Design and Construction Risks for a Shipping Port and Container Terminal: Case Study

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Abstract: This paper presents the risk identification process, a checklist of 215 different risks, and an associated risk breakdown structure (RBS) for the design and construction phases for a shipping port and associated container terminal. The case study project scope for the research includes a 3,500-m breakwater, 80 ha of reclaimed land, a 1,000-m-long quay wall, port equipment, and buildings. The checklist is categorized according to the project work breakdown structure (WBS) and includes risks associated with (1) breakwater, (2) reclaimed land, (3) entrance canal and basin, (4) quay wall, (5) container yard and buildings, (6) power supply, and (7) project management office. Since the research outcome was developed by subject matter experts during an actual project, it can be used during risk identification, as a completeness check after risk identification on similar projects, or for individual activities (e.g., quay wall construction) per the required project scope. The research also includes a list of risks that specifically relate to marine construction. **DOI: 10.1061/(ASCE)WW.1943-5460.0000537.**

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Introduction

Although it can be assumed that "design and construction risks" are applicable to "design and construction risks for a shipping port and container terminal," very little peer-reviewed research was found in a literature review regarding the more specific risks associated with the design and construction of shipping ports and associated container terminals. This paper therefore attempts to fill this research gap by presenting a checklist and risk breakdown structure (RBS) that can be used in the risk identification process when designing and constructing a shipping port with an associated container terminal. A RBS is a high-level process map that can be used to aid risk identification (Chapman 2006). It is hierarchically organized by risk and risk subcategory and identifies the various areas and causes of potential risks (Project Management Institute 2013).

The checklist derived as part of this research contains 215 risks related to the design and construction of the following parts of a shipping port and container terminal: (1) breakwater, (2) reclaimed land, (3) entrance canal and basin, (4) quay wall, (5) container yard and buildings, (6) power supply, and (7) project management office.

The checklist is useful because (1) it was obtained and refined during an actual construction project using either one-on-one interviews or structured risk workshops as part of the research process, (2) it was developed in collaboration with experienced subject matter experts, (3) it may be used in sections as it is broken down into different parts of a shipping port construction project (quay wall, dredging, etc.), and (4) it contains various categories of project risk: technical, delivery/logistics, contractor/supplier, quality, and out-of-area location. The subject matter experts include personnel who have worked on multiple port and container terminal projects, such as senior marine design engineers, dredging engineers, senior quay wall construction engineers, project managers, and so forth.

It should be noted that, since the intent of this article is to present a checklist that may be used by others during the risk identification process, its scope is limited to (1) the risk identification process that was followed for this project and (2) some lessons learned during risk identification. This implies that other parts of the ISO31000:2009 risk management process (American Society of Safety Engineers 2011b) are excluded from discussion: (1) risk analysis, (2) risk evaluation, (3) risk treatment, (4) monitoring and review, and (5) communication and consultation. Risk sources, their consequences, and their respective treatment plans are not discussed in any detail.

Case Study Background

The context used to identify construction risks is important because it explains which risks are included in the paper as part of the current research focus and which ones are not. In the research case study, the client appointed an engineering and project management consultant (EPMC), whose scope of services was to manage the implementation and construction of the shipping port and container terminal. The following facilities were included in the EPMC's scope considered in this research case study:

- Marine works, which included (1) a 3,500-m breakwater, (2) all dredging and reclamation, and (3) a 1,000-m quay wall.
- Land works, which included (1) container storage yard paving works, (2) mechanical/electrical/plumbing works, and (3) container gate.
- Buildings and amenities, which included (among others) (1) operations and administration building, (2) maintenance building (offices, warehouse, storage rooms for hazardous

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materials, workshops), (3) gate building, (4) fuel station, (5) port equipment (ship-to-shore cranes, rubber-tired gantries, reefer stacks), and (6) backup power generation plant.

