

## Passage Planning System in Ports: An Overview

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**ABSTRACT:** A conceptual model is proposed to monitor marine traffic through precautionary areas, which can provide us with a systematic control of passage planning in ports. On one hand, vessel traffic control has its special features and is fundamentally different from highway, air and pedestrian traffic control. The existing traffic control systems cannot be simply extended to vessel traffic control without addressing marine traffic features. On the other hand, existing vessel traffic control focuses on one ship or two ships but does not address the flows of marine traffic.

### 1 INTRODUCTION

Constantly growing global seaborne containerised trade leads to increasing flows of containers in seaports. Increasing number of handled containers is visible at global, regional and national level. Generally speaking, this increasing trend is depended on the economic development, for which the main indicator is Gross Domestic Product (GDP).

On 22 March 2008 (9:30 pm), a Ukrainian vessel *Neftegaz-67* collided against a Chinese bulk carrier *Yao Hai* in Hong Kong, and 18 seamen were lost. There will be a need to establish a next generation of vessel traffic service in an extreme busy port like Hong Kong. In 2013, Hong Kong port received over 500 arrivals per day.

Marine traffic has its special features and is fundamentally different from highway, air and pedestrian traffic. Although traffic science has been a prolific field for highway, air and pedestrian traffic, the existing understanding on traffic is not very helpful to marine traffic. The assumption of homogeneity in many traffic models is significantly

violated in marine traffic. The manoeuvrability of a ship is largely related to its length. The ship lengths range from a few metres to over 300 metres, while the highway vehicle lengths are limited to about 20 metres. Therefore, in marine traffic, heterogeneity of vessels clearly exists due to the varying ship manoeuvrability.

Marine traffic management in congested waterways may not be a new issue. The first radar based VTC was introduced at the port of Douglas and Liverpool in 1948. The first guideline of vessel traffic services (VTS) was internationally adopted in 1985. VTS are used in ports, harbours, coastal waters, and international straits (e.g. Dover Strait, and Malacca Strait). The conflict among several ships becomes clearly critical for either high density or highly heterogeneous traffic.

We propose the concept of passage planning system (PPS) for a next generation of VTS. Based on a predetermined set of criteria, the PPS will accept or reject the passage request of vessels, before a number of vessels are going to cross a strategic location, e.g. a precautionary area. In this respect, the system

objectives mirror the human-centred automation models that are being developed by NASA for air traffic control applications, so-called arrival planning in air traffic management. The PPS will enhance port safety with the new navigation aids (e.g., ECDIS, AIS).

In the pre-implementation phase, a survey of marine traffic in strategic areas should be conducted and the local field value of marine traffic properties should be determined. The PPS will be developed based on local understanding of marine traffic flow. Moreover, the effectiveness of PPS as a proposed element of VTS will be assessed.

A new concept of Passage Planning System (PPS) is proposed to enhance marine safety in strategic areas. When a ship master makes a passage plan, the PPS of vessel traffic services (VTS) will advise the ship master and pilots of potential vessel conflicts and the PPS will approve or reject the proposed passage plan. In response to the rapid growth in port traffic, efforts are being made to improve the effectiveness and efficiency of VTS. Many countries have invested heavily in VTS recently, since it has been identified that ship accidents in ports have become more serious. The financial, environmental and social costs of incidents have risen steeply in recent years.

Recently, a review of marine traffic risk in ports concluded that ship collision is the major hazard in port traffic. The existing traffic control concepts are not helpful to understand the marine traffic, which is different from highway, air and pedestrian traffic. Existing vessel traffic control focuses on one ship or two ships but does not address the marine traffic flows in congested ports, providing our motivation to analyze the regulation of marine traffic in busy ports. One reason for this is because most marine accidents involve one or two ships and the effect of background traffic level on marine accidents has been ignored. Another reason is because ship masters, rather than port authorities, are the ones who are liable for any ship accidents and ship handling appears to be the solution of collision-avoidance.

The port traffic in Hong Kong is the busiest in the world. Many fairways in Hong Kong have more than 2,000 vessel movements every day. The safety and its reliability are key issues of port developments. The PPS is proposed to serve as a base for the next generation of VTS. The proposed PPS will be able to enhance port safety. Many ports, as they continue to develop, will face similar traffic control issues observed in Hong Kong port today in the near future.

