HIGH VOLUME TRANSPORT:
Rapid assessment of research gaps in port operations and technical aspects

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SECTION 1
Background and introduction

Purpose
Evidence on Demand has been commissioned by Department for International Development (DFID) to conduct a rapid desk based study on research gaps in port engineering, operations and related technical aspects for ports of high volume operations in Low Income Countries (LICs). The objective of the study is to inform DFID’s thinking and scoping of future work.

Port System – Harbours and Terminals
A port can range from a small quay for berthing a ship to a very large scale centre with many terminals and a cluster of industries and services. Ports need not necessarily be only seaports. In some countries, the term port denotes multimodal port facilities including seaports, airports and other intermodal facilities such as railway and road connections. In a similar vein, non-sea related activities can also fall under the wider definition of ports, for instance inland ports, intermodal terminals, inland container depots, inland clearance depots, dry ports, free ports, etc. Note that the last three facilities require either a bond or a sealed internal transit regime by Customs and other border control agencies. For the purpose of this study, we will cover both seaports and dry ports. Ports that deviate from commercial ship and cargo handling, e.g. fishing, military, and cruise ports are outside the scope of this Report.

Even within the boundaries of commercial ports, port assets, operations, services and functions, can be broad in scope and nature. Typically, ports are categorised by cargo (commodity) or ship type, for instance dry bulk ports, liquid bulk ports, break-bulk and general cargo ports, etc. Further categorisation divides ports into specialised terminals. Modern port engineering, layout and operating systems are increasingly designed and operated to serve a particular trade, ship or cargo type, e.g. oil terminals, chemical terminals, liquefied natural gas (LNG) and liquefied petroleum gas (LPG) terminals, coal terminals, iron-ore terminals, container terminals, car terminals, etc; although several ports around the world still operate multipurpose facilities. Where relevant, this Report will discuss both common and specific research gaps across and within ports and specialised terminals.

Ports systems can also be divided into three main generic sub-systems: the nautical infrastructure (access channels, breakwaters, jetties, etc.), the terminal infrastructure (quay walls, berths, yards, etc.), and port superstructure (port equipment, vehicles, sheds, warehouses, gates, etc.). Sometimes a port system can be extended to include inland and intermodal facilities and connections, for instance in the case of dry ports and inland container depots. Table 1 provides a generic categorisation of the main port and terminal facilities and services.
Too often though, the role of ports exceeds the simple function of services to ships and their cargo. The cross-functional dimension of ports means that their roles can range from a simple berthing facility to a large distribution and logistics hub. Such diverse portfolio may require a redefinition of port's functional attributes in that the port system not only serves as an integral component of the transport system, but also is a major sub-system of the broader production and logistics system. The definition of port core businesses poses a dilemma as to where the demarcation line lies between port and non-port functions, with many ports in the world shifting to more profitable non-maritime business interests such as property developments and recreational activities. The degree to which the port business should be limited to or associated with ship/shore, goods transfer or cargo-flows management still remain key questions.

Table 1 Categorisation of main port assets and services (Author)

<table>
<thead>
<tr>
<th>Port Infrastructure</th>
<th>Port superstructure</th>
<th>Marine services</th>
<th>Terminal services</th>
<th>Landside port logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakwaters</td>
<td>Quay cranes</td>
<td>Conservancy &amp; protection</td>
<td>Berthing</td>
<td>Bonding, documentation, customs clearance</td>
</tr>
<tr>
<td>Entrance channels</td>
<td>Mobile cranes</td>
<td>Access &amp; navigation</td>
<td>Stevedoring</td>
<td>Processing, sub-assembly, cross-docking, consolidation, break bulk</td>
</tr>
<tr>
<td>Port and harbour</td>
<td>Yard cranes</td>
<td>Dredging &amp; maintenance</td>
<td>Ship loading/</td>
<td>Labelling, palletising/packing, itemization, unitization, bar coding</td>
</tr>
<tr>
<td>lights</td>
<td>Pumps, loading arms</td>
<td>Vessel traffic systems</td>
<td>discharging</td>
<td>Postponement, customisation, decoupling</td>
</tr>
<tr>
<td>Jetties</td>
<td>Conveyors, wagons</td>
<td>Pilotage and towage</td>
<td>Quay transfer</td>
<td>Information services, tracking and tracing, port community systems</td>
</tr>
<tr>
<td>Dolphins, buoys,</td>
<td>Shore ramps</td>
<td>Salvage and rescue</td>
<td>operations</td>
<td>Quality control, testing, sampling, inspection, certification</td>
</tr>
<tr>
<td>mooring points</td>
<td>Trucks and vehicles</td>
<td>Ship repair and</td>
<td>Cargo storage &amp;</td>
<td>Reverse logistics, recycling &amp; repair</td>
</tr>
<tr>
<td>Locks</td>
<td>Storage</td>
<td>maintenance</td>
<td>stacking</td>
<td></td>
</tr>
<tr>
<td>Docks / Piers,</td>
<td>warehouses</td>
<td>Bunkering</td>
<td>Equipment services</td>
<td></td>
</tr>
<tr>
<td>Quays</td>
<td>Tank farms</td>
<td>Chandlers and supply</td>
<td>Port policing,</td>
<td></td>
</tr>
<tr>
<td>Yards and</td>
<td>Refrigeration</td>
<td>Ancillary services</td>
<td>cargo security</td>
<td></td>
</tr>
<tr>
<td>Terminals</td>
<td>IT and testing</td>
<td></td>
<td>HAZMAT &amp; Health</td>
<td></td>
</tr>
<tr>
<td>reception</td>
<td>equipment</td>
<td></td>
<td>control &amp; waste</td>
<td></td>
</tr>
<tr>
<td>facilities</td>
<td>Scanners,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermodal</td>
<td>security &amp; safety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>connections</td>
<td>equipment</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pipelines</td>
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<td></td>
<td></td>
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<tr>
<td>River/ waterway</td>
<td></td>
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<tr>
<td>connections</td>
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</tr>
</tbody>
</table>

