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Joint Industry Programme (JIP) in partnership with MPA, SSA and NAMIC

ADDITIVE MANUFACTURING FOR MARINE PARTS

A MARKET FEASIBILITY STUDY

with Singapore Perspective

Report No.: 2019-9172P, Rev. 1

Document No.: 11EMDQ19-1

Date: 2019-10-30

ADDITIVE MANUFACTURING MARKET FEASIBILITY STUDY

Project key stakeholders, lead research performer, partners and collaborators

JIP sponsors and initiator	JIP Lead Research Performer	JIP Partners From SSA	
MPA SINGAPORE	DNV·GL	ANGLO-EASTERN	PIL
SSA SINGAPORE SHIPPING ASSOCIATION	**JIP Collaborators**	BSM BERNHARD SCHULTE SHIPMANAGEMENT	SYNERGY GROUP
NAMIC NATIONAL ADDITIVE MANUFACTURING INNOVATION CLUSTER	WÄRTSILÄ	CMA CGM	THOME GROUP
	sembcorp marine	EASTERN PACIFIC SHIPPING	Wilhelmsen
	SpareParts3D	OSM MARITIME	ZEABORN
	ivaldi		

About this report :

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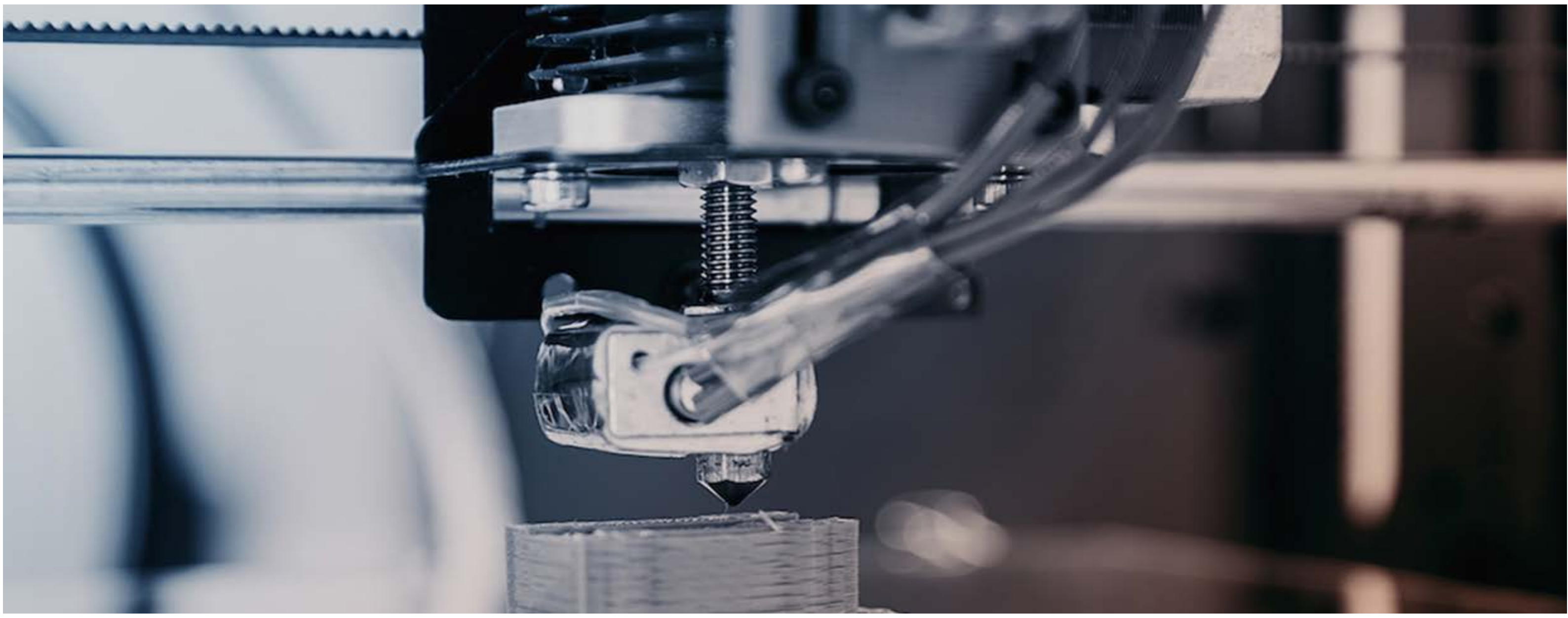

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1. EXECUTIVE SUMMARY

The Maritime and Port Authority of Singapore (MPA), National Additive Manufacturing Innovation Cluster (NAMIC) and Singapore Shipping Association (SSA) have launched a Joint Industry Programme (JIP) to establish the commercial viability, technological feasibility and regulatory requirements behind the use of Additive Manufacturing (AM, or 3D Printing) for marine parts. DNV GL was selected through open JIP call as the lead researcher for the first phase, to conduct a market feasibility study to establish the commercial viability of AM for marine parts based on the list of parts most commonly ordered by the SSA member JIP partners when their ships call at the Port of Singapore. In the course of six months, a systematic research study was conducted that include multiple interviews, surveys, data gathering & analysis and workshops with 14 JIP participant companies within the maritime ecosystem in Singapore. This report provides a summary of the background literature study, project research methodology, findings, analysis and validation of the results.

Singapore is an important hub for the supply of marine parts, supporting a diverse ecosystem of shipping lines and maritime companies. However, there are challenges in the procuring of marine parts, and these include high transportation and inventory cost, long lead time and obsolete parts that are hard to find. These challenges could potentially be overcome through the adoption of AM which is a key enabler for more digital, connected and leaner workflows. AM, used as a lever, could potentially strengthen Singapore's position as a global port and one-stop destination, as well as a hub for digital manufacturing.

As part of this research, a literature study was conducted to highlight the potential opportunities for 3D printing for spare parts in the maritime industry in terms of supply chain optimization, productivity improvement, design opportunities, and digital inventories. Correspondingly, the most appropriate challenges that hinder the adoption of AM in Maritime were discussed based on the technological aspects, financial and skills considerations, as well as qualification and certification requirements.

A consolidated database of nearly 600,000 marine parts orders, based on the information shared by JIP partners, was put together through a series data collection surveys, workshops, and interviews, taking into consideration local market conditions and partners' concerns. Subsequently, 100 common marine spare parts were shortlisted, based on various commercial drivers such as value proposition, frequency of demand, and inventory portfolio and lead time; these represent strong business potential for novel technologies. The findings were then further validated with JIP partners through surveys and interviews. This iterative process allowed the research team to formulate a methodology for shortlisting of most potential marine spare parts for AM based on their commercial viability.

As part of the analysis work, a score based AM Potential Matrix was developed based on commercial and supply chain factors such as lead time reduction, inventory efficiency, and cost-savings as well as technological factors such as redesign possibility, functional performance confidence, AM technology readiness for size, weight and material etc. Certain hypotheses were taken into consideration when semi-quantitatively analysing the suitability and benefits of adopting AM. Then the shortlisted 100 common parts were ranked using the average scores based on their commercial viability and technical feasibility for AM adoption.

In addition the above, the 100 shortlisted parts were further assessed to categorise into following three categories: (a) Highly feasible for 3D printing without class certification (b) Highly feasible for 3D Printable with class certification(c) Not feasible for 3D printing. This was done based on the analysis results from AM potential matrix and also as far as practicable using the project lead researcher team's knowledge on certification of materials for class. The comprehensive analysis of 100 parts derived through this study provides a good starting point for both maritime industry stakeholders as well as AM suppliers to further explore the application of AM technology in supplying on-demand spare parts in Singapore.

The report also highlights key challenges and opportunities in deploying AM for these marine parts and concludes with recommendations for further work. Due to the limited scope and short duration this research focussed on shortlisting only 100 potential parts suitable for AM route, but this work sets direction for further research that could focus on gathering and analysing the data from a large pool of SSA member companies to identify many more thousands of marine spare parts that could be commercially viable for producing though AM route which would solve a variety of ship operational issues such as unwarranted vessel downtime and equipment obsolescence due to unavailability of spare parts.

2. INTRODUCTION

Maritime assets are capital intensive and downtime can have severe financial consequences. Forecasting of the spare parts for ships is challenging because unlike other businesses, it is not only about “How Much” but also about “When”. A spare part might be required by the end of the business day in some cases, or it may not be required until a very long time in future. For successful operations, the right spares should be available, in the right quantity, at the right time. These challenges with spare parts management are an evergreen topic for the maritime for which there may never be perfect solutions. However, the maritime industry will be able to overcome this biggest challenge by focusing on a few strategic approaches.

Additive Manufacturing (AM) technology is poised to bring about a revolution in the way products are designed, manufactured, and distributed to end-users. On-site manufacturing for maintenance becomes an important application of AM. More generally, goods can be printed locally via a distributed network of AM printers, thereby reducing lead times and transport costs. For example, instead of waiting days for spare parts to be shipped, they can be printed on-site in a ship.

However, while the Singapore maritime sector is currently making impressive strides to implement new technologies, the adoption level of the newly emerging additive manufacturing technology is very low compared to other sectors such as aerospace and medical. Essentially, there is a lack of confidence in using AM parts in place of the products produced by traditional means in the maritime supply chain. Some of the other reasons for maritime sector's cautious approach towards additive manufacturing are the lack of awareness, lack of optimised cost-effective AM technologies suitable for large size maritime parts and lack of commonly accepted qualification and certification approaches.

AM technologies are emerging as key enablers for more digital, more connected and leaner workflows. As a leading maritime hub, Singapore encourages new technologies such as additive manufacturing for on-demand digital spares which could proactively prepare the industry for current and future challenges. As a result, AM based supply chains can potentially offer maritime industry stakeholders a strong value and a competitive advantage, from lower costs and lead times to greater flexibility and agility. Additive manufacturing can help ship owners, other maritime-related asset owners, original equipment makers, and other maritime stakeholders, to undertake supply chain transformation initiatives. The current adoption level of AM for the marine parts is close to non-existent, despite the consensus that such technology could have potential applications for spare parts, repair and even new builds.

The Industry experts believe the time is now ripe to leverage new technologies such as additive manufacturing to ensure Maritime Singapore stays ahead of the curve as a world-class port and international maritime centre. 3D printing of spare parts is one such opportunity that requires attention from policymakers, viability funding from funding agencies and commitment from key stakeholders.

