Impact of Disruptive Technologies on Maritime Trade and Maritime Industry

Blockchain, 3D Printing, e-Commerce & Battery Technology (for Harbour Craft)

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Table of Contents

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Executive Summary

Disruptions from rapid technological shifts, whilst impacting areas like employment, skills, and business models, are also creating opportunities for improving operational efficiency and changing the competitive landscape for existing industries. Maritime stakeholders must consider the opportunities enabled by advances of technologies which will change the way how businesses are run, interconnected within and without the ecosystem and jobs are redefined and performed.

Disruptive technologies are introducing new threats and opportunities for companies, government bodies, and economies. Understanding the impact of disruptive technologies is a priority for industry leaders and policymakers across all economic sectors. For the maritime sector, the impact of rapid technological change can be categorised into two key areas: i) impact on the maritime industry itself through changing business models driven by technology; ii) impact on maritime trade caused by upstream technological changes in other sectors, e.g. in manufacturing.

This project focuses on the following four disruptive technologies and aims to generate new insights on the impact of these technologies on maritime trade and maritime industry:

3D Printing: The increasing focus on developing 3D printing both in Singapore and worldwide could affect the global movements of certain goods. Understanding its potential implication for global trade flows and shipping, and also potential opportunities to improve customer service, reduce inventory, or provide new services is important to maritime and smart manufacturing hubs like Singapore.

Blockchain: The emergence of blockchain based solutions opens up possibilities for streamlining processes, increasing productivity and lowering transaction costs in a complex multi-party transaction seen in maritime supply chains. Quantification of benefits and identification of key areas where such benefits can be realised will increase the competitiveness of maritime services.

e-Commerce: The rise of e-commerce especially in the Asia pacific region necessitates a better understanding of its impact on supply chains and motivations for new supply chain pathways and services such as multi-modal transportation services (e.g. sea-air) and extensive local distribution networks.

Battery Technology for Harbour Craft (HC): With the implementation of stricter environmental regulations in the maritime sector, the industry is actively looking for solutions beyond fossil fuel, such as battery, biodiesel, methanol, biogas and hydrogen. Among them, battery is the readiest technology in the short term with the highest technology readiness level 9. With the rapidly decreasing battery costs fueled by the development of electric vehicles, vessel electrification becomes more economically feasible. Among various vessel types, harbour crafts are good candidates for battery technology in view of their relatively short travel distance per trip, sizeable CO_2 emissions and successful demonstration projects. Therefore, this report focuses on the adoption of battery technology for harbour craft.

All the four technologies would have potential implications to maritime trade and maritime industry, through the change of global supply chains, flow of information and finances, physical cargo movement, infrastructure development and environmental impact. It is important to understand those potential impact and implications for stakeholders better preparing themselves for future opportunities and challenges.

Impact on Maritime Trade and Maritime Industry

Whilst we analyse these technologies individually, we also look at implications and recommendations based on the identified commonalities in trends.

The impact of e-commerce, blockchain and battery technology on maritime trade and industry could be felt in the next five years, whilst 3D printing could take longer in its impact. The initial impact of 3D printing would be on custom manufacturing, rapid prototyping, new designs, and the spare parts industry, with opportunities for ports and shipping lines to use 3D printing for their spare parts, potentially improving product availability and customer service level. As adoption of 3D printing grows beyond custom products, it would take at least 10 years before there are tangible changes in global trade and shipping patterns. The detailed impact of these technologies on maritime trade and maritime industry is summarized in Table 1.

Table 1: Summary of Key Impact of the Four Technologies on Maritime Trade and Maritime Industry

3D Printing	
Maritime Trade	Maritime Industry
1) 3D printing could potentially lead to reduction in volumes of finished goods trade, with the possibility to manufacture on demand for small quantities. This assumes that 3D printing substitutes traditional manufacturing for finished goods products rather than new product or product categories being created. 2) The extent of substitution depends on the level of technology readiness and cost effectiveness of 3D printing technology versus mass manufacturing, as well as other factors such as industry certification of 3D printed products, and legal frameworks regarding product liability and intellectual property rights. In any case, 3D printing will sit side by side with traditional manufacturing to make the final product. 3) Whilst 3D printing is growing rapidly at around 25% per year, it does so from a low market share of global manufacturing at 0.07%, and current applications are in custom products and low volume applications. The impact on global trade in finished goods and container shipping is likely to be negligible till the mid-2030s. Beyond that, depending on adoption rates continues, 3D printing could have an impact of between 5% to 16.5% on shipping volumes around 2045, with a medium scenario at 7%. This assumes that 3D printing is substituting traditional manufacturing and not creating new types of products. 4) Current 3D printer companies and 3D material companies are primarily in the US and Europe. This could also mean potential changes in current manufacturing trade flows from developing to developed countries, as 3D printing becomes more widespread. 5) If adoption of 3D printing becomes more widespread, the manufacturing landscape will become correspondingly more decentralised. This could lead to smaller but more numerous factories, and more local warehouses for raw materials to support local production	1) 3D printing can reduce the level of finished goods inventories which companies in the maritime industry and manufacturing industry in general need to carry, especially in areas such as spare parts. 2) This can potentially lead to new business models, for example manufacturing service bureaus providing products on demand, or with ports like PSA providing spare parts at their global network of ports for shipping lines upon docking

e-Commerce	
Maritime Trade	Maritime Industry
1) Whist e-commerce has been growing rapidly in China, e-commerce in Southeast Asia is just starting to take off. The rise of cross-border e-commerce will change retail shipping patterns towards multi-modal modes of shipping, including airfreight and ground delivery. e-Commerce deliveries are more decentralised, with methods of points of customer order and modes of customer deliveries. Maritime trade players would need to think beyond seafreight to look at multi-modal offerings. 2) The impact of e-commerce on maritime container shipping depends on the business model adopted. In marketplace models, the e-commerce company provides a platform for independent vendors to list and sell their products. For small volume shipments, LCL (less than container load) or airfreight modes of transportation are more likely to be used. In e-tailer models where the e-commerce company acts like a retailer through purchasing products or selling products on a consignment basis, consolidation and container shipping will continue to be required. 3) The growth of e-commerce in Southeast Asia will require a wider network of distribution centres for consolidation and delivery. In Southeast Asia, Singapore and Johor, Malaysia could be positioned as regional distribution hubs to support demand in Southeast Asia countries. The location will depend on volumes, and cost and time trade-offs for delivery to customers, with possible segmentation of fast moving and high value products hubbed in Singapore, and low value and slower moving products hubbed in Johor. 4) The need for warehouse and logistics infrastructure could also present new business opportunities for logistics companies, and infrastructure companies such as construction, finance and property companies.	1) e-Commerce is likely to have impact on supply chain structures across industries rather than specific industries. While e-commerce volumes in Southeast Asia are relatively small currently compared to overall retail volumes, their continued growth trajectory could make them significant new customers for maritime shipping and logistics services in future. 2) Maritime players such as port operators and shipping lines should look at opportunities to diversify into multi-modal infrastructure and solutions offerings in order to better capture the opportunities of e-commerce.

Blockchain	
Maritime Industry	Maritime Trade
1) Blockchain could well address the pain points in the industry regarding inefficiency, transparency and quality assurance 2) Government agencies, ship owners and marine service providers being the top 3 parties which would benefit the most from adopting blockchain (Refer to Figure 13 for details). 3) If blockchain is deployed to digitise shipping documents, including bills of lading: • US$200-451 billion total gross saving is expected for global container shipping from 2019 to 2040. • US$3-7 billion total gross saving is expected for Singapore container shipping from 2019 to 2040. • US$43-96 saving per loaded container (in TEU) is expected for maritime supply chains. • The two largest benefits of blockchain from digitizing shipping documents are 1) efficiency gains from reduced conflicting data records and 2) savings from eliminated printing and postage of original bills of lading. • When blockchain adoption speed doubles, the gained benefits are more than doubled.	1) Through cost efficiencies in speeding up transactions, blockchain could make it easier for cross border trade, especially with low-cost developing countries, to take place. This reduction in trade friction would be expected to improve the level of global trade and hence the movement of goods and services. 2) New services for trade financing and electronic document handling could be provided for companies in the maritime trade value chain, providing opportunities for existing players or for technology providers.

Battery Technology for Harbour Craft	
Maritime Industry (Harbour Craft Sector)	Maritime Trade
1) In the near term, passenger craft is the most suitable harbour craft type for vessel electrification. The payback period can be less than 5 years. 2) If the battery system level price can be as low as US$200/kWh (S$282/kWh) and LSMGO price is no more than US$743/ton, the electricity price should at least drop to US$0.067/kWh (S$0.094/kWh) to make battery system competitive compared with traditional diesel system for vessels. 3) Given the current LSMGO being around US$250/ton[1], battery system is not competitive with traditional diesel system. 4) Battery-Solar PV systems are useful to support vessel operations during idling time and reduce greenhouse gas emissions: • A reduction of 4,400–5,700 tons of CO_2 equivalent per year can be achieved by tapping on battery-solar energy for Singapore HC sector, excluding SR type craft[2]. 5) Due to restrictions of available surface area of HC, the effective energy generated by solar panels on HC is about 2% of the energy generated by auxiliary engine during idling and standby period.	There is no foreseeable impact of battery technology for harbour craft on maritime trade.

Policy and Business Recommendations

Based on the results of online survey, interviews and team's analysis, this report identifies some strategies (see Table 2) for both public and private sectors to capture the opportunities and unlock the potential savings provided by the four technologies, as well as to address key challenges and enhance key drivers that affect the adoption of these technologies in maritime trade and maritime industry.

[1] Based on the Singapore bunker price between 1 April 2020 and 15 May 2020.
[2] Vessel used for any other purpose. See Appendix 6 for Singapore's HC classification.

Table 2: Key Recommendations

<table>
<tr><td rowspan="3">Blockchain</td><th>For Public Sector</th><th>For Private Sector</th></tr>
<tr><td colspan="2">Strengthen education and training of maritime workforce in alignment with blockchain transformation
▪ Actively facilitate/participate in blockchain knowledge sharing among academia, industry and public sectors (e.g. organise specialized blockchain workshops/ forums)</td></tr>
<tr><td>Speed up to build a clear and supportive regulatory environment of using blockchain to promote earlier adoption and maximise the benefits for the society
▪ Legal recognition of blockchain-based information, e.g. electronic bills of lading and electronic bunker delivery note
▪ Involve in development of technical standards for blockchain, e.g. standards for blockchain data structure and smart contracts
▪ Establish and facilitate regulatory sandbox for blockchain

Establish excellence in blockchain adoption for maritime industry
▪ Take the leading role by deploying blockchain for public services in the maritime industry
- e.g. customs clearance, port registry, & maritime surveillance
▪ Create test bed environment for blockchain innovation and adoption in the maritime sector
- e.g. sandbox for blockchain
▪ Encourage and support research to study blockchain use cases in the maritime industry and timely disseminate findings to maritime community</td><td>▪ Start/prioritise use cases of blockchain for data management and electronic bills of lading
▪ Start small and from areas where least legal issues are involved, e.g. non-transferable bills of lading
▪ Seek alternative solutions to handle sensitive information, e.g. off-chain storage for sensitive data
▪ Careful selection of blockchain partner, i.e. choose reputable and experienced blockchain developers to reduce potential security threats
▪ Build a wide and deep blockchain ecosystem by facilitating stakeholders getting on board
▪ Strengthen industrial collaboration horizontally and vertically</td></tr>
<tr><td></td><th>For Public Sector</th><th>For Private Sector</th></tr>
<tr><td rowspan="2">3D Printing and E-Commerce</td><td colspan="2">Shipping should not be seen in isolation, but together with the supply chain ecosystem and manufacturing technologies. Differentiate through the smart use of technologies, and integrating shipping flows with information flows and overall manufacturing and trade flows.</td></tr>
<tr><td>Overall government policy would be geared towards creating centres of excellence in emerging technologies and developing the ecosystem to support digitalization of manufacturing (example 3D printing, automation, analytics, IOT), and the digitalization of retail (e-commerce).
▪ Take a multi-modal and integrated approach towards the development of transportation infrastructure and policy
- looking at a holistic view of how sea, air and land transport come together to support businesses
▪ A multi-prong approach towards the development of maritime infrastructure, including supply chain information networks and financial networks
▪ Develop legal frameworks for adoption of 3D printing, e.g. in product liability and intellectual property rights</td><td>For companies in maritime and logistics sector
▪ Look into developing prototypes and trials of 3D printed products, to understand cost-benefit of using the technology
▪ Tap on availability of government grants and capability of academic research institutes
▪ Diversify into different supply chain sectors to provide a multi-modal offering for customers, as well as supply chain services, in order to capture new opportunities from logistics for e-commerce and 3D printing.</td></tr>
</table>

<table>
<tr><td rowspan="2">3D Printing and E-Commerce</td><th>For Public Sector</th><th>For Private Sector</th></tr>
<tr><td>▪ Develop standards for communication of 3D digital blueprints to facilitate adoption.
- This could be done together with input industry bodies, trade associations and technology service providers
- These standards need to be inter-operable and may be regional or international
▪ Reach out to newly emerging players in 3D printing and e-commerce to drive investment and growth opportunities for the future</td><td>▪ Develop new business models such as trade and information integration of the supply chain, on-demand manufacturing of parts
▪ Monitor developments in 3D printing and expected growth rates beyond 2025 to understand the technology trajectory and impact
For Service providers
▪ Build legal and arbitration competencies in 3D printing service bureau business models, intellectual property, and contractual arrangements
▪ Develop data centre and cloud infrastructure for storage and use of digital data, to cater to requirements for e-commerce and 3D blueprints</td></tr>
<tr><td rowspan="3">Battery Technology for Harbour Craft</td><th>For Public Sector</th><th>For Private Sector</th></tr>
<tr><td colspan="2">Collaborate closely with each other to establish regulations to specify which standards/guidelines/ rules to follow in the following areas:
▪ Vessel's charging stations
▪ Electrical equipment and installations on board vessels
▪ Safe operations of battery systems</td></tr>
<tr><td>Establish R&D excellence in battery, charging and energy system design technologies, focusing on below areas:
▪ Battery:
- Improve battery lifespan
- Lower battery cost
- Classification and qualification of battery
- Hot-swappable batteries
- Battery life-diagnostic tool
▪ Charging:
- Fast charging technology
- Improve charging efficiency
▪ Energy System:
- Improve efficient energy management system

Consider providing incentives to early movers which have high investment cost to establish feasibility, e.g. tax rebate, grants.

Plan port infrastructure to support vessel electrification
▪ Charging infrastructure, which requires
- Studies on optimum location, space, capacity, carbon footprint and traffic management of charging stations
- Clarity in ownership, responsibility and liability of charging infrastructure operators
▪ Supporting infrastructure to tow/repair/recharge electric HC in case of emergency like battery failure, e.g. battery-charging tugboat as a portable charging station to provide emergency charging to vessels at sea.</td><td>For HC owners/operators:
▪ Keep a good record of HC operational data for better understanding of vessel's operating profile and easier system design
▪ Start with new built HC in more regular and predictable routes or an existing vessel with a well-defined operating profile
▪ Training, skill update and mindset changing for crew to handle electric craft
For technology/system providers
▪ Develop expertise/skills in battery, charging and energy system design technologies
▪ Develop simpler and more user-friendly system
▪ Provide strong after-sales technical support
For other stakeholders
▪ Support battery adoption by providing class and insurance acceptance, relevant insurance coverage and financial supports</td></tr>
</table>

Specific Recommendations to Singapore

More specifically to Singapore as an information and financial hub in maritime services and trading, we assess that 3D Printing, blockchain and battery technology are important areas for Singapore to leverage to achieve the ITM (Transport Industry Transformation Map) 2025 target[3] and drive Singapore's IMC (International Maritime Centre) 2030 vision[4]. The development of value-added capabilities would in fact also position companies to value-add to customers beyond cost reduction and cost competition.

Therefore, the key opportunities identified are to **position Singapore as a hub for 3D printing, blockchain and battery technology innovation in maritime trade and maritime industry**. Several strategies are recommended to government to achieve this goal:

1) **Establish Singapore as a leader of global maritime standards and excellence in the areas of 3D printing, blockchain and battery technology**
    - Speed up building a regulatory environment that recognises digital documents/contracts legally
    - Develop rules, standards, and guidelines of 3D printing, blockchain and battery for harbour crafts by strong collaboration with industrial players, industry associations, other governments and international organizations. As supply chains involve multiple players and multiple IT systems, standards and supply chain integration would be necessary. Collaboration could be extended more broadly into areas of digital trade, digital manufacturing and supply chain integration.
    - Create test bed environments for innovation and adoption of 3D printing, blockchain and battery technology
2) **Develop rich ecosystems and promote network effects for 3D printing, e-commerce, blockchain and battery technology**
    - Promote a wide and deep blockchain ecosystem by facilitating stakeholders getting on board
    - Prepare and provide outreach to newly emerging players for those technologies to set up offices and manufacturing in Singapore
    - Strengthen industrial collaboration horizontally and vertically within the technology and maritime ecosystem
3) **Develop digitalised skillsets and transform the mindset for maritime workforce**
    - Strengthen the education and training of maritime workforce in alignment with these technological transformation
    - Encourage knowledge sharing among academia, industry and government agencies
4) **Take a multi-modal approach towards logistics policies and infrastructure development**
    - Set up multi-modal logistics policies to ensure the integration of air, sea and land offerings to provide overall competitiveness of the country

[3] ITM 2025 target: Grow the sector's value-add by S$4.5 billion and create more than 5,000 good jobs by 2025
[4] IMC 2030 vision: Be the global Maritime Hub for Connectivity, Innovation, and Talent.

- Set up zones for loose cargo handling and breakbulk operations such as previously Keppel Distripark, to cater to the development of e-commerce and 3D printing, which both require warehouse networks
- To mitigate higher cost structure of labour compared to regional countries, polices can promote the use of warehouse automation to make operations more cost-effective for handling large volumes of e-commerce operations

5) **Leverage on Singapore's strength as a financial hub for regional infrastructure development**
    - Tap on the potential for REITs and funding and investment needs for logistics infrastructure. Singapore as a leading destination for REITS also put it in good stead to benefit from the likely increase in regional warehousing solutions
    - Work with funding agencies such as World Bank and Asian Development Bank, and private investors to fund regional projects, and also identify potential synergies and information integration with Singapore's shipping and logistics hub

List of Tables

List of Figures

1 Introduction

Disruptions from rapid technological shifts, whilst impacting areas like employment, skills, and business models, are also creating opportunities for improving operational efficiency and changing the competitive landscape for existing industries. For the maritime industry, the impact of rapid technological change can be categorised into two key areas: i) impact on maritime trade caused by upstream technological changes in other sectors, e.g. in manufacturing and retail, and therefore impacting the maritime sector, and ii) impact on the maritime industry itself through changing business models and ways of operation driven by technology;

This project focuses on the following four disruptive technologies and aims to generate new insights on the impact of these technologies on maritime trade and maritime industry:

3D Printing: The increasing focus on developing 3D printing both in Singapore and worldwide could affect the global movements of certain goods. Understanding its potential implication for global trade flows and shipping, and also potential opportunities for companies to use 3D printing to improve customer service, reduce inventory, or provide new services is important to maritime and smart manufacturing hubs like Singapore.

Blockchain: The emergence of blockchain based solutions opens up possibilities for streamlining processes, increasing productivity and lowering transaction costs in a complex multi-party transaction seen in maritime supply chains. Quantification of benefits and identification of key areas where such benefits can be realised will increase the competitiveness of maritime services.

e-Commerce: Within Asia, China leads in e-commerce adoption but Southeast Asia is growing rapidly. The rise of e-commerce creates new channels of product distribution, and correspondingly, this would require changes in supply chain pathways and services such as multi-modal transportation services (e.g. sea-air) and the need for extensive local distribution networks.

