# Simulation of Traffic Capacity of Inland Waterway Network

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*Abstract*—The inland waterborne transportation is viewed as an economic, safe and environmentally friendly alternative to the congested road network. The traffic capacity are the critical indicator of the inland shipping performance. Actually, interacted under the complicated factors, it is challenging to conduct studies on the capacity in the networks of the inland waterways. Simulation modeling is a proven method that provides more insight into the complicated traffic situations, so that it can reveal the potential bottlenecks (e.g. locks, local narrowness of the network or terminals) and support to optimize the vessel traffic services, which is subject to the complexity of vessel traffic behaviors and flexible route choices within the networks. As a case study, a city-wide inland waterway network in the North region of Zhejiang Province, China, is demonstrated. The traffic flow in this network is simulated via SIVAK software. The simulation investigates different scenarios, e.g., normal (two-lane shipping) and traffic control (one-lane shipping, suspended and hybrid mode) and illustrates vessel capacity, waiting time, and mean velocity in each scenario.

Keywords—Waterway network; Traffic capacity; Robustness; Delay time; Traffic management

#### 1. INTRODUCTION

The inland waterborne transportation is an economic, safe and environmentally friendly transportation mode and playing more and more important role in the sustainable society developments. It is well known that the capacity and the efficiency are the most elementary indicators of the inland shipping performance. During the past decades many studies have been done on the capacity of waterways, while, most of them focused on harbors, narrowing of waterways and locks. Simulation modeling, as a proven method that provides more insight into the complicated traffic situations, is widely used in these studies (Yeo, 2007; Hasegawa, 2009). Simulation is also applicable to detect potential bottlenecks and will allow an optimization of the vessel traffic services (Skocibusic, 2012). Since intersection is the very basic component of waterway, and involving with dangerous encounters of vessels and traffic delays, the traffic processes at waterway intersections were recently attracted by more attention then ever (Majzner, 2010; Chen 2012; Cai 2012).

Generally, inland waterways are characterized with network. With contrast to a navigable corridor, a complex channel network with high density traffic will very much interfere the inherent capacity. It is explicit that in a waterway network, if accidents or congestion happens in one node or link, there is an alternative route for ships and the transport will not be entirely paralysed.

A simulation case has been conducted for a city-wide inland waterway network in the North region of Zhejiang Province, China. Via SIVAK software, the simulation investigates different scenarios, e.g., normal (two-lane shipping) and traffic control (one-lane shipping, suspended and hybrid mode) and demonstrate the results of vessel capacity, waiting time, and mean velocity in each

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scenario. It will support the traffic management to maximize the waterway capacity and at the same time minimize the passing time.

## 2. RESEACH AREA

For the study of traffic capacity of inland waterway network, a part of waterway network in North Zhejiang is selected with a range from Latitude  $120^{\circ}6$ ' E to  $120^{\circ}42'$  E, and Longitude  $30^{\circ}42$ ' N to  $30^{\circ}54$ ' N (Fig.1). Changhushen and Hujiashen are two main Fairways in this region. Huzhou Lock and Wushenmen Lock are two deserted locks located in the two fairways, but presently functiones as stations to observe the traffic flow.



Fig. 1. Research area

## 3. SIMULATION OF INLAND WATERWAY NETWORK

## A. SIVAK

The simulation model SIVAK (SImulatie VAarwegen en Kunstwerken, Simulation model for waterways and civil works) is made by Rijkswaterstaat (Public Works Agency) in the Netherlands to analyse traffic flows of ships and road traffic at bridges, locks, narrowing and waterway sections. The heart of SIVAK is a PROSIM model that runs in a PROSIM environment. The model is based on simulating the processes that occur (De Gans, 2010).

## B. Input

# 1) Waterway section

To simplify the model, the waterway network is converted to the topological structure in Fig.2. There are 11 waterway sections. Waterway section  $\widehat{T}$  is a Class IV fairway of China with width of 40 meters and depth of 2.5 meters. The others sections are Class III fairway of China with width of 45 meters and depth of 3.2 meters.



