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Abstract

This deliverable aims to specify vulnerability methodologies that can be applied to seismic risk analysis of ports. In the first section is briefly reported for reference the taxonomy for the components of harbor facilities. Details for the typologies, fragility analysis models, damage states definitions and performance indicators of the different elements are given in deliverable D3.9 (Kakderi et al, 2010). The performance measures are further described in deliverable D2.7 (Kakderi and Pitilakis, 2011). In the next section the general framework for the systemic vulnerability analysis as well as the inter- and intra- dependencies of harbors are described. The last section presents the software implementation and the structure of classes and sub-classes for the port facilities.

*Keywords: harbor facilities, port operations, simulation, systemic loss*
Acknowledgments

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1 Taxonomy of harbors

1.1 GENERAL DESCRIPTION

Port transportation systems are vital lifelines whose primary function is to transport cargos and people. They contain a wide variety of facilities for passenger operations and transport, cargo handling and storage, rail and road transport of facility users and cargoes, communication, guidance, maintenance, administration, utilities, and various supporting operations.

The following elements exist within port facilities:

- Waterfront structures.
- Cargo handling and storage components.
- Infrastructures.
  - Buildings (sheds and warehouses, office buildings, maintenance buildings, passenger terminals, traffic control buildings).
  - Utility systems (electric power system, water system, waste-water system, natural gas system, liquid fuel system, communications system, fire-fighting system).
  - Transportation infrastructures (roadway system, railway system, bridges).

The main characteristic of these complex systems is the multiple interactions existing within their elements and with the external supplying or/and supplied systems and infrastructures. The ports’ functionality is dependent on the functioning of each system/component, taking also into consideration the interactions between them. For the systemic vulnerability and loss of lifeline systems and infrastructure facilities in harbors (buildings, utility systems and transportation infrastructures), the reader is referred to the respective deliverables [D5.1 “Systemic vulnerability and loss for building aggregates in urban scale” (Gehl et al., 2011), D5.2 “Systemic vulnerability and loss for electric power systems” (Pinto et al., 2011), D5.3 “Systemic vulnerability and loss for gas and oil networks” (Esposito and Iervolino, 2011), D5.4 “Systemic vulnerability and loss for water and waste-water systems” (Argyroudis et al., 2011), D5.5 “Systemic vulnerability and loss for transportation systems” (Pinto et al., 2012)]. In the followings, focus is given to the description of the general framework for the systemic vulnerability analysis of harbors accounting for the interdependencies among their components. The software implementation and the structure of classes and sub-classes for the port facilities are also presented.

As explained in the deliverable D2.1 “General methodology for systemic seismic vulnerability assessment” (Franchin et al 2011), components may be classified essentially in “point-like” components (critical facilities) or “line-like” (network)
components, in respect to the geometric point of view and the approaches used for the characterization and definition of the vulnerability. The internal classification and distribution of the utilities and infrastructures within port facilities can be in general distinguished in “point-like” critical facilities and “line-like” (network) components. An example is given for the water supply network. The water supply system as a whole is composed of a number of point-like critical facilities (water sources, treatment plants, pumping stations, storage tanks) and of the water distribution network itself. The internal logic of the critical facilities and their function in the management of the whole system should be modeled explicitly. The network portion of the system is made of: pipelines, tunnels and canals and the supervisory control and data acquisition (SCADA) sub-system.

Especially for port facilities, cargo handling and storage components comprise point-like critical facilities, whose internal logic and function in the management of the whole system should be modeled explicitly. Waterfront structures are “line-like” (network) components. From a topological point of view, they follow the external boundaries of piers and/of the coastline.