Port System – Dry ports and logistics centres

In international shipping and logistics, seaports can be treated as maritime logistics centres when they provide logistics services at the seashore and shore-land interfaces. Many ports in the world have an established body of knowledge and experience in providing value-added logistics activities for ship-cargo consignments, but not all ports can claim a logistics centre status. Typical logistics functions of ports include cargo handling and transfer operations, storage and warehousing, break bulk and consolidation, value added activities, information management, and other related services.
Ports may also be seen as inland logistics centres when they operate as nodal interfaces intersecting the different segments of the inland transport system, such as in terms of road/rail, road/road, rail/rail, and even rail/road and air combinations. In recent years, there has been some emphasis on the role of inland ports, where all logistical operations not necessarily requiring to be carried out in the seaport area can take place. Opportunities for developing port facilities that can provide logistics-like services at some distance away from traditional seaport locations arose from several experiences around the world.

The core function of an inland port is to serve as an inland terminal where goods are stored and consolidated/deconsolidated from small/large shipments into large/small ones. Such a terminal can be thought of as a node in a transport network and/or serve other storage or customs purposes. As a result, some new concepts such as distribution centres (DCs), inland terminals, and distriparks have emerged recently. Other generic terms include dry ports and inland clearance depots (ICDs), both bounded by customs presence and common-user service arrangements. Nevertheless, there is no clear-cut separation between all such facilities in terms of spatial dimension, functional or organisational status, but the following categorisation may help underlining some of the differences.

- **Intermodal terminal**: Main function is transferring goods from road/rail to-from another mode (rail, air or water) using interoperable operational and technical standards, for instance by transferring and storing (including related logistics services such as refrigeration) of ISO types of containers.

- **Inland clearance depot (ICD)/Dry port**: Customs and other border control agencies are present, for final clearance of imported goods and release to importers. Customs will require either a bond or a sealed ‘internal transit’ regime for the transfer of containers from the port inland.

- **Logistics zone/platforms**: In addition to the above, components received at the terminal are assembled into final products (value added logistics), e.g. packaging, ticketing, customisation, cross-docking, etc.

- **Free trade zone/special economic zone**: Those are logistics zones operating under customs surveillance, so that both inputs and outputs are exempt from import duty.

From a spatial and geographical perspective, the relationship between freight flows and port inland development is better understood through the concepts of gateways, articulation points, corridors, and distribution centres.

- **Gateways** are usually defined as locations that bring together different modes of transportation, along with warehousing, freight forwarding, customs broking and related logistics services. Many textbooks separate transport gateways as hubs for major regions, from freight gateways serving smaller regional areas and cities. Inland ports and local seaports may fall under the second category. An illustration of this may be found at the port of NY/NJ being an industrial and logistics hub (freight gateway), joined by the inland port of Albany (transportation gateway) designated to receive freight containers barged from the main hub port.

- **Articulation points** are nodal locations that interface between different spatial systems and serves as a gateway between spheres of production and consumption. It is more than an interchange point since it includes the consideration of terminal facilities, distribution, warehousing, and trading centres. The difference between gateways and articulation points is that the latter are viewed from an urban perspective, whereas gateways do not necessarily need to be located at city-interfaces. In this context,
seaports are usually considered as 'hard' terminals since they are 'immoveable', whereas inland terminals dispose of a great degree of locational flexibility.

- **Freight corridors**, opposed to passenger corridors, represent transport links of freight transportation supported by an accumulation of transport infrastructures and activities servicing these flows. Traditionally, flows in freight corridors tended to be fragmented and segmented since each mode tried to exploit its own advantages in terms of cost, service, reliability and safety. Maritime corridors traditionally correspond to geographical trade routes (regional or international), but recurrent changes in global production and logistics systems, such as in terms of hub-spoke and transhipment networks, currently reduce the capacity of freight corridors to accommodate different patterns of maritime transportation.

