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Yang, Mengyao; Lam, Jasmine Siu Lee

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Mengyao YANG [a, b] and Jasmine Siu Lee LAM [c]
[a] *School of Civil and Environmental Engineering, Nanyang Technological University, Singapore*
Email: mengyao001@e.ntu.edu.sg
[b] *Maritime Energy and Sustainable Development Centre of Excellence, Nanyang Technological University, Singapore*
Email: mengyao.yang@ntu.edu.sg
[c] *Department of Technology, Management and Economics, Technical University of Denmark, Denmark*
Email: jasmlam@dtu.dk

Abstract
Maritime transportation is important for international trade and the global economy. There is a growing demand for sustainability in the maritime industry, driven by public policy and commerce. The International Maritime Organization (IMO) has adopted a strategy aiming at achieving net zero greenhouse gas (GHG) emissions from international shipping by 2050 (IMO, 2023). Given the huge amount of energy consumed by ships, maritime stakeholders are working towards an energy transition using alternative marine fuels, including hydrogen, ammonia, methanol, biofuels, etc. (Bilgili, 2023). As a carbon-free fuel, ammonia has received attention for sustainable shipping. The ammonia bunker supply chain (ABSC) includes ammonia production, storage, transportation, bunkering and fuel consumption processes (Yang and Lam, 2023). The major challenges for general supply chain management are uncertainty and dynamics, which can cause a bullwhip effect and ripple effect (Ivanov et al., 2014). Unlike the bullwhip effect, which explains the amplification of demand variations in the upstream supply chain, the ripple effect shows the propagation of disruptions and changes in supply chain structural dynamics due to low-frequency and high-impact disruptions (Dolgui et al., 2020). In global supply chain networks, the causes of these disruptions include weather anomalies, military conflicts, nautical accidents, vessel groundings, etc. In addition, port and shipping are the most uncertain components within the supply chain (Sanchez-Rodrigues et al., 2010). There is a pressing need for a more comprehensive understanding of ammonia bunker fuel at ports.
This study aims to develop a framework for evaluating the ripple effect of ammonia supply disruptions on the ammonia bunker supply chain, considering ammonia bunker demand dynamics. A simulation method can estimate the direct and indirect impacts of a disruption along a supply chain. Due to the dynamic behaviour associated with risks, we built a Coloured Petri Nets (CPN) model to assess the impact of the disruption on the system performance.
To demonstrate the model, Gladstone, Australia and Singapore ports were selected as the green ammonia export port and green ammonia import and bunkering port, respectively. This study uses the CPN model's stepwise process and characteristics of an efficient environment to simulate ammonia flows along the supply chain. Bunkering operational cost, bunkering service time and GHG emission reduction are the indicators for system performance evaluation. One result shows that the ripple effect can increase by around 50% when ammonia bunker demand rises from 20% to 100% at a bunkering port when the bunkering service time is the performance indicator.
This study fills the gaps in the uncertainty and dynamics of the ammonia bunker supply chain. The results provide implications for researchers to know about the relationships between ammonia supply uncertainty and ammonia bunker demand dynamics. Moreover, analysing how events propagate throughout the supply chain and their impact on individual components allows maritime industry practitioners to focus on vulnerable areas and discover more effective mitigation actions.

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