2.1. BACKGROUND AND MOTIVATION

This JIP leverages the strengths and needs of maritime, digitalisation and manufacturing domains. The maritime sector is a key pillar of Singapore's economy. The maritime industry contributes about 7% of Singapore's Gross Domestic Product (GDP) and employs over 170,000 people. Singapore will continue to strengthen its maritime industry to enhance its long-term competitiveness and value proposition to shipping companies and maritime service providers. The Maritime and Port Authority of Singapore (MPA) recently launched the Sea Transport Industry Transformation Map (ITM). The ITM builds on MPA's strategic long-term plans to develop Singapore's next-generation port and to catalyse innovation, drive productivity improvements, and enhance the skills of the maritime workforce.

The recently launched Industry Transformation Map for Sea Transport by MPA is also expected to reduce the gap between invention and adoption of digital technologies. It will result in creating an environment that is conducive to innovation and is suitable to accelerating the digitalisation of marine spare parts.

Manufacturing is also a major pillar of Singapore's economy, contributing approximately 20 per cent of GDP. Today, Singapore's manufacturing sector has moved into high value-added verticals, such as aerospace, oil & gas, and complex equipment manufacturing. This JIP leverages the strengths and needs of Maritime, digitalisation and manufacturing domains.

As part of the initiative to promote the interest and enhance the competitiveness of local maritime companies to accelerate the adoption of AM by industry stakeholders, MPA has partnered with SSA and NAMIC to launch a Joint Industry Programme (JIP) on the Feasibility of Additive Manufacturing for Marine Parts. The study aims to establish the viability of AM for marine parts, and also aims to highlight key challenges and opportunities in deploying AM for shortlisted marine parts. The JIP will bring together a comprehensive ecosystem of partners from across the value chain. This collaboration will strengthen Singapore's role as a hub for ship supplies and provide the maritime industry with clarity on the challenges, opportunities and potential test cases for deploying AM for marine parts.

The results aim to encourage the industry players to embrace the upcoming changes that the AM technology could offer for marine spare parts supply and to create an environment that is conducive to innovation and is suitable to accelerating the digitalisation of marine spare parts.

2.2. PROJECT SCOPE AND OBJECTIVES

The overall objective of the JIP initiated by MPA-NAMIC-SSA consortium is to establish the commercial viability, technological feasibility and regulatory requirements behind the use of AM marine spare parts. It also aims to highlight key challenges and opportunities in deploying AM for marine parts (to be shortlisted), including the approval, qualification and certification processes required by classification societies. The JIP could potentially spin off further developmental projects amongst interested industry players, tech providers and classification societies that are keen to develop expertise and facilities in AM testing, qualification and certification.

The study would establish the commercial viability of AM for marine parts, based on the list of parts most commonly ordered when ships call at the Port of Singapore. Study would also highlight key challenges and opportunities in digitalisation and AM deployment for these marine parts. The outcome of this study should be a list of selected parts with good potentials for AM, and these would be analysed on the commercial viability, supply chain effects and AM suitability.

- To conduct a 'Market Feasibility Study' on the most commonly ordered list of marine parts when ships call at the Port of Singapore based on workshops, interviews and surveys with the participating shipping lines, ship management companies and other relevant partners and collaborators.
- To prepare a comprehensive list of parts that are most commonly required/ordered when ships call at the Port of Singapore as well as the list of the most common marine parts being delivered by ship chandlers/parts suppliers in Singapore.
- To carry out an analysis of the listed parts according to their value proposition, frequency of demand, inventory portfolio, manufacturing requirements, class certification requirements and supply chain considerations of each part being studied. As well as an analysis of the listed parts for their feasibility level for 3D printability based on a risk-based assessment and professional judgement.
- To classify the listed parts into the following 3 categories

  Categorization of 100 selected parts into 3 categories:

  (a) Highly feasible for 3D printing without class certification

  (b) Highly feasible for 3D Printable with class certification

  (c) Not feasible for 3D printing
- To write a market feasibility study report that highlights key challenges and opportunities in deploying AM for these marine parts as well as summary and recommendations for further work.

2.3. RELEVANCE, LIMITATIONS & CONSTRAINTS

The disruptive potential of AM has only seen a moderate uptake in the industry so far. This technology can help not only to reduce costs of producing spare parts for vessels but also to radically reinvent the production and logistics including using completely new and more suitable materials. However, the challenges of marine parts inventory include not only inventory costs, low utilisation rates and parts obsolescence, but also complex supply chains and accompanying logistics costs.

To date, there is little to no research to find out the potential for utilising 3D printing technology in the maritime industry based on the procurement or supply data from ship owning, ship management and ship equipment OEM suppliers. In this study, multiple sources of information and data are used to obtain a basis for results and summary. For consistency, the research is being conducted as transparent as possible to assure validity and reliability by involving all the stakeholders actively with interviews, questionnaires, surveys, data sharing and validation etc. The parts procurement data shared by ten member companies of the Singapore Ship Association that is up to 600 000 lines brings the highest credibility to this study.

However, this research study has a number of limitations and constraints. The first limitation is the vessel types, tonnage, value and age of the world maritime fleet are so diverse that it is difficult to get a 100% clear and holistic perspective when we only involve a limited number of ship owners and ship management companies. It would not be appropriate to generalise the outcomes of this research study to the entire maritime industry as the various geographical segments have different identities, characteristics, and interests. To really understand the possible implications of additive manufacturing, every segment should be treated and researched as a separate case. This research only draws a larger picture of the common marine spare parts that are commercially and technologically feasible in the current local market in Singapore.

The second limitation is that the data obtained from JIP partners was not a uniform format because the nature of data management in each company is different from each other. Most of the data received was retrieved from text registration systems, relational/object database systems, semi-structured / XL database systems, or a combination of free text, structured data, and semi-structured data. The third limitation of this study is that the duration of the project is relatively short (6 months in total), and data cleansing and integration of different information has consumed significant time and efforts.

The fourth limitation of this study is the scope is limited to commercial drivers and no technical information about parts such as material, size, weight etc. was gathered. However, the potential AM feasibility of shortlisted parts requires such technical information that was not readily available. Hence, the project team utilised the knowledge on such parts and AM technology to provide quantitative weightage. Moreover, the assumptions for AM feasibility were made on current capabilities of the AM, but they may be inaccurate in some occasions as the upcoming development is subjective and can only be estimated.

This report has been prepared based on quantitative work within the scope of the JIP. Any added qualitative opinions, summary or recommendations expressed in this report are those of the author(s) and the project team for indicative purpose only hence do not necessarily reflect the views of MPA, SSA, NAMIC, DNV GL or JIP stakeholders.

2.4. JIP STAKEHOLDERS PARTNERS AND COLLABORATORS

For this joint industry program (JIP), DNV GL has been appointed as the Lead Research Performer by the MPA-NAMIC-SSA consortium to manage the project and facilitate the execution of the study through market research and its own in-house expertise to establish the commercial viability of AM for marine parts. The technical committee of Singapore Shipping Association (SSA) in collaboration with NAMIC & MPA has selected 10 member companies of SSA to the JIP. In addition, several other key industry partners such as Wartsila, SembCorp Marine, SpareParts3D and Ivaldi have joined the JIP as collaborators. Both the SSA partners and collaborators have provided the data and knowledge requested by the lead research performer regarding the demand, inventory portfolio and supply chain considerations of marine parts.

These JIP partners from SSA could also become test-bedding partners for demonstrator parts in subsequent R&D and test-bedding work. Table 1 shows the names of the participants in the Joint Industry Project. Refer to Appendix A for a short profile of JIP stakeholders and partners.

JIP sponsors and initiator	**JIP Lead Research Performer**	**JIP Partners From SSA**	
MPA	DNV GL	ANGLO EASTERN	PIL
NAMIC	**JIP Collaborators**	BSM	SYNERGY MARINE
SSA	SEMBCORPMARINE	CMA CGM	THOME
	SPAREPARTS 3D	EASTERN PACIFIC	WILHELMSEN
	WARTSILA	OSM	ZEABORN
	IVALDI		

Table 1 : Name list of JIP key stakeholders, JIP partners and collaborators.

3. BACKGROUND-LITERATURE REVIEW

We have conducted literature research as one of the forms to collect and analyse the references related to the adoption of AM in the Maritime industry. The number of maritime organisations and professionals that are familiar or even working with the technology seems limited. Hence, in this section, we have summarised the potential benefits and challenges for 3D printing in the maritime industry.

3.1. POTENTIAL OPPORTUNITIES FOR 3D PRINTING IN THE MARITIME INDUSTRY

It is widely recognised that additive manufacturing (AM) is an essential pillar of the fourth industrial revolution, accompanied by the internet of things (IoT), artificial intelligence (AI), etc. AM's unique processes, techniques and technologies open new ground for innovation and offer a range of logistical, commercial and technological advantages. An estimation of AM impact to ASEAN is that US$100 billion of incremental value will be generated by 2025, impacting the projected real GDP by 1.5% to 2% [1]. AM represents huge potentials for maritime industry, based on the tremendous benefits in the near future and small penetration for now [2]. This section will discuss the AM opportunities for the maritime industry in Singapore, with a focus on the impact of design, productivity and supply chain. Forming AM business clusters could create opportunities for cross-pollination of ideas between companies, accelerating innovation.

3.1.1. SUPPLY CHAIN OPTIMISATION

1. MORE EFFICIENT INVENTORY

AM can lower handling costs, while on-demand and on-location production can lower inventory stock and hence cost. This reduces complexity in the supply chain and brings manufacturing closer to the customer for better alignment and quality assurance [3]. By 2022, 85% of the spare parts suppliers will incorporate 3D printing into their business [4]. The Rotterdam Additive Manufacturing LAB (RAMLAB) aims to 3D print replacement metal parts for the maritime industry, and it successfully printed the class certified ship propeller in 2017 [5].

2. LEAD TIME / COST REDUCTION

AM has the capacity to simplify and shorten the manufacturing supply chain [3]. AM significantly reduces the lead time which makes the market become more responsive. Current maritime fleet spends approximately 13 billion USD a year on spare parts and 50% of these vessels older than 15 years are suffering from limited part availability (Clarksons Marine Fleet). For low-volume production, AM offers faster lead times than traditional manufacturing methods as it produces near-net-shape workpieces. The US Navy successfully 3D printed the hull of a small submarine in under a month and under $60, 000 [6]. With the use of AM, Ford managed to develop multiple iterations of the piece in only four days, only costing $3,000 [7].