Battery Technology for Harbour Craft (HC): With the implementation of stricter environmental regulations in the maritime sector, the industry is actively looking for solutions beyond fossil fuel, such as battery, biodiesel, methanol, biogas and hydrogen. Among them, battery is the readiest technology in the short term with the highest technology readiness level 9 (National Academies of Sciences, Engineering and Medicine and others, 2016). With the rapidly decreasing battery costs fueled by the development of electric vehicles, vessel electrification becomes more economically feasible. Among all vessel types, harbour crafts are good candidates for battery technology in view of their short travel distance per trip, sizeable CO_2 emission[5] and successful demonstration projects. Therefore, this report focuses on the adoption of battery technology for harbour craft.

All the four technologies would have potential implications to maritime trade and maritime industry, through the change of global supply chains, flow of information and finances, physical cargo movement and environmental impact. It is important to understand those potential impact and implications for stakeholders better preparing themselves for future opportunities and challenges.

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[5] In Singapore, CO_2 emission from harbour craft ranks No.4 among the emissions from all vessel types, including tanker, container, bulk carrier, general cargo etc (source from MPA).

This report composes five sections. Section 1 provides an introduction and reasons to analyse the four disruptive technologies. Section 2 provides an overview of the four technologies. Section 3 and 4 analyse the impact of these technologies on maritime trade and maritime industry respectively, together with industry opinions and recommendations. Section 5 concludes the report.

2 Overview of the Four Technologies in the Maritime Industry

2.1 Blockchain

As defined by UNCTAD (2018), blockchain is "a distributed ledger technology that enables peer-to-peer transactions that are securely recorded, as in a ledger, in multiple locations at once and across multiple organizations and individuals, without the need for a central administration or intermediaries". This technology has attracted large attention from the population and various industries owing to the extreme price surge of Bitcoin since 2013.

As a new technology which provides benefits of immutability, high transparency, one-way cryptography and high traceability, blockchain technology started to be tested by major banks and financial institutions in the areas of financial services around 2015 (Wild, Arnold, & Stafford, 2015). It was then expanded into non-financial industries such as electronic health records, ownership management, and supply chain. As a special and critical part of the global supply chain, maritime industry is also proactively exploring the potential of leveraging the blockchain technology to improve its operational efficiency and reduce costs.

Table 3 summarises the technical features of blockchain that are key enablers of applications in the maritime industry.

Table 3: Key Features of Blockchain Technology that are Enablers of Applications in Maritime Industry

Key Features	Description
Immutability	The uploaded transactions cannot be changed or deleted in general (Berke, 2017; Xu et al., 2016, 2017).
Peer-to-peer transmission	Direct communications and transactions between parties without involving a central party (Berke, 2017; Christidis & Devetsikiotis, 2016; World Economic Forum, 2015).
Time-Stamped data	Any updates of information can only be appended to blockchain, which form time-stamped data and become valuable source for tracing and auditing (Xu et al., 2016; Yuan & Wang, 2016).
Visibility	The information in the chain is transparent to all participants in a permissionless blockchain or selected participants in a permissioned blockchain (World Economic Forum, 2015; Xu et al., 2016, 2017).
Smart contracts	Logic or computational rules can be added in the chain via programming. The execution of smart contracts is automatic and independent (Berke, 2017; Yuan & Wang, 2016).
Asymmetric Cryptography	It refers to one-way hash functions, with which non-recipients cannot decrypt the message but can verify the message (Yuan & Wang, 2016). This can be applied to digital signature and authentication.

Blockchain provides a range of opportunities for the maritime industry in improving efficiency and reducing costs. It replaces redundant data entry, improves data transparency and cuts fraud with a single source updated in real-time. Apart from bills of lading and trade finance, it can also be applied in various maritime sectors. Table 4 summarises all the contextualised use cases that blockchain could be applied in the maritime industry together with the potential efficiency gains.

Table 4: Summary of Use Cases of Blockchain In the Maritime Industry with Analysis of Potential Efficiency Gains

Categories of Use Cases	Examples	Potential Efficiency Gains
Trade Finance	• Bills of Lading • Letter of Credit	✓ Reduce the processing time of documentation and increase operational efficiency in shipping and maritime trade ✓ Reduce costs, for example 15-20% of total transportation fee could be saved through digitizing documents in container shipping (Longman, 2017) ✓ Ensure uniqueness and security of documents with cryptographic authentication ✓ Provide traceability and auditability of documents with time-stamped and tamper-proof record ✓ Easy verification of documents ✓ Reduce fraud in documentation ✓ Reduce the processing time of documentation and increase operational efficiency in shipping and maritime trade
Digitise Documents	• Classification Society Certificates • Seafarer Certificates • Ship Registry and Class Registry • Other Shipping Documents (e.g. Customs Documents)	
Information Management	• Enhance Information Sharing • Track and Trace Information	✓ Real-time and tamper-proof information sharing and transparent visibility ✓ Cost reduction in operations[6] ✓ Better planning and optimisation of resources ✓ Resolve confidentiality concerns with cryptography and peer-to-peer transmission
Ship Finance	• Cross-Border Remittance • Ship Financing • Escrow	✓ Faster and cheaper cross-border remittance[7] ✓ Alternate financing source for maritime companies ✓ Lower entry for the public to invest shipping business ✓ Automatic and independent execution of escrow and free from interference of transacting parties
Marine Insurance	• Underwriting • Claims	✓ More accurate and smarter premium based on changes in situations ✓ Streamline the process of claims ✓ Reduced fraud ✓ Increased visibility and transparency of information on the insured.
Marine Manufacturing	• 3D Printing for marine parts	✓ Seamless and secure data storage and transfer

2.2 3D Printing

3D printing, otherwise known as additive manufacturing, builds products one at a time through layering of raw materials on top of each other, through a 3D printer. Using 3D modelling software, machine equipment and layering material, additive manufacturing equipment reads data from

[6] Shipping costs can save up to US$300 per container with effective and timely information sharing (Seatrade, 2018).

[7] The costs of overseas payment can be reduced to 2%-3% of the amount remitted, while the current costs are about 5%-20% of the amount remitted (Martin, 2017).

CAD files and applies layers of liquid, powder, paste or sheet material, to fabricate a 3D object (Mayer, 2018).

There are a number of methods for 3D printing, with the most common being Selective Laser Sintering (SLS), where material such as metal or polymer are fused together by laser, and Fused Deposition Modelling (FDM), where material such as plastic is deposited through a nozzle layer by layer (Stratasys, 2019).

In addition to plastic materials, metallic materials such as steel, pure titanium and titanium alloys, aluminum casting alloys, nickel-based superalloys, cobalt-chromium alloys, gold and silver, are also used (Frazier, 2014).

The key differences between traditional manufacturing and 3D printing are summed up as follows:

Table 5: Differences Between Traditional Manufacturing and 3D Printing

Traditional Manufacturing	3D Printing
Having been used for decades or centuries	Widely adopted from early 2010s
Relatively inexpensive production per part in large volume	More expensive to produce a unit part than traditional manufacturing
Producing each part in minutes or seconds	Producing each part in hours
End products are of lower value, e.g. commodities or worth pennies	Product value varies from hundreds to thousands of dollars
Requires the creation of molds and tools to create a custom component	No re-tooling or mold needed
Wastage caused by smoothing and milling of excess material	Less wastage of material as the process is "additive" and not "reductive"
Complex designs are not easy to make	Fewer topological constraints, allowing for more complex designs

Source: Authors, based on Deloitte Insights, 2019; DHL, 2016

Traditional methods of manufacturing rely on mass production, creating economies of scale through high volume. The use of 3D printing potentially reduces the amount of finished goods inventory, and the need to ship finished goods between countries, as finished goods can be printed on site. 3D printed materials are also lighter and use less raw materials. This is also expected to improve environmental sustainability and reduce carbon footprint.

3D printing currently accounts for around 0.07% of global manufacturing volumes, with an estimated market size of US$9.9 billion in 2018, compared to the market size of global manufacturing at US$14 trillion in 2018 (Markets and Markets, 2019; World Bank, 2019). Nonetheless, it has been growing rapidly, with estimates of growth rates of 23.2% per annum till 2025, and is expected to reach US $34.8 billion by 2024 (Markets and Markets, 2019).

The initial use of 3D printing on specialty or customs parts is likely to have minimal impact on maritime trade and shipping, but its gradual adoption to a larger variety of low and mid volume components and products would have implications for maritime trade and shipping.

In the case of spare parts, these are mass produced to save production costs, and then positioned into central or regional warehouses to support customers (spare-parts-3D.com, 2017), suggesting that the first leg of the transportation journey is by sea.

Airbus prototyped an entire small size pilotless aircraft out of 3D printing, and in 2017, introduced its first part 3D printed part in a serial production aircraft (Airbus, 2019). Boeing has used 3D printing on 60,000 parts in its aircraft, out of an estimated 6 million parts in an airplane (Kottasová, 2018). China-based start-up Pix Moving is using AI to design cars and convert into blueprints for 3D manufacturing, and have a customer in the US or elsewhere to download the digital blueprint, 3D print, and assemble the car. (Liu & Tabeta, 2019).

2.3 e-Commerce

Started in the 1990s, when the internet was opened to commercial use, e-commerce allows the process of buying and selling product using electronic means such as mobile applications and online website via the internet. Ever since, more and more businesses have reached out to their customers via the web. e-commerce value was US$19 billion in 1999, US$38 billion in 2000, US$54 billion in 2001 (Forbes, Kelley, and Hoffman, 2005), and is now projected to reach US$4.9 trillion worldwide by 2021 (eMarketer, 2018).

In e-commerce, customers are not bounded by geographical restrictions; they can buy from any e-commerce website all over the world, anytime (24/7), anywhere (geographically) and in various ways (mobile, tablet and computer). They can also compare and select the best product with the most competitive offerings. In the context of a typical retail supply chain, e-commerce allows the customer to order at any point in that supply chain flow.

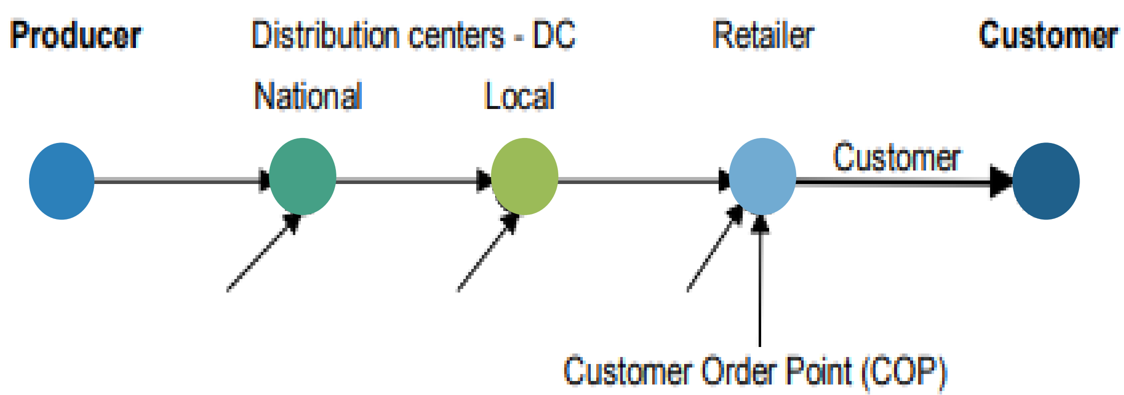


Figure 1: A Typical Retail Supply Chain

e-Commerce, over the last 25 years, has gradually transformed the retail scene and now looks set to gain a bigger share of the retail sector globally, as well as grow rapidly in Southeast Asia. e-Commerce includes marketplace models, where an e-commerce site acts as a portal for independent third-party companies to list their products, and e-models, where an e-commerce site actually takes responsibility for the inventory through ownership or consignment basis. Different types and business models of e-commerce are shown in Table 6. The larger e-commerce companies would follow more than one business model, depending on the type and volume of product which it is carrying.

Table 6: Types of e-Commerce Business Models

Classification	Type of e-Commerce	Examples	
E- tailers Individual websites and is usually fulfilled by its own operations.	B2B(Business-to-Business) B2C(Business-to-Consumer)	Amazon Zalora Asos	Zara Nike
Marketplace Provide a platform for sellers to list their products. Fulfillment can be done by either seller o marketplace. *Has the option to provide aggregated logistics services for their sellers.(Consignment)	B2B(Business-to-Business) B2B(Business-to-Business) C2B(Consumer-to-Business) C2C(Consumer-to-Consumer)	eBay Amazon* T-Mall* Taobao* Alibaba	Zalora* Lazada* Carousel Ezbuy*
Cross-border services for buyers (Service Provider) Provide logistics services for buyers who purchase from overseas E-Commerce website. Provide overseas warehouse address and consolidating overseas order.	B2B(Business-to-Business) B2C(Business-to-Consumer) C2B(Consumer-to-Business) C2C(Consumer-to-Consumer)	Ezbuy SGship Singpost vPost	
Cross-border services for sellers (Service Provider) Provide logistic services for sellers who sell to overseas customers.	B2B(Business-to-Business) B2C(Business-to-Consumer) C2B(Consumer-to-Business) C2C(Consumer-to-Consumer)	Ezbuy SGship Singpost vPost	DHL FedEx SF Express

Traditional retail business models rely on large volumes, economies of scale, and use of containerised seafreight. On the other hand, e-commerce retail is more fragmented, with multiple vendors, and multiple modes of shipping (air, sea, and trucking) to millions of end customers. This implies also that the distribution network for e-commerce will be more complicated, including multi-modal and the use of widespread warehouse network to place products near to customers. Figure 2 illustrates the possible ways in which products can move from an overseas factory to a consumer in Singapore.

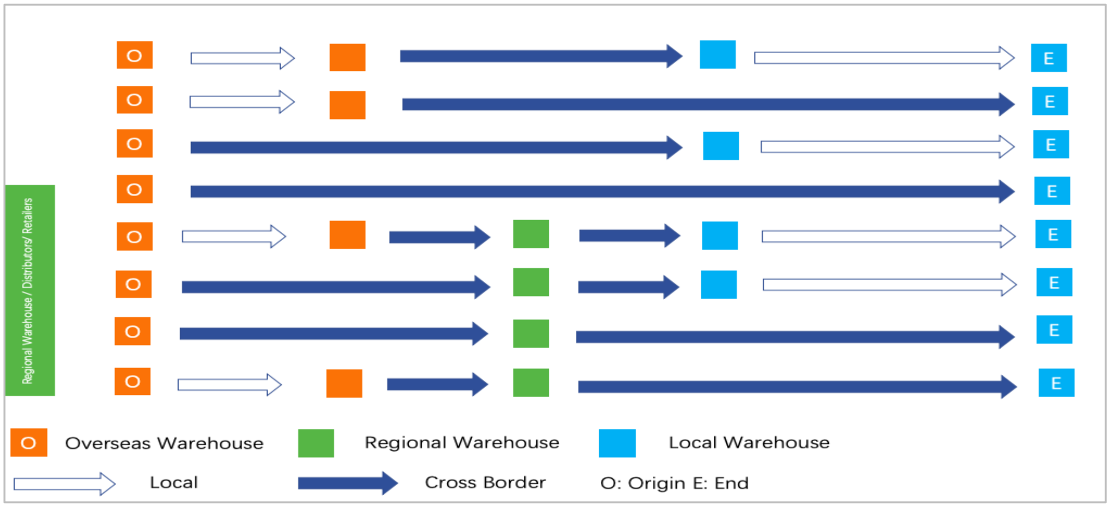


Figure 2: Possible ways for e-commerce product flows from an overseas factory to a consumer in Singapore

2.4 Battery Technology for Harbour Craft

With increasing concerns on environmental sustainability, the International Maritime Organisation (IMO) is making efforts to reduce air pollution and greenhouse gas (GHG) emission from vessels by imposing stricter environmental regulations in shipping, such as the IMO 2020 fuel oil sulphur cap and GHG reduction strategy. Those regulations are pushing the maritime industry to actively look for solutions beyond fossil fuel. Some alternative energy technologies for vessels include battery, biodiesel, methanol, biogas, and hydrogen. Among them, battery is assessed the most feasible technology in the short term with the highest technology readiness level 9 (National Academies of Sciences, Engineering and Medicine and others, 2016). Meanwhile, with the rapidly decreasing battery costs fueled by the development of electric vehicles, vessel electrification becomes more economically feasible.

Table 7 compares different battery technologies for energy storage based on the following technical characteristics: energy density, charge and discharge efficiency, life span, and eco-friendliness. Based on this table, Lithium-ion batteries are regarded as the most promising ones for vessels. However, Lithium-ion battery technology still faces a few challenges for effective adoption, such as long charging time (2-3 hours for a full recharge and about 30 mins under quick charging), high battery cost (USD300-USD500/kWh) and potential thermal runaway which may result in fire and explosion.

Table 7: Comparison of Different Battery Technologies

Battery Technologies	Energy Density (kW/kg)	Charge and Discharge Efficiency (%)	Life Span (years)	Eco-friendliness
Lithium-ion	150-250	95	10-15	Yes
Sodium-sulphur	125-150	75-85	10-15	No
Flow	60-80	70-75	20-25	No
Nickel-cadmium	40-60	60-80	5-10	No
Lead-acid	30-50	60-70	3-6	No

Source: (Asian Development Bank, 2018)

Among all vessel types such as tanker, container and bulk carrier, harbour crafts are good candidates for battery technology in view of their short travel distance, sizeable CO_2 emission[8] and successful demonstration projects. Therefore, this report focuses on the adoption of battery technology for harbour craft.

The advantages and disadvantages of applying battery technology for harbour craft are listed in

Table 8. The adoption needs commitments from government such as providing sufficient waterfront space for infrastructure or building infrastructure which requires a huge up-front investment.

Table 8: Advantages and Disadvantages of Battery Technology for Harbour Craft

Advantages	Disadvantages
1 **Technology Readiness Level (TRL) 9** Higher TRL versus other sources of alternative energy	1 **Waterfront space for infrastructure at a cost**
2 **Flexibility** Batteries allow for multiple power sources and are easy to be upgraded or replaced	2 **Additional costs on shore** Additional maintenance and electrical costs by port authority/ operator
3 **Reduce green house emission and noise**	3 **Limited energy storage capacity**
4 **Performance reliability**	4 **Manufacturing of batteries is energy intensive** In full life cycle view, it is not zero emission.
5 **Safe**	
6 **Reduce O&M costs**	

There are over 2,300 registered harbour crafts in Singapore. They are categorised into five groups, namely SB, SC, SP, ST and SR (see Appendix 6). Figure 3 shows the profile of harbour craft. 70% are running on fossil fuel, while the rest are non-motorised. Singapore's harbour craft can be more carbon efficient.

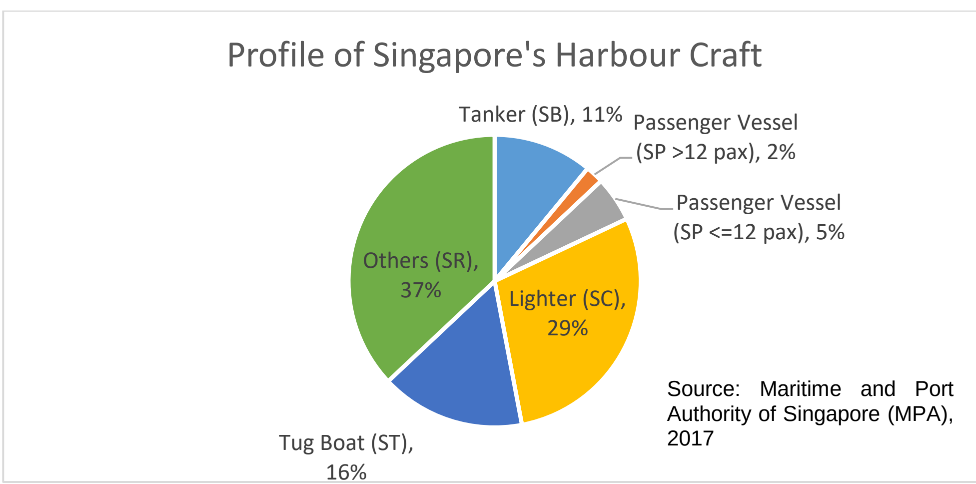


Figure 3: Profile of Singapore's Harbour Craft

[8] In Singapore, CO_2 emission from harbour craft ranks No.4 among the emissions from all vessel types, including tanker, container, bulk carrier, general cargo etc (source from MPA).

