NUS National University of Singapore | Centre of Excellence in Modelling and Simulation for Next Generation Ports Faculty of Engineering

SINGAPORE'S MEGA TERMINALS

ANALYZING BATTERY-POWERED VEHICLES

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The growing increase of fossil fuel consumption and greenhouse gas emissions around the world are causing concern among people and governments. Singapore has introduced a tax on the carbon emissions of industrial facilities which began on January 1, 2019. This was aimed at maintaining a high-quality living environment. The Maritime Port Authority of Singapore (MPA) has introduced the 'Green Port Programme' under the Maritime Singapore Green Initiative, which aims to promote clean and green shipping in Singapore by adopting shipping practices over and above the minimum required by IMO Conventions.

Green operations have long been important in Singapore. In 2011, PSA embraced environment-friendly equipment, such as electric gantry cranes, hybrid, and electric automatic guided vehicles (AGVs). The future Tuas Port would consider battery-powered vehicles (BVs) instead of diesel-powered container trucks (BVs have been proven to be effective in reducing greenhouse gas emissions and mitigating oil dependency).

BATTERY-POWERED VEHICLES

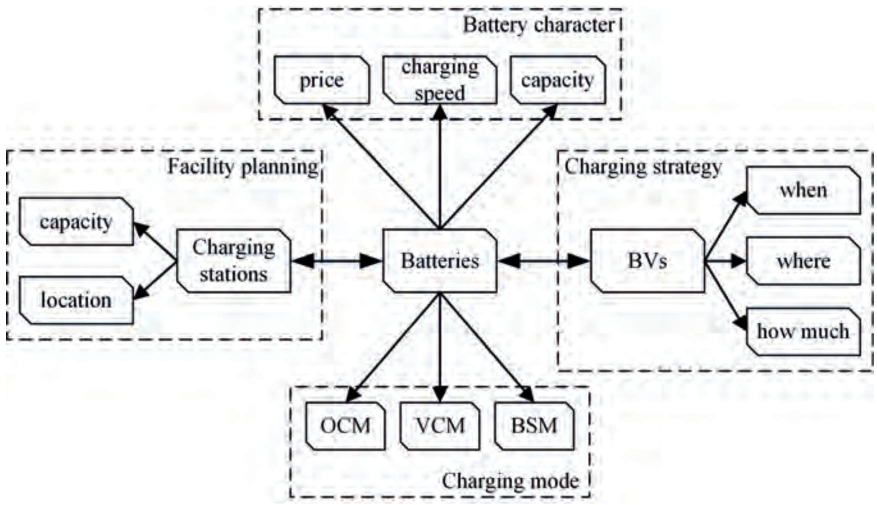
The limited range of operation and long recharging times of BVs used to be their biggest drawbacks that prevented them from being widely adopted in container terminals. However, with recent advancements in BV and fast-charge technology, these problems have been alleviated greatly. For example, Kalmar has recently developed technology that can charge a heavy battery to full in just five minutes, with the maximum charging power of 600kW. Toyota Motor and Panasonic are also teaming up to develop next-generation batteries, aiming to manufacture them for electric vehicles.

When designing a BV charging system, key design factors affecting the performance of the terminal system include battery types, charging modes, number and location of charging stations, as well as a charging strategy for controlling battery recharging. Most importantly, one needs to consider the battery types. Depending on the chemical make-up of the battery, there will be differences in depletion and charging rates. One can then use this information to help determine the number of charging stations required to serve the vehicles and location of charging stations. Lastly, depending on the nature of work schedules in the industry, one will decide which charging strategy is most suitable for the system.

We at the Centre for Excellence in Modelling and Simulation for Next Generation Ports (C4NGP) at the National University of Singapore are working on finding the configuration of these factors that will provide the highest efficiency for ports. C4NGP is aiming to use a simulation-optimization approach to resolve this problem.