Unlike existing VTS, PPS is proactive which may cause significant change in port traffic risks. The range of usage is highly innovative and complies with all future international ship safety and environmental requirements.

## 2 LITERATURE REVIEW

Systematic studies of traffic flow have been conducted for more than five decades. A basic building block is the kinematic waves in traffic

(Lighthill and Whitham 1995; Richards 1956), which relates the macroscopic traffic flow, the traffic speed and the traffic density. The focus of the paper is related to the models of marine traffic flow (e.g. Yip, 2012).

Highway traffic has attracted considerable attention for decades, for example, Gazis (2002). Many highway traffic models assume the homogenous vehicles are not applicable to marine traffic. The heterogeneity is recently considered in highway traffic research, for example, Wong and Wong (2002), Park et al. (2010). They however did not consider as a whole where the passage planning can be used as part of vessel traffic control.

In the air traffic control, Andersson et al. (2003) proposed a novel optimization approach to analyse collaborative airport arrival planning. Ship manoeuvring simulators are common in many maritime countries and generally operate in the time domain. Their use ranges from the full mission bridge simulator to PC-based simulator. Existing Traffic Alert and Collision Avoidance System (known as TACS II) is used to detect the altitudes of aircraft and then resolve (altitude crossing) encounters in the vertical domain. If an encounter is identified, TACS II will command one aircraft to climb and the other to descend. However, ships can only manoeuvre horizontally and ships have different manoeuvrability. Different from air traffic control, VTS is only an advisory service for ships; ship masters are responsible for a ship's course, speed and safety.

Previous research may not be applicable to marine traffic, as existing studies do not take into consideration the differences between ships. Traffic in previous models is considered as continuous flow and not as single ships with their individual characteristics of type, dimensions and velocity. Real marine traffic is not consisted of ships of equal size moving at equal velocity. The depth of water has considerable influence on the rate of ship's turn which may be obtained at a given rudder angle. If navigation in confined waters require large alternations of course, the turning manoeuvres must be commenced in due time with the knowledge of how much room the ship needs to carry out the alteration of course. This will, especially with regard to large ships, necessitate pre-conceived planning.

Ship-ship collision models have been developed on the basis of geometrical distribution and/or encounter-to-collision. Pedersen (2002; 2010), Montewka et al. (2010), Debnath and Chin (2010), Tan and Otay (1999) developed geometrical collision probability models that describe the geometrical probability model of collision. Fowler and Sorgard (2000) estimated the collision based on encounters by assuming the traffic is independent or uncorrelated. USCG (1999) found different types of encounters have different relative significance, with crossings more hazardous than head-on encounters, which are in turn more risk prone than over-takings. These assumptions are applicable only when the traffic density is low. In reality, ships may change speed or direction so as to avoid possible collisions (Merrick et al. 2002). The crossing traffic models cover only a crossing situation of two vessels. In particular, in

heavily trafficked ports, like Hong Kong, three or even more ships may approach an area at the same time. In this kind of situation, a collision is more difficult to avoid when the actions of several other vessels need to be observed.

### 3 PASSAGE PLANNING SYSTEM

A vessel traffic service (“VTS”) is a service implemented by a competent authority, designed to improve safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with traffic and respond to traffic situations developing in the VTS area. A VTS should be in compliance with the requirements, guidelines and recommendations promulgated by the IMO and the IALA (IMO, 1985). A VTS contributes to:

- 1 improving the safety of VTS participating vessels with regard to incidents of collision and grounding;
- 2 reducing the risk of damage to VTS participating vessels and principle waterways;
- 3 enhancing the efficiency of traffic movements for VTS participating vessels; and
- 4 supporting port administration.

A VTC serves the following functions:

- 1 monitoring all vessels and their movements within the VTS waters and its approaches used by vessels;
- 2 identifying all VTS participating vessels, collecting and evaluating data on their movements and interaction with other vessels, and coordinating and regulating their movements within VTS waters;
- 3 providing vessel traffic information and advice to VTS participating vessels to assist them in making navigational decisions;
- 4 maintaining and operating a database on the particulars and movements of VTS participating vessels; and
- 5 supporting allied activities, including immigration, customs and quarantine controls; pilotage and tug services; entry and clearance activities; port state control; collection of fees; and emergency services (e.g. pollution control, search and rescue).

