Securing a port's future through Circular Economy: Experiences from the port of Gävle in contributing to sustainability

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Abstract:

Ports are an important player in the world, due to their role in global production and distributions systems. They are major intermodal transport hubs, linking the sea to the land. For all ports, a key requirement for commercial and economic viability is to retain ships using them and to remain accessible to those ships. Ports need to find approaches to help them remain open. They must ensure their continued economic viability. At the same time, they face increasing pressure to become more environmentally and socially conscious. This paper examines the approach taken by the Port of Gävle, Sweden, which used contaminated dredged materials to create new land using principles of Circular Economy. The paper illustrates that using Circular Economy principles can be a viable way in securing a port's future and contributing to its sustainability, and that of the city/region where it operates.

Keywords: sustainability in ports; circular economy; dredging; quay construction; Port of Gävle, Sweden

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Dr. Angela Carpenter and Prof. Rodrigo Lozano carried out the literature review and discussed the structure and logical flow of the paper. Linda Astner provided the data of the case study. Dr. Kaisu Sammalisto checked for consistency in the writing and the details. All the authors discussed the paper and provided insights for it.

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1 INTRODUCTION

Ports are an important player in the world, due to their role in global production and distribution systems, by trading over 10.3 billion metric tons annually (UNCTAD, 2017). Globally, in 2012, 36 out of the 50 most competitive cities were port cities, while of the top 20 cities ranked according to Human Capital Indicators, 14 are port cities (Girard, 2013). More than 75% of Europe's external trade and 37% of internal trade is seaborne. Ports in European Union (EU) Member States play a vital role in the movement of goods and passengers both within the EU and globally, with more than 90% of goods imported into the EU entering through such ports (Saxe & Larsen, 2004). Port are major intermodal transport hubs (Wakeman, 1996) and are gateways between the sea and land through transporting goods and people. They are, generally, man-made locations where ships can take shelter in rough weather. Port activities frequently dominate local and regional economies, providing a source of economic wellbeing and instilling a sense of place and identity for local and wider communities (Pinder, 2003).

Ports differ widely in terms of size (from very large container ports to very small fishing ports), in ownership (including publicly owned and operated, privately owned and operated, and charitable trust ports, for example), and in the wide range activities that take place in them (e.g. unloading/loading of cargo, cruise ship or passenger ferry terminals, oil terminals) (Bichou and Gray, 2005).

For all ports, a key requirement for commercial and economic viability is to retain the business of the ships using them and to remain accessible to those ships. With the growth in ship sizes, many industrial ports have been unable to continue to operate without significant investment in dredging channels, improved transport links, and new cranes. Ports must ensure their continued economic viability through safe and successful commercial operations (Wooldridge, et al., 1999). In addition, ports are under increasing pressure to become more environmentally and socially conscious (ESPO, 2010; Dinwoodie, et al., 2012; Hall, 2007; Wooldridge, et al., 1999), A myriad of environmental impacts of port related industrial activities have long been recognized (releases to water, air and soil, waste production, noise, and dredging) (Carpenter & Macgill, 2003; Dinwoodie, et al., 2012; Hall, 2007; Wooldridge, et. al., 1999), as well as social issues including loss of jobs (Wooldridge, et al., 1999). These phenomena have forced ports to comply with ever stricter regulatory requirements for environmental protection, and they are increasingly being held responsible for their sustainability performance to ensure community support. These developments pose great challenges to ports' current business models and their competitive advantage. With ports facing challenges to find new ways to use their assets, for example their waterfront zones, as efficiently and productively as possible in economic, environmental, and social terms (Daamen and Vries (2013), including legal, organisational, and technical (Dinwoodie, et al., 2012; Wooldridge, et al., 1999).

Many challenges are facing the port industry globally including: the need to accommodate very large ships; competition from new ports; environmental issues such as air, land and water pollution from ships; and transport bottlenecks for the movement of goods, raw materials and people between the land

and the sea. The need of ports and the companies operating them to remain viable, competitive and profitable. The concept of Circular Economy (CE) can help ports to respond to such challenges, and ensure their competitiveness in a resource-constrained world, while fostering innovation, and reducing environmental impacts (Cerceau et al., 2014; Hollen, van den Bosch & Volberda, 2015; Merk, 2013; Van Dooren & Braam, 2015). Research on circular economy in ports is limited, although there are a number of practical examples in European ports. This paper builds on port life-cycle literature and circular economy literature to present a case study which demonstrates how both can be combined to help secure a sustainable future for one of Sweden's largest container (industrial) ports.

This paper is structured in the following way: section 2 examines the lifecycle of ports and their integration of sustainability; section 3 discusses the CE concept; section 4 presents the approach taken by the Port of Gävle in Sweden, where the port has used dredged contaminated material to create entirely new land to expand the existing footprint of two areas of the port, including expanding the port's cargo terminal outward into a deepened shipping channel; and section 5 provides the conclusions.

