritization results are similar among the three LES systems with only slight differences. Commodities of services, fuel and power, clothing and footwear are given higher priorities than other commodities in all three systems. Alcohol is given the lowest priority in all three systems.

2.15 "A review of strategic mobility models and analysis" (Schank et al., 1991)

In RAND's report of reviewing and comparing five strategic mobility models, one comparison step is to prioritize cargo for shipping. The prioritization methods for the five models are shown in Table 6.

Table 6 Assigning Priorities to Cargoes

Priority	MIDAS	RAPIDSIM	TFE	SEACOP	FLOGEN
First	RDD-time	LAD	LAD	LAD-time	LAD-time
Second	RLD	ALD	Channel		
Third			CINC's priority		
Fourth			Priority add-on		
Option					CINC's priority

The MIDAS, SEACOP and FLOGEN models all prioritize cargo based on the predicted latest shipping date by subtracting the estimated time for loading, travelling and offloading from the Required Delivery Date (RDD) or the Latest Arrival Date (LAD). The RDD and LAD models deliver very similar prioritization results since the two factors are highly interrelated with each other. The FLOGEN model sometimes employs the Commander in Chief (CINC)'s priority method instead of the LAD-time approach. In Table 6, RLD represents the "Ready to Load Date" and ALD indicates the "Available to Load Date".

2.16 "Coconut program area research planning and prioritization" (Aragon, 2000)

This paper contains a commodity prioritization method based on selected statistical parameters by the Science and Technology Coordinating Council (STCC) in the Philippines to examine the current research situation of its coconut industry. The authors assign a score to each commodity for each statistical parameter and calculate the weighted average of the assigned scores to prioritize commodity. Three groups of statistical parameters are selected to produce three weighted averages of assigned scores for each commodity. The final prioritization decision is made upon the prioritization results from the various statistical parameter groups.

2.17 "Who should set airlift priorities during foreign humanitarian assistance/disaster relief operations and on what basis" (Weinberger, 2010)

The system of Department of Defense transportation movement priorities is introduced in this paper. This system does not explicitly indicate which type of cargo or passenger should be prioritized for transportation but determine the relative importance of the missions/activities/programs/projects that the cargo or the passenger is involved with. The lift manager needs to provide transportation resources to the cargo or the passenger associated with missions of highest priority levels if the demand of transportation exceeds the available capacity. In general, this priority system is a requirement-based operational guide rather than a cargo-based prioritization approach.

2.18 "Strategy to enhance international supply chain security" (USDHS, 2007)

This report puts forth a strategic plan for international supply chain security. The plan includes prioritizing commodities locally and nationally for transportation during the trade resumption phase. The following issues are considered in prioritizing local commodity movement:

- Vessel security: whether the vessel is cleared for entry and whether it contains a high risk commodity

- Berthing: whether the vessel can travel to or from its berth in terms of berthing/space/facility availability and whether the waterway functionality places detrimental impact to the vessel's berthing activity

- Port infrastructure: whether the port infrastructure has sufficient capacity to unload and transport the cargoes out of the port

- Commodity needs: demand level of the commodity is considered for this issue

- Commodity movement: whether the commodity should be moved out of the port to prevent further disasters

The following goods are given priority in meeting national security requirements:
- Goods that are in emergency need to save lives

- Goods necessary to carry out response actions to the incident

- Goods that recover the immediate commodity shortage due to the incident

- Goods that are associated with national security influenced by the incident

In addition to the above general prioritization principles, a decision tree is utilized to prioritize commodities and a scoring system to support rapid prioritization is recommended by the authors.

2.19 "National strategy for maritime security: The maritime infrastructure recovery plan" (USDHS, 2006)

This report proposes a Maritime Infrastructure Recovery Plan (MIRP) to restore sea transport capabilities and minimize negative effects of the Transportation Security Incident (TSI). When considering TSI response and recovery, the authors state that the recovery stage should include a

step of setting priorities for passenger and cargo movements at the national, regional and local levels. Several types of inbound transit cargo are prioritized including fuel oil (specific to cold weather ports in winter), gas and diesel, perishable commodities, and assembly line components (in winter and summer).

3. Prioritization Model Comparison

Among the reviewed papers, we did not observe a commonly agreed upon cargo prioritization model for general application or specifically for inland waterway transportation. The prioritization methods employed in the reviewed papers are usually simple or implicit approaches without detailed methodology descriptions since the cargo prioritization decision itself is not the main focus of the majority of these papers but simply a necessary step to support their core models. Moreover, the existing cargo prioritization approaches are varied in technique and associated factors due to their diverse application contexts. Table 7 summarizes the collective features of the prioritization techniques found in the twenty selected papers.

3.1 Comparison Criteria

We select three criteria to compare the cargo prioritization techniques: "*Prioritization Technique*", "*Specific Application Context*", and "*Number of Factors*". Review of the comparison matrix provides a high-level understanding of the basic prioritization approach each paper employs, whether the method is used in a specific application context, and how many factors the author considers in cargo prioritization.

3.2 Model Comparison

A summary description of the Table 7 model comparison based on each of the three criteria is provided in this section:

- "*Prioritization Technique*": Five papers provide a number of standards or guidelines one should consider when prioritizing cargo without indicating an explicit assessment methodology (EPA, 1999; Sinclair & Dyk, 1987; Weinberger, 2010; USDHS, 2007; SUDHS, 2006). Another six papers include both criteria and prioritization technique in their approaches, either quantitatively or qualitatively (Bennett, 2002; Ibrahim & Ayyub, 1992; Hansen & Cowi, 2003; Grandjean & Newbury, 2001; EPA, 1995; Aragon, 2000). All of the six papers adopt a particular method to evaluate the criteria for each type of cargo and synthesize the evaluation results of all criteria. A single paper utilizes the questionnaire approach to prioritize cargo through information collection from the public (Kemp, 1996). Papers not appearing in the category of "*Prioritization Technique*" employ a simple prioritization approach – prioritizing cargo based on a single factor – rather than a systematic technique.

- "*Specific Application Context*": Although the reviewed papers consider a dozen of diverse application contexts, environmental and military application contexts appear more frequently than other application sectors. Three papers consider prioritization based on environmental issues such as minimizing negative environmental impacts (Hansen & Cowi, 2003; EPA, 1999; EPA, 1995). Four papers consider prioritization to satisfy military objectives such as establishing the appropriate strategic plan for cargo movement (Grandjean & Newbury, 2001; Armstrong et al., 1983; Schank et al., 1991; Weinberger, 2010).

- "*Number of Factors*": The prioritization methods employed are almost evenly split between utilizing single and multiple factors for prioritizing cargo. The six papers with a single factor have the most straightforward prioritization approach by which the cargo

prioritization order is determined based on a single factor value (Nagy & Quddus, 1998; Mar Inc., 1987; Lau et al., 2009; Armstrong et al., 1983; Ahanotu et al., 2007; Madden, 1995). For papers with multiple factors, either a prioritization technique is proposed to synthesize the factor impacts and deliver the final prioritization order or the paper simply provides a list of factors that influence the prioritization without explicitly indicating prioritization approach. In total, there are three papers that consider two factors in their prioritization approach (Hansen & Cowi, 2003; Grandjean & Newbury, 2001; Manyong et al., 2009) and eight papers that utilize multiple factors (Bennett, 2002; Ibrahim & Ayyub, 1992; EPA, 1999; EPA, 1995; Schank et al., 1991; Aragon, 2000; USDHS, 2007; SUDHS, 2006).

Table 7 Comparison Matrix for Cargo Prioritization Methods

Reference	Prioritization Technique			Specific Application Context			Number of Factors		
	Standards	Criteria Assessment	Questionnaire	Environmental	Military	Other	Single	Two	Multiple
Bennett, 2002		-Assign score to each criterion -Estimate the total score				-Market scoping			-Profitability -Traditionally important -Seasonal advantage, etc.
Ibrahim and Ayyub, 1992		-Fuzzy multi-criterion risk-based ranking				-Component inspection			-Economic risk -Human risk, etc.
Hansen and Cowi, 2003		-Summation of criteria values		-Negative environmental impact by industrial products				-Loss of resources -Energy consumption	
Grandjean, and Newbury, 2001		-Uniform Material Movement and Issue Priority System			-Navy's logistics system			-Urgency of Need Designator -Force Activity Designator	
Kemp, 1996			-Survey from students			-Scarce commodity allocation			
Nagy and Quddus, 1998						-Research funding decision	-Net Present Value (NPV)		
MAR Inc., 1987						-Cargo sequence decision	-Cargo draft		
EPA, 1999	-Five factors			-Volatile Organic Compounds (VOC)					-The uses, benefits, and commercial demand of consumer and commercial product, etc.
EPA, 1995		-Eight criteria		-Volatile Organic Compounds (VOC)					-Utility -Commercial demand, etc.
Lau et al., 2009						-Multi-pallet loading problem	-Revenue		

Table 7 Comparison Matrix for Cargo Prioritization Methods (Cont.)

Reference	Prioritization Technique			Specific Application Context			Number of Factors		
	Standards	Criteria Assessment	Questionnaire	Environmental	Military	Other	Single	Two	Multiple
Armstrong et al., 1983					-Strategic airlift scheduling		-Aircraft preference/ Earliest due date/ Smallest weight/ Largest weight/ Slack per operation		
Manyong, 2009						-Agricultural research decision		-Net Present Value (NPV) -Internal Rates of Return (IRR)	
Ahanotu, 2007						-Database modification	-Weighted average of commodity amount in different directions		
Sinclair and Dyk, 1987	-Movement priority criteria					-Tractor-trailer problem			
Madden, 1995						-Indirect and direct taxation	-Marginal Revenue Cost (MRC)		
Schank, 1991					-Strategic mobility				-Latest Arrival Date -Commander in Chief -Ready to Load Date, etc.
Aragon, 2000		-Assign score to varied statistical parameters				-Coconut research			-Value of production -Number of beneficiaries, etc.
Weinberger, 2010	-DOD Transportation Movement Priorities				-Airlift during Foreign Relief Operations				
DHS, 2007	-Guidelines for commodity movement locally and nationally					-International supply chain security			-Commodity needs -Commodity movement -Port infrastructure, etc.
DHS, 2006	-Priorities for cargo movements					-Maritime security			-Gas and diesel -Perishable commodity, etc.

4. Conclusions

This paper reviews existing cargo prioritization techniques found in the literature and compares technique features based on three selected criteria. It provides a useful knowledge base for the development of a cargo prioritization model for inland waterway transportation. Our future research focuses on formulating a deterministic mathematical programming model for cargo prioritization in inland waterway transportation. This model will provide the authorities along inland waterways as well as private industry with a decision support tool to prioritize cargo on barges in the event of inland waterway disruption and transload them to other modes in an efficient and rational manner.

Appendix 1

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This memorandum is to confirm that Jingjing Tong is the first author of the following article and completed at least 51% of the work for the article.

"A review of cargo prioritization techniques within inland waterway transportation"

Appendix 2

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June 23, 2014

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For: "A review of cargo prioritization techniques within inland waterway transportation"

For: "Multi-attribute decision model for cargo prioritization within inland waterway transportation"

Authors: Jingjing Tong and Heather Nachtmann

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4. CARGO PRIORITIZATION AND TERMINAL ALLOCATION PROBLEM FOR INLAND WATERWAY DISRUPTIONS

Jingjing Tong, M.S.

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Abstract

To mitigate inland waterway disruption impacts, we introduce the cargo prioritization and terminal allocation problem (CPTAP) to minimize the total value loss of disrupted barge cargoes. CPTAP is formulated as a nonlinear binary integer program, and problems of realistic size can be efficiently and effectively solved with a genetic algorithm approach. The final solution identifies an accessible alternative terminal for each disrupted barge and the prioritized offload turn that each barge takes at its assigned terminal. Implementation of CPTAP results in reduced cargo value loss and response time when compared to a naïve minimize distance approach.

Key Words: Maritime Transportation; Inland Waterway; Freight; Cargo Prioritization; Integer Programming; Genetic Algorithm

1. Introduction

The commercially important United States (U.S.) inland navigation system is comprised of approximately twelve thousand miles of navigable waterways managed by the U.S. Army Corps of Engineers (USACE) (Stern, 2010). This inland waterway system serves thirty-eight states across the U.S. and carries one-twelfth of U.S. freight across nearly two hundred commercially active lock sites (Stern, 2010; USACE, 2009). These marine highways are considered a critical

transportation mode for certain commodities and geographical regions as they transport approximately twenty percent of coal, twenty-two percent of petroleum and sixty percent of the farm exports in the U.S. (USACE, 2009). Unexpected disruptions to the system due to natural disasters, vessel accidents, or terrorist attacks can cause non-navigable water levels or destroy major navigation infrastructures (e.g. bridges, locks and dams), resulting in short or long term closures of the inland waterway. During a long term closure event, barge cargoes need to be offloaded from the waterway and transported to their final destination via an alternative land-based transportation mode. This shift to land-based transportation is a challenging because the existing capacity of accessible terminals and alternative modes of transportation may not be sufficient to handle all of the disrupted cargo. Each barge tow commonly consists of a towing vessel pushing nine to fifteen barges, and each barge has a much larger cargo capacity than alternative land-based vehicles (i.e. the cargo capacity of a single barge is approximately equal to sixty tractor trailers or fifteen railcars). As time elapses during a closure, the value of the disrupted cargo decreases in terms of economic value, societal benefit, and customer satisfaction. In order to mitigate negative disruption impacts, key maritime stakeholders including the U.S. Coast Guard (USCG) and USACE need pre- and post- disruption response plans which support prioritizing and redirecting disrupted barges in order to minimize the total value loss of the impacted system.

This paper introduces the cargo prioritization and terminal allocation problem (CPTAP) which minimizes the total value loss by optimally prioritizing disrupted barges through consideration of multiple prioritization factors including commodity type, cargo value, terminal capacity, and barge draft. The terminal allocation feature of CPTAP is similar to the berth allocation problem (BAP) which seeks to assign vessels to the berths in order to minimize the total service time of

the vessels (see original work by Imai et al., 1997; Imai et al., 2001; Imai et al., 2003). CPTAP and BAP are both three dimensional assignment problems that involve two decisions, the barge/ship-to-terminal/berth assignment and the offload/service order at the terminal/berth. In addition, the elapsed time of a barge/ship that is incorporated into the objective function partially depends on its predecessors. Two primary differences between CPTAP and BAP are: 1) CPTAP considers the type of cargo carried by the barges in its optimization, which is not considered in BAP, and 2) CPTAP minimizes total value loss while most BAPs minimize total service time. In order to handle problems of realistic size, we formulate CPTAP as a nonlinear binary integer program and develop a genetic algorithm (GA) solution approach. The minimized CPTAP solution indicates the terminal that each disrupted barge is assigned to and the prioritized turn each barge takes at its assigned terminal.

This paper presents a literature review of relevant work focused on cargo prioritization and BAP and then provides a problem definition to illustrate and further define CPTAP. The model formulation is described next, followed by discussion of our GA approaches and CPTAP results. The conclusions section summarizes the paper and discusses our future research directions.

2. Literature Review

To establish a knowledge base of existing cargo prioritization methods, we identified and reviewed twenty papers that include prioritization methods across a diverse set of application contexts (Manuscript Authors, 20XX). We selected three criteria to compare the cargo prioritization techniques found in the literature:

- Prioritization Technique: Five papers provide standards and/or guidelines to consider when prioritizing cargo (EPA, 1999; Sinclair and Dyk, 1987; Weinberger, 2010; USDHS,

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2007; USDHS, 2006), another six papers include criteria and a prioritization technique (Bennett, 2002; Ibrahim and Ayyub, 1992; Hansen and Cowi, 2003; Grandjean and Newbury, 2001; EPA, 1995; Aragon, 2000), and one paper utilizes a questionnaire to prioritize cargo through public information collection (Kemp, 1996).

- Application Context: Applying cargo prioritization within environmental and military contexts appears more frequently than other application contexts. Three papers prioritize based on environmental issues (Hansen and Cowi, 2003; EPA, 1999; EPA, 1995), and four papers prioritize cargo to satisfy military objectives (Grandjean and Newbury, 2001; Armstrong et al., 1983; Schank et al., 1991; Weinberger, 2010).

- Number of Factors Considered: Six papers employ a single factor cargo prioritization approach (Nagy and Quddus, 1998; Mar Inc., 1987; Lau et al., 2009; Armstrong et al., 1983; Ahanotu et al., 2003; Madden, 1995), three papers consider two prioritization factors (Hansen and Cowi, 2003; Grandjean and Newbury, 2001; Manyong et al., 2009), and eight papers utilize more than two factors (Bennett, 2002; Ibrahim and Ayyub, 1992; EPA, 1999; EPA, 1995; Schank et al., 1991; Aragon, 2000; USDHS, 2007; USDHS, 2006).

The literature-based factor matrix shown in Table 1 suggests the aspects one should recognize and contemplate during cargo prioritization.

Table 1 Cargo Prioritization Factor Matrix

Classification	Prioritization Factor	Source
Value/Cost/ Revenue	Profitability	Bennett, 2002
	Revenue	Lau et al., 2009
	Efficiency Index	Nagy & Quddus, 1998
	Commercial Demand	EPA, 1999
	Marginal Revenue Costs	Madden, 1995
	Value of Production	Aragon, 2000
Time	Earliest Due Date	Armstrong et al., 1983; Sinclair & Dyk, 1987; Schank et al., 1991
	Latest Arrival Date	Schank et al., 1991
	Ready to Load date	Schank et al., 1991
	Available to Load date	Schank et al., 1991
Risk	Economic Risk	Ibrahim & Ayyub, 1992
	Human Risk	Ibrahim & Ayyub, 1992
	Health/Safety Function	EPA, 1999
	Security Status	USDHS, 2007
Weight	Cargo Draft	Mar Inc., 1987
	Smallest Weight	Armstrong et al., 1983
	Largest Weight	Armstrong et al., 1983
Quantity	Commodity Transport Direction Volume	Ahanotu et al., 2003
Environment	Product's Loss of Resources	Hansen & Cowi, 2003
	Energy Consumption	Hansen & Cowi, 2003
	Volatile Organic Compound Emissions	EPA, 1999
Urgency	Urgency of Need	Grandjean & Newbury, 2001
	Force Activity	Grandjean & Newbury, 2001
	National Commodity Priorities	USDHS, 2007
Importance	Important for Food Security	Bennett, 2002
	Traditionally Important	Bennett, 2002
	Commodity Needs	USDHS, 2007
	National Security	USDHS, 2007
Others	Seasonal Advantages	Bennett, 2002
	Availability of Substitute Materials	EPA, 1999
	Export vs. Import Movements	Sinclair & Dyk, 1987
	Refrigerated vs. Nonrefrigerated	Sinclair & Dyk, 1987
	Commander in Chief Priority	Schank et al., 1991
	Offload Capacity of Port Infrastructure	USDHS, 2007
	Vessels Transport Ability	USDHS, 2007
	Fuel Oil Presence	USDHS, 2006
	Presence of Perishable Cargo	USDHS, 2006
	Assembly Line Component Presence	USDHS, 2006

As previously discussed, CPTAP has similar features to BAP. Imai et al. (1997) pioneered the static berth allocation problem formulated as a bi-objective nonlinear integer program which minimizes total vessel staying time and dissatisfaction with berthing order. Imai et al. (2001) later considered a dynamic berth allocation problem (DBAP) where vessels may arrive to a

single berth location during the planning horizon, which they formulated as a mixed integer program and solved problems of realistic size through Lagrangian relaxation. Nishimura et al. (2001) expanded DBAP to allow each berth to accept multiple vessels within quay capacity limitations by employing a GA approach. Imai et al. (2003) further extended DBAP to consider vessel size and cargo volume service priority (referred to as PBAP), which they attempted to use Lagrangian relaxation initially but the computational burden led them to adopt a GA approach. Cordeau et al. (2005) proposed a new BAP formulation – the multi-depot vehicle routing problem with time windows (MDVRPTW) which considers the weighted sum of the service times and time windows of the berthing times. They employed a Tabu search heuristic which is capable of obtaining optimal solutions for small size problems and improved solutions for large size problems over a truncated branch-and-bound algorithm. Boile et al. (2006) reformulated the Imai et al. (2003) mixed integer nonlinear program for PBAP as a mixed integer program and developed a heuristic to solve the problem. Their linear reformulation is further considered in terms of its solution approach by Theofanis et al. (2007). Imai's group (2007) continued their work on BAP and developed the bi-objective BAP which minimizes both delay time and service time and found that a GA approach achieves better solutions than a subgradient optimization approach. The multi-objective BAP is further investigated by Golias et al. (2009) by employing a GA to optimize conflicting objectives of minimizing service time for various vessel groups and minimizing service time for all the vessels at the terminal. Other recent BAP extensions handle uncertainty (Zhen and Chang, 2012), integrate quay crane allocation (Han et al., 2010; Raa et al., 2011), consider water depth and tidal conditions (Xu et al., 2012), and address bulk cargo ports (Umang et al., 2013) and environmental concerns (Golias et al., 2010; Du et al., 2011; Wang et al., 2013).

3. Problem Definition

CPTAP is graphically described in Figure 1 through the depiction of a recent inland waterway disruption event. On January 20, 2014, a railroad bridge over the Arkansas River suffered a mechanical failure which halted all barge traffic on that section of the river (Magsam and McGeeney, 2014). Five locks and dams (L/Ds) serve that river section, and ten terminals are located along both sides of the river (locations shown in Figure 1). Each terminal is capable of offloading specific commodity types of cargo depending on its handling facilities. According to the USACE Lock Performance Monitoring System (2014), eight barge tows, commonly consisting of nine to fifteen barges each, are traveling up and down the disrupted river section at the time of the event as shown in Figure 1. Since the disruption prohibits barge traffic at the bridge location, the six barge tows (consisting of approximately 60 disrupted barges) that are traveling towards and beyond the damaged bridge (shaded in black) are disrupted and need to be prioritized and redirected through implementation of CPTAP. The two barge tows that have already passed under the damaged bridge and are traveling away from the disruption point (shaded in white) are not impacted. Since the disrupted barges are no longer able to travel to their original designation along the disrupted inland waterway, CPTAP determines an accessible terminal for offloading and rerouting the cargo on each disrupted barge and the barge's offload order at the designated terminal since more than one barge may be sent to a given terminal. Because the disruption has effectively divided the inland waterway into two sections, CPTAP is typically employed twice, once for disrupted barges located on the river above the disruption and once for disrupted barges located on the river below the bridge.

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Figure 1 Arkansas River Disruption

Several decision attributes are identified as important to CPTAP and are considered in our model:

- We achieve our objective to mitigate the total system disruption impacts by minimizing the total value loss of all barge cargoes within the inland waterway system whose transport is impacted by the disruption.

- The value loss of a barge's cargo depends on the total value of the cargo when the disruption occurs, the cargo volume, the total time it takes the cargo to reach its final destination, and the value decreasing rate which represents the rate at which the cargo's economic and

societal value diminishes as time elapses. This rate is determined by the decision maker(s) and reflects the amount that the value of the cargo decreases per unit volume per unit time. Higher rates decrease the cargo's value more rapidly as response time elapses, and CPTAP generally assigns earlier priority to cargo with a high decreasing rate in order to minimize total value loss.

- Terminals have varying capacities for accepting different commodity types of cargo that are transported along the inland waterway including the possibility of not accepting one or more commodity types.

- Water depth of the terminal is considered when assigning barges to terminals because the draft depth of a given barge cannot exceed its assigned terminal's water depth. A safety level is set as a buffer in CPTAP to achieve a desired distance gap between barge draft depth and terminal water depth to ensure that the current water level allows barges to safely travel into the terminal.

- The multiple barges in a single barge tow may be assigned to different terminals, and we assume there are sufficient towing vessels to transport the individual barges to their assigned terminals.

- Because barges can be anchored along the river bank, we assume there is no limit to the number of barges that can be assigned to a given terminal. However, due to offload equipment limitations, we assume that only one barge is offloaded at a terminal at a given time.

- Given limited terminal offloading capacities and alternative land-based transportation modes with relatively limited cargo volume capacity, the total time it takes to transport the cargo to its final destination may be large resulting in an unacceptable value loss. Unacceptable value

loss is computed using a pre-defined sinking threshold which the allowable percent of value loss that a barge's cargo may diminish before the value loss is deemed unacceptable. When this occurs, it is no longer prudent to redirect and offload this cargo with the assumption that customer demands are met through another means and eventual salvage of the barge occurs. In addition, there may be disrupted barge that cannot be offloaded by any terminal in the response area due to water depth or terminal capacity limitations. In these cases, we assume that these barges remain on the inland waterway which is represented in CPTAP by a dummy terminal with unrestricted terminal water depth and cargo capacity to accept non-hazardous cargoes.

- We assume that all barges carrying hazardous cargo are removed from the inland waterway during the disruption response in accordance with USCG practice. Barges carrying hazardous cargo are prohibited from dummy terminal assignment since these barges are not permitted to remain on the waterway due to potential hazardous impacts on the environment and population in the disruption vicinity.