- **Freight distribution centres** serve as a location for cargo transfer and distribution to regional or extended markets, depending on corridor capacity (facilities) and articulation point links. Conventionally, many distribution centres were located close to central areas mainly as a factor of market proximity, but are currently relocating to peripheral areas. Functionally, a freight distribution is the combination of a freight corridor and an articulation point or a gateway.

### High Volume Port Operations and Low Income Countries

There is no international standard or definition which demarcates between ‘high’ and ‘low’ volume port operations, and it would be almost impossible to do this at the port level given the types and sizes and evolution of ships and cargoes handled. However, it is possible to relate high volume operations to certain thresholds of ships’ sizes and cargo throughputs at the level of specialised ports and terminals. Table 2 outlines the main sizes of major ship types and highlights what is considered by the industry as ‘high’ volume.

<table>
<thead>
<tr>
<th></th>
<th>Dry bulk vessels</th>
<th>Oil tankers</th>
<th>Gas Carriers</th>
<th>Container vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low size</strong></td>
<td>Mini-bulkers (&lt;10k dwt)</td>
<td>Handy (10k -50k dwt)</td>
<td>&lt;50,000 m³</td>
<td>&lt;2,000 TEU</td>
</tr>
<tr>
<td></td>
<td>Handysize (10k -35k dwt)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium size</strong></td>
<td>Handymax (35k -50k dwt)</td>
<td>Panamax (50k - 70k dwt)</td>
<td>50k m³-150k m³</td>
<td>2,000 - 8000 TEU</td>
</tr>
<tr>
<td></td>
<td>Supramax (50k - 60k dwt)</td>
<td>Aframax (70k- 100k dwt)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Panamax (55k - 85k dwt)</td>
<td>Suezmax (100k-200k dwt)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Large size</strong></td>
<td>Capesize (85k - 150k dwt)</td>
<td>VLCC (200k - 300k dwt)</td>
<td>&gt; 150k m³</td>
<td>&gt;8,000 TEU</td>
</tr>
<tr>
<td></td>
<td>Largest ship: MS Vale</td>
<td>ULCC (&gt;300k dwt)</td>
<td>Largest size Q-Max ’ (&gt;250k m³)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Valemакс’ (&gt;400k dwt)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Main sizes of cargo vessels

Unlike in many other transport systems, there is no obvious correlation between the volume of a port’s throughput and the level of the country’s income. Several factors explain this situation, including:

- Economies of scale and scope in ports favouring large-scale port projects

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1 dwt: dead weight tonnage (Amount of weight a ship can carry without riding dangerously low in the water)
2 TEU: Twenty-Foot Equivalent Unit (20-foot long standard-size container)
The deregulation of the port industry (since the 1980s/1990s) has opened the door to foreign and private sector interests to invest in and operate LIC’s ports.

Many LIC’s are large exporters / importers of low-value commodities.

The predominance of transhipment and hub and spoke services in liner shipping has led to the mushrooming of large transhipment hubs in developing countries.

The consolidation of port operations among few international terminal operators.

Capacity constraints on existing ports and preference for Greenfield port projects.

Indeed, many LICs (e.g. Djibouti, Bangladesh) have port facilities, particularly container terminals, which match international standards in terminal operations and technology. Going further, the share of developing countries in port operations (and shipping and international trade) has grown dramatically over the past two decades. As shown in Table 3, the list of top container ports in the world is dominated by ports from developing countries particularly those of China and South East Asia.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Port</th>
<th>Throughput in TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2012</td>
</tr>
<tr>
<td>1</td>
<td>Shanghai</td>
<td>32,530,000</td>
</tr>
<tr>
<td>2</td>
<td>Singapore</td>
<td>31,650,000</td>
</tr>
<tr>
<td>3</td>
<td>Hong Kong</td>
<td>23,120,000</td>
</tr>
<tr>
<td>4</td>
<td>Shenzhen</td>
<td>22,940,000</td>
</tr>
<tr>
<td>5</td>
<td>Busan</td>
<td>17,040,000</td>
</tr>
<tr>
<td>6</td>
<td>Ningbo-Zhoushan</td>
<td>16,830,000</td>
</tr>
<tr>
<td>7</td>
<td>Guangzhou</td>
<td>14,740,000</td>
</tr>
<tr>
<td>8</td>
<td>Qingdao</td>
<td>14,500,000</td>
</tr>
<tr>
<td>9</td>
<td>Jebel Ali/Dubai</td>
<td>13,300,000</td>
</tr>
<tr>
<td>10</td>
<td>Tianjin</td>
<td>12,300,000</td>
</tr>
<tr>
<td>11</td>
<td>Rotterdam</td>
<td>11,870,000</td>
</tr>
<tr>
<td>12</td>
<td>Port Klang</td>
<td>10,000,000</td>
</tr>
<tr>
<td>13</td>
<td>Kaohsiung</td>
<td>9,780,000</td>
</tr>
<tr>
<td>14</td>
<td>Hamburg</td>
<td>8,860,000</td>
</tr>
<tr>
<td>15</td>
<td>Antwerp</td>
<td>8,640,000</td>
</tr>
<tr>
<td>16</td>
<td>Los Angeles</td>
<td>8,080,000</td>
</tr>
<tr>
<td>17</td>
<td>Dalian</td>
<td>8,060,000</td>
</tr>
<tr>
<td>18</td>
<td>Tanjung-Pelepas</td>
<td>7,700,000</td>
</tr>
<tr>
<td>19</td>
<td>Xiamen</td>
<td>7,200,000</td>
</tr>
<tr>
<td>20</td>
<td>Bremen-Bremerhaven</td>
<td>6,134,000</td>
</tr>
</tbody>
</table>