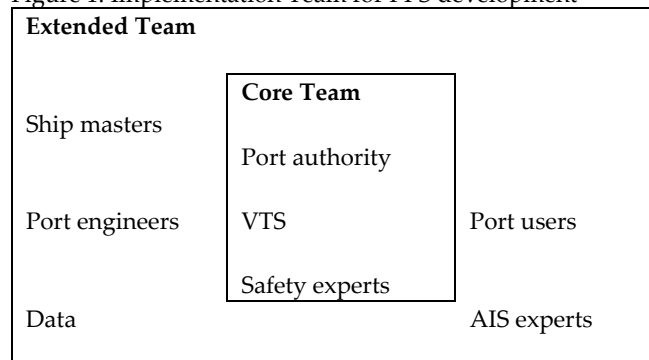
The development of PPS can be divided into three phases and nine major steps (Table 1).

| Step                                  | Process                            | Activities   |
|---------------------------------------|------------------------------------|--|
| Phase 1 – Pre-Implementation Phase    |                                    |  |
| 1                                     | Operational requirements           | Collect port user requirements; Seek regulatory requirements |
| 2                                     | Create teams                       | Recruit team members   |
| 3                                     | Define PPS                         | Agree scope, objectives, and time schedules                  |
| 4                                     | Analyse reference scenarios        | Conduct traffic survey; Assess waterway capabilities         |
| 5                                     | Safety and performance criteria    | Conduct risk assessment                                      |
| Phase 2 – Procedure Development Phase |                                    |  |
| 6                                     | Development of hypothetical models | Define assumptions, constraints                              |
| 7                                     | Procedure developments             | Design initial procedure; Design routes; Design volumes      |
| Phase 3 – Procedure Validation Phase  |                                    |  |
| 8                                     | Trail                              | Launch PPS   |
| 9                                     | Implementation                     | Operate PPS; Validate the system                             |

#### 3.1 Phase 1 – Pre-Implementation Phase

Depending on the local situation, the development of PPS may be initiated by different stakeholders such as port authority, and port operators. The whole team may be divided into the core team and the extended team (Figure 1). The core team should be the one who will conduct pilot implementation along the development.

Figure 1. Implementation Team for PPS development



The first step is to analyse the marine traffic data. Traditionally, radar data is used. The radar data can be captured at regular time intervals (e.g., 1 minute). Owing to the presence of radar blind sectors, ship’s tracks have been broken. Inevitably the tracking has significant measurement errors and the frequency of occurrence of tracking errors is quite high. The accuracy of the ship tracks obtained depends mainly on the resolution of radar and the size of radar blind sectors.

The Automatic Identification System (AIS) provides a new source of marine traffic data. AIS is designed for ships and vessel traffic services to electronically exchange information with each other. AIS allows VTS to observe marine traffic and to inform vessels for example about passage planning. AIS operates primarily on two dedicated radio channels but it is capable of being switched to alternative channels. A portable AIS receiver can be used to track ships, when and where each ship is moving to. Ship track data with ship identification

Table 1. A Passage Planning System

numbers are very suitable to establish reliable ship tracks.

To investigate the marine traffic, two or three sites will be selected for data collection. The data obtained at the selected sites should be adequate and reliable for calculating the navigation speeds of ships, and marine traffic flow rates. Non-consecutive days of survey should be conducted to assess the marine traffic activity. Traffic survey collecting data via Automatic Identification System (AIS) can be compared against data collected in the VTS, Pilot Booking Schedule, operators' data and other records.

A database of traffic routes will be developed, such routes having been determined from a comprehensive analysis of radar data or AIS data over a period of time. A PPS should need the following data:

- 1 Waterway data - Data on the fairway situation, electronic nautical chart, etc.
- 2 Vessel data - Data on vessel type and length, Estimated Time of Arrival (ETA) to a particular way point, vessel speed, etc.
- 3 Traffic situation data - Data on number of vessels, intended movements with respect to maneuvers, destination and routing, etc.