4. Model Formulation

We define the following sets, variables and parameters for CPTAP formulation:

Sets
J – Set of barges with non-hazardous cargo
H – Set of barges with hazardous cargo
I – Set of real terminals
D – Set of dummy terminal (one)
K – Set of barge orders at a given terminal
N – Set of commodity cargo types

Decision variables

$x_{ijk} \in \{0, 1\}$ 1 if barge j is assigned to terminal i in the kth order; 0 otherwise

Parameters

t_{ij} Water transport time of barge j from its location at the time of disruption to terminal i

h_{ij} Handling time of barge j at terminal i

a_{ij} Actual contributing time of barge j that is assigned to terminal i in the kth order

r_{ij} Land transport time of barge j cargo from terminal i to its final destination by alternative

    mode of transportation

α_j Value decreasing rate of barge j cargo per unit volume per unit time

u_{in} Offload capacity for cargo n at terminal i during the disruption response

c_j Cargo volume on barge j

w_i Water depth at terminal i

d_j Draft depth of barge j

e_{jn} 1 if barge j carries cargo n; 0 otherwise

s Safety level

v_j Total value of barge j cargo

p Sinking threshold

Actual contributing time is defined as the amount of time it takes for a disrupted barge to be transported by water to its assigned terminal, to incur any wait time until its prioritized offload order is reached, and to have its cargo offloaded. As shown in Equation 1 and Figure 2, when a barge is assigned the first offload turn, it incurs no waiting time and its actual contributing time a_{ij} reduces to the sum of its water transport time t_{ij} and its handling time h_{ij}. Also observed in Equation 1 and Figure 2, there are two cases for barges assigned to the second or later offload turn at a given terminal: Case 1) when a barge arrives to its assigned terminal before barges with earlier offload turns complete their water transportation and offloading, it must wait until any barge(s) with higher priority (earlier offload turn) arrives and is offloaded before its

own offloading may begin. Therefore, its actual contributing time reduces to its handling time h_{ij}; and Case 2) when a barge arrives to its assigned terminal after any barge(s) with higher priority (earlier offload turn) completes its water transportation and offloading, its actual contributing time is the sum of its water transport time t_{ij} and handling time h_{ij} minus the cumulative actual contributing time of the preceding barge(s).

$$a_{ij} = \begin{cases} t_{ij} + h_{ij} & k = 1 \\ h_{ij} & k \neq 1 \quad t_{ij} \leq \sum_{m \in J \cup H} \sum_{k \in K-1} a_{im} \\ t_{ij} + h_{ij} - \sum_{m \in J+H} \sum_{k \in K-1} a_{im} & k \neq 1 \quad t_{ij} > \sum_{m \in J \cup H} \sum_{k \in K-1} a_{im} \end{cases} \quad (1)$$
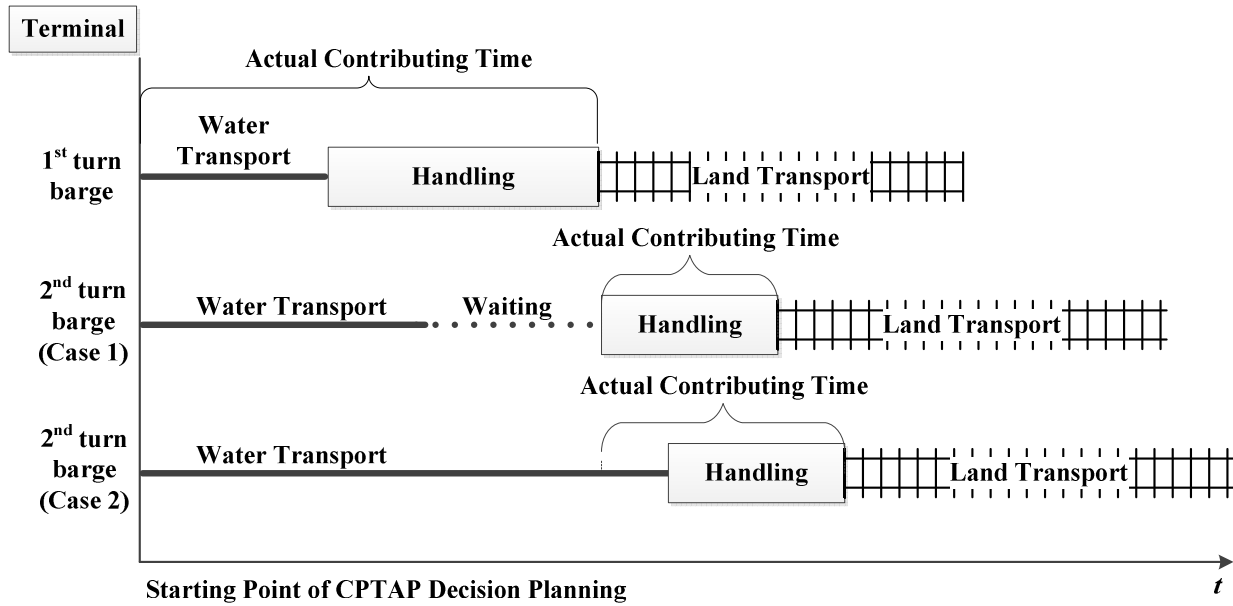
Figure 2 Graphical Representation of Actual Contributing Time

The CPTAP is formulated as a nonlinear integer program (NLIP) as follows:

Min

$$\sum_{i \in I} \sum_{j \in J \cup H} \sum_{k \in K} \left\{ \left(\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij} \right) c_j \alpha_j x_{ijk} \right\} + \sum_{i \in D} \sum_{j \in J} \sum_{k \in K} v_j x_{ijk}$$

s.t.

$$\sum_{i \in I \cup D} \sum_{k \in K} x_{ijk} = 1 \qquad \forall j \in J \qquad (2)$$

$$\sum_{i \in I} \sum_{k \in K} x_{ijk} = 1 \qquad \forall j \in H \qquad (3)$$

$$\sum_{j \in J \cup H} x_{ijk} \leq 1 \qquad \forall i \in I, k \in K \qquad (4)$$

$$\sum_{j \in J \cup H} x_{ijk} \geq \sum_{j \in J \cup H} x_{ij(k+1)} \qquad \forall i \in I \cup D, k \in K/|K| \qquad (5)$$

$$\sum_{j \in J \cup H} \sum_{k \in K} c_j e_{jn} x_{ijk} \leq u_{in} \qquad \forall i \in I \cup D, n \in N \qquad (6)$$

$$\sum_{i \in I} \sum_{k \in K} (w_i - d_j) x_{ijk} \geq s \qquad \forall j \in J \cup H \qquad (7)$$

$$\sum_{i \in I} \sum_{k \in K} \{ (\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij}) c_j \alpha_j x_{ijk} \} \leq v_j p \qquad \forall j \in J \cup H \qquad (8)$$

$$x_{ijk} \in \{0,1\} \qquad \forall i \in I \cup D, k \in K, j \in J \cup H \qquad (9)$$

The CPTAP objective function minimizes the total value loss of the disrupted barge cargoes within the inland waterway response area. The first term of the objective function handles barge cargoes that are offloaded and transported to the final destination through an alternative land-based transportation mode. As described earlier, the value decreasing rate is used to represent the rate at which the cargo's economic and societal value decreases over time per unit volume per unit time. In addition to the cargo's value decreasing rate, the value loss is also associated with the cargo volume and the total time it takes the cargo to reach its final destination. The second term of the objective function considers the non-hazardous cargoes that remain on the inland waterway and are assumed to lose total value. Constraint set (2) ensures that each barge with non-hazardous cargo either transports for offloading at an alternative terminal in some priority order or remains on the inland waterway (assigned to the dummy terminal). Constraint set (3) guarantees that all barges with hazardous cargo must be offloaded at a terminal in some priority order. Constraint set (4) assures that each terminal offloads no more than one barge at each priority order (e.g. a terminal can only offload one barge at a time). Constraint sets (2-4)

are adapted from the original BAP work (Imai et al., 1997; Imai et al., 2001; Imai et al., 2003). Constraint set (5) aesthetically ensures that the priority order at each terminal starts from the first priority turn. While the priority order of the assigned barges remains unchanged, the first turn may be skipped at the terminal and the highest priority barge may be assigned to the second or later turns without this constraint set. Constraint set (6) indicates that the overall terminal offload capacity for a particular cargo commodity type is not exceeded. Constraint set (7) ensures that the barge draft plus the safety level cannot exceed the water depth at the terminal (adapted from Nishimura et al., 2001). Constraint set (8) ensures that the total value loss of the barge cargo that is transported for offloading to an alternative transportation mode is less than or equal to the product of the sinking threshold and the total cargo value. For example, if a sinking threshold of 90% is employed, the barge cargo will be assigned to a terminal as long as the value loss of the cargo after it arrives to its final destination is less than 90% of its original value. Barges whose total value loss exceeds 90% will remain on the waterway and are assumed to incur a total value loss. Constraint set (9) defines the decision variables as binary variables.

5. Genetic Algorithm Approaches

Even for relatively short sections of the inland waterway system, solution strategies for CPTAP will generally need to be capable of handling disruption scenarios of at least fifty barges and ten or more terminals. Exact solution approaches to CPTAP can only solve problems of size fourteen or less (where problem size equals the number of barges plus the number of terminals) due to the computational demands associated with generating the actual contributing time of every possible barge assignment order sequence. We adopted a GA approach because of GA's success in effectively solving BAP where again no exact approach can handle the problem in

polynomial time (Golias et al., 2010; Yang et al., 2012). The pseudocode of our GA approach is summarized in Figure 3.

CPTAP GA Approach Pseudocode
1:     READ data of general information of terminal, barge and cargo
2:     FOR each chromosome in the initial population
3:         WHILE the generated chromosome is not feasible
4:            Generate a new chromosome
5:         ENDWHILE
6:     ENDFOR
7:     SET m to 1
8:     WHILE m < Iteration number
9:         Conduct Tournament selection to select two parents
10:       Conduct Crossover to produce two children
11:       Conduct Mutation on the two children
12:       Conduct Repair to produce two structurally feasible[a] children
13:       CALL SolutionValue RETURNING objective function values of two children
14:       IF the child does not share the same objective function value with chromosomes in population
15:         IF the child performs better than the worst chromosome in the population
16:           Include the child into the population
17:         ENDIF
18:       ENDIF
19:       INCREMENT m
20:     ENDWHILE
a: "structurally feasible" – chromosome has no duplicate natural numbers or redundant zeroes

Figure 3 GA Approach Pseudocode

5.1 Chromosome Representation

A popular chromosome representation found in the BAP literature is a numerical string that represents berths and vessels (Nishimura et al., 2001; Golias et al., 2010). We employ a similar representation in CPTAP where zeroes are used to distinguish the terminals with the dummy terminal designated as the last terminal in the string and natural numbers indicate numbered barges. Figure 4 presents an example CPTAP chromosome with two real terminals, a dummy terminal, and ten barges. Each barge gene in the chromosome may store one or more digits that represent the numbered barges up to the total number of disrupted barges. The sequence of the

natural numbers assigned to a given terminal represents the priority order in which the barges

should be offloaded at their assigned terminal. The natural numbers after the last zero represent

the barges that have been assigned to the dummy terminal and will therefore remain on the

inland waterway. In the example chromosome shown in Figure 4, Barges 5, 10, and 6 will be

offloaded at Terminal 1 in order first, second, and third respectively, Barges 1, 8, 7, and 2 will be

offloaded in order at Terminal 2, and Barges 3, 4 and 9 will remain on the waterway.

5	10	6	0	1	8	7	2	0	9	3	4

Terminal 1   Terminal 2   Dummy Terminal
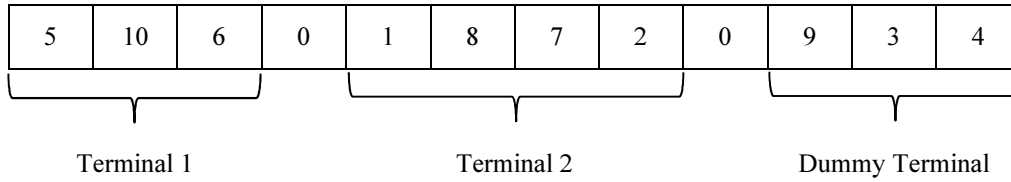
Figure 4 GA Chromosome Representation

5.2 Operator and Parameter Setting

The selection of GA operators and parameters influences the performance of the heuristic. Thus,

we conduct a formal investigation through a two-level fractional factorial design to select the

best combination of three operators and three parameters for our GA approach.

Tournament selection is used to choose two parent chromosomes in the current population to

produce two child chromosomes through the crossover operator. Two crossover methods, *one-point* crossover (crossover point is randomly generated) and *two-point* crossover (sub-chromosomes are interchanged), are considered for our GA design. The mutation operator

enables the GA to explore new solution areas. Two types of mutation operators are considered

in our GA design, *replace* and *swap*. During the *replace* mutation operator, one gene in the

chromosome is randomly chosen as the mutation location and is replaced with another randomly

selected number from zero to the total number of disrupted barges. The *swap* mutation operator

randomly selects two genes in the chromosome and swaps them according to a predefined

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mutation rate. Duplicate genes are likely to appear in the child chromosomes after the crossover and mutation operations. Therefore, the resulting structurally infeasible child chromosomes with duplicate barge numbers or extra number of terminals in the chromosomes must be repaired before their objective function values are evaluated. We repair the child chromosomes to structurally feasible solutions by deleting the duplicate barge numbers and/or redundant zeroes and adding in any missing barge numbers and/or zeroes. We considered two potential repair operators in our GA design: *ordered* repair and *random* repair. After removing the redundant barges and zeros, the *ordered* repair operator adds the missing natural numbers in increasing order and then adds zeroes to the remaining vacant genes. In *random* repair, the order of the missing numbers and zeros are scrambled at random before being inserted into the empty child chromosome genes.

Two levels of each factor are considered as shown in Table 2. Problem instances of small (five terminals and five barges), medium (ten terminals and thirty barges), and large (fifteen terminals and fifty barges) size are considered. Resolution IV and ten replicates are employed in the fractional factorial design, resulting in 160 factor combinations. Ten instances are generated for each problem size, and the average objective function value for each factor combination is the response. This two-level fractional factorial design is implemented in Minitab 16, and Table 2 summarizes the results. Small size problems are not sensitive to the various factor combinations. Medium and large size problems perform better at the same levels for all six factors. Our GA design is set to one-point crossover, swap mutation, random repair, population size of 50 chromosomes, 0.6 crossover rate, and 0.6 mutation rate.

Table 2 Fractional Factorial Design Results

Factors	Levels	Small	Medium	Large	Final Selection
Crossover	One-point	−	×	×	**One-Point**
Operator	Two-point	−	−	−	
Mutation	Replace	−	−	−	**SWAP**
Operator	SWAP	−	×	×	
Repair	Ordered	−	−	−	**Random**
Operator	Random	−	×	×	
Population	30	−	−	−	**50**
Size	50	−	×	×	
Crossover	0.2	−	−	−	**0.6**
Rate	0.6	−	×	×	
Mutation Rate	0.2	−	−	−	**0.6**
	0.6	−	×	×	

5.3 Termination

The number of generations is another critical GA design parameter that we examine by studying

solution convergence. Figure 5 displays the convergence results for the same set of small,

medium, and large size problems. Based on these results, we set 20,000 generations as the

termination rule for our GA approach. Although the objective function value may further

improve after 20,000 generations, additional generations do not appear to result in practical

improvement of the objective function value.
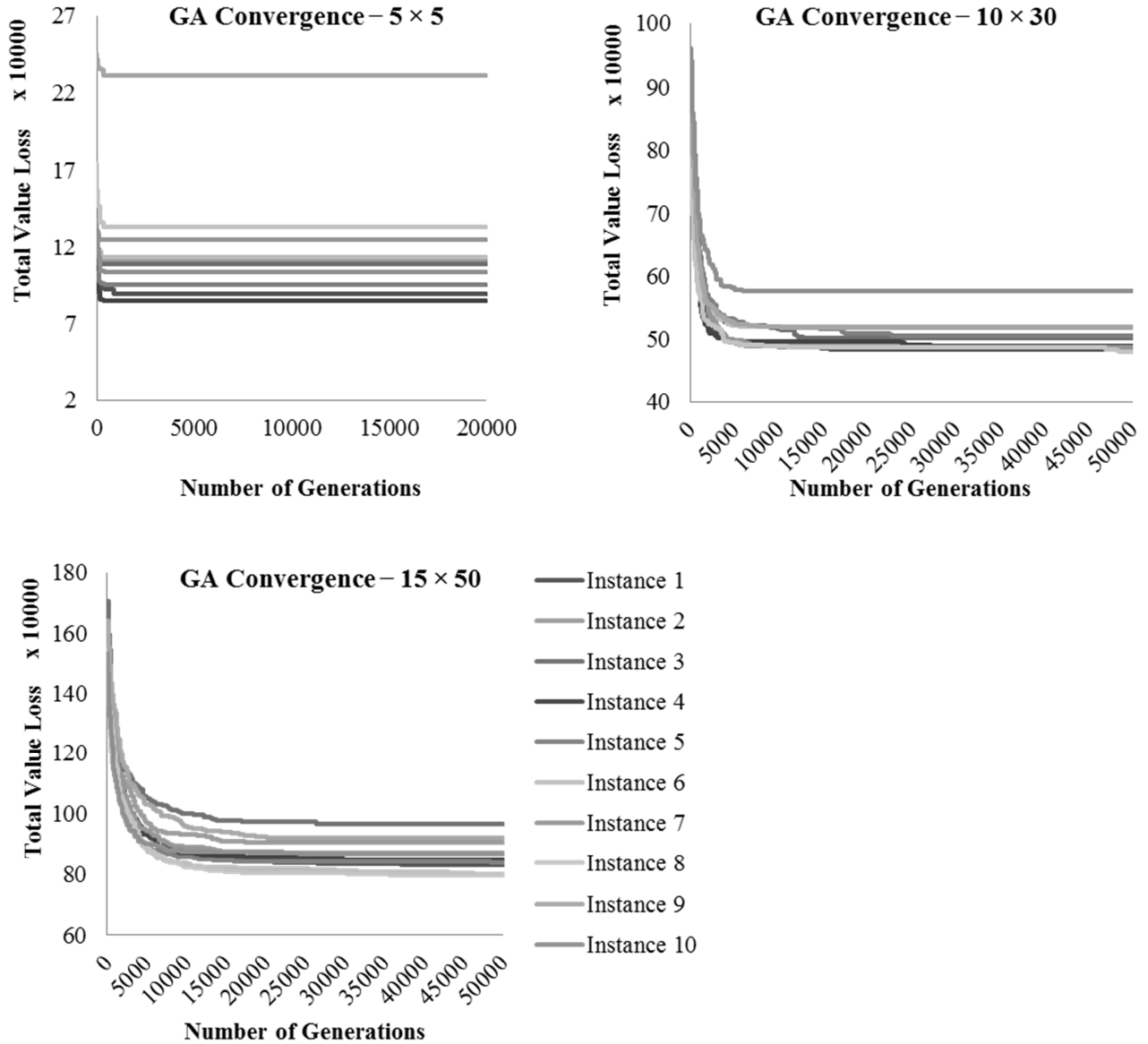
Figure 5 GA Convergence Results for Small, Medium and Large Size Problems

5.4 Longest Common Subsequence GA

To avoid the necessary step of repairing structurally infeasible child solutions, we develop a

second GA approach that employs a Longest Common Subsequence (LCS) crossover operator to

prevent the occurrence of structurally infeasible chromosomes (Iyer and Saxena, 2004). All

other GA design operators and parameters are identical to our Traditional GA approach as

discussed earlier in this section. The LCS crossover operator preserves the relative positions of the parents' genes to generate structurally feasible child chromosomes. Our CPTAP chromosome can easily consist of more than 70 genes, which makes it difficult to quickly identify the LCS. Iyer and Saxena (2004) suggest a dynamic programming approach to identify LCS efficiently, which is an exponential-time recursive algorithm developed by Cormen et al. (2009). We construct and employ a recursive algorithm to compute the length and constitution of the LCS of our parent chromosomes. The performance of our LCS GA approach is compared to our Traditional GA approach in Section 6.4.

6. CPTAP Results

6.1 Scenario Generation

All experimental instances are systematically generated from freight data collected from the Upper Mississippi River. Depicted in Figure 6, the study region is a 154-mile section of the Upper Mississippi River, starting from L/D No. 14 near Davenport, Iowa to L/D No. 19 in Keokuk, Iowa. This inland waterway segment includes six L/Ds, nine bridges, and nineteen active terminals with offload capacity and railway access.
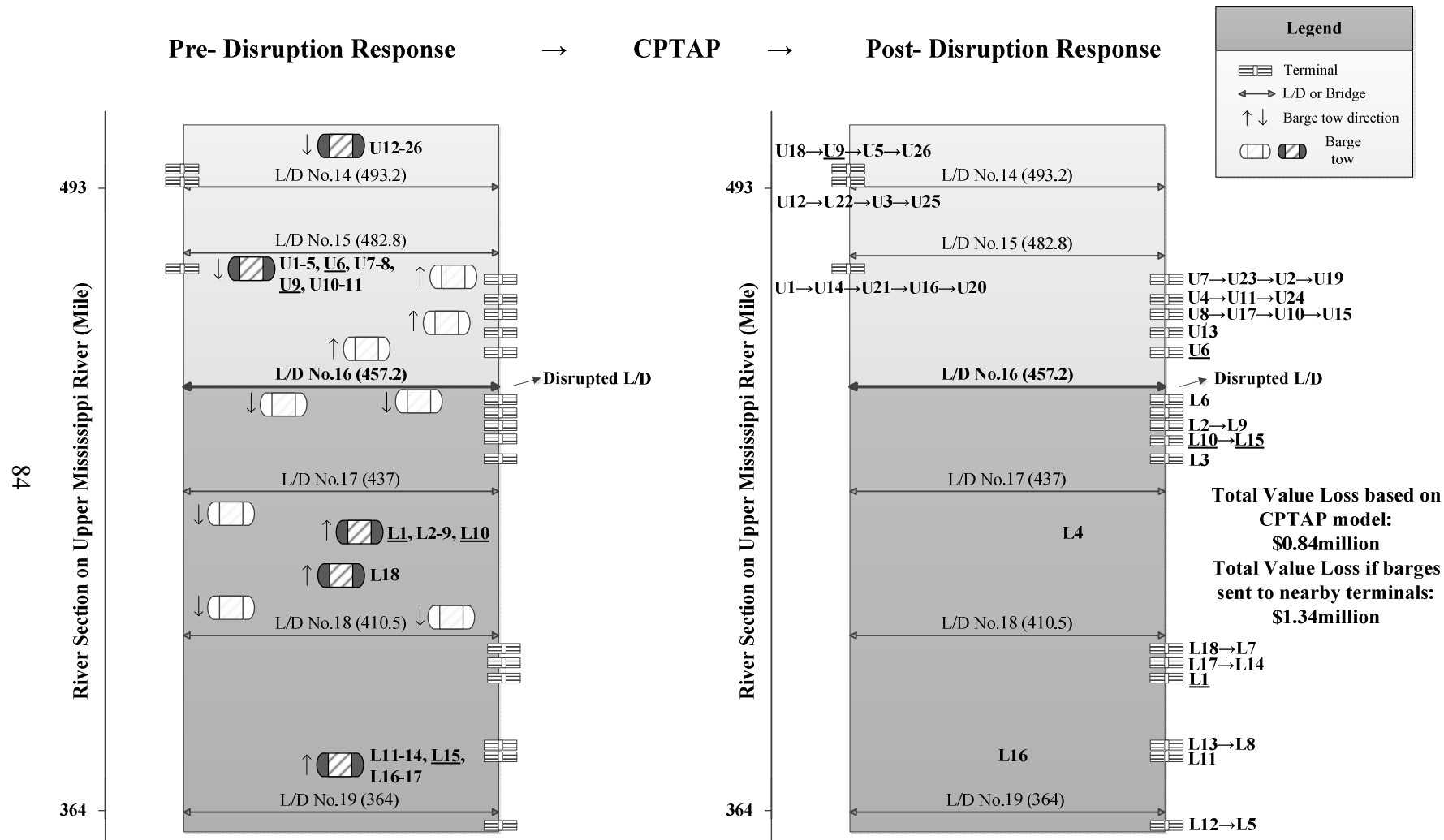
Figure 6 Upper Mississippi River Disruption Pre- and Post- CPTAP Response

Based on the number of terminals in the instances and their corresponding locations, barge locations are uniformly distributed across the study region. The average barge speed is assumed to be five miles per hour. Based on the barge and terminal locations and barge speed, we calculate the water transport time of each barge from its current location to each terminal. The offload time and land transport time which correspond to each pair of barge and terminal assignments are uniformly distributed as five to ten hours and eighteen to ninety-six hours respectively. Table 3 displays the two-digit USACE commodity type classification and their 2012 tonnage data for this region. The probability density function of the cargo commodity type is estimated from this data and used to set the commodity type of the cargo carried by each barge. We assume that 100% of the petroleum and 50% of the chemicals are hazardous cargoes as is generally accepted. Cargo volume is assumed to be 1000 tons per barge, and terminal capacity is assumed to be 5000 tons for each commodity type. The probability density function of barge draft is estimated from the draft data of vessel trips published on the USACE Navigation Data Center (USACE, 2012) and used to determine the draft depth for each barge in the scenario. The barge draft generally ranges between six and fourteen feet. The safety level and sinking threshold parameters are set to one foot and 90% respectively.

Given the barge volume of 1000 tons, we are able to calculate a value decreasing rate per 1000 tons per hour for each commodity type. Hazardous cargoes (Petroleum and Chemicals) are given the highest value decreasing rates ($600 per 1000 tons per hour) which depict their high economic value as well as their unstable and hazardous features which may negatively impact society. Nonhazardous Chemicals and perishable products (Food and Farm Products) have the second highest value decreasing rates ($400 per 1000 tons per hour), followed by Crude Materials ($300 per barge per hour) and Primary Manufactured Goods ($300 per 1000 tons per

hour). Coal is assigned the lowest value decreasing rate ($100 per 1000 tons per hour) given its comparatively stable value function. The total cargo value of each barge is estimated by multiplying its cargo volume and an estimated market price of the cargo. The market prices are assumed to be $403.39 for Petroleum, $36.29 per ton for Coal, $399.88 per ton for Chemicals, $134.61 per ton for Crude Materials, $396.45 per ton for Primary Manufactured Goods, and $164.52 per ton for Food and Farm Products, which are based on data from the International Monetary Fund, U.S. Energy Information Administration, Alibaba.com and other multiple open sources.

Table 3 Commodity Types and Tonnage Data on the Study Area (USACE, 2012)

Two-digit Code	Cargo Commodity Type	Tonnage Data
10	Coal, Lignite and Coal Coke	10288.25
20	Petroleum and Petroleum Products	1238.20
30	Chemicals and Related Product	18331.33
40	Crude Materials, Inedible, Except Fuels	11364.99
50	Primary Manufactured Goods	7843.58
60	Food and Farm Products	58670.63

6.2 Scenario Demonstration

We apply CPTAP and our Traditional GA approach to the realistic scenario of an Upper Mississippi River disruption shown in Figure 6. Six lock and dam systems and nineteen accessible terminals are located on this 154-mile inland waterway section. Thirteen barge tows are traveling along the river section as shown in Table 4. A disruption occurs at L/D No. 16, and vessels can no longer travel up or down the river past this point. Eight of these barge tows (shaded in white) are beyond and traveling away from the disruption point and are therefore not impacted by the disruption. Five barge tows (shaded in black) consisting of forty-four barges in total (twenty-six barges above the disruption and eighteen barges below the disruption) were

traveling towards and beyond the disruption point and are relevant to the disruption response effort. The other data inputs are discussed in Section 6.1.

Table 4 CPTAP River Scenario

Barge Tow Number	Barge Tow Location (River Mile)	Number of Barges	Direction
1	427.628	10	up
2	373.287	7	up
3	461.480	1	up
4	469.610	5	up
5	422.644	1	up
6	476.220	2	up
7	454.999	15	down
8	416.198	15	down
9	455.260	15	down
10	478.187	11	down
11	502.731	15	down
12	415.752	12	down
13	427.778	15	down

Figure 6 displays barges on the disrupted river section pre- (on left) and post- (on right) response. Since river traffic is halted at L/D No. 16 and no barge tows can travel beyond this point, the decision becomes two separate CPTAP sub-problems, one above (Upper, shaded in light gray) and one below (Lower, shaded in dark gray) the disruption point. To respond to the entire disruption, CPTAP is applied independently to the Upper and Lower sub-problems. The barge tows present at the time of disruption range from one to fifteen barges as shown on the left side of Figure 6, and each barge is numbered, denoted as contained in the Upper (U) or Lower (L) sub-problem, and underlined if the barge is carrying hazardous cargo. The right side of Figure 6 illustrates the river segment after CPTAP has been employed. Observing the post-response river segment, we see that all barge tows are assigned and offloaded at terminals in the indicated priority order with the exception of Barges L4 and L16 which remain on the waterway during the

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response effort because their draft depth exceeds the accessible terminals' water depths. The barge terminal and offload order is further displayed in Figure 7. Here we observe that all hazardous cargo is offloaded with early priority and non-hazardous cargo is offloaded in accordance with their commodity-based value decreasing rate with high decreasing rate cargo offloaded earlier than commodities with lower value decreasing rates. The total response time to complete the water transport and cargo offloading in the Upper and Lower river sections are 39.3 and 25.5 hours respectively, by which time the unaffected barge tows (shaded in white) have traveled outside of the response area and are no longer visible on the right side of Figure 6. The combined objective function values of the Upper and Lower CPTAP sub-problems result a total value loss of $0.84 million. To emulate a human decision surrogate solution, we employ a minimum distance integer program solved in AMPL-CPLEX to assign barges to their nearest feasible terminal. This naïve approach results in a higher total value loss of $1.34 million and a greater response time.
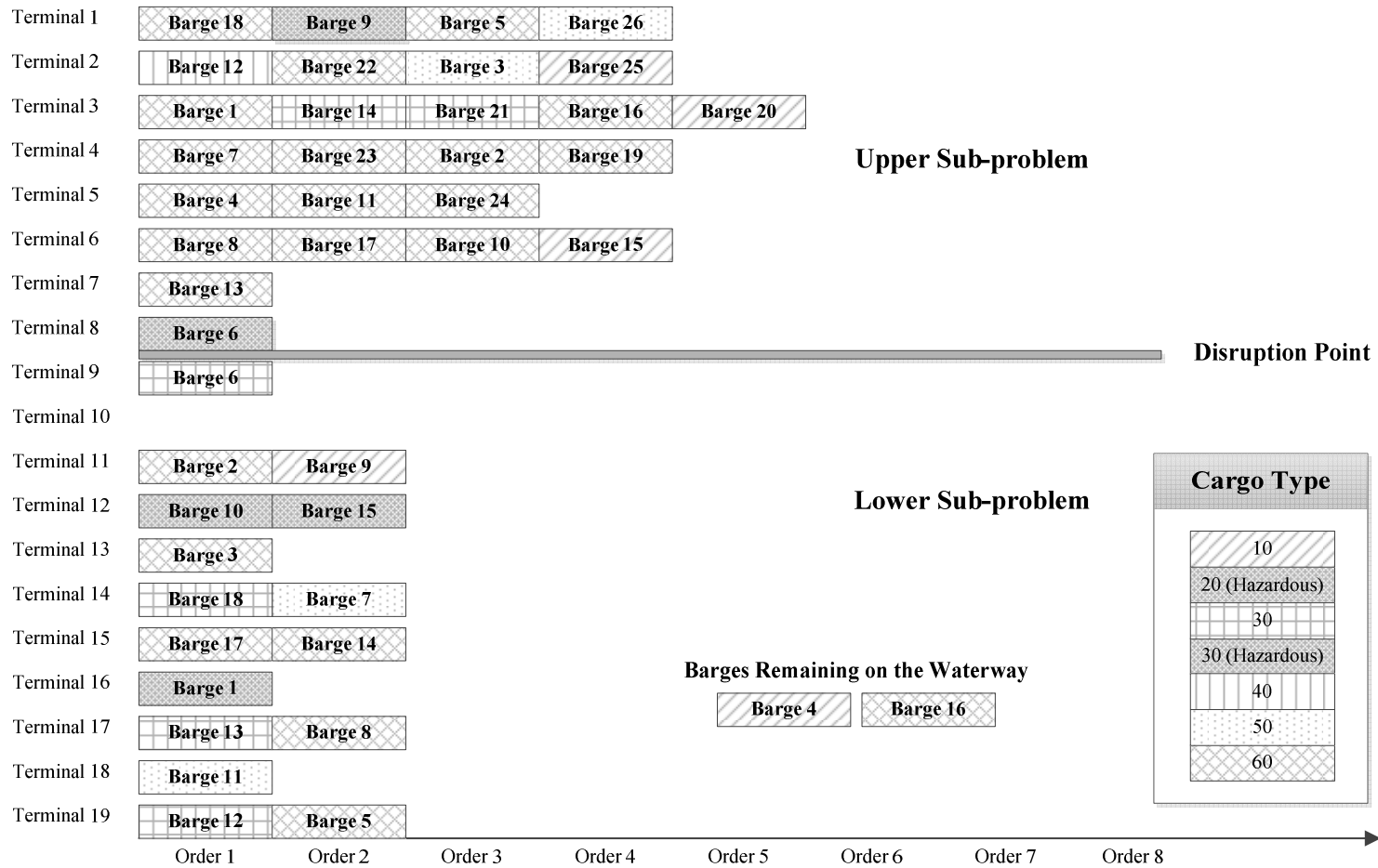
Figure 7 Cargo Prioritization Results at Each Terminal

6.3 Sensitivity Analysis

To examine how the sinking threshold p and value decreasing rate α parameters impact the CPTAP results, we conduct a sensitivity analysis on a realistic scenario with ten terminals and thirty barges. Figure 8 shows how the total value loss and the number of barges that remain on the waterway vary under three parameter settings of p (0.9, 0.8, and 0.7) and α ($\alpha \times 1$, $\alpha \times 2$, and $\alpha \times 3$). We observe that the total value loss increases with each increase of the value decreasing rate parameter setting, and while total value loss is the same for the 0.9 and 0.8 sinking threshold settings, it is observed to increase when a lower sinking threshold of 0.7 is employed. Regardless of the value of p, the number of barges that remain on the waterway does not change for value decreasing rates of $\alpha \times 1$ and $\alpha \times 2$. However, we observe a sharp increase in the number of barges that remain on the waterway when a high value decreasing rate of $\alpha \times 3$ is employed. While initiatively a cargo owner or shipper may be in favor of a low sinking threshold p assuming that more barge cargo will be offloaded and transported via an alternative land-based mode, in contrast we observe that a lower sinking threshold leads to a higher total value loss and more barges remaining on the waterway. When a lower sinking threshold is employed, barge cargoes exceed their offloading opportunity more frequently resulting in more barges remaining on the waterway and losing their total value since customer demand is met through other means, which in turn increases the total value loss of the disruption.