3.1.2. PRODUCTIVITY IMPROVEMENT

Since AM is constructed layer-by-layer with minimal raw material for part production, it could substantially reduce the scrap and save cost in material as compared to traditional manufacturing methods [8]. The ratio of material used in traditional manufacturing can be as high as 20 to 1, which means manufacturers need to buy 20 times the final usable piece [9]. AM allows for cheap, low-volume production and facilitates personalized and customized products, which enables more applications flexibility [10].

3.1.3. DESIGN OPPORTUNITIES

1. REDESIGN FOR WEIGHT REDUCTION AND SIMPLER STRUCTURES

AM provides the ability to reduce weight or volume with the freedom of a more optimal design [3] [8]. By applying topology optimisation and working with the lattice structures, the weight and cost of the parts can be reduced [11]. Naval Group and Centrale Nantes successfully 3D printed a stainless steel hollow propeller to improve energy efficiency, reduce radiated noise and vibrations as compared to conventional propellers [12]. This is accomplished by using different feedstock or blinders for different fractions of the model. Having multiple materials or designs on a product can similarly reduce its overall weight and cost [13] [14].

2. REDESIGN FOR IMPROVED FUNCTIONALITY

AM takes away design restrictions that constrain traditional methods of producing parts. Some functionality improvements could be achieved with more flexibility and complexity. AM can help create many of these variations with little extra cost [3]. Some spare parts could also be redesigned to improve functionality. The prototypes are being able to develop with enough time before the final production and the quality could be tested way before the production starts [11]. It also simultaneously creates custom alloys and composites materials in order to increase mechanical strength, modify the thermal expansion coefficient and control the material properties of metal [15]. Recently, Wartsila worked with DNV GL on a 3D printed steel nozzle, which enables better spray adjustment and performance, but only achievable with AM [16].

3.1.4. DIGITAL INVENTORIES

1. DIGITAL DATABASE FOR AM

The digital inventory is a database of every part that can be made using AM. The geometrical properties and parameters of each part are entered into the database (based on computer-aided design), thus creating the part’s digital twin. Each part entered into the inventory is catalogued and credited to the originating source. The digital database enabled by AM would be valuable for the digitalisation of Industry 4.0, as well as the Internet of Things and Artificial Intelligence initiatives in the near future [17].

The advancement of additive manufacturing (AM) has opened numerous new possibilities for more complex structures and geometries, greater material efficiencies, higher performance and better environmental sustainability [18] [19] [14]. However, AM technology is still in its infancy for maritime applications [20]. The technology is not sufficiently mature in some scenarios to offer a cost-effective replacement to conventional methods for mass production [21].

3.2. GAPS, NEEDS AND CHALLENGES TO BE ADDRESSED FOR FACILITATING ADPOTION

3.2.1. TECHNICAL CHALLENGES

1. PRODUCTION AND LOGISTICS:

The commercial benefit of AM is inversely related to the production quantity [19], and thus it is presently not a cost-effective method for mass production [22] [23] [24]. The National Additive Manufacturing Innovation Cluster (NAMIC) is currently working international consortiums to identify parts suited to AM in many sectors including the marine industry [25]. These efforts, coupled with advancements in technology to the printing speed, will offset the present production and supply chain challenges faced by AM in the years to come.

2. QUALITY CONSISTENCY:

AM is considerably new and complex due to a wide range of materials and production methods, each creating its own specific set of variables. Confidence in the AM part depends on the whole process, including pre-processing (e.g. feedstock analysis, preparation, etc), post-processing (e.g. surface, stress, heat treatment, etc), and destructive or non-destructive evaluation. However, with the advent of machine learning [26], coupled with a growing interest in AM among researchers [19], general understanding about AM and quality control will mature significantly in the coming years. The class societies have been advancing rapidly on the qualification and certification of AM facilities and processes, which plays an invaluable role in ensuring the quality consistency of AM printed parts. These efforts will potentially make it commercially viable for maritime applications in the foreseeable future.

3.2.2. FINANCIAL AND SKILLS CONSIDERATIONS

1. FINANCIAL BARRIERS:

The upfront capital expenditures for machines and facilities necessary to set up AM production are considerable [23] [27] – most large-scale commercial-grade printers are minimally in the tens of thousands of dollars [28]. A suitable business model to reduce the initial barriers to entry and concurrently decrease the financial risk undertaken by the companies during the trial period is to collaborate with a 3rd party AM company or to form a consortium for the joint industry projects.

2. SMALL TALENT POOL:

As a new type of technology, there is a limited number of people who are professionally trained in AM [29] [30]. Technical and engineering skills required for successful AM deployment range widely from new design processes, new material processing knowledge, and testing data management. For AM to revolutionise manufacturing in the maritime industry, a well-trained and capable workforce will be required [30]. At present, NAMIC, universities and research institutes in Singapore have all taken steps to further the R&D and training of AM.

3.2.3. QUALIFICATION AND CERTIFICATION

1. INDUSTRIAL STANDARDISATION:

There is a demanding request for a set of standards to provide much-needed assurances to businesses and manufacturers that AM processes, materials and technologies are safe and reliable. The International Organisation for Standardisation (ISO) and ASTM International came together to jointly develop the AM Standards Development Structure [31]. NAMIC joined ASTM International's Global AM Centre of Excellence as strategic partner. The new AM structure does not confine the scope of work for any standards organisation but provides a framework in which most standards needs can be met. There are presently no AM standards specific to the maritime industry [19] [20]. The consistent quality and reliability of products need to be ensured for AM to be widely adopted [11].

2. QUALIFICATION AND CERTIFICATION:

Standards and regulation guidelines specific to the maritime industry must be developed to address the specific issues that arise through the process. Without these governing standards, industry players will face a challenge in determining what is acceptable to the industry based on the generic ISO/ASTM standards [32]. Such a situation is not desirable as it leaves room for ambiguity and can result in the use of parts which lack the appropriate certification. Companies like DNV GL can fill this gap by applying our expertise in materials testing and the maritime industry to develop industry-specific service specifications, standards and recommended practices based on the ISO/ASTM standards. With this, we will be able to certify parts created by companies for use in their operations. [33] [11].

4. RESEARCH METHODOLOGY FOLLOWED IN THIS STUDY

4.1. RESEARCH OUTLINE

The approach undertaken in the project is split into four stages as shown in Figure 1. Further discussions regarding each of the stages are made in the following sections.

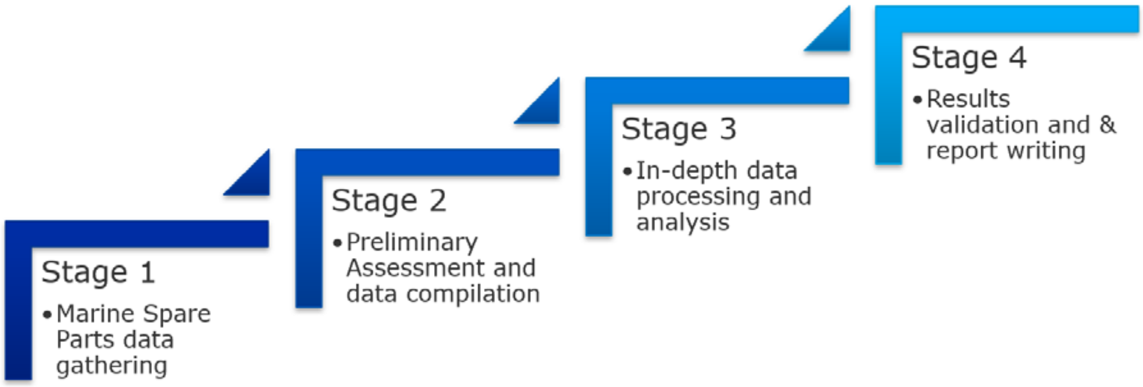


Figure 1: Four stages defining the project methodology.

4.1.1. STAGE 1 – MARINE SPARE PARTS DATA GATHERING

The objective of stage 1 would be to identify the list of marine parts being ordered by the ship owners/ship managers in Singapore as well as a list of marine parts being delivered by ship chandlers/parts suppliers in Singapore. This collection of primary data is done by conducting internal interviews with key client account managers and subject matter experts within global DNV GL organisation. Key market leaders (ship owners, ship managers, surveyors etc.) were identified and external interviews were conducted by DNV GL to understand their market perspectives. Secondary data is also obtained through leading shipyards, owners, scholarly articles, published research papers, published market reports and newspapers. DNV GL customers and market intelligence database of its customers will also be utilised to provide the latest and accurate market insights.

4.1.2. STAGE 2 – PRELIMINARY ASSESSMENT AND DATA COMPLIATION

The second stage involves the formulation and assessment to derive value proposition, frequency of demand, inventory portfolio and supply chain considerations of each/all parts being studied. This is done by performing literature research/interviews to determine the types of the value proposition for those listed spare parts based on manufacturing, transportation and storage costs. A frequency and probabilistic feature of demand of the spare parts is developed and categorized under: i) Equipment criticality, ii) availability/ lead times and iii) operational needs /requirements. Further categorization is shown in the AM Potential Matrix.

4.1.3. STAGE 3 – IN-DEPTH DATA PROCESSING AND ANALYSIS

The third stage involves categorisation of parts according to (i) Ship safety, (ii) Ship operations and (iii) Ship stores. This is done by performing a technical assessment to categorise those identified parts according to (i), (ii) and (iii). The list will be validated with the participants through interviews/surveys/workshop

Additionally, a high-level plan is developed for the item (i) and (ii) i.e. quality control plan, material, applicable rules/regulations/standards, AM printing type, to assess those parts for quick execution for next project phase. A supply chain analysis for the listed parts is also conducted together with an assessment if AM reduces the chain of supply and evaluate its impact on the business and ship operation eco-system

4.1.4. STAGE 4 – RESULTS VALIDATION AND REPORT WRITING

The fourth stage involves consolidating all the findings and develop the final feasibility study report including recommendations. This includes the interpretations and evaluations of market outlook, development of business risks and criticality of success factors and recommendation of selected parts. The feasibility study report will include all findings and analysis, as well as all details specific to the documented analysis. Finally, a conclusion presentation will be conducted by the project team.