BATTERY SPECIFICS

Each type of battery has its own characteristics. These include acquisition price, battery capacity, recharge speed, and maintenance requirements. There are four major types of batteries: lead-acid, nickel-cadmium, nickel metal-hydride, and lithium-Ion batteries. The cost of lead-acid batteries is the lowest among whole batteries. The nickel-cadmium batteries have double capacity, but can be thrice expensive as lead-acid batteries. However, lead and cadmium cause these batteries to be environmentally harmful. Not only are nickel metal-hydride batteries environmentally safe, they provide higher power and capacity than nickel-cadmium batteries. Lithium batteries are lightweight and have more than five times as much capacity as that of lead-acid batteries. The volatile lithium electrolyte should operate under controlled temperatures.



Relationships of design factors

BATTERY CHARGING STRATEGIES

As the batteries of the BVs run low, recharging or swapping the batteries is necessary. Currently there are three charging modes implemented in actual operation, i.e., opportunity charging mode (OCM), vehicle charging mode (VCM), and battery swapping mode (BSM).

In BSM, low capacity batteries will be swapped by full capacity ones at the swapping station. OCM permits batteries to be charged several times during the work cycle. It is suitable for yard blocks of end-loading layout. The vehicles will be charged when staying or waiting at the yard area and not be charged when leaving the yard. In VCM, the vehicles need to park at stations to charge, and then depart after a length of time. Now port operators can choose the charging models according to different preferences. Some contemporary examples of ports and terminals that are using this are: Shanghai Yangshan Port, China (BSM); Qingdao Port, Xiamen Yuanhai Port, both China (OCM); HHLA Terminal Altenwerder, Germany (VCM).

In addition, the location and number of charging stations will affect the efficiency of the port. It is crucial to build a suitable number of charging stations to achieve a decent charging waiting time. Ports will have to balance the cost of building additional charging stations against the average charging waiting time. The charging stations can be situated either in a centralized or decentralized layout. The centralized design deploys the charging stations together in the terminal. The decentralized design distributes the charging stations equally between the yard block's end-points. Applying a centralized or decentralized design is often affected by the battery charging modes. Generally, for the swapping mode, the centralized layout will be used, while decentralized layout is suitable for the OCM and VCM. However, the distance that BVs need to travel to access charging stations should also be taken into consideration when deciding which layout to use.

Unlike diesel vehicles, the BVs are followed up by a recharging break after handling several container moves. It is important to decide the charging strategies for the BVs, including when, where and how much the BVs are sent for recharging. One could implement either a smart strategy or a rule-based strategy. For the smart strategy, the BVs will be sent for charging dynamically based on the workload of the terminal and vehicle conditions.

For the rule-based strategy, one can choose to send the BVs for recharging whenever they are not working. This is suitable for industries that have work cycles in-built, meaning one can utilize predictable idle times. A charging schedule can then be planned around the gaps of time the BVs are not working, thereby preventing interruptions to the work cycles. This is commonly known as 'opportunity charging'. A threshold charging rule is also widely adopted in industries. In this model, BVs are automatically scheduled for battery charging once their battery level falls below a pre-determined percentage.

C4NGP has performed a simulation-optimization approach to conduct capacity planning for newly design container ports. The proposed framework can test the number and the layout of charging stations as well as the recharging threshold for automatic charging. These results can carry out the optimal number and location of charging stations for a given configuration. C4NGP will continue to use its simulation and modelling technologies to resolve the operational problems involved of BVs in container terminals.

ABOUT THE AUTHORS

Dr. Ma Ning, Doctorial Research Fellow, and Dr. Zhou Chenhao, Assistant Professor (Research), are from the Centre of Excellence in Modeling and Simulation for Next Generation Ports (C4NGP), National University of Singapore (NUS). Dr. Ma is focusing on operation optimization of battery vehicles in container terminals. His publications can be found in Computers & Operations Research, etc. Dr. Zhou is leading the research team under C4NGP to work on maritime projects.

ABOUT THE ORGANIZATION

Established in 2018, C4NGP is an S$18 million Research Centre to help Singapore's maritime and port industries develop innovative capabilities and enhance their global competitiveness. C4NGP aims to be a global leading Research Centre in modelling, simulation, and optimization of maritime systems, collaborating closely with companies in Singapore's maritime and port sectors to improve their technical know-how, efficiency and productivity, contributing to Singapore's economic development and society.

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