Table 3 Top Container Ports (Alphaliner, 2013)

At the same time, many LICs’ ports operate well below international benchmarks both in terms of operational and technical standards. Indeed, in many LCIs a two-tier port system exists: ports which are built, operated and managed by international operators thus benefiting from the latest technological changes and operational standards, and ports being still operated by local operators or governmental agencies thus lagging behind their international counterparts. A common shortcoming across LICs is the lack of capacity and inefficiency of the port’s landside system, e.g. intermodal transport, hinterland and
infrastructure connections, city-port interface, and this is increasingly interfering with other transport and planning problems most notably urban transport and town planning. In this report, and given the ever increasing consolidation and globalisation of the port industry, we will cover research gaps that address both the port industry globally as well as in LICs countries.
SECTION 2

Approach and Methodology

In this study, the following triangulation approach was used to identify the main research gaps in port operations and related technical aspects:

- Review existing relevant port academic and practical research
- Based on the above, develop a themed approach to categorise research needs
- Identify research gaps by theme and port/asset type
- Review and analysis of contemporary trends and future challenges in the port industry
- Match research gaps to industry needs
- Select and highlight gaps and needs relevant to LIC ports.

Literature Review

The approach used to highlight industry trends, scan existing research and identify possible gaps consisted of the following:

1. Brief review of industry, professional and trade journals and publications in the field
2. Quick scan of the academic literature on the subject of port operations,
3. Review of professional publications including industry and policy reports, and
4. Expert review from the author’s own experience and from colleagues at the Global Port Research Alliance between Imperial College, MISCI, MIT, NUS, the University of Hamburg, the University of Sydney, and the Hong Kong Polytechnic University.

The main sources of data and information used are listed in Table 4. In addition, relevant publications and data from international organisations such as UNCTAD, the OECD, the EU TEN-T, the World Bank, etc. as well as from the proceedings of major academic and professional conferences in the field, e.g. the International Association of Maritime Economists annual conference, TOC annual conferences; have also been reviewed.

<table>
<thead>
<tr>
<th>Trade Journals</th>
<th>Academic Journals</th>
<th>Conference Proceedings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Coastal News</td>
<td>Ocean Engineering</td>
<td>Int. Ass. of Ports and Harbours</td>
</tr>
<tr>
<td>Dredging International</td>
<td>Transportation Planning</td>
<td>Int. Ass. of American Port Authorities</td>
</tr>
<tr>
<td>Port Technology</td>
<td>Technology</td>
<td>International Cargo Handling</td>
</tr>
<tr>
<td>Cargo world</td>
<td>Ports and Harbours</td>
<td>Coordination Ass.</td>
</tr>
<tr>
<td>Cargo systems</td>
<td>Maritime Engineering &amp; Technology</td>
<td>Port Equipment</td>
</tr>
<tr>
<td>Fairplay</td>
<td>Maritime Studies</td>
<td>Manufacturers Ass.</td>
</tr>
<tr>
<td>Lloyd’s List</td>
<td>Marine Engineering Review</td>
<td>International Maritime Organisation</td>
</tr>
<tr>
<td>Port strategy</td>
<td>Marine Science and Engineering</td>
<td>European Sea Ports Organisation</td>
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<tr>
<td>Containerisation</td>
<td>Int. J of Shipping &amp; Transport</td>
<td>Int. Harbours Masters Ass.</td>
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<td>International</td>
<td>Logistics</td>
<td>World Ass. for Waterborne</td>
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<td>American Shipper</td>
<td>Maritime Policy &amp; Management</td>
<td>Int. Ass. of Ports and Cities</td>
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<td>Journal of Commerce</td>
<td>J. of Transportation Engineering</td>
<td>Int. Ass. of Dredging Companies</td>
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<td>Hazardous Cargo Bulletin</td>
<td>Transport Reviews</td>
<td>Int. Chamber of Shipping</td>
</tr>
<tr>
<td>Maritime Journal</td>
<td>Int. J of Production Economics</td>
<td></td>
</tr>
<tr>
<td>Maritime News</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4 Main sources surveyed in this study

Research by Themes

An electronic search of articles with relevant topics for the period 2005-2013 has been conducted, leading to a shortlist of 1582 articles. Further refinement has narrowed down the list of relevant articles to 645. In reviewing this shortlist, the articles and papers have been classified by major and minor theme using an iterative approach. First, articles on the same topic and defined research themes were grouped, as relevant to the scope of this study. For instance, ‘port planning’, ‘terminal operations’, and ‘port technology’, were included, whilst articles on areas such as ‘port policy’ and ‘port governance’ were excluded. The research themes were then clustered in industry-broad categories, for instance ‘transport safety’, ‘transport planning’, ‘Intelligent Transport Systems (ITS)’; such classification is widely used across transport modes and infrastructure sectors.