3 Impact of Disruptive Technologies on Maritime Trade

The key impact on maritime trade amongst the four technologies would come from 3D printing and e-commerce. These two technologies can potentially change trade flows and therefore would have an impact on shipping patterns as well.

3.1 3D Printing

3.1.1 Impact of 3D Printing on Supply Chain

3D printing impacts supply chains in various ways. It allows for efficiency of production in small quantities, thereby helping with a reduction in inventory. As products can be manufactured on demand, this allows for customization of products, and with the repair and reproduction of obsolete parts. It can also shorten supply chains by manufacturing of products closer to home markets.

3D printing allows a manufacturer to manufacture and test a product throughout the innovation and development process. It reduces complexity during prototyping where parts and components, assembly steps and costs can be significantly reduced.

A higher degree of co-creation is possible, as a supplier can evaluate a prototype product with an end-user (e.g. a ship owner) at an early stage.

3.1.2 Quantitative Impact of 3D Printing on Shipping Volumes

Whilst 3D printing can lead to manufacturing innovation, increased efficiencies in product development, and lower inventory, it can also have a potential impact on reducing finished goods shipments.

In estimating the potential impact of 3D printing on global shipping volumes, a baseline projection of shipping volume without 3D printing impact was done using global shipping volumes and world trade growth (UNCTADstat, 2019), and a simulation of expected impact of 3D printing based on different growth scenarios.

From a business point of view, there is still a fair bit of uncertainty on the disruptive effect of 3D printing. The simulation is not meant to give a definitive projection of numbers, given so many variables over a long period of time, but to identify scenarios and sensitivity analysis for management decision making.

3D printing is assumed to substitute for traditional mass manufacturing rather than create new products or new product categories which do not cannibalise existing products. Growth was based on a normal curve of technology adoption as per the Rogers technology adoption model, with variance of growth rates and peak period of growth. The shipment of raw materials to 3D printing factories or homes is unlikely to make up for the slowdown in finished goods shipment, as the ratio of raw materials to finished goods is less in 3D printing as compared to traditional manufacturing, i.e. there is greater wastage of raw materials in traditional manufacturing.

Figure 4 shows a projection of shipping volumes, based on a baseline projection of world trade growth without 3D printing, and a high, low and average scenario of impact of 3D printing, which is expected to reduce the shipping volumes. Prior to 2030, 3D printing would have a negligible impact on volumes, and a tangible impact on shipping volumes might take place from the mid-2030s onwards.

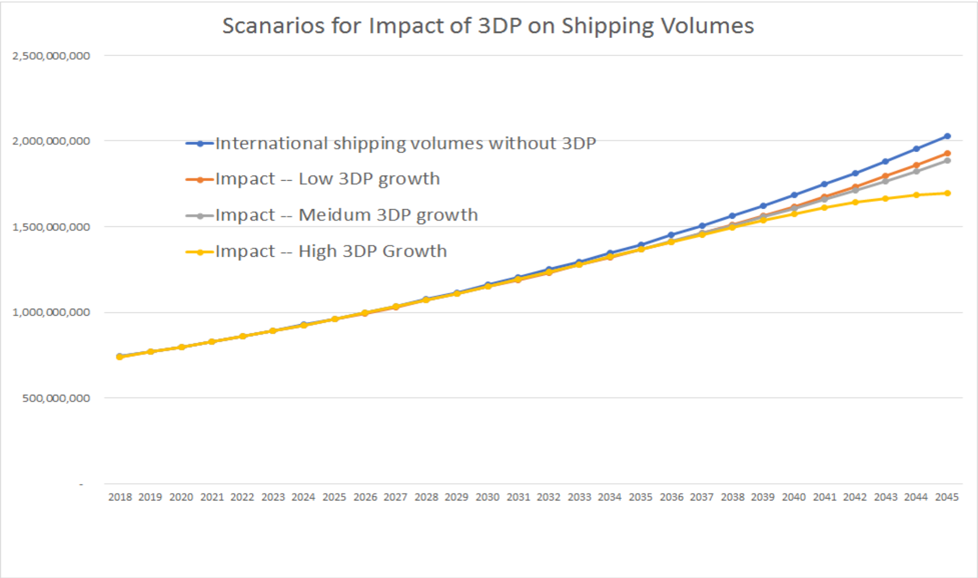


Figure 4: Scenarios for Impact of 3D Printing on Shipping Volumes in TEU from 2020 to 2045

In 2045, there could be a 5% to 16.5% reduction in shipping volume of finished goods compared to the baseline scenario, based on growth peaking around 2027, growing strongly and peaking around 2034 respectively. The likely impact could also fall somewhere in between, for example, one medium scenario might be growth peaking around 2030 with a possible 7% impact in 2045.

These numbers are also in line with current understanding of 3D printing technology capability. According to a NAMIC study, 3D printing technology is capable of manufacturing up to 40% to 50% of products. Taking into account considerations such as design complexity, cost, lead time for delivery, quantity and frequency of orders, 3D printing can be adopted for up to 10% of products (Ho, 2019).

Rather than a direct substitute, 3D printing will sit side by side with traditional manufacturing to make the final product. It should be emphasized that while 3D printing is transformational in manufacturing, for example in prototyping, custom products and on-demand creation, its impact on shipping volumes depends on its level of mass adoption for finished products.

The growth rate of 3D printing and extent of substitution of traditional manufacturing will depend on the actual technology development and cost effectiveness of 3DP versus mass manufacturing, as well as the developing of supporting legal frameworks, industry standards, and digital infrastructure. These will determine whether 3D printing exists as a supplementary technology, or as a transformative technology. As a management guide, keeping track of projected growth rates beyond 2025 and 2030s would give us an idea of its technology trajectory and potential impact on maritime trade and shipping.

3.1.3 Decentralization of Manufacturing with Use of “Micro” Factories and Local Warehouses

Rather than mass production in mega factories relying on economies of scale through volume, 3D printing encourages smaller production, and therefore the number of “micro” factories will spread. Correspondingly there will be a need for more warehouses to store raw materials and / or 3D printers. Figure 5 shows what a decentralised network of 3D printing and warehouses might look like. World trade is likely to become more mono-directional, driven by the raw materials, whilst finished goods are produced on-shore or near-shore.

In recent years, there have been attempts to create new business models of manufacturing using the sharing economy, of which 3D printing is one of the prime technologies in use. For example, Fictiv, the AirBNB of manufacturing using providing on-demand manufacturing using 3D printing, raised US$15million to expand into China and the US (Feldman, 2018). Techniplas Prime in the US aims to use its inhouse design and engineering capabilities combined with the spare 3D printing capacity of small companies to provide manufacturing services to automotive manufacturers (Vinoksi, 2019).

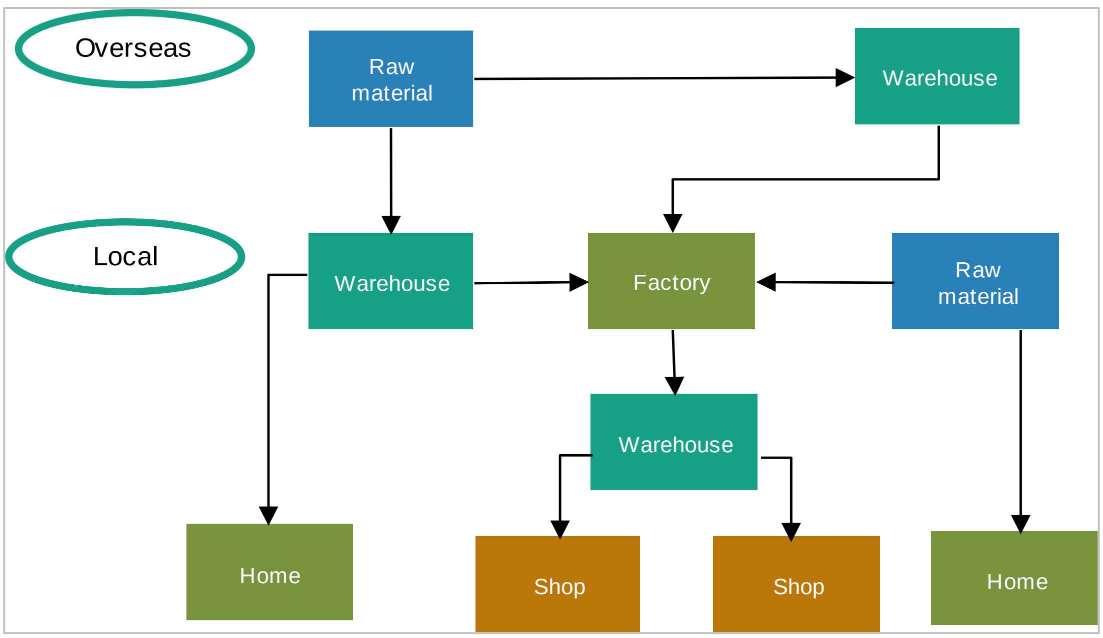


Figure 5: Decentralised Network of 3D Printing and Warehouses

3.1.3.1 Reversal of manufacturing trade flows from developed to developing countries

The major 3D printer companies and the source of composite materials for 3D printing today are based in the US and Europe. The current beneficiaries of 3D printing are companies in developed countries, and this could create a potential reverse export flow of 3D materials from developed to developing countries. Furthermore, as the unit cost of 3D printing remains the same regardless of volumes, the advantages of low-cost countries with respect to mass manufacturing will become less important. Of course, over time, it should also be expected that traditional mass manufacturing hubs will seek to develop their own 3D manufacturing capability for printers and materials, or could possibly be locations for mass production of 3D printers, as the technology becomes more mature.

Table 9: Major 3D Printing Companies

Company	Country of origin
Stratasys	US
3D systems	US
EOS Gmbh	Germany
GE Additive	US
Materialise	Belgium
SLM Solutions	Germany
ExOne	US
Voxeljet	Germany
HP	US
EnvisionTEC	Germany

Source:(Markets and Markets, 2019)

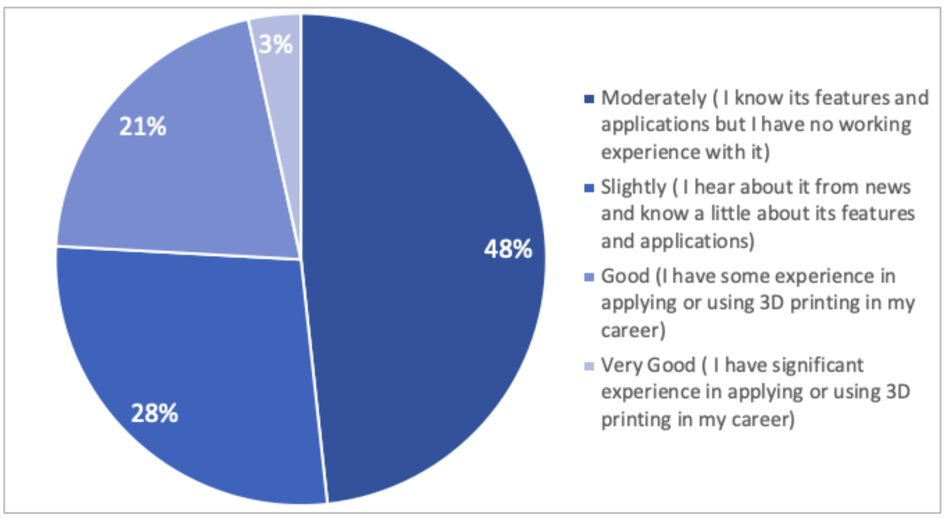
Table 10: Major 3D Printing Materials Companies

Company	Country of origin
Arcam /GE	Sweden
EOS	German
Höganäs	Sweden
Sandvik	Sweden
Solvay	Belgium
Concept Laser	German
ExOne	US
Renishaw	UK

Source:(Technavio, 2016)

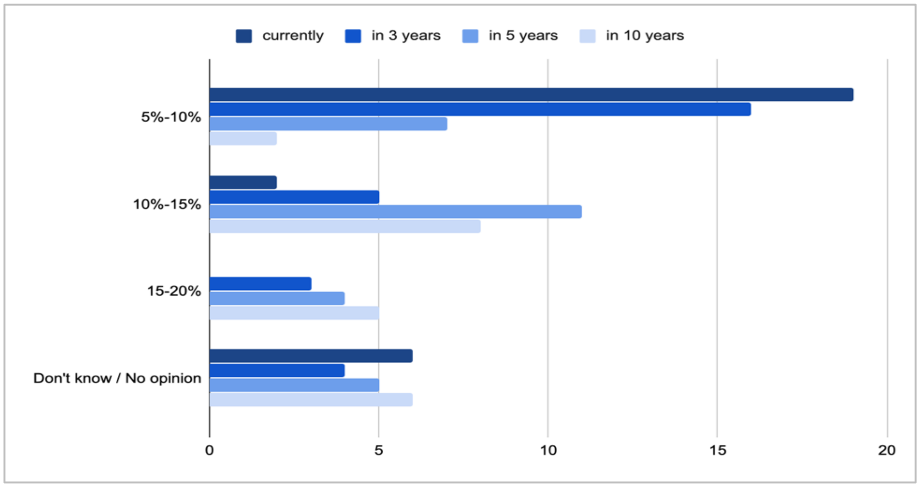
3.1.4 Survey of Maritime Companies on Impact of 3D Printing

A survey of representatives from the maritime industry was conducted on their readiness for 3D printing during a forum jointly organised with the Singapore Maritime Institute in Oct 2019 in Singapore. In total there were 25 valid responses from 17 different companies. The profile of these companies included marine companies, engineering companies, marine consulting and professional services.



In the question: Which of the following best describes your degree of familiarization in the features and applications of 3D printing, about half of the interviewees are moderately familiar with 3D printing, that is they know the features of 3D printing but have no working experience with that. About 27% only heard about it but do not know much about its features and applications.

Question: What do you think the adoption rate of 3D Printing in the maritime trade and maritime industry is/ will be?

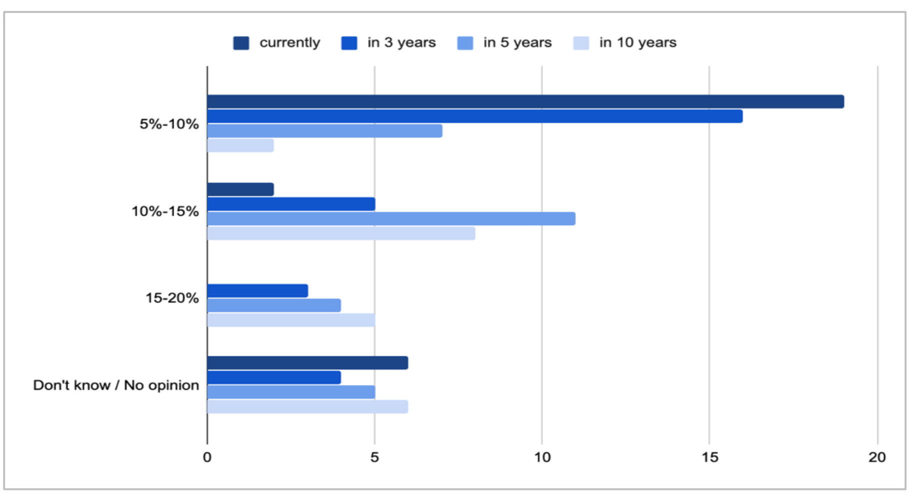


About 75% interviewees think the current adoption rate of 3D printing in maritime trade and in maritime industry is approximately 5%-10%, which indicates the development of 3D-printing is in the early stage of adoption.

About 60% of the interviewees estimate that the adoption rate would also remain at 5-10% in three years' time. In 5 years, 40% of interviewees consider the adoption rate of 3D printing would increase to 10%-15%.

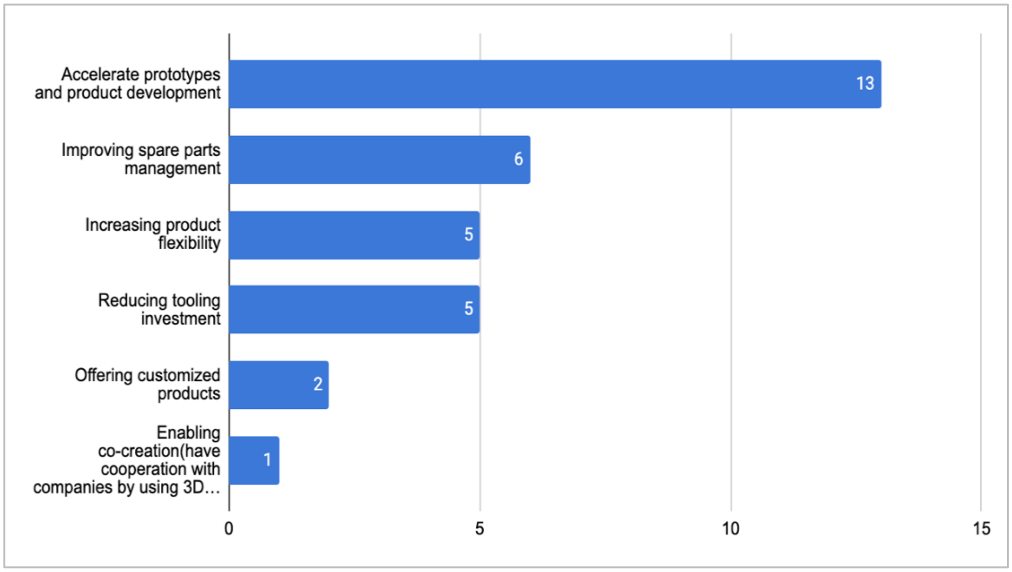
Finally, when it comes to the prediction after 10 years, 30% interviewees think the adoption rate would stay at 10%-15%, 20% interviewees consider the adoption rate would increase to 15%-20%, less than 10% interviewees suppose the adoption rate would be more than 20%-25%.

Question: What percentage of your company's total production volume is currently being done / will be done using 3D printing?



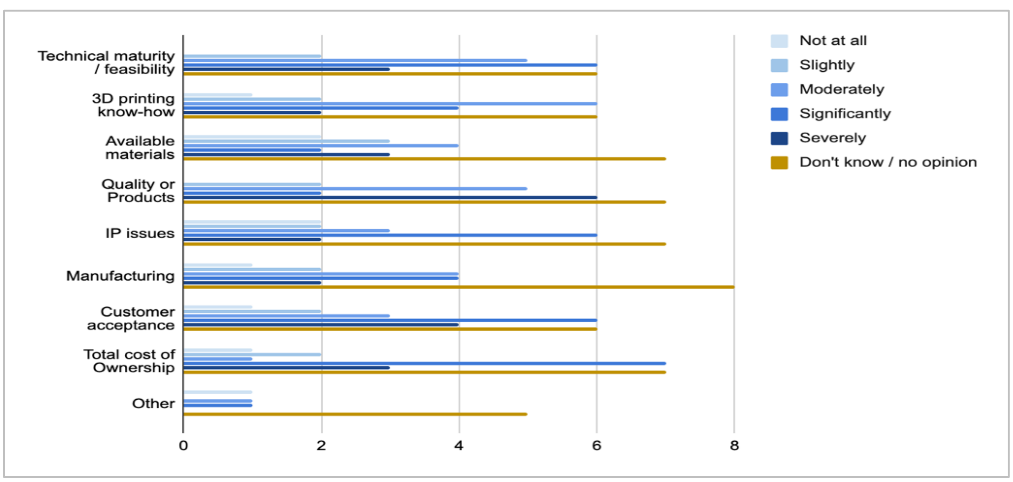
The majority of interviewees do not know about the proportion of using 3D printing in total production volume, so it is difficult to make predictions for the development in the future. However, for those who responded, there is an increasing percentage of 3D printing usage, with the most expecting that 3D printing could contribute to 10% to 15% of their production volume after more than 10 years.