Fig. 2. Topology of the inland waterway network

#### 2) Arrival pattern

The flow of traffic can be primarily described by the arrival pattern. For this case, the data from GPS based vessel traffic monitoring system in 2011 and measured data in 2012 of Huzhou Lock and Wushenmen Lock are collected. It is noted that not all the ships sailing in the network carries GPS, and therefore the arrival pattern for each entrance is analyzed via the following 4 steps:

- Step 1: analyze the 2011 GPS data to get the traffic density of each waterway section.
- Step 2: compare the GPS data and measured data of Huzhou Lock and Wushenmen Lock to find out the error matrix.
- Step 3: calculate the percentage of ships come from each entrance pass through Huzhou Lock and Wushenmen Lock to determine the weight of the error.
- Step 4: reckon the arrival pattern of each entrance with the traffic density, error and the weight.

The arrival pattern with one week span in the simulation is shown in Fig.3.



Fig. 3. Arrival pattern for each entrance of the waterway network (one week)

3) Ship class

The ships sailing in the waterway network are summarized into nine classes as shown in TABLE I. Fig. 4 shows the pie chart of the ship classes. It can be seen that most of the ships are class WN5 and WN6 and more than 95% of the ships are shorter than 50m.

Ship class	DWT	Width(m)	Length(m)
WN 1	21-42	3.4-4.41	15.95-20
WN 2	38-98	3.8-5.4	20.1-25
WN 3	60-240	4.6-6.2	25.1-30
WN 4	80-530	4.98-7.18	30.03-35
WN 5	126-550	5.5-8.48	35.01-40
WN 6	183-830	5.6-9.97	40.04-45
WN 7	296-800	7.6-10	45.1-49.9
WN 8	450-1010	6.6-11.85	50.1-55
WN 9	830-1450	10.19-11.8	55.1-60

SHIP CLASSES

TABLE I.



Fig. 4. Ship classes distribution

## *4) Fleet share and fleet*

The fleet share determines the number of ships generated per week at each entrance. Fleet is used to define the percentage of ships from one entrance to another. Fig.5 shows the 100% of the number of ships in the simulation (i.e. the actual situation in 2011).



Fig. 5. Fleet share and fleet

## C. Model setup

1) The generation of ships

The generation of ships is done in two stages (De Gans, 2010):

• Firstly, the arrival times were determined base on the above-mentioned input. The arrival pattern is normalized and converted into a cumulative distribution function of the time points. A random number  $p_i$  ( $0 \le p_i \le 1$ ) from a uniform distribution is created. The first point of intersection of the horizontal line by  $p_i$  with the curve of the cumulative distribution function determines the time of arrival  $t_i$ .

- Secondly, the ship classes were granted to the generated ships in proportion according to the fleet share.
- 2) Sailing and collision avoidance

In waterway section, ships keep sailing on the right and may encountered two situations: meeting and overtaking. As shown in Fig.6, ship A is overtaking ship B and meeting ship C. Five parameters are set for the safety. In the simulation,  $L_{before}$  and  $L_{past}$  are the length of ship being overtaken.  $D_{meet}$  and  $D_{over}$  are the width of it.  $D_{bank}$  is 0.2 width of the ship.



Fig. 6. Meeting and overtaking in waterway section

As to the nodes, the intersection of two waterway section, "a ship will only start sailing a link as soon as a predecessor (if there is one) has completely entered the link" (De Gans, 2010), i.e. the ships pass through a node once a time. Though, the waiting time and waiting percentage are higher than reality as a consequence, the waiting time is an important index to compare different scenarios with same traffic volume. The waiting percentage is also meaningful to represent the collision rate.

## D. Output

SIVAK provides many output. For this research, the following output are used:

- Passage time: the time it takes for the ship from passing the entrance to the destination.
- Waiting time: including the time a ship is waiting at a node and the time ship waiting to enter the network after generating.
- Waiting percentage: the percentage of ships that have to wait.
- Number of ships sailing out and en route.

## E. Validation

Measured data of Huzhou Lock and Wushenmen Lock are used to test and verify the simulation model (Fig.7). The simulation results and the measured data are analyzed by paired-sample T test. The results indicate that the simulation matches the measured data well meaning that this simulation model can be applied to the study of traffic flow in the research area.