The above review was based on reviews of the abstract and/or the scanning of paper keywords and themes of research using such free tools such as Keyword Density Analyser and Google Keyword Tool. The exercise also led to the identification of major themes and sub-themes. Once the sub-themes were defined, the classification and orientation of port research was scrutinised. Table 5 summarises the main outcome of this review exercise. The list of academic references are included in Annex 1 of this Report.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-theme</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port planning</td>
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</tr>
<tr>
<td></td>
<td>Dredging and channels</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Building materials</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Terminal design and layout</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Equipment manufacturing</td>
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<tr>
<td></td>
<td>Port capacity and resilience</td>
<td>12</td>
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<tr>
<td></td>
<td>Traffic forecasting</td>
<td>35</td>
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<tr>
<td>Port Operations</td>
<td>Navigation and ship movements</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Handling systems</td>
<td>40</td>
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<tr>
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<td>Storage systems</td>
<td>25</td>
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<td>Port performance</td>
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<td></td>
<td>Terminal optimisation</td>
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<td>Reliability and risk</td>
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<td>Handling of hazardous cargo</td>
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<tr>
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<td>Accidents research</td>
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<td>07</td>
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<td>Climate change and sustainability</td>
<td>06</td>
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</tbody>
</table>
The results from table 5 shows the predominance of port planning and port operations themes at the detriment of port safety, port ICT and port environmental themes. Per sub-theme, the less port researched topics are climate change and sustainability, energy efficiency, accidents, human health and safety and the handling of hazardous cargoes, port capacity and resilience, building materials, environmental regulation, port automation, risk and reliability, and ITS applications.
Overview of the Main Trends and Challenges in the Port Industry

In this section, we highlight what is widely considered as the main trends and future challenges faced by the port industry worldwide, with focus on LICs and high volume port operations. In our view, there are 20 main challenges faced by the industry today:

1. Impacts of ship’s size and specialisation
2. Impacts of containerisation and standardisation of cargo packaging
3. Impacts of automation and technological change
4. Increased competition due to deregulation and globalisation
5. Changes in port ownership, organisational and institutional structures
6. Consolidation strategies in shipping and ports
7. Shifts in global logistics and supply chain patterns
8. Developments in international waterways and maritime routes
9. Increasing share of South-South trade and regional integration
10. Changing dynamics of port demand and supply balances
11. Rising energy and bunker fuel prices and related operating costs
12. Customer’s focus on performance differentials and competitive benchmarks
13. Focus on port landside logistics, intermodal and hinterland connections
14. Port city-interface and development
15. Greater emphasis on maritime piracy, port and supply chain security
16. Increasing concerns and interests in occupational health and safety in ports
17. Impacts of global climate changes and environmental policy agenda
18. Skills Gaps and the lack of specialized and highly qualified workforce
19. Increasing private sector participation through PPP and concession arrangements
20. Recession-led adjustments in port finance, risk and investment

From the above, five key areas are particularly relevant to high volume ports and LICs. Areas which are outside the scope of this study such as dry ports and intermodal connections, institutional reform and port policy, port pricing and regulation, and port finance and investments are not covered herein.

1. **Impact of growing ship’s size:** Bigger ships require capital intensive investment, larger and deeper port facilities, and high-technology port equipment and operation processes. The past few years have seen significant changes in ship’s sizes (see table 2 above), while many LICs ports are still small or unsuited to modern and large ships. At the same time the economies of size and scale in the international shipping industry has led to the formation of global shipping alliances and consortia, most recently the P3 alliance between the largest three container shipping companies. Consolidation strategies in the shipping and transport industry often lead to changes in transport networks, service routes, and choice of ports of calls. LIC ports have to adapt their planning, design and operations strategies accordingly. An example of the impact of ship’s size on port equipment is provided in Table 6 below.
<table>
<thead>
<tr>
<th>Generation</th>
<th>Ship name</th>
<th>Capacity (TEU)</th>
<th>DWT (Tons)</th>
<th>Dimensions (metres)</th>
<th>Arrangement (rows)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panamax- Max</td>
<td>Zim Savannah</td>
<td>5,000</td>
<td>67,000</td>
<td>295 x 32.3 x 13.5</td>
<td>8-6-13</td>
</tr>
<tr>
<td>Post Panamax I</td>
<td>Rio Negro</td>
<td>5,900</td>
<td>74,000</td>
<td>286 x 40 x 13.5</td>
<td>9-5-16</td>
</tr>
<tr>
<td>Post Panamax II</td>
<td>Sovereign Maersk</td>
<td>8,500</td>
<td>105,000</td>
<td>347 x 42.8 x 14.5</td>
<td>9-6-18</td>
</tr>
<tr>
<td>Post Panamax II</td>
<td>New Panamax</td>
<td>12,500</td>
<td>120,000</td>
<td>366 x 49 x 15.2</td>
<td>10-6-19/20</td>
</tr>
<tr>
<td>Post Panamax III</td>
<td>MSC Daniela</td>
<td>14,000</td>
<td>165,000</td>
<td>366 x 51.2 x 15</td>
<td>10-6-20</td>
</tr>
<tr>
<td>Post Panamax III</td>
<td>Emma Maersk</td>
<td>14,500</td>
<td>157,000</td>
<td>396 x 56.4 x 15.5</td>
<td>10-6-22</td>
</tr>
<tr>
<td>Malacca-max</td>
<td>Maersk Triple E</td>
<td>18,000</td>
<td>240,000</td>
<td>396 x 68 x 21</td>
<td>13-8-23</td>
</tr>
</tbody>
</table>