Question: Which 3D printing-related area is your top priority for your company?



When it comes to the top priority for 3D printing utilization, the highest proportion of 56.5% is to accelerate prototypes and product development. And the second top priority benefit is improving spare parts management which is 43.5%. Also increasing product flexibility, reducing tooling investment and offering customer products are another three important uses in maritime trade and maritime industry.

Question: To what extent does your company encounter these challenges in using 3D printing?



The greatest challenge to application of 3D printing is customer acceptance of 3D printed products, followed by uncertainty over the manufacturing quality of production. About 30% think immature technology of 3D printing is still a challenge for wider utilization, while 22% identify having little knowledge of how to use the advantages of 3D printing. About a third of interviewers do not have an opinion about the challenges of adopting 3D printing, suggesting again that this is still fairly new in the maritime industry.

3.1.5 Adoption of 3D Printing in the Maritime Industry

A Port of Rotterdam study on 3D printing of marine spares in 2016 found that around 50% of 30 typical marine spares could potentially be manufactured using AM (Port of Rotterdam.com, 2016). These products were primarily in the bearings, engine spares and auxiliary engine spares categories. Besides direct cost comparison, other factors such as product availability and custom design should also be taken into account in the cost benefit analysis. For 3D printing to have wider adoption, issues such as standardization, quality control, validation of design and product, and international standards and certification, would need to be put in place.

In Singapore, PSA Corporation, the National Additive Manufacturing Innovation Cluster (NAMIC), Maritime and Port Authority of Singapore (MPA) and local 3D printing firm 3D MetalForge also signed an MOU to collaborate on the use of 3D printing for port applications (Ngai, 2018).

The study by PSA identified 2,000 parts out of 14,000 parts in inventory which could be made through additive manufacturing. Through more investigation on their printability, estimated cost of print to be commercially viable and other considerations, less than 200 parts are potentially feasible for development.

PSA shortlisted limited parts for additive manufacturing to better understand the technical, operational and regulatory requirements for partnership with technology providers and suppliers. The aim in the medium term is to have up to 4% of its parts requirements manufactured through AM, and in the long term, potentially to provide a parts replenishment service to shipping lines calling at PSA ports. More information on the PSA case study can be found on Appendix 1 of the report.

Shipping company Wilhelmsen has also embarked on the trial of 3D printing in Singapore to create customised on-demand spare parts, serving its own ships as well as those owned and operated by its partners (Soumik, 2019).

3.2 e-Commerce

3.2.1 e-Commerce Shipping and Distribution Patterns

In marketplace models, the e-commerce company provides a platform for independent vendors to list and sell their products. This model is likely to lead to substitution of sea freight to alternative modes. In e-tailer models, the e-commerce company acts like a retailer, either purchasing products and centralizing storage, or getting and selling products on a consignment basis. This model will likely require consolidation and shipping. The extent of change depends on whether the companies adopt a marketplace model or an e-tailer model. It would be clear however, that e-commerce would require more multi-modal modes of freight and transportation to cater to different order points and customer locations.

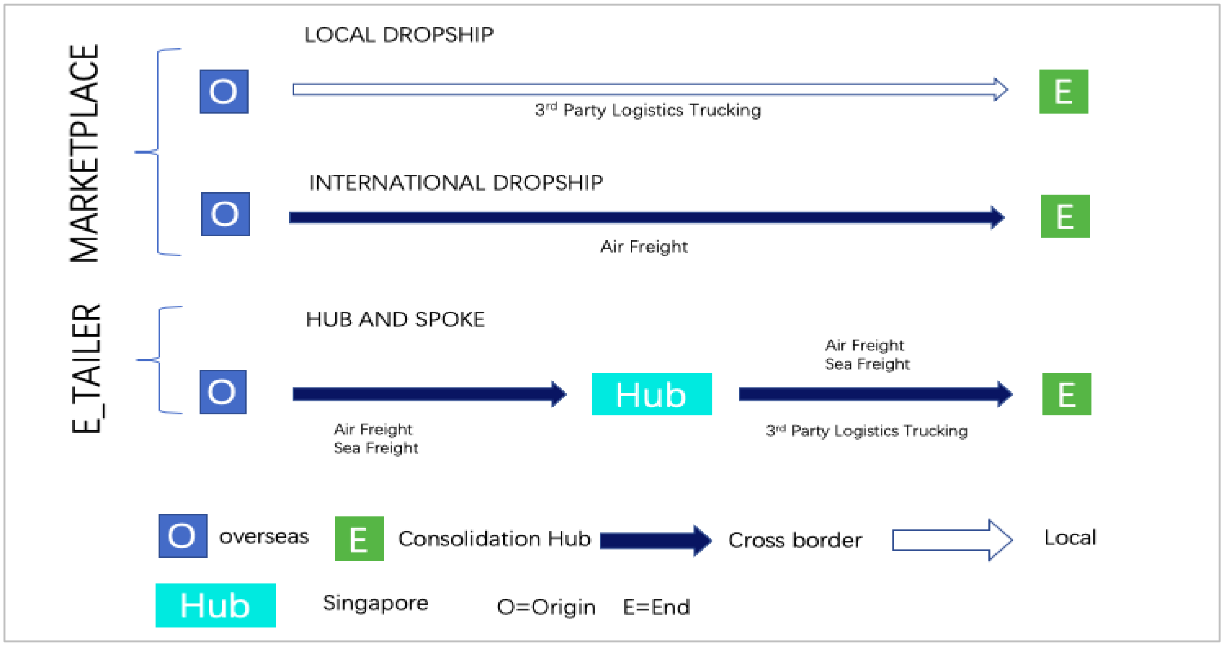


Figure 5: Two e-commerce Business Models

An interview with one of the major e-commerce companies in Southeast Asia estimates that 70% to 80% of cross border shipments could be handled by seafreight, while 20% to 30% are handled by airfreight. The distribution structure of an e-commerce company is also more complicated than a retail distribution, as there are many more customers to serve (delivery to consumers rather than delivery to retail store or retail distribution centre), and will therefore utilise multiple modes of delivery to cater to different customer locations and service lead times. For more information, please refer to Appendix 2.

e-Commerce in Singapore currently accounts for 11% of retail (Statista, 2019b). Current e-commerce adoption varies over a fairly wide range, at over 12% of retail in the US (Federal Bank of St. Louis Economic Research, 2020), and over 30% of retail in China (Statista, 2019a). This suggests that there is room for e-commerce to grow in Singapore in the coming years, given the fast growing trends in e-commerce in Asia.

3.2.2 Logistics Hubs for e-Commerce in Southeast Asia Will Depend on Cost and Time Trade-Offs

A study reveals that there is possibility for a location like Johor in Malaysia to be used as a regional fulfillment centre for Southeast Asia. A comparison of operating cost in Singapore and Johor in Table 11 shows that there is potentially a 50% cost difference between the 2 locations for warehouse and manpower. This means that Johor can be used effectively as a fulfillment hub to send orders in Singapore or to replenish a small warehouse in Singapore for time-sensitive items. It should be noted however that Johor to Singapore shipments would also include additional transportation and customs duties charges.

As shown in Table 12, an analysis of the major e-commerce players and their committed delivery lead times also indicates that the use of a Johor location is possible, since they commit to at least

2 days delivery time for most of the delivery requirements. This provides sufficient time for delivery to Singapore from Johor, or the use of replenishment modes to Singapore warehouse.

Table 11: Comparison of Warehouse and Operating Costs between Singapore and Johor (Source: compiled from GO DC; Commercialguru.com.sg; Robertwalters.com)

Logistics costs comparison	Singapore (SGD)	Johor (SGD)
Rental (PSF)	0.60 – 1.60	0.26 - 0.36
Worker Cost (Annual)	40,000 – 80,000	17,800 – 33,000
Additional Transportation Cost (per trip)	NA	165 - 330
Toll and Customs Fee (per trip)	NA	77- 106

Table 12: Major E-Commerce Companies in Singapore and The Delivery Lead Time (Source: Compiled from market research and company websites)

Player			Delivery choice	Lead time	Delivery fee (SGD)	Service provider
Lazada	Sold by Lazada	External/ 3rd party suppliers	Home delivery	2-5 days	$1.49-$1.99	Lazada Express, 3PL
			Collection point	2-5 days	Free	
			Priority delivery	1-2 days	$2.99-$3.99	
	Sold by seller	Local independent boutique/brands	NA	NA	NA	3PL
Shopee	Sold by Shopee	External/ 3rd party suppliers	NA	days	0-$1.9 (<$25) Free (> $40)	3PL
	Sold by seller	Local independent boutique/brands	Local 3PL	1-5 days	NA	3PL
		International independent boutique/brands	Standard express Standard economy Registered air mail	9-17 days 12-22 days 14-24 days	0- $2.9 0-$1.69 $2.9-$6.9	
Zalora	Sold by Zalora	Item source from Zalora	Home delivery/ Collection point	1-3 days	$4.99 (<$40) Free (>$40)	Zalora Express, 3PL
		External/ 3rd party suppliers		7-9 days		
	Sold by seller	1. Local independent boutiques/brands 2. International independent boutique/brands	NA	2-5 days 5-14 days	NA	3PL

The e-commerce delivery market could be segmented, with fast moving items and high value products being stored in Singapore, whilst low value, high volume products might be kept in hubs in Malaysia. There are also possibilities for the growth of airfreight shipments by drop ship from overseas suppliers to local companies or consumers.

As the volume for e-commerce grows, these e-commerce companies could become the new major shippers. For example, in the case e-commerce company EZBuy (Ezbuy.sg, 2019), customers purchase from overseas e-commerce website and delivers it to EZBuy's overseas warehouse. EZBuy would then consolidate and ship the customer's items to their local warehouse in Singapore. Upon arrival at their local warehouse, they will sort the items for delivery based on the selected collection or delivery method. Such consolidation models to reduce the cost of shipping and transportation also suggest that e-commerce companies are taking on some form of freight forwarding functions. There is an opportunity to cultivate such e-commerce companies as potential major shipping customers for the future.

3.2.3 Impact of e-Commerce on Shipping Volumes

The impact of e-commerce on maritime container shipping depends on the business model adopted by the e-commerce companies. In marketplace models, the e-commerce company provides a platform for independent vendors to list and sell their products. This model is likely to lead to substitution of full container sea freight to alternative modes such as LCL (less than container load) or airfreight.

In e-tailer models where the e-commerce company acts like a retailer through purchasing products or selling products on a consignment basis, consolidation and container shipping will continue to be required.

Whilst the majority of shipments will likely continue to be seafreight to keep cost of shipments low, multi-modal and multi-tiered distribution structures would be needed. In particular, the need for last mile distribution capabilities also provides a role for companies in warehousing and home deliveries, with optimal inventory and transport planning solutions, information visibility and supply chain integration.

3.3 Recommendations

A multi-prong approach is suggested – to look at shipping in the wider context of ports and supply chains, and to consider the physical flow, information flow and financial flow in the movement of goods.

e-Commerce and 3D printing will lead to the decentralization of supply chains in the areas of warehousing and manufacturing. Trade flows and demand still exist, just in different ways. Countries and companies have an opportunity to create differentiation through the smart use of technologies, and integrating shipping flows with information flows and overall manufacturing and trade flows.

In the Singapore context, there is an opportunity to leverage on its trade, finance, maritime and logistics strengths to generate feedback loop benefits where physical, information, and trade networks work in tandem. This would allow it to continue to value-add beyond the regional competition for ports and shipping, with their lower cost and more abundant labour resources,

Strengthening physical operations and operating efficiency

The centralization of port facilities and the use of automation and optimization technologies in the Tuas Megaport will continue to ensure that the physical efficiency of port operations can provide an effective cost benefit for transshipment.

A multi-modal view of supply chain is also important. Transportation modes will involve sea, air, land, integrated with warehousing. A holistic view of multi-modal logistics policies to ensure the integration of air, sea and land offerings can help to provide overall competitiveness for the supply chain in and out of Singapore. It could involve taking a customer-centric view of cargo movement from end-to end so as to provide cost-effective solutions taking into account trade-offs between cost and time.

This could include setting up logistics zones close to the port for loose cargo handling and breakbulk operations, to cater to the development of e-commerce and 3D printing, which both require warehouse networks. To mitigate the higher labour cost structure compared to regional countries, warehouse operations can promote the use of robotics and automation to reduce overall operating cost, and also enable high throughput of operations.

Building technology capability

3D printing is one of the key technologies in advanced manufacturing. The setup of a robust 3D printing ecosystem plays to Singapore's strengths: use of high technology, focus on high-end and value-added products; availability of highly skilled manpower, design and customization of products; logistics infrastructure such as warehouses and data centres for storing of raw materials and 3D cloud services respectively; a legal and arbitration centre that can provide leadership in business models and contractual arrangements.

Within the maritime industry, 3D printing offers an opportunity to improve efficiency and customer service through on-demand manufacturing. For example, the initiatives by PSA and shipping company Wilhelmsen are possibilities in the use of 3D printing for improving internal efficiency and improving efficiency, and also providing a new parts service to partners and customers. This can help to increase customer stickiness through further sharing of demand information and needs.

Ship supply companies which traditionally have to keep inventory to serve their customers may find that there is possibility to reduce the amount of stock for some items, thereby improving cashflow. Potentially, it could also be a threat to the existing ship supply business model in future if companies are not able to adapt.

Warehousing and infrastructure solutions

With the growth in e-commerce in the region, more warehouses would be needed to cater to last mile delivery needs. Over time, the growth of 3D printing may also mean more need for regional warehouses for storing raw materials, to support the decentralization of manufacturing by positioning raw materials close to the points of consumption.

This would create opportunities for companies in the logistics, REITs, and construction industries, to build up a network of warehousing. Such decentralization of both retail and manufacturing would also spur the development of transportation infrastructure to enable good local and regional distribution to reach to customers.

4 Impact of Disruptive Technologies on Maritime Industry

The maritime industry would be affected by all the four technologies in the way of new business models and shifts in labor skillsets. However, the industry would feel more direct and immediate impact from blockchain and battery technology for harbour craft. These two technologies directly address some key issues of the maritime industry such as operational inefficiency and greenhouse gas emissions. Therefore, this sector will focus on the specific impact of blockchain and battery technology.

4.1 Blockchain

4.1.1 Current Status and Industry Opinions of Blockchain Adoption in Singapore's Maritime Industry

A survey was conducted targeting at Singapore's maritime stakeholders to gain insights into the current status and opinion of blockchain application in Singapore's maritime sector.

A total of 53 responses have been received. A majority of them hold roles of upper management and C-suite level (see Table 13). Their companies represent various sectors in the maritime industry (see Appendix 5).

Table 13: Profile of Respondents

Job Roles	Frequency
Chairman/C-Suite/Partner	17%
Upper Management[9]	47%
Senior Manager/Manager	26%
Others[10]	9%

4.1.1.1 Current Status of Blockchain Adoption in Singapore's Maritime Industry

Over 90% of respondents have some knowledge of blockchain and 87% know some use cases of blockchain. This indicates that although blockchain is still at its initial stage of adoption in the maritime industry, it has already gained attention from the industry.

8% of respondent companies have already set blockchain technology as a top-five priority. Among those companies at which blockchain is yet a priority now, about 12% will consider prioritizing blockchain adoption next year and about 41% will do so in three to five years.

Although a minority put blockchain a top-five priority, it is interesting to note that about 27% have already initiated a blockchain project (see Figure 6). A total of 19 maritime blockchain initiatives

[9] Upper management includes business head/director/general manager/managing director/ president/vice president.
[10] Others include the following roles: counsellor, ship operator, pilot, consultant and researcher.

are recorded in the survey. They concentrate on three areas - track and trace information, digitizing documents, and electronic bills of lading, with few targeting at ship finance, marine insurance underwriting, cross-border payment and marine parts 3D printing (see Figure 7). Most of those initiatives are under the stage of either development (42%) or pilot (32%). A small amount of blockchain initiatives has been live in a small scale and only one project has been applied in a large scale. Among those initiatives, the top three popular distributed ledger platforms used are Hyperledger Fabric, Vechain and Ethereum (see Figure 8). Regarding how much they have invested in blockchain technology, polarised distribution is observed with high density at both a low level (less than US$100,000) and a high level (more than US$500,000).