For the facilities just listed, the EPMC was responsible for the following project management disciplines:

- Overall project management;
- Scope management;
- Project controls (which include risk management);
- Procurement management;
- Contract management;
- Site construction management and supervision;
- Health, safety, security, environment, and social performance management;
- Quality assurance and quality control management; and
- Interface management between the various construction and consultancy services contracts and client-supplied equipment and utilities.

The main reason for the construction of the port was limited capacity at the West African country's main commercial port. The project is expected to treble the current port's annual traffic of about 1 million 20-foot equivalent units.

Research Method and Paper Structure

The research method followed in this paper is exploratory in nature (Cooper and Schindler 2013), with risk identification methods based on aspects of a literature review. The case study method, combined with data collection from a panel or focus group functioning in a risk workshop context, was then used to establish a checklist containing design and construction risks for the shipping port and container. This paper is structured as follows:

1. Literature review including discussions on the following topics:
   - Since the purpose of this paper is to produce a checklist, the first section deals with some risk identification techniques and the validity of checklists as a risk identification technique. This section concludes with a discussion of some advantages and disadvantages of checklists.
   - Published research on risks that can be found on construction projects.
2. Results presented in terms of the following:
   - Some lessons learned regarding what worked well during the risk identification process are presented in terms of (1) useful checklists employed, (2) how the workshops were structured as part of the research process, (3) the use of risk management software, (4) naming conventions used, and (5) a structured approach to identification of interface risks.
   - Some lessons learned regarding where process improvements were required during the risk identification process are presented in terms of (1) a gap in the initial risk register where production and placement risks (rock, concrete armor units, caissons) were not included in all packages, (2) risks related to the management of procurement, and (3) risks related to a mismatch between the production equipment and the schedule.
   - The proposed checklist is presented and discussed in terms of the various parts of the work breakdown structure (WBS).
   - A proposal is made regarding a RBS that can be used on similar projects.
3. Discussion of results in terms of (1) validity of the checklist and proposed RBS, (2) differences between "generic" construction risks and risks identified during this research, (3) benefits, and (4) shortcomings of the research results.
4. Conclusion, acknowledgements, and references.

Literature Review

Checklists as a Valid Risk Identification Technique: Aspects of a Literature Review

Although there are some limitations in using checklists as a risk assessment technique (Hillson 2002b; Cooper et al. 2014; American Society of Safety Engineers 2011a), checklists are easy to use and remain helpful because they may ensure that common problems are not forgotten (American Society of Safety Engineers 2011a).

As for the term *risk*, there are various definitions for the term *risk identification*. Cooper et al. (2014) state that risk identification determines what might happen that could have an effect on achieving project objectives, and how these things might happen. Other definitions include (1) the process of determining which risks may affect the project and documenting their characteristics as referenced by the Project Management Institute (2009); (2) the process of finding, recognizing, and recording risk (American Society of Safety Engineers 2011b); and (3) a very simple definition of finding risks (Hillson 2009).

Risk identification is therefore a clearly defined step, found in the processes described in *PMBOK* (Project Management Institute 2009) and ISO31000:2009 (American Society of Safety Engineers 2011a). This is an important step in the risk management process because it identifies the sources of risks, which can in turn be used to determine treatment plans.

Numerous risk identification techniques are known and documented. The American Society of Safety Engineers' publication *Risk Assessment Techniques* is the American adaptation of ISO31010:2009 (American Society of Safety Engineers 2011a) and identifies six different types of risk assessment tool:

- Lookup methods: checklists, preliminary hazard analysis;
- Supporting methods: structured interviews and brainstorming;
- Scenario analysis: root cause analysis, fault tree analysis;
- Function analysis: failure mode and effects analysis (FMEA), hazard and operability (HAZOP) study;
- Controls assessment: layers of protection analysis, bow tie analysis; and
- Statistical techniques: Markov analysis, Monte Carlo analysis.

A total of 31 techniques are described for these six types of risk assessment tool, each discussed in terms of its application in (i) risk identification, (ii) likelihood and consequence estimation, (iii) level of risk and (iv) risk evaluation (American Society of Safety Engineers 2011a).