Finally, for the characterization and definition of the vulnerability, both waterfront structures (HBR01) and cargo handling and storage components (HBR03) can be considered as “line-like” components, and the vulnerability methodology explained below will be referred to those components. For the rest of the port components' systemic vulnerability [buildings (HBR04), electric system (HBR_A), water system (HBR_B), waste-water system (HBR_C), gas system (HBR_D), oil system (HBR_E), communication system (HBR_F), fire-fighting system (HBR_G), roadway (HBR_H) and railway (HBR_I) networks] the reader is referred to the respective deliverables, while earthen embankments (HBR02) are not considered in the analysis. In summary, lifeline and infrastructure systems which are present inside port facilities (components HBR_A to HBR_I) are comprised of both “point-like” and “line-like” components. For example, a water supply network consists of “point-like” critical facilities (like pumping stations and storage tanks), while pipelines are considered “line-like” components. On the other hand, in the SYNER-G methodology, buildings and building aggregates are considered as area-type objects and they are represented by abstract cell elements (Gehl et al. 2011).

1.2 PORT SYSTEM COMPONENTS

HBR01 Waterfront Structures

Include retaining structures/dikes (e.g. at wharves, embankment, breakwaters, and dredged shipping lanes and waterway) and berthing structures.

- Gravity retaining structures along the waterfront (quay walls/piers): concrete block walls, massive walls, concrete caissons, cantilever structures, cellular sheet pile structures, steel plate cylindrical caissons or crib-work quay walls. Founded on rubble and soil or rock.
Sheet pile wharves with auxiliary structures for anchoring or sheet pile with platform (horizontal pile-supported slab). Foundation on sheet pile, pile, fill-soil.

Piers usually of deck slabs supported on pile caps and piles from wood, steel or concrete (with or without batter piles). Structures on columns with auxiliary structures for horizontal force absorption.

Mooring and breasting dolphins. Monolithic gravity structures, founded on rubble and soil or rock or piles, or pile structures.

Breakwaters: gravity structure, piled structure, or rubble mound.

HBR02 Earthen Embankments
They include hydraulic fills and native soil materials.

HBR03 Cargo Handling and Storage Components
They include cranes, tanks and other cargo handling and storage components.

Cranes - rail, tire and track mounted gantry and revolver cranes, mobile cranes and crane foundations and power supply systems.

Tanks - anchored and unanchored, above grade and partially buried, tank foundations and containment berms.

Other cargo handling and storage components (cargo) – port equipment (stationary or mounted on rails) and structural systems used for material handling and transport (cranes, conveyors, transfer towers and stacker/reclaimer equipment), tunnels and pipelines, and temporary transitional storage and containment components.

HBR04 Buildings
They can be classified as following:

Sheds and warehouses (large, open, frame-type structures with long-span roof systems, usually braced in one or two directions. Walls of concrete, masonry or medal siding.)

Office buildings (single or multi-storey steel, timber, concrete or masonry construction).

Maintenance buildings (similar to shed and warehouse structures).

Passenger terminals (usually long-span structures from concrete, masonry, steel or wood.).

Control and clock towers (tall, narrow tower-type structures, usually steel-framed with exterior masonry or other cladding).

Older unreinforced masonry and non-ductile concrete frame structures, prior to seismic codes, often exist in port facilities and have been used for warehouse, offices, maintenance, and passenger terminals buildings.
Finally, harbors are serviced by a number of other systems including: electric system (HBR_A), water system (HBR_B), waste-water system (HBR_C), gas system (HBR_D), oil system (HBR_E), communication system (HBR_F), fire-fighting system (HBR_G), roadway (HBR_H), railway (HBR_I).
2 Systemic vulnerability methodology

Current engineering practice for seismic risk reduction for port facilities is typically based on design or retrofit criteria for individual physical components (e.g., wharf structures) expressed as prescribed levels of displacement, strain, etc. However, the resilience and continuity of shipping operations after an earthquake depends not only on the performance of these individual components, but on their locations, redundancy, and physical and operational connectivity as well; that is, on the port system as a whole.

