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Is It Time for the Maritime Industry to Embrace 3d Printed Spare Parts?

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ABSTRACT: New technology comes with benefits for companies that choose to adopt. Additive manufacturing (AM) or 3d printing as it is commonly known has been already implemented in various sectors (industrial and consumer products, medical, automotive, aerospace, etc.). The shipping industry is characterized as conservative to changes. As AM is starting to consolidate in the industry, can offer lessons guiding changes. Application in industries with similar to shipping characteristics (industries with moving assets), reveals the potential of applying it in the shipping industry. The availability of spare parts is important for the vessel maintenance. Additive manufacturing could shorten the space parts supply chain in the maritime industry, since the part could be made near the place it is needed.

1 INTRODUCTION

According to the Resolution MSC.192(79) "Adoption Additive manufacturing (AM) or 3d printing as it is commonly known has been already implemented in various sectors (industrial and consumer products, medical, automotive, aerospace, etc.). It is based in the principle of the construction in layers by directly converting the 3D data into physical objects. It can produce functionally integrated components (including spare parts) in a single production step, in small batches. Among the benefits of this technology is that it allows the flexible production of various items at no extra cost in terms of manufacturing. This is achieved by directly converting the 3D data into physical objects, without the need of additional tools or molds. Furthermore, the principle of the construction in layers can produce functionally integrated components in a single production step, thereby obviating the need for the assembly stage. In comparison to conventional manufacturing, it has a number of advantages in terms of better energy efficiency, cutback in emissions, better design handling and lower manufacturing lead time.

Maritime assets are capital-intensive and their out of service time has economic consequences. They usually operate away from the home base at remote locations and are on continuous move. Other sectors with similar characteristics are aircraft/aerospace, defense units, and automotive. Based on literature, we will try to explore how lessons learned from the other sectors, could be applied in shipping.

Furthermore, we conducted interviews with people working in the shipping industry, in order to get an understanding of the supply chain of the spare parts of the ships, and get an idea of how this can be changed with the introduction of additive manufacturing.

2 THE AVAILABLE TECHNOLOGY

Additive manufacturing is the official industry standard term (ASTM F2792) for all applications of the technology. It is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Figure 1. shows the principle of building the part from the basic construction unit (voxel).

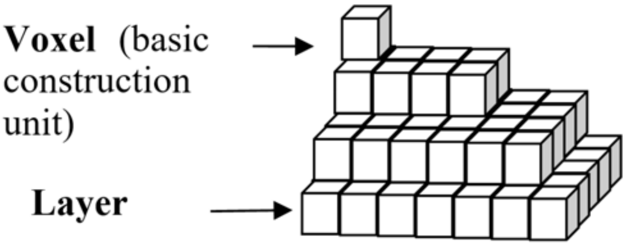

Figure 1. Building the part layer upon layer

Synonyms are additive fabrication, additive Synonyms are additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.

Under the umbrella of AM there are many processes. ASTM groups them in seven types (Piazza & Alexander, 2015): 1) Binder jetting (3D printing)– AM process where a liquid bonding agent is deposited to join powdered materials together. 2) Direct energy deposition (direct manufacturing)–AM process where thermal energy fuses or melts materials together as they are added. 3) Material extrusion (fused deposition modeling)– AM process that allows for depositing material via a nozzle. 4) Material jetting-AM process where droplets of material are deposited. 5) Powder bed fusion (laser sintering)–AM process where thermal energy fuses or melts material from a powder bed. 6) Sheet welding (e-beam welding, laminated object manufacturing)-AM process where sheets of materials are Bonded together and 7) Vat photo-polymerization (digital light processing)-AM process where liquid photopolymer in vat is cured by light.

In some processes the material is squirted, squeezed or sprayed and in others fused, bind or glued. The power source is thermal, high-powered laser beam, electron beam, ultraviolet laser, or photo curing.

All of the aforementioned techniques rely on the application of gravity to assist in the construction process. While additive manufacturing can build a wide variety of products in a controlled and static environment the use of such techniques afloat creates questions about the viability of the process. This should not eliminate AM from consideration for the marine industry. However it does seem that at this time it will be contained to construction and repair facilities or platforms with little to no relative motion (Strickland, 2016). As the technology matures solutions are found to overcome drawbacks as the aforementioned.