2. Strategies for keeping ports open

Many ports are located in urban areas - towns and cities which grew up around them over centuries - and have a varied and unique history and culture (Wakeman, 1996; Girard, 2013), with many of them having a strong naval tradition (Pinder, 2003; Gordon, 1999). In recent times, a number of factors have led ports to adapt in order to continue to operate and to meet the needs of shipping (and other) companies operating through them (see for example Haralambides, et. al., 2002). These include: the distance between ports serving a common hinterland and levels of cooperation and competition between those ports (Heaver, et. al., 2001); ports lacking the space to expand to accommodate the increasingly large ships without port functions having to move into deeper waters (Hoyle, 2000); the relationship between urban ports and other parts of the metropolitan area leading to competing demands for space (McManus, 2007); lack access to adequate transport links (road, rail, inland waterway) necessary to operate as modern intermodal transport hubs, especially for older ports (Wakeman, 1996); derelict buildings and abandoned spaces due to improved working practices or operations where goods transit the port area more rapidly via improved road and rail links and a consequent reduction in need for on-site warehousing, (Wakeman, 1996); decline of traditional industries within, or in close proximity to, the port, such as the port of Cardiff, which had been the dominant port for the export of coal from South Wales since 1860 (Pinder, 2003); and threats from newly developed mega-ports, e.g. in the Middle East, where space is not limited, regulations are often less stringent, and there is room for the warehouses, large equipment, processing plants, transport connections and infrastructure necessary to accommodate very large vessels and operate a modern port (Haralambides et al., 2002; Hall 2007).

Many ports face the possibility of obsolescence and dereliction resulting from industry changes, such as limited access to large ships and no room for necessary infrastructure and transportation links. They therefore need to consider how they can achieve some form of redevelopment or adopt new activities which will allow them to continue to operate and generate an income for their owners, rather than leave port areas derelict and abandoned.

Successful redevelopments should capitalise on any instrument that can bring in the maximum possible benefit to the community around the port, or a waterfront area, taking into account the preferences and tastes of the local population (Vayona, 2011). Success may also be the result of recognition that there is a need to preserve the cultural heritage and history of a port and its wider urban environment.

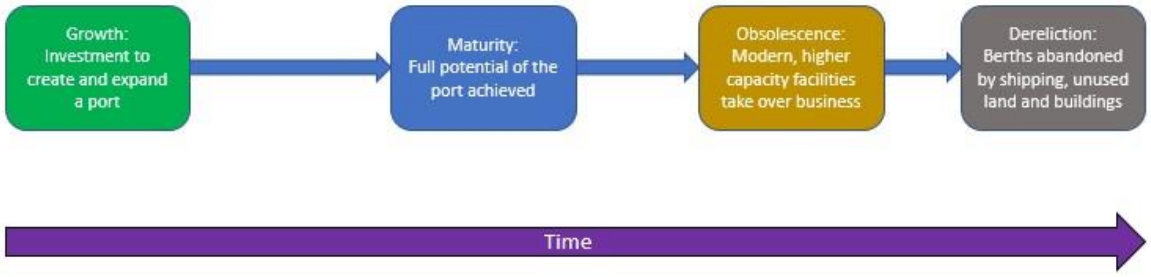
The examples of Millers Point in Sydney (Waitt and McGuirk, 1996) and the Old Town waterfront in Mombasa (Hoyle, 2001) illustrate that problems can exist about the cultural heritage of a port area, and the reason why is it being considered for redevelopment. Heritage tourism was a driver of the waterfront redevelopment at Millers Point in the late 1980's but the heritage being retained was its history as the oldest British colony (established 1788) in Australia, and as a merchant society during the second half of the 19th century and ignored many aspects of Australian national identity such as its indigenous population, and the area's more recent 20th century industrial heritage (warehouses, wharves, overcrowded housing with inadequate sanitation in the 'company town' constructed by the Sydney Harbour Board) (Waitt and McGuirk, 1996). This industrial area fell into dereliction during the mid-20th century and although the area has been redeveloped, only what was deemed significant to the founding of the modern Australian nation was prioritised as part of the heritage of Millers Point, ignoring the experiences and knowledge of the (ageing and dwindling) local community.

According to Hoyle (2001), the Old Town waterfront in the Mombasa area of Kenya had become neglected and disassociated from modern urban growth on Mombasa Island, and had reached the dereliction stage in the life-cycle model. It had also been replaced by the development of the new Port of Mombasa/Kilindini deep-water port located away from the original port area. Redevelopment had to take into account factors such as the very long history of trading through the Old Town (since the 11th Century), conservation of historical buildings including a mosque and an old fish market, improving public spaces, finding new uses for buildings, cultural attitudes of the local population, and identify how to bring money and jobs into the local economy (through tourism for example) and benefit the local community (education and training facilities, for example).

While redevelopment has taken place in both these examples, it is not through redevelopment of port facilities, but instead has resulted in a complete change of use. However, in the former example the local community was effectively excluded from the decisions on how change should take place, while tourism was the viewed as the highest priority. In the latter example the community and its needs were included in the redevelopment process, and while the needs of tourists were included in the process, so too were the needs of local people living in the area.

In both these examples, the port has effectively ceased to exist, and there has been no redevelopment of port facilities. This is illustrated in the linear life cycle set out in Figure 1, which provides a representation of the two examples discussed above.

Figure 1: Linear Port Life-Cycle, from growth to dereliction **Double column fitting image**



In the linear life-cycle the time taken between each stage becomes shorter. Ports will have grown over time in response to customer/industry needs until they reach maturity and are achieving their full potential. However, they are no longer able to change this approach, due to lack of space or other reasons, and so reach a position of obsolescence where they begin to lose business to more modern and higher capacity facilities elsewhere. As business is lost the number of ships calling into a port falls and its berths become abandoned through lack of use, and there is a consequent decline in the need for land and buildings. At this stage ports are faced with a decision about what, if anything, they can do to continue operating (perhaps at a much smaller, more local scale), and should also take into account sustainability in any decisions about how they proceed in the future.