Table 6 Relationship between ship size and port engineering and equipment requirements

2. **Impact of containerisation, automation and technological change:** Traditionally, LICs have a low than average propensity (or intensity) rate of containerisation (share of containerisation in break bulk and general cargo traffic). As container transport becomes more affordable, both technically and economically, many LICs are witnessing a rise in their rate of containerisation propensity, but this also poses numerous challenges in terms of specialised port facilities, engineering systems, cargo handling equipment, and related IT and operating processes.

Modern terminal operations and processes are now largely automated with a high level of capital and technology resources. On the other hand, no LIC port currently has a fully automated terminal facility and LIC ports have inherited or are still working with conventional manual systems. LICs must therefore adapt their terminal infrastructure, operations, equipment and IT systems accordingly and there is a huge need to train and educate highly qualified and technically specialised port workforce.

Some may argue that port automation may be harmful to LICs in terms of job losses or loss of competitiveness. However, as proven in the 1950s through to the 1980s in developed countries, automation actually creates more jobs and improves economic competitiveness and operational efficiency. Thanks to automation, new jobs would be required for designing, operating, and maintaining port automated equipment and ICT systems. At the same time, LICs have little choice but to embrace port automation as such a trend is being implemented globally as standard models for operations by international terminal operators. LICs would therefore need to invest in the appropriate skills required for port automation, and this would not only improve the quality and earning potential of a port’s workforce but also improve a port’s efficiency and reduce trade and logistics costs.

3. **Developments in ship size, maritime routes and port efficiency:** The impact of the new Panama-canal, prospects of a Nicaragua canal, the potential widening of the Suez Canal, and the new possibilities from the North-Sea passage will all have an impact on maritime routes and services, hence offering opportunities but also posing constraints to many LIC ports which have to upgrade engineering capacity and improve operational efficiency to retain existing or gain new market shares. Such developments are coupled with the increase in ship’s size and technology and the development of large transhipment and hub-and-spoke systems. The introduction of very large vessels has contributed to a widening gap between few large efficient ports, which benefit from the economies of scale, leaving many LIC ports increasingly relying on feeder services.
At the same time, shipping lines, shippers, freight forwarders and other port customers are now benchmarking ports’ efficiency and require from ports higher levels of performance standards. Poor port efficiency is usually embedded in higher ship turnaround time, cargo dwell time, and queuing and congestion time; and translates into additional shipping and port surcharges as well as higher transport and trade costs. LIC ports will have to achieve major leaps in port performance and efficiency and significantly reduce congestion and ship’s turn-around times. Many LIC ports particularly those in Sub-Saharan Africa and South Asia are experiencing severe congestions and long delays and unless extra capacity is provided, either through productivity improvement or through new expansion.

4. **Greater emphasis on port safety and security:**
   Over the past decade or so, there has been a greater emphasis on port security and most ports around the world should now have security plans, systems and procedures in line with international and local security regulations, most notably the ISPS Code (IMO International Ship and Port Facility Security Code). However, many trading nations and global industry operators require security systems and procedures that go beyond the ISPS Code standards, for instance in terms of secure terminal design and layout, security equipment and machinery, cargo integrity, electronic seals and scanning technology.

   In port health and occupational safety, there is no internationally enforceable port safety standard despite growing evidence of risks and incidents from ship’s safety in ports, the quality of port pavement and pathways, the handling and storage of hazardous materials (HAZMAT), port traffic hazards, the operations and maintenance of port equipment and machinery, electrical and chemical installations, and excess weight of containers and other cargo packaging units.

   In LIC ports, both safety and security incidents are too high and often go unreported. At the same time, many LIC ports are becoming major load and storage centres of bulk commodities such as oil, grain, minerals, and others. Enhancing port safety and security requires adherence to higher levels of infrastructure build, terminal design, equipment and operational standards, IT, human and management processes.