The raw materials for the process are: polymers, metals, ceramics, composites, and biological materials. The starting materials could be liquid, filament/paste, powder, or solid sheet. Currently, the most common metallic materials are steels (tool steel and stainless), pure titanium and titanium alloys, aluminum casting alloys, nickel-based super alloys, cobalt-chromium alloys, gold, and silver (Frazier, 2014).

3 THE GROWTH OF THE ADDITIVE MANUFACTURING INDUSTRY

According to Wohlers Report 2016, the additive manufacturing (AM) industry grew 25.9% (CAGR – Corporate Annual Growth Rate) to $5.165 billion in 2015. Frequently called 3D printing by those outside of manufacturing circles, the industry growth consists of all AM products and services worldwide.

The CAGR for the previous three years was 33.8%. Over the past 27 years, the CAGR for the industry is an impressive 26.2% (McCue, 2016).

The ARK Invest (2016) summarizes in a chart the growth projections from reputable firms.

As it can be seen in figure 2 McKensy estimates that 3D printing market could reach $180-490 by 2025. The 3D printing industry has one of the highest projections for economic growth.

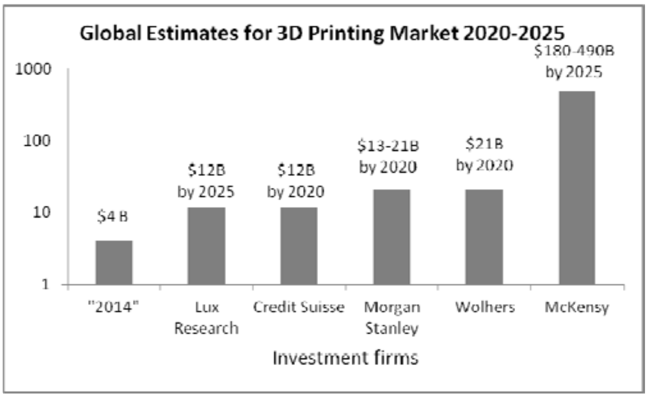

Figure 2 Global Estimates for 3D Printing Market 2020-2025 (Modified from ARK Invest, 2016)

4 IMPACT OF ADDITIVE MANUFACTURING ON PRODUCTION, SUPPLY CHAIN AND TRANSPORT

Market surveys predict that the introduction AM will have a major impact on industries and manufacturing (Weller, Kleer, & Piller 2015). The new technology eliminated stages of production (e.g. assembly) and thus simplify production line. The place of production moves closer to demand. The sale is made before the production of the product, upsetting the known production process.

The production facilities can now be located closer to the customer in Europe or North America, where it is more direct response to market needs (Manners-Bell & Lyon 2012).

The concept of constructing products in large complex facilities could become obsolete as companies adopt the more flexible model of additive manufacturing (Cottrill 2011).

3D printing is expected to have a significant impact on domestic and international freight operators, in particular regarding the reduction of the importance of some transport paths, and possibly lead to the opening of new ones. A recent analysis (Tipping, Schmahl, & Duiven 2015) for Strategy& about two dozen industry sectors, found that up to 41 percent of the air cargo business and 37 per cent of businesses container ocean carriers is at risk because of 3D printing.

Ye et al., (2015) based on a model, conclude that, in the next two decades, 3D printing is not likely to pose a threat, on the concept of significant production capacity, or reduce the transport flow, in terms of global container traffic. As the GDP of the world's population is not likely to decline over the next 50 years, world trade will probably continue to cause high demand for transport.

5 CHARACTERISTICS OF THE MARITIME SECTOR

The shipping industry is characterized as conservative to changes. As AM is starting to consolidate in industry, can offer lessons guiding changes. It is understood that any lessons learned before applied should take into account the specific characteristics of the maritime industry.

Maritime assets are capital intensive and downtime has financial consequences. Usually operate away from the base in remote areas and are in constant movement. Other sectors with similar characteristics are aircraft / aerospace, defense units and road transport. Ships are operating under random environments in isolation from repair facilities and spare parts storage.

Maintenance networks are involving many actors, such as the owners of the assets, systems integrators, original equipment manufacturers (OEM), the service providers and their logistics service providers. The International Maritime Organization and classification societies impose rules that the ships have to follow (such as periodic inspections, mandatory equipment).

The spare parts inventory planning and supply chain include decisions such as determining the appropriate spare parts procurement policies, quantification and distribution of stocks of spare parts and design of service networks, taking into account, for example, emergency transport, side transshipments and joint spare pool (Eruguz, Tan, & van Houtum 2015).