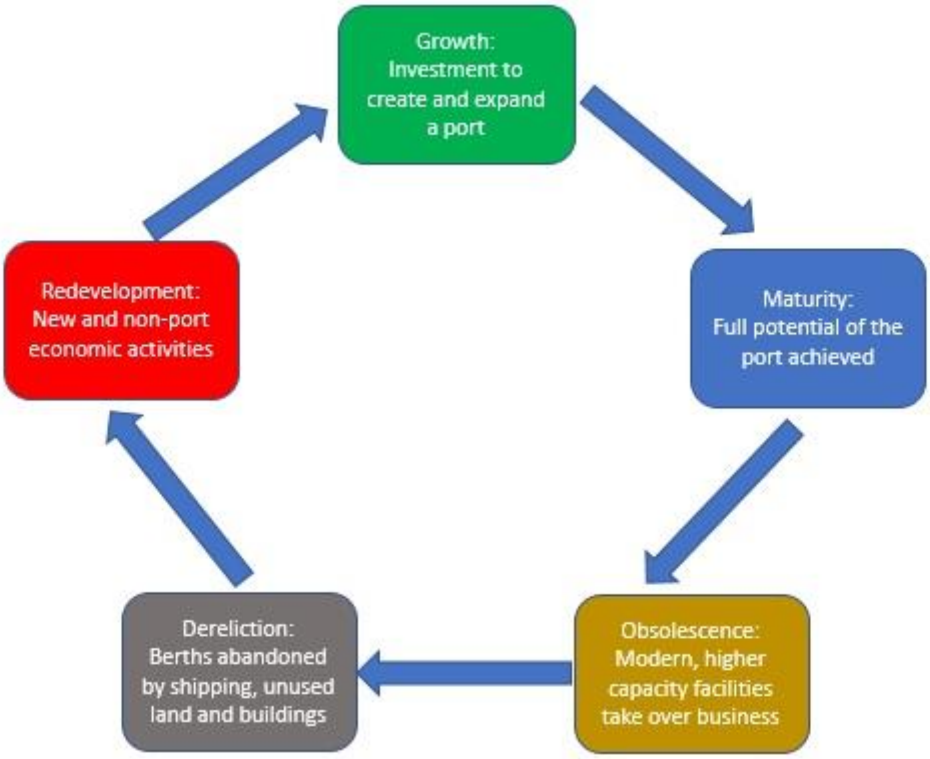
2.1 Port life-cycle

The traditional life-cycle (see Figure 2) identifies how facilities within a port area, rather than the whole port, progress through five stages (Wiegmans and Louw, 2011): i) *growth*, where investment helps create and expand the facility; ii) *maturity*, where the full potential of the facility has been achieved; iii) *obsolescence*, where modern, higher capacity facilities take over business; iv) *dereliction*, where the berths are abandoned by shipping; and v) *redevelopment*, where new and non-port economic activities occur. Figure 2 illustrates this Life-Cycle Concept for port facilities.

Dry port redevelopment (inland terminals to and from which shipping lines can issue their bill of lading (UNCTAD (1982) definition) can prolong the growth and/or maturity phases of this life-cycle, where solutions for port development are necessary to take into account a port's needs for expansion due to growth of trade, environmental considerations, community restrictions (including spatial restrictions) and evolution of freight transport and logistics (Cullinane and Wilmsmeier, 2011).

Practical examples of waterfront developments range from the regeneration of the Mersey Basin in North West England (Wood and Handley, 1999) to high profile redevelopment projects in Tokyo and New York City (Cybriwsky, 1999).

Figure 2 –Port Facilities Life-Cycle Concept **Single column fitting image**



Port redevelopment may be for a specific purpose, for example where a city is to host a world exposition, or the building of an iconic new cultural destination such as the Opera House in Oslo (Smith and von Krogh Strand, 2011), or as a result of a change in the physical relationship between a port and its surrounding urban area. This is exemplified in the case of Hamburg, discussed in more detail in section 2.2, where factors such as a lack of space meant that the port was no longer able to expand out into the surrounding area while the city needed to find new space to house a growing population.

2.2 Sustainability in port redevelopment approaches

According to Wakeman (1996), a benefit of using a sustainability approach to port redevelopment is that it recognises the need to diversify, reuse or adapt so that the port and its maritime activities remain viable in the face of economic or environmental shifts. By looking at ports from the perspective of sustainability, it can help redefine the relationship between the port and the urban region around it, which could lead to a renaissance of the port and the city.

The case of redevelopment of the Toronto waterfront was guided by a "three pillars" concept for sustainability – balancing economic development, environmental protection, and social growth – to create a localised understanding of what is required to redevelop the waterfront area (Bunce, 2009). Redevelopment should take into account economic, environmental, and social factors when considering the wider urban redevelopment of port cities and surrounding urban areas, such as

Rotterdam, Barcelona, Liverpool, Tokyo, and Hamburg, which has resulted in a range of new, creative and innovative developments, both in the ports and in the wider cities of which they are a part (Girard, 2013).

The Port of Hamburg can help to illustrate sustainability in ports. By the mid-1950s the port was unable to accommodate the newer, bigger container ships requiring deeper draughts (depth of water) that were being developed as its existing harbour basins were too shallow and lacking sufficient storage capacity to meet the requirements of such ships (Grossman, 2008). Consequently, dedicated cargo facilities on the southern bank of the Elbe were developed and then, in 1997, a decision was taken to extend the container terminal at Altenwerder[1] and that came into use in 2002. At the same time, it was also decided to create a new city area in Hamburg itself through the HafenCity project, Europe's largest inner city development project along the Hamburg waterfront[2]. 157 hectares of former port and industrial land in the centre of Hamburg was redeveloped for work and residential use, with cultural, leisure, retail and tourist facilities also included in the redevelopment. This enlarged the Hamburg city centre by 40%.