Sensitive Analysis − 10 × 30
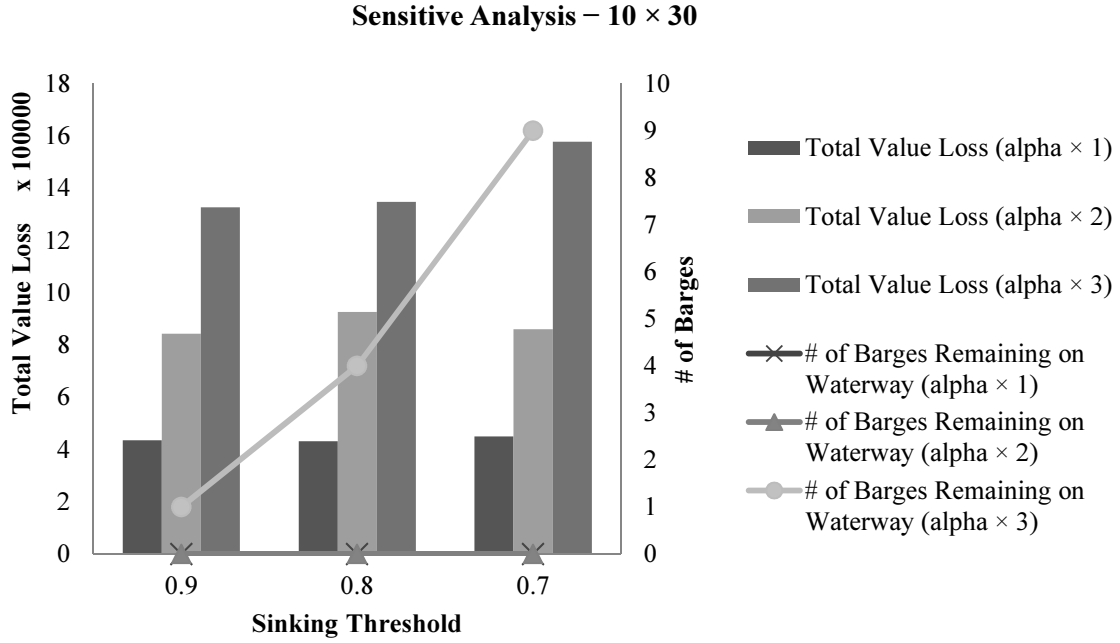
Figure 8 Sensitivity Analysis

6.4 Experimental Comparison

Here we present and compare the experimental results of our CPTAP solution approaches. Our

Traditional and LCS GA approaches are executed and experimental instances are generated

using "C++" code. AMPL/Knitro is used to find the lower bound (LB) of relatively small size

problem instances. Both AMPL/Knitro and C++ are run on a Dell Intel Core i7 CPU with

4.00GB of RAM. We employ total enumeration through MATLAB R2011a and the high

performance computers of the _____ High Performance Computing Center at the University of

_____ to obtain optimal solutions of small problem instances. We define problem size as the

number of terminals plus the number of barges. Optimal solutions can be found for problems of

size thirteen or less through total enumeration before memory capacity problems occur. Because

the actual contributing time a_{ij} of a given barge depends on any and all barges that are assigned

to the same terminal with an earlier priority, the complexity of CPTAP rapidly increases as the

problem size increases. By replacing the accurate a_{ij} with an overestimated contributing time equal to the sum of the barge's water transport time, handling time, and land transport time, we can generate the LB of the optimal solution of CPTAP model through a NLIP solved with AMPL/Knitro for problems of size fourteen or less. A linearization of the problem is possible for small size problems; however the necessity to generate the a_{ij} matrix for all possible prioritization assignment prohibits its use on problems that even begin to approach the size of a real world disruption scenario.

Table 5 compares the numerical results for five problem sizes (number of terminals plus number of barges): ten (5+5), twelve (5+7), fourteen (5+9), forty (10+30), and sixty-five (15+50). The presented results include the optimal total value loss (Opt) found through total enumeration (sizes ten and twelve), the LB found through NLIP (sizes ten, twelve, and fourteen) and the average total value loss (Obj) of multiple runs consisting of the best solution obtained from multiple instances within each run obtained by the Traditional GA (all sizes) and LCS GA (all sizes).

The estimated gaps between the LB (lb) and the optimal solution $c(s^*)$, the GA solution $c(s^H)$ and the optimal solution, the GA solution and the LB, and the LCS GA solution $c(s^{HL})$ and the Traditional GA solution $c(s^{HT})$ are computed with Equations 10, 11, 12 and 13 respectively and shown in Table 5.

$$Gap = \frac{lb - c(s^*)}{c(s^*)} \times 100\%. \tag{10}$$

$$Gap = \frac{c(s^H) - c(s^*)}{c(s^*)} \times 100\%. \tag{11}$$

$$Gap = \frac{c(s^H) - lb}{lb} \times 100\%. \tag{12}$$

$$Gap = \frac{c(s^{HL}) - c(s^{HT})}{c(s^{HT})} \times 100\%. \tag{13}$$

Both GA approaches find the optimal solution in all size ten and twelve problem instances. For size fourteen problem instances, the Traditional GA and LCS GA approaches result in a gap of 11.1% from the LB. The LCS GA approach results in a slightly worse average objective function value (<1% gap) than the Traditional GA for size forty and sixty-five problems with a longer CPU time. The LCS GA approach also exhibits a higher worst-case minimum objective function value (1.5% gap) and larger standard deviation (15.5% gap) on average compared to Traditional GA approach for size sixty-five problems. All CPU times shown fall well within an acceptable time range for a real-life disruption scenario response. Based on the need to solve problems much larger than size thirteen and slightly better performance, the Traditional GA approach is selected as the recommended CPTAP solution approach.

Table 5 CPTAP Experimental Comparison

# of Terminals + # of Barges	Problem Size	# of instances/ runs	Opt ($)	NLIP		GA Approach					
				LB ($)	Gap (%)	Traditional GA			LCS GA		
						Obj ($)	Gap (%)	CPU (s)	Obj ($)	Gap (%)	CPU (s)
(5+5)	10	5/10	97969	93645	-4.4	97969	0	8.63	97969	0	10.22
(5+7)	12	5/10	105082	96558	-4.4	105082	0	9.34	105082	0	11.65
(5+9)	14	5/10	−	139196	−	154648	11.1	11.58	154648	11.1	12.68
(10+30)	40	10/10	−		−	501801	−	37.57	503102	0.26	51.42
(15+50)	65	30/10	−		−	817102	−	192.55	819048	0.24	208.38

7. Conclusions

The contributions of this paper to the literature include a systematic review of cargo prioritization methods and factors and the first systematic approach to cargo prioritization and terminal allocation during disruption response for the inland waterway navigation system. We develop CPTAP to provide decision support for disruption response stakeholders in order to minimize the total value loss of cargo disruptions on the inland waterways. In addition, CPTAP can be employed in pre-event planning by assessing the resiliency of the inland waterway transportation system to handle potentially disrupted cargo based on the existing commodity capacity of the offload terminals and alternative modes of land-based transportation. The CPTAP framework is established through literature review and frequent guidance from the USCG and USACE. An important merit of CPTAP is that it considers several important factors that influence the cargo prioritization decision such as terminal capacity and barge characteristics in an objective and quantitative manner and handles the intricacies of the U.S. inland waterway transportation system. Two GA approaches are developed and tested on small, medium, and large problem instances that capture real-world data and features with respect to vessel location, cargo, economic value, and terminals. The recommended Traditional GA approach obtains prioritization decisions efficiently (in terms of CPU solution time) and effectively (in terms of consistency with assumptions and optimality on small problems). A realistic disrupted river scenario is tested, and the total value loss difference between CPTAP and a naïve minimum distance approach is substantially less. CPTAP can assist responsible parties in responding promptly to inland waterway disruptions with system-level efficient barge-terminal assignments that consider economic and societal impacts.

The work presented here is part of a larger project conducted by the University _____ and University _____ to develop a prototype decision support system for the U.S. Department of Homeland Security that will integrate geographic information system technology with the overall goal to provide timely knowledge and awareness of what cargoes should be prioritized for offloading during disruption response and what infrastructure exhibits low resiliency in terms of modal capacity to potential attacks or natural disasters against inland waterway transportation systems. Future work includes: 1) involving additional real-world system attributes to the model, e.g., time windows could be incorporated to consider expected cargo arrival dates; 2) examining additional solution approaches for the CPTAP model such as Tabu Search, network representation, and memetic algorithm approaches; 3) evaluating the resiliency of the inland waterway system to handle hazardous and high volume cargo and guide investment towards increasing capacity at key terminals by investigating where increased capacity of the terminals best mitigates system value loss; and 4) developing a scalability plan for expanding the decision support system throughout the U.S. inland waterway transportation system.

Appendix 1

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"Cargo prioritization and terminal allocation problem for inland waterway disruptions"

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5. A TABU SEARCH APPROACH TO THE CARGO PRIORITIZATION AND TERMINAL ALLOCATION PROBLEM

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Abstract

To mitigate inland waterway disruption impacts, we develop a tabu search (TS) approach to solve the cargo prioritization and terminal allocation problem (CPTAP) to minimize the total value loss of disrupted barge cargoes. CPTAP is formulated as a nonlinear binary integer program, and problems of realistic size can be efficiently and effectively solved with an efficient heuristic approach. Given different neighborhood structures, multiple TS variants are attempted and compared. Solving CPTAP with our TS heuristic leads to the lowest cargo value loss and the shortest response time for the disrupted barges compared to a genetic algorithm approach and a naïve minimize distance strategy.

Key Words: Maritime Transportation; Inland Waterway; Cargo Prioritization; Tabu Search

1. Introduction

Composed of waterways, rivers, locks and dams, canals, and bridges, the 12,000 navigable miles of United States' inland waterway system (USACE, 2012a) is a crucial transportation mode for moving large quantities of bulk cargo to their destinations. The vast inland waterway transportation system serves thirty-eight States with four major navigation channels –Mississippi River, Ohio River, Gulf Intercoastal Waterway, and Pacific Coast System (ASCE, 2009). In

2013, a total of 2.3 billion tons of domestic and international freight was transported by water (USACE, 2013). Measured by percent of total inland waterborne tonnage, the major commodities transported on the inland waterways are petroleum (41%), coal (14%), and food and farm products (12%) (USACE, 2013). In addition to its low transportation rate, barge transportation is recognized as an environment-friendly and capacity-efficient transportation mode that reduces surface transportation congestion and improves the air quality.

As described in Authors (20##), an unexpected disruption to the inland waterway transportation system due to a natural disaster, vessel accident, or terrorist attack may result in a non-navigable water level or destruction of major navigation infrastructure (e.g. bridges, locks and dams) that shuts down the navigation channel and requires barge cargoes to be offloaded and transported to their final destination via an alternative land-based transportation mode. A barge tow typically consists of nine to fifteen barges, each with the capacity to carry approximately sixty truckloads or fifteen railcar loads of cargo. The disrupted cargo may exceed the existing capacity of accessible terminals and alternative modes of transportation, and the cargo's value diminishes in terms of economic value, societal benefit, and customer satisfaction as response time elapses.

This paper presents a tabu search (TS) approach to the cargo prioritization and terminal allocation problem (CPTAP) which was introduced by Authors (20##) and minimizes the total value loss by optimally prioritizing disrupted barges through consideration of multiple prioritization factors including commodity type, cargo value, terminal capacity, and barge draft. CPTAP is a combinatorial optimization problem that cannot be solved by an exact solution approach under realistic problem size conditions. In our previous work, we formulated CPTAP as a nonlinear binary integer program, and problems of realistic size were efficiently and effectively solved with a genetic algorithm approach (Authors, 20##). The details of CPTAP and

its similarities to the berth allocation problem (BAP) (see original work by Imai et al., 1997; Imai et al., 2001; Imai et al., 2003) are discussed in Authors (20##). CPTAP is a three dimensional assignment problems that involves two decisions, barge/ship-to-terminal/berth assignment and offload/service order at the terminal/berth, and the elapsed time of a barge/ship that is incorporated into the objective function partially depends on its predecessors (Authors, 20##).

We were motivated to explore TS as a solution approach to CPTAP primarily for two reasons: 1) two principles guide the development of metaheuristics, population search and local search (Cordeau et al., 2002). Our prior work employed a population search strategy, a GA-based heuristic that recombines a number of parent solutions to generate child solutions. The TS heuristic is a local search strategy which obtains new solutions through a neighborhood search. Our investigation of the CPTAP TS heuristic will reveal the performance of a local search solution approach to CPTAP and enable us to compare these two principles for CPTAP in terms of the solution quality, computational efforts and robustness, and 2) CPTAP has similarities to BAP, and TS has been successfully applied to BAP as evidenced by the literature (Cordeau et al., 2005; Meisel and Bierwirth, 2009; Giallombardo et al., 2010).

As a local search metaheuristic, TS examines the solution space by conducting a neighborhood search based on the current solution, picking up the best found solution according to a penalized cost function, and then searching the neighborhood of the new solution. The new solution may not be a feasible solution but could be admitted to allow for exploration of its neighborhood space. Cycling of a set of solutions may occur since the selection of current solution does not follow a fixed path such as increasing/decreasing objective function values. Therefore, a tabu mechanism is used to store the solution modifications in previous steps, and these modifications are not allowed in the next couple of iterations in order to avoid exploring investigated space

repeatedly (Braysy and Gendreau, 2005; Taillard et al., 2001). TS heuristic has been widely applied to many problem settings, among which the vehicle routing problem (VRP) is one of the most popular problems where TS is implemented as a solution approach.

The contribution of this work is to develop and evaluate a TS heuristic that comprises its characteristics discussed above for a relatively new problem – CPTAP. We identify a most suitable TS approach for CPTAP, the Unified TS heuristic (Cordeau et al., 2001), among the many TS heuristics found in literature. We present three neighborhood structures for the TS and examine which is most efficient for solving CPTAP in terms of solution quality and computation time. In addition we compare our best TS CPTAP approach to two other cargo prioritization strategies (CPTAP solved by GA heuristic (Authors, 20##) and a simple minimize distance strategy) and verify the effectiveness of the TS CPTAP solution approach.

The structure of the paper is organized as follows: Section 2 provides the detailed description of the CPTAP and introduces the mathematical model of the problem. Sections 3 and 4 summarize the relevant TS literature, present a flow chart of the proposed heuristic and describe its major components. Section 5 and 6 respectively discuss the parameter setting and experimental work for our TS heuristic. Section 7 compares the multiple cargo prioritization strategies. We conclude the work in Section 8 and discuss future work in this area.

2. CPTAP Description and Model Formulation

As previously described in Manuscript Authors (20##), CPTAP is graphically represented in Figure 1 through the depiction of a recent inland waterway disruption event:

- On January 20, 2014, a railroad bridge over the Arkansas River suffered a mechanical failure which halted all barge traffic on that section of the river (Magsam and McGeeney, 2014).

Five locks and dams (L/Ds) serve that river section, and ten terminals are located along both sides of the river (locations shown in Figure 1). Each terminal is capable of offloading specific commodity types of cargo depending on its handling facilities.

- According to the USACE Lock Performance Monitoring System (2014), eight barge tows, commonly consisting of nine to fifteen barges each, were traveling up and down the disrupted river section at the time of the event as shown in Figure 1. Since the disruption prohibits barge traffic at the bridge location, the six barge tows (consisting of approximately 60 disrupted barges) that are traveling towards and beyond the damaged bridge (shaded in black) are disrupted and need to be prioritized and redirected through implementation of CPTAP. The two barge tows that have already passed under the damaged bridge and are traveling away from the disruption point (shaded in white) are not impacted.

- Since the disrupted barges are no longer able to travel to their original designation along the disrupted inland waterway, CPTAP determines an accessible terminal for offloading and rerouting the cargo on each disrupted barge and the barge's offload order at the designated terminal since more than one barge may be sent to a given terminal. Because the disruption has effectively divided the inland waterway into two sections, CPTAP is typically employed twice, once for disrupted barges located on the river above the disruption and once for disrupted barges located on the river below the bridge.

Legend

Terminal Barge tow

L/D or Bridge

★ Hazardous cargo

● Non-hazardous cargo

↑↓ Barge tow direction

W.D. Mayo L/D

Broken Bridge

James W. Trimble L/D

Murray L/D

Emmett Sanders L/D

Wilbur D. Mills L/D

Figure 1 Arkansas River Disruption (Authors, 20##)

The widely-studied BAP shares a similar decision structure to our CPTAP, and the original work

in BAP supported the development of our model formulation (Imai et al., 1997; Imai et al., 2001;

Nishimura et al., 2001; Imai et al., 2003). The focus of CPTAP is to assign barges to terminals

with consideration of cargo offloading priorities at a terminal while BAP assign vessels to berths

with consideration of vessel ordering at a berth. We adopt the three dimensional decision

variable that is a common variable type in BAP papers and adapt some of the constraints found

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in BAP literature (Imai et al., 1997; Imai et al., 2001; Nishimura et al., 2001; Imai et al., 2003) to develop our CPTAP model formulation (constraint sets (2), (3), (4) and (7)).

The sets, variables and parameters of CPTAP formulation are described as follows (Authors, 20##):

Sets
J – Set of barges with non-hazardous cargo
H – Set of barges with hazardous cargo
I – Set of real terminals
D – Set of dummy terminal (one)
K – Set of barge orders at a given terminal
N – Set of commodity cargo types

Decision variables
$x_{ijk} \in \{0, 1\}$ 1 if barge j is assigned to terminal i in the kth order; 0 otherwise

Parameters
t_{ij} Water transport time of barge j from its location at the time of disruption to terminal i
h_{ij} Handling time of barge j at terminal i
a_{ij} Actual contributing time of barge j that is assigned to terminal i in the kth order
r_{ij} Land transport time of barge j cargo from terminal i to its final destination by alternative mode of transportation
α_j Value decreasing rate of barge j cargo per unit volume per unit time
u_{in} Offload capacity for cargo n at terminal i during the disruption response
c_j Cargo volume on barge j
w_i Water depth at terminal i
d_j Draft depth of barge j
e_{jn} 1 if barge j carries cargo n; 0 otherwise
s Safety level

v_j Total value of barge j cargo

p Sinking threshold

$$a_{ij} = \begin{cases} t_{ij} + h_{ij} & k = 1 \\ h_{ij} & k \neq 1 \quad t_{ij} \leq \sum_{m \in J \cup H} \sum_{k \in K-1} a_{im} \\ t_{ij} + h_{ij} - \sum_{m \in J+H} \sum_{k \in K-1} a_{im} & k \neq 1 \quad t_{ij} > \sum_{m \in J \cup H} \sum_{k \in K-1} a_{im} \end{cases} \quad (1)$$

The CPTAP is formulated as a nonlinear integer program (NLIP) as follows (Authors, 20##):

Min

$$\sum_{i \in I} \sum_{j \in J \cup H} \sum_{k \in K} \left\{ \left(\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij} \right) c_j \alpha_j x_{ijk} \right\} + \sum_{i \in D} \sum_{j \in J} \sum_{k \in K} v_j x_{ijk}$$

s.t.

$$\sum_{i \in I \cup D} \sum_{k \in K} x_{ijk} = 1 \qquad\qquad \forall j \in J \qquad\qquad (2)$$

$$\sum_{i \in I} \sum_{k \in K} x_{ijk} = 1 \qquad\qquad \forall j \in H \qquad\qquad (3)$$

$$\sum_{j \in J \cup H} x_{ijk} \leq 1 \qquad\qquad \forall i \in I, k \in K \qquad\qquad (4)$$

$$\sum_{j \in J \cup H} x_{ijk} \geq \sum_{j \in J \cup H} x_{ij(k+1)} \qquad\qquad \forall i \in I \cup D, k \in K/|K| \quad (5)$$

$$\sum_{j \in J \cup H} \sum_{k \in K} c_j e_{jn} x_{ijk} \leq u_{in} \qquad\qquad \forall i \in I \cup D, n \in N \qquad\qquad (6)$$

$$\sum_{i \in I} \sum_{k \in K} (w_i - d_j) x_{ijk} \geq s \qquad\qquad \forall j \in J \cup H \qquad\qquad (7)$$

$$\sum_{i \in I} \sum_{k \in K} \left\{ \left(\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij} \right) c_j \alpha_j x_{ijk} \right\} \leq v_j p \quad \forall j \in J \cup H \qquad (8)$$

$$x_{ijk} \in \{0,1\} \qquad\qquad \forall i \in I \cup D, k \in K, j \in J \cup H \quad (9)$$

Constraints that are actively involved into the TS process are the capacity constraint set (6), draft constraint set (7), and value loss constraint set (8). Additional explanation of the model and associated assumptions can be found in Authors (20##).

3. Literature Review

We investigated papers that employ a TS heuristic to solve the BAP and VRP. The BAP TS literature was most valuable in developing our TS heuristic since it has the similar framework with CTPAP. However, since a limited number of BAP papers focus on the TS heuristic, we extended our literature review to include the VRP literature because considerable papers have investigated TS implementation in VRP.

TS in BAP

Cordeau et al. (2005) proposed a new formulation approach for the discrete berth allocation problem (BAP) – the multi-depot VRP with time windows (MDVRPTW) formulation which handles the weighted sum of the service times and the time windows of the berthing times. They employed a TS heuristic to solve the discrete case with an extension for the continuous BAP, which is capable of obtaining optimal solutions for small size instances and better solutions for large size instances when compared to a truncated branch-and-bound algorithm. Meisel and Bierwirth (2009) integrated the BAP and crane assignment problem (BACAP) to provide an integer linear program model that incorporates the practical impact of the crane resources on the handling time. Both squeaky wheel optimization and TS heuristic are employed and compared in solving a set of benchmark problems. Giallombardo et al. (2010) studied the BACAP as a mixed integer linear program formulation where TS is used to solve their BAP decision (adapted from Cordeau et al., 2005) and obtains good solutions within a satisfactory amount of time.

TS in VRP

A steady, thorough, and extensive evolution of VRP heuristics has been observed in the last forty years, among which the TS heuristic is identified as one of the best metaheuristics for the VRP (Cordeau and Laporte, 2005; Taillard et al., 2001). More than fifty papers have been published

on this topic since the first TS implementation to the VRP in 1989 (Laporte, 2009). Multiple survey papers have summarized the TS literature in VRP (Eksioglu et al., 2009; Laporte, 2009; Braysy and Gendreau, 2005; Cordeau, et al., 2002; Cordeau and Laporte, 2005) and identified TS as a competitive metaheuristic method to solve VRP. Some researchers consider TS to be the best metaheuristic method for solving the VRP (Cordeau, et al., 2002). Nine papers were found to be the most informative to our work and are summarized in Table 1. Among these TS heuristics, the Unified TS is chosen as the most suitable TS method for CPTAP due to its proved efficiency, robustness (small number of parameters to be determined), and compatibility to our CPTAP structure.

Table 1 Comparison of Select TS VRP Literature

TS Approach	Author(s)	Year	VRP Type(s)	Unique Feature(s)
Unified TS	Cordeau et al.	1997	Periodic VRP & Multi-depot VRP	• Generate one initial solution irrespective of feasibility • Employ the penalized function with self-adjusting coefficients • Use limited user-controlled parameters
	Cordeau et al.	2001	Multi-depot VRP with Time Windows (VRPTW)	• Apply a very simple exchange procedure for a predetermined number of iterations
	Cote and Potvin	2009	VRP with Private Fleet and Common Carrier (VRPPC)	• Use a union of two neighborhoods as the neighborhood structure
Taburoute TS	Gendreau et al.	1994	VRP	• Include a generalized insertion routine procedure to periodically improve the tours of the solution in order to decrease the chance of being trapped in a local optimum
	Gendreau et al.	2008	Capacitated VRP with Two-dimensional Weighted Item (2L-CVRP)	• Use constraints to express the two-dimensional loading feature of the items • Accept moves that cause the infeasibility of either weight constraints or loading constraints
TS with Adaptive Memory Procedure	Rochat and Taillard	1995	Capacitated VRP (CVRP)	• Generate multiple initial solutions to form a solution pool which produces a number of tours • Extract tours according to a probabilistic technique to form a new solution
	Tarantilis	2005	Capacitated VRP (CVRP)	• Utilize the sequence of nodes to create the new solution instead of extracting and combining routes • Select the elite parts according to deterministic selection criteria rather than the probabilistic routes selection
Other TS	Wassan et al.	2008	VRP with Pickups and Deliveries (VRPPD)	• Create an innovative procedure to check the feasibility of the insertions without increasing the computational complexity of the neighborhood search
	Bolduc et al.	2010	VRP with Production and Demand Calendars (VRPPDC)	• Employ two new neighbor reduction strategies • Include an improvement phase after the tabu iterations are completed

4. Tabu Search Heuristic for CPTAP

In this section, we describe our CPTAP TS heuristic. The general CPTAP TS framework is developed from the Unified TS proposed by Cordeau et al. (2001). We adapt their heuristic according to the characteristics of CPTAP and consider additional heuristic design components including two potential initial solution generation approaches based on the CPTAP solution structure, three possible neighborhood structures to select the best neighborhood scheme, two alternative tabu management approaches, and possible incorporation of a post-optimization step utilizing a local swap structure.