5. **Relationship to landside logistics, hinterland connections, and city-interface:**
   Along with the trend of optimisation and standardisation of quay-side operations, physical and capacity constraints at berths and the interplays between freight distribution requirements and urban and city plan, all suggest that more focus must be placed on port inland interface and intermodal connectivity. On the one hand, the increase in trade volumes and the emergence of new distribution patterns, means that the demand on port seashore infrastructure (and the immediate land behind it) is nearing capacity, hence the need to expand land-wise to and connect to hinterland and intermodal systems. On the other hand, reported inefficiencies in ports indicate that landside operations are far behind their optimal efficiency lagging both in intermodal infrastructure, connectivity and interoperability.

   In ports, interoperability must be achieved at both operational and technology levels. Operational interoperability refers to the ability of port systems to handle various types and sizes of ships and their cargoes, including for conforming to operating requirements and safety standards. The capability to integrate various intermodal systems (e.g. railroads) is also a key to achieving a high degree of operational interoperability in ports. Communication and IT interoperability between port and intermodal systems can be achieved through the exchange of documentation, data and information in interoperable semantics, communication protocols, and file
In LICs, the lack of interoperability between ports and intermodal connections is a major impediment against developing successful port operations.

For LICs, the structure of the economy and the low levels of urbanisation would normally mean that strategies of inland integration, if properly planned and operated, will have less disruptive impacts on land use and urban congestion, waterfront management, and environmental sustainability. The reality though is that in most LICs, ports are embedded in capital or commercial cities resulting into port and city congestions. Port access to and from land transport corridors are poor due to insufficient or inadequate intermodal and hinterland infrastructure and connections. The port-city interface in many LICs is marked by various negative impacts, including on air quality, water, waste, noise, odours and urban and freight traffic. Furthermore, landlocked LICs rely heavily on landside port logistics, including dry ports and transit connections, for unlocking trade and transport bottlenecks and boosting their competitiveness in the international market.

6. Climate change impacts and policy agenda for environmental sustainability:
Climate change is one of the greatest challenges facing our societies, economic structures and environmental systems. Climate change risks for ports include accelerated coastal erosion, port and coastal inundation or restrictions on access to docks, increased run-offs and situations requiring further dredging, and deterioration of conditions and problems with the structural integrity of pavements. Many LIC ports, particularly those in small-island developing States (SIDS), are located in sensitive coastal zones, low-lying areas and deltas, and must design and implement appropriate adaptation and mitigation strategies to global climate change risks and impacts.

Typically, climate adaptation in ports can be generically divided into two categories:

- Building capacity for future change through awareness raising, skill development, data collecting, monitoring and research, and
- Implementing adaptation initiatives such as technological, engineering change, planning, design, legal/regulatory, insurance/financial measures and management system change.

Once a port has identified vulnerabilities and risks within both current and future contexts, analysed and evaluated them, it is then possible to propose and assess adaptation options to reduce and/or mitigate environmental and climate change risks. Examples of adaptation actions could include one or a combination of the following:

- Design & Engineering: robust breakwater, quay wall, equipment, etc. port systems
- Planning: Port plans should be flexible and adaptable to different scenarios of environmental and climate change risks.
- Technology: Use of technological advances to predict / mitigate environmental risks, e.g. automation, low emission equipment & operations, ITS & Optical Character Recognition (OCR) systems, etc.
- Management & Insurance: Adapt Occupational Health & Safety (OHS), emergency, risk management and response systems, enrol in and purchase appropriate insurance schemes.

There are however several barriers to climate adaptation in ports, including inconsistency between organisational planning time frames (5 – 15 years) compared with climate projections of 30 – 90 years; and the uncertainty of local climate
projections leading to decision-makers delaying action until there is perceived to be more certainty.
Matching Research Gaps to LICs Port Needs

From the combination of the LICs’ needs and challenges above and the research gaps listed in Section 2, we have identified several gap areas in port research grouped into 5 themes and 15 sub-themes as flows:

1. **Port Planning**
   1.1 Port Capacity and resilience
   1.2 Building materials, port protection and maintenance
   1.3 Next generation terminal design and layout

2. **Port Operations**
   2.1 Port efficiency and benchmarking
   2.2 Port and equipment optimisation
   2.3 Intermodal operability
   2.4 Port training and capacity building

3. **Port Technology**
   3.1 Port automation
   3.2 ITS applications in ports
   3.3 Technological interoperability

4. **Port Safety and Security**
   4.1 Port occupational health and safety
   4.2 Port accidents and reporting
   4.3 Port security and supply chain risk
   4.4 Risk modelling and analysis in ports

5. **Port environmental sustainability**
   4.5 Climate change impact and adaptation strategies
   4.6 Environmental regulation and impact of emission control areas (ECA)
   4.7 Energy efficiency and use in ports