3. Sustainability in ports through Circular Economy

A particular way that ports can transition to becoming more sustainable is through CE[3] (see Cerceau et al., 2014; Hollen, van den Bosch & Volberda, 2015; Merk, 2013; Van Dooren & Braam, 2015). CE aims at 'closing loops'. The concept was first discussed by Leontief (Leontief, 1928, 1991) in 1928, but the first at international level effort was in 1996 that the German Parliament passed a law on CE (Kreislaufwirtschaft) (Bilitewski, 2012). The concept has been promoted in China and other Asian countries since the end of the 1990s to solve environmental problems (Andersen, 2006; Yong, 2007; Yuan, Bi, & Moriguichi, 2006).

In circular economy waste is used as a resource in other parts of the value chain by shifting the focus to closing material loops (through reduction, reuse, and recycling (Feng 2004) at the system level (European Commission, 2014a, 2014b). This requires a complete reform of the whole system of human activity, including production processes and consumption activities (Bilitewski, 2012; Yuan et al., 2006). These include changes in technology to cleaner production, better reuse and recycling of waste, (Bilitewski, 2012), prices that reflect full costs (Webster, 2013), social and organisational changes (European Commission, 2014b), as well as economic and legal tools to promote the circular economy (Bilitewski, 2012). Switching to a circular economy needs the involvement and commitment of many different stakeholders (European Commission, 2014a). Some examples of moving towards a more

[1] For further information about Hamburg Port see: https://hhla.de/en/container/cta.html
[2] For further information about the Hamburg HafenCity Project see: http://www.hafencity.com/en/overview/the-hafencity-project.html
[3] Unlike sustainability which considers economic, environmental and social factors, CE only considers two factors – economic and environmental

circular economy include: efficiency, reducing the use of energy and materials in production and use phases; substitution, reducing the use of materials that are hazardous or difficult to recycle in products and production processes; reducing, incentivising and supporting waste reduction and high-quality separation by consumers; industrial symbiosis, facilitating the clustering of activities to prevent by-products from becoming wastes; and new business models, encouraging wider and better consumer choice through renting, lending or sharing services (European Commission, 2014b).

In general, CE activities focus on three levels (Yong, 2007; Yuan et al., 2006): micro-level, focusing on improving the environmental performance of individual companies or enterprises, by reducing resource consumption and pollution discharges, or by designing more environmentally-friendly products; meso-level, focusing on eco-industrial networks that will improve both regional production systems and environmental protection, energy cascading, exchanging by-products, recycling waste and sharing local infrastructure. A typical practice at this level is the development of eco-industrial parks; and macro-level, focusing on regions, cities, municipalities, or provinces to develop a sustainable production as well as consumption system.

Some of the challenges faced when moving towards a more Circular Economy include: knowing the contribution of a particular economic activity to the environment (Andersen, 2006); equipping the labour force with the relevant skills (European Commission, 2014b), raising awareness and increasing capacity in companies, modifying current linear economic systems, developing and investing in new business models, changing behaviour of consumers, changing relationships between consumer and producer liability regimes, pricing goods and services to reflect full costs, and set up policies that promote circular economy (European Commission, 2014a)[4].

CE has focused on areas including: food waste, hazardous waste, plastic waste, recycling of critical raw materials, illegal waste shipments, and recycling of phosphorus (European Commission, 2014b). In terms of waste one of the biggest sources in ports globally is the result of dredging to keep shipping channels open. The University of Wisconsin Sea Grant Institute (UWSGI) (2013) notes that several hundred million cubic yards of material are dredged annually to maintain access for ships into US ports, harbours, marinas and waterways; however, of that dredged material, only clean (non-contaminated) material (less than half of all dredged material) can be used for land creation and construction fills, for beach nourishment, creation of topsoil, and habitat creation or restoration, for example. Contaminated material has to be contained in specific containment facilities (UWSGI, 2013).

CE in ports focusses on: (1) minimising the use of inputs and the elimination of waste and pollution; (2) maximising the value created at each stage; (3) managing flows of bio-based resources and recovery of flows of non-renewable resources in closed loop; and (4) establishing mutually beneficial relationships between companies within each circular chain (Van Dooren & Braam, 2015). CE within

[4] For more information on the EU approach to Circular Economy see http://ec.europa.eu/environment/circular-economy/index_en.htm

ports is, therefore, a synergistic approach which combines economic, logistic and industrial activities with the cultural heritage of the port and the creativity of its wider community, resulting in a dynamic, complex and sustainable system (Girard, 2013).

Many initiatives at ports go beyond legal requirements (e.g. Directive 2008/98/EC on establishing a legal framework for the treatment of waste within the Community (European Commission, 2008); and Directive 2000/59/EC on port reception facilities for ship generated waste and cargo residues (European Commission, 2000), such as cases of industrial symbiosis or circular economy research and innovation centres (e.g. the Biopark Terneuzen of the Port of Zeeland (Port of Zeeland, 2015) or the Circularity Centre of the Port of Rotterdam (Port of Rotterdam, 2014)). Port authorities have been the main drivers of these developments (Cerceau et al., 2014). As hubs of global resource flows, hosts to large industrial complexes, and inter-modal platforms with strong connections with their hinterland and urban areas, ports can be ascribed a unique and highly important role in stimulating circular economy practice, with their influence transcending far beyond their own industrial complexes (Kuipers, 2015).