4.1 CPTAP Tabu Search Heuristic Flowchart

Figure 2 presents a flowchart of the CPTAP TS heuristic.
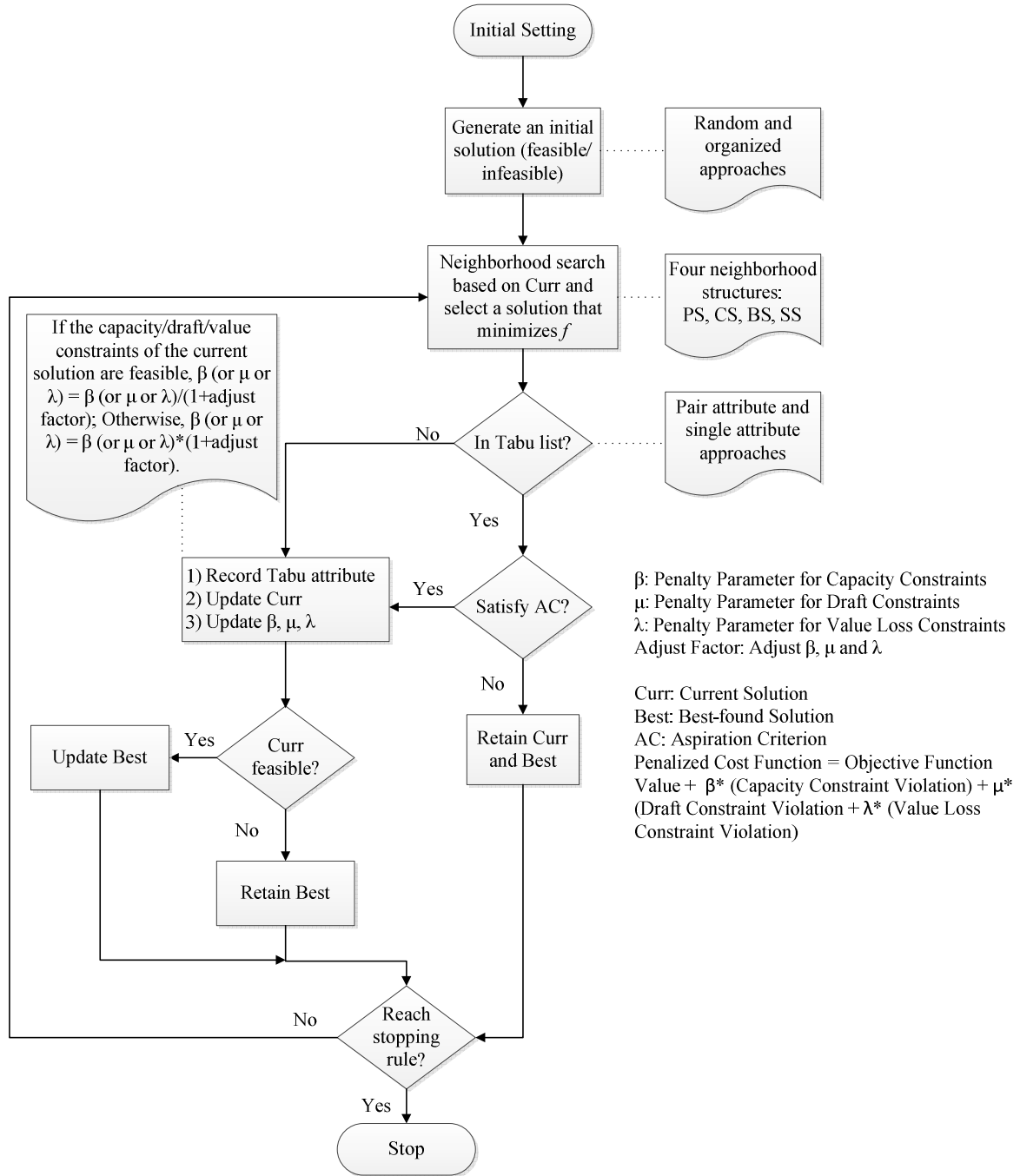
Figure 2 CPTAP TS Flowchart

4.2 Initial Solution

An initial solution is required to start the CPTAP TS search process. This initial solution may be found to be infeasible since our heuristic explores feasible and infeasible solution spaces. Two

methods for generating an initial solution are developed and compared: *Random Generation* (randomly produces a solution without any restriction on the solution structure) and *Organized Generation* (attempts to find a "near-feasible" initial solution that meets the draft constraints (constraint set (7)) and is not likely to violate the capacity constraints (constraint set (6)). The *Organized Generation* approach is more likely to quickly generate a feasible initial solution and is described below:

1. Record the acceptable barges for each terminal in terms of barge draft restriction:

    - For each real terminal i, assign the barges that the terminal can accept according to the draft constraint;

    - For dummy terminal d, assign the barges that carry non-hazardous cargo to the dummy terminal.

2. For $i = 1, \ldots, I - 1$, conduct the following processes:

    - Determine the type of cargo each barge carries;

    - If adding the next barge will cause the capacity violation of a specific cargo type, remove the barge from the assigned terminal; otherwise, keep the barge.

3. Delete the duplicate barges that have appeared in the previous terminals.

Preliminary experimentation indicated that the *Random Generation* produces better CPTAP solutions compared to *Organized Generation* when controlling for the other TS constituents and parameters. Therefore, we will select *Random Generation* as the initial solution generation approach for our CPTAP TS heuristic.

4.3 Penalized Cost Function

In the Unified TS (Cordeau et al., 2001), a penalized cost function is used to evaluate solutions as a replacement for the objective function. Solution x represents a decision result from CPTAP

that could be feasible or infeasible. $f(x)$ denotes the original objective function value (i.e. the total value loss of the disrupted barge cargo); $c(x), d(x)$ and $v(x)$ denote the total violation of the constraint sets – capacity constraint (constraint set (6)), draft constraint (constraint set (7)) and value loss constraint (constraint set (8)). The violated amount of each constraint set is added to the objective function to form the penalized cost function as follows:

$$P(x) = f(x) + \beta c(x) + \mu d(x) + \lambda v(x) \tag{10}$$

Where

$f(x) = \sum_{i \in I} \sum_{j \in J \cup H} \sum_{k \in K} \left\{ \left(\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij} \right) c_j \alpha_j x_{ijk} \right\} + \sum_{i \in D} \sum_{j \in J} \sum_{k \in K} x_{ijk} tv_j;$

$c(x) = \sum_{i \in I \cup D} \sum_{n \in N} \max\{\sum_{j \in J \cup H} \sum_{k \in K} c_j m_{jn} x_{ijk} - u_{in}, 0\};$

$d(x) = \sum_{j \in J \cup H} \max\{s - \sum_{i \in I} \sum_{k \in K} (wd_i - d_j) x_{ijk}, 0\};$

$v(x) = \sum_{j \in J \cup H} \max\{\sum_{i \in I} \sum_{k \in K} \left\{ \left(\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij} \right) c_j \alpha_j x_{ijk} \right\} - tv_j p, 0\};$

β, μ and λ are positive self-adjusting parameters.

Functions $c(x), d(x)$, and $v(x)$ assure that only the violated amounts of the infeasible constraints are penalized in the cost function. The function values of $c(x), d(x)$, and $v(x)$ for a feasible solution are equal to zero. In order to diversify the search space, parameters β, μ, and λ are updated by a positive factor δ according to the current solution. If the current solution is feasible with respect to capacity/draft/value loss constraints, $\beta (\mu \ or \ \lambda) = \beta (\mu \ or \ \lambda)/(1 + \delta)$; otherwise, $\beta (\mu \ or \ \lambda) = \beta (\mu \ or \ \lambda) \times (1 + \delta)$. Explanation of this diversification step is that we tend to penalize the constraint set lightly once a feasible constraint of that constraint set appears. This is because we have reached a feasible area associated with the constraint set so we should extend the search space by allowing the search to reach more infeasible space. On the other hand, if the constraint is infeasible at a given iteration, it means we are already searching the infeasible space relating to that constraint. To ensure we return to a feasible space to produce an acceptable

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solution, we increase the penalty cost to force the search back to a feasible solution. This updating process is carried out at the end of each iteration in order to adapt the search at the next iteration.

4.4 Neighborhood Structure

Neighborhood search is an important step in any TS heuristic as it determines the transition between the current solutions of different iterations (Ceschia et al., 2011). Several papers employing the Unified TS incorporate an insertion step to complete their neighborhood search (Cordeau et al., 1997; Cordeau et al., 2001). Based on the features of our CPTAP model, we consider the following four neighborhood search methods:

a. **Partial Shift (PS):** This neighborhood move is defined by removing a barge j from the current assigned terminal i and reinserting it to another terminal i^* with a random prioritization order k given at the terminal i^*. New current solution candidate set includes moving each barge j to each terminal i^* (other than the original assigned terminal i). The prioritized order at the new terminal is randomly generated in order to reduce the computational effort. Barge j can be reinserted with any order at the last terminal (the dummy terminal) because there is no actual prioritization for barges that stay on the disrupted waterway.

b. **Complete Shift (CS):** The difference between CS and PS is the priority turn the barge takes at the new assigned terminal i^*. Instead of randomly generating the insertion location in PS, the turn that barge j should take in CS is selected by comparing the penalized cost function values for all the potential insertion locations at terminal i^*. Consequently, much more time will be consumed to find a new current solution (Cordeau et al., 2001).

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c. **Blind SWAP Search (BS):** This move takes a liberal perspective on neighborhood search by randomly exchanging two genes in the solution chromosome irrespective of their representation of barge or terminal. BS conducts the exchange on a predetermined number of SWAP pairs.

d. **Switch SWAP Search (SS):** Adapted from BS Search, SS Search exchanges two barges at two different terminals, and the two barges take each other's priority turn as the insertion location. SS conducts the exchange on a predetermined number of SWAP pairs.

Based on preliminary experimentation, we determined that the computational time of the CS may exceed several hours for a realistic size CPTAP instance, which is not acceptable in a decision scenario where prompt response is expected by the decision makers. Therefore we eliminate CS as a viable neighborhood search method for the CPTAP TS heuristic and focus on the other three neighborhood search methods as discussed in Section 6.

4.5 Tabu Management and Aspiration Criterion

In TS, solutions with certain attributes are prohibited from a certain number of iterations in order to avoid cycling around a local minimum (Braysy and Gendreau, 2005). The selection of the attribute (also called tabu management) is critical since it influences the solution selection. Two tabu management approaches are considered in the development of our CPTAP TS heuristic: *Pair Attribute* and *Single Attribute*:

a. **Pair Attribute:** Two elements are included in the Pair Attribute approach. The attribute structures are different for the Shift (CS and PS) and SWAP (BS and SS) neighborhood searches as follows:

- For PS and CS: $A(x) = \{(i, j)$: barge j is offloaded at terminal $i\}$. When a neighborhood move of removing barge j from terminal i and inserting j into terminal

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i^* is completed, the attribute (i, j) is declared *tabu*, which means barge j cannot be reassigned to be offloaded at terminal i for a predefined number of iterations.

- For BS and SS: $A(x) = \{(j, j'): \text{barge } j \text{ and } j' \text{ are exchanged}\}$. Similarly, if attribute (j, j') is recorded in the tabu list, it means the two barges cannot be switched for the next certain number of iterations. A special case in BS is to exchange a value zero (for terminals) instead of a nature number (for barges). Since there are multiple zeroes representing different terminals, we do not include the Pair Attribute into the tabu list if one or both exchanging components are zero.

b. **Single Attribute:** Different from the Pair Attribute that considers two elements in a pairwise fashion, Single Attribute maintains the records of the two elements separately. For example, the Pair Attribute for PS and CS neighborhood search is $A(x) = \{(i, j): \text{barge } j \text{ is offloaded at terminal } i\}$. The translation in Single Attribute is $A(x) = \{(i) \text{ and } (j): \text{barge } j \text{ is offloaded at terminal } i\}$, which means that any solution that relates to the move of barge j or the insertion at terminal i in the following number of iterations based on the tabu list length will not be selected as the current solution.

Preliminary experimentation suggests that the *Pair Attribute* approach performs better than the *Single Attribute* in influencing CPTAP solution quality. Therefore, we select the *Pair Attribute* tabu management approach for the CPTAP TS heuristic.

No matter which attribute is adopted, tabu can be overruled by the aspiration criterion that allows a tabued solution to be accepted. Various definitions of aspiration criterion are introduced in literature, e.g. improving the current best solution (Nguyen et al., 2013) or improving the best feasible/infeasible solution yet found (Brandao, 2009). In our CPTAP TS heuristic, we define the aspiration criterion as a prohibited move is revoked if it is better than the current optimal solution

(the current best feasible solution found). Our employed aspiration criterion ensures that we do not miss a "good" feasible solution that may be hidden by the tabu scheme.

4.6 Post-optimization Step

After obtaining the best-found solution s^* through TS procedures, we consider a post-optimization Local SWAP step after the selection of parameter values and the best neighborhood structure to potentially find a better feasible solution. For a best-found solution s^* (which is feasible), several pairs of barges at each terminal are interchanged to produce a new solution s'. Since the assignment of barges to a terminal is not changed, the capacity and draft constraints are guaranteed to be feasible. However, the new assignment may violate value loss constraints. Therefore, the value loss constraints are checked for the new solution s'. If the solution is still feasible and the new solution s' produces better penalized cost function value, the original best-found solution s^* will be replaced by the new solution s'. Preliminary experimentation suggests a very slight decrease of the objective function value which does not support further consideration of incorporating a post-optimization step into the CPTAP TS heuristic.

5. Parameter Analysis

In this section we set the parameter values of our CPTAP TS heuristic systematically through a one-way sensitive analysis in order to maximize the heuristic's performance. Since the penalty parameters $\beta, \mu,$ and λ will be modified frequently by adjustment factor δ, we focus the analysis on the adjustment factor instead of the initial parameter values. Based on preliminary analysis, the initial penalty parameters $\beta, \mu,$ and λ are set to 10, 100, and 10. A sequential parameter determination approach is employed in the following sequence:

    a. Adjustment factor δ of the penalty parameters

b. Length of tabu list

c. Number of iterations.

Once a parameter's value is set, it is adopted for the reminder of the analysis. As we discussed in Section 4, random generation and pair attribute are employed as the initial solution generation approach and the tabu management method respectively. The size of CPTAP problem instances are classified into small (five terminals and five/seven/nine barges), medium (ten terminals and thirty barges), and large (fifteen terminals and fifty barges). Preliminary analysis indicates that the CPTAP TS heuristic performance on small-sized problems is not sensitive to changes in the parameter settings so we limit our discussion to our sensitivity analysis on medium and large size problems.

5.1 Adjustment Factor

Based on our preliminary experiments and related literature (Cordeau, et al., 1997; Gendreau, et al., 2008), the appropriate value of δ should vary within the range [0.01, 5]. If the value of δ is too small, the heuristic cannot deliver a feasible solution if the search locates a good infeasible area. On the other hand, if the value of δ is too large, the search jumps drastically around the solution area and may prevent the search from investigating consecutive solutions. We consider six values (0.01, 0.05, 0.1, 0.5, 1 and 5) within the interval [0.01, 5]. Ten medium size instances are run ten times under each of the six values of δ, resulting in 100 solutions for each δ value. Maximum, minimum, and average objective function (total value loss) results for each δ value are summarized in the stock charts shown in Figure 3. The upmost point and the downmost point of each vertical line indicate the maximum and minimum solutions among the 100 solutions, while the marker in the middle represents the average solution result. According to Figure 3 results for the medium size instances, the average values obtained when δ is set at 1 or 5 is

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undesirably higher than those found by the lower δ values. Therefore, we reduce the parameter candidate pool to those that fall between 0.01 and 0.5. Appendix 1 displays detailed maximum, minimum, and average objective function results of the medium size problem. When δ is set to 0.05, there are more instances that have the lowest minimum and average results (shaded cells in Appendix 1). In addition, Figure 3 for the medium size instances shows that δ equal to 0.05 produces the smallest solution variance. Therefore, we select 0.05 as the adjustment factor value for medium size problems. The same experiments were conducted on large size CPTAP instances, and we draw the same conclusion that δ should be set to 0.05 (see large size results in Figure 3 and Appendix 1).
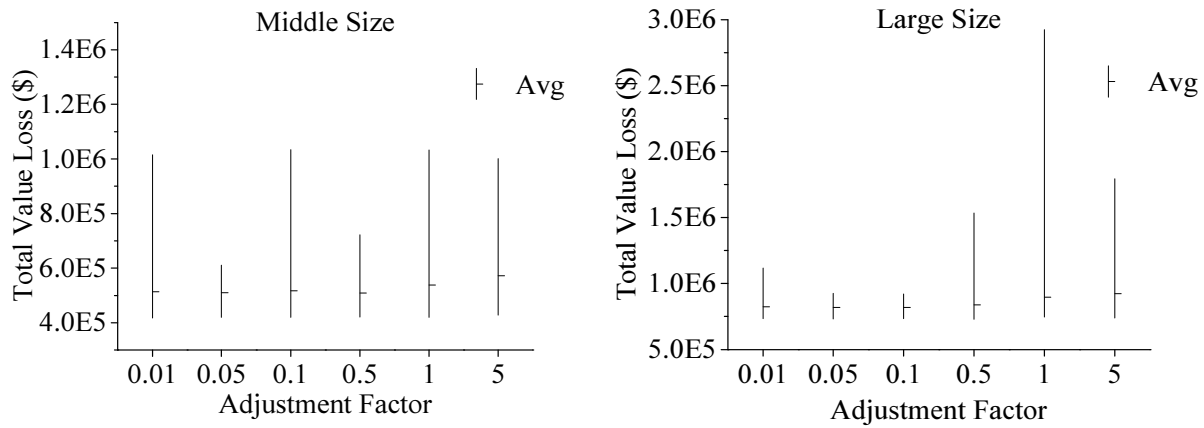
Figure 3 Sensitive Analysis Results of Adjustment Factor δ

5.2 Length of Tabu List

We also conduct a one-way sensitivity analysis on ten instances of medium and large size problems to investigate the length of the tabu list that produces the best quality solutions. Based on preliminary experimentation, we set the tabu list interval as [20, 80] and considered four values as the candidate tabu list lengths (20, 40, 60, and 80). Each instance is run 10 times for each tabu list length value. The average and minimum objective function results among ten runs

are calculated for each instance with each candidate value. Figure 4 summarizes the CPTAP TS heuristic performance for each tabu list length. Because CPTAP is a minimization problem, we want the parameter value that delivers the most instances with minimum objective function value and the minimum average objective function value at the same time. We observe that 20, 40, and 60 tabu list lengths are on the pareto frontier for the medium size instances, and 20 is the only pareto point for the large size instances. Combining the results from the two scenarios displayed in Figure 4, a tabu list length of 20 is selected in order to find the best solution (minimum objective function value) and stay robust (minimum average objective function value).
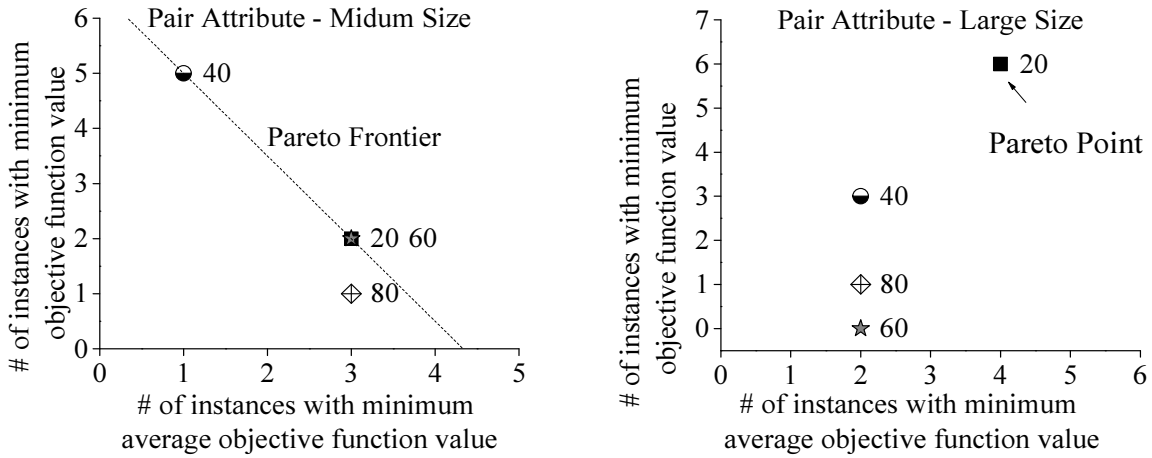
Figure 4 Sensitive Analysis of the Length of Tabu List

5.3 Termination Condition

To determine the stopping rule of the CPTAP TS heuristic, we develop charts of the current and best-found solution values versus the iteration number for one medium size instance and one large size instance as shown in Figure 5. Interesting phenomena that are shown in both problem sizes are: 1) the current solution is generally worse (larger penalized cost function value) than the best solution found so far. It is likely that the current solution is frequently infeasible; therefore its objective function is penalized and larger than the best-found solution, and 2) the best-found

solution is improved dramatically in the first several hundreds of iterations. Then the

improvement slows down with no practical improvement after 4,500 iterations. A number of

local optimum can be identified through the "big" steps of the best-found solutions. Based on the

results shown in both charts of Figure 5, we set the final number of iterations to 5,000 to ensure a

good-quality solution.
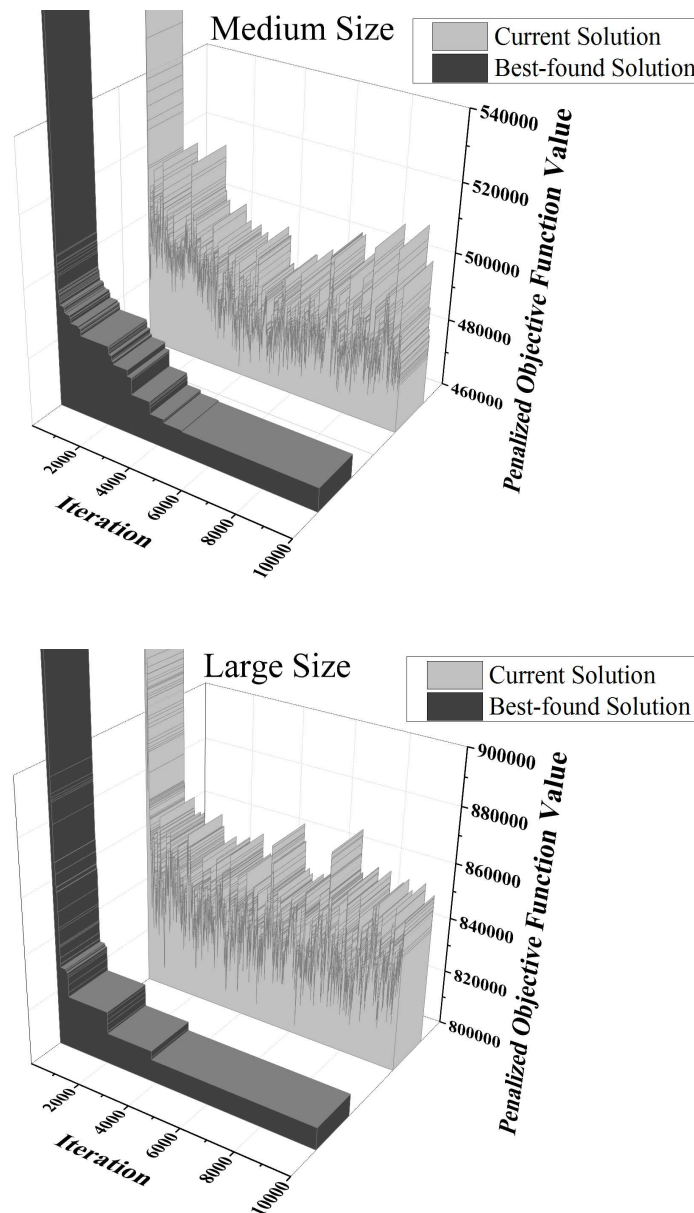
Figure 5 Heuristic Termination Analyses

6. Computational Results

In this section, we determine the best TS heuristic variant and compare the resulting CPTAP TS heuristic with the benchmark results of the CPTAP GA method (Manuscript Authors, 20##). The CPTAP TS heuristic is coded in C++ language and run on a Dell Intel Core i7 CPU with 4.00GB of RAM.

In order to compare the two heuristics, we run the same instances that were generated previously for CPTAP GA-based heuristic (Manuscript Authors, 20##). The instances are systematically generated from a data set collected on the Upper Mississippi River (Authors, 20##). The study area is a 154-mile river section of the Upper Mississippi River, starting from Lock and Dam No.14 north of Davenport, Iowa (Moline, Illinois) to Lock and Dam No.19 at Keokuk, Iowa. Barge locations are generated uniformly over the study region according to the number of the terminals in the instance and the locations of the terminals. Water transport time of each barge from its current location to each terminal is calculated based on barge location, terminal location, and barge speed (assumed five miles per hour). With each pair of terminal and barge assignment, the offload time and the land transport time are estimated over uniform distributions of five to ten hours and eighteen to ninety-six hours respectively. We assume barge volume to be 1000 per ton and the terminal capacity to be 5000 tons per commodity type. Two digit commodity type classification by USACE (2012b) is used as the cargo types and their 2012 tonnage data for the study region and the market price are displayed in Table 2. We set the cargo type for each barge on the basis of the tonnage data and calculate the total cargo value on a barge by multiplying the barge volume and the market price. 100% of the petroleum and 50% of the chemicals are considered as the hazardous cargo. Barge draft (ranging from six to fourteen feet) is determined according to its probability density function that is estimated from the draft data of vessel trips

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(USACE, 2012c). We assign one foot and 90% to safety level and sinking threshold respectively. Value decreasing rate for each commodity type is given as follows: Hazardous cargo receives the highest value decreasing rate ($600 per 1000 tons per hour) due to their high economic value and the dangerous feature to environment and people; nonhazardous chemicals and perishable cargo (food and form products) are given the second highest value decreasing rate ($400 per 1000 tons per hour); the third highest value decreasing rate goes to crude materials and primary manufactured goods ($300 per 1000 tons per hour); the lowest value decreasing rate is assigned to coal ($100 per 1000 tons per hour) because of its stable value function. Problem size is defined as the sum of number of terminals and number of barges. Instances that fall into three problem size categories are investigated because problem size may be an influencing factor in the TS performance, which are small-size instances (five terminals and five/seven/nine barges), medium-size instances (ten terminals and thirty barges), and large-size instances (fifteen terminals and fifty barges). The CPTAP TS heuristic is run ten times for all the instances, which is in accordance with the CPTAP GA-based heuristic.

Table 2 Commodity Types, Tonnage Data and Market Price on the Study Region (USACE, 2012b)

Two-digit Code	Cargo Commodity Type	Tonnage Data	Market Price
10	Coal, Lignite and Coal Coke	10288.25	$36.29/ton
20	Petroleum and Petroleum Products	1238.20	$403.39/ton
30	Chemicals and Related Product	18331.33	$399.88/ton
40	Crude Materials, Inedible, Except Fuels	11364.99	$134.61/ton
50	Primary Manufactured Goods	7843.58	$396.45/ton
60	Food and Farm Products	58670.63	$164.52/ton

A summary of our CPTAP GA approach is described here, and more detail can be found in (Manuscript Authors, 20##). We first use a numerical string to represent a CPTAP solution.

Natural numbers indicate the numbered barges and zeroes distinguish the terminals with the dummy terminal located at the end of the string. We employ tournament selection to choose two parent chromosomes in the population as the foundation to generate child chromosomes. The major components of the CPTAP GA are a crossover operator that produces two child chromosomes, a mutation operator that enables the GA to explore new solution areas, and a repair operator that restores the structurally infeasible chromosome(s) caused by the first two operators.

Table 3 exhibits our experimental results of the CPTAP TS heuristic under three different neighborhood structures – Partial Shift (PS), Blind SWAP (BS) and Switch SWAP (SS). As previously mentioned, random generation is used for initial solution generation, and pair attribute is the tabu management scheme employed. Problem of sizes ten, twelve, and fourteen are included in the small size problem experiments with five instances for each problem size. Experiments on ten instances of medium and large size problem are conducted. The optimal solutions (Opt) are presented in Table 3, which are found through the total enumeration program run on the high performance computers of the _____ High Performance Computing Center at the University of _____. We can only determine optimal solutions for small size problems of size less than fourteen due to the memory limit. The total value loss (Min) and the CPU time (CPU) of the CPTAP GA approach are expressed in dollars and seconds respectively in Table 3. Let $c(s^{GA})$ and $c(s^{TS})$ denote the total value loss of the CPTAP GA solution s^{GA} and CPTAP TS solution s^{TS}. The estimated gap between the two heuristic results is given by

$$Min\ Gap = \frac{c(s^{TS}) - c(s^{GA})}{c(s^{GA})} \times 100\% \tag{11}$$

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Similarly, we also calculate the CPU Gap of the two heuristics. TS-BS finds the same solution as the CPTAP GA for all the small size instances (two thirds are optimal), and TS-PS obtains the same solution as the CPTAP GA for thirteen out of fifteen small size instances. Both TS heuristics require higher CPU time with average gap of 36.6% for TS-PS and 515.8% for TS-BS. A dramatic deterioration of the solution quality can be observed from the TS-SS over small size instances. TS-SS does not perform as well as the CPTAP GA on any of the fifteen small size instances with a considerable higher total value loss of 10.73% on average. The poor comparative performance is anticipated to continue as problem size increases, and therefore TS-SS is excluded as a competitive alternative for the comparisons on medium and large size instances. When comparing TS-PS and CPTAP GA results for medium and large size problems, neither approach produces consistently better results than the other. On average, TS-PS yields higher total value loss than CPTAP by 0.31% on medium size instances but lower than the CPTAP GA on large size instances by 1.43%. The computation time of TS-PS is substantially slower on average than the CPTAP GA for medium (784.95%) and large (1162.14%) size instances. TS-BS improves the total value loss produced by the CPTAP GA on all twenty instances of the medium and large size problems with 2.15% and 3.14% decreases on average. The average CPU time of TS-BS is higher on average than the CPTAP GA for medium (384.96%) and large (192.11%) size problem instances.

