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Simulation modeling of Houston Ship Channel vessel traffic for optimal closure scheduling

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ABSTRACT

This paper focuses on simulation and analysis of the Houston Ship Channel vessel traffic and operation, through a discrete event model in Arena. The model is applied to mitigate the consequences of the channel closure for constructing a new bridge over the waterway. To evaluate different closure scenarios, real world data is analyzed, and a single factor ANOVA is used to find significant vessel waiting time differences. In addition, Fisher pairwise comparison method is applied to specify the best closure alternative. The results reveal that the best closure scenario will decrease waiting time up to 70%. The model can be used for assessing the performance of the system under different decision making frameworks.

1. Introduction

The Port of Houston, ranked second in US in terms of overall tonnage, has a significant role in the country's economic growth. In 2014, 210.7 million tons of cargo were imported and exported through the port of Houston, equal to 16.1% of Texas state GDP. Public and private terminals along the Houston Ship Channel (HSC) created 1,666,216 direct, indirect, induced and related jobs, $75.4 billion income, $405.6 billion economic output and $21.2 billion state and local taxes in 2014 [1].

The channel is frequently subject to scheduled and unscheduled closures due to maintenance, deepening, dredging, construction projects, oil spills, fog and thunder storms. Temporarily closures cause delays, customer dissatisfaction, rerouting to alternative ports, increased operational costs for ports and carriers. As a result of increased fuel consumption, closures have environmental impact, including increased CO_2 emissions, as well [2]. Historical data shows that HSC was subjected to 17 and 20 days of closure in 2015 and 2016, respectively. The major focus of this paper is on the best closure schedule for Sam Houston bridge construction over the channel. Since demurrage cost is calculated based on extra waiting time, in this study the effect of channel closure is determined based on waiting time imposed to vessels.

The contribution of this paper is three fold; first a model is developed which simulates the logic of vessel operations throughout the waterway, second the real world data of vessel operations such as arrival rate and operation time at docks are analyzed and the results are presented, and finally the model is applied to determine the best closure schedule with

Abbreviations: ANOVA, Analysis of variance; CON, Container ship; GEN, General cargo; LPG, Liquefied petroleum gas; RORO, Roll-on/Roll-off; T&B, Tug and Barge; TCO, Chemical/Oil tanker; TNK, Tanker; TPD, Product Tanker.

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minimum vessel waiting time. The developed model can be used to evaluate the performance of the system under different decision making frameworks.

The paper is developed as follows; in Section 2 a thorough review of literature is presented, in Section 3 the problem is defined, in Section 4 the input data is analyzed and the simulation model is presented in Section 5. The warm up period and number of replications are determined in Section 6 and the developed model is validated, in Section 7 the results are discussed and finally Section 8 concludes the paper.

2. Literature review

The simulation approach is used widely in transportation problems to predict the system behavior [3]. The operational vulnerability of London Heathrow airport due to severe weather closures is studied at Pejovic et al. [2]. The paper focuses on costs associated with delays, flight rerouting to alternate airports, flight cancellations, and CO_2 emissions. Modeling emission and main factors that influence traveler behavior decision making in route choice is done through simulation in [4]. They model can be used for to optimize ferry service and reduce emissions. Kamrani et al. [5] used Arena to predict the effect of signalizing junctions to reduce traffic congestion. Their results show signalizing can reduce vehicle waiting time by 53% and number in queue by 60%. Motraghi and Marinov [6] developed an Arena simulation model to analyze existing metro rail in Newcastle. The results showed that rail is competitive to other type of transportation in urban freight delivery and it could save money for freight providers in long term and also has positive effects on environment.

Maritime industry is a dominant research area in transportation with topics such as port management, shipping market and economic impact, competitiveness, efficiency and waterway traffic and container terminals [7]. Wang et al. [8] used a simulation model for container inspection in port of Dalian. Gori and Petrelli [9] simulated Port of Civitavecchia operations using real world data. The model considered vessels arrival time, explicit representation of the berth capacity and correlated berth allocation problem. Bielli et al. [10] developed a simulation model in Java programming language as a tool in port decision support system to assess different storage policies in yard. Kulak et al. [11] developed a container terminal model in Arena to analyze terminal operation in order to identify bottlenecks of the system to highlight future potential developments. Planimate is used in [12,13] to model maritime terminal operations to assess and develop sea-side operation through simulation models. Solari et al. [14] developed an integrated model for harbor management to verify operational and performance of system using failure and waiting measures. Petering et al. [15] built up a discrete event simulation model for query crane terminals. They mentioned yard crane dispatching algorithms which avoid deadlocks are preferable to look ahead yard crane dispatching schemes. Petering [16] assessed the effect of dual yard truck on container based terminals. A combination of simulation and optimization techniques for container based terminals can be seen in [17]. The study improved simulation optimization model for loading operation in container terminals, where the key factors for improving container terminals are fully discussed in [18].

Another area of Simulation application in maritime study is risk assessment. Sormunen et al. [19] assess the risk of collision leads to chemical spill in gulf of Finland through simulation. Merrick et al. [20] study the impact of ferry service expansions in San Francisco Bay to demonstrate the use of Bayesian simulation techniques to propagate uncertainty throughout the analysis. The impact of human descriptive error in a maritime system is studied in [21].

Simulation is also used to model channels and waterways. Almaz and Altiok [22] investigated the effect of deepening Delaware river on navigational efficiency and analyzed the risk of three different scenarios: increasing vessel arrival, deepening the river and shifting to large vessels. In a similar research Franzese et al. [23] developed a model for Panama canal using Arena and used their model as a strategic planning tool to simulate Panama canal. Liu et al. [24] modeled a dynamic ship domain, taking into consideration navigable waterway conditions, ship behaviors, ship types and sizes, and operators' skills in a holistic manner. They considered safety and capacity restriction of waterway in their Arena simulation model. Qu and Meng [25] used cellular automata model for Singapore strait traffic by considering different navigational scenarios to predict the effect of global maritime trade increase on the strait. Qi et al. [26] used cellular automata to model ship traffic follow by considering dynamic ship domain, bottleneck of waterway and spatial-logical mapping rule. Xu et al. [27] developed simulation model for waterway with multiple channel using C++ programming language.

While simulation models are widely used in the literature, none has evaluated the vessel delays (waiting time) associated with waterway closures. In this paper, we have determined the optimal closure schedule through a simulation model to minimize vessel waiting time. We have assessed the effects of temporary channel closures on docks and traffic congestion to support Houston Pilots to select the best closure alternative for constructing a bridge.

3. Problem definition and assumptions

In order to expand the Sam Houston tollway, Harris County Toll Road Authority (HCTRA) plans on constructing a new cable-stayed suspension bridge over the Houston Ship Channel. This project requires coordination between different agencies and stockholders, including HCTRA, US coast guard and Houston Pilots, which is highly affected by this construction. In order to propose a closure schedule that reduces the impacts of construction, in this section we go through the details of the method of construction (erection method), daily construction schedule, hourly operation during closure, hourly closure scenarios, closure location and daylight restriction imposed on LPG tankers.