4.2. DATA ACQUISITION APPROACH

To achieve the Project Objectives, an approach in Figure 2 was adopted. The approach is by no means linear and is illustrated here to indicate general scope and deliverable as defined in the project proposal.

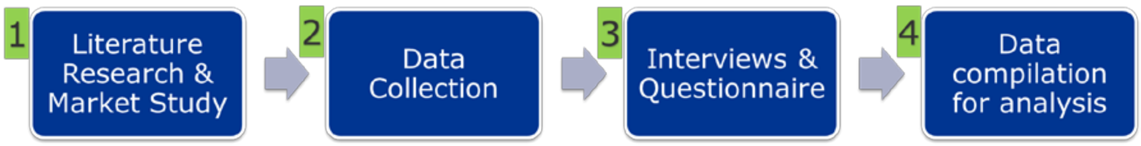


Figure 2: Data acquisition approach

5. DATA ANALYSIS AND DEVELOPMENT OF PARTS RANKING MATRIX

5.1. ANALYSIS OF ACQUIRED DATA

Part identification (within the inventory portfolio) is key to determining which of the spare parts could be 3D printed. Therefore, most of the request for information was made based on identifying the parts. This is done through identifying the part category, drawings and application. Additionally, whether the part has a unique identification number either given from the manufacturer or based on the internal procurement system. Part identification can also be based from which vessel the request originates. This, in turn, requires information regarding the vessel – that is, vessel name and IMO number.

In value proposition or price, a price breakdown of the parts is required. This includes the costs of parts in terms of manufacturing and freight/ transportation. The costs of the parts could further be described in terms of absolute or relative (percentage) costs, the parts dimensions as well as the location of its destinations.

In supply chain considerations, questions relating lead time, main supplier, status, stock level and services rendered are asked. In the frequency of demand, the quantity purchased for a three-year period is requested. This provides greater accuracy as to the actual number that is ordered within the timeframe.

5.2. HYPOTHESIS

Figure 3 illustrates the linking of data, hypothesis and deliverables of the project. Key to the project is to formulate and validate the hypothesis with regards to the benefits of AM under these specific headers:

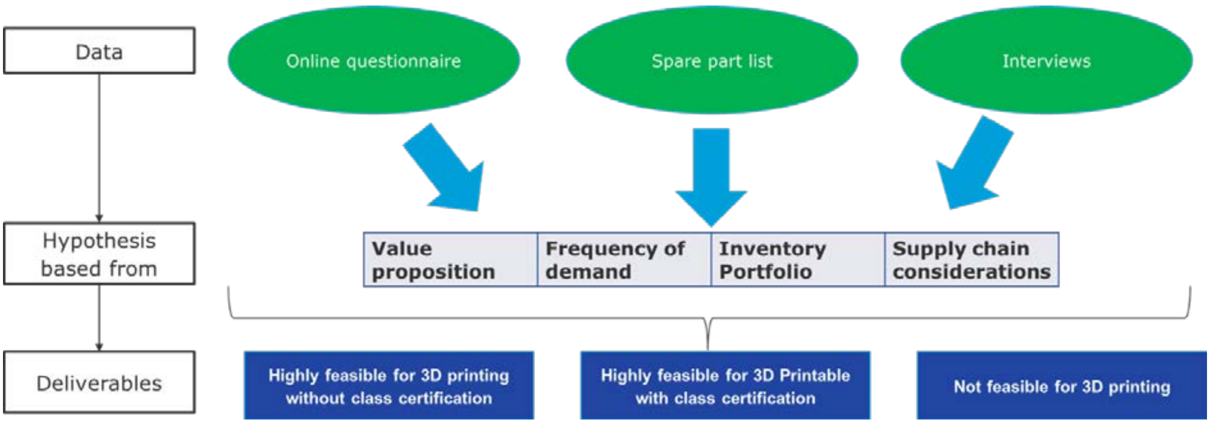


Figure 3: Linking Data, Hypothesis and Deliverables of the project

5.2.1. COMMERCIAL FACTORS CONSIDERED TO VALIDATE HYPOTHESIS

This research study has taken into consideration following factors to gather, analyse the data and validate . value proposition, frequency of demand, inventory portfolio, and supply chain considerations of each part being studied

- Value proposition

The selected spare parts are based on the past 3 years data, and they are assumed to represent relatively high value for the near future (next 5 years) for the maritime industry in Singapore. Cost-saving is estimated from the cost difference between conventional method and additive manufacturing (including feedstock, AM process, post-processing, parts evaluation, certification, etc).

- Frequency of demand

The number of parts ordered will illustrate the regularity of required parts, which the ordering pattern can be analysed to correspond with the printability of the parts, such as enhancing the production process of the parts. The down-selected spare parts are based on past 3 years data, and they are assumed to represent relatively high frequency of demand for the near future (next 5 years) for the maritime industry in Singapore.

- Inventory portfolio and lead time

The inventory efficiency refers to the optimisation of turnover ratio and stock utilisation within a timeframe. Ideally, more stock should be in place for commonly requested spare parts, but minimal stock for the rarely requested spare parts.

- Redesign possibility

Based on the domain knowledge and experience, some spare parts could be redesigned for additive manufacturing in order to achieve reduced weight/volume or improved functionality. The class certification requirements are established based on the existing manufacturing methods, and these will be discussed and benchmarked with additive manufactured parts.

- Performance confidence

Based on domain knowledge and experience, some spare parts could achieve the same or better properties through additive manufacturing. The performance confidence needs to consider the following factors: application criticality, safety risks, geometry, volume, complexity, post-processing, surface conditions, etc.

- AM readiness for size & weight and material

Size & weight and material are still under development for the AM development of industrial adoption. Based on the domain knowledge and experience, the technological readiness for the AM process (including feedstock, process setup, manufacturing, post-processing, surface treatment, etc) is evaluated for each of the spare parts based on complexity, requirements and state-of-the-art technological capability for now.

5.3. ANALYSIS OF PARTS LIST

By conducting an in-depth analysis using the data gathered, the results established the building blocks of an AM Benefits Scoring Matrix which will be further elaborated later in the report.

Subsequently, once the data was collected, a series of interviews were scheduled with the different stakeholders to clarify any doubts with regards to the answers from the online questionnaire and the set of lists provided by them. Concurrently, the platform was also used as a feedback session with the stakeholders to provide any insights as well as strengthen the collaboration relationship.

5.4. DEVELOPMENT OF PARTS RANKING MATRIX

The marine spare parts that were identified were given a score using a decision scoring matrix on the basis of two main headers as shown in Table 2, Current market commercial suitability and potential benefits by AM route with regards to supply chain as well as commercial aspects & AM technological aspects.

Table2: Headers for AM potential scoring matrix

Main Headers	Categories
Weightage based on current market commercial drivers	The cost spent on purchasing spare parts (SGD/unit)
	Quantity of spare part ordered (pcs)
	Lead time for delivery
Weightage based on potential AM benefits (Supply chain and commercial aspects)	Potential to reduce procurement lead time compared to traditional supply chain
	Potential to reduce intermediate inventory at stockyards compared to traditional supply chain
	Potential cost savings in terms of 'total cost of ownership' compared to traditional supply chain
Weightage based on potential AM benefits (AM technological aspects)	Potential opportunities to improve functionality or reduce complexity with better design
	Estimated functional performance of AM parts as intended compared to traditional parts
	Estimated readiness level of AM technology for adoption (size & weight)
	Estimated readiness level of AM technology for adoption (material)
	Potential benefits from the AM spare parts

While the current market commercial suitability scores were derived based on the data consolidated and the methodology covered in section 4, the potential benefits by AM route in terms of commercial and technological were based on the preliminary assessment conducted by the researcher team AM experts. Further quantitative research needs to be carried out with more substantial information such as dimension, materials composition and parts complexity on the specific marine spare parts to determine the full AM potential of the printed spare parts.

6. RESULTS AND DISCUSSIONS

This chapter summarises and presents various deliverables of this research project. To support those deliverables this section presents the results from overall data analysis as well as results from the analysis of a list of 100 selected spare parts using a part ranking matrix methodology.

6.1. LIST OF 100 SELECTED PARTS CONSOLIDATED FROM OVERALL DATA ANALYSIS

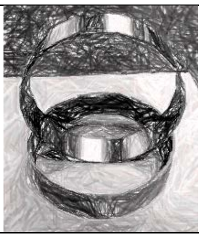
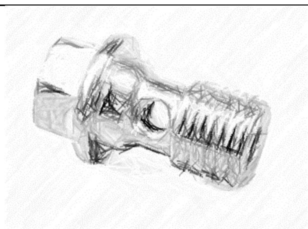
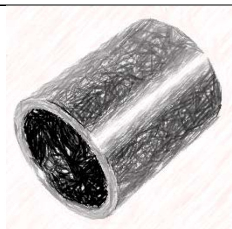
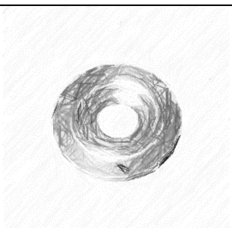
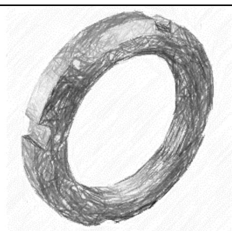
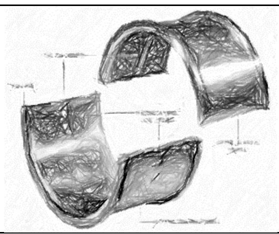
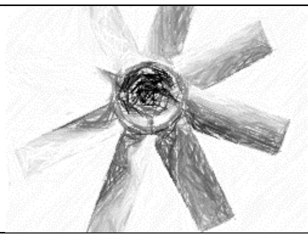
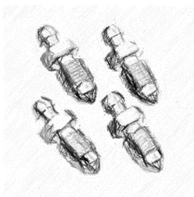
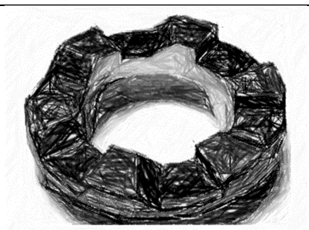
One of the prime deliverables of this JIP was to list of the most common marine parts being delivered by ship chandlers/ parts suppliers in Singapore when ships call at the Port of Singapore. With regards to the analysis done in Section 4, a list of 100 parts was selected as shown in Table 3. The sketches of the parts can be seen in Table 4.