Table 3 Experimental Results of the Three TS Variants

Size (Terminal × Barge)	N_i	Opt ($)	CPTAP GA Min ($)	CPTAP GA CPU (s)	TS-PS Min Gap	TS-PS CPU Gap	TS-BS Min Gap	TS-BS CPU Gap	TS-SS Min Gap	TS-SS CPU Gap
Small (5×5)	1	89756	89756	8.8	0.0%	-4.3%	0.0%	523.2%	18.5%	524.9%
	2	110906	110906	8.6	0.0%	-5.1%	0.0%	539.3%	0.2%	546.9%
	3	109112	109112	8.6	0.0%	13.5%	0.0%	524.9%	5.8%	535.9%
	4	84804	84804	8.6	0.0%	4.0%	0.0%	531.1%	1.0%	544.5%
	5	95268	95268	8.6	0.0%	5.4%	0.0%	537.7%	1.2%	555.1%
Small (5×7)	1	106700	106700	9.3	2.2%	43.1%	0.0%	543.6%	4.0%	555.0%
	2	78032	78032	9.4	0.0%	44.4%	0.0%	539.4%	27.9%	555.9%
	3	100828	100828	9.4	0.0%	55.6%	0.0%	535.1%	10.8%	539.0%
	4	105402	105402	9.4	0.0%	31.6%	0.0%	533.4%	3.4%	540.3%
	5	134448	134448	9.3	0.0%	39.9%	0.0%	537.6%	7.3%	547.5%
Small (5×9)	1	–	160330	10.5	0.0%	81.5%	0.0%	526.7%	8.7%	527.8%
	2	–	156186	14.1	0.0%	44.0%	0.0%	366.6%	19.3%	369.6%
	3	–	147344	12.8	0.0%	41.3%	0.0%	430.3%	13.1%	417.4%
	4	–	133528	10.6	0.6%	70.2%	0.0%	516.4%	9.8%	515.4%
	5	–	175852	10.0	0.0%	84.4%	0.0%	551.0%	30.0%	589.7%
Medium (10×30)	1	–	485006	47.2	0.4%	515.4%	-3.7%	242.5%	–	–
	2	–	501560	24.9	1.6%	1066.4%	-0.3%	545.4%	–	–
	3	–	505892	45.6	-1.8%	488.0%	-2.6%	325.5%	–	–
	4	–	549308	68.6	-0.4%	422.8%	-2.3%	131.0%	–	–
	5	–	424098	25.5	3.2%	1088.2%	-2.1%	517.1%	–	–
	6	–	505930	29.8	-1.1%	838.1%	-3.4%	432.0%	–	–
	7	–	480822	53.1	2.1%	456.2%	-1.8%	198.7%	–	–
	8	–	547550	28.7	-0.8%	859.8%	-3.1%	456.5%	–	–
	9	–	524986	27.3	0.2%	1000.9%	-1.1%	477.2%	–	–
	10	–	492860	25.2	-0.3%	1113.7%	-1.1%	523.7%	–	–
Large (15×50)	1	–	766914	104.8	2.2%	930.9%	-1.5%	148.6%	–	–
	2	–	804202	318.2	-0.1%	245.6%	-3.1%	-20.2%	–	–
	3	–	835728	182.4	-0.3%	532.0%	-2.9%	40.5%	–	–
	4	–	837088	60.3	-3.7%	1559.4%	-4.5%	311.5%	–	–
	5	–	768902	47.8	-3.4%	2103.4%	-4.6%	414.4%	–	–
	6	–	795378	102.4	-1.2%	893.8%	-4.3%	139.8%	–	–
	7	–	762148	48.8	-1.2%	2456.9%	-3.2%	400.7%	–	–
	8	–	849272	179.5	-2.8%	410.4%	-3.4%	38.9%	–	–
	9	–	902236	60.4	-4.0%	1588.7%	-4.3%	309.6%	–	–
	10	–	738176	115.7	0.2%	900.3%	-2.3%	137.3%	–	–

To summarize Table 3, TS-BS is identified as the best CPTAP TS heuristic. TS-BS is the only CPTAP TS variant that produces either as good as or improved solutions in all thirty-five experimental instances over the CPTAP GA. In fact, it produces the best-found result for all the medium and large size instances where optimal solutions cannot be obtained. In terms of the computational time, although TS-BS consumes more time than TS-PS for small size instances, its actual CPU time is as small as approximately one minute which definitely falls within an acceptable range. In medium and large size instances that more closely resemble realistic decision scenarios, TS-BS requires quite a bit less time than the TS-PS approach.

If we consider solution quality and computation time to compare the heuristic results in Table 3, the TS-BS and CPTAP GA do not dominate each other although TS-BS produces solutions with lower objective function values. In Figure 6, we show summarized computational results when reduce the number of iterations to 1000 for the three CPTAP TS heuristic variants (TS-PS, TS-BS, and TS-SS) in order to make them comparable to the CPTAP GA (GA). For each heuristic scheme, average total value loss and CPU time of five instances are presented for both medium and large problem sizes. The best average total value loss is obtained by TS-BS in both problem sizes, which is in accordance with the previous discussion. Moreover, this heuristic generates the solution very quickly. For medium size instances, TS-BS computation time is slightly slower than TS-SS (< 1s) and faster than the other two heuristic variants (+10s). Since TS-SS produces much higher average total value loss (approximately $95,000 more than TS-BS), TS-BS is considered an overall better choice than TS-SS. Moreover, TS-BS is the fastest approach for solving large size problem instances. The other three heuristic variants require more time to obtain worse solutions when compared to TS-BS.
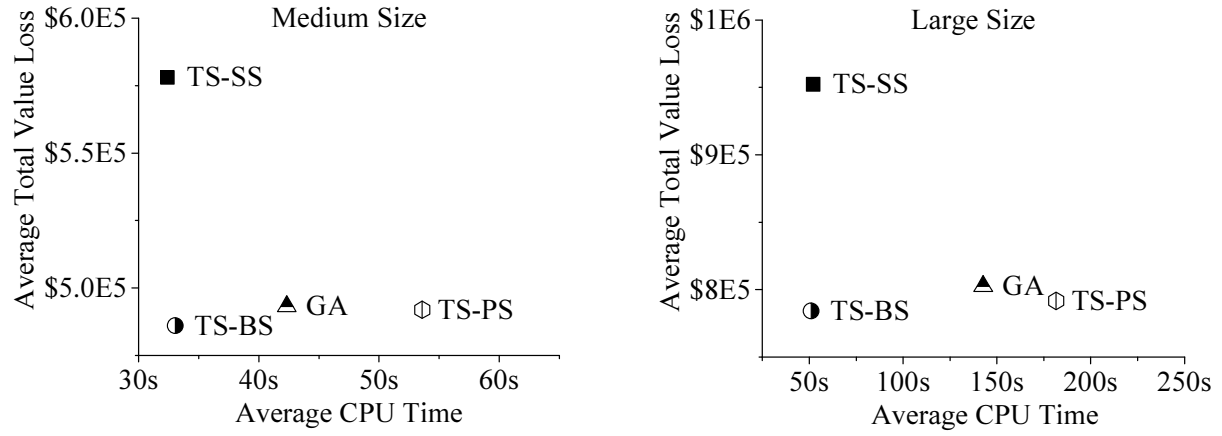
Figure 6 Quality vs Time of GA and TS Heuristics for CPTAP

7. CPTAP Strategy Comparison

We further investigate the impact of applying CPTAP and its solution technique to realistic inland waterway disruption scenario. A naive approach to inland waterway disruption response is to assign the disrupted barge cargoes to their nearest feasible terminals. The objective function in this approach is to minimize the total distance of all disrupted barges transport to their assigned terminals. In this minimize distance (MD) approach, each terminal still serves one barge at a time, and every disrupted barge must be handled by a terminal. Capacity and draft constraints (constraint sets (6) and (7)) are again considered to ensure the barge can be accepted by the terminal. However, cargo type is not a critical factor in the MD strategy. Hazardous cargo is not being treated differently from nonhazardous cargo, and value loss does not influence the barge-terminal assignments. An integer programming model with linear objective function and constraints is developed to implement the MD approach and solved with AMPL-CPLEX. In Figure 7, we show the comparative results of three cargo prioritization strategies (MD, CPTAP TS, and CPTAP GA) for two performance measures – Total Value Loss and Response Time. Total value loss is the objective function value for the CPTAP TS and CPTAP GA approaches.

For the MD approach, we calculate its total value loss after the optimal minimum distance barge-terminal assignments are determined. We compute the Response Time, the total time to complete water transport and cargo offloading of all disrupted barges, for all three approaches based on their optimal/best solutions. In disruption response, a rapidly-cleared river reduces the chance of secondary disaster and helps the maritime stakeholders resume transportation on the waterway as soon as possible. Therefore, a smaller response time is preferred when we select a cargo prioritization strategy. According to Figure 7, the greater total value loss and response time are obtained when employing MD strategy as compared to CPTAP TS and GA strategies for all medium size instances. The CPTAP TS heuristic again produces a lower total value loss than the CPTAP GA-based heuristic in four out of the five medium instances and an equal value for the one instance. Prioritization results from TS consumes less time than GA to transport all the disrupted barge cargoes off the waterway in three out of five instances and equal time to the GA in one instance. For large size instances, the TS results in the lowest total value loss and delivers the quickest response time for all the five large size instances. Overall, the results in Figure 7 indicate that involving cargo, barge and terminal features to intelligently prioritize the barge cargoes in CPTAP has a profound impact on the disruption response of inland waterway transportation, which mitigates the negative impacts of the disruption and provides an improved response towards waterway recovery, and the CPTAP TS method is again shown to perform better than the CPTAP GA-based heuristic according to the required response time.
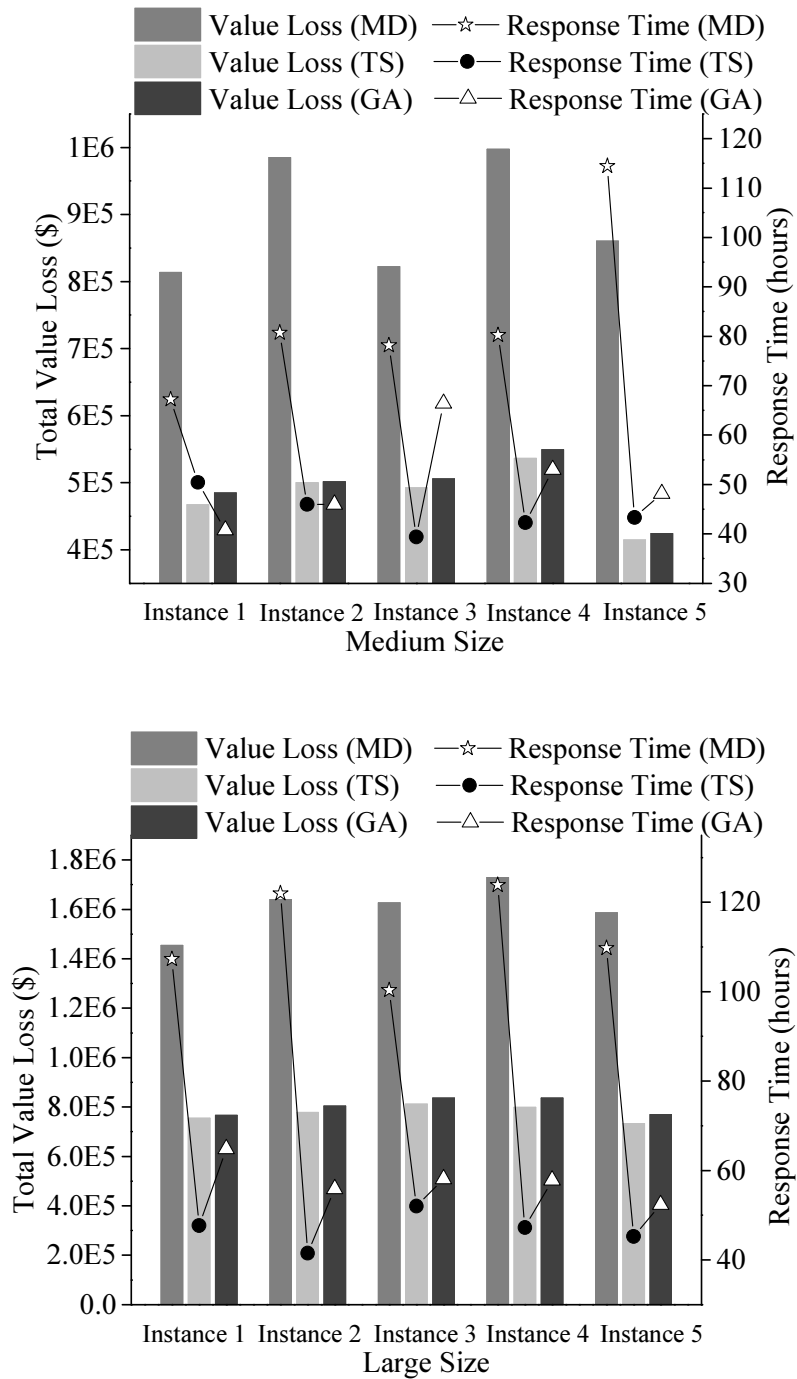
Figure 7 Comparison of Multiple Strategies for Cargo Prioritization and Terminal Allocation

8. Conclusions

This paper developed an TS heuristic for a novel problem – cargo prioritization and terminal allocation problem (CPTAP), which prioritizes and reassigns cargo of a disrupted inland waterway transportation system (Manuscript Authors, 20##). We implemented and tested multiple TS variants on small, medium, and large size experimental instances and identified TS-BS as producing the best-quality results in a fastest manner. The TS-BS heuristic outperforms the previously recommended CPTAP GA approach, and our analysis indicates that CPTAP solved by either heuristic approach significantly decreases total value loss and response time compared to a naive prioritization strategy based simply on assigning disrupted barges to the closest feasible terminal.

The contributions of this paper are twofold: 1) a robust TS heuristic that outperforms a previously developed GA approach to find improved solutions for CPTAP within a satisfactory amount of time; 2) the significance of applying CPTAP to disrupted inland waterway is systematically validated. Both contributions are crucial steps that lead to our future research on improving CPTAP model and solution methods. Planned future work includes: 1) application of the CPTAP TS heuristic during a real world CPTAP decision scenario to assess its implementation performance; 2) development of a heuristic that incorporates merits from both population search (GA) and local search (TS); and 3) development of other potential solution approaches to CPTAP such as column generation.

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Appendix 1

Sensitive Analysis of Adjustment Factor δ – Medium Size

δ	Measure	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
0.01	Min	468260	500262	502680	543066	417490	490974	471088	529108	525192	489976
	Max	501994	540404	536826	564870	464320	522830	492974	588262	562880	1015100
	Avg	478897	513601	513249	550386	430833	506982	478180	544279	539187	570917
0.05	Min	469292	498828	500042	535242	420566	492892	472560	529978	525638	486634
	Max	499602	549956	610628	576392	448472	541750	512364	545672	563866	546172
	Avg	475421	515212	532202	551445	430036	504842	485764	539817	539750	510955
0.1	Min	468566	499960	499902	539076	419826	489864	473718	531186	521474	492968
	Max	501806	1034390	539228	568978	697284	539546	499744	581774	566688	626150
	Avg	476438	564519	515414	550669	456380	505651	484981	547479	538989	523867
0.5	Min	467576	501084	500320	537338	420692	491610	471596	534374	522756	488680
	Max	721930	542292	533818	553856	444786	528738	494876	551608	569246	596714
	Avg	500057	516235	510592	543990	433158	510028	478182	545004	539802	506539

Sensitive Analysis of Adjustment Factor δ – Large Size

δ	Measure	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
0.01	Min	745988	790482	819916	809676	744606	781412	735530	824798	871038	734114
	Max	821098	844952	923410	831460	795676	843334	1116330	913888	975758	820886
	Avg	775654	808814	861995	819139	764411	814701	801249	865024	901020	766060
0.05	Min	750728	795806	807768	814862	746654	777466	755600	827902	867112	731990
	Max	873062	873836	915014	860866	813458	831334	844802	901902	925860	821164
	Avg	786841	817420	844974	835372	764812	799855	786603	854604	889624	760604
0.1	Min	759814	791476	823380	804048	747732	775898	738076	836572	872780	734944
	Max	904902	830528	902392	854226	783476	851178	823522	903562	920554	786548
	Avg	795840	806532	853423	826009	759188	804354	763340	859153	895221	751655
0.5	Min	747636	791158	832768	819180	742990	780546	749976	839644	873534	728932
	Max	802270	843958	977614	1533170	798138	880738	769370	1036340	922444	821308
	Avg	774637	814536	869909	929983	765973	816014	761511	897562	905384	758568

Appendix 2

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This memorandum is to confirm that Jingjing Tong is the first author of the following article and completed at least 51% of the work for the article.

"A tabu search approach to the cargo prioritization and terminal allocation problem"

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6. VALUE-FOCUSED ASSESSMENT OF CARGO VALUE DECREASING RATE

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Abstract

The transportation system is an essential component of any economy, and the disruption of cargo transport can have substantial economic and societal impacts. These detrimental consequences can be mitigated through quantitative assessment and prioritization of disrupted cargoes such that the critical cargo is redirected intelligently. This paper presents a literature review of the value-focused thinking (VFT) literature in transportation, logistics, and supply chain application areas and a VFT approach to determine a value decreasing rate for disrupted cargoes in support of efficient and effective transportation disruption response.

Key Words: Cargo Prioritization; Value-focused Thinking; Value Decreasing Rate; Disruption Response; Transportation; Inland Waterways

1. Introduction

The freight transportation system is heavily utilized by the increasing economic activities among/within countries as the result of product specialization and globalization (Chopra and Meindl, 2007). Globally in 2008, more than $16 trillion cargoes are exported from the manufacturing countries to the destination markets by maritime vessels, inland waterway barges, airplanes, trucks, and trains (U.S. Department of Transportation (USDOT), 2010). As the leading economy, the United States has the world's largest transportation network including 25,000

miles of navigable waterways, 4 million miles of public roads, 140,000 miles of railways, and considerable transportation infrastructure (USDOT, 2010). In 2012, the U.S. freight system moved approximately 11.7 billion tons of cargo that as valued at \$13.6 trillion (USDOT, 2013). The majority of this cargo (86% of the total value and 96% of the total volume) was carried by a single mode with highway dominating the other transportation modes with 74% of the value and 70% of the tonnage (USDOT, 2013). The freight transportation system is at risk of disruption from natural disasters and manmade events. The high demand and frequency of cargo carried by transportation system suggests the significant impacts that will result from disrupted freight movement. The major 2007 bridge collapse in Minneapolis influenced approximately 140,000 daily vehicle trips and led to \$400,000 daily cost to the commercial vehicles and road users for rerouting (Zhu and Levinson, 2012). A series of events including gate failure and inspection closed the Ohio River at Hannibal Locks and Dam for five days and resulted in a conservative estimated cost \$5.1 million (U.S. Army Corps of Engineers (USACE), 2006). To mitigate the high cost of disruptive events, intelligent cargo prioritization techniques are needed to redirect the disrupted cargo given that the value of these cargoes decreases in terms of economic value, societal benefit, and customer satisfaction as time elapses during disruption response period. In order to minimize the total value loss from the cargo disruption, there is a need for a methodology to comprehensively assess the value decreasing rates of the disrupted cargoes in support of efficient and effective disruption response planning by transportation stakeholders.

In this paper, we employ value-focused thinking (VFT) to develop a cargo value decreasing rate (CVDR), the rate at which the cargo's economic and societal value diminishes as time elapses. VFT incorporates values into decision making because values are what decision makers are concerned with and what should be the driving force in decision making (Keeney, 1992). VFT

can stimulate creativity in revealing hidden values (Shoviak, 2001). This is important for the

CVDR assessment because the CVDR is related to complex societal and economic issues, which

requires comprehensive assessment to identify all crucial values. The VFT methodology has

been successfully applied in a wide range of decision contexts (Braziel et al., 2007; Parnell et al.,

2013) and is well-suited to assessing a CVDR by evaluating and ranking all the involved cargo

types and translating the alternative VFT scores into numerical CVDRs.

Following a comprehensive literature review to describe existing relevant VFT analysis in

transportation, logistics, and supply chain, this paper demonstrates a systematic and step-by-step

VFT approach to generate CVDRs. An example based on barge cargoes transported on the

inland waterways is incorporated into the discussion to exemplify the developed method. The

major contribution of this work is to provide a rigorous method for CVDR assessment. The input

of the well-constructed CVDRs contributes to the better quality of the cargo prioritization

models. Moreover, if multiple stakeholders from different organizations with various interests

are involved into the CVDR assessment, the developed methodology can result in improved

communication and decision making as a group instead of individually prioritizing cargo based

strictly on their own experience and estimation. By detailing the values possessed in the decision

framework, the VFT methodology provides multiple decision makers with a basis to find the

common ground and to reach a consensus when assessing CVDRs.

2. Literature Review (Tong et al., 2013)

Our previous work has investigated the related literature to provide a sufficient knowledge base

in the VFT application area (Tong et al., 2013). Since the appearance of VFT by Ralph Keeney

in 1992, a large number of papers have discussed or applied this unique methodology in various

decision making scenarios. According to the recently published VFT survey (Parnell et al., 2013), there are eighty-nine journal papers that implemented VFT in their analysis from 1992 to 2010. The number of studies is even larger if VFT books and thesis/dissertations are included. In our review, we selected the literature whose application context is closely related to our problem domain – the VFT papers that study transportation, logistics, and supply chain (TLSC).

2.1 Literature Summary

The seven VFT papers within the TLSC field are reviewed, and a brief summary of each paper is presented.

Supply Chain Risk Identification with Value-focused Process Engineering (Neiger et al., 2009). This article proposes a novel supply chain risk identification methodology on the basis of value-focused process engineering (VFPE), which integrates the principles from VFT and extended-event-driven process chain (e-EPC). The contribution of VFT in this article is to provide a unique perspective in which the supply chain is composed of multiple interconnected value-adding processes and risk objectives (defined as "minimizing the chance of an adverse event") which are considered as the mean objectives that can fit into the VFT framework. Together with e-EPC methodology, VFT aids the researchers to model the process-based risks with a thorough consideration of processes, objectives, and risk sources. Figure 1 displays the first three steps of the VFPE-based risk identification process, which illustrate how VFT functions in the scheme and how it interacts with other components. In Step One, functional risk objectives are identified by providing each supply chain activity with a generic risk objective, while in Step Two, VFT is used to generate value risk objectives through decomposing the higher-level process objective of minimizing process failure risk. Based on the delivery from the first two steps, a completely decomposed risk objectives structure is developed in Step Three.

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Figure 1 Step 1-3 of VFPE-based Supply Chain Risk Identification (Neiger et al., 2009)

Value-focused Supply Chain Risk Analysis-Book Chapter (Olson & Wu, 2010). This

research investigates the plant location decision for the supply chain participant with

consideration of supply chain risk. VFT is mainly used to establish the value hierarchy for the

supply chain and to create the alternatives. The SMART technique is applied to conduct the

remaining multi-attribute decision analysis. The authors strengthen the importance of values in

structuring the value hierarchy – VFT aims to develop a hierarchy that gains a wide spectrum of

values. Beginning with searching for the overall values, the authors develop a three-level value

hierarchy for the supply chain risk and point out that every element in the hierarchy is able to be

used to locate the risks for any specific supply chain situation. It is also suggested that

alternatives should be generated in the hierarchical development process. In terms of the number

of alternatives that should be created, two to seven alternatives are recommended for multiple

attribute decision analysis.

A Value Focused Thinking Tutorial for Supply Chain Application (Jordan, 2012). This

research discusses the VFT application in supply chain decision making. According to the author,

various multi-criteria approaches are widely used to model supply chain and logistics problems.

However VFT is rarely considered in this field; thus the author presents a detailed VFT tutorial

and conducts VFT analysis on a common logistics problem – the supplier selection. The bottom-

up method is used to construct the supplier selection hierarchy, followed by a complete analysis

directed by the VFT methodology. Important strengths of VFT for supply chain problems are

that a VFT approach can reveal the true value that an alternative has for the decision and alert the

decision maker to derive better alternatives if the existing alternatives do not have a satisfying

value to the decision. It is a powerful feature for the supply chain problem which regularly has a

large number of alternatives. The new alternatives can be quickly valued and compared with the

others.

Transportation Readiness Assessment and Valuation for Emergency Logistics (Nachtmann

& Pohl, 2013). This article examines the readiness level of transportation considered by local

and state operation planners in their emergency preparedness plans. The transportation readiness

assessment and valuation for emergency logistics (TRAVEL) scorecard is developed to help the

operation planners identify the deficient areas in their emergency operations plans (EOP) and

improve them through evaluating the EOP quality with regards to transportation readiness. VFT

framework is applied in developing the TRAVEL tool and spreadsheet is used to provide

software platform for TRAVEL. Figure 2 shows the eight-step VFT processes that create

TRAVEL. The top-down method is employed to develop the value hierarchy in Step Two. Under the fundamental problem of assessing transportation readiness of EOP, four supporting objectives are placed at the second level, each of which further splits into several measurable attributes. Three county-level EOPs are assessed by the authors to validate the TRAVEL scorecard. The analysis results show that TRVEL can quickly identify the shortcomings of the EOP with respect to transportation and enables the operation planners to revise the EOP promptly.

Figure 2 TRAVEL Development Process (Nachtmann & Pohl, 2013)

Value Focused Thinking Analysis of the Pacific Theater's Future Air Mobility En Route System (Axtell, 2011). This study provides the decision makers in the Air Mobility Command (AMC) with a validated decision tool to evaluate the locations in the future en route system in the Pacific Theater. VFT methodology is used to analyze whether the proposed en route locations have appropriate level of access in the Pacific Theater. A six-level value hierarchy with twenty-seven attributes termed "En Route Base Selection Tactical Sub-model" developed by previous researchers has been utilized as part of the overall value hierarchy (see Figure 3) in this study. As can be seen in Figure 3, the tactical sub-model is included as one of the three supporting objectives under the fundamental objective "Operational Value Score." The case study includes twenty current and eight future en route locations and evaluates each location based on the operational value hierarchy. The author points out that the proposed VFT decision analysis tool advocates replacing the existing en route linear system with a more integrated one.

Figure 3 Operational Value Hierarchy (Axtell, 2011)

Decision Analysis with Value-focused Thinking as a Methodology in Structuring the Civil Engineering Operations Flight (Katzer, 2002). This study investigates how to help the operations flight commander select the best organizational structure of the civil engineer operations flight. The author believes that VFT methodology is one of the most ideally suited approaches that can answer the two-fold questions regarding the selection decision – what values are important to the decision and how the ranking of the alternatives changes with various situations. Figure 4 displays operations flight value hierarchy. As described by the author, the first-level fundamental objective is identified, followed by the brainstorming sessions of asking "what does that mean" which further identifies four supporting values that are placed at the second level. This question is asked repeatedly until the lowest level values are measurable. The final alternative ranking reveals the extent to which the alternative meets the values from the operations flight commander's perspective in order to reach the fundamental objective.

Figure 4 Operations Flight Value Hierarchy (Katzer, 2002)

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Technology Selection for the Air Force Research Laboratory Air Vehicles Directorate: An Analysis Using Value Focused Thinking (Winthrop, 1999). This paper focuses on exploring the technology direction that is most supportive to the U.S. Air Force values, which should be given more consideration by the air vehicles directorate (VA) when they have sufficient funds. Both VFT and optimization approaches are used in this analysis. Research and development (R&D) literature are first reviewed to help identify the fundamental objective and supporting objectives in the value hierarchy. In order to assure the value hierarchy represents the core values of VA, a number of VA experts and leaders are involved in developing and confirming the value definitions and the final hierarchy. Among over one hundred identified VA R&D programs, a couple of them are selected in the case study. An additive value model is employed to evaluate the overall score for each alternative, and sensitivity analysis is conducted at last.

2.2 Literature Assessment

To gain further insights from these VFT studies within TLSC domain, we continue examining the select literature in the form of answering research questions with respect to these studies. We use the research questions developed in a recent survey paper (Parnell et al., 2013) and create a matrix to present the answers to these questions based on the contents of each study. Table 1 displays the literature assessment matrix.