Several researchers have studied the seismic performance of the network systems such as highway, power supply, and water distribution network. However, the available approaches for the seismic performance of port system are limited. In almost all past studies the evaluation of the post-earthquake performance of the lifeline system is based on the simulation of the damage states of each component under given scenario earthquakes; it is hence a typical seismic risk assessment (SRA) methodology. They do not consider how damage and downtime of these structures might disrupt the overall port system’s ship handling operations and the regional, national, and even international economic impacts that could result from extended earthquake-induced disruption of a major port. They basically remain at the estimation of direct physical losses (structural damage and replacement and repair costs) (NIBS, 2004). In few cases direct (economic loss to direct physical damage, such as business interruption and income loss) (Pachakis and Kiremidjian 2003, 2004; Na et al. 2007, 2008) and indirect (economic impact that is driven by the damages in other sectors led by an earthquake) (Rix et al. 2009) economic losses are assessed, while in general the interaction effects and the integrated response of the port system are not taken into consideration.

The available methodologies for the evaluation of port seismic performance are summarized in deliverable D2.7 (Kakderi and Pitilakis, 2011).

2.1 SYSTEM COMPONENTS VULNERABILITY

Within the seismic vulnerability analysis of port systems, port facilities (e.g. waterfront structures, cargo handling and storage components), and port infrastructures (e.g. buildings, utility systems, transportation infrastructures) are considered as vulnerable components. Fragility functions for port facilities are provided in the deliverable D3.9 “Fragility functions for harbor elements” (Kakderi et al., 2010), while for port infrastructures fragility functions are described in the respective deliverables of WP3.
2.2 SYSTEM PERFORMANCE INDICATORS

In general, the measures used to assess the performance of any system are defined based on the following criteria:

- Inventory Functions – physical characteristics, numbers of facilities, labor, equipment.
- Engineering – structural integrity, deterioration.
- Operational Reliability – delay, closures.
- Economical and Financial – Cost/Benefit Analysis, capital and financial resources.
- Demand - Traffic volumes and flows.
- Safety and Security.

Ports are essentially providers of service activities, in particular for vessels, cargo and inland transport. As such, it is possible that a port may provide sound service to vessel operators on the one hand and unsatisfactory service to cargo or inland transport operators on the other. Therefore, port performance cannot normally be assessed on the basis of a single value or measure.

Traditional approaches to port performance consider the port as an industry which, like any other industry, measures its performance, mainly based on efficiency analysis. On the other hand, many simulation models of port operations, especially container port operations, have been developed. Finally, the effect of an earthquake event on port operations has been addressed only by two recent studies (Na and Shinozuka, 2009; Pachakis and Kiremidjian, 2004).

The available system performance indicators are summarized in deliverable D2.7 (Kakderi and Pittilakis, 2011). More generally, container throughput is unquestionably the most important and widely accepted indicator of port or terminal output (in general throughput volume). Almost all previous studies treat it as an output variable because it closely relates to the need for cargo-related facilities and services and is the primary basis upon which container ports are compared, especially in assessing their relative size, investment magnitude or activity levels. Based on this, port throughput (with appropriate differentiations according to port commodities) is intrinsically the main indicator that will be used for the assessment of port performance within SYNER-G.

2.3 INTER-DEPENDENCIES

The inter-dependencies between harbor facilities and the other systems are described in Table 2.1. They are distinguished in physical (direct) and informational, geographic, restoration, substitute (indirect) inter-dependencies. Furthermore, they are classified as crucial, important and secondary. Within SYNER-G it was decided to study only the direct/crucial interactions in the "crisis short-term" period.
### Table 1

**Inter-dependencies between harbor and other networks as identified in SYNER-G.**

<table>
<thead>
<tr>
<th>Impacts</th>
<th>BDG</th>
<th>EPN</th>
<th>WSS</th>
<th>WWN</th>
<th>GAS</th>
<th>OIL</th>
<th>RDN</th>
<th>HBR</th>
<th>HCS</th>
<th>FFS</th>
<th>SHM</th>
<th>HIM</th>
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<tbody>
<tr>
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<td>BDG</td>
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<td>Electric power network</td>
<td>EPN</td>
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<tr>
<td>Potable water network</td>
<td>WSS</td>
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<td>Wastewater network</td>
<td>WWN</td>
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<td>Gas network</td>
<td>GAS</td>
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<td>1-Phy / Geo , 3-Res</td>
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<tr>
<td>Health-care system</td>
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<td>Fire-fighting system</td>
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<td>Shelter model</td>
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<tr>
<td>Health impact model</td>
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</tbody>
</table>

**Priorities definitions:**

1-Crucial dependencies (that MUST be both well described and implemented).