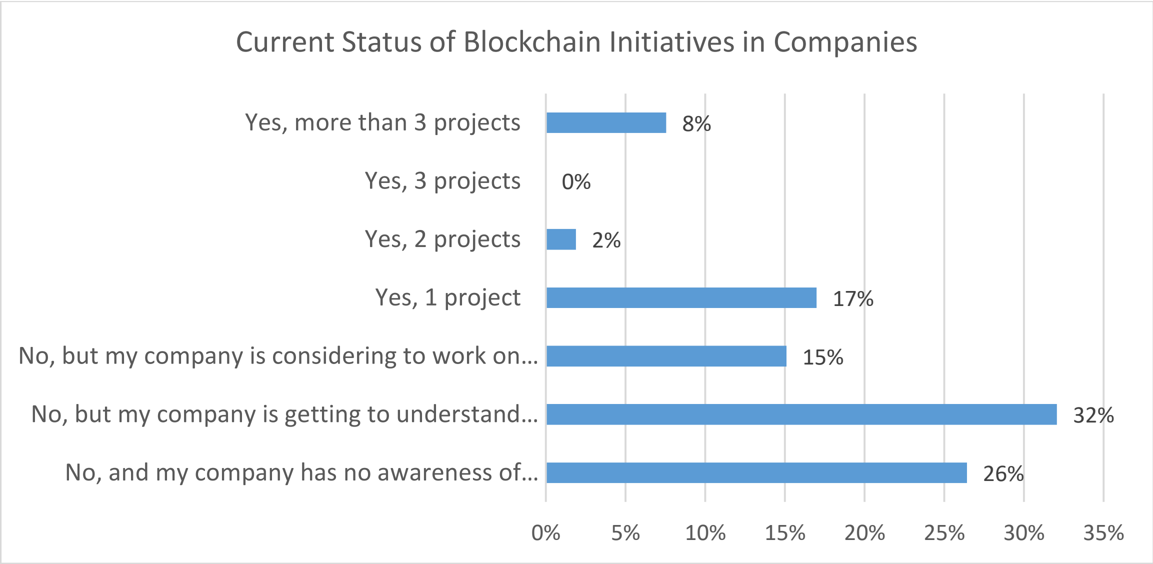


Figure 6: Current Status of Blockchain Initiatives in Companies

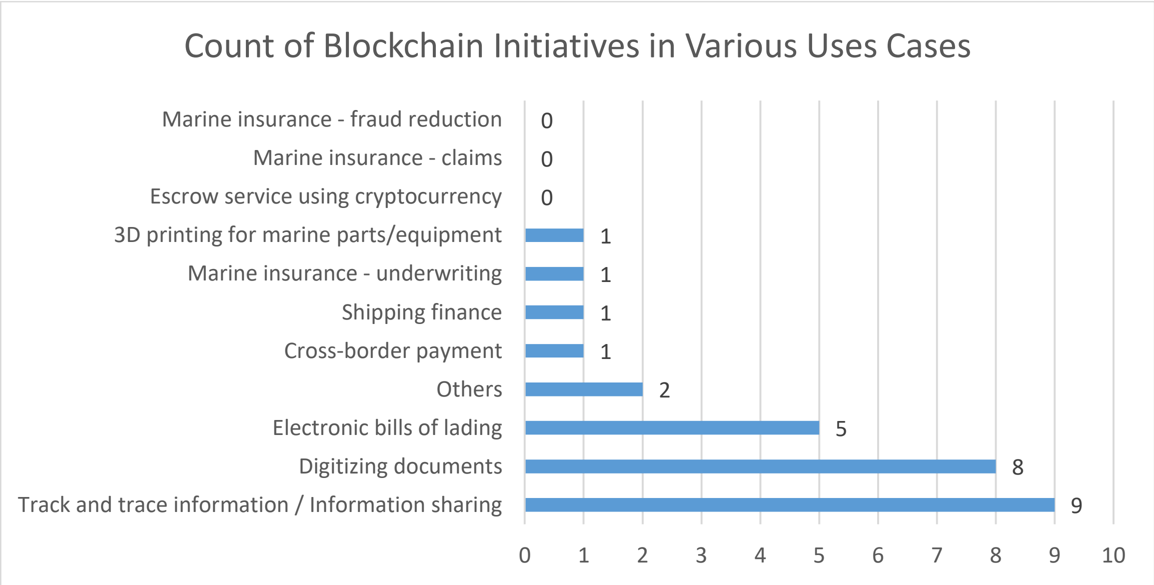


Figure 7: Count of Use Cases of Blockchain in Maritime Companies

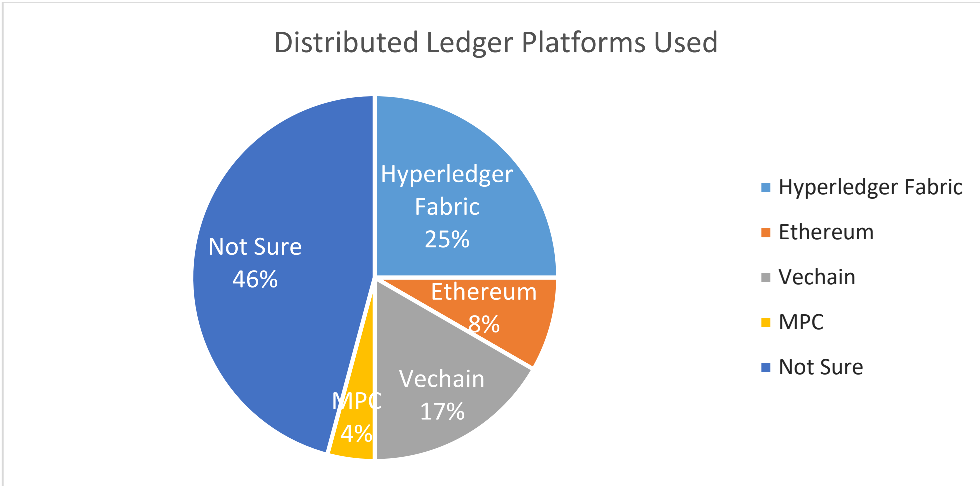


Figure 8: Distribution of Distributed Ledger Platforms Used by Maritime Blockchain Initiatives

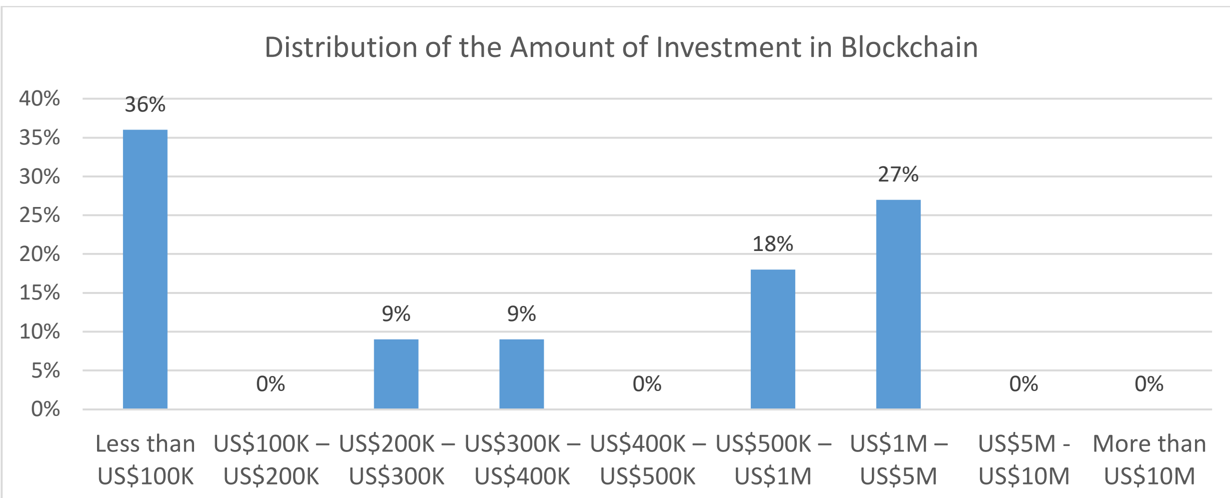


Figure 9: Distribution of the Amount of Investment in Blockchain

For those who have not initiated a blockchain project, 35% are not interested to try a proof of concept (POC) test (see Figure 10). For the rest, they are willing to try a POC within an acceptable budget. While the most popular budget is less than US$100,000, followed by the range of US$200,000 – US$300,000, there are still 8% companies which are willing to invest more than US$1 million for blockchain POC. With regard to the format of adopting blockchain, 42% of respondents would like to join a consortium rather than doing it alone, while 53% are not sure which one to go for (see Figure 11). While planning to join a consortium, the most important factors that companies would consider are company's own goal of joining the consortium, governance structure of the consortium and leadership of the consortium (see Figure 12).

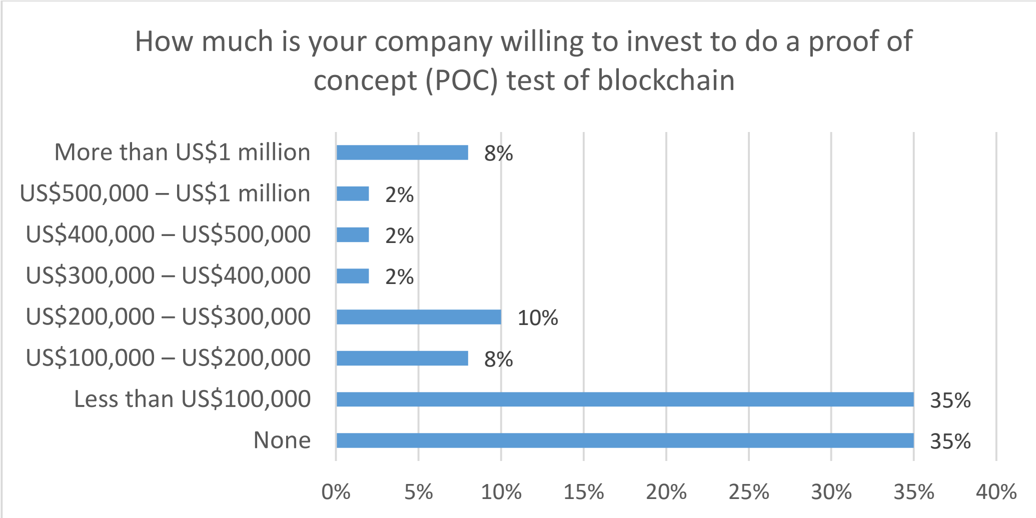


Figure 10: Acceptable Budget for Blockchain POC among Companies who have not Adopted Blockchain

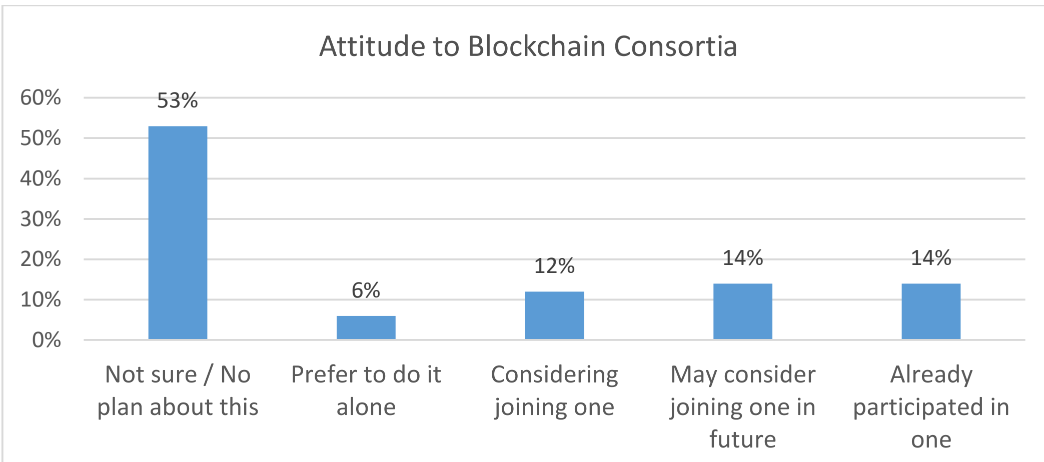


Figure 11: Attitude to Blockchain Consortia

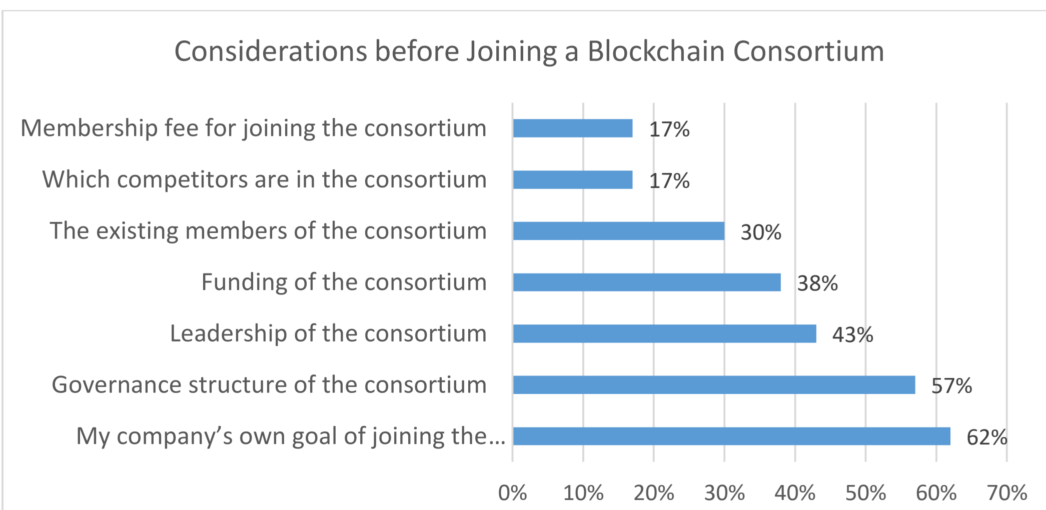


Figure 12: Factors to Consider Before Joining a Blockchain Consortium

4.1.1.2 Opinions on Blockchain Adoption

Table 14 presents the survey results of the top three drivers and challenges faced by companies which have engaged in blockchain projects. It also shows the top three reasons why companies do not adopt blockchain and the top three key success factors.

Table 14: Opinions of Respondents on Drivers, Barriers, Challenges and Key Success Factors of Blockchain Adoption

Top Three Drivers to Adopt Blockchain	Top Three Reasons Not to Adopt Blockchain
• Reduce operational costs (73%) • Reduce human errors and manipulation (73%) • Enhance information transparency and traceability (64%)	• Not current business priority (53%) • Unclear or no use cases for blockchain application (43%) • Regulatory uncertainty (34%)
Top Three Key Success Factors to establish blockchain across multiple parties	**Top Three Challenges Faced during Blockchain Adoption Process**
▪ Industry collaboration (65%) ▪ Clear and supportive regulatory framework (50%) • Technology standardization (46%)	• Lack of in-house blockchain capabilities (Mean: 3.36[11]) • Concerns on sharing sensitive information (Mean: 3.36) ▪ Potential security threats (Mean: 3.27)

Table 15 tabulates industry's opinions on the potential Impact of Blockchain on the Maritime Industry. Only the first four impacts listed in the table are accepted by the industry statistically at 95% confidence interval.

Table 15: Statistical Acceptance of the Statements on the Impact of Blockchain on the Maritime Industry at 95% Confidence Interval

Statements on the Impact of Blockchain on the Maritime Industry and Their Statistical Acceptance at 95% Confidence Interval
☑ Blockchain can cut costs and improve the efficiency of maritime industry and maritime trade ☑ Blockchain can lead to a shift in requirements of labor skills in the maritime industry ☑ Blockchain can increase the competitiveness of the maritime industry ☑ Blockchain will reduce the cost of auditing in orgainsations
☒ Blockchain technology will disrupt maritime industry. ☒ Suppliers, customers, and/or competitors are discussing or working on blockchain solutions to address challenges in the maritime industry. ☒ My company will lose competitive advantage if we don't adopt blockchain technology ☒ Blockchain is overhyped and cannot reach mainstream adoption.

4.1.2 Qualitative Assessment of Blockchain's Impact on Maritime Industry

Blockchain affects various maritime players from the perspectives of innovation, efficiency, transparency, fraud reduction, quality assurance, carbon footprint, cyber security, level of collaboration, workforce relevance and workforce reskilling. The detailed analysis is provided in Figure 13. The key insights are drawn as follows:

[11] This is the mean value of the extent of the challenges faced by companies based on 1-5 Likert Scale (1 – Not at all, 2 – To a small extent, 3 - To a moderate extent, 4 - To a great extent, 5 - To a very great extent)

- The lack of government recognition and industrial standards makes compliance difficult for adopters, which further restricts a wide adoption of blockchain in the industry.
- Blockchain could address the pain points in the industry regarding inefficiency, transparency and quality assurance, which are affecting the core value proposition of the majority of maritime stakeholders
- Among all the maritime stakeholders, ship owners/operators would obtain the highest positive impact from blockchain.
- The new skillsets and knowledge base required due to blockchain adoption is a challenge for most maritime stakeholders.

Maritime Player	Innovation	Efficiency	Transparency	Fraud Reduction	Quality Assurance	Carbon Footprint	Foster Collaboration	Cyber Security	Workforce Relevance	Workforce Reskilling
Government Agencies	+	+	+	+	+	+	+	+/=	-	=
Ship Owners	+	+	+	+	+	+	+	+/=	-	=
Terminal Operators	+	+	+	=	+	+	+	+/=	-	=
Classification Societies	+	+	+	+	=	+	=	+/=	=	=
Equipment Manufacturers	=	+	+	+	+	=	=	+/=	-	=
Marine Service Providers	+	+	+	+	+	+	+	+/=	-	=
Ship Yards	=	=	+	=	+	=	=	+/=	-	=
Technology Providers	+	=	+	=	=	=	+	+/=	+/=	=

Note: + means positive Impacts
- means negative impacts
= means neutral impacts / not relevant

Figure 13: Qualitative Impact Analysis of Blockchain on Maritime Stakeholders

4.1.3 Quantitative Assessment of Blockchain's Impact on Maritime Industry via Digitising Shipping Documents

Among the various maritime use cases of blockchain, digitising shipping documents including bills of lading is the most promising and popular case in the industry. Therefore, it is meaningful to assess the degree of benefits that blockchain could bring to the industry through digitising shipping documents.

4.1.3.1 The Model

Inspired by the model used by Forrester Research (2018), the benefits of blockchain to container shipping include two main parts: direct cost saving and efficiency gains (see Figure 14). Under direct cost saving, three benefits are identified, namely 1) saving from reduced paper printing and storage, 2) saving from reduced bills of lading fraud, and 3) saving from eliminated printing and postage of original bills of lading (OBL). Under efficiency gains, another three benefits are identified, namely 1) gains from reduced conflicting records, 2) gains from reduced processing time for documents, and 3) gains from eliminated letter of indemnity for discharging cargoes without original bills of lading.

While the full potential benefits of blockchain from digitizing shipping documents can be estimated by assuming 100% adoption rate, the realistic benefits of blockchain depend on the actual adoption rate and the adoption speed. In this model, the adoption rate and adoption speed are measured through an indicator - the number of years to reach 50% adoption rate. The analysis is performed for global container shipping and Singapore's container shipping.

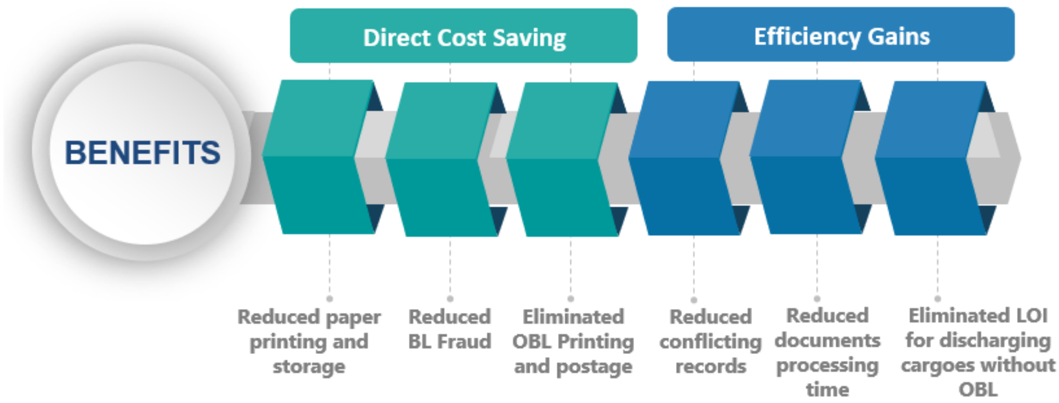


Figure 14: Quantitative Model to Calculate the Gross Benefits of Blockchain through Digitizing Shipping Documents

4.1.3.2 For Global Container Shipping

The assessment assumes 3.2% growth rate of global port throughput and 8% discount rate. With that, the potential benefits of blockchain if it is fully adopted in the global container shipping industry is estimated and provided in Figure 15. The analysis shows that if blockchain is fully adopted in global container shipping, the global container shipping industry could realise a saving of about US$200-451 billion by 2040. The estimated saving to global container shipping is about US$43-96 per loaded container (in TEU).