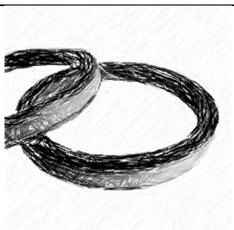
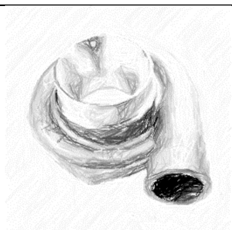
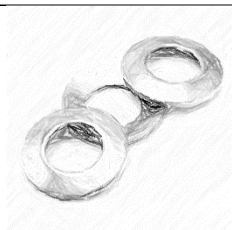
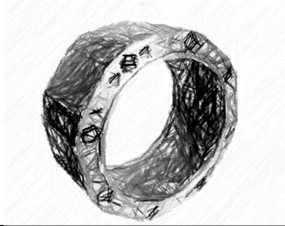
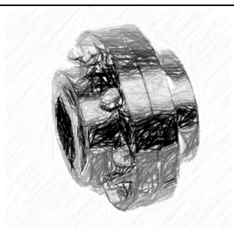
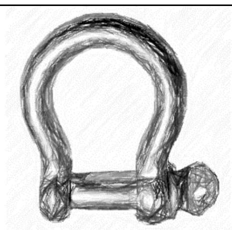
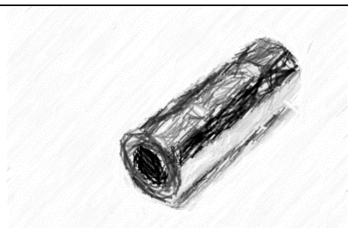
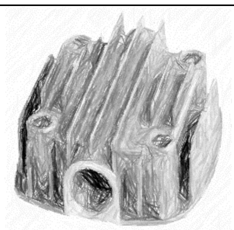
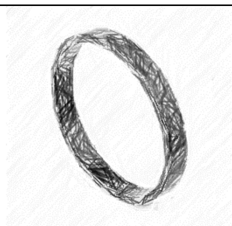
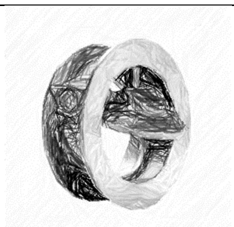
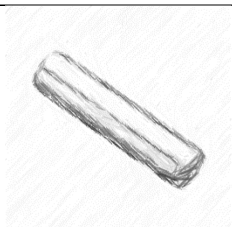
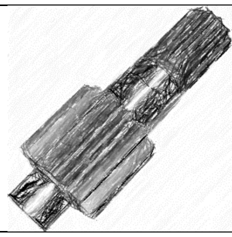
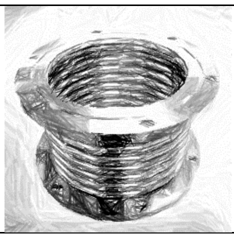
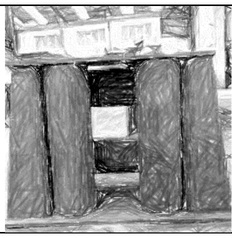
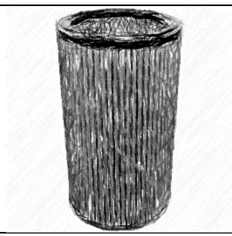
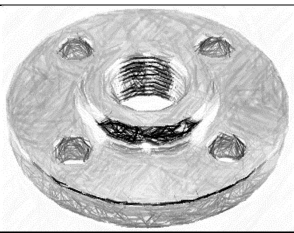
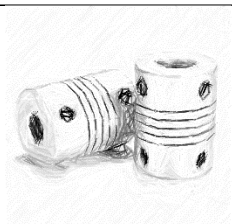
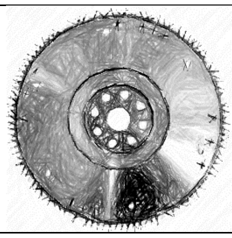
Table 3: List of 100 selected parts from overall data analysis

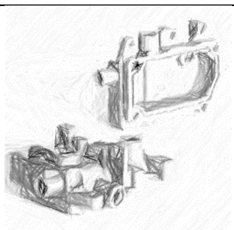
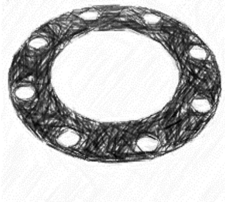
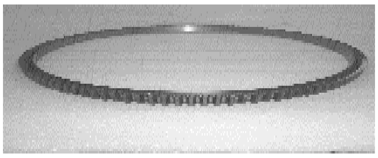
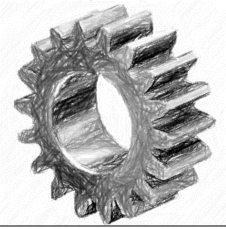
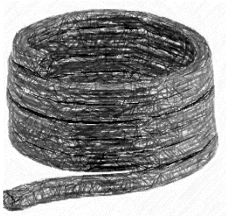
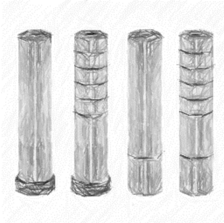
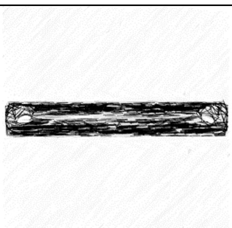
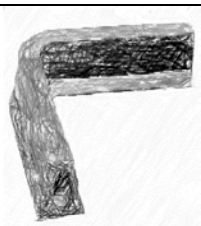
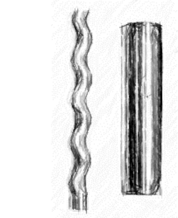
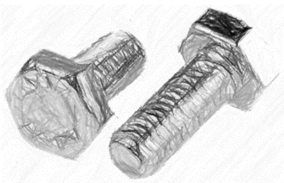
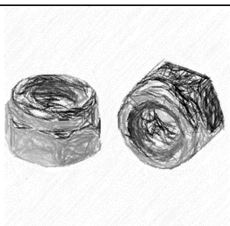
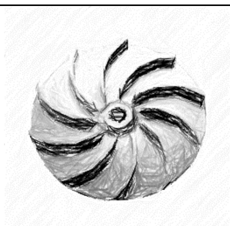
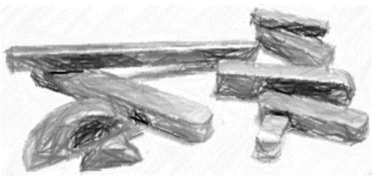
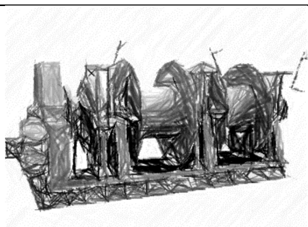
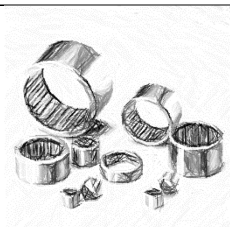
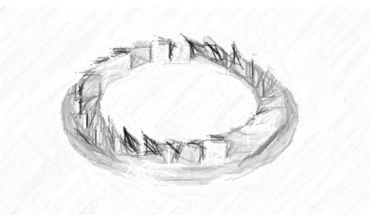
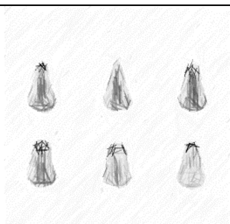
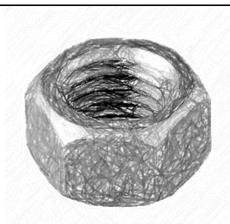
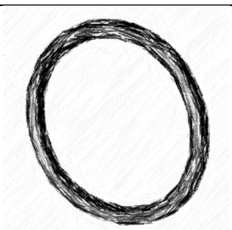
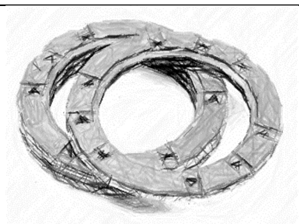
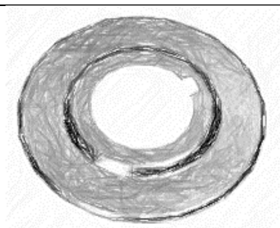
No.	Name	No.	Name	No.	Name	No.	Name
1	AIR COMPRESSOR ELBOW	26	CRANE SHACKLE	51	IMPELLER NUT	76	SEAL VALVE STEM
2	ANGULAR BALL BEARING	27	CRANK PIN	52	KEY	77	SHAFT
3	ANODE	28	CYLINDER COVER	53	MOORING WINCH DRUM	78	SPINDLE GUIDE
4	ANTI POLISHING RING	29	CYLINDER LINER	54	NEEDLE ROLLER BEARING	79	SPIRAL GEAR
5	BAND BRAKE LINING	30	DAMPER RING	55	NOZZLE RING	80	SPRING
6	BANJO PLUG	31	DISC VALVE	56	NOZZLE TIP	81	SPRING CARRIER
7	BEARING BUSH	32	DOWEL PIN	57	NUT	82	STEEL BALL
8	BEARING COVER	33	DRIVE PINION	58	O RING	83	SWIRLER
9	BEARING HOUSING	34	EXPANSION JOINT	59	OIL SCRAPER RING (STUFFING BOX)	84	TAPPERED BUSH
10	BEARING NUT	35	FAIRLEAD	60	OIL SLINGER	85	THRUST COLLAR
11	BEARING SHELL	36	FILTER CARTRIDGE	61	PINTLE BUSH	86	THRUST PIECE
12	BLADE (AIR COMPRESSOR)	37	FLANGE	62	PIPE CLAMP	87	THRUST SPINDLE
13	BLEED SCREW	38	FLEXIBLE COUPLING	63	PISTON CROWN	88	TURBINE DIFFUSER
14	BOLT REAMER	39	FLYWHEEL	64	PISTON RING	89	V PULLEY
15	BURSTING DISC	40	FUEL PUMP TOP COVER	65	PLATE FOR CONDENSER/EVAPORATOR	90	VALVE BRIDGE
16	CLAW CLUTCH	41	GASKET	66	PLUNGER BARREL	91	VALVE COTTER
17	CLUTCH SHOE	42	GEAR	67	POLYURETHANE BUFFER	92	VALVE GUIDE
18	COMPRESSED SEALING RING	43	GEAR RING	68	PURIFIER BOWL	93	VALVE PLUG
19	COMPRESSOR DRIVING PULLEY	44	GLAND PACKING	69	QUICK ACTING CLEATS	94	VALVE ROTATOR
20	COMPRESSOR HOUSING	45	GUIDE PIN	70	RETAINER RING	95	VALVE SEAT
21	CONED DISC SPRING	46	HANDLE AXLE	71	ROCKER ARM BRACKET	96	VALVE SPINDLE
22	CONNECTING ROD	47	HATCH COVER PACKING	72	ROLLER GUIDE HOUSING	97	VALVE SPRING
23	CONNECTION NIPPLE	48	HELICAL ROTOR	73	ROTARY CUP	98	WASHER
24	COOLING WATER JACKET	49	HEXAGON SCREW	74	SCREW	99	WORM GEAR
25	COUPLING	50	IMPELLER	75	SEA CHEST STRAINER	100	WRIST PIN BUSHING

