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Agent-based model of maritime traffic in piracy-affected waters

Ondřej Vaněk *, Michal Jakob, Ondřej Hrstka, Michal Pěchouček

Department of Computer Science and Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague, Karlovo Náměstí 13, Praha 127 00, Czech Republic

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ABSTRACT

Contemporary maritime piracy presents a significant threat to global shipping industry, with annual costs estimated at up to US$7bn. To counter the threat, policymakers, shipping operators and navy commanders need new data-driven decision-support tools that will allow them to plan and execute counter-piracy operations most effectively. So far, the provision of such tools has been limited. In cooperation with maritime domain stakeholders, we have therefore developed AgentC, a data-driven agent-based simulation model of maritime traffic that explicitly models pirate activity and piracy countermeasures. Modeling the behavior and interactions of thousands of individually simulated vessels, the model is capable of capturing the complex dynamics of the maritime transportation system threatened by maritime piracy and allows assessing the potential of a range of piracy countermeasures. We demonstrate the what-if analysis capabilities of the model on a real-world case study of designing a new transit corridor system in the Indian Ocean. The simulation results reveal that the positive past experience with the transit corridor in the narrow Gulf of Aden does not directly translate to the vast and open waters of the Indian Ocean and that additional factors have to be considered when designing corridor systems. The agent-based simulation development and calibration process used for building the presented model is general and can be used for developing simulation models of other maritime transportation phenomena.

1. Introduction

Global maritime shipping lanes are a critical part of the world's transportation infrastructure. 90% of internationally traded goods are transported by sea at least one point in their journey (Earnest and Yetiv, 2009). In the past years, the global maritime transportation system has come under a serious threat from maritime piracy. As a major security and economic threat costing the global economy up to estimated US$7bn (Bowden et al., 2011), contemporary maritime piracy has solicited a concerted international response which has, finally, led to the reduction of the success rate of pirate attacks. The number of pirate attacks, average amount of ransom paid and the number of seafarers held in captivity, however, remain high. In 2011 and for Somali-based piracy alone, there were 181 attacks reported for Somalia, 28 vessels hijacked and 1118 seafarers were taken hostage.[1] Containing piracy also required and continues to require extensive deployment of naval forces which is unsustainable in a long term.

From the many levels on which solutions of the problem are sought, we focus on the operational management of the situation at sea, as this is the arena where progress can be made in the short term, before long-term sustainable solutions can

* Corresponding author. Tel.: +420 22 43 57 581.
E-mail addresses: ondrej.vanek@agents.fel.cvut.cz (O. Vaněk), michal.jakob@agents.fel.cvut.cz (M. Jakob), ondrej.hrstka@agents.fel.cvut.cz (O. Hrstka), michal.pechoucek@agents.fel.cvut.cz (M. Pěchouček).

[1] Source: International Maritime Bureau (IMB) Piracy Reporting Centre (website: http://www.icc-ccs.org/piracy-reporting-centre).

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be developed onshore. To date, military, governmental and industry stakeholders have proposed several types of piracy countermeasures to increase the security of maritime transit, including recommended transit corridors, group transit, escorted convoy schemes, coordinated patrol deployments and on-board security teams. When properly designed and implemented, such measures can significantly improve maritime transportation security with reasonable additional cost. However, due to complex spatial and temporal dependencies between individual countermeasures and external factors, discovering effective, synergistic combinations of piracy countermeasures presents a major challenge.

To address this challenge, we have built AgentC, a data-driven agent-based simulation model of maritime activity in piracy-affected waters. The model aims at helping decision makers reduce uncertainty about the effects of their operational control and regulatory interventions. The model incorporates a wide range of real-world data and, to our best knowledge, is the first computational model that simulates deep sea shipping down to the level of individual vessels. This is crucial for accurately capturing emergent, collective effects arising from the context-dependent interactions of merchant, pirate and navy vessels.