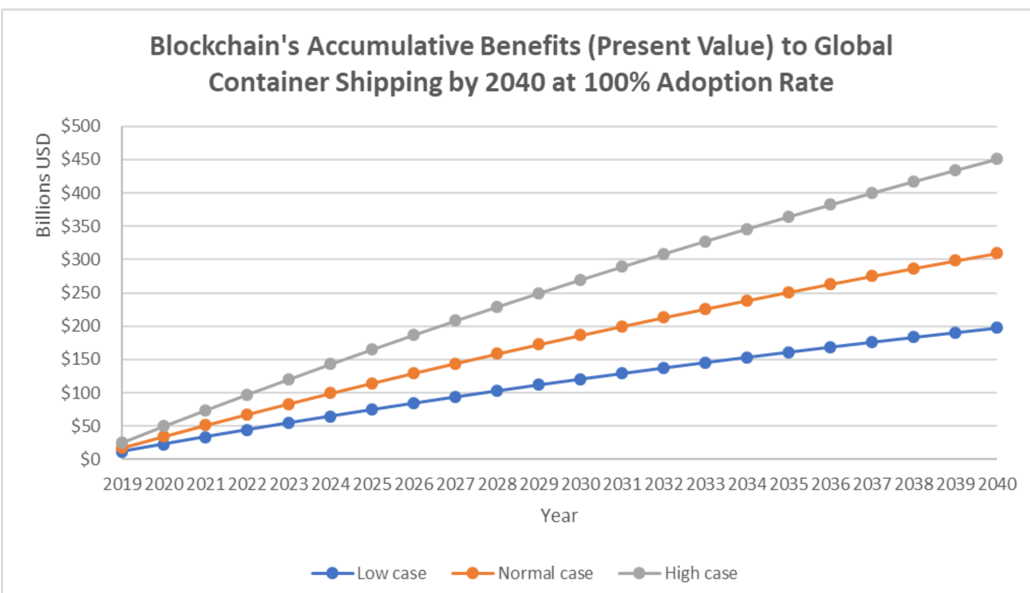


Figure 15: Blockchain's Accumulative Gross Benefits (Present Value) to Global Container Shipping by 2040, at 100% Adoption Rate

The percentage contribution of each saving item at each scenario is tabulated in

Table 16. It indicates that reducing conflicting records and eliminating paper OBL printing and postage are the top two contributors of blockchain benefits to the container shipping industry.

Table 16: The Percentage Contribution of Detailed Blockchain Gross Benefits to Global Container Shipping

Gross Benefits of Blockchain from Digitizing Paper Documents	Low Case	Normal Case	High Case
Saving from reduced paper printing and storage	4.6%	3.0%	2.1%
Saving from reduced BL Fraud	3.1%	2.1%	1.4%
Saving from eliminated OBL Printing and Postage	28.9%	19.1%	13.3%
Gains from reduced conflicting records	53.9%	66.7%	74.6%
Gains from reduced documents processing time	8.9%	8.8%	8.2%
Gains from eliminated letter of indemnity for discharging cargoes without OBL	0.5%	0.3%	0.2%
Total Benefits of Blockchain for Global Container Shipping	100.0%	100.0%	100.0%

Figure 16 shows how the realised blockchain benefits by 2040 would be affected by adoption speed. When blockchain adoption speed doubles, the gained benefits are more than doubled.

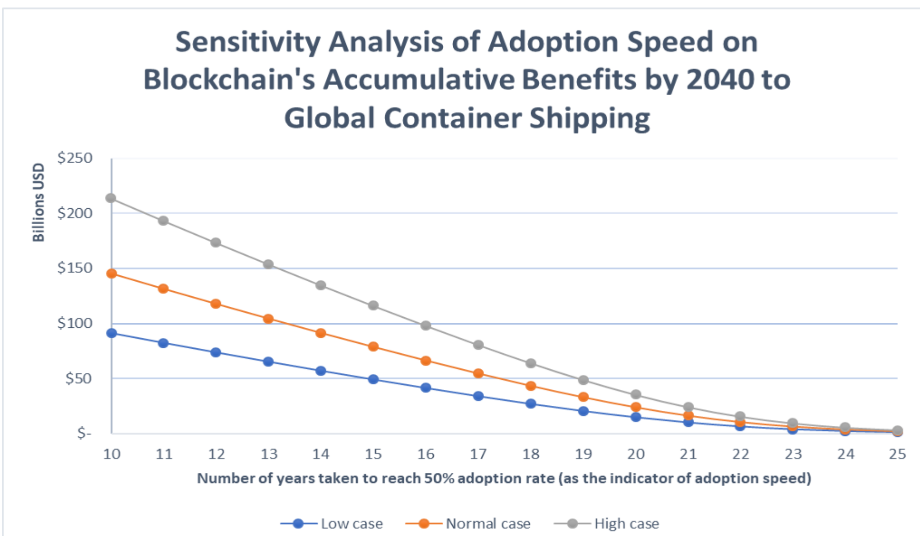


Figure 16: Sensitivity Analysis of Adoption Speed on Blockchain's Accumulative Gross Benefits by 2040 to Global Container Shipping

4.1.3.3 For Singapore's Container Shipping

The assessment assumes 3% growth rate of Singapore port throughput and 8% discount rate. Figure 17 shows the potential benefits of blockchain to Singapore's container shipping till 2040 if it is fully adopted. Based on the analysis, Singapore's container shipping could potentially unlock value of between US$3-7 billion by 2040 from using blockchain to digitizing shipping documents.

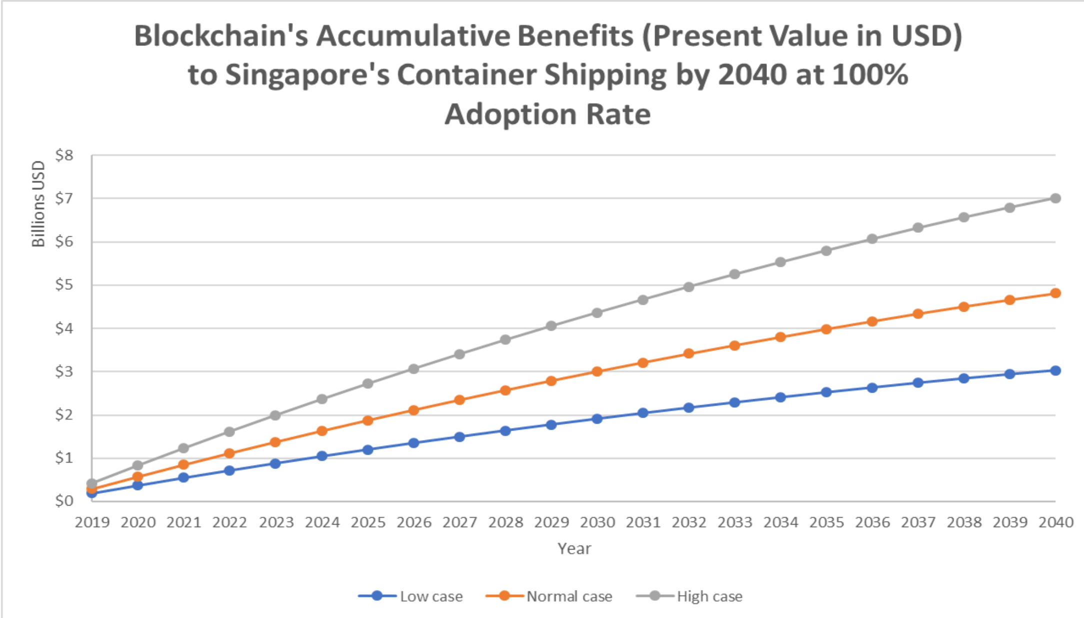


Figure 17: Blockchain's Accumulative Gross Benefits (Present Value) to Singapore's Container Shipping by 2040 at 100% Adoption Rate

Table 17 provides the percentage contribution of each blockchain benefit in the context of Singapore container shipping market. Compared with the global market, the Singapore market has a higher weightage of paper printing and storage. This could be attributed to the high land price in Singapore.

Table 17: The Percentage Contribution of Detailed Blockchain Gross Benefits to Singapore's Container Shipping

Gross Benefits of Blockchain from Digitizing Paper Documents	Low Case	Normal Case	High Case
Savings from reduced paper printing and storage	7.4%	4.8%	3.4%
Saving from reduced BL Fraud	2.4%	1.6%	1.1%
Saving from eliminated OBL Printing and Postage	24.1%	15.7%	10.9%
Gains from reduced conflicting records	55.9%	68.3%	75.9%
Gains from reduced documents processing time	9.2%	9.0%	8.4%
Gains from eliminated letter of indemnity for discharging cargoes without OBL	0.9%	0.6%	0.4%
Total Benefits of Blockchain for Singapore's Container Shipping	100.0%	100.0%	100.0%

Figure 18 represents how the benefits of blockchain to Singapore's container shipping industry could be affected by the adoption speed. If Singapore's container shipping sector could reach 50% adoption rate of blockchain in 10 years from now, it could achieve a saving of up to US$10.4 billion. If it takes 20 years to reach 50% adoption rate, the maximum saving would be reduced to about US$2.2 billion.

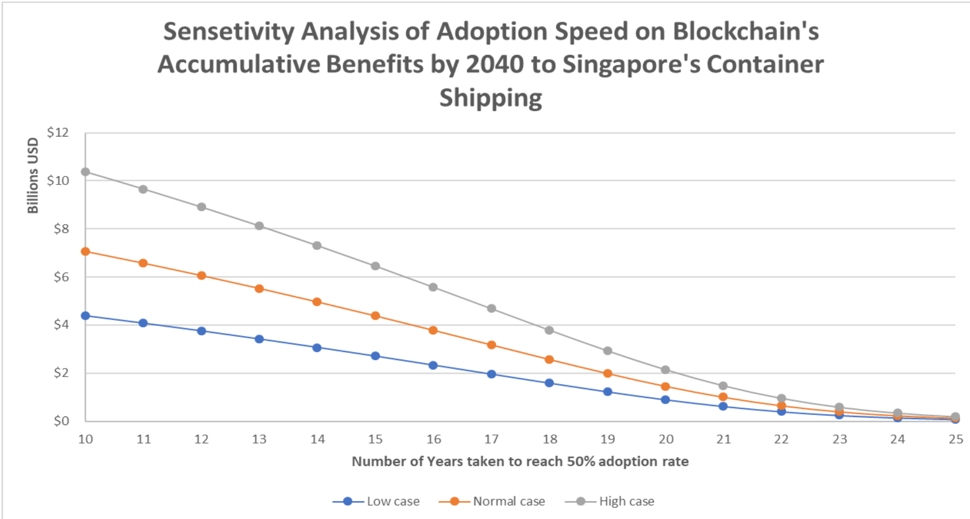


Figure 18: Sensitivity Analysis of Adoption Speed on Blockchain's Accumulative Gross Benefits by 2040 to Singapore's Container Shipping

4.1.4 Recommendations

Based on the above analysis, recommendations are provided in Table 18 to public and private sectors to address the challenges and promote the adoption of blockchain technology in the maritime industry:

Table 18: Recommendations to Public and Private Sectors on Blockchain Adoption in the Maritime Industry

Public Sector	Private Sector
• Strengthen **education and training of maritime workforce** in alignment with blockchain transformation ▪ Actively **facilitate/participate in blockchain knowledge sharing** among academia, industry and public sectors (e.g. organise blockchain workshops/ forums)	
• Speed up to build a **clear and supportive regulatory environment** of using blockchain to promote earlier adoption and maximise the benefits for the society ▪ **Legal recognition** of blockchain-based information, e.g. electronic bills of lading ▪ Involve in **development of technical standards** for blockchain, e.g. standards for blockchain data structure and smart contracts ▪ Establish and facilitate **regulatory sandbox** for blockchain • Establish **excellence in blockchain adoption** for maritime industry ▪ Take the leading role by **testing/adopting blockchain for public services** in the maritime industry - e.g. customs clearance, port registry, & maritime surveillance ▪ Create **test bed environment** for blockchain innovation and adoption in the maritime sector - e.g. sandbox for blockchain ▪ **Encourage/support researches** to study blockchain use cases in the maritime industry and **timely disseminate findings** to maritime community	▪ Start/prioritise use cases of blockchain for **data management** and **electronic bills of lading** ▪ **Start small** and from areas where **least legal issues** are involved, e.g. non-transferable bills of lading ▪ Seek **alternative solutions to handle sensitive information**, e.g. off-chain storage for sensitive data ▪ Careful selection of **blockchain partner** (choose reputable and experienced blockchain developers to reduce potential security threats) ▪ Build a wide and deep **blockchain ecosystem** by facilitating stakeholders getting on board ▪ Strengthen **industrial collaboration** horizontally and vertically

4.2 Battery Technology for Harbour Craft

4.2.1 Threshold of Electricity Price to Make Battery System Competitive with Diesel System for Vessels

According to MAN Energy Solutions (2019), the current retrofits for battery system costs around US$1000/kWh(S$1413/kWh) and a battery system of large-scale new builds costs around US$500/kWh (S$706/kWh) at a minimum level. Therefore, this report considers different levels of battery system price, including US$1000/kWh(S$1413/kWh) for retrofits, US$500/kWh (S$706/kWh) for new builds, and US$400(S$565/kWh), US$300(S$424/kWh), US$200/kWh (S$283/kWh) for future battery price. Based on the bunker price history in Singapore from July 2019 to Feb 2020, four scenarios of very low sulphur fuel oil (VLSFO[12]) are also discussed, namely US$250/ton, US$520/ton, US$578.5/ton, and US$741/ton, respectively.

Table 19 presents the threshold of electricity cost at different battery price to make battery system competitive with diesel system. The results show that if battery is more than US$400/kWh(S$565/kWh) at the system level, the electricity cost must be negative to make battery system competitive with diesel system. If the battery system level price is at US$300/kWh(S$424/kWh), the threshold of electricity price can be positive or negative, depending on the scenario of VLSFO price. If the battery system level price can be reduced to US$200/kWh(S$283/kWh), the electricity cost should be reduced at least below US$0.067/kWh(S$0.094/kWh) to make battery system competitive with diesel system.

Similarly, the threshold of electricity cost to vessels using low sulphur marine gas oil (LSMGO) such as harbour craft is presented in Table 20. The results show that in order to make battery system competitive with diesel system, the electricity price should at least drop to US$0.028/kWh(S$0.039/kWh) if battery system level price can be reduced to US$300/kWh(S$424/kWh) and LSMGO price is no more than US$743/ton. If the battery system level price can be reduced even further to US$200(S$283/kWh), the threshold of electricity price is US$0.067/kWh(S$0.094/kWh) to make battery and diesel systems competitive. If the battery system level price is more than US$400/kWh(S$565/kWh), the electricity cost must be negative to make battery system competitive with diesel system, which is generally impractical.

Therefore, in view of the current very low price of fuel oil (both VLSFO and LSMGO are around US$250/ton[13]), it is not economically feasible to replace diesel system with battery system for harbour crafts. However, if in the future the battery system level price can be reduced to below US$300/kWh(S$424/kWh), there are cases where battery system could be competitive with diesel system depending on the price of fuel oil. Lastly, it is worth to mention that this analysis has limitations as it only considers financial factors for battery adoption. In practice, the adoption of battery is also constrained by the density capacity and volumetric capacity of batteries, which would affect vessel's travel distance and loading capacity in terms of weight and volume.

[12] VLSFO is max 0.5% Sulfur fuel, also known as IMO2020 grade bunkers.

[13] Based on the Singapore bunker price between 1 April 2020 and 15 May 2020.

Table 19: Threshold of Electricity Cost to Make Battery System Competitive with Diesel System Using VLSFO

Different system level price of battery	**US$1000/kWh (S$1413/kWh)**	**US$500/kWh (S$706/kWh)**	**US$400/kWh (S$565/kWh)**	**US$300/kWh (S$424/kWh)**	**US$200/kWh (S$283/kWh)**
Threshold of electricity cost in **super low case** scenario (when **VLSFO** price being US$250/ton)	-US$0.340/kWh (-S$0.479/kWh)	-US$0.146/kWh (-S$0.205/kWh)	-US$0.107/kWh (-S$0.151/kWh)	-US$0.068/kWh (-S$0.096/kWh)	-US$0.029/kWh (-S$0.041/kWh)
Threshold of electricity cost in **low case** scenario (when **VLSFO** price being US$520/ton)	-US$0.287/kWh (-S$0.405/kWh)	-US$0.093/kWh (-S$0.131/kWh)	-US$0.054/kWh (-S$0.076/kWh)	-US$0.015/kWh (-S$0.021/kWh)	US$0.024/kWh (S$0.033/kWh)
Threshold of electricity cost in **average case** scenario (when **VLSFO** price being US$578.5/ton)	-US$0.275/kWh (-S$0.388/kWh)	-US$0.081/kWh (-S$0.115/kWh)	-US$0.043/kWh (-S$0.060/kWh)	-US$0.004/kWh (-S$0.006/kWh)	US$0.035/kWh (S$0.049/kWh)
Threshold of electricity cost in **high case** scenario (when **VLSFO** price being US$741/ton)	-US$0.243/kWh (-S$0.343/kWh)	-US0.050/kWh (-S$0.071/kWh)	-US$0.011/kWh (-S$0.015/kWh)	US$0.028//kWh (S$0.039/kWh)	US$0.067/kWh (S$0.094/kWh)

Table 20: Threshold of Electricity Cost to Make Battery System Competitive with Diesel System Using LSMGO

Different system level price of battery	**US$1000/kWh (S$1413/kWh)**	**US$500/kWh (S$706/kWh)**	**US$400/kWh (S$565/kWh)**	**US$300/kWh (S$424/kWh)**	**US$200/kWh (S$283/kWh)**
Threshold of electricity cost in **super low case** scenario (when **LSMGO** price being US$250/ton)	-US$0.340/kWh (-S$0.479/kWh)	-US$0.146/kWh (-S$0.205/kWh)	-US$0.107/kWh (-S$0.151/kWh)	-US$0.068/kWh (-S$0.096/kWh)	-US$0.029/kWh (-S$0.041/kWh)
Threshold of electricity cost in **low case** scenario (when **LSMGO** price being US$537.5/ton)	-US$0.283/kWh (-S$0.399/kWh)	-US$0.089/kWh (-S$0.126/kWh)	-US$0.050/kWh (-S$0.071/kWh)	-US$0.012/kWh (-S$0.017/kWh)	US$0.027/kWh (S$0.038/kWh)
Threshold of electricity cost in **average case** scenario (when **LSMGO** price being US$604/ton)	-US$0.270/kWh (-S$0.381/kWh)	-US$0.076/kWh (-S$0.108/kWh)	-US$0.038/kWh (-S$0.053/kWh)	US$0.001/kWh (S$0.002/kWh)	US$0.040/kWh (S$0.056/kWh)
Threshold of electricity cost in **high case** scenario (when **LSMGO** price being US$743/ton)	-US$0.243/kWh (-S$0.343/kWh)	-US$0.050/kWh (-S$0.071/kWh)	-US$0.011/kWh (-S$0.015/kWh)	US$0.028/kWh (S$0.039/kWh)	US$0.067/kWh (S$0.094/kWh)

Figure 19 shows the projections of Lithium-ion battery pack price and system level price for vessel retrofits and new builds from 2019 to 2040, assuming 18% learning rate (BloombergNEF, 2019) and 22.7% compound annual growth rate (CAGR) for Lithium-ion battery production (Interact Analysis, 2019). The projection of Lithium-ion battery pack price is close to, but slightly higher than that of BloombergNEF. The projections of battery system price suggest that the maritime industry would likely start to feel strong disruptions of battery technology in vessel new builds and retrofits after 2028 and 2040 respectively, subject to the bunker price at that time. The result also suggests that organisations could start with new builds when considering vessel electrification.