Existing CE initiatives at ports have ranged from the micro-level, such as reusing waste streams within a single company, to the a meso-level, i.e. industrial symbiosis between two or more companies at the port (see e.g. the Industrial Ecology Approach of the Port of Bristol (GreenPort, 2009), to interregional port-industry networks for exchange of secondary resources at the macro-level (e.g. the Bioport of Europe project of the Port of Rotterdam). The initiatives have varied from short-term demonstration projects (see e.g. the Port of Antwerp's Sustainability Strategy), to more innovation and optimization focused medium-term initiatives (see e.g. the Biopark Terneuzen project of the Port of Zeeland), to long-term vision strategies (see the visions for 2030 of the Port of Amsterdam (2014) and Port of Rotterdam (2011)); (Cerceau et al., 2014).

4. Securing a sustainable future through circular economy: The Port of Gävle Approach

The Port of Gävle is located on the Baltic east coast of Sweden, north of Stockholm. It is the largest container port on the east coast and third largest in Sweden. The port has eight terminals, serving chiefly the wood and steel industries, bulk containers, and liquids for Arlanda (Stockholm) Airport (jet fuel), other fuel oils and vegetable oils. Around 20 trains depart from the port each day with a fully automated rail loading facility with daily shuttle trains to the airport. The Port of Gävle provides a hub for around 1,000 large ships visiting the port annually to load or unload cargo[5]. The port is surrounded by green space (see Figure 3) including a golf club, and has road and rail links into the hinterland of Sweden. The port has plans to double volumes of traffic over a 15-year period, and as part of this has built a new cargo terminal area at Frederiksskans, due to open in mid-2019, using material dredged from

[5] For further information on the Port of Gävle see http://gavlehamn.se/EN/

deepening the shipping channel to accommodate larger vessels (see Figure 4, area outlined in red in the centre of the image), together with a second area at Granudden (see Figure 4, area outlined in red at the top left of the image).

Figure 3: Overhead View looking towards the Port of Gävle **Single column fitting image**

Figure 4: Port of Gävle with new land areas created 2012–2014 **Single column fitting image**

Note: The new areas built using dredged material are outlined in red. The Granudden area appears at the top left of the image while the new cargo terminal at Fredriksskans appears towards the middle of the image.

As in the case of the port of Hamburg, the Port of Gävle also moved from its original location of Alderholmen, located close to the original centre of Gävle on the river Gavleån, Fredriksskans area (closer to the sea). The move was necessary for similar reasons to that of Hamburg, i.e. a need to accommodate bigger vessels, together with the long fairway and hence extensive dredging that would have been necessary for continued use of the inner quays. The Fredriksskans area started to grow (physically, in land area, and business wise) at the beginning of the 20^{th} century (circa 1905) and has continued to grow and expand since that time. Most recently, dredging has been undertaken to deepen and widen the shipping channel, while the large volumes of dredged contaminated sediments extracted during that process were treated and used to create new land.

The most recent port expansion project commenced in 2007, in response to a large increase in traffic volumes over the preceding 2 years. It was recognised that there was a need for both new land areas and an increase in the length of the quays to accommodate larger vessels. At the same time, the Swedish Maritime Authority (SMA) approached the Port Authority to develop a common project to upgrade the fairway, the navigable channel in the harbour area of the port. The impetus for this project was recognition that a deeper, wider fairway was required to accommodate larger vessels and to maintain the existence of Port of Gavle as a major Swedish port hub.

Based on calculations made by the Port Authority, it was estimated that around 4 million m^3 of dredged sediments would need to be removed of which approximately 1 million m^3 was expected to be polluted with levels of heavy metals and polyaromatic hydrocarbons (PAHs) at levels above those accepted by the Swedish Environmental Protection Agency. Criteria for environmental quality include the degree of hazard posed by the contaminations and the potential for their migration (Swedish EPA, 2002), with dredged material having a high potential for mobilization of heavy-metals, for example, once the sea-bed is disturbed by their removal (Toes, et al., 2008). The polluted sediments in the bay around the Port of Gävle were contained mostly within the upper 0.5 m sediment layer, the boundary for which was determined through extensive sediment sampling across the bay areas. Those sediments consisted of loosely compacted materials and clays, with a water content of up to 90% in some areas, and the standard approach is to excavate those materials and dispose of them at a site away from the channel and harbour areas (Wang and Leonard, 1976).

Swedish contaminant classifications for heavy metals in surface sediments are derived from a standard Swedish method against which samples are measured (see Swedish Environmental Protection Agency, 2000, Table 36). Class 1 is where the sample shows no or only insignificant deviation from a reference value, Class 2 slight deviation, Class 3 significant deviation, Class 4 large deviation and Class 5 very large deviation. As an example of the results from sediment sampling for heavy metals undertaken between 12 and 13 October 2010, sampling took place at 10 locations and at different depths (between 0 - 10 cm for upper layer sediments and between 55 and 70 cm for deeper layers, depending on location). Very large levels of lead were found in three locations in the upper sediment layer, two of those locations also having very large levels of mercury and one of these additionally had very large levels of copper. Chromium was found in two locations in very large levels in the deeper sediment layer, and at large levels in the upper sediment layer in three further locations. Organic pollutants such as PCBs and PAHs were also identified in the different sediment levels, again measured against classifications identified by the Swedish Environmental Protection Agency (2000; see Table 30, page 64). For these substances Class 1 is where none of the substance is found while Class 5 is where very high levels are found. While only 2 locations showed high or very high total levels of PCBs from the October 2010 testing, one location showed very high levels of 9 different PAHs, and a further 2 PAHs at high levels, in the upper sediment level. A number of other locations had high or very high levels of different PAHs, also in the upper sediment level.