Lookup methods such as checklists are useful because they may be used by nonexperts and can help ensure that common problems are not forgotten. Limitations include their tendency to limit imagination and their potential to ignore "unknown unknowns." Checklists are most useful when applied to check that all important aspects have been covered by more imaginative techniques (American Society of Safety Engineers 2011a). Lyons and Skitmore (2004) and (Chapman 1998) have identified checklists as risk identification tools. Chapman also discusses the use of checklists in an article dealing with the effectiveness of working-group risk identification and assessment techniques (Chapman 1998). This supports the use of a literature review to create a checklist of risks related to the design and construction of a shipping port and container terminal, and partly supports the case study focus reported in this paper. It should be noted that, although checklists are useful, individual projects should still establish their own context-specific risks.

Published Research on Construction Project Risks

The design risks associated with the various parts of a port and container terminal have been widely described and include

(1) breakwater design (Koc 2009), (2) quay wall design (Roubos et al. 2018), (3) land reclamation (Lendering et al. 2015), and (4) dredging (Nebot et al. 2017). When conducting a literature review on peer-reviewed research containing checklists that can be used in risk identification for construction projects, it appears that publications can be categorized as follows:

- Geographical location: these checklists relate to risks associated with construction projects in different countries (e.g., China and South Africa).
- Project stakeholder perspective: these lists relate to risks associated with contractors, designers, project owners, and other stakeholders.
- Project scope: these lists contain risks that are more specific to the scope of the project: railways, power plants, tunnels and bridges, ports and container terminals.

These categories, together with some research examples and outcomes, are summarized in Table 1.

When specifically searching for articles related to marine project risks as part of this research, only the article by Tam and Shen (2012) could be found. The literature review indicated that risk-related research on marine projects tended to focus on port operational safety (Alises et al. 2014; Kim and Kim 2009; Yang et al. 2014; Zheng et al. 2011), environmental risk (Zheng et al. 2011), and investment risk (Kakimoto and Seneviratne 2000).

Results

Lessons Learned: What Worked Well as Part of the Risk Identification Process

The important lessons learned during the risk identification process are discussed in this section in terms of (1) useful checklists employed, (2) workshop structure, (3) naming conventions used, (4) structured approach for identification of interface risks, and (5) use of project risk management software. These lessons relate to positive research results during the risk identification process.

Useful Checklists

During the risk identification workshops, several checklists identified in the literature review and other relevant sources as part of the research process were used and are discussed in terms of lists for (1) megaprojects risks, (2) out-of-area risks, and (3) technical risks.

Megaprojects. As preparation for the risk identification sessions, a search for useful checklists was conducted. Several sources, such as reviewed literature on risks identified in megaprojects, were found. Flyvbjerg et al. (2003) dealt with a wide variety of megaprojects (including a large number of public–private partnerships), such as the Channel Tunnel, the Concorde, the Sydney Opera House, and the German MAGLEV train between Berlin and Hamburg. The discussion included problems with these projects, misinformation used to justify project implementation, and the significant contribution of inaccurate estimates to project overruns (Flyvbjerg et al. 2003).

Other sources identified in the literature review contained lists of potential risks. Cooper et al. (2014) included a section called "Examples of Risks and their Treatments" drawn from a number of different projects. Kendrick (2003) concluded his book with a list, although not as exhaustive as that provided by Cooper et al. The paper by Joubert (2016) was also used during these initial risk identification sessions.

Out-of-Area Risks. Since the project team comprised mostly expatriates not always conversant with local customs, the checklist provided by Cooper et al. (2014) on out-of-area risks was used as input to the risk identification workshops. These risks covered topics such as communications, culture and customs, health, language, legal/regulatory, offshore location, politics, religion, security, and staffing. The inclusion of local (i.e., nonexpatriate) colleagues proved invaluable during this phase of risk identification as they were far more familiar with the local context and customs than their expatriate colleagues.