2-Important dependencies [that NEED to be well described and that SHOULD be implemented (if possible, using simplifications if necessary)].

3-Optional/secondary dependencies (that should be mentioned, but whose implementation is not necessary).
Types of interactions:

*Direct:*

*Indirect:*
Inf: Cyber, informational interdependency
Geo: Collocation, geographic, space interdependency - physical damage propagation.
Res: Restoration - recovery interdependency.
Sub: Substitute interdependency.
Seq: Sequential interdependency - scaling effects.
Log: Logical interdependency, financial markets - policy/procedural interdependency.
Gen: General interaction.
Soc: Societal interdependency.

2.4 INTRA-DEPENDENCIES

The intra-dependencies between port facilities and infrastructures are described in Table 2.2. They are distinguished in physical (direct) and informational, geographic, restoration, substitute (indirect) inter-dependencies. Furthermore, they are classified as crucial, important and secondary. Within SYNER-G it was decided to study only the direct/crucial interactions in the "crisis short-term" period.
<table>
<thead>
<tr>
<th>Impacts</th>
<th>HBR01</th>
<th>HBR02</th>
<th>HBR03</th>
<th>HBR04</th>
<th>HBR_A</th>
<th>HBR_B</th>
<th>HBR_C</th>
<th>HBR_D</th>
<th>HBR_E</th>
<th>HBR_F</th>
<th>HBR_G</th>
<th>HBR_H</th>
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<td>1- Phy</td>
<td>1- Phy</td>
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<tr>
<td>Cargo handling and Storage</td>
<td>HBR03</td>
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<td>Water system</td>
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<td>2- Phy</td>
<td>2- Sub</td>
<td>3- Phy</td>
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Table: Intra-dependencies in port facilities as identified in SYNER-G.
### Systemic vulnerability methodology

<table>
<thead>
<tr>
<th>Roadway</th>
<th>HBR_H</th>
<th>2- Phy</th>
<th>2- Phy</th>
<th>3- Res</th>
<th>3- Res</th>
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<th>2- Sub</th>
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<tbody>
<tr>
<td>Railway</td>
<td>HBR_I</td>
<td>2- Phy</td>
<td>2- Phy</td>
<td>3- Res</td>
<td>3- Res</td>
<td>3- Geo, 3- Res</td>
<td>3- Geo, 3- Res</td>
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<td>3- Geo, 3- Res</td>
<td>1- Phy, 3- Res, 3- Geo</td>
<td>2- Sub</td>
</tr>
</tbody>
</table>

**Priorities definitions:**

1. Crucial dependencies (that MUST be both well described and implemented).
2. Important dependencies (that NEED to be well described and that SHOULD be implemented (if possible, using simplifications if necessary)).
3. Optional/secondary dependencies (that should be mentioned, but whose implementation is not necessary).

**Types of interactions:**

*Direct:*

*Indirect:*
- Inf: Cyber, informational interdependency
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- Sub: Substitute interdependency.
- Seq: Sequential interdependency - scaling effects.
- Gen: General interaction.
- Soc: Societal interdependency.
2.5 SYSTEMIC VULNERABILITY APPROACH

For the assessment of the systemic vulnerability of harbors, it is essential to simulate port operations, as long as the derivation of performance in case of perturbations, such as the occurrence of an earthquake event. Normal operations include movement of cargos (containers and bulk cargo) and people.