Other monitoring activities undertaken throughout the duration of the project included water quality and turbidity sampling, noise level monitoring, and monitoring of marine flora and fauna, for example.

Although deposition of dredged sediments on land can be a viable solution for confining pollutants as an alternative to depositing the material within the same system (area) (Toes et al, 2008), there was insufficient vacant land on which to deposit the approximately 1 million m^3 of contaminated sediment that would be produced as a result of the fairway upgrade. It was identified that the nearest area that could accommodate the sediments, and where a permit was held for handing such large amounts, was a bay in Norway. Transport of dredged materials would have necessitated many thousands of lorries transporting that material between Sweden and Norway, and also would have led to high levels of greenhouse gas emissions from road transport.

As an alternative, it was considered that the dredged materials could be used as a resource to build new quays and land. This was in keeping with earlier port developments as, historically, much of the port area had been derived from dredged sediments that had been turned into land areas. However, again historically, there had been no regulations for treating run-off of excess water from the dredged materials, for example, and this was no longer the case. Also, while smaller volumes of material had been used during the earlier land-building process, with the material being left to solidify for several years before it was used, the port expansion required new land to be built over a much shorter period of time.

In order to take the land-creation process forward, the port considered work conducted by the Swedish Geotechnical Institute (SGI) within a Swedish-Norwegian Consortium on stabilisation/solidification (s/s) of contaminated sediments and dredged materials (STABCON Project; see STABCON, 2011). The method used by STABCON was the mixing of contaminated sediments and dredged materials with cement (as a binding material) in an excavator in order to form a solid material. However, this was on a much smaller scale that was required by the Port of Gävle; the equipment was not suitable to achieve a consistently mixed material at the depth of 10-13 metres required by the port, while the cost of cement as a binder was very high, making its use uneconomical at a larger scale. The port therefore sought out alternative materials and it was identified that Vattenfall, the Swedish state-owned energy company, had a heating plant in Uppsala (approximately 100 km from Gävle) which produced large volumes of ashes from the incineration of bio-fuels, with Vattenfall seeking ways to use those ashes.

Subsequent to obtaining a permit for stabilization/solidification and construction of new quays and landfill from the Swedish Environmental Court (2008), the port worked with a group including SGI, Luleå Technical University, Sweden, the Port of Kokkola, Finland, and others on what subsequently became the part EU-funded Sustainable Management of Contaminated Sediments (SMOCS) in the Baltic Sea Project, taking place under the Baltic Sea Programme. That project ran between 2007 and 2013 (SMOCS, 2013[6]). The port subsequently obtained a permit for dredging the fairway in 2011 (Swedish Environmental Court, 2011).

As part of the SMOCS project, guidelines for sustainable management of contaminated sediments were developed (SMOCS, 2013). Those guidelines considered all aspects relating to the disposal or beneficial use of contaminated dredged sediments including, for example, requirements for assessing site suitability, risk assessment, and Environmental Impact Assessment. A field test was conducted in the Port of Gävle in 2010 as a work package of SMOCS in order to demonstrate the applicability of the s/s method as they related to the geotechnical and environmental properties of treated contaminated dredged sediments; behaviour of the construction with the treated material behind a sheet pile wall, and the influence of the materials on their surroundings (SMOCS, 2014). A recipe for mixing loose sediments with binders (a combination of cement, fly ash and merit) was developed through laboratory testing and a subsequent field trial in proportions that meant that the quays and landfill were solid enough to support the heavy weight of cranes and containers, while not releasing contaminants to the sea over time, in line with relevant Swedish EPA standards.

It was necessary to demonstrate that the method and materials would be successful for the proposed full scale works in the port. It was also necessary to ensure an adequate supply of the binders and establish the logistics for their storage. The full scale project ultimately required 2 years production of fly ash from Uppsala, warehoused in the port, together with large amounts of cement and also Merit 5000 (MEROX; slag from a local steelworks) to complete the process. This makes use of a number of circular economy approaches including a variation on substitution, i.e. where the hazardous materials are converted to a non-hazardous form using waste from a local energy producer (fly ash) and a local steel producer (Merit), beneficially resulting in waste reduction for those industries. This approach is