Technical Risks. Regarding technical risks, the book *Construction Risk in Coastal Engineering* (Simm and Cruickshank 1998) was invaluable, as it contains well-structured sets of specific technical risks related to (1) rock works, (2) concrete armor units, (3) caisson works, (4) navigational dredging works, and (5) beach nourishment. Specific reference is made to the obstacles a project might encounter when interfacing with nature, including geotechnical, weather, and seawater risks. In each section, risks are discussed in terms of their place in the construction process. For example, caisson risks are discussed in terms of (1) fabrication, (2) transport, (3) positioning, and (4) backfilling (Simm and Cruickshank 1998).

Initial Risk Workshops

Before the first risk identification sessions in the research case study commenced, basic risk management and identification training was presented. This was done to align participants to the language and process described by ISO31000:2009. During the initial risk identification sessions, focus was placed on a particular part of the work breakdown structure, with input from the design engineer and/or construction manager.

The first step in these workshops was to set the context by identifying the main parts of the construction sequence as laid out in the WBS. For example, rock supply risks were identified in terms of the following WBS tasks: (1) quarry mobilization, (2) quarry production, (3) rock transport, and (4) on-site delivery.

Table 1. Construction risk checklists

Category	Reference	Outcome
Geographical location	Windapo and Cattell (2013)	List of risks based on research done in South Africa
	Zou et al. (2007)	List of risks based on research done in China
Project stakeholder perspective	Chan et al. (2011)	Ranked list of risks for client, contractor, and consultants
	Karim et al. (2012)	Ranked list of risks for contractors
	Rezakhani (2012)	List of risks broken down into various categories
	Zou et al. (2006)	List of risks per stakeholder per project phase
Project scope	Jergeas (2008)	List of risks associated with pipeline project
	Lam (1999)	List of risks per sector (power, highway, bridges, tunnels, airports, and rail projects)
	Mohan (2017)	List of risks associated with offshore construction
	Špačková (2012)	Dissertation on risks associated with tunneling
	Tam and Shen (2012)	List of risks associated with marine projects

The prepared checklists were used to check completeness of the identified risks. The main reason they were not employed as the first step was that they might inhibit imagination, address only the known knowns, and miss problems not readily visible (American Society of Safety Engineers 2011a). Checklist preparation was useful to the risk workshop facilitator in that it helped to provide information related to similar projects. A total of 151 risks were identified during these initial sessions, as summarized in Table 2.

Project Risk Management Software

Managing and reporting on a risk register where risks have multiple sources, treatment plans, due dates, and treatment plan owners is virtually impossible when using MS Excel only. The risk register contained 215 risks, allocated to 15 WBS categories, together with 414 treatment plans with different due dates as well as 15 treatment plan owners. Risks were captured in proprietary software that allowed a single risk to have multiple risk sources, each with an appropriate treatment plan, plan owner, and due date. The main reason for the use of such software was that spreadsheet-based risk registers are difficult to use to manage risks and identify outstanding tasks and task owners, specifically if multiple risk sources and treatments are captured in single cells.

Specific Key Performance Indicators for Project Risk Management

Risk management activities took place throughout the project life cycle, with at least monthly updates. At the beginning of each month, the risk management software produced various risk registers, status reports, top-20 lists, and to-do lists for upcoming and overdue tasks. These reports were distributed electronically. The risk manager was responsible for ensuring follow-up on the various risks and their treatment plans. The monthly risk status report also included key performance indicators for the risk management process, which included (among others) the following:

- Number of risks and opportunities and risk status (emerging/realized/closed);
- New risks, newly realized risks, and recently closed risks;
- Number of treatment plans (total/with due tasks/with due tasks next month);
- Number of risks last updated more than 90 days ago;
- Number of overdue tasks and treatments, including task owners; and
- Number of updates during the last month (risks/treatment plans/comments).

These performance indicators gave management and the project risk manager some confidence that regular risk reviews and updates were taking place; they also proved useful in compliance audits.

Table 2. Risks identified during initial risk workshops

WBS element	Number of risks
Breakwater	24
Building and land construction	6
Building and land design	8
Dredging	16
Engineering and project management	26
General site	3
Health and safety	10
Marine works general	11
Quay	21
Rock supply (for breakwater)	11
Reclamation and soil improvement	15
Total	151

Risk-Naming Conventions and Categories

As the risk identification process continued, the large number of risks identified made it clear that a more structured naming convention was required. A naming convention was then implemented where the short risk name was preceded by the associated WBS category. In practical terms, risk names started looking like this:

- Breakwater: rock-loading delays on site; and
- Breakwater: concrete armor unit placement.

This approach turned out to be problematic, especially for those sections of the WBS with many associated risks. It was then decided to include a number after the WBS category to indicate the sequence in which activities would take place so that the software would list them alphabetically, showing the risks associated with earlier parts of the construction process first. Thus, the first 12 risks for the breakwater were followed by placement risks:

- Breakwater: 01 Concrete armor unit specification;
- Breakwater: 01 Design delays;
- Breakwater: 01 Specification compliance;
- Breakwater: 01 Surveys delayed;
- Breakwater: 02 Deterioration of armor stone rock during handling;
- Breakwater: 02 Inadequate site rock truck resources;
- Breakwater: 02 Rock-loading delays on-site;
- Breakwater: 03 Concrete armor unit placement;
- Breakwater: 03 Construction at beach crossing; and
- Breakwater: 03 Loss of material during rock placement

This approach was taken in all subsequent risk identification and review sessions. Additionally, all risks were categorized in terms of (1) extended risk breakdown structure, (2) whether the risk could affect the critical path, and (3) whether the particular risk involved an interface with the sea. A total of 80 risks were placed on the critical path, and of these 8 had a direct interface with the sea. This was important, as the treatment options for these risks were in many cases limited to making adequate provision for them in the project schedule. Examples of this included the following:

- Breakwater: 03 Loss of material during rock placement (due to sea action);
- Breakwater: 03 Rock outloading bottlenecks (due to limited space on the breakwater); and
- Breakwater: 04 Rock core damaged after exposure (due to inclement weather).

Structured Approach to Identifying Interface Risks

Identification of interface risks took place a year after the initial risk workshops were held and mainly dealt with interface risks between (1) quay wall and (2) reclamation and soil improvement; and building packages such as (1) administration buildings, (2) workshops, (3) customs inspection building, and (4) fuel station. These risks are important because they relate to risks associated with different packages, different design engineers, and different construction companies. The management of interface risks also forms part of the EPMC's scope of tasks.

The methodology followed was similar to that for conducting a HAZOP study (International Electrotechnical Commission 2001; Dunjóa et al. 2010). HAZOP studies are structured and systematic examinations of a process, procedure, or system. It uses deviation guide words (high flow, low flow, reverse flow, etc.) and nodes (which are specific to a design) to identify hazards associated with the operation of machinery or a system. The methodology was adapted by replacing the HAZOP study nodes with combination pairs of input packages (e.g., quay wall/admin buildings) and by replacing the normal HAZOP guide words with guide words related to interface types. Four sets of guide words were used:

- Design/technical information exchange/approvals;

- Schedule/sequence/tie-in;
- Laydown areas/traffic/site access; and
- Operating facility.

In practical terms, a question was formulated as "When looking at the quay wall and admin building design, are there any *design/technical information exchange/approval risks?*" If any were identified, the risk was further analyzed. If not, the question would become "When looking at the quay wall and admin building design, are there any *schedule/sequence/tie-in risks?*" The process continued until all input package pairs and guide words were cycled through. The process took some time, but helped to identify 24 new risks, of which typical examples included

- Land package design: rear crane beam/services alignment;
- Land package design: scanner design unknown; and
- Land package design: ship-to-shore crane turnover pits.

This process was particularly helpful in identifying design interface risks, of which the majority were treated by simply changing the related designs. All such risks were transferred to the risk management software and reviewed as part of the normal monthly risk review.

Lessons Learned: Where Improvement Was Required

The risk review revealed some lessons that needed to be incorporated into the initial risk identification sessions of future projects. These lessons mainly relate to (1) a gap in the initial risk register where production and placement risks (rock, concrete armor units, caissons) were not included in all packages, (2) procurement management, and (3) mismatches between the production equipment and the schedule. The last two are related, and their combined effect may severely impact the efforts of any project to meet its schedule objectives.

Missing Risks: Production and Placement Risks

During the initial risk assessment, several risks related to the supply and placement of rock on the breakwater were identified, since discussions with the engineers and input from the client risk register indicated that this was expected to be problematic. As the project progressed and production of the concrete armor units started, some risks indicated that there was a lack of control over the production of concrete armor units.

The risks related to production and placement of concrete armor units were reviewed, and the outcome was used to ensure that each of part of the WBS included both production and placement risks. This lesson was also rolled out to future projects to ensure that construction would be covered in terms of production and placement, especially where the placement had a direct interface with the sea. Typical examples of these risk pairs are as follows:

- Breakwater: 03 Concrete armor unit production delays;
- Breakwater: 03 Concrete armor unit placement (direct interface with the sea);
- Land construction package: 03 Paving block production rates;
- Quay: 03 Caisson production rates; and
- Quay: 05 Caisson placement delays at sea (direct interface with the sea).

Included Risks: Procurement Management

Procurement management risks involve not having equipment on site *in time* to support the schedule. Their sources are mainly lack of planning that in turn translates into (1) not ensuring that the correct equipment is ordered, (2) not taking equipment lead times into consideration, (3) late start of the procurement process, and (4) customs delays. Typical risks are as follows:

- Dredging: 02 Cutter suction dredger required and not available;
- Quay: 02 Caisson suitability of ordered formwork;
- Quay: 02 Caisson semisubmersible barge unavailable; and
- Rock supply: 02 Insufficient trucks and other equipment.

These risks can be eliminated by fully visible equipment procurement schedules that are discussed in weekly meetings.

Included Risks: Production Equipment–Schedule Mismatch

The consequences of mismatches between equipment and schedule involve not maintaining schedule progress because of (1) inappropriate and/or insufficient equipment on-site or (2) not being able to translate schedule requirements into appropriate production resources. This differs from the previous set of risks in that the risks discussed here relate to having "correct" equipment on site that cannot produce at the rate required by the schedule. This can mean either that the equipment is insufficient or that the schedule is unrealistic. As with procurement risks, the sources of these risks relate to lack of planning, which in turn translates into (1) not understanding production rates of the available equipment or (2) agreeing to an unrealistic schedule. Typical risks are as follows:

- Rock supply: 02 Insufficient trucks and other equipment;
- Breakwater: 03 Rock-outloading bottlenecks (on breakwater);
- Breakwater: 04 Traffic congestion on breakwater;
- Dredging: 02 Cutter suction dredger required and not available;
- Dredging: 03 Breakdown of dredger;
- Quay: 03 Caisson-casting quality;

Table 3. Number of risks per WBS element

Level 1: project scope	Level 2: design/construction	Unique risks
Breakwater	Design	6
	Construction	56
Reclaimed land	Site conditions	3
	Construction	22
Entrance canal and basin	Design	3
	Construction	4
Quay	Design	6
	Construction	34
Buildings and container yard	Design	15
	Construction	18
Power supply	Design	5
	Construction	6
Project management office	Permitting and site access	6
	Planning and schedule management	6
	Scope management	7
	Commercial management	8
	Quality management	2
	Human resource management	4
	Health, safety, and environment management	4
Total		215

Table 4. Breakwater: design risks

Level 3: risk category	Level 4: individual risks
Specification compliance	• Additional design measures required to treat long wave action • Compliance with European design specifications • Concrete armor unit specification compliance • Severe long-term beach erosion due to port layout and design
Completion delays	• Design rework after modeling • Delayed geotechnical and bathymetric surveys

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- Quay: 03 Caisson production rates;
- Quay: 04 Caisson-loading submersible barge delays;
- Quay: 04 Dredger production rates; and
- Quay: 05 Caisson placement delays at sea.

These risks can be eliminated by thorough interrogation of planned equipment productivity and by fully visible contractor procurement schedules that are discussed in weekly meetings.

Table 5. Breakwater: construction risks

Level 3: risk category	Level 4: individual risks
Rock supply from quarries	• Quarry mobilization delays • Quarry production delays • Rock quantity for breakwater underestimated • Rock specification (hardness and weight) compliance
Transportation of rock to site	• Insufficient trucks and other equipment shortfalls • Rock-loading delays at quarry • Road traffic congestion • Road traffic limitations (axle weights)
Placement of rock by split barges, trucks, and cranes	• Delays in construction of beach crossing • Deterioration of armor stone rock during handling • Excessive loss of material during rock placement • Reduced space for on-site stockpiles as construction progresses • Truck-loading delays on-site from stockpiles • Traffic congestion on breakwater • Fuel supply interruptions (trucks/dredger/generators) • Rock loading onto split barges bottlenecks • Rock-placing delays by cranes on breakwater • Temporary jetty out of operation (weather/maintenance issues/damage by vessels) • Breakwater crane accidents • Offshore barge working problems and delays
Concrete armor units	• Concrete armor unit production delays • Concrete armor unit placement delays
Natural environment	• Overtopping of breakwater during construction • Rock core damaged/exposed after severe storms • Insurance claims not paid due to concrete armor units not in place to protect breakwater • Settlement of breakwater requiring more rock • Geotechnical problems during construction • Seabed changes during construction (siltation)
Health, safety, and environment	Risks at quarry: • Blasting failures at quarry • Theft of explosives and blasting caps • Dust pollution at quarry Transportation risks to site: • Rocks falling off trucks during transportation • Traffic accidents (on-site and public) Risks at project site: • Site access accidents and delays • Traffic accidents at rail level crossing at site • Damage to railway and level crossings by loaded trucks carrying rock • Wildlife—sharks and snakes • Truck and personnel safety/traffic management on site • Unauthorized discharges/spills by trucks • Asbestos and other hazardous materials (HAZMAT) • Waste concrete being dumped on site • Contractor safety culture • Potable water availability • Infectious disease outbreak • Site security • Obstructed emergency access during construction • Safety noncompliance by contractors • Flooding of active work areas during storms Marine operational risks: • Fire at sea • Unauthorized discharge/spills • Vessel collision incidents • Damage to dredger and other vessels during storms • Vessel groundings • Storm warning procedure not in place • Safe human accessibility of marine plant • Inclement weather

Proposed Checklist

As part of the research, the identified risks were reviewed and reclassified to create a risk breakdown structure (RBS) that can be used for similar projects. Based on the project context, the WBS, and identified risks, the RBS was organized into four levels (Table 3) as follows:

1. Six main parts of the project scope (breakwater, reclaimed land, entrance canal and basin, quay wall, container yard and buildings, power supply) as well as the project management office (PMO);
2. Risks classified as either design or construction;
3. Breakdown of Level-2 risk categories into more discrete parts of the project value chain; and
4. Individual risks.

Breakwater: Design

Breakwater design risks relate to (1) compliance of designs with operational requirements and international specifications and (2) on-time completion of designs. All designs completed by the contractor were verified by a third-party design consultant and are summarized in Table 4.

Breakwater: Construction

The breakwater required more than 3.5 million tons of rock to be mined from various quarries and then transported by truck to the site. The rock was either stockpiled on-site or placed on the breakwater by trucks, cranes, or split barges. Split barges were used to dump breakwater core rock onto the seabed. When the core was high enough, trucks placed more rock. Cranes were used to place armor rock. The last step in protecting the breakwater was placement of concrete armor units (accropodes). There was an on-site batching plant for the more than 30,000 accropodes that had to be manufactured. The project site was close to the equator with a yearly monsoon season from July to September.

Breakwater construction risks involved (1) rock supply, (2) transportation of rock to the site, (3) placement of rock on the breakwater by split barges, trucks