Table 1 Literature Assessment Matrix

Research Questions	Neiger et al., 2009	Olson & Wu, 2010	Jordan, 2012	Nachtmann & Pohl, 2013	Axtell, 2011	Katzer, 2002	Winthrop, 1999
Publication	Journal	Book Chapter	Dissertation	Journal	Thesis	Thesis	Thesis
Authors	Australia	U.S.	U.S.	U.S.	U.S.	U.S.	U.S.
Year of Publication	2009	2010	2012	2012	2011	2002	1999
Type of Study	Theory	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study
Problem Domain	Supply chain	Supply chain	Supply chain	Transport	Transport	Transport	Transport
Clients	Corporate leaders	Corporate leaders	Corporate leaders	Government policy makers	Military leaders	Military leaders	Military leaders
Alternatives by VFT	N/A	Previously known	Previously known	Previously known	Previously known	Previously known	Previously known
Value/Utility Model	N/A	Value model	Value model	Value model	Value model	Value model	Value model
Number of Measures	N/A	12 (Case study)	8 (Case study)	8 (Model)	29 (Model)	10 (Model)	31 (Model)
Other OR/MS Technique	e-EPC	SMART	None	None	GERBIL	None	LP

As is shown in Table 1, ten research questions are selected (with slight revision from Parnell et al., 2013) as the criteria to investigate and compare the literature. Based on the seven TLSC VFT studies, answers to the research questions are summarized as follows:

- *Publication*. Among the seven studies, we found that one is published as a book chapter, two as journal articles, and four as a thesis or dissertation.

- *Authors*. All authors are from the U.S. except for one group of authors who are from Australia.

- *Year of Publication*. Five out of seven studies are published within the past five years. The other two studies are published in 2002 and 1999 respectively.

- *Type of study*. One research focuses mainly on building a theoretical model while the others include both a theoretical methodology and a case study.

- *Problem domain.* Within TLSC, four studies are related to transportation, and three focus on the supply chain.

- *Clients.* Corporate and military leaders are the two largest groups for which the select VFT studies serve (each is involved in three papers). Only one study is conducted for government policy makers.

- *Alternatives by VFT.* None of them actually use a VFT concept to design or improve the alternatives. Alternatives are generated based on collected data/information.

- *Value/Utility model.* Not surprisingly, the value model dominates the utility model among the literature. Six studies employ the additive value model.

- *Number of measures.* The number of measures in the value model range from eight to thirty-one. Four papers determine the measures when the VFT framework is constructed. Two publications identify the measures only in the case study.

- *Other operations research or management science (OR/MS) technique.* Four studies integrate VFT and other OR/MS techniques in developing the methodology framework. The techniques referred in these studies include extended-event-driven process chain (e-EPC), simple multi-attribute rating theory (SMART), global en route basing infrastructure location model (GERBIL), and linear programming (LP).

3. VFT Methodology for CVDR Assessment

In VFT, the values and preferences of the decision makers are structured into a holistic framework to guide the decision process of ranking alternatives (Chambal, 2003). Figure 5 presents a widely-used VFT framework consisting of ten steps, which is developed by Shoviak (2001) and Braziel et al. (2007) based on the seminal works of Keeney (1992) and Kirkwood

(1997). The first three steps (Steps 1-3) define the framework input including the decision

maker's goal, values, and evaluation measures. Steps 4 to 7 constitute the decision model that

determines the framework output. The last three steps (Steps 8-10) function as the result analysis

process. In addition to describing each of the ten steps in detail, an example based on developing

the CVDRs of inland waterway barge cargoes is provided to demonstrate the CVDR assessment

application.
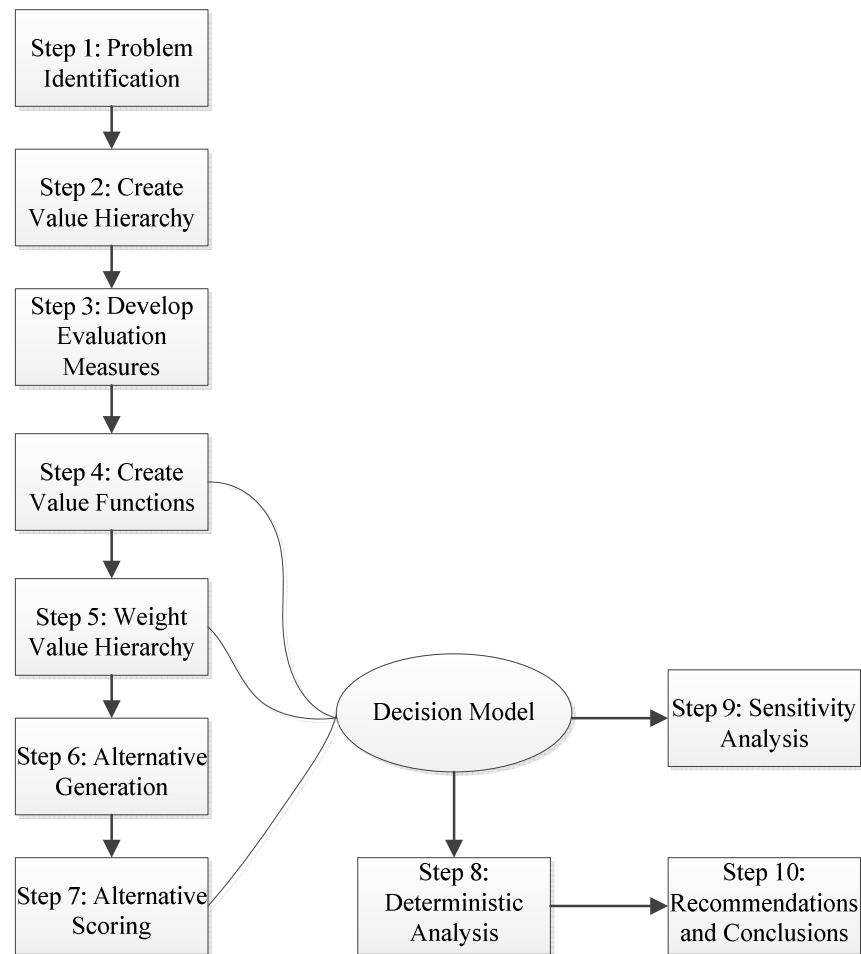
Figure 5 VFT Framework (Braziel et al., 2007)

The cargo prioritization problem for inland waterway disruptions is graphically shown in Figure

6 (Tong et al., 2013). One of the lock and dam (L/D) systems located along the river section is

disrupted and no longer functioning, which causes the inland waterway to close thus halting

traffic traveling up and down the river at the point of disruption. Other disruptions could include

non-navigable water level due to drought or flood, vessel allision or collision, and other

infrastructure disruptions. The barge tows (typically consisting of nine to fifteen barges each)

that are traveling in the direction away from the disruption are unaffected and able to continue

transport to their destination. Barge tows (depicted in bold) that are traveling towards and

beyond the disrupted L/D are affected and no longer able to travel to their destination via the

disrupted waterway. The cargo on the disrupted barges is the focus of the CVDR assessment

presented here.

Figure 6 Graphical Description of Cargo Prioritization Problem (Tong et al., 2013)

Step 1 Problem Identification

As discussed in the Section 1, the fundamental objective of this paper is to assess the value decreasing rate of disrupted cargo. By establishing the qualitative value model to determine the CVDRs of different cargo types, we can translate their relative importance into the numerical values on the basis of a predefined mapping approach.
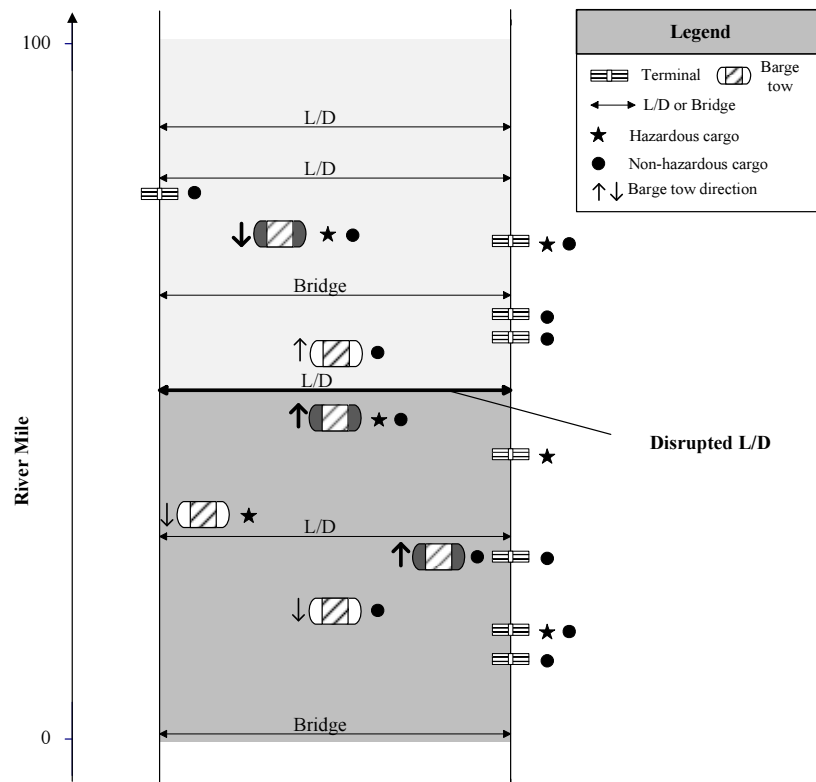
Step 2 Create Value Hierarchy

The value hierarchy serves as the foundational and essential stage in VFT framework that will guide the analysis that determines the priorities of the CVDRs. Keeney (1992) points out that substantial time, money, and effort is needed to evaluate the alternatives based on a value hierarchy that includes all the important values to the decision maker. Therefore, decision makers must take care to understand the values and spend sufficient time to structure the values in the value model. Parnell (2008) recommends several data sources to derive values regarding the decision scenario including existing documents (gold standard), interviews with senior decision makers and stakeholders (platinum standard), and data from stakeholders' representatives (silver standard). We use a combination of data sources that include both gold standard and platinum standard sources. Two documents published by the Department of Homeland Security (DHS) provide commodity import/export priorities in order to support incident management activities (DHS, 2006; DHS, 2007). In addition, other values are identified through interviews with transportation stakeholders including the USACE and U.S. Coast Guard.

The qualitative value modeling approach developed by Parnell (2008) is implemented to establish the value hierarchy. An affinity diagram is used to group the values into a collectively exhaustive and mutually exclusive hierarchical structure shown in Figure 7. The fundamental objective is placed at the top level of the value hierarchy. According to the definition of CVDR,

the rate at which cargo's economic and societal value diminishes as time elapses, two supporting

objectives are identified as the second-tier values (Societal Need and Economic Value) that have

positive relationship with the numerical values of CVDRs. Societal Need is further divided into

three elements due to its wide coverage of societal aspects (National Priorities, Local Priorities,

and Risk Minimization). National Priorities is broken down further into four societal needs at the

national level, which are Emergency Need, Response Need, Community Need, and Military

Need. To distinguish between the risk to harm people and the environment, Risk Minimization is

divided into Public Health and Environment Security. Economic Value is comprised of Market

Value and Perishability which influence cargo's economic worth. Altogether there are nine

values evaluated at the lowest-tier of the hierarchy.
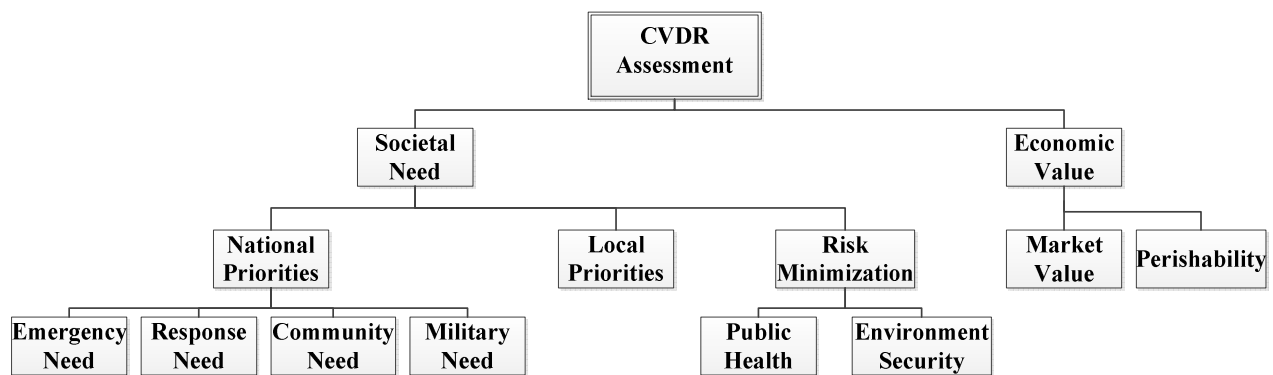
Figure 7 Value Hierarchy for CVDR Assessment

Step 3 Develop Evaluation Measures

The values in the value hierarchy do not directly connect to the alternatives. Evaluation measures

for all nine lowest-level values are developed to assess the alternatives with respect to their

degree of attainment on each value. Two approaches to construct the evaluation measure are

typically found in literature – natural scale and constructed scale (Sperling, 1999). A natural

scale uses a natural and quantitative attribute to evaluate the value directly, while a constructed

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scale establishes the measure based on information/components that is/are closely related to the value that is difficult to measure quantitatively. Eight out of nine values use a constructed scale as their evaluation measure due to their qualitative characteristics. The natural scale is applied to Market Value because of the availability of the quantitative data to directly assess the alternatives on the value. We define the evaluation measure for each of the nine lowest-level values as follows:

- **Emergency Need Value**

Emergency Need is defined as the value associated with the saving and continuation of life during incident management (DHS, 2006; DHS, 2007). We construct the evaluation measure for this value based on the disaster needs of multiple types of hazards published by the International Federation of Red Cross and Red Crescent Societies (2000) and establish a constructed scale from 1 to 5 as shown in Table 2. The decision maker assigns an appropriate score to each alternative cargo type according to the disruption the cargo is associated with and the count of emergency needs the cargo addresses.

Table 2 Evaluation Measure for Emergency Need Value

Essential Components						
Hazard Environment	Food	Shelter	Search & Rescue Equipment	Medical Care	Potable Water	Water Purification
Earthquakes	×	×	×	×	×	
Mud and debris flows		×	×	×		
Landslides		×	×			
Volcanic eruptions	×	×	×	×	×	
Tsunamis	×	×	×	×	×	
Droughts				×		
Floods	×	×	×	×	×	×
Tropical cyclones	×	×		×	×	×
Chemical & industrial accidents				×	×	×

Score	Description
5	Cargo addresses all emergency needs in a hazard environment
4	Cargo addresses most of the emergency needs in a hazard environment
3	Cargo addresses some of the emergency needs in a hazard environment
2	Cargo addresses few of the emergency needs in a hazard environment
1	Cargo addresses none of the emergency needs in a hazard environment

- **Response Need Value**

According to DHS (2006; 2007), equipment that is vital to disruption response operations possess a high Response Need value. There are various guidelines and standards regarding the equipment that is necessary when responding to different disaster scenarios (Fatah et al., 2002; Lawson and Vettori, 2005). The Federal Emergency Management Agency (FEMA)

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released an online catalogue of national resources, the Resource Typing Library Tool (RTLT), which contains definitions of the equipment used prior to, during, and after an incident (FEMA, 2014). We summarize the RTLT equipment to construct the evaluation measure for the Response Need value in Table 3. The constructed scale is 1 or 2 with 2 assigned to cargo that is considered as equipment that supports incident response according to the FEMA RTLT system and 1 otherwise.

Table 3 Evaluation Measure for Response Need Value

Essential Components		
Name	Discipline	Primary Core Capability
Field/Mobile Kitchen Unit	Mass Care	Mass Care Services
Law Enforcement Aviation	Law Enforcement	Interdiction and Disruption
Aerial Lift Equipment	Public Works	Public and Private Services and Resources
Air Compressor	Public Works	Public and Private Services and Resources
Air Conditioner/ Heater	Public Works	Public and Private Services and Resources
Air Curtain Burners	Public Works	Public and Private Services and Resources
Buses	Public Works	Public and Private Services and Resources
Concrete Cutter/Multi-Processor for Hydraulic Excavator	Public Works	Public and Private Services and Resources
Cranes, All Terrain/Rough Terrain/Crawler	Public Works	Public and Private Services and Resources
Floodlights	Public Works	Infrastructure Systems
Generators	Public Works	Infrastructure Systems
Grader	Public Works	Infrastructure Systems
Hydraulic Excavator (Large/Medium/ Compact Mass Excavation)	Public Works	Infrastructure Systems
Road Sweeper	Public Works	Public and Private Services and Resources
Snow Blower (Chassis/Loader Mounted)	Public Works	Critical Transportation
Snow Cat	Public Works	Public and Private Services and Resources
Trailer Equipment	Public Works	Public and Private Services and Resources
Truck (Plow/Tractor Trailer)	Public Works	Public and Private Services and Resources
Tug Boat (General)	Public Works	Public and Private Services and Resources
Wheel Loaders Equipment	Public Works	Public and Private Services and Resources
Wood Chipper/Tub Grinder	Public Works	Public and Private Services and Resources
Engine/ Aerial Apparatus, Fire	Fire and HazMat	Public and Private Services and Resources
Fire Boat/Truck/helicopter	Fire and HazMat	Public and Private Services and Resources
Foam/Fuel/Water Tender	Fire and HazMat	Public and Private Services and Resources
Mobile Communications Unit (Law/Fire)	Fire and HazMat	Operational Communications
Portable Pump	Fire and HazMat	Public and Private Services and Resources
Epidemiology (Surveillance and Investigation)	Medical and Public Health	Public Health and Medical Services
Incident Management Team Animal Protection	Animal Emergency Response	Operational Coordination
Track Loader	Public Works	Public and Private Services and Resources
Electronic Boards, Arrow Boards/Variable Message Signs (VMS)	Public Works	Public Information and Warning
Scraper, Earth Moving	Public Works	Public and Private Services and Resources
Truck, Sewer Flusher & On-Road /Off-Road Dump	Public Works	Public and Private Services and Resources
Trailer, Dump (one type/example only)/ Gooseneck Tractor	Public Works	Public and Private Services and Resources
Track Dozer	Public Works	Public and Private Services and Resources
Chillers & Air Handlers	Public Works	Public and Private Services and Resources

Score	Description
2	FEMA considers cargo to be equipment supporting incident response
1	FEMA does not consider cargo to be equipment supporting incident response

- **Community Need Value**

The Community Need value relates to the value of addressing the cargo shortage in a community after the disaster occurs (DHS, 2006; DHS, 2007). Different from the Emergency Need value concerned with immediate recovery, the Community Need value focuses on long-term restoration of individuals and community activities that are impacted by a disaster. The evaluation measure is thus constructed to consider the major components of the Community Need value (Lindell, 2013; FEMA, 2011) as shown in Table 4. We use the scale 1 to 5 to assess the cargo alternatives.

Table 4 Evaluation Measure for Community Need Value

Essential Components
- Housing Recovery-Long-term housing including housing that recognizes the need for accessibility and affordability   - Psychological recovery-Long-term mental and behavioral health concerns for children and adults in relation to traumatic events induced or exacerbated by the disaster. Example cargoes are toys and clean clothes.   - Business recovery-Industry Continuity. Example cargoes are crude oil, heating oil, and chemicals.   - Rural/Urban recovery-Different commodity needs due to the community type

Score	Description
5	Cargo addresses all four community need essential components
4	Cargo addresses three community need essential components
3	Cargo addresses two community need essential components
2	Cargo addresses one community need essential component
1	Cargo addresses none of the community need essential components

- **Military Need Value**

The Military Need value (DHS, 2006; DHS, 2007) highlights the cargo's value in supporting national security concerns. Its evaluation measure is constructed on the basis of the Uniform Material Movement and Issue Priority System (UMMIPS) prescribed by Department of Defense (DOD) in 2003 that determines the relative importance of the material movements in military sector (Grandjean and Newbury, 2001; USAF, 2012). Two designators – Urgency of Need Designator (UND) and Force Activity Designator (FAD) – constitute the UMMIPS. Identified by letters A, B, and C, UND is the designator assigned to the cargo based on its urgency level for a military mission. Using five Roman numbers, FAD is the designator assigned to the mission based on its importance to DOD objectives. The UMMIPS framework is established using both UND and FAD to create fifteen priority levels. We first identify a cargo alternative with a proper requisition priority designator according to UMMIPS and then use the constructed scale from 1 to 4 to score it as shown in Table 5.

Table 5 Evaluation Measure for Military Need Value

Essential Component			
	Urgency of Need Designator		
	A: Cannot Perform Mission	B: Mission Capability Impaired	C: Requirements and Stock Replenishment
Force Activity Designator	Requisition Priority Designator		
I: In Combat	01	04	11
II: Positioned for Combat	02	05	12
III: Positioned to Deploy	03	06	13
IV: Active Reserve	07	09	14
V: All other	08	10	15

Score	Description
4	Cargo falls into Military Requisition Priority Designators 01-05
3	Cargo falls into Military Requisition Priority Designators 06-10
2	Cargo falls into Military Requisition Priority Designators 11-15
1	Cargo is not required by a military mission

- **Local Priorities Value**

We summarized the Local Priorities value listed in the DHS documents (2006 & 2007) as the essential components to construct the evaluation measure in Table 6. A constructed scale from 1 to 4 is used to score the alternatives.

Table 6 Evaluation Measure for Local Priorities Value

Essential Components
- Cargo that supports heating or cooling demand - Cargo that relates to power generation - Cargo that assures the assembly line continuity

Score	Description
4	Cargo exhibits all three local priorities
3	Cargo exhibits two of the local priorities
2	Cargo exhibits one of the local priorities
1	Cargo exhibits none of the local priorities

- **Public Health Value**

Since risk of human casualty is a straightforward means of assessing value to Public Health, we use a scale of 1 to 3 to construct an evaluation measure that addresses human casualty as shown in Table 7. Individuals that may be injured from the disrupted cargo include staff related to freight movement (e.g. crew members, port workers, and truck/train drivers),

passengers if affected vehicles carry passengers and cargo), and people in the vicinity of incident site.

Table 7 Evaluation Measure for Public Health Value

Score	Description
3	Cargo exhibits high potential to result in human casualty
2	Cargo exhibits low potential to result in human casualty
1	Cargo exhibits no potential to result in human casualty

- **Environmental Security Value**

The Environment Security value considers the risks to the environment after the transportation disruption occurs. Prioritizing cargo that has potential to harm the environment can mitigate environmental damage. Its evaluation measure is developed to assess environmental risk (Mullai, 2006), and a scale from 1 to 5 is constructed to determine the score of the cargo alternatives as shown in Table 8.

Table 8 Evaluation Measure for Environment Security Value

Essential Components
- Loss of wildlife
- Habitat degradation
- Geological and archaeological resources damages
- Damages to tourism and recreation

Score	Description
5	Cargo has the potential to damage all four environmental security components
4	Cargo has the potential to damage three environmental security components
3	Cargo has the potential to damage two environmental security components
2	Cargo has the potential to damage one environmental security component
1	Cargo has no potential to damage any environmental security component

- **Market Value**

Average market price, as a natural evaluation measure, measures the Market Value of each alternative. The decision makers are required to collect the relevant market price data for each alternative.

- **Perishability Value**

The measure of the Perishability value is constructed to assess if the cargo is perishable or not as shown in Table 9. The value of perishable cargo deteriorates with the changes in temperature, humidity or other environmental condition (Kantola and Karwowski, 2012). Typical perishable cargo includes fruit and vegetables, seafood and fish, fresh/frozen meat, bakery, and plants. A constructed scale of 1 or 2 is established to score each alternative with a 2 if the cargo is perishable and 1 otherwise.

Table 9 Evaluation Measure for Perishability Value

Score	Description
2	Cargo exhibits certain level of perishable feature
1	Cargo exhibits no perishable feature

Step 4 Create Value Function

The evaluation measures are developed with various scales and units. In order to derive an aggregate score for each cargo alternative, a single dimension value function (SDVF) is created to unify the evaluation measures. There are multiple types of SDVF such as discrete, linear, or monotonically increasing/decreasing exponential value functions (Braziel et al., 2007). We employ the discrete SDVFs to translate the different scales and units into a normalized scale from 0 to 1 with each measure's highest raw score being 1 and its lowest raw score being 0. The

intermediate value units are selected by the research team according to the natural behavior of

the evaluation measure. Figure 8 contains recommended SDVFs for the eight constructed

evaluation measures, which can be adjusted as needed by the decision maker. For the Emergency

Need measure, addressing only one emergency need does not significantly contribute to the

disaster management operation. Thus its SDVF is set to be flat at first and then becomes steeper.

The measures for Response Need, Community Need, Local Priorities, and Perishability use a

linear SDVF because there is a steady linear relationship between the raw score of the evaluation

measure and the value unit in the value function. A large jump of value at the initial stage of the

SDVF for the Military Need measure indicates the increase in value if the cargo is involved into

a military mission. The value increment drops once the cargo is within the range of measure

scores associated with a certain level of contribution to its military mission. The research team

assigned minimal tolerance to the risk of harm to humans and the environment. Therefore, the

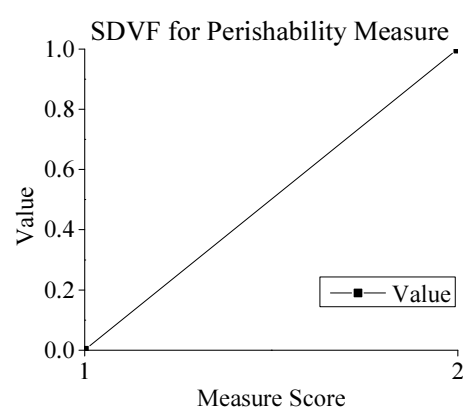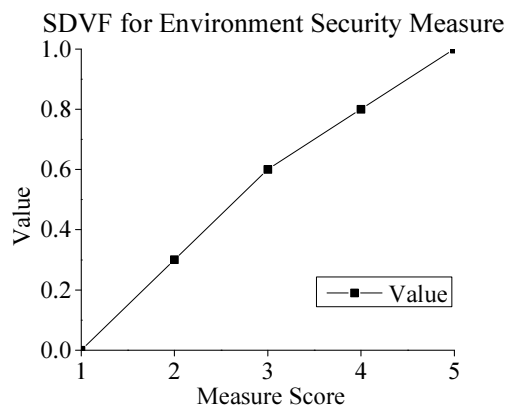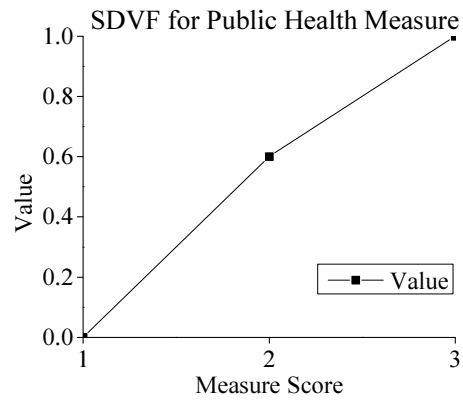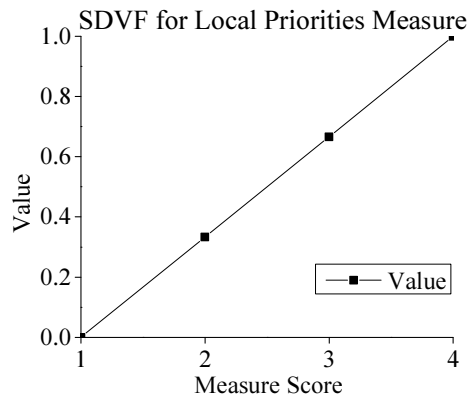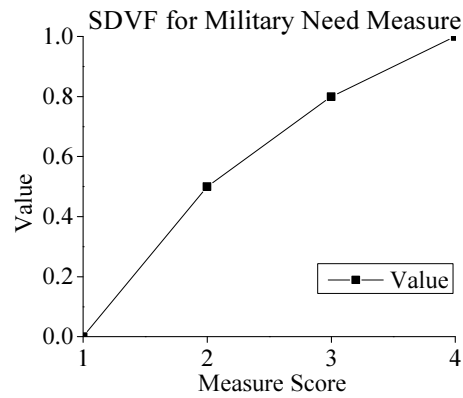SDVFs for Public Health and Environment Security measures are initially steep.
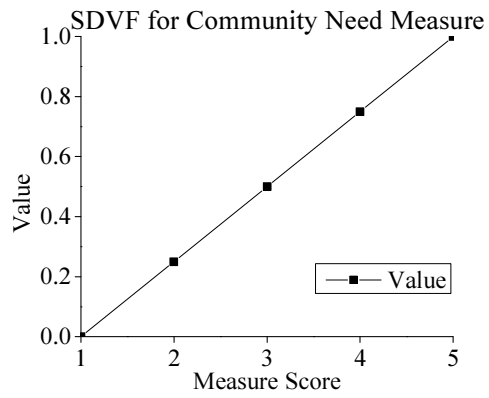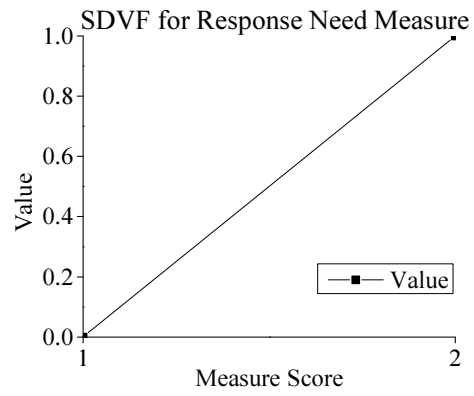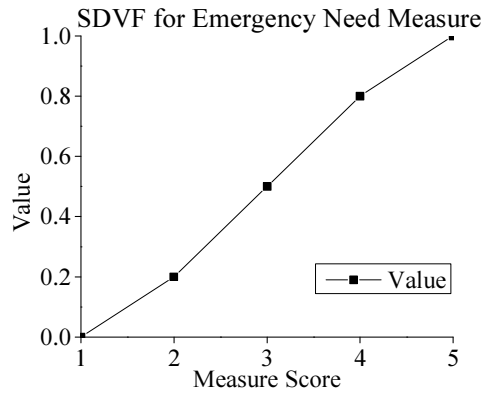
Figure 8 SDVFs for Constructed Evaluation Measures

Figure 9 shows the SDVF for Market Value, which is a step chart that represents the relationship between market price and the value unit.
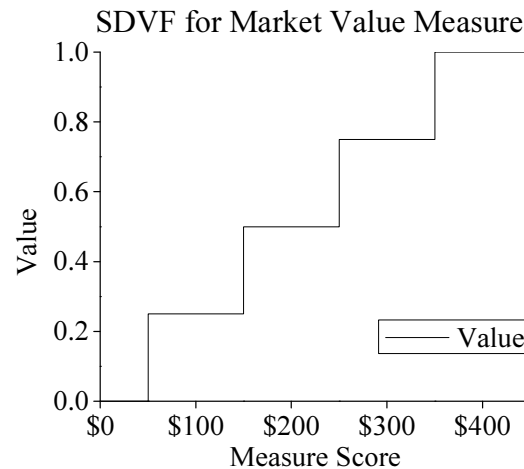
Figure 9 SDVF for Natural Evaluation Measure

Step 5 Weight Value Hierarchy

The values may not be equally important to the decision maker, and therefore weights are assigned to distinguish between any differences in importance. Local weights are first assigned to each tier within a particular branch of the value hierarchy, and global weights are calculated by multiplying the local weight of each value by the local weight(s) of the value(s) that is/are above it successively in the hierarchy (Mills et al., 2009). Various weighting methods are found in the literature including direct weighting, swing weighting, relative weighting, and "100 marble" method (Sperling, 1999; Pruitt, 2003; Nachtmann and Pohl, 2013). The decision makers can select the weighting method they are most comfortable with. The final weights may require extensive discussion and recalculation if multiple decision makers are involved. We utilize the "100 marble" method to assign local weights in the example presented here and then calculate the global weights for each lowest-tier value as shown in Figure 10.