Since most of the dry cargo in modern ports is containerized, the operations of a port consisting of container terminals should be studied. Moreover, bulk cargo is also important from the viewpoint of risk management on economic activities such as industrial and insurance market. In the case of Kobe earthquake, large amount of losses occurred for container cargo by ground shaking. Bulk cargo was also suffered severe damage. The potential of damage risk for bulk cargo due to liquefaction as well as Tsunami is higher than the risk due to ground shaking.

The passenger movement is also an important element to monitor a depression and recovery process of port function. Nevertheless, there is not enough data on passenger movement to assess the vulnerability in past earthquake events, such as the 1995 Kobe Earthquake. From this point of view, it would be difficult to develop simulation models.

Based on this, it was decided to simulate container and bulk cargo movements of ports. The assumption of discrete port functions per terminal is made (container terminals and bulk cargo terminals are defined). The elements studied include the piers and berths (waterfront) and cargo handling equipment. Pier is a linear sum of berths close to each other. The berth (ship) length is estimated based on the pier's operational depth. Also each crane capacity (lifts per hour) is considered in the evaluation. The main Performance Indicator (PI) used is the total cargo handled in a pre-defined time frame per terminal and for the whole port system.

An important interdependency considered within SYNER-G is between the cargo handling equipment and EPN, in particular about the electric power supply to the cranes. If a crane node is not fed by the reference EPN node (electric supply station) with power, and the crane does not have a back-up power supply, then the crane itself is considered out of service. Another dependency that could be taken into account includes road closures due to potential building collapses. In this case, the cargo movements from the terminals to the port gates could be hampered.

The functionality of the harbor is assessed through several system-level Performance Indicators (PIs), as evaluated starting from the effects of seismic events (Fig. 3.1). As a general outline of the method, PIs are evaluated for each modeled event, and then annual rates of exceedance are evaluated from a given number of events sampled from the seismic hazard. For each event and for all components, physical damages are sampled from their probability of occurrence, as assessed from fragility curves for sampled IMs. In case of components which are sensible to both ground shaking (e.g., PGA) and ground failure (e.g., PGD), like for example cranes, multiple IMs and damage probabilities are assessed in parallel and the results are combined through a Fault Tree Analysis (OR gate). Based on the sampled physical damages for each event, the functional state of each component is assessed, also taking into account system inter-
and intra-dependencies. Finally, the PIs for the modeled event are evaluated, based on component characteristics.

**Fig. Error! No text of specified style in document.**

In the followings, we will describe in more details the PIs selected for the harbor system, and the modeling strategy adopted.

### 2.5.1 Container terminals

1. **Terminal**

The terminal performance is measured in terms of:

\[
T_{CoH} = \text{total number of containers handled (loaded and unloaded) per DAY, in Twenty-foot Equivalent Units (TEU)}
\]

For all container terminals, the sum of the various PIs could be considered.

*Initial input data* include:

- the terminal considered,
- the number and location of piers,
- the operational depth of piers,
- the Vs30 at each pier,
- the location and pier of the cranes,
- the electric power demand EPN node connected with each crane,
- the type of each crane (anchored or not),
- the type of the waterfront-pier (gravity or sheet-pile wall),
- the crane productivity (lifts per hour) \(r\),
- the vulnerability or not of each component,
- the Intensity Measure (IM) type for the vulnerable classes,
the seismic hazard input, in common for all systems in SYNER-G, either single scenario (one fault) or a complete hazard (see D2.1, Franchin et al. 2011).

The berth (ship) length is estimated based on the pier’s operational depth, through the following equation (Pachakis and Kiremidjian, 2005).

\[
\text{Draft} = \begin{cases} 
-0.100 + 0.056 \cdot \text{LOA}, & \text{for } \text{LOA} \leq 200 \text{m} \\
7.668 + 0.018 \cdot \text{LOA}, & \text{for } \text{LOA} > 200 \text{m}
\end{cases}
\]

(0.1)

where \(\text{draft} = \) the depth of the pier, and \(\text{LOA} = \) berth (ship) length.