The repair can be executed and stocks of spare parts can be stored on the ship itself, ashore by asset owners, system integrators, service providers, or makers. Assets can be classified as long-lived, since they have a useful life of about 25 years.

The vessel is in an isolated environment. There are workshops on board, at least at the larger ships. Vessels are staffed by technicians, who have to solve the problems of the mechanical equipment that appear, working in harsh conditions. The environment is highly corrosive, with turbulence and vibrations.

6 LESSONS LEARNED FROM THE INTRODUCTION OF ADDITIVE MANUFACTURING IN OTHER INDUSTRIES

The published work regarding the observations from the actual implementation of additive manufacturing as it is finding its way into mainstream manufacturing industry reveals its benefits and challenges.

There are many active investments by various industries for utilization of AM parts to capitalize on the value-added properties provided by AM as shown by Seifi, Salem, Beuth, Harrysson, & Lewandowski, (2016), which highlights some industrial examples for AM parts. In particular, General Electric (GE) has received Federal Aviation Administration (FAA) certification for fuel nozzle implementation in the GE LEAP engine. In this case, AM reduced the total part count and replaced more complex brazing of multiple components to create a lighter, simpler, and more durable product.

Compared to conventional manufacturing, it has a number of advantages in terms of better energy efficiency, cutback in emissions, better design handling and lower manufacturing lead time.

Mokasdar's work (2012) evaluated additive manufacturing impact on the aircraft spare parts supply chain. Conversely, the manufacturing lead time is small compared to these conventional processes, and hence the author with his work tries to advocate this feature of additive manufacturing to demonstrate how the total inventory of spare parts held in an aircraft spare parts supply chain, can be significantly reduced using additive manufacturing.

Other authors (Liu, Huang, Mokasdar, Zhou, & Hou, 2014) studied the impact of AM in the aircraft spare parts industry, with an emphasis on the use of distributed manufacturing strategy to reduce inventory cost. They concluded that on-demand and centralized production of spare parts is most likely to succeed.

The feasibility of localized manufacturing is also explored by Khajavi, Partanen, & Holmström, (2014), who studied the fabrication of spare parts through a quantitative cost-based assessment. It was demonstrated that currently AM is both capital and labor intensive, making centralized production preferable on financial measures.

Eyers & Potter, (2015) suggest that, it is necessary to bridge research in e-commerce, AM, and supply chain management. In order to understand better the way in which eCAM may be applied in the supply chain, Their research based on the interviews with localized manufacturers of aerospace spare parts is suggesting that costs of machines and operators, together with issues regarding quality assurance and material supply chain co-ordination would further consideration before wide-scale adoption of this eCAM model, for cost reductions and increased efficiency that may not automatically follow.

In a project (Sterkman, 2015) focused on the impact that Additive Manufacturing can have on the after sales services supply chains in the aerospace industry the conclusion was that at this moment, AM can better be outsourced. This is more favorable because: AM machines are still expensive, low utilization cannot justify these investment costs, rapid technology developments are expected and there will be need for specialized personnel.

The most important goal in the defense is to secure the supply of spare parts, followed by respectively improving service and reducing costs as Balistreri, (2015) states.

Augustsson & Becevic, (2015) investigated the inventory costs for low turnover spare parts for a truck manufacturer. They concluded that costs can be lowered, but still offer the same availability by using additive manufacturing in the automotive industry. This could implicate that the main benefit of using additive manufacturing is a big increase in customer service. Daimler, which owns the Mercedes-Benz brand, and has more than 100,000 printed prototype parts, and according to Reuters(Taylor & Cremer, 2016) it will expand production using 3D printing methods.

Abbink, Karsten, & Basten, (2015) based on modeling choices, concludes that AM is typically not beneficial for low demand, single-item situations. This is the case for both in-house printing, as well as outsourced printing. For a multi-item situation however, where the printer is sufficiently utilized, AM can be cheaper than traditional means of manufacturing.

Table 1. Lessons learned from other industries

Automotive (truck manufacturer)
The inventory costs for low turnover spare parts can be lowered. Increase in customer service (Augustsson & Becevic2015).
Spare parts for capital goods
AM is typically not beneficial for low demand, single-item situations (Abbink, 2015).
Aircraft spare parts industry
Centralized production of spare parts is most likely to succeed (Liu, et al., 2014)
Aerospace industry
Better to outsource AM (Sterkman, 2015)
Aeronautics industry
Centralized production preferable on financial measures (Khajavi et al., 2014)
Aircraft companies and operators
The total inventory of spare part can be significantly be reduced using additive manufacturing (Mokasdar, 2012)
Aerospace
The use of e-commerce with AM has often been oversimplified (Eyers & Potter, 2015)
Defense
The most important goal is to secure the supply of spare parts, followed by respectively improving service and reducing costs (Balistreri, 2015).