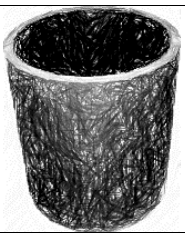
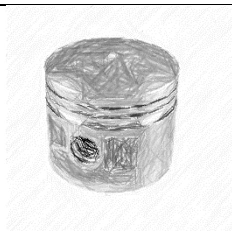
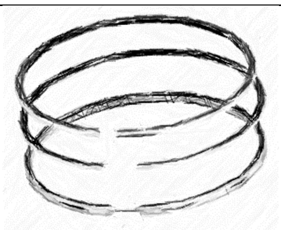
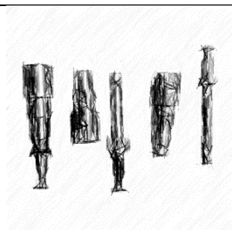
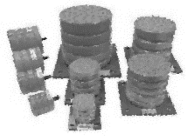
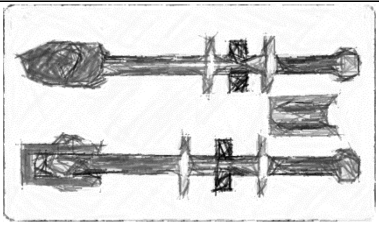
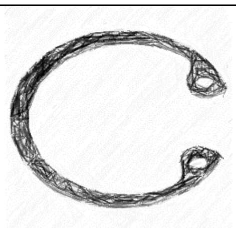
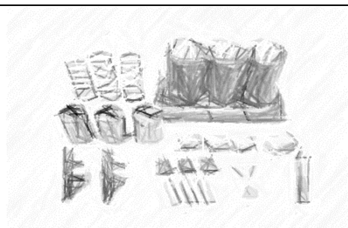
Table 4: Line sketches of 100 shortlisted parts (for illustration purposes only)

Note that pictures presented here are only for example hence shall not be considered for accuracy.

		
1: Air Compressor Elbow	*2: Angular Ball Bearing*	*3: Anode*
		
4: Anti Polishing Ring	*5: Banjo Plug*	*6: Bearing Bush*
		
7: Bearing Cover	*8: Bearing Housing*	*9: Bearing Nut*
		
10: Bearing Shell	*11: Blade, Air Compressor*	*12: Bleed Screw*
		
13: Bolt Reamer	*14: Brake Lining*	*15: Bursting Disc*
		
16: Claw Clutch	*17: Clutch Shoe*	*18: Compressor Driving Pulley*

		
19: Compressed Sealing Ring	*20: Compressor Housing*	*21: Coned Disc Spring*
		
22: Connecting Rod	*23: Connection Nipple*	*24: Cooling Water Jacket*
		
25: Coupling	*26: Crane Shackle*	*27: Crank Pin*
		
28: Cylinder Head Cover Air	*29: Cylinder Liner*	*30: Damper Ring*
		
31: Disc Valve	*32: Dowel Pin*	*33: Drive Pinion*
		
34: Expansion Joint	*35: Fairlead (Roller)*	*36: Filter Cartridge*
		
37: Flange	*38: Flexible Coupling*	*39: Flywheel*

		
40: Fuel Pump Top Cover	*41: Gasket*	*42: Gear Ring*
		
43: Gear	*44: Gland Packing*	*45: Guide Pin*
		
46: Handle Axle	*47: Hatch Cover Packing*	*48: Helical Rotor*
		
49: Hexagon Screw	*50: Impeller Nut*	*51: Impeller*
		
52: Key	*53: Mooring Winch Drum*	*54: Needle Roller Bearing*
		
55: Nozzle Ring	*56: Nozzle Tip*	*57: Nut*
		
58: O Ring	*59: Oil Scraper Ring (Stuffing Box)*	*60: Oil Slinger*

		
61: Pintle Bush	*62: Pipe Clamp*	*63: Piston Crown*
		
64: Piston Ring	*65: Plate for Condenser*	*66: Plunger Barrel*
		
67: Polyurethane Buffer	*68: Purifier Bowl*	*69: Quick Acting Cleats*
		
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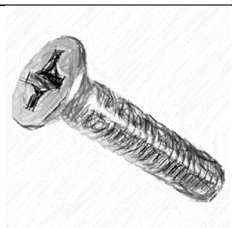
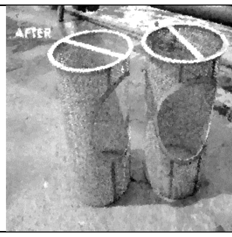
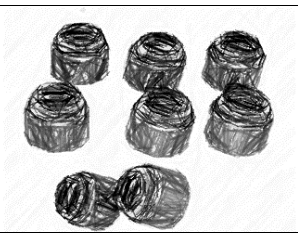
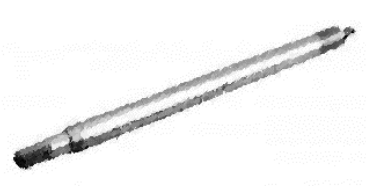
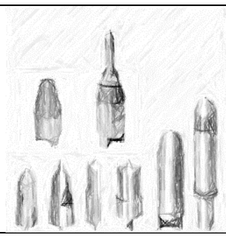
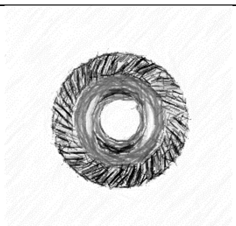
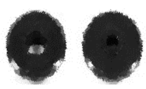
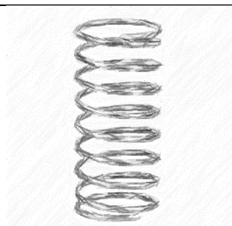
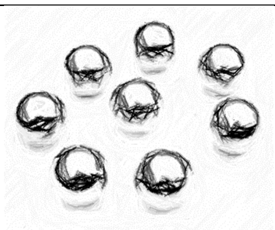
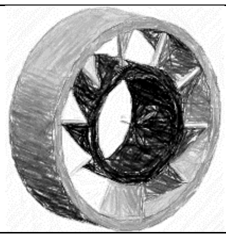
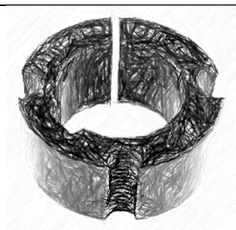
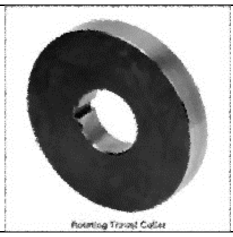
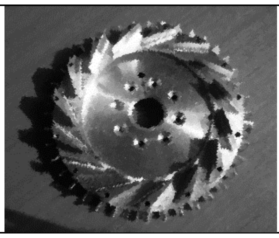
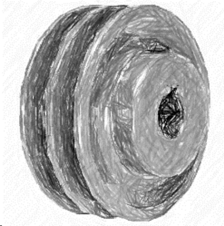
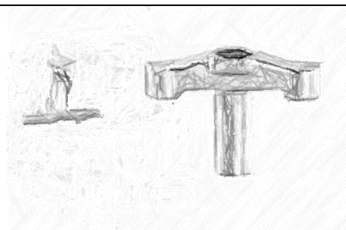
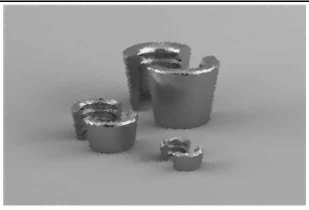
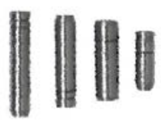
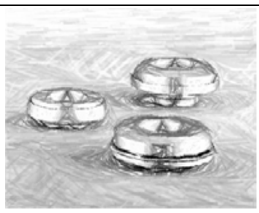
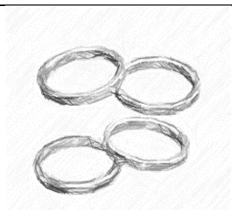
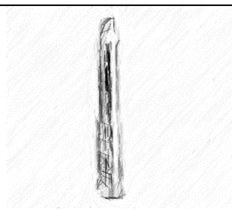
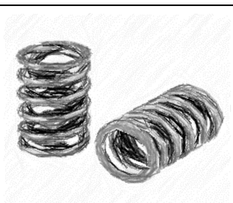
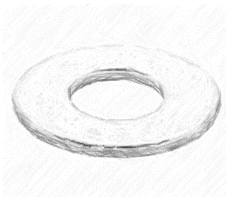
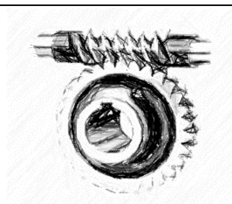
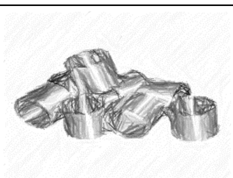
		
73: Rotary Cup	*74: Screw*	*75: Sea Chest Strainer*
		
76: Seal Valve Stem	*77: Shaft*	*78: Spindle Guide*
		
79: Spiral Gear	*80: Spring Carrier*	*81: Spring*

		
82: Steel Ball	*83: Swirler*	*84: Tapered Bush*
		
85: Thrust Collar	*86: Thrust Piece*	*87: Thrust Spindle*
		
88: Turbine Diffuser	*89: V Pulley*	*90: Valve Bridge*
		
91: Valve Cotter	*92: Valve Guide*	*93: Valve Plug*
		
94: Valve Rotator	*95: Valve Seat*	*96: Valve Spindle*
		
97: Valve Spring	*98: Washer*	*99: Worm Gear*
		
100: Wrist Pin Bushing		

6.2. CATEGORISATION OF 100 SELECTED PARTS INTO 3 CATEGORIES

Categorization of the listed 100 parts into the three following categories

(a) Highly feasible for 3D printing without class certification
(b) Highly feasible for 3D Printable with class certification
(c) Not feasible for 3D printing

In this project, the lead research team collected data from JIP partners for assessing market feasibility and commercial viability of the potential parts that could be 3D printed. Given the timeframe and scope of work, specific technical data such as material type, weight, geometry, application area, certification requirements were not easily available with the JIP partners. Hence project team made some assumptions and categorised shortlisted parts into above mentioned 3 categories as shown in Table 5. Additionally, the verification and validity of accuracy of these parts cannot be established without specifically identifying the application area and with exact verification of technical details.