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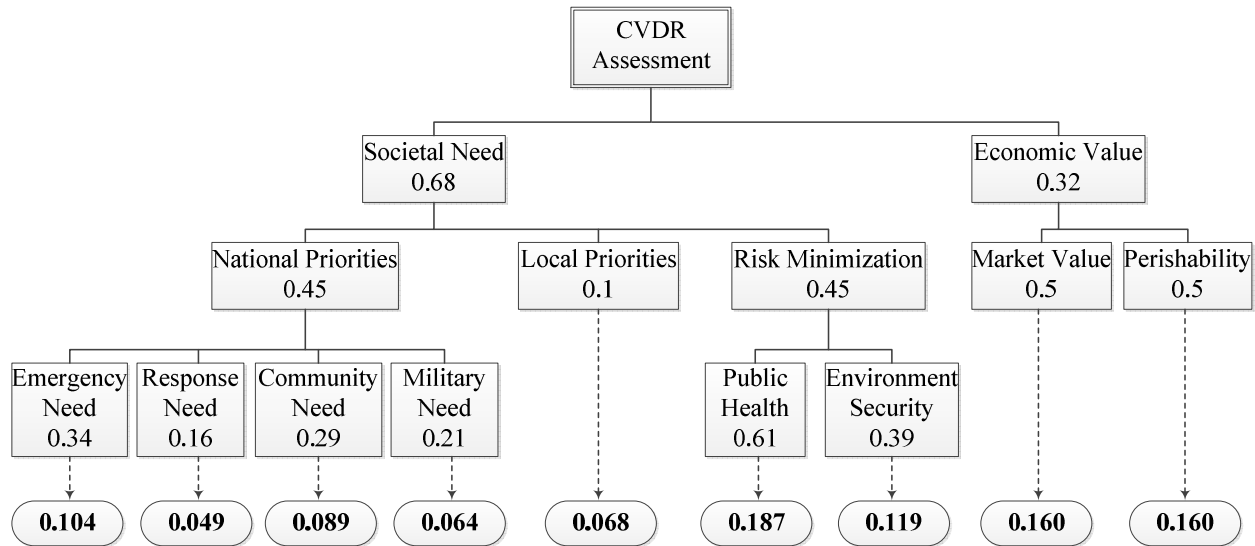
Figure 10 Local and Global Weights for Inland Waterway Example

Step 6 Alternative Generation

One notable advantage of VFT is that the values guide the creation of better alternatives (Keeney, 1996). However, in our CVDR assessment, the cargo alternatives are pre-determined as the cargo types that are being transported on the disrupted transportation system during the decision period. In our example, we have six two-digit commodity types (USACE, 2014) as the cargo alternatives shown in Table 10, which provide a general coverage of all the cargo types that are transported on the inland waterway system. In general, CVDR users determine the cargo alternatives based on historical data or current information regarding the cargo types that travel along the disrupted transportation segment.

Table 10 Example Cargo Alternatives (USACE, 2014)

Two-digit Code	Cargo Type	Market Price
10	Coal, Lignite and Coal Coke	$36.29/ton
20	Petroleum and Petroleum Products	$403.39/ton
30	Chemicals and Related Product	$399.88/ton
40	Crude Materials, Inedible, Except Fuels	$134.61/ton
50	Primary Manufactured Goods	$396.45/ton
60	Food and Farm Products	$164.52/ton

Step 7 Alternative Scoring

Once the evaluation measures and cargo alternatives are determined, the alternatives are scored with regards to each measure. Table 10 includes the market price data for each cargo type found in our example from International Monetary Fund (IMF, 2014) and U.S. Energy Information Administration (USEIA, 2014) to measure the Market Value. In order to assess the cargo alternatives on the constructed evaluation measures, the research team conducted each scoring process under careful assessment and consideration regarding the level at which each alternative addresses components of constructed measures. Table 11 presents the scores given to the inland waterway barge cargo alternatives on the eight constructed measures in our example.

Table 11 Example Alternative Constructed Measures Scoring

Cargo Type	Emergency Need	Response Need	Community Need	Military Need	Local Priorities	Public Health	Environment Security	Perishability
Coal	2	1	3	1	3	2	3	1
Petroleum	2	1	3	4	4	3	5	1
Chemicals	3	1	3	3	2	3	5	1
Crude Materials	1	1	4	1	2	2	3	1
Primary Mfd. Goods	4	2	3	2	2	2	3	1
Food and Farm Products	3	1	2	4	1	1	3	2

Step 8 Deterministic Analysis

The immediate result we obtain in Step 8 is the aggregate score of each cargo alternative and subsequently their overall ranking from the additive value function in Equation 1 (Dillon-Merrill, 2008):

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i), \text{ where } \sum_{i=1}^{n} w_i = 1 \tag{1}$$

where w_i denotes the global weights developed in Step 5 for each value I and $v_i(x_i)$ denotes the SDVF with measure score x_i assigned in Step 7. Once the aggregate score of each cargo alternative is estimated and the overall ranking is summarized, decision makers can derive the CVDRs using a mapping system to convert the alternative overall score into the CVDR. The decision makers first determine the estimated high and low CVDRs based on their expertise regarding the features of cargoes transported on their applicable transportation system. As a rate representing how much the cargo's economic and societal value diminishes as time elapses, decision makers must ensure that the CVDR takes time and volume into consideration and the

money unit must be in accordance with that of the market price. The high and low CVDRs we assign in our example are $1.50 and $0.50 per ton per hour respectively. The decision maker calculates the CVDR for alternative k according to Equation 2:

$$CVDR_k = CVDR_{max} - \frac{(VS_{max} - VS_k) \times (CVDR_{max} - CVDR_{min})}{VS_{max} - VS_{min}} \qquad (2)$$

where $CVDR_{max}$ and $CVDR_{min}$ denote the high and low CVDRs assigned by the decision maker(s); VS_{max} and VS_{min} represent the maximum and minimum VFT scores calculated from Equation 1; and VS_k is the VFT score of alternative k. Equation 2 is used to normalize the VFT score into the CVDR range to obtain its CVDR value. Table 12 shows the total VFT score and the CVDR for each cargo alternative in our example. Petroleum, the alternative with the maximum aggregate score, is aligned with the upper-bound CVDR value ($1.50 per ton per hour). The Coal alternative is assigned the lower-bound CVDR value ($0.50 per ton per hour) due to its lowest VFT score. The remaining cargo alternatives are mapped with the CVDR according to their VFT scores. Figure 11 exhibits the contribution of each lowest-tier value to the overall VFT score of each cargo type, which allows the decision maker(s) to review and validate the VFT scores as well as the CVDR results. The Petroleum, Chemicals, and Primary Manufactured Goods alternatives have the highest VFT scores (thus the highest CVDRs) due primarily to their high scores on the three most heavily weighted values: Public Health, Environment Security, and Market Value. In general, the cargo alternatives with high VFT scores as well as the corresponding CVDRs address greater societal and economic need, and their value decreases more rapidly during the disruption response.

Table 12 Inland Waterway Disruption Example CVDR Results

Alternatives		VFT Score	CVDR ($ per ton per hour)
Two-digit Code	Cargo Commodity Type		
10	Coal, Lignite and Coal Coke	0.294	0.50
20	Petroleum and Petroleum Products	0.663	1.50
30	Chemicals and Related Product	0.636	1.43
40	Crude Materials, Inedible, Except Fuels	0.313	0.55
50	Primary Manufactured Goods	0.575	1.26
60	Food and Farm Products	0.450	0.92
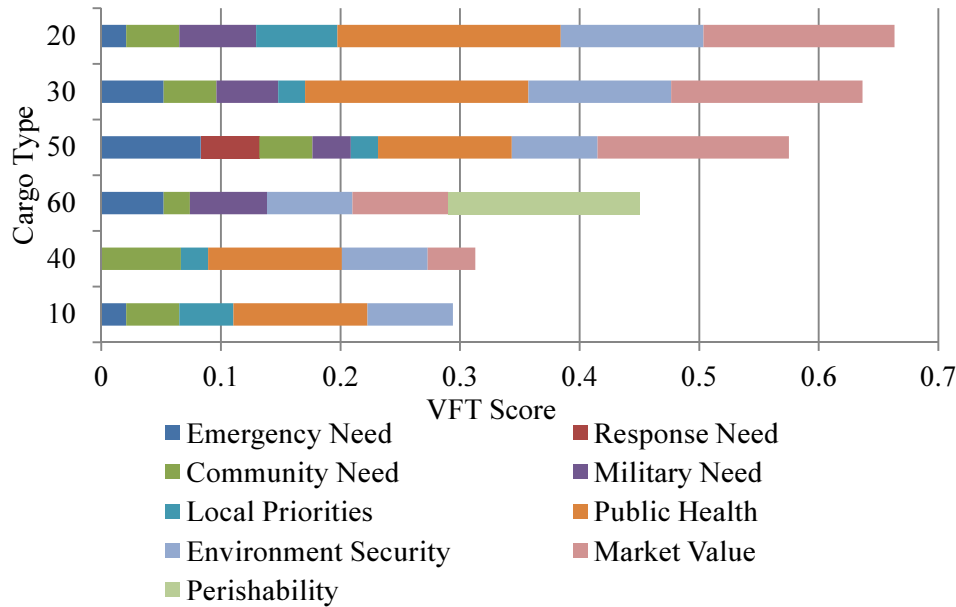
Figure 11 Inland Waterway Disruption Example Results by Value

Step 9 Sensitivity Analysis

A sensitivity analysis is conducted to examine the influence of weights of the second-tier values on the alternative VFT scores. Figure 12 displays the sensitivity analysis results when the proportion of the second-tier values is varied from 0%/100% to 100%/0% (the weight proportion is represented by "weight of Societal Need/weight of Economic Value"). The base weight

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proportion (68%/32%) of the two second-tier values is represented as the vertical dashed line that

leads to the same results as shown in Table 12 and Figure 11. In general, all of the six

alternatives are sensitive to changes in the importance of the second-tier values since none of

them rank the same when weight proportion varies. However, we observe stability from the

alternatives if the weight changes within a certain range. For example, if the decision maker

attaches greater importance to Economic Value over Societal Need, Food and Farm Products

cargo dominates all of the other alternatives when the weight of Economic Value is larger than

65% (and Societal Need is less than 35%). If the decision maker stresses the importance of

Societal Need and increases its weight beyond 50%, three cargo alternatives, Petroleum,

Chemicals, and Primary Manufactured Goods, form a group dominating the other three cargo

alternatives and are insensitive to changes in the weights given to Societal Need and Economic

Value. Coal, Crude Materials, and Food and Farm Products cargoes still exhibit some sensitivity

within this range according to their changing priority orders. The sensitivity analysis provides

additional insight into the impact of the importance weights on the final alternative CVDR
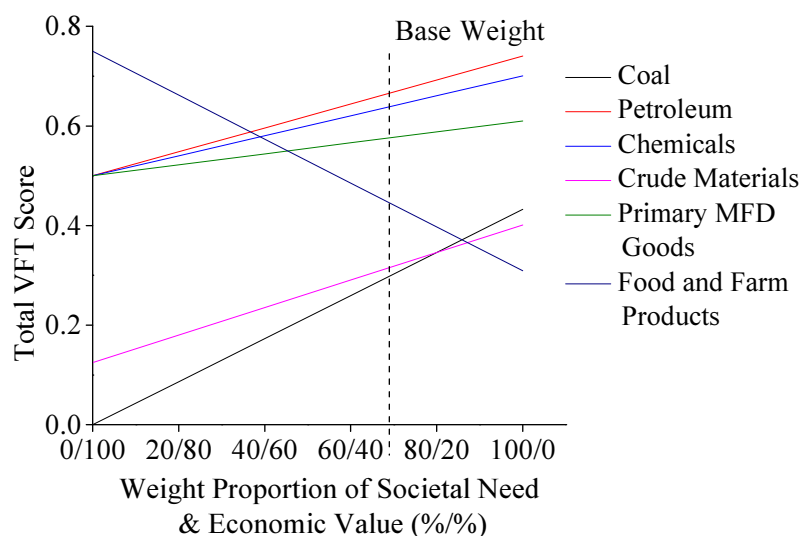
results.

Figure 12 Sensitivity Analysis of Value Weights on CVDR Results

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Step 10 Recommendations and Conclusions

In this step, decision makers review and validate the previous nine steps, finalize the VFT scores

and rankings, and calculate the CVDRs to support the transportation disruption response. In our

inland waterway barge cargo example, the final VFT scores are Petroleum (0.663), Chemicals

(0.636), Primary Manufactured Goods (0.575), Food and Farm Products (0.450), Crude

Materials (0.313), and Coal (0.294). The alternative rankings are generally in accordance with

our expectations, and the total VFT scores provide more precise evaluation of the cargo

alternatives. Based on the VFT results together with the estimated CVDR range, the CVDRs per

ton per hour for the inland waterway barge cargo example are finalized as Petroleum ($1.50),

Chemicals ($1.43), Primary Manufactured Goods ($1.26), Food and Farm Products ($0.92),

Crude Materials ($0.55), and Coal ($0.50).

4. Practical Implications for Engineering Managers

During the transportation disruption response period, engineering managers supervising the

freight movement of a transportation segment are confronted with the challenge of rerouting the

disrupted cargo while mitigating system impacts. The value of the disrupted cargo is influenced

by societal and economic aspects. Therefore, cargo value loss should be considered as the critical

or even guiding indicator to make the most effective cargo prioritization decision among

strategies to reroute the disrupted cargo. The proposed methodology fills in a methodology gap

in the literature by providing an assessment mechanism for developing CVDRs, and engineering

managers can incorporate this method to calculate the value decreasing rates of disrupted

cargo/freight in their prioritization and rerouting decision making.

5. Conclusions and Future Work

Disruptions caused by unexpected events may happen on any segment in the freight transportation network. Cargo prioritization models are required to reroute cargo in order to achieve the minimal disturbance impacts on the transportation system, and total value loss is a valid approach to evaluate the most effective cargo prioritization decision. In this paper, we provided a comprehensive methodology based on VFT to assist decision makers in determining a numerical CVDR to measure the total value loss of the disrupted cargo. Based on the VFT concept, along with relevant governmental documents and solicited expert opinions from transportation stakeholders, we developed a value hierarchy that incorporates all key values considered by the decision makers during the transportation disruption response period. Evaluation measures, value functions, and weights are developed to address each value in the hierarchy. The overall VFT scores of the cargo types (alternatives) serve as the basis to produce the CVDRs. Sensitivity analysis demonstrates how sensitive the alternative scores and rankings are when the second-tier values' weight proportion varies. A barge cargo example based on an inland waterway disruption is embedded in the methodology description. Similar applications of our VFT CVDR methodology can be implemented by the decision makers for different cargo alternatives associated with the transportation disruption. The first four steps in the ten-step VFT framework can be used directly by any decision maker with customized adjustment on the next six steps.

Among the merits of the developed VFT CVDR methodology, keeping the decision makers focus on the core values is ranked at the top of the list. The most important values to these transportation-related decision makers are retained at the center of the analysis and make a direct

impact on all of the assessment steps. Our VFT CVDR method provides guidance to soliciting expert opinions in an informative, rigorous, and structured way.

There are several opportunities related to the future extensions of this work. The first one is to explore additional approaches to convert the final VFT scores into the CVDRs. Second opportunity is to evaluate CVDRs based on VFT by applying them to the cargo prioritization models as the model input. In our previous studies (Authors, 20##), we developed a model for the cargo prioritization and terminal allocation problem (CPTAP) for inland waterway disruptions, which presents an opportunity to implement the VFT CVDRs in practice and examine their influence on the prioritization decision. We also would like to implement the VFT CVDR methodology, together with the CPTAP model, during a real-world scenario in order to examine the extent of its practical contributions. At last, we are interested in developing an Excel VBA program to facilitate the application of the VFT CVDR methodology. This tool can be used as part of disaster preparedness and response for which transportation engineering managers estimate the regular cargo movement on their investigating transportation segment and derive the CVDRs for future use.

Appendix 1

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Subject: Multi-author Documentation

This memorandum is to confirm that Jingjing Tong is the first author of the following article and completed at least 51% of the work for the article.

"Value-focused assessment of cargo value decreasing rate"

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7. MULTI-ATTRIBUTE DECISION MODEL FOR CARGO PRIORITIZATION WITHIN INLAND WATERWAY TRANSPORTATION[7]

Jingjing Tong, M.S.

Heather Nachtmann, Ph.D.

Abstract

Inland waterways are an integral part of the Nation's transportation system. Disruption of the inland waterways can have widespread economic and social impacts. These detrimental consequences can be mitigated by prioritizing the barge cargoes for offloading to ensure that the most essential cargoes are identified and moved from the inland waterway promptly. A number of characteristics are attached to the cargoes, which enable the decision maker to prioritize among them. For example, we want to prioritize removal of hazardous cargo to mitigate risk and movement of essential cargoes for industry continuity. We present a multi-attribute decision approach using the Analytic Hierarchy Process (AHP) that integrates multiple factors to indicate the prioritized ordering of barge cargoes. Higher priority cargo is given the greatest consideration for offloading, while the lower priority cargo is least preferred according to the model and may be retained on the inland waterway.

Key Words: Inland Waterways; Cargo Prioritization; Multi-attribute Decision Making; Analytic Hierarchy Process

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1. Introduction

The commercially important U.S. inland waterway system is an open system consisting of 12,000 miles of navigable waterways managed by the U.S. Army Corps of Engineers (Clark et al., 2005). Inland and intracoastal waterways serve thirty-eight States with nearly 200 commercially active lock sites (USACE, 2009). The Nation's "marine highways" are an important component of the nation's transportation system and considered as a critical transportation mode for certain commodities and geographical regions. Disruptions on the inland waterway system can have widespread economic and societal impacts. In order to mitigate these impacts, the research funded by the U.S. Department of Homeland Security has been conducted to formulate and solve a nonlinear integer program of cargo prioritization and terminal allocation problem (CPTAP) that minimizes the total value loss of the barge cargoes due to disruption on the inland waterway transportation system (Tong and Nachtmann, 2012). Several important attributes are identified as important to the CPTAP including hazardous cargo, terminal capacity, barge draft, cargo value, and commodity type. However, there are additional qualitative factors that can influence the offloading priority of barge cargoes. The objective of this paper is to develop a multi-attribute decision model that integrates multiple tangible and intangible factors to offer a new perspective to solve the cargo prioritization problem for inland waterway disruptions. We employ the Analytic Hierarchy Process (AHP) approach to establish the multi-attribute decision model. It was developed by Saaty in the middle of 1970s, which converts the subjective evaluation for the intangible (qualitative) factors to numerical values and includes both quantitative and qualitative factors to draw the final decision (Bandeira et al., 2009). The remainder of this paper is organized as follows: *Literature Review* includes a concise literature review of select papers focused on cargo prioritization as well as AHP application in

prioritization and ranking, *Problem Description* describes the cargo prioritization problem within inland waterway transportation, the general model is constructed in *AHP Model*, the model application is illustrated in *Case Study*, and the *Conclusions* summarizes the paper and discusses our future research directions.

2. Literature Review

The literature contains cargo prioritization techniques in various application contexts (Tong and Nachtmann, 2013). Lau et al. (2009) introduced a profit-based loading heuristic, one step of which is sorting cargo based on shipping cost paid by the cargo owners as measured by the chargeable weight of the cargo. Bennett (2002) examined the marketing environment for rural communities and prioritizes products based on their economic and social importance in order to identify products that should receive additional marketing attention. The U.S. Navy's logistics system employs a uniform material movement and issue priority system (UMMIPS) to prioritize the materials according to movement importance (Grandjean and Newbury, 2001). Ibrahim and Ayyub (1992) proposed a fuzzy multi-criterion risk-based prioritization method to determine the order in which the critical components of a system are inspected for enhancing the inspection effectiveness. A cargo prioritization and terminal allocation problem (CPTAP) model is developed to provide decision support to disruption response stakeholders on how to respond to the disruption and redirect affected barge traffic in order to minimize detrimental effects (Tong and Nachtmann, 2013). The model delivery indicates the terminal that each disrupted barge is assigned to for offloading and the prioritized turn each barge takes at its assigned terminal. AHP is widely used by decision makers and researchers to solve different problems, and a large number of papers have been published relating to the AHP application. Vaidya and Kumar (2006)

classified the AHP papers according to the theme such as "selection, evaluation, benefit-cost analysis, allocations, planning and development, priority and ranking, and decision-making." We primarily focus on the papers that fall into the "priority and ranking" category which is more similar to our proposed cargo prioritization problem. Bandeira et al. (2009) applied AHP technique to prioritize the maritime booking confirmations in the event of the scarcity of the transportation supply. Financial, managerial and organizational factors are incorporated in the evaluation process of the clients, which is on the consensus of both the sales team and the top executives. Farhan and Fwa (2009) explored the AHP application on the prioritization of the pavement maintenance activities with the objective of reflecting the engineering opinions of a group of highway agencies and engineers. Three AHP forms are considered and compared in terms of their suitability and effectiveness in the priority assessments according to a direct assessment method. Modarres and Zarei (2002) examined the city vehicle transport network for the earthquake crisis preparation, using an AHP model to determine the trip priorities and the shortest path theory to identify the fastest and safest routes. Hafeez et al. (2002) looked into how to determine a firm's key capabilities in order to improve its core competencies and adopted AHP to construct the evaluation framework. Contributions of firm capabilities are assessed for both financial and non-financial performances. An interesting field in which AHP approach is also widely employed as the decision method is the sports management. One example is Bodin and Epstein (2000)'s paper of using AHP to rank the players in the professional baseball team for the expansion draft. Braglia (2000) explored the effectiveness of AHP by proposing the multi-attribute failure mode analysis (MAFMA). It uses an AHP-based method to prioritize failures identified in the reliability research in order to determine the most appropriate corrective actions.

3. Problem Description

The cargo prioritization problem for inland waterway disruptions is graphically shown in Figure 1. As an example, one of the lock and dam (L/D) systems located along the river section is disrupted and no longer functioning, which causes the inland waterway to close thus halting traffic traveling up and down the river at the point of disruption. Other disruptions could include non-navigable water level due to drought or flood, vessel allision or collision, and other infrastructure disruptions. The barge tows (typically consisting of five to twelve barges) that are traveling in the direction away from the disruption are unaffected and able to continue transport to their destination. Barge tows (depicted in bold) that are traveling towards and beyond the disrupted L/D are affected and no longer able to travel to their destination via the disrupted waterway. The cargo on the disrupted barges is the focus of our cargo prioritization model. We aim to identify the most essential cargoes based on the select influencing factors and remove these cargoes from inland waterway promptly. The higher priority cargoes are given the greatest consideration for offloading (e.g. given the first order at the nearest capacity-allowed terminal); while the lower priority cargoes are least preferred according to the model and may be retained on the inland waterway.

We assume that there are sufficient towing vessels to transport the individual barges to their redirected alternative terminals. Since the marine highway system is effectively divided into two sections by the disrupted L/D, there are actually two cargo prioritization decisions to make; one for the river section above the disruption and one for the river section below the disruption.
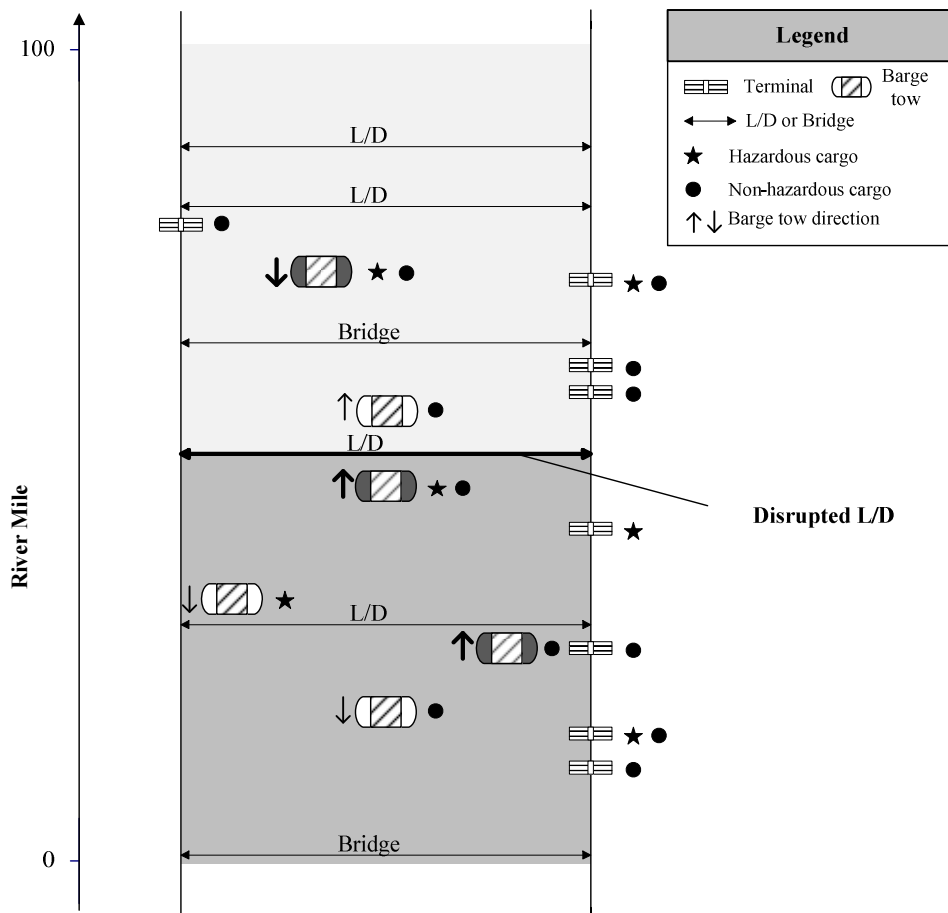
Figure 1 Graphical Description of Cargo Prioritization Problem

4. AHP Model

The basis of the cargo prioritization problem above is a set of prioritization factors associated with the cargoes, which can assist the decision maker in distinguishing between the barge cargoes and prioritize them in a desirable manner. A multi-attribute decision model that integrates these multiple factors is a promising approach to assess the prioritized ordering of the barge cargoes.