Summing up the literature review of actual case studies one can conclude that additive manufacturing is a promising technology. The inventory costs for low turnover spare parts can be lowered and at the same time increase in customer service. AM could be beneficial for low demand, single-item situations, if it is difficult to make it otherwise. The centralized production of spare parts is most likely to succeed. That is also preferable on financial measures. The total inventory of spare part can be significantly reduced using additive manufacturing. The most important goal is to secure the supply of spare parts, followed by respectively improving service and reducing costs.

7 ADDITIVE MANUFACTURING IN/AND THE MARITIME INDUSTRY

Maritime will not be left out of technological developments on the information technology. Although there are only few published case studies of application in real situations, there are initiatives in place. Apart from general prototyping applications, there are about parts maker tests and application in ships, both in the defense sector, and the commercial.

A pilot project '3D Printing Marine Spares', (2016) was initiated by Innovation Quarter, the Port of Rotterdam Authority and RDM Makerspace with the participation of 28 businesses and agencies. The consortium partners selected and redesigned parts, had them printed and tested the results. Making use of three different production processes, the advantages of the various methods for additive manufacturing and the maturity of the technology was experienced. Thus the project brought a wealth of information on the current and near future state of 3D printing as an alternative method for producing maritime parts. The conclusion was that 3D printing indeed holds promises for a number of parts, and that product requirements can be met in a number of cases. Also the business case can be positive, especially when time to market is essential. On the other hand the findings also indicate that extra work needs to be done to get regulations adjusted to be able to qualify 3D printed parts (Zanardini, Bacchetti, Zanoni, & Ashourpour, 2016).

Following a rigorous testing process, verified by Bureau Veritas, the world's first class approved 3D printed ship's propeller, the WAAMpeller (2017), has been unveiled at Damen Shipyard Group's headquarters in the Netherlands. This ground-breaking success is the result of a close collaboration between RAMLAB, Promarin, Autodesk, Bureau Veritas and Damen.

Green Ship of the Future (2016) and 20+ industry partners have explored the opportunity space of 3D printing and additive manufacturing, in order to assess and comprehend the potential of the technology and derived opportunities for the maritime industry. They end up with the need to explore how shipping and the maritime industry can be on the forefront of development and be part of the disruption.

US Navy has already tested the technology for maintenance activities (Scheck et al., 2016). The maintenance has given the Navy the time needed to permanently install, and test out a 3D printer on board. In the meantime, the crewmembers on board the ship have been busy printing out anything from plastic syringes, to oil tank caps, to model planes used for the mock-up of the flight deck. The US Navy argues that they are still several years away from being able to print out actual spare parts for aircraft or the ship itself, but it is certainly a good starting point. The reason why AM technologies are under evaluation is the possibility to reduce the time to supply spare parts and components to remote zone, eliminating unnecessary actors and lead time.

One of the world's largest container shipping companies, Maersk, explored 3D printing as a way to fabricate spare parts on container ships. In June 2015, the company revealed that will install 3D printers on board. The printers were capable of printing a small amount of components, according to the materials used, ABS thermoplastics. However, the company considers the possible utilization of powder based metal laser sintering printers in order to enhance the range of printed components. The main advantage is related to the possibility to immediately repair broken components, instead to be supplied with a spare part when the vessel is moored in a port (Zanardini et al., 2016). However, official information of results has not been published yet.

Published maritime cases are rare, since most examples come from the air industry. The pilot project '3D Printing Marine Spares', (2016) culminated in the printing practical appliance of seven maritime parts: a propeller, cooled valve seat, spacer ring, hinge, T-connector, seal jig and manifold. Tru-Marine (Loke, D. W. S., 2014), has developed a proprietary AM process. AM is used in actual industry level for the repair of turbocharger nozzle rings.

Wilhelmsen has partnered with Ivaldi Group to deploy additive manufacturing, starting in a facility in Singapore. The local micro factory capable of on-demand production provides 3D printed parts to select partners as part of their early adopters program (Griffiths, L. 2018).