Therefore, categorisation of parts specified in the table 5 is made with assumptions and limitations described below and any interpretation of this data for classification shall be exercised with caution.

Assumptions and limitations:

1. Parts listed under 'Highly feasible for 3D printing with class certification' are assumed to be used in components that are critical areas for ship safety hence are subjected to class certification such as main and auxiliary engine etc.
2. Parts listed under 'Highly feasible for 3D printing without class certification' are assumed to be used in components that are not critical for ship safety hence are not subjected to class certification. However, some of these parts may be used in components that are subjected to class certification.
3. Parts listed under 'Not feasible for 3D printing' are selected based on AM benefits score given by the project lead research team based on our professional judgement. Not highly feasible may be interpreted as either commercially or technically not suitable due to various reasons such as shape, weight or material type.

Table 5: Categorisation of 100 selected parts into 3 categories

Highly feasible for 3D printing without class certification	Highly feasible for 3D Printable with class certification	Not highly feasible for 3D printing
Bearing shell	Air compressor elbow	Angular ball bearing
Compressor housing	Anti-polishing ring	Anode
Fuel pump top cover	Banjo plug	Band brake lining
Plate for condenser/evaporator	Bearing bush	Bearing housing
Shaft	Bearing cover	Bolt reamer
Turbine diffuser	Bleed screw	Compressed sealing ring
Valve plug	Bursting disc	Compressor driving pulley
Bearing nut	Connecting rod	Coned disc spring
Blade (air compressor)	Cooling water jacket	Crane shackle
Claw clutch	Crank pin	Dowel pin
Clutch shoe	Drive pinion	Fairlead
Connection nipple	Flange	Gasket
Coupling	Flexible coupling	Gear ring
Cylinder liner	Gear	Gland packing
Damper ring	Guide pin	Hexagon screw
Expansion joint	Handle axle	Impeller nut
Flywheel	Hatch cover packing	Key
Helical rotor	Impeller	Mooring winch drum
Nozzle ring	Needle roller bearing	Oil scraper ring (stuffing box)
Piston ring	Nozzle tip	Pipe clamp
Plunger barrel	O ring	Piston crown
Rocker arm bracket	Oil slinger	Purifier bowl
Roller guide housing	Pintle bush	Screw
Rotary cup	Polyurethane buffer	Spring
Spindle guide	Quick acting cleats	Steel ball
Tapered bush	Retainer ring	V pulley
Thrust collar	Sea chest strainer	Valve spring
Thrust piece	Seal valve stem	Filter cartridge
Valve guide	Spiral gear	
Valve seat	Spring carrier	
Valve spindle	Swirler	
Worm gear	Thrust spindle	
Nut	Valve bridge	
	Valve cotter	
	Washer	
	Wrist pin bushing	
	Cylinder cover	
	Disc valve	
	Valve rotator	

7. SUMMARY AND RECOMMENDATIONS

7.1. SUMMARY

The project consortium team conducted a 'Market Feasibility Study' through workshops, interviews and surveys with participating shipping lines and ship management companies and established the commercial viability of AM for selected marine parts. This report was based on the extensive list of parts most commonly ordered by shipping lines and ship management companies when ships call at the Port of Singapore.

The comprehensive data of spare parts ordered by JIP partners consists of approximately 600,000 parts within last 3 years period was analysed using various iterative methodologies by taking into consideration of various commercial drivers such as the value proposition, frequency of demand, inventory portfolio and supply chain considerations of each part being studied. As a result, a list of 100 parts was shortlisted for further analysis. The list of 100 parts was analysed based on current market commercial drivers such as price, lead time and quantity ordered, and ranked the parts based on a derived relative weighted score. An assessment methodology based on the project lead researcher's AM expertise and professional judgement was used to establish an estimated weight score to rank each part in the 100 parts list for their feasibility level for 3D printability.

Categorisation of shortlisted parts into 3 categories (a) Highly feasible for 3D printing without class certification (b) Highly feasible for 3D Printable with class certification (c) Not feasible for 3D printing was made based on the analysis results and also by class rules knowledge of the project lead researcher team. Some specific technical data such as material type, weight, geometry, application area, certification requirements were not available from the JIP partners. Hence, the project team made some assumptions and categorised shortlisted parts into the above mentioned 3 categories. Additionally, the verification and accuracy validity of these parts cannot be established without specifically identifying the application area or exact verification of technical details. Therefore, utilising the parts categorisation list for classification purpose shall require further evaluation in in subsequent R&D efforts.

The research work carried out in this market feasibility study is summarised into this report, and also highlighted key challenges and opportunities in deploying AM for these marine parts as well as summary and recommendations for further work.

Finally, the limited scope of this research was conducted in a 6 months period, which is not proportionate to the size and significance of the maritime industry from an economic perspective. However, it provides clear direction for further research to build upon. The comprehensive list of 100 parts derived in this study can certainly provide a good starting point for both maritime industry stakeholders as well as AM suppliers to further explore the AM technology for the supply of on-demand spare parts.

In addition, while the focus of this research is on Singapore's context, other countries could work with Singapore to extend the reach of the study, which is limited to Singapore context and to the maritime industry that is relevant to JIP partners. Even though six months of research is an extensive period of time and information from literature, interviews, and public documents are gathered, it still is a relatively short period. To really study and understand the possible implications of additive manufacturing more time needs to be spent by researchers which embody quantitative research. A large amount of quantitative information means that more professionals are being reached which enables the gathering of statistical and empirical results. From this large database, it is easier to derive analytical findings. This is however only feasible when more organisations and individuals are aware of the technology, potential, and possible implications.

7.2. RECOMMENDATIONS FOR ENCOURAGING FUTURE ADOPTION

Maritime assets are capital intensive and downtime has financial consequences, but the industry is traditionally conservative in technological adoption due to its size and various regulations. In the recent past, the shipping industry is welcoming new technology with open arms. As a result, Additive Manufacturing (AM) is gaining increasing interest in the maritime industry due to the technology's ability to reduce lead time in parts supply, and to store digital version of spare parts and reproduce obsoleted parts more cost-effectively, etc. The industry gains new capabilities to make in-situ repairs, print tools and spare parts where and when they are needed, which means carrying fewer spares and, ultimately, transforming the maritime maintenance and logistics supply chain.

However, the decision-making of using 3D printing as a way to enhance current processes and service delivery is likely to be positive only when there is a significant return on investment. Before AM technology becomes viable, management is likely to calculate the total cost of ownership. Maritime organisations may want to wait and see what extent the technology is viable for operational purposes. Alternatively, maritime companies can also choose to work with AM service providers.

From the technological point of view, as a relatively new technology, there are limits as to how much 3D printing can actually cater to the maritime industry. There are many unknowns, including how to license products from suppliers. Considering the amount of investment and accelerated development going into additive manufacturing technology, it is not going to be long before the limitations are worked out and printers installed on ships or in ports could make manufacturing parts a normal, everyday occurrence. It is the future, and the opportunities are endless. To maintain as the current market leader, it is now very crucial for Singapore's maritime industry stakeholders to take lead for more widespread adoption of the additive manufacturing technology and encourage as many maritime players as possible to adopt AM to optimise their spare parts supply. The best way forward in the development of AM in Maritime is collaboration across the ecosystem.

AM technology can definitely make maritime organisations and their supply chain more effective and productive, but only when the people within these organisations actually use the new technology. End-user adoption is not only achieved by technology readiness or training users on how to use the new technology, but also by gaining buy-in and commitment, implementing new technology, and disrupting the daily routine of users. If these are not addressed, it could lead to frustration and resistance by the key stakeholders.

Recommended activities for further work in the near future to accelerate the adoption of AM in maritime in Singapore are:

1. Create AM strategy roadmap for Singapore Maritime and unlock the opportunities by launching strategic collaborative projects.
2. Offer dedicated support to overcome technical and regulatory challenges.
3. Provide financial and regulatory incentives to encourage adoption.

8. ACKNOWLEDGEMENTS

This project has been co-funded by MPA and DNV GL as part of the Maritime Innovation and Technology (MINT) Fund. We are also thankful to SSA (Singapore Shipping Association) and NAMIC (The National Additive Manufacturing Innovation Cluster) for their inputs, without which this study would not have been possible.

We also gratefully acknowledge and thank SSA participants from each organisation for their in-kind contribution of resources and sharing data during the execution of this project. We sincerely thank our management for the extraordinary cooperation and funding the project with in-kind contribution.

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APPENDIX A: PROFILE OF JIP STAKEHOLDERS PARTNERS AND COLLABORATORS

A1 PROFILE OF JIP STAKEHOLDERS PARTNERS AND COLLABORATORS

A1.1 Maritime Port Authority (MPA)

The Maritime and Port Authority of Singapore (MPA) was established on 2 February 1996, with the mission to develop Singapore as a premier global hub port and international maritime centre (IMC) and to advance and safeguard Singapore's strategic maritime interests. MPA is the driving force behind Singapore's port and maritime development, taking on the roles of Port Authority, Port Regulator, Port Planner, IMC Champion, and National Maritime Representative. MPA partners the industry and other agencies to enhance safety, security and environmental protection in our port waters, facilitate port operations and growth, expand the cluster of maritime ancillary services, and promote maritime R&D and manpower development.