The number of births is defined in such way, in order to have an integer number \(\geq\) of the estimated berth length. To each berth the closest crane is assigned. Then, for the cranes with no birth assignment, the closest berth is defined and assigned at. In this way, each berth has at least one crane assigned.

The electric power supply to the cranes is assumed to be provided from a demand node (substation) through non-vulnerable lines. In case of failure of power supply, cranes can work with their back-up power supply, where there is one. The functionality of the demand node is generally based on \(\text{EPN}\) system analysis (see D5.2, Pinto et al. 2011). In cases where a power flow analysis cannot be performed, connectivity analysis is proposed as an alternative.

For the PI estimation, the following rules are set:

- Waterfront-pier (berth) \(\rightarrow\) functional if \(D < \) Moderate (for each IMtype).
- Crane \(\rightarrow\) functional if \(D < \) Moderate AND there is electric power supply (from the electric network or from the back-up supply).
- Berth \(\rightarrow\) functional if the waterfront and at least 1 crane is functional, otherwise \(\text{PI}_{bi} = 0\).

At every berth there is at least one crane – in case of more than one cranes they can work simultaneously to load/ upload containers from the same ship – the time the ship stays at each berth is then reduced.

- CraneCapacity = \(r \times 24\) \(\text{TEU/day}\) (Twenty-foot Equivalent Units per day) an assumption is made of 24 hours shifts
- Berth \(\rightarrow\) \(\text{PI}_{bi} = \) \(\text{Ncrane} \times \text{CraneCapacity}\)
- Pier \(\rightarrow\) \(\text{PI}_{pm} = \Sigma \text{PI}_{bi}\)
- Terminal \(\rightarrow\) \(\text{PI}_{tr} = \Sigma \text{PI}_{pm}\)
- Harbour \(\rightarrow\) \(\text{PI}_{H} = \Sigma \text{PI}_{tr}\)

2. Gate

The port performance at the gate is measured in terms of:

\(\text{TCoM} = \) total number of containers’ movements per DAY, in Twenty-foot Equivalent Units (TEU) (in the whole harbor facility)
In this case the total number of containers' movements per DAY is equal to the sum of total number of containers handled per DAY in each container terminal, given the fact that there are no road closures.

For the assessment of TCoM, in addition to the input parameters reported above, it is necessary to input the road system (RDN) that connects each terminal to the harbor’s gate, as well as the buildings inside the harbor that may collapse on such roads (see D5.5, Pinto et al., 2012 and D5.1, Gehl et al., 2011). To do so, as regards the HRB input, the necessary input is:

- link to a RND node for exit from each terminal
- link to a RND node for the harbor’s gate

The connectivity between terminals and harbor’s gate is based on the RDN system analysis (D5.5, Pinto et al., 2012). Finally, the harbor’s TCoM is set as the sum of terminals’ TCoMs, which is set equal to its TCoH, if the terminal is connected to the gate, otherwise to 0.

### 2.5.2 Bulk cargo terminals

1. **Terminal**

   The terminal performance is measured in terms of:

   \[ TCaH = \text{total cargo handled (loaded and unloaded) per DAY, in tones} \]

   For all container terminals, the sum of the various PIs could be considered. The same methodology can be used as for the container terminals, with the following modifications:

   - The crane productivity \( r \) is given in tones per hour.
   - CraneCapacity = \( r \times 24 \) tones/day (an assumption is made of 24 hours shifts).