Fig. 7. Comparison of measured data and simulation results

## F. Scenarios and traffic volume

In order to get the characteristics of traffic flow in the inland waterway network, 100%, 150%, 200%, 250% and 300% of the 2011 traffic volume in 4 scenarios are investigated:

• Normal/NO: all the waterway sections are two-lane shipping;

- Control 1/C1: waterway section (6) is one-lane shipping;
- Control 2/C2: both waterway section (5) and (6) are one-lane shipping, section (5) for upstream while section (6) for downstream;
- Control 3/C3: waterway section <sup>6</sup> is closed.

#### G. Results and discussion

The result of the study that shows that the four scenarios are almost the same in the number of ships sailing out per hour, but have a significant difference in waiting times. The comparison is depicted in Fig.8.

- The number of ships en route sailing and sailing out increases when the traffic volume increases;
- In each scenario, the number of ship sail out is about 150ships/hr when 300% of the number of ships in 2011 sailing in;
- The waiting time present a trend of rising but fall at 200% (C1) and 250% (C2);
- The waiting time of N0 is the longest while that of C2 is lowest because the traffic situation in C2 is simplest and in section (5), (6) does not exist meeting. What's more, fewer ships come to a node at the same time.





The difference of waiting time also causes the difference in number of ships sailing. The longer waiting time is, the more ships waiting at the nodes, the total number of ships in the waterway network will strictly increase until congestion. So the index PWT is introduced to measure the waiting time and to judge when the network is saturated.

$$PWT = \frac{\text{waiting time}}{\text{passing time of corresponding scenario with 100\% ships}}$$

In Fig.9, the PWT of N0, C1 and C3 is over 100% when there are 250% of the number of ships in 2011. In addition, more than 80% of the ships wait at the nodes. Under these circumstances, it is reasonable to say that the waterway network is saturated. The PWT of C2 remains at a low level in the simulation and the network is far from saturated.

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From the perspective of waterway section, section (5), (6) are busiest, accordingly, waiting time is longer and velocity is lower. Fig.10 a and c are results for scenario of N0, while b and d shown the results for of 100% of ships in each scenario. These figures demonstrate that:

- Waiting time increases and velocity decrease with the growth of number of ships;
- C2 has the lowest waiting time almost in every waterway section and a relatively balanced velocity;
- The main difference between C2 and others is the waiting time in section (5), (6);
- In C1, C2, C3, section (5) carries more ships than others, which leads to longer waiting time and low velocity.



Fig. 10. waiting time and velocity in each waterway section

# 4. CONCLUSIONS

In this paper, a part of an inland waterway network in the North part of Zhejiang Province, China, is studied. The traffic flow in this network is simulated via SIVAK, applying four scenarios, normal (N0, two-lane shipping) and traffic control (C1, waterway section (6) is one-lane shipping; C2, both waterway section (5) and (6) are one-lane shipping; C3, waterway section (6) is closed). Analysis of capacity, waiting time, and mean velocity in each case is carried out based on the simulations. The simulation results illustrate that:

• SIVAK can be used for inland waterway network.

The simulation data and measured data in Huzhou Lock and Wushenmen Lock match well.

• When the waiting time is longer than the normal passing time, the waterway network is regarded as saturated.

In the research region, it saturated in N0, C1 and C3 when the number of ships generated is 250% of 2011volume with 150ship sail out per hour and more than 900 ships en route.

• A proper traffic control can simplify the traffic situation and may decrease the waiting time and increase the capacity of a waterway network.

C2 has the lowest waiting time almost in every waterway section and a relatively balanced velocity. C2 is not saturated even when the number of ships generated is 300% of 2011.

• The four scenarios make no difference in the number of ships sailing out per hour when the number of ships generated is the same.

## ACKNOWLEDGMENT

The work presented in this paper is financially supported by NSFC and NOW (Sino-Dutch Cooperation, Grant no. 51061130548), Zhejiang Provincial Department of Communication in China (Grant no. 2010W11) and Self-determined and Innovative Research Funds of WUT.

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