Abstract

Sea-borne shipping is considered environmentally efficient as it participates in carrying more than 90% of the world trade as mentioned in IMO (2014). With the enhancement of global trade, maritime logistics has become one of the principal modes of transportation and researchers are showing genuine interest in addressing the complex operations associated with the sea-borne trade. Managing appropriate time window at the ports is one such complexity related to maritime transportation. Predominantly it is observed that either the ship arrives early at the ports, or it departs very late owing to some additional port charges due to waiting or delay. Possible measures need to be incorporated for improving the service level at the port or reduce the total operation time for each vessel. For this purpose, all the port operations including loading/unloading of containers should specifically be carried out within a specified time window. Increasing trade globally necessitates the requirement of an efficient mathematical model that can resolve the challenges associated with maritime transportation. Reducing fuel consumption and carbon emission within the maritime transportation domain remains one of the most significant challenges as it addresses the sustainability aspects. Carbon emissions from shipping industry are directly associated with the total fuel consumption. There is a need to investigate the possible ways of considering bunker fuel management and reducing carbon emission in ship routing and scheduling.

In the first stage of the research, sustainable ship routing and scheduling problem is addressed for satisfying the demand at different ports during the planning horizon while exploring the possibilities of integrating slow steaming policy within shipping operations. A mathematical model is presented considering various scheduling and routing constraints, loading/unloading constraints and vessel capacity constraints. The non-linear equation between fuel consumption and vessel speed has been incorporated to capture the sustainability aspects. Time window concept is included in the mathematical model to enhance the service level at each port. Penalty costs are incurred if the ship arrives early before the starting of the time window or if it finishes its operation after the ending of the time window. Costs associated with the violation of time window helps in maintaining a proper port discipline.

The second stage of the research aims to integrate different shipping operations like routing and scheduling of ships with port's time window concept, discrete planning horizon, container loading/unloading operation with carbon emission from the vessel and ship's draft restriction

for maintaining the vessel safety while entering/exiting from the port. A mathematical model is presented capturing various maritime operations and incorporating the relationship between fuel consumption and vessel speed optimization for estimating of the overall fuel consumed and carbon emission from each vessel. Time window concept considering the high tidal scenario for ensuring the safe passage of the vessel while entering or exiting the port is taken into consideration.

The sustainable container shipping problem integrated with fuel bunker management and recovery policies for countering disruption within maritime transportation forms the third stage of the research. A mathematical model is developed aiming to maximize the profit of the shipping company by addressing the routing and scheduling decisions of the vessel, loading/unloading of containers, selection of bunkering ports and bunkered amount for different types of fuel – marine diesel oil (MDO) and heavy fuel oil (HFO). Recovery strategies are considered such as port swapping and rescheduling of vessel route to deal with disruptions associated with weather adversities on a particular route and port closure. The relationships between variables and constraints of the formulation are used to propose a mathematical model-based heuristic and integrated with variable neighborhood search algorithm.

The three devised mathematical models are validated using various problem instances generated after thoroughly studying the real world problems associated with the international shipping companies. The focus of the research is mainly on the development of the mathematical formulations and validating the results obtained.

Keywords: Ship routing and scheduling, Maritime transportation, Slow steaming, Fuel consumption, Carbon emission, Bunker Fuel Management and Vessel draft restriction.