As a multi-attribute decision making tool, AHP was developed by Saaty in 1970s and has been widely used in many fields. It successfully incorporates both qualitative and quantitative factors

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to assess the multiple alternatives in a mathematically rigorous manner. It is a proven and effective approach to weight multiple attributes, evaluate data describing the attributes and alternatives, and check the comparison consistency of the decision makers. AHP relies on the belief that an individual can reasonably perform the pairwise comparisons (Bandeira et al., 2009). This technique is capable of synthesizing the subjective judgments of multiple individuals and draws a reconciled conclusion. For the cargo prioritization problem we are investigating which involves multiple attributes and alternatives, AHP is a simple, straightforward and effective approach.

Figure 2 displays the four-level AHP decision hierarchy for the cargo prioritization problem in the context of inland waterway transportation. At the top level is the overall goal: "*How to minimize the negative impacts of the inland waterway transportation disruption*?" The attributes and the subattributes are located at the second and the third levels respectively, and the bottom level consists of the alternatives – the barge cargoes whose transportation is interrupted by the disrupted inland waterway.
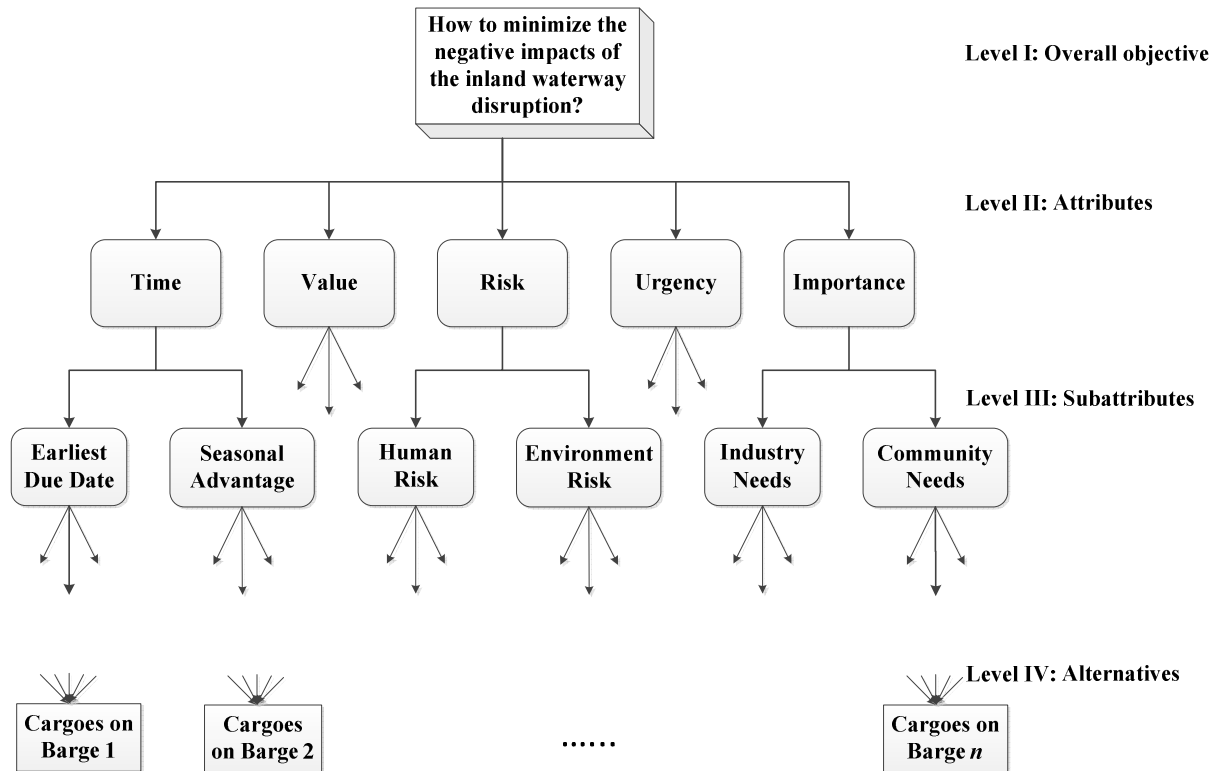
Figure 2 AHP Decision Hierarchy for Cargo Prioritization within Inland Waterway Transportation

In terms of how to choose the attributes and subattributes, we rely on a systematic literature review of existing cargo prioritization models, which was carried out in our preliminary research (Tong and Nachtmann, 2012). In our review, twenty pertinent papers were selected including publications from governmental agencies and academic institutions. The factors obtained from the selected papers were organized in a factor matrix that describes and categorizes each factor. The attributes and the subattributes are derived from carefully contemplating each factor in the factor matrix and selecting the factors that best fit the inland waterway transportation disruption context. The brief explanation of the attributes and subattributes is provided below:

- *Time* – A temporal attribute that is broken down into two subattributes:

- *Earliest Due Date* (EDD) (Armstrong et al., 1983) – EDD is one of the most popular criteria in the cargo prioritization literature. The wide usage is due to its close relevance to the quality of customer service. Prioritization based on EDD guarantees that the cargoes are sequenced and delivered to the customers in order to minimize the total due date violation, which correspondingly increases the total customer satisfaction level. However, EDD may not be readily available for all the barge cargoes.

- *Seasonal Advantage* (Bennett, 2002) – Since seasonal cargo is not consistently available at all times of the year, it is assumed to have higher priority when it is present on the inland waterway. For example, grain is generally transported during its harvest season and prioritized to some extent due to its scarcity in other seasons. When considering this factor, the perishability of certain cargo is accounted for at the same time.

- *Value* (Aragon, 2000) – More valuable cargo receives higher priority.

- *Risk* – The cargo that exposes the relevant objects to potential harm is prioritized to be offloaded from inland waterway. Hazardous cargo is given greater weight regarding to this attribute and is usually prioritized due to its potential detrimental impact. Risk has the following two subattributes:

  - *Human Risk* (Ibrahim and Ayyub, 1992) – It is the risk to the humans on the barge tow and in the vicinity of the nearby river section.

  - *Environment Risk* (Hansen and Cowi, 2003) – It is the risk to the waterway and surrounding land nearby.

- *Urgency* (Grandjean and Newbury, 2001; USDHS, 2007) – The cargo is given a higher priority if it is required to fulfill urgent needs such as for military or medical use. It is defined from military or public perspective instead of private or customer perspective. Strategic commodities are often considered urgent in the literature.

- *Importance* – This attribute is divided into two subattributes:

  - *Industry Needs* (USDHS, 2007) – The cargo that is important for industrial continuity is prioritized.

  - *Community Needs* (USDHS, 2007) – The cargo that is important for ordinary life is prioritized.

The construction of the decision hierarchy is an essential first step in developing an AHP model. Based on the model structure, we then proceed to evaluate attributes, subattributes and alternatives in order to draw the final cargo prioritization decision.

5. Case Study

We utilize six alternatives for the case study, each representing the cargo on a disrupted barge. We focus on the two-digit cargo commodities defined by the USACE that are most commonly transported on the inland waterway transportation system (USACE, 2012). A brief description of the alternatives is presented below. The cargo volume on each barge is assumed to be 1000 tons per barge.

- Alternative 1: Coal is being transported on the inland waterway and scheduled to arrive *Factory A* in two weeks. Its value is $74,315 per ton in the market. In general, coal products are not considered to be hazardous cargo. It is moderately important as fuel for energy and heating generation.

- Alternative 2: The barge is transporting petroleum to the customer location *B* in four weeks. The market value is $220,893 per ton. Due to its flammable nature, petroleum products have great potential to cause severe harm to humans and environment.

- Alternative 3: Chemicals are being moved on the waterway transportation to reach *Company C* in two weeks. The market value is $86,714 per ton. The chemicals being carried by the barge are dangerous to humans and environment upon exposure, and they are necessary commodities for the chemical industry.

- Alternative 4: Crude materials are transported by the barge for further processing operation at *Factory D*. It is required to enter the production line by the end of next week. Its value is $130,920 per ton in the market. These minimally processed products are comparatively steady in state and have little negative impact on humans and the environment. These crude materials are important raw materials for many industries.

- Alternative 5: This barge is transporting primary manufactured goods that are being transported to *Retailer E* without any specific due date. Its market value is $271,830 per ton. These are urgently needed products for the medical industry.

- Alternative 6: Food and farm products are being transported by barge to *Community F* with a due date of four weeks. The products have a market value of $220,835 per ton. They are important products for community continuity.

The six alternatives are indicated in the bottom level of the decision hierarchy in Figure 2, forming an integrated AHP hierarchy for the case study. Then we determine the priorities of the elements at each hierarchical level in regard to the each element at the higher hierarchical level and calculate the overall priorities for alternatives. Table 1 is the nine-point comparison scale

that is used to carry out the pairwise comparisons of the elements in order to compute their priorities.

Table 1 AHP Comparison Scale (Canada et al., 2005)

Definition	Value
Equally important/preferred	1
Moderately more important/preferred	3
Strongly more important/preferred	5
Very strongly more important/preferred	7
Absolutely more important/preferred	9
Intermediate values	2, 4, 6, 8

Priority Evaluation of Attributes and Subattributes

Table 2 presented the relative importance of the attributes with respect to the overall goal. We compare all possible attributes pairs using the comparison scale in Table 1. The last column contains the computed priorities of each attribute: Risk has the highest priority (0.480), followed by Urgency (0.233), Importance (0.146), Time (0.091) and Value (0.051). The consistency ratio is 0.058 indicating that the judgmental consistency is acceptable. Table 3 indicates the relative importance of the subattributes with respect to their associated attributes.

Table 2 Attribute Priority Evaluation

Attribute	Time	Value	Risk	Urgency	Importance	Priority
Time	1	3	1/7	1/3	1/2	0.091
Value	1/3	1	1/6	1/2	1/3	0.051
Risk	7	6	1	3	3	0.480
Urgency	3	5	1/3	1	2	0.233
Importance	2	3	1/3	1/2	1	0.146
Consistency Ratio = 0.058						

Table 3 Subattribute Priority Evaluation

Attribute	Subattribute	
Time	EDD	Seasonal Advantage
	0.7	0.3
Risk	Human	Environment
	0.6	0.4
Importance	Industry	Community
	0.4	0.6

Priority Evaluation of Alternatives

According to the AHP hierarchy presented in Figure 2, alternative comparisons needs to be

undertaken for all eight elements in both attribute and subattribute levels. Priority evaluation is

accomplished using either subjective judgments or quantified performance data. The relative

importance of the alternatives with regard to subattribute *EDD* and *Human Risk* are presented

below as examples. The performance data of *EDD* is available from the alternative description.

Alternative 5 does not provide the *EDD*. We assume there is no requirement of *EDD* and thus

assign a comparatively large value 50 to Alternative 5. Since higher priority is given to

alternatives with earlier *EDDs*, we first calculate the ratio of the earliest *EDD* to each

alternative's *EDD* and then normalize the ratios as shown in Table 4. Alternative 4 is given the

highest priority due to its earliest *EDD*, while Alternative 5 which has no *EDD* requirement

obtains the lowest priority value.

The subjective judgment of pairwise comparisons is employed to determine the alternative

priorities with regard to the subattribute – *Human Risk* – for which no performance data is

provided. Pairwise comparisons are taken on the basis of the cargo characteristic described in the

alternative description. The results show that Alternatives 2 and 3 are prioritized as the top two

alternatives in terms of their potential risk to human, which is in accordance with the fact that

Alternatives 2 and 3 are the hazardous cargoes of petroleum products and chemicals. The

consistency ratio is within the acceptance level.

Table 4 Alternative Priority Evaluation (EDD)

	EDD	Ratio	Priority
A1	2	0.5	0.198
A2	4	0.25	0.099
A3	2	0.5	0.198
A4	1	1	0.397
A5	50	0.02	0.008
A6	4	0.25	0.099

Table 5 Alternative Priority Evaluation (Human Risk)

	A1	A2	A3	A4	A5	A6	Priority
A1	1	1/7	1/6	1	1	1	0.059
A2	7	1	3	7	7	7	0.480
A3	6	1/3	1	5	5	5	0.279
A4	1	1/7	1/5	1	1	1	0.061
A5	1	1/7	1/5	1	1	1	0.061
A6	1	1/7	1/5	1	1	1	0.061

Consistency Ratio = 0.0125

Other calculations of alternative priority evaluation can be found in the Appendix 1. We assume

only Alternative 6 (farm and food products) is a seasonal cargo. The general guidelines of

carrying out the pairwise comparisons with respect to attributes/subattributes are described at the

beginning of Section 5. We did encounter the situation where the consistency ratio is larger than

0.1 and solved the inconsistent judgment issue by adjusting the entries for several pairwise

comparisons.

Alternative Priority

Once the priority assessments of the attributes, subattributes and alternatives are complete, we

derive the overall alternative priorities, which are shown in Table 6. Table 6 summarizes the

results of all priority evaluations and utilizes the following formula to calculate the overall

alternative priorities.

Alternative k priority = $\sum_{\text{all } i \text{ subdivided attributes}}$ (priority weight$_i \times \sum_{\text{all } j \text{ subattributes derived from } i}$ (priority

weight$_j \times$ evaluation priority$_{ijk}$)) + $\sum_{\text{all } i \text{ attributes}}$ (priority weight$_i \times$ evaluation priority$_{ik}$)

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Table 6 Overall Alternative Priority

Alter-natives	Time (0.091)		Value (0.051)	Risk (0.480)		Urgency (0.233)	Importance (0.146)		Overall Alternative Priority
	EDD (0.7)	Seasonal (0.3)		Human (0.6)	Envir. (0.4)		Industry (0.4)	Comm. (0.6)	
A1	0.198	0.125	0.074	0.059	0.107	0.063	0.078	0.075	0.083
A2	0.099	0.125	0.220	0.480	0.453	0.392	0.144	0.148	0.359
A3	0.198	0.125	0.086	0.279	0.251	0.064	0.211	0.043	0.180
A4	0.397	0.125	0.130	0.061	0.048	0.068	0.465	0.044	0.109
A5	0.008	0.125	0.270	0.061	0.092	0.228	0.038	0.262	0.131
A6	0.099	0.375	0.220	0.061	0.048	0.185	0.064	0.429	0.139

The petroleum products in Alternative 2 obtain the highest priority (0.359) in large part due to their high rankings with regard to the two most prioritized attributes – *Risk* and *Urgency*. The chemicals in Alternative 3 have the second highest priority (0.180). The third to sixth priorities are given to food and farm products in Alternative 6 (0.139), primary manufactured goods in Alternative 5 (0.131), crude materials in Alternative 4 (0.109) and coal in Alternative 1 (0.083) respectively. Among the last four alternatives, some of them have the highest priority with respect to a particular attribute/subattribute, e.g. food and farm products in Alternative 6 ranks highest on the subattribute "community needs". However, the attribute/subattribute does not contribute sufficiently to the overall goal.

After determining the overall alternative priorities we make transportation plans to move the cargo alternatives with the highest priorities. For instance, in the case study, the petroleum products in Alternative 2 are assigned to the nearest terminal that has the necessary conditions and capacity to receive this barge. Planners would need to make sure that the terminal facilities and laborers are ready to offload these barges. The second prioritized cargo, the chemicals in Alternative 3, are assigned to the nearest capacity-allowed terminal for offloading under the

condition that they do not influence the handling operation for the cargo alternatives with higher priorities. If they do, they are sent to the second-nearest feasible terminal, so on so forth for the remaining alternatives. The lowest priority alternatives may need to remain on the inland waterway instead of transporting to a terminal.

6. Conclusions

This paper has presented a multi-attribute decision making approach to tackle the cargo prioritization problem within an inland waterway transportation disruption. AHP is selected as the multi-attribute decision tool that can integrate both qualitative and quantitative factors to determine the final alternative priorities. An AHP decision hierarchy is established for the inland waterway disruption decision based on a literature review of existing cargo prioritization research. We provide a case study of six alternatives barge cargoes to illustrate the AHP application and derive a solid priority decision that is in accordance to the alternative assumptions.

A forthcoming extension of this paper is to apply the presented AHP model to a realistic waterway disruption scenario. Ho (2008) pointed out that the focus of AHP application has transformed from stand-alone AHP to integrated AHP, which combines AHP with other techniques such as mathematical programming, meta-heuristic and SWOT analysis. The integrated AHP is another interesting direction for future work. One way is to use AHP to prioritize the factors identified in the literature instead of the cargo alternatives and construct a mathematical model to cover the most essential factors observed from the AHP results.

Acknowledgement

Appendix 1

Alternative Priority Evaluation (Value)

	Value	Priority
A1	74315	0.074
A2	220893	0.220
A3	86714	0.086
A4	130920	0.130
A5	271830	0.270
A6	220835	0.220

Alternative Priority Evaluation (Seasonal Advantage)

	A1	A2	A3	A4	A5	A6	Priority
A1	1	1	1	1	1	1/3	0.125
A2	1	1	1	1	1	1/3	0.125
A3	1	1	1	1	1	1/3	0.125
A4	1	1	1	1	1	1/3	0.125
A5	1	1	1	1	1	1/3	0.125
A6	3	3	3	3	3	1	0.375

Consistency Ratio = 0

Alternative Priority Evaluation (Environment Risk)

	A1	A2	A3	A4	A5	A6	Priority
A1	1	1/5	1/4	3	1	3	0.107
A2	5	1	3	7	5	7	0.453
A3	4	1/3	1	5	3	5	0.251
A4	1/3	1/7	1/5	1	1/2	1	0.048
A5	1	1/5	1/3	2	1	2	0.092
A6	1/3	1/7	1/5	1	1/2	1	0.048

Consistency Ratio = 0.026

Alternative Priority Evaluation (Urgency)

	A1	A2	A3	A4	A5	A6	Priority
A1	1	1/5	1	1	1/5	1/3	0.063
A2	5	1	7	6	2	2	0.392
A3	1	1/7	1	1	1/3	1/3	0.064
A4	1	1/6	1	1	1/4	1/2	0.068
A5	5	1/2	3	4	1	1	0.228
A6	3	1/2	3	2	1	1	0.185

Consistency Ratio = 0.011

Alternative Priority Evaluation (Industry Needs)

	A1	A2	A3	A4	A5	A6	Priority
A1	1	1/3	1/5	1/7	3	2	0.078
A2	3	1	1/2	1/7	5	3	0.144
A3	5	2	1	1/3	5	3	0.211
A4	7	7	3	1	7	5	0.465
A5	1/3	1/5	1/5	1/7	1	2	0.038
A6	1/2	1/3	1/3	1/5	1/2	1	0.064

Consistency Ratio = 0.068

Alternative Priority Evaluation (Community Needs)

	A1	A2	A3	A4	A5	A6	Priority
A1	1	1/3	3	2	1/5	1/7	0.075
A2	3	1	4	5	1/3	1/5	0.148
A3	1/3	1/4	1	1	1/5	1/7	0.043
A4	1/2	1/5	1	1	1/5	1/7	0.044
A5	5	3	5	5	1	1/2	0.262
A6	7	5	7	7	2	1	0.429

Consistency Ratio = 0.048

Appendix 2

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This memorandum is to confirm that Jingjing Tong is the first author of the following article and completed at least 51% of the work for the article.

"Multi-attribute decision model for cargo prioritization within inland waterway transportation"

Appendix 3

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June 23, 2014

Jingjing Tong, M.S.
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Regards,
Donna Calvert

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8. CONCLUSIONS AND FUTURE WORK

This chapter reviews the four main contributions of this dissertation, highlights the findings from the dissertation research, and provides extensions for future work. All four contributions focus on providing decision support for inland waterway stakeholders during disruption response. Specifically, we emphasize our research on the management of disrupted cargoes in such scenario; that is, how to handle cargoes being transported on the inland waterway when the disruption occurs with the goal of minimizing their total value loss. By intelligently managing this essential component of the inland waterway transportation, negative system impacts from the interruptive events can be mitigated effectively.

In the first contribution of this dissertation (Chapter 4), we conduct a thorough literature review regarding cargo prioritization methods and factors within general applications and reveal the lack of a systematic cargo prioritization methodology for inland waterway disruption response. In order to fill this gap, we first provide a detailed description of the identified Cargo Prioritization and Terminal Allocation Problem (CPTAP) on the inland waterways when disruption happens. Assumptions and influential factors for CPTAP are listed to clarify this novel problem that is defined within the inland waterway context for the first time. We develop a binary nonlinear integer program to model CPTAP with the objective function of minimizing total value loss of the disrupted cargoes. The model takes important factors into consideration such as terminal capacity, terminal water depth, barge volume, barge draft, cargo type, and cargo price. By quantitatively considering and integrating the characteristics and restrictions from various aspects associated to waterway freight movement, the CPTAP model delivers a cargo prioritization decision that is both near optimized and applicable to real world decision scenarios. We investigate two Genetic Algorithm (GA) approaches as part of our first endeavor to solve

CPTAP model. The test problem instances are carefully generated based on the real-world data related to inland waterway terminals, barges, and cargoes. With experiments conducted on small, medium, and large size instances, we find that both GA methods can obtain optimal solutions for small size instances and our Traditional GA approach outperforms our LCS GA approach for medium and large size instances since on average it produces better CPTAP results using less computation time. We also test the model and our Traditional GA on a realistic disrupted river scenario and find a substantial lower total value loss and response time compared to a naïve minimize distance approach. To summarize, the first research contribution provides complete disruption response guidance of what cargo should be prioritized for offloading and which terminal the cargo should be assigned to for the inland waterway decision makers. The achievement of the first contribution is threefold: a comprehensive definition of CPTAP, a well-grounded optimization model for CPTAP, and a first effective solution approach to realistic CPTAP decisions. Opportunities exist to expand the work in all of these three aspects. The problem definition and model may be improved by including additional real-world system attributes. Currently, we only prioritize cargo that is located on the river at the time of disruption. However, barges may travel into the disrupted area during the response period due to the absence of the available offloading terminals or the delayed disruption information. Further study on this stochastic scenario is of interest to us. Other problem and model variants may be needed due to additional restrictions or regulations in particular geographic regions, e.g. terminal labor limits may be a constraint in some areas. We are interested in examining these additional factors for potential inclusion in the model. Another extension opportunity is that additional solution approaches that fit CPTAP structure can be explored for better model results. In the second contribution, a Tabu search heuristic is examined with promising results for CPTAP. We believe

there may be classic optimization methods that are worth investigating including column generation and memetic algorithms.

As previously mentioned, we develop a Tabu Search (TS) heuristic for the CPTAP model in Chapter 5, which is the second major contribution. Though diversified in many aspects, heuristic development is typically governed by one of two principles, population search or local search. Since the GA method in Chapter 4 is a population search approach, examining the local-search TS heuristic satisfies our curiosity in its performance in solving the CPTAP and provides the opportunity to compare the two search principles for our problem. We first carry out a literature review on TS applications and identify the most potential TS heuristic – Unified TS – from multiple TS categories for CPTAP. Three TS variants are proposed based on different neighborhood structures and then compared to each other as well as to the recommended GA method presented in Chapter 4. We find that one of the three TS variants, TS with Blind Swap (TS-BS), is the best choice among the multiple TS variants in terms of both solution quality and computational efforts. Moreover, it also dominates the GA approach with smaller total value loss and the CPU time results. Our more depth analysis further confirms the success of TS heuristic as the second attempt on CPTAP solution method. It outperforms GA method with less response time which is a critical evaluation measure of the CPTAP heuristic effectiveness. Five medium and five large size instances are tested to compare cargo prioritization decisions based on CPTAP and a naïve distance minimization approach. We find that the cargo prioritization decision guided by CPTAP model solved by either GA or TS heuristic consistently and significantly improves the prioritization decision over simply minimizing distance and assigning disrupted cargoes to their nearest feasible terminals. In summary, the major achievement of the second contribution is a new TS heuristic proposed as CPTAP solution method and proven to be

a better approach than our first attempt to solve the CPTAP using GA method. Several opportunities exist for extending the work in Chapter 5. First, all experiments conducted in this contribution use generated instances instead of real-world disruption cases. We recently documented an inland waterway disruption event on the Arkansas River and are interested in consolidating the collected data to develop a real-case data set to test the CPTAP TS heuristic. Secondly, since local search has shown strong potential in solving the CPTAP model, other local search heuristics could be investigated as alternative CPTAP solution approaches including simulated annealing, hill climbing, and local beam.

Chapter 6 contains the third major contribution of this dissertation. During our research on the first two contributions for CPTAP, we identified a need for a systematic methodology to determine a value decreasing rate to measure the total value loss of disrupted cargo/freight. We derive a comprehensive methodology employing Value-focused Thinking (VFT) to address this need. Disruptive events happen on all modes of transportation, and the decision makers are confronted with the challenge to develop a rigorous cargo prioritization decision models to prioritize and reroute disrupted cargo/freight, in which the CVDR can be a crucial model component. We create the CVDR value hierarchy to include all critical values that influence cargo value loss to guide the evaluation process. One of the important advantages of our VFT CVDR methodology lies in this value hierarchy that uses the values to guide the practice of soliciting multiple expert opinions and integrating them to determine CVDRs. We provide the methodology in a step-by-step manner and include an example based on disrupted inland waterway barge cargo to clearly illustrate how the proposed methodology works. We develop a function based on the estimated CVDR range provided by the decision makers to translate the overall VFT scores to the CVDRs for each alternative and conduct a sensitivity analysis to

provide additional insights to the decision makers. To summarize, the third contribution is a complete and concise methodology to determine CVDRs for transportation systems. It is particularly helpful for our CPTAP model of the first two contributions that can now contain well-defined value decreasing rate parameters. Future work related to this contribution is to develop a more rigorous mapping system to convert the VFT scores directly to CVDRs. We believe there are multiple ways to perform the conversion process, and it is of interest to investigate and compare these to our current translation approach. Another opportunity to extend this work is to apply the VFT CVDR method to cargo prioritization models and evaluate their influences on the model output. Our developed cargo prioritization model for inland waterway disruption will be the first attempt to assess VFT CVDRs, followed by applications to cargo prioritization models in other transportation environments.

In Chapter 7, we present the fourth main contribution of this dissertation. The first three contributions focus on developing and supporting the mathematical modeling of the cargo prioritization for inland waterway disruption. However, there are intangible factors affecting the prioritization decision that cannot be easily incorporated into the pure mathematical formulation. Thus the fourth contribution contains our first attempt to investigate cargo prioritization problem through a multi-attribute decision model – the Analytic Hierarchy Process (AHP) – that involves both tangible and intangible attributes. The output of our AHP model is the prioritization ranking of the disrupted barge cargo. We construct an AHP decision hierarchy that includes all the attributes extracted from a literature review of the existing cargo prioritization models and identified as a good fit to the inland waterway disruption context. A case study of six different types of cargo carried by barge is used to illustrate the procedures of evaluating attributes and alternatives in order to derive the cargo prioritization decision. Different from heavily relying on

the real-world barge, cargo, and terminal data to draw the prioritization conclusion, the AHP methodology presented in Chapter 7 turns to the experienced experts (or decision makers) to find the solution (although we incorporated a limited amount of real data). In addition to provide another perspective to examine the cargo prioritization problem, the developed AHP methodology for inland waterway cargo prioritization may be more applicable in some areas or scenarios where data is not available, missing in large quantity, or cannot be collected in a short amount of time. Opportunities for the future work exist in testing the developed AHP methodology in a real waterway disruption response scenario, and developing terminal allocation approach that assigns the prioritized barge cargo to different terminals.

In addition to the future work discussed above, there are additional extensions to this dissertation research: 1) CPTAP model improvement. The primary reason that made the current CPTAP model hard to be solved by an exact approach is the unfixed parameter, the actual contributing time. By changing the decision variable and/or creating multiple time-related parameters to replace the actual contributing time, there is the possibility of remove this parameter and considerably reduces the model complexity. 2) CPTAP heuristic improvement. We have investigated heuristics that fall into both population search (GA) and local search (TS) categories. One direction that may further improve the solution is to combine these two search schemes together, by which we develop a heuristic benefits from both search capabilities. 3) Comparison of cargo prioritization decisions governed by CPTAP and AHP. Two completely different theories are behind this two proposed cargo prioritization methods: one is a pure mathematical model, and the other is a multi-attribute decision model. We are interested in comparing both approaches and identifying if there is significant disparity between these two models and the reasons such disparity may exist. One thing to note is that we need determine a solid terminal

allocation strategy for the AHP cargo prioritization method before conducting the comparison. (4) Cargo prioritization decision in other context. All of the models and methods in this dissertation research are developed under the assumption that public agencies (such as USCG and USACE) have absolute authority during the disruption management period. In real world scenarios, there are opportunities for the barge carriers/shippers to determine their actions once the inland waterway is disrupted and cargo prioritization decision tools should consider the interests of the carriers/shippers. We have developed a finite-horizon Markov decision process (MDP) model as the preliminary work in this area, which we will expand in the future.