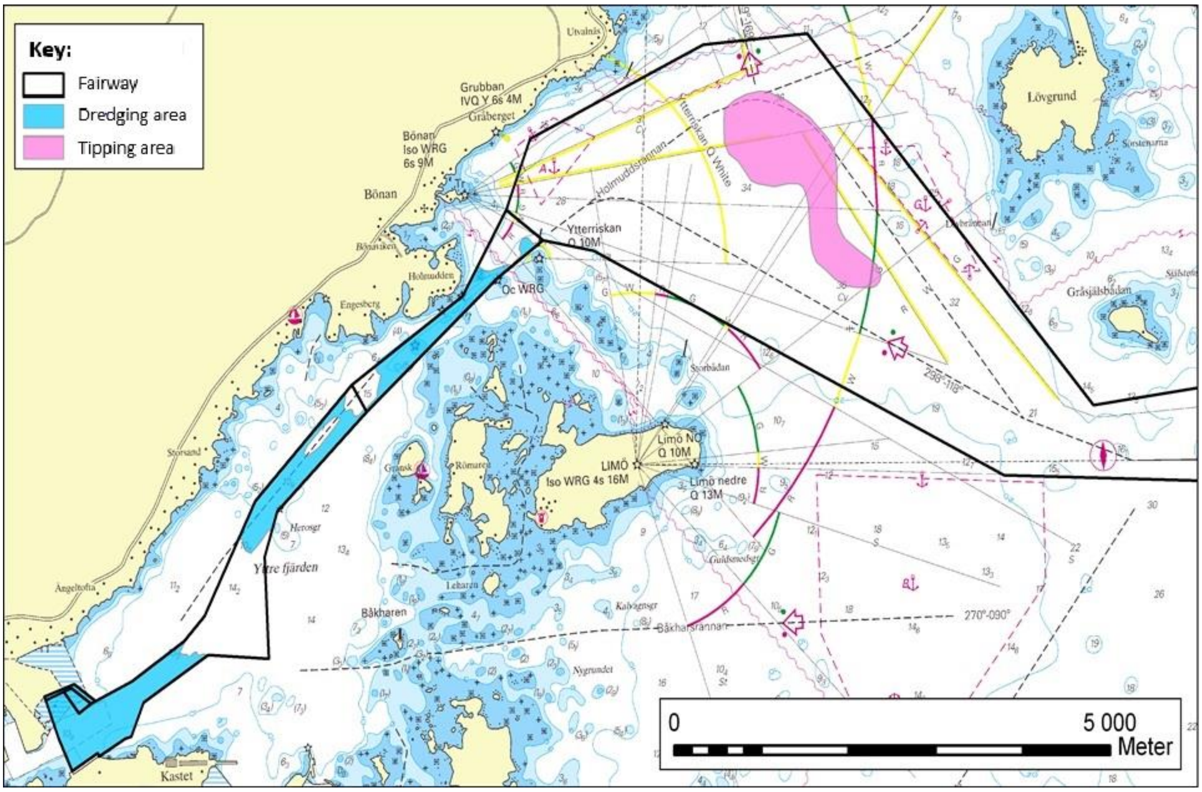
[6] For further information on the SMOCS project see www.smocs.eu

also an example of industrial symbiosis, i.e. it facilitates the clustering of activities, taking by-products from energy and steel production and converting them into useable materials rather than waste.

The port was also required to develop a method and logistics for the construction of quay walls, preparatory work which took place between 2010 and 2012, subsequent to which dredging took place with sediments transported to shore on barges, mixed in a machine to produce the material to fill in the area behind the new quay walls through the use of castings (pouring the material into a mould). Material for the quay walls (delineating the quays for the new container terminal), consisted of approximately 400,000 m^3 of stone and gravel between 0-600 mm in diameter, and was derived locally by the port, from an adjacent undeveloped land area some 100 m from the port. By using this approach, the Port of Gävle could also prepare this undeveloped land and gain an additional area suitable for planned future logistic port cluster activities. At the same time the port gained the stone and gravel required for quay constructions and, not the least, minimised the need for transport. The port calculated with saving the environment from climate gases equivalent to about 25 turns around the globe with a heavy truck – just from the reduction in transport distance by using this area instead of the closest commercial "gravel pit".

The full-scale project took place between 2012 and 2014 with dredging activities removing around 600,000 m^3 of dredged material, out of a total of around 4.2 million m^3 of sediments, the vast majority of which was deposited in the area north of Holmudden, appearing in pink in Figure 5. This material was removed from around 8-10 km of fairway, contaminated sediments lying within the 0.5 m upper layer. The majority of water in the dredged sediments was used within the process of mixing sediments with binders. Excess water was filtrated through wide stone piers that had a base of 30-45 m, mainly made up of gravel of 0-600 mm diameter. This is also in line with the circular economy approach of waste reduction as the water was used in the material creation aspect of the project.

Figure 5 – Fairway, Dredging and Tipping Areas in Gävle Bay **Double column fitting image**



Note: The fairway area is outlined in black from the bottom left to upper middle of the figure, dredged areas within the fairway appear in blue and the tipping area for non-contaminated waste is the solid pink area.

As a result of the full-scale project more than 300,000 m^2 of new land has been created (see Figure 4) and, after being left to settle for 2 years, the land became partly accessible for use in the handling of goods (it was possible to walk on the material within a few days of it being deposited). The Port of Gävle is currently (September 2017) in the process of constructing a new container terminal (outlined in red in the centre of Figure 4), doubling the size of the existing terminal, on one of two new land areas that have been created. The Fredriksskans area of the port has been extended from 200,000 TEU capacity (i.e. able to accommodate 200,000 twenty-foot equivalent containers; a volume based on a 20-foot long (6.1 m) containers) to 400,000 TEU capacity. The new container terminal will be open for vessel traffic from mid-2019. The Granudden terminal is also being developed on a second area of new land and will be of a similar size to the new container terminal area, with a doubling of the quay length (the former quay was 350 m and the new quay is 700 m).