2. **Gate**

   The port performance at the gate is measured in terms of:

   \[ TCaM = \text{total cargo movements per DAY, in tones (in the whole harbor facility)} \]

   In this case the total cargo movements per DAY are equal to the sum of total cargo handled per DAY in each bulk cargo terminal, given the fact that there are no road closures. The additional parameters, with respect to TCaH, and the procedure adopted to assess TCaM are analogous to the ones described above for TCoM.
3 Software implementation

3.1 HRB CLASSES

The harbor system is made up of *structures* (terminals, piers and berths) that include nodes and sides (cranes and waterfronts, respectively). Structures have a logical hierarchy (each terminal includes one or more piers, which are made up of one or more berths). Cranes and waterfronts own to one specific pier and terminal, information that is input by the user. The position and the configuration of berths are automatically assigned by the software. Following the naming convention set up for other systems (e.g., WSS system in D5.4, Argyroudis et al. 2011), the harbor’s elements are classified in the following *classes* (Fig. 3.2):

- **Harbour**: part of the “network” class
- **HRBnode**: which includes Cranes
- **HRBside**: which includes Waterfronts
- **HRBstructure**: which includes Terminals, Piers, and Berths (internal class – not explicit to the user)

![Class diagram for the harbor classes](image)

In the following, the *properties of the HRB class* are listed. The names follow the naming convention adopted for variables in developing the prototype software, whereby multi-word names have no blank spaces in between words and the latter are separated
by capitalizing the initial letter of each word. This list is still provisional, and can be updated during the application period of SYNER-G. It is split into five parts:

1. Several pointers, including:
   - **Parent**: this is a pointer to the parent object which, in this case, is the Infrastructure (the object from the Infrastructure class).
   - **Crane**: pointers to all the cranes in the system, objects from the Crane class.
   - **Waterfront**: pointers to all the cranes in the system, objects from the Waterfront class.
   - **Berth**: pointers to all the cranes in the system, objects from the Berth class.
   - **Pier**: pointers to all the cranes in the system, objects from the Pier class.
   - **Terminal**: pointers to all the cranes in the system, objects from the Terminal class.

2. *Harbor system global properties*, including:
   - Counters as `nWaterfronts`, `nCranes`, `nBerths`, `nPiers`, `nTerminals`, etc.
   - `RDNnodeID`: link to a RDN node, indicating the position in the road network of the Harbor’s gate.

3. *Subclass characteristics* that include the main features of sides, nodes and structures. As regards sides and nodes, such characteristics are in common with the other systems (e.g., as links and nodes in D5.4, Argyroudis et al. 2011), and include structural characteristics (e.g., vulnerable or not, IM type), geographical positioning (e.g., coordinates) and site characteristics (e.g., Vs30, susceptibilities). Structure characteristics include names, typologies, and other descriptive properties.

4. *Properties that record the state of the HRB for each event*, including the property states that consists of a `nE×1` collection of properties that describe the current state for each of the `nE` events. States include the evaluation of Pls (TCoH, TCoM, TCaH, TCaM) and relative statistics (e.g., see D5.4, Argyroudis et al. 2011).

5. *Properties that assess the global performance of the HRB* at the end of the simulation, including the property MAF, which is the Mean Annual Frequency of exceedance values for the considered system level Pls.

The main methods of the HRB class include functions to assess Pls (and relative statistics), to retrieve the EPN and RDN states, to locate and characterize Berths, and to plot the system configuration and state.
3.2 HRB SUBCLASSES: NODE, SIDE AND STRUCTURE

The HRBnode and HRBside classes include *positioning and descriptive properties, general characteristics* (e.g., crane capacity, waterfront depth, etc), *reference structures’ IDs* (pier and terminal), and *methods* assessing, for each event (scenario), physical damages and functional consequences. The performance of these classes is stored in a *states* collection (as above), which includes physical and functional state for each event (scenario).

The HRBstructure class includes *positioning and descriptive properties*, and *links* to HRBlinks and HRBnodes that each structure includes. The Berth subclass includes references IDs to terminal and pier in which it is located. The Pier subclass includes a reference ID to the terminal to which it owns. The Terminal subclass includes a link to a RDN node, which indicates the starting position of the road leading to the harbor gate. The performance of these classes is stored in a *states* collection (as above), which includes PIs estimation and statistics at each subclass for each event (scenario).
References


Kakderi K., Pitilakis K. (2011). Deliverable 2.7 - Definition of system components and the formulation of system functions to evaluate the performance of ports, SYNER-G Project.