8 PORTS AS ADDITIVE MANUFACTURING HUBS

It is common knowledge that ship relay for certain maintenance works while at port. Also they receive the needed spare parts at / or near the port. That is why there are many workshops and spare part warehouses near the ports. One of the benefits of AM is to produce the part by the end user at the place it is needed, the time it is needed, avoiding the part inventory. Obviously the best place is onboard. But there are some obstacle to that choice. One obstacle is the vessel environment (constant vibrations). So the next best place it is near the port.

9 THE SPARE PARTS SUPPLY CHAIN IN THE MARITIME INDUSTRY

Maritime industry is characterized by heavy utilization of equipment and machinery and by really specific operating conditions. Ships work in a very unique operational context, and that makes the requirements of reliability and safety particularly critical (Nenni & Schiraldi, 2013).

The type and quantity of the spare parts that must be on board a ship is imposed by the authorities for its safety, or suggested by the original equipment manufacturer (OEM) in order to avoid unexpected breakdowns and ship downtime, or even by experience.

Spare parts inventory is necessary, but it costs (mainly in capital, and in some cases in available space). Various optimization techniques are used. Nenni & Schiraldi, (2013) propose an approach to calculate the optimum level of inventory for spare parts of ship equipment. Eruguz, Tan, & van Houtum, (2015) consider an integrated maintenance and spare part optimization problem for a single critical component of a moving asset for which the degradation level is observable.

We conducted interviews (semi structured) with people working in the maritime industry, in order to get an understanding of the supply chain of the spare parts of the ships, and get an idea of how this can be changed with the introduction of additive manufacturing.

The need for a replacement may occur either because the predetermined stock has fallen below the threshold, or before a predetermined maintenance or because of an extraordinary damage. If the replacement is not in stock at the ship, then a request is send to the land office (usually by the chief engineer). In the land office, after approval from the technical department, the request passes it to the procurement department.

The purchasing process is pretty much typical (Purchase Order, Request Quotations, Receive Quotations, Select the supplier, Order, Receive order, Invoice).

In this simplified diagram (fig. 3), one must note that the ship is away from the base and changes location. The spare must be timely delivered at the next port that the ship will reach. There is also an option to purchase an imitation of the spare part, or order it at a local workshop. If the requested spare part is out of stock in the chosen supplier's inventory, that must be requested from the regional warehouse, the peripheral warehouse, or finally at the OEM. If it is out of stock at the OEM, then it will be manufactured (as soon as there is economic batch).

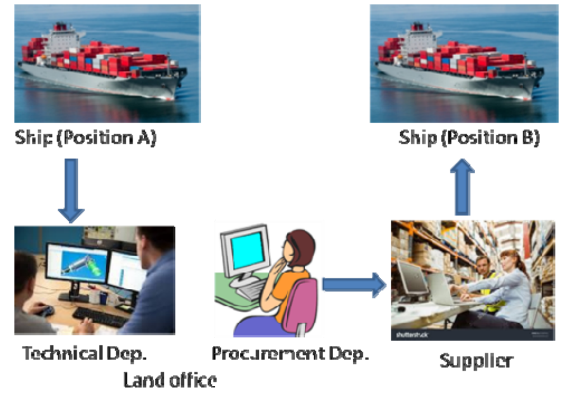

Figure 3. The purchasing process.

Most of the people we talked had an idea of what 3D printing is (we did not ask about AM). Almost all had a positive attitude for the new technology and the rest were skeptical, but not negative. Their main concern was if the spare part made by the AM is comparable with the part made by the traditional method. Another concern was the cost of the AM machine, and the cost to build the part.