A2.1 Singapore Shipping Association (SSA)

The Singapore Shipping Association (SSA) represents a wide spectrum of shipping companies and other businesses allied to the shipping industry. It is a national trade association formed in 1985 to serve and promote the interests of its partners and to enhance the competitiveness of Singapore as an International Maritime Centre. The SSA engages and collaborate with the shipping industry key stakeholder and is a trusted advisor and partner to related government agencies. The SSA also plays an active role in promoting the interests of shipping in Singapore and internationally. Today, the SSA represents over 460-member companies; comprising ship owners and operators, ship managers, ship agents and other ancillary companies such as shipbrokers, classification societies, marine insurers, bunker suppliers, maritime lawyers, and shipping bankers amongst others

A3.1 National Additive Manufacturing Innovation Cluster (NAMIC)

The National Additive Manufacturing Innovation Cluster (NAMIC), led by NTUitive, was launched in October 2015 to address the challenges, and accelerate Singapore's industrial adoption of additive manufacturing. It identifies and nurtures promising AM technologies and start-ups, jumpstarts public-private cross-collaborations, acting as a connector between industry, research performers and public agencies. NAMIC also assists companies seeking to lower the barriers towards AM adoption through joint project funding and leveraging on its investor networks

A4.1 DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organisations to advance the safety and sustainability of their business. We provide classification, technical assurance, software, and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.

A5.1 ANGLO-EASTERN

Anglo-Eastern is a leading global provider of ship management services where they have been working with shipowners and their clients for over 40 years, driven by their passion for ships. They are committed and engage in all areas of ship management, crew management and technical services for all types and sizes of ships. Anglo-Eastern operates all around the world, with their head office in Hong Kong and over 25 office locations in Asia-Pacific, Europe and the Americas. They want to create a positive impact on the communities, and they do this by doing the right things the right way, and by remaining true to themselves – genuine, spirited, practical and empathetic.

A6.1 BERNHARD SCHULTE SHIPMANGEMENT (BSM)

Bernhard Schulte Shipmanagement (BSM) is an integrated maritime solutions leader, with a strong heritage spanning more than 135 years in the shipping industry and trusted as a partner by responsible and demanding customers worldwide. Managing a fleet of around 600 vessels, 20,000 employees enable the delivery of safe, reliable, and efficient ship management services through a network of 9 ship management, 24 crew service and 6 wholly-owned maritime training centers across the world. Alongside comprehensive ship management services, BSM offers a suite of complementary maritime solutions that are customized to meet individual customer requirements.

A7.1 CMA CGM Group

CMA CGM Group provides a seamless shipping experience to its clients by leveraging on its global expertise in maritime transport and logistics. Combining efficiency, reliability and a global network of experts and agencies, CMA CGM Group offers unique cargo solutions to business needs. Present in over 160 countries through 755 agencies, 750 warehouses, and 110,000 employees and a diverse fleet of 509 vessels. CMA CGM serves 420 of the world's 521 commercial ports and operates on more than 200 shipping lines.

A8.1 EASTERN PACIFIC

Eastern Pacific is a world-leading ship management company. They are committed to providing the best customer service while maintaining the highest standards of safety for their crew, environment, cargo, and ships. Their mission is to be the safe and efficient transportation provider of choice to the maritime industry.

A9.1 IVALDI GROUP

Ivaldi Group offers Parts Replacement as a Service (PRaaS), delivering secure, scalable and cost-effective digitized inventory and on-site production solutions. Working with leading partners across maritime, offshore and the construction industries, the Ivaldi PRaaS Solution reduces inventory, warehousing needs, delivery times and cost of logistics by allowing organisations to send files, not parts.

A10.1 OSM MARINE

OSM Maritime Group is the leading provider of full-service solutions to the Offshore and Maritime Industry. OSM Maritime Group brings over 25 years of experience in the Maritime Industry, more than 11,000 employees, 30 office locations, 500 vessels under management. With a global footprint, OSM Maritime Group offers flexibility and opportunity for clients to expand their presence in new regions and the peace of mind that comes with efficient and transparent management systems that always keep them informed.

A11.1 PACIFIC INTERNATIONAL LINES (PIL)

Incorporated since 1967 and has its origin in a newly independent Singapore, PIL has grown to become one of the largest ship-owners in Southeast Asia. PIL operates a range of businesses spanning from its core business in container shipping to container manufacturing and other logistics-related services globally and employs about 18,000 employees worldwide.

A12.1 SPAREPARTS3D

Spare Parts 3D supports manufacturers and industrial spare parts users to increase the availability of their spare by producing them on-demand using Additive Manufacturing. They digitize spare parts inventory and enable them to produce them anywhere, anytime, in the shortest delay, leveraging on their worldwide network of 3D printers. The technology drastically cuts warehousing costs and shortens the supply chain. Additive manufacturing can produce on-demand and locally, and they believe it is a game-changer for the industry.

A13.1 THOME GROUP

Thome Group is a dynamic provider of integrated services to the international shipping and offshore industries. With more than half a century of experience, the Thome Group represents a unique combination of the best elements of Scandinavian shipping tradition with the modern drive of Asian business enterprise, offering a wide range of maritime services available under one 'Thome Roof'. From ship management to offshore structure management; crewing and training; Thome offers a complete range of products and services essential in managing a wide range of marine assets worldwide.

A14.1 WARTSILA

Wartsila is a global leader in smart technologies and complete lifecycle solutions for the marine and energy markets. By emphasizing sustainable innovation, total efficiency and data analytics, Wartsila maximizes the environmental and economic performance of the vessels and power plants of its customers.

A15.1 WILHELMSEN

Wilhelmsen is a global maritime industry group that has a presence in 2200 locations worldwide. Driven by innovation, expertise, quality products and services, they can meet the challenges and needs of the world's global fleet. Wilhelmsen provides shipping services ranging from Ships Service, Ship Management to Insurance Services, Maritime Trainings, Car and ro-ro and Governmental Services.

A16.1 SEMBCORP MARINE

Sembcorp Marine provides innovative engineering solutions to the global offshore, marine and energy industries. Drawing upon more than 50 years of track record and an extensive network of facilities and expertise, the Group focuses on four key capabilities, namely, Rigs & Floaters; Repairs & Upgrades; Offshore Platforms and Specialised Shipbuilding. Operating shipyards strategically located in Singapore, Indonesia, the United Kingdom and Brazil. Its customers include major oil companies, drilling contractors, shipping companies as well as owners and operators of floating production units.

A17.1 SYNERGY MARINE

The Synergy Group, with over a decade of experience as a leading ship manager, offers end-to-end maritime solutions and services tailored to the specific requirements of clients. In-depth technical expertise and a diverse product portfolio enable Synergy to generate efficiency and productivity gains to enhance the customer experience for all clients. Headquartered in the globally connected city-state of Singapore, Synergy has 13 offices located in seven key maritime centres. With over 270 vessels from a diverse range of vessels under their management.

A18.1 ZEABORN

ZEABORN Group was founded in 2013 as a global, integrated shipping company that provides service along the entire value-added chain and caters for capital market requirements. Till date, it is already managing the fifth-largest fleet worldwide. ZEABORN Group has 4 main businesses consisting of Tramp Services, Liner Services, Shipmanagement and Ship owning.

APPENDIX B: EXAMPLE USER CASES FROM IVALDI DEMONSTRATING COMMERCIAL VIABILITY OF AM FOR MARINE SPARES

Utilizing nearly three years of in-depth market research, Ivaldi (one of the JIP collaborators) has developed a proprietary digitalisation methodology making AM economically viable for the maritime industry. Wilhelmsen Ship Services(WSS) is using their own facility located in the Port of Singapore to make on-demand AM parts and delivered the parts to various WSS customers, providing significant cost and time savings.

The following case-studies have been highlighted for reference purposes.

Cast-Iron Handwheel:

Traditional cast-iron handwheels often damage vessel valve stems. Damaged valve stems lead to costly equipment replacement and delays. Ivaldi utilized AM proprietary technologies to replace cast-iron production material with polyamide and nylon. Polymer handwheels prevent damage to valve stems caused by traditional cast-iron handwheels, minimizing the costly and labour-intensive replacement. Polymer handwheels manufactured at the WSS Singapore LMC are helping vessel managers avoid these unnecessary expenses.

Guide Bar:

AM technologies help maritime companies reduce longtail costs. At the request of a maritime customer, Ivaldi manufactured a stainless steel guide bar. Traditional procurement processes took up to 12 weeks and had an average cost of $2000.00 USD. Replacement guide bars are not mass produced, so procurement is timely and expensive. Manufacturing and delivery using the Ivaldi platform cost $1250.00 USD and was completed in less than 72 hours. This is an approximate 38% cost savings to the end-user.

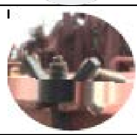
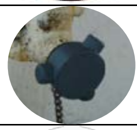
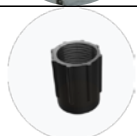
Engine Holding Bolt Cover:

Vessel visits conducted by the Ivaldi team allowed for the discovery of polymer cylinder caps used to cover engine bolts used in the engine room. These bolt covers damage easily and require frequent replacement. The team came across multiple vessels with the same issue. At the request of crew members, Ivaldi engineers redesigned the bolt covers to include threading to help hold the covers in place. This allowed the crew members to cut down on replacement costs of additional bolt covers.

Scupper Plugs

AM and Ivaldi technology allow for the creation of multi-component parts, such as the scupper plugs, at a competitive price and delivery speed. The Ivaldi platform gives end-users access to individual component pieces not readily available by traditional manufacturers. Crewmembers may elect to replace individual component pieces instead of the entire scupper-plug, greatly decreasing total replacement cost.

Table D1 : Table showing an example list of various marine spare parts digitalised using additive manufacturing highlighting its associated commercial benefits.

Part name	**Original Material**	**AM material**	**AM part printing Time**	**Average price savings per part**	**AM part picture**
Handwheel	Cast iron	Polyamide/ Nylon	19 hrs	$5.89	
Scupper Plug	Brass and Rubber	Polyamide/Nylon + Thermoplastic polyurethane	17 hrs*	$4.50	
U-Bolt	Galvanised steel	Durable Resin	2 hrs	$11.26	
Guide Bar	Low alloyed Mn-V Steel	Steel	8 hrs	$ 1965.00	
Nut Wing	Brass	Carbon Fibre Nylon	5 hrs*	$2.95	
Pipe Covers / Dust Caps	Brass/ Steel	Polyamide/ Nylon	3 hrs	$3.96	
Bolt Covers	Acrylonitrile Butadiene Styrene (ABS)	Polyamide/ Nylon	19 hrs*	$10.44	

**Largest component*

About DNV GL

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