While most collision-avoidance manoeuvres are defined by the Steering Rules from the International Rules for the Prevention of Collisions at Sea (Cockcroft and Lameijer, 1996), these may be superseded by local rules in congested waterways. Such considerations depend largely on the size and type of each ship. The traffic data should be analyzed to reveal current and local practice in maritime traffic and their contemporary operations. Marine traffic activities on routes from AIS data will be factored for different ship types (e.g., ocean-going vessels, coastal vessels, high speed craft, fishing ships, etc.). The manoeuvrability of different vessel types and sizes will be determined.

### 3.2 Phase 2 – Procedure Development Phase

Hypothetical models will be developed in this Phase. The models will be used for studying the procedure and behaviours of marine traffic. Through this model, we are able to determine not only marine traffic but also any possible traffic with heterogeneous ability of passage. The hypothetical models will be a core element of the passage planning system.

In hypothetical models for vessel traffic control and passage planning system, we should incorporate the heterogeneous manoeuvrability (of different vessel types and sizes) and introduce the concept of imperfect turning (sub-optimal turning). For some reasons, a ship does not turn as much as it should. The amount of imperfect turning depends on variables of ship manoeuvring upon encounters. The amount of imperfect turning also depends on a wide series of human factors associated with perception of the ship masters, the decision taken, bridge team co-ordination, and the interaction of both ships as a collision is averted or not.

In the navigation literature, collision-avoidance turning is triggered by the closet point of approach

(CPA) between adjacent vessels, if the CPA drops below a prescribed minimum value, an avoiding action is initiated. It should be noted that we will determine "encounters", which occur when ships within the model activity take steps (change of course and/or speed) to avoid another ship. These events are not collision events in themselves but the initiating events for a potential collision. The likelihood of an incident then occurring embraces the degree of imperfect turning.

Ship steering and turning can be modeled by the second-order Nomoto model (1957), Norrbinn model (1963), and Bech model (1968). Suppose that there exists a minimal turning of collision-avoidance, and the ship master intends to turn the ship a certain degree. Imperfect turning does occur. If the imperfect turning is larger than the minimal turning, a collision will be avoided; but otherwise a collision will be the result. The introduction of imperfect turning allows us to investigate a wide range of factors of near collision events.

### 3.3 Phase 3 – Procedure Validation Phase

After gaining the knowledge of the marine traffic in strategic areas, a Passage Planning System (PPS) can be tested in simulated environments. The concept of PPS is mainly concerned with vessel traffic to and from a waterway junction, likely a precautionary area. The development of PPS should take account of the nature of waterways and the properties of marine traffic. The PPS should predict which vessels will be located in which strategic locations in which particular period of time, based on hypothetical models. As the manoeuvrability of a ship is closely related to its particulars (length, draft, ship type, tonnage), hypothetical models are used to predict ship movements after the comprehensive analysis of marine traffic versus a number of parameters.

The PPS will be developed to receive and process passage plans from a ship which will provide information on its proposed arrival / departure time, destination within or exit from the port limits and clear information on the proposed route and speed of navigation.

The PPS may be tested in the simulation for maritime traffic systems, with a focus on passage planning at strategic locations in ports. A series of experiments will be carried out in the simulated environment to explore PPS strategies of vessel traffic control. The track of manoeuvring can be recorded. Many repeated runs can be carried out and overlaid so as to obtain the spread of multiple tracks of one given scenario.

VTS operators, harbour pilots and some other stakeholders should be invited to comment on the effectiveness of the PPS. The purpose of PPS is to improve the safety and efficiency of navigation, safety of life at sea and the protection of the marine environment. Therefore, it is critical to review how well the PPS assists the decision-making of the ship master concerning the actual navigation and manoeuvring of the ship.

## 4 CONCLUSIONS AND DISCUSSION

Recent developments in ship simulation and real-time AIS data survey create the opportunities for integrating elements of the proposed PPS within VTS architecture. The benefits of implementing a PPS are that the PPS allows identification and monitoring of vessels, strategic planning of vessel passage and provision of navigational information and assistance. The potential to enhance VTS systems with real-time AIS data identifying the relative risks of different passage plans allows the port authorities to move to the control of marine traffic in the safest manner with the greatest efficiency.

In this paper, the idea of PPS and procedures in principle are suggested. The technique of air traffic control is proposed to be extended to vessel traffic management in congested waters. Future work of this research is to develop generic hypothetical models. These models should include all of the safety criteria such as minimum under keel clearance, safe speed, and ship manoeuvrability.

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