Due to the lack of prior work on the topic, the development of the model prompted the development of a novel methodology for agent-based maritime transportation modeling. Some parts of the methodology could be borrowed from more mature transportation modeling fields; other parts had to be developed from scratch. In addition to the AgentC model, the developed methodology, presented alongside the model itself, is therefore the second major contribution of the paper.

The rest of the paper is organized as follows. After reviewing related work, we describe the AgentC simulation model, detailing how the maritime environment, vessel behaviors and vessel interactions are modeled. We then briefly comment on the implementation aspects of the simulation model and devote significant space to discussing calibration of the model. Finally, we show how the developed model was employed to help answering specific operations research questions concerning the design of maritime transit corridor systems.

2. Related work

The use of agent-based or simulation-based models to support policy design and operational management has a very long-standing tradition in the transportation field. The vast majority of the work, however, focuses on ground transportation (e.g. Hidas, 2002; Waraich et al., 2013) and, to a lesser extent, on air transportation (e.g. Tang et al., 2012).

In the maritime domain, applications of simulation models are surprisingly scarce, as analyzed, e.g., by Davidsson et al. (2005). Existing work either focuses on traffic in ports and national, coastal waters (Hasegawa et al., 2004) or uses high-level equation-based models (Bourdon et al., 2007) unfit for capturing individual-level behavior and inter-vessel interactions essential for modeling maritime piracy. Furthermore, none of the above models is concerned with the security of maritime shipping lanes. Advanced computational methods have been applied in the maritime domain to optimize ship routing (e.g. Norstad et al., 2011; Øvstebø et al., 2011), albeit not taking the security aspect into account. In both cases, the authors use mathematical programming rather than simulation to solve the problem.

As far as the security angle on transportation systems is concerned, existing simulations focus on modeling activities in and around terminals rather than within transportation networks themselves. This is true both for airport security (Chawdhry, 2009) and port security (Koch, 2007). Port security has also been listed as an important area for the application of operations research methods (Crainic et al., 2009), of which simulations are an important representative. The spatial, network aspect of transportation security has been touched upon in the work on modeling critical infrastructures (Barton and Stamber, 2000), however, the emphasis there is mostly on other than transportation types of infrastructures. The problem of securing transportation infrastructures and logistical networks has only been studied in the military context (Ghanmi et al., 2011).

Focusing on the very phenomenon of maritime piracy, existing work is concentrated primarily in the fields of security studies, international relations and global policy (Onuoha, 2010). Only recently, initial attempts at applying computational modeling and optimization to maritime piracy have emerged but focus exclusively on military aspects of the problem: Bruzzone et al. (2011) model piracy around the Gulf of Aden using the discrete-event simulator PANOPEA. The authors focus on evaluating the efficiency and effectiveness of different Command and Control models; only main actors in the Gulf of Aden are considered and the simulation is not scaled to the Indian Ocean where the merchant traffic model is significantly more complicated.

Tsilis (2011) employs the MANA agent-based modeling framework (Lauren and Stephen, 2002) to identify key factors affecting the escort of vulnerable merchant vessels through the Gulf of Aden. The escorting scenario is modeled on a tactical level, focusing on positioning of individual ships and protection of one group of merchant vessels; this is different from our model which adopts a whole-system perspective and considers the security of maritime transportation system as a whole. The MANA framework is also used by Decraene et al. (2010) to analyze requirements on non-lethal deterrents for defending large merchant vessels against pirate attacks; again, the focus is on the tactical level of modeling a single encounter in detail, rather than the system as a whole.

Slootmaker (2011) describes *Next-generation Piracy Performance Surface (PPSN)* model which employs meteorological forecasts, intelligence reports and historical pirate incidents to predict areas conductive to pirate activity around the Horn of Africa. Hansen et al. (2011) further improve the PPSN model by refining the environment model and adding a probabilistic behavioral pirate model, resulting into the *Pirate Attack Risk Surface (PARS)* model. Both PPSN and PARS models are numerical