Table 7 below outlines how the identified research gaps translate into LICs needs in port engineering and operations.
<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-theme</th>
<th>Relevant areas to LIC ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Planning</td>
<td>Port Capacity and resilience</td>
<td>Maritime spatial planning, port rehabilitation (after periods of wars, neglect, etc.), hydrographical surveys, access channels &amp; navigational aids, deep construction dredging, small ports for SIDS, railway and road infrastructure, capacity reliability, resilience to large scale events (terrorist attacks, earthquakes, tsunamis, etc.), design for redundancy.</td>
</tr>
<tr>
<td>Building materials, protection &amp; maintenance</td>
<td></td>
<td>New types / structures of quay walls and jetties, pavement, maintenance dredging, sustainable materials, Environmental impact analysis (EIA), integrated coastal zone management (ICZM).</td>
</tr>
<tr>
<td>Next generation terminal design and layout</td>
<td></td>
<td>Offshore and onshore terminal layout, specialised terminal layout, automated terminals, inland terminal design (incl. dry ports, rail yards, etc.), storage and tank farms, handling and equipment redesign</td>
</tr>
<tr>
<td>Port Operations</td>
<td>Port efficiency and benchmarking</td>
<td>Equipment engineering standards, crane efficiency, ship scheduling, queuing systems, operational processing, terminal productivity.</td>
</tr>
<tr>
<td>Port equipment and optimisation</td>
<td>Specialised equipment (e.g. refrigeration), equipment design and maintenance, optimising crane scheduling and operations, path finding, container location, port modelling and simulation, decision support systems in ports.</td>
<td></td>
</tr>
<tr>
<td>Intermodal operability</td>
<td>Port-ship interoperability, port-rail and port-road interoperability, operating requirements and working standards, integrated intermodal systems, seaport and dry port interoperability, interoperable transit systems.</td>
<td></td>
</tr>
<tr>
<td>Port training and capacity building</td>
<td>Port engineers and designers, port planners, quay crane drivers, port automation and optimisation personnel, training for technology applications in ports, port engineering and operations training modules, safety and security training.</td>
<td></td>
</tr>
<tr>
<td>Port Technology</td>
<td>Port automation</td>
<td>Automated terminals, automated guided vehicles (AGV) and automated staking cranes (ASC), automated mooring systems, automated gate and intermodal operations, automation control.</td>
</tr>
<tr>
<td>Port ITS applications</td>
<td>Wireless port data and communications, vehicle (equipment) electronics, automatic steering and sensing, Fleet management systems, collision avoidance systems, tracking, tracing and real time location, automated identification systems, telemetry image processing, electronic data transmission and port community systems, GPS and applications in ports, data integration and ERP applications in ports, electronic payments and e-commerce, terminal operating systems (TOS), scanning and security technology.</td>
<td></td>
</tr>
<tr>
<td>Technological interoperability</td>
<td>Enterprise interoperability standardised and harmonized port community systems, interoperable semantics and communication protocols, interoperable software, interoperable intermodal technology (ship-terminal-railroad), VTS and SAR interoperability, e-payment and e-government interoperability.</td>
<td></td>
</tr>
<tr>
<td>Port Safety and Security</td>
<td>Port occupational health and safety</td>
<td>Terminal safety, equipment safety, navigation and traffic safety, equipment safety, OHS during port construction and repairs, Port labour OHS, safe operations during extreme conditions,</td>
</tr>
<tr>
<td>Port accidents and reporting</td>
<td>Traffic separation schemes, GIS, GMDSSE and DSS systems and connectivity, SAR (search and rescue) facilities &amp; equipment, accident reporting systems, emergency and contingency plans.</td>
<td></td>
</tr>
<tr>
<td>Theme</td>
<td>Sub-theme</td>
<td>Relevant areas to LIC ports</td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Port security and supply chain risk</td>
<td>Safety and security engineering, infrastructure security, ship security, port and terminal security, equipment security, network security, supply chain security, design of security systems, security standards and processes,</td>
<td></td>
</tr>
<tr>
<td>Risk modelling and analysis in ports</td>
<td>Safety and security threats to port, port vulnerability, models for safety and security assessment, engineering risk analysis, models for port shutdowns and mass evacuation, safety risk management, risk modelling for port security</td>
<td></td>
</tr>
<tr>
<td>Climate change impact and adaptation strategies</td>
<td>Models for sustainable infrastructure design and operations, warning systems and applications, climate resilient seaports, adaptation engineering tools and technologies for ports.</td>
<td></td>
</tr>
<tr>
<td>Environmental regulation and impact of ECAs</td>
<td>Emission control and inventory, handling of hazardous cargoes, LNG bunkering, cleaner fuels, environmental protection, equipment and systems to prevent and mitigate marine pollution, port engineering and industrial pollution, port reception facilities.</td>
<td></td>
</tr>
<tr>
<td>Energy efficiency and use in ports</td>
<td>Electrical mooring / unmooring, electrical equipment, technical and operating models, models for reducing energy use, hybrid and electrically powered equipment, equipment retrofitting and rebuilding, reuse of waste waters and dredged materials,</td>
<td></td>
</tr>
</tbody>
</table>

Table 7 Main research gaps and implications for LIC ports
ANNEX 1

Academic References