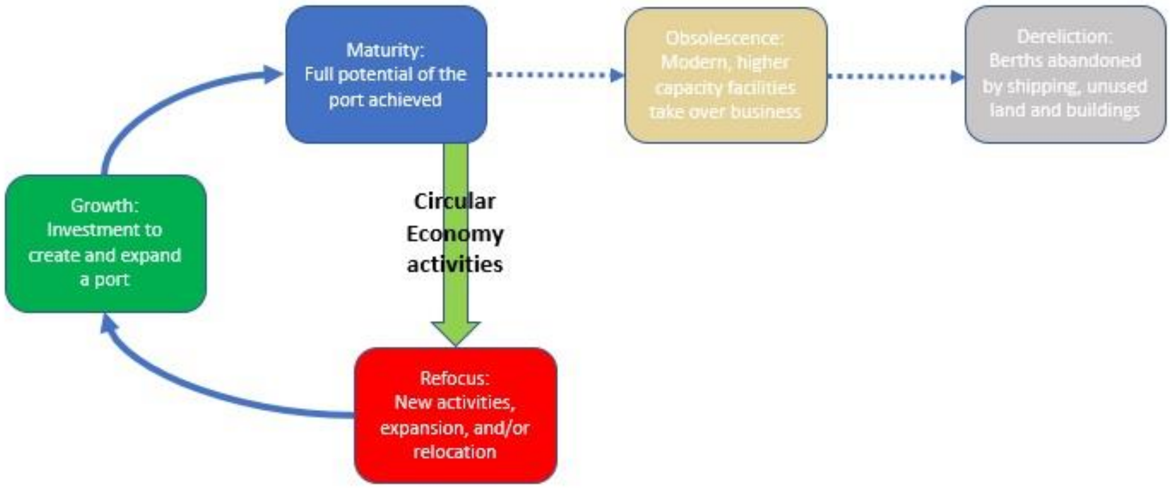
By undertaking this land creation approach the port has avoided the obsolescence stage in the traditional life-cycle approach (Figure 2) and the linear life cycle (Figure 1) by expanding its current area and improving its port facilities to take advantage of new activities. As a result of the creation of new land, the new terminal areas are now accessible to much larger vessels than was previously possible. Before dredging took place, the fairway had a depth of 10.9 m and was, at its narrowest point, around 60m wide. The new fairway depth is 13.5 m and is 126 m at its narrowest point. Prior to dredging the fairway could accommodate vessels measuring 220 m length, 30 m wide (beam) and 9 m depth (draught). The dimensions post-dredging are 245 m x 45 m x 12.2 m respectively.

By using contaminated sediments, while depositing the uncontaminated material elsewhere (see Figure 5, area highlighted in pink) the Port of Gävle exemplifies a circular economy approach through the use of the contaminated sediments as a resource, thus reducing the use of energy and materials (see European Commission, 2014a). Combining dredged contaminated sediments that would normally require storage or go to landfill with waste from other industrial processes (energy production and steel industry), some of which might also go to landfill, this means that the waste is now used as a resource and contributes to closing material loops through reduction, recycling, reuse (see European Commission, 2014a; Feng, 2004).

The Port of Gävle has adopted a CE approach in its land creation process, both though the use of waste as a resource (reduction, recycling, reuse approach) and through industrial symbiosis, i.e. clustering its activities with local energy and steel production companies. At the same time, it also contributes to the zero-waste target of the European Union (European Commission, 2014b). This project also demonstrates a sustainability approach, by removing contaminated material from the marine environment and rendering that material non-hazardous through the s/s process. Finally, it has minimised the transportation needed to move the materials and the consequent emissions to air that would have been the result of transporting the material to Norway for handling; the alternative to using the materials in situ.

In the case of the Port of Gävle, a micro-level approach has been taken to the expansion of the port area to meet modern industry needs, and this is illustrated in Figure 6 where the obsolescence and dereliction stages in the port life-cycle approach (Figure 2) and linear port life cycle (Figure 1) are no longer applicable. The result is a revised port life-cycle incorporating a Circular Economy Approach. Through its recent development phase, the Port of Gävle has effectively ensured its survival as a major industrial port while enabling its core business to thrive and expand through the redevelopment of its land and water areas. By taking a CE approach, the port has avoided the obsolescence and dereliction phases of the life-cycle approach illustrated in Figure 2, and has closed the loop by refocusing for expansion, illustrated in Figure 6.

Figure 6: Revised Port Life Cycle and Circular Economy Approach **Double column fitting image**



5. Conclusions

Ports are an important player in the corporate world, due to their role in global production and distributions systems. For all ports, a key requirement for commercial and economic viability is to retain the business of the ships using them and to remain accessible to those ships. In addition, ports are under increasing pressure to become more environmentally and socially integrated and friendly. Many challenges are facing the port industry globally including: the need to accommodate very large ships; competition from new ports; environmental issues such as air, land and water pollution from ships; and transport bottlenecks for the movement of goods, raw materials and people between the land and the sea. At the same time ports, and the companies operating within them, need them to remain viable, competitive and profitable. The concept of Circular Economy can help ports to respond to such challenges, and ensure their competitiveness in a resource-constrained world, while fostering innovation, and reducing environmental impacts. Research on circular economy in ports is limited, although there are a number of practical examples in European ports. This paper builds on port life-cycle literature and circular economy literature to present a case study which demonstrates how both can be combined to help secure a sustainable future for one of Sweden's largest container (industrial) ports.

The traditional life-cycle concept progresses through five stages (*growth*, *maturity*, *obsolescence*, *dereliction*, and *redevelopment*). Most efforts have focussed on contracting or redeveloping such port facilities. For the former, the results have been a slow decay and closure of ports. For the latter, redevelopment has taking place through relocation and, in some cases, through land expansion using new materials. The Port of Gävle example shows that using Circular Economy principles, contaminated dredge material can be used to create new land, thus fulfilling two purposes: expanding the port to be ready for more and bigger ships, and encapsulating polluted material that would otherwise be too costly to manage or treat. The paper shows that Circular Economy can be a viable way in keeping securing a port's future and contributing to its sustainability and that of the city/region where it operates.

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