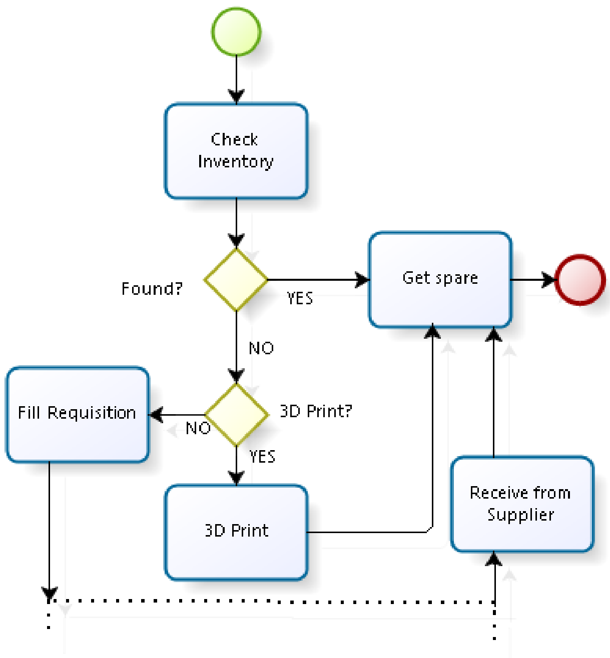

Figure 4. 3D printing decision

10 A FUTURE SCENARIO

In a future scenario the needed spare part could be made by the end user at the place it is needed, the time it is needed, avoiding the part inventory. What one would need is the proper machine, a file with the information to instruct the machine, and the raw material. With the push of a button the machine will start to make the part. The decisions that must be made are (fig. 4): 1) are the needed (machine, file, and raw material) available? 2) Is it more economic to make than buying the part?

In every place that is kept inventory (fig. 5) of spare parts to meet the part demand (on board the ship, at the supplier, the local, the regional, the central warehouse or the OEM), the AM process could take its place, in order to get the new technology benefits.

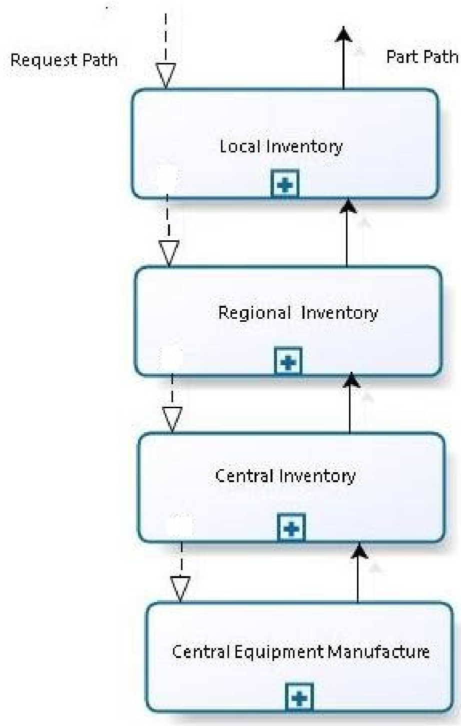

Figure 5. Places where that inventory is kept.

Paradigms show that it can be done today (sections 6 &8). But there are challenges pointed out in the literature, and by the people we interviewed.

11 DISCUSSION

It is enraging that most of the people we interviewed had an idea of what 3D printing is, and almost all had a positive attitude although skeptical.

Their concern if the spare part made by the AM is comparable with the part made by the traditional method could be overcome by the development of standard methods to test processes and parts (Monzón, Ortega, Martínez, & Ortega, 2014). For the time been there are standards to test the row materials, and the parts could be tested with the ways the conventional parts are tested.

As far as the cost is concerned, as the market advances, patents expire, and demand grows, the machine cost as well as the production cost will fall.

Obviously there are more issues to be phased. As it was mentioned in section 2, there are too many AM processes available. Which of the processes best suits the installation on board a ship? How will the intellectual rights be protected? How the required files will be distributed? Where in the supply chain is optimum to have the AM of the parts? How will the personnel be trained in the new technology, taking into consideration that the salesman at the supplier will be made manufacturer.

12 CONCLUSIONS

Among the benefits of AM is the flexible production of customized products, in small batches. The direct transformation of the three-dimensional data stored in a file, simply by supplying the raw materials to the machine and the production of natural objects, obviating the need for the assembly step can be applied to the manufacture of spare parts. The consequence will be change in the supply chain. This will ensure the supply of spare parts, with consequent improvement in the provided services and cost reduction.

The case studies of AM implementation, in industries with similar to maritime characteristics, have to offer several lessons. The cost of inventories for low use parts can be reduced while improving customer service time. When the printer is utilized sufficiently, the AM may be cheaper than the production applying traditional means. The AM could be beneficial for low demand situations of individual parts, if it is difficult to manufacture them otherwise. The central production of parts is more likely to succeed. This is also preferable in economic basis. The total stock of spare parts can be greatly reduced by the use of AM. The most important goal is to ensure the supply of spare parts, followed by an improvement in services and cost reductions.

As far as people we interviewed are concerned, AM is a promising technology and it should be seriously taken into account by the maritime industry.

Forthcoming standards will assure that there will be methods to ensure processes and test parts. The more the market advances, the patents expire, and the demand grows, the more the machine cost as well as the production cost will fall. The maritime industry can learn from other industries that already adapted AM in one way or the other, but further study that will take into consideration the special characteristics, is needed.

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