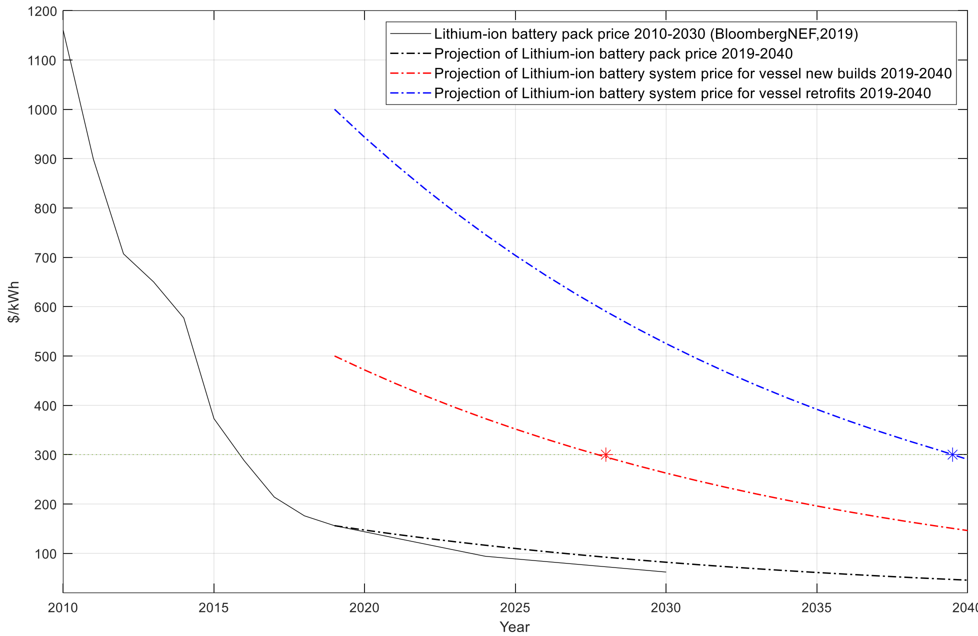


Figure 19: Projection of Lithium-ion Battery System Level Price for Marine Applications

4.2.2 Industry Opinions of Harbour Craft Electrification

<u>Online Survey</u>

72 respondents from Singapore's harbour craft community responded to an online survey on the electrification of harbour crafts in Singapore.

53% of respondents opine that the maritime Singapore ecosystem is now technologically ready and willing to start piloting full electric harbour craft (see Figure 20). In fact, 57% of harbour craft owners already have plans to switch to full electric harbour craft (see Figure 21). Passenger crafts especially those with less than 12 pax capacity are considered the most suitable candidate craft for electrification pilot in the near term (see Figure 22).

More than 69% of the respondents agree that solar PV systems are useful to support vessel operations during idling time (see Figure 23), thus reducing greenhouse gas emissions. This supports a further investigation on the impact of carbon footprint reduction by adopting battery-solar PV systems for harbour craft (to be discussed in Section 4.2.3). 31% disagree with the usefulness of solar panels, mainly due to concerns on efficiency, weight, cost, and space of solar PV systems.

81% of the respondents suggest that Singapore should embark on developing greater capabilities in full electric harbour craft now and strive to be a regional leader (see Figure 24). The kind of capabilities to build will be examined in the next section on interviews with industry experts.

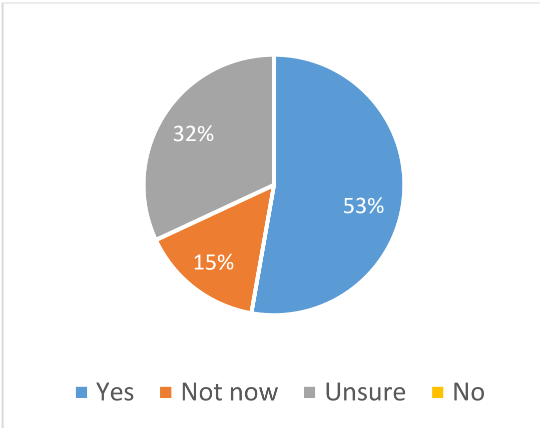


Figure 20: Is Maritime Singapore Ecosystem Technologically Ready?

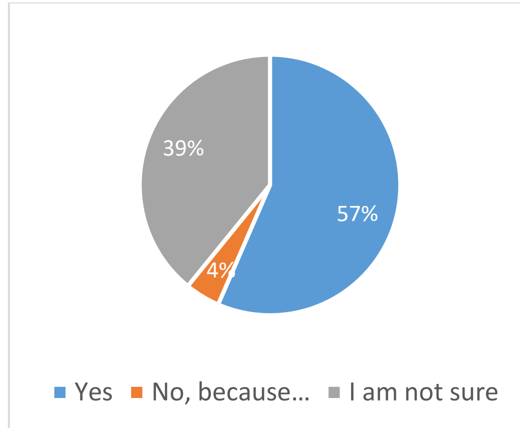


Figure 21: Harbour Craft Owners' Plan to Switch to Full Electric Harbour Craft

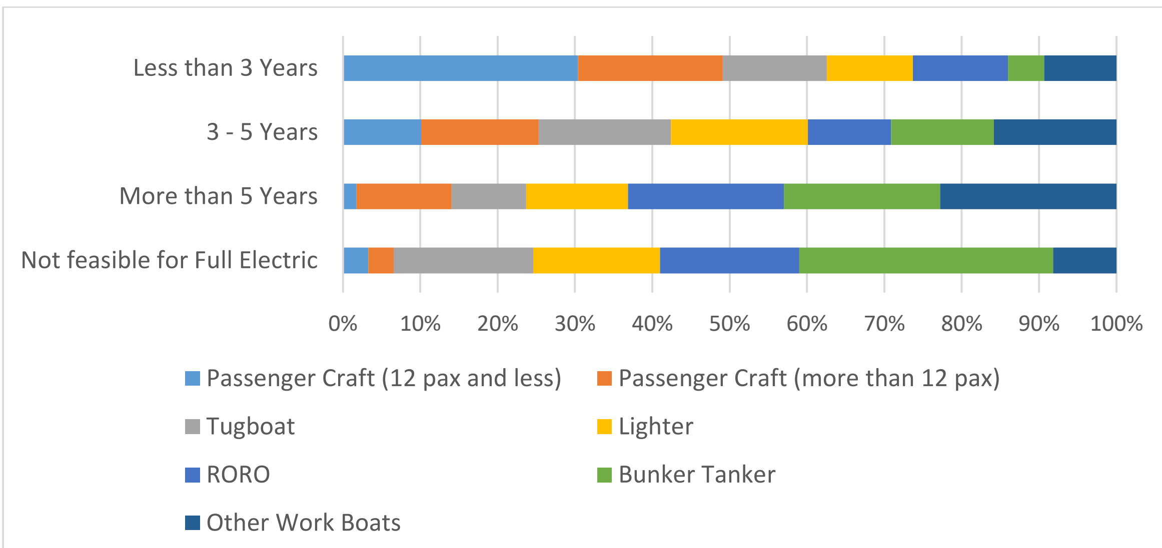


Figure 22: The Most Suitable Harbour Craft Type to Pilot Electrification in the Specified Timeframe

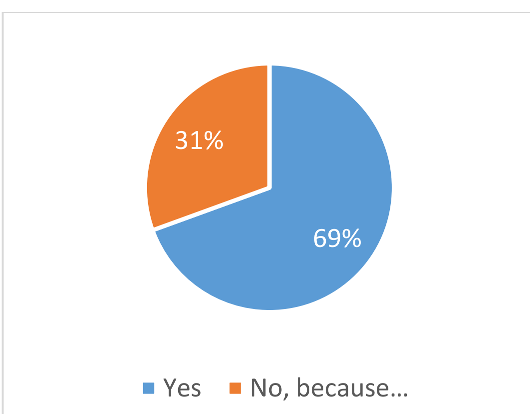


Figure 23: Usefulness of Solar Panels to Support Vessel Operations during Idling Time

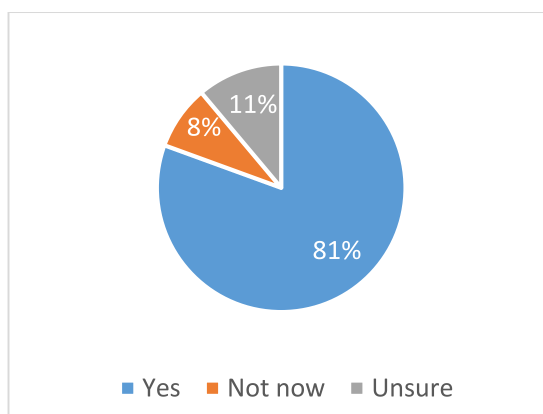


Figure 24: Should Singapore Embark to Develop Greater Capabilities in Full Electric Harbour Craft?

Interviews

In addition, interviews are conducted to obtain industry opinions on harbour craft electrification. Key challenges and opportunities are identified accordingly. Table 21 identifies the key success factors, drivers, capabilities and operational considerations for harbour craft electrification.

Economically, harbour craft operators are worried about the **potential high investment cost being an early mover**, which makes them reluctant to adopt battery technology. However, recent pilot cases of hybrid passenger craft show that a **payback period of less than 5 years** can be achieved. Therefore, it could be economically feasible for harbour craft operators to adopt battery technology.

There is also **regulatory uncertainty** around charging systems for electric vessels in Singapore. Whilst there are Singapore standards (TR25-600) initiated by Energy Market Authority (EMA) for electric vehicle (EV) charging systems, it is not clear if these standards can be applied to charging systems for vessels.

The operating profiles of harbour craft are diverse. Some voyage at regular and fixed routes, while others may be irregular in terms of distance, frequency and duration. It is challenging to deploy the right battery configuration for the latter case as it is difficult to optimise the design of battery system for such vessels with unpredictable energy consumption patterns.

Another operational challenge is the **technical limitations of batteries** such as energy density, volumetric density, and power density. The adoption of batteries may affect vessels' operational performance in terms of speed, range and loading capacity.

Despite many challenges, the **aging population of Singapore's harbour craft provides opportunities for Singapore** to foster the implementation of battery technology in the sector. It is easier and more flexible to install battery technology into new harbour crafts than retrofitting old crafts which have many restrictions, require major modifications and may not be cost efficient.

Table 21: Summary of Industry Opinions on Harbour Craft Electrification

Key Success Factors	Key Drivers
▪ **Energy efficiency** ▪ **Available technologies** (e.g. fast charging technology and charging standard) ▪ **Safety in operations** ▪ **Ease of operations and maintenance** ▪ **Accessibility of system design**	**Clear regulations, guidelines and standards** of vessel's charging stations and electrical equipment and installations on board vessels ▪ Regulations to indicate which standards to follow for vessel's charging stations and which guidelines/rules to follow for electrical equipment and installations on board vessels ▪ Propose to include standards for performance, emission and energy efficiency of battery systems **Commercial supports** ▪ Strong after-sales technical support ▪ Available insurance coverage **Government policy** ▪ Environmental regulations, e.g. emission restrictions and carbon tax ▪ Incentives to early movers which have high investment cost to establish feasibility

Key Capabilities to Build	Key Operational Considerations
Battery related capabilities ▪ Improve battery lifespan ▪ Lower battery cost ▪ Classification and qualification of battery ▪ Hot-swappable batteries ▪ Battery life-diagnostic tool **Charging related capabilities** ▪ Fast charging technology (ideally comparable with current bunkering speed) ▪ Improve charging efficiency **System design related capabilities** ▪ Efficient energy management system ▪ New vessel design for electric vessels with high system level efficiency	**Return on investment** ▪ Investment costs would be high for early movers **Performance of battery systems** ▪ Size, weight, power density – those would affect vessel's speed and loading capacity ▪ Lifespan, safety, maintenance, disposal and recycling ▪ Speed and distance that battery can support **Port Charging infrastructure** ▪ Availability, location, capacity, cost, carbon footprint and charging time ▪ Charging interface (wireless, ship-ship or shore-ship) ▪ Charging standards need to be harmonised **Manpower/Crew capabilities** ▪ If there are capable crew/electrician to support and maintain battery systems ▪ Training, skill update and mindset changing for crew to handle electric craft **Operating profile of craft** for system and engineering design ▪ Operating profile of craft determines the feasibility and the system design ▪ Vessels with fixed and predictable routes such as passenger craft (<12 pax) and RORO are ideal for electrification ▪ Design for new vessels can achieve higher system efficiency than retrofitting existing vessels

4.2.3 Environmental Impact of Battery-Solar Photovoltaic System on Singapore's Harbour Craft

This section analyses the potential carbon footprint reduction by deploying battery-solar photovoltaic systems for Singapore's harbour craft.

Among the various solar photovoltaic modules, **mono-Si** (Monocrystalline silicon) and **CIGS** (copper indium gallium (di)selenide) are chosen for this study. Mono-si cells have the highest conversion efficiency and a large market share in the photovoltaic technology market. However, Mono-si cells are heavy and cannot be folded or rolled up. CIGS cells are light and flexible to change shape, which makes them very suitable for harbour craft although its conversion efficiency is slightly lower than mono-Si cells.

If solar panels are installed on all suitable harbour crafts excluding SR type (e.g. barges), the total effective energy generated by solar panels is about 2% of the energy from auxiliary engine during idling and standby period. This is mainly due to the restricted surface area of most harbour crafts to install solar panels. Therefore, installing solar panels with battery systems could only supplement the use of energy needed for ship operations.

Figure 25 and Figure 26 reflect the potential carbon footprint reduction by applying mono-Si and CIGS PV systems respectively for harbour craft excluding SR type in Singapore. **The results show that about 4,400 – 5,700 tons of CO_2 equivalent can be saved per year by tapping on battery-solar energy for supporting harbour craft's operations.** Mono-Si has a better performance in carbon footprint reduction than CIGS. But CIGS has a better performance in weight and flexibility.

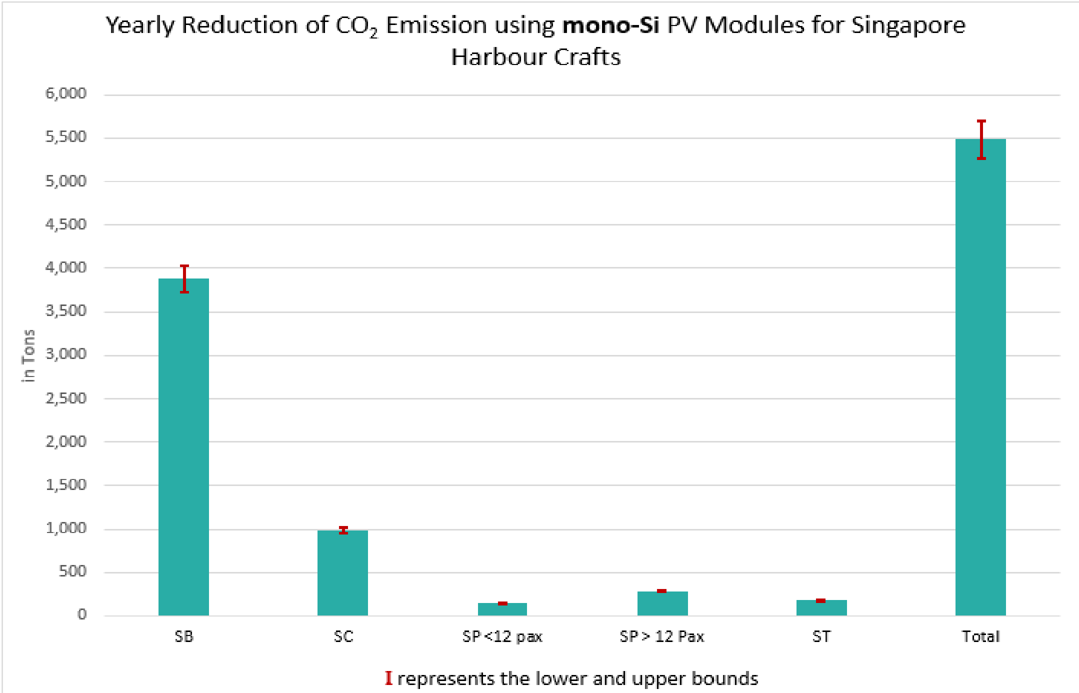


Figure 25: Yearly Reduction of CO2 Emission by Using mono-Si PV Modules for Singapore

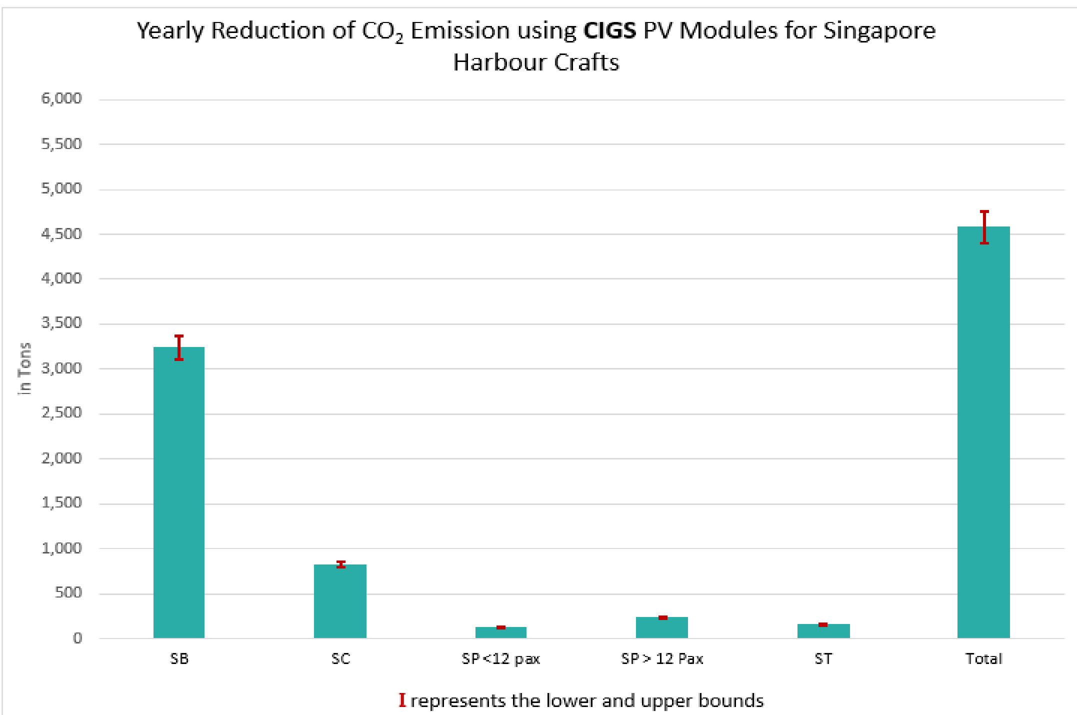


Figure 26: Yearly Reduction of CO2 Emission by Using CIGS PV Modules for Singapore Harbour Craft

4.2.4 Recommendations

Based on the above analysis, recommendations are provided in

Table 22 to public and private sectors to address the challenges and promote the adoption and development of battery technology for harbour craft:

Table 22: Recommendations to Public and Private Sectors on Harbour Craft Electrification

<table>
<tr><th>For Public Sector</th><th>For Private Sector</th></tr>
<tr><td colspan="2">Collaborate closely with each other to establish regulations to specify which standards/guidelines/rules to follow in the following areas:
▪ Charging stations for vessels
▪ Electrical equipment and installations on board vessels
▪ Safe operations of battery systems</td></tr>
<tr><td>Establish R&D excellence in battery, charging and energy system design technologies, focusing on below areas:
▪ Battery:
- Improve battery lifespan
- Lower battery cost
- Classification and qualification of battery
- Hot-swappable batteries
- Battery life-diagnostic tool
▪ Charging:
- Fast charging technology
- Improve charging efficiency
▪ Energy System:
- Improve Efficient energy management system

Consider providing incentives to early movers who are worried about high investment cost to establish feasibility, e.g. tax rebate, grants, etc.

Plan port infrastructure to support vessel electrification
▪ Charging infrastructure, which requires
- Studies on optimum location, space, capacity, carbon footprint and traffic management of charging stations
- Clarity in ownership, responsibility and liability of charging infrastructure operators
▪ Supporting infrastructure to tow/repair/recharge electric HC in case of emergency like battery failure, e.g. battery-charging tugboat as a portable charging station to provide emergency charging to vessels at sea.</td><td>For HC owners/operators:
▪ Keep well record of HC operational data for easier system design
▪ Start with new built HC to be used in more fixed and predictable routes. If no new built plan in the short term, start with retrofitting an existing vessel with a well-defined operating profile
▪ Training, skill update and mindset changing for crew to handle electric craft

For technology/system providers
▪ Develop expertise/skills in battery, charging and energy system design technologies
▪ Develop simpler and more user-friendly system
▪ Provide strong after-sales technical support

For other stakeholders
▪ Support the battery adoption by providing class and insurance recognition, relevant insurance coverage and financial supports</td></tr>
</table>

5 Conclusion

In all, the penetration of e-commerce and the emergence of 3D printing, blockchain, and battery technology impact on maritime trade and maritime industry in three dimensions:

i. Reduction and decentralization of demand for maritime transport (3D printing and e-commerce)
ii. Transformation of digitalization for vessel operations such as information handling and data integrity (blockchain and 3D printing)
iii. Enhancement of energy and emission efficiency of vessels through better ship design and optimised energy management (battery technology)

The impact of e-commerce, blockchain and battery technology on maritime trade and industry could be felt in the next five years, whilst 3D printing could take longer in its impact. The initial impact of 3D printing would be on the provision of spare parts, whilst it would take at least 10 years before there are tangible changes in global trade and shipping patterns.

These impacts could have implications to new business models and new ways of operations, which bring opportunities to maritime stakeholders to address issues in the current market and operational process and environmental requirements. However, how to tap on these technologies to outperform remains challenging. A key take-away is that these technologies are not necessarily isolated in their impact and should be addressed, developed and integrated in a holistic way.

More specifically to Singapore, as an information and financial hub in maritime services and trading, it has an opportunity to differentiate itself through the smart use of these technologies and integrating its shipping flows with information flows and overall manufacturing and trade flows. This integrated approach would allow Singapore and the companies operating here to continue to value-add with a sum is greater than its parts approach.

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- **Penguin International Limited:** Mr. James Tham, Managing Director; Mr. Chan Ying Kwok, General Manager; and Mr. Yaw Joo Heng, Assistant Design Manager
- **PSA Corporation Pte Ltd :** Mr. Alvin Foo, Head of Engineering; Mr. Tan Tiam Her, Assistant Vice President of Engineering and Equipment Development; and Mr. Teng Chee Meng, Senior Manager of Engineering and Equipment Development
- **Other interviewed companies and the involved staff who wish to remain anonymous**
- **All the survey respondents and participants in the project forum/workshop**

Appendix 1 - Case Study of Additive Manufacturing in the Port of Singapore – PSA International Pte Ltd

PSA has cooperated with NAMIC and 3D Metalforge for a pilot project on the use of 3D printing in its operations. It first assessed the parts which can be 3D printed, and then selected items from there to use in the trial. Out of 14,000 parts, around 2000 were assessed to be 3D-printable.

It further identified 200 parts which had high inventory turnover, so that it would have a chance to deploy the 3D printed parts. It also wanted to ensure that the 3D company providing the service would be able to survive by having actual business on these parts. Eventually, it did the trial on selected parts. The following summary s PSA's plan for the use of 3D printing in its operations.

Table 23:Summary of 3D Printing Roadmap of PSA

Business plan	Main activity	Explanation
Short term	Selection of parts to print and develop those 3D model	Digitalise ~200 parts Develop production-grade printed parts
Medium term	• Internal usage of spare parts • Start to print fast-moving parts, in order to get minimum qty supplier contract and gain certain margin profit	• 3D printing of 4% of products parts • Keep inventory for fast-moving parts
Long term	3D printing of spare parts for ships. Shipping lines that call at Singapore port or other PSA ports can have the spare parts serviced as well	Shipping lines that call at Singapore port or other PSA ports can have the spare parts serviced as well

PSA has identified several requirements in the business model for 3D printing:

1) **Ownership of IP rights of the 3D model.** There are different possible business models in industry for co-development and ownership of IP rights. These business models need to be explored further with the different stakeholders to ensure long term sustainability.

2) **Getting price of 3D printed parts to be comparable to current prices**. This is still challenging for the moment due to the higher costs of technology. A holistic cost benefit perspective would need to be taken for faster response time and service.

3) **Creating the digital blueprint of the part.** This process actually takes time as digital blueprints may require changes in the design of the part itself. Safety and certification requirements also need to be considered.

In the long run, PSA will expand the scope of these services to the wider maritime industry, including ship owners, to help build its business adjacencies.

Appendix 2 - Case Study of e-Commerce Company in Singapore

ECC (name has been disguised by request from management) is a leading online company in Southeast Asia. It is present in Malaysia, Indonesia, Singapore, Hong Kong, Vietnam, Thailand, Philippines and Brunei, with over 1500 international and local labels, including over 30,000 products online in categories such as womenswear, menswear, footwear and accessories, tech products, beauty essentials, sporting equipment, etc. Currently, it has over 200 million visits and 24 million apps downloads.

Distribution model

ECC uses a mix of sea and air freight for overseas suppliers, with sea freight according for 70% to 80% of volumes, whilst airfreight accounts 20% to 30% of deliveries. In the case of local suppliers, the local suppliers will delivery directly to end customer.

For overseas suppliers, the goods can be consolidated in a regional warehouse first, before being shipped to a country warehouse; or the goods can be shipped directly from overseas suppliers to the country warehouse. In some cases, overseas suppliers can also deliver directly to customers, in what is known as drop-shipping. **Error! Reference source not found.** summarises the different m odes of distribution of ECC.

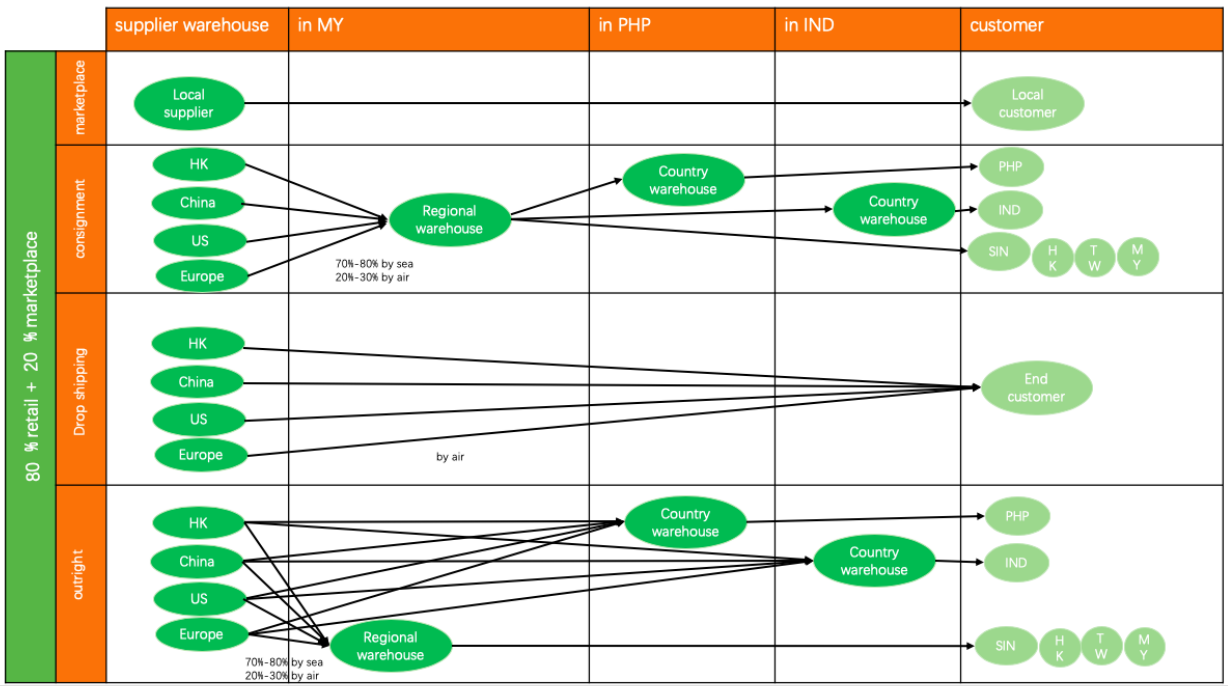


Figure 27: Distribution Modes of ECF to End Customers

ECC uses its Indonesia and the Philippines warehouses for serving the local market only, without any international fulfillment, whilst its Malaysia warehouse acts as a regional consolidation hub for Southeast Asia. Its Malaysia warehouse in Johor has a lower cost structure and is used to replenish a smaller warehouse in Singapore when necessary, or to do direct trucking from Johor to Singapore.

Figure 24: Geographical coverage of country distribution centres

Location	Scale	Serving market	Main function	Cost
Malaysia	Large	MY, SG, HK(small), TW(small)	Inventory Consolidation Ship to IND and PHP warehouse Reduce warehouse cost for SG market	Medium
Philippines	Small	PHP	Shorten delivery lead time No international fulfillment	Low
Indonesia	Small	IND	Shorten delivery lead time No international fulfillment	Low

Appendix 3 - Case Study of Blockchain in Singapore's Container Shipping – Pacific International Lines (PIL)

Pacific International Lines (PIL) was privately incorporated in Singapore in 1967. Since then, its business has been transitioned from primarily breakbulk to container shipping. As of May 2, 2019, PIL is ranked 9th in terms of the number of owned and chartered vessels among the world's leading container shipping companies (Statista, 2019). Besides, its business also covers container manufacturing and other logistics services.

In Jan 2019, PIL conducted a live trial to use IBM's electronic bills of lading (eBOL) system in a shipment carrying mandarin oranges from China to Singapore for traditional Lunar New Year Celebrations. Here below is a brief summary of the trail.

This blockchain trial handled only non-negotiable bills of lading, which did not involve legal problems of transferring title of goods. The whole shipping process is supported by Maritime and Port Authority of Singapore, Singapore Shipping Association, Infocomm Media Development Authority, Singapore Customs (National TradePlatform) and Bank of China Limited Singapore Branch.

The trial achieved very positive results in improving operational efficiency. The processing time to transfer negotiable bills of lading was significantly reduced from five to seven days to just one second. The faster document processing and expedited custom clearing for cargoes could shorten the overall shipping time and benefit all shipping companies, especially those involved in handling perishable items.

To conclude, the blockchain trial conducted by PIL delivers a positive signal to the company and also to the industry that blockchain is a promising technology to solve the pain points of the industry in handling bills of lading and other shipping documents.

Appendix 4 - Case Study of Battery Technology for Harbour Craft – Penguin International Limited

Penguin International Limited is a Singaporean homegrown, publicly listed designer, builder, owner and operator of aluminum high-speed craft. It operates a fleet of crewboats, passenger ferries, as well as shipyards in Singapore and Batam, Indonesia.

The company made solar electrification retrofits for a high-speed craft – Penguin Redeem, which provides ferry services in Singapore with a capacity of 260 pax. During non-operating hours, electricity is required for 6-7 live-aboard crew. Previously, the main diesel generator was used to generate electricity. However, the generator was running at a very low load, which led to a very low efficiency of fuel oil. To solve this problem, Penguin looked for installing solar panels and batteries on the roof for powering the vessel for after-hours ops, as shown in Figure 28.

Some data facts of the project are supplied as follows:

Solar panel installed on the roof:	10kW
Battery storage capacity:	24kWh
Total weight of the system:	<700kg
Total project duration:	about 2 months
Payback:	< 5 years

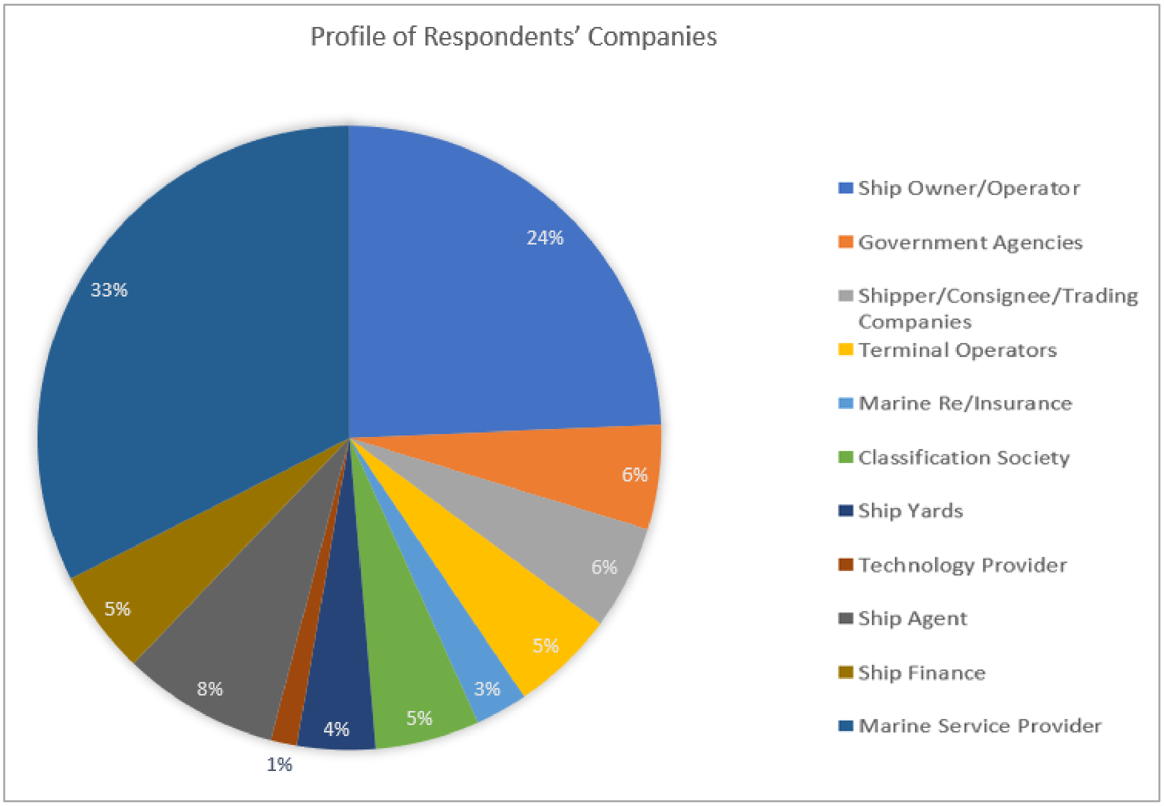
Figure 28: Solar Panels on the Roof of Penguin Redeem

The retrofit of the ship is accomplished without compromising the passenger carrying capacity (still 260 pax) and speed performance. The energy generated by the solar panel during daytime can power the vessel at night without the need to turn on on-board diesel generator. Operational costs are reduced since the generator is now only running at 12/7 basis. The vessel is much quieter at night without running generator – crew can sleep better.

In future, the company plans to commercialise the battery and solar panel system and sell the whole package to customers.

Appendix 5 - Details of Blockchain Online Survey Results

Which of the following sectors does your organization primarily belong to?



Which of the following can best describe your degree of familiarization in the features of blockchain/distributed technology? (Respondents could only choose a **single** response)

Response	20% 40% 60% 80% 100%	Frequency	Count
Not at all		8%	4
Slightly		32%	17
Moderately		43%	23
Good		15%	8
Very Good		2%	1
Valid Responses			53

Which of the following can best describe your degree of familiarization in the applications/use cases of blockchain/distributed technology? (Respondents could only choose a **single** response)

Response	20% 40% 60% 80% 100%	Frequency	Count
Not at all		13%	7
Slightly		34%	18
Moderately		32%	17
Good		21%	11
Very Good		0%	0
Valid Responses			53

What is your organization's current view of the relevance and priority of blockchain adoption in your organization? (Respondents could only choose a **single** response)

Response	20% 40% 60% 80% 100%	Frequency	Count
Critical – in our top 5 strategic priorities now		8%	4
Important, but not in the top 5 strategic priorities now		19%	10
Relevant, but not a strategic priority now		23%	12
Not much relevant now, but may be in the future		42%	22
Will not be relevant		0%	0
Unsure/no conclusion		9%	5
Valid Responses			53

When will your company consider prioritizing blockchain adoption?
(Respondents could only choose a **single** response)

Response	20% 40% 60% 80% 100%	Frequency	Count
In one year		12%	6
In three years		20%	10
In five years		20%	10
More than five years		8%	4
Not sure / No conclusion		39%	19
Valid Responses			49

What are the top 3 reasons for your company to adopt blockchain?
(Respondents were allowed to choose **multiple** responses)

Response	20% 40% 60% 80% 100%	Frequency	Count
Reduce operational costs		73%	8
Reduce human error/manipulation		73%	8
Enhance information transparency and traceability		64%	7
Reduce fraud		45%	5
Gain competitive advantage		27%	3
Have better security of our IT systems		18%	2
Follow Competitors		0%	0
We have enough budget		0%	0
Others (Please specify)		0%	0
Valid Responses			11

What are the top 3 key success factors to establish blockchain across multiple operational and financial processes in the maritime sector? (Respondents were allowed to choose **multiple** responses)

Response	20% 40% 60% 80% 100%	Frequency	Count
Industry collaboration		65%	31
Clear and supportive regulatory framework		50%	24
Technology standardization		46%	22
Top management support		44%	21
Technology maturity (i.e., in terms of scalability etc.)		33%	16
Rich ecosystem (i.e., having enough network users at each maritime stage)		25%	12
Interoperability		23%	11
Others (Please specify)		6%	3
Valid Responses			48

Has your company faced the below challenges/difficulties while adopting blockchain and to what extent?

(Respondents could only choose a **single** response for each topic)

Challenges	Not at all	To a small extent	To a moderate extent	To a great extent	To a very great extent	Total	Mean
Lack of in-house blockchain understanding/skills/capabilities	0%	18%	36%	36%	9%	100%	3.36
Concerns on sharing sensitive information	0%	18%	36%	36%	9%	100%	3.36
Potential security threats	0%	18%	36%	46%	0%	100%	3.27
Regulatory uncertainty	9%	18%	27%	36%	9%	100%	3.18
Difficulty to replace or adapt to legacy systems	9%	9%	46%	27%	9%	100%	3.18
Lack of scalability of the used blockchain system	0%	27%	27%	46%	0%	100%	3.18
Lack of trust among users	9%	27%	46%	9%	9%	100%	2.82
Interoperability among different blockchains	9%	46%	27%	18%	0%	100%	2.55
Difficulty to get other organizations to join the network	18%	36%	27%	9%	9%	100%	2.55

Choose the level of disagreement or agreement with each of the following statements regarding blockchain technology in maritime industry.

(Respondents could only choose a **single** response for each topic)

Impact	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
Blockchain can cut costs and improve efficiency of the maritime industry and maritime trade.	4%	2%	21%	45%	28%	100%	3.89
Blockchain can lead to a shift in requirements of labor skills in the maritime industry.	2%	0%	34%	36%	28%	100%	3.87
Blockchain can increase competitiveness of the maritime industry.	6%	4%	19%	47%	23%	100%	3.77
Blockchain will reduce the cost of auditing in orgainsations.	4%	6%	36%	32%	21%	100%	3.60
Blockchain technology will disrupt maritime industry.	11%	13%	36%	21%	19%	100%	3.26
Suppliers, customers, and/or competitors are discussing or working on blockchain solutions to address challenges in the maritime industry.	13%	19%	38%	21%	9%	100%	2.94
My company will lose competitive advantage if we don’t adopt blockchain technology.	13%	17%	40%	26%	4%	100%	2.91
Blockchain is overhyped and cannot reach mainstream adoption.	17%	34%	30%	17%	2%	100%	2.53

Appendix 6 - Classification of Singapore's Harbour Craft

SB	Vessel used for the carriage in bulk of petroleum, liquefied gases, liquid chemicals or vegetable/animal oils
SC	Vessel used for the carriage of dry or packaged cargoes
SP	Vessel used for the carriage of passengers
ST	Vessel used for towing, pushing or pulling other vessels. The minimum engine shaft power of a tugboat shall not be less than 150 kilowatt (200 brake horsepower). All tugs of steel construction of 750 kilowatt power and above that operate within port limits must be outfitted with anti-oil pollution.
SR	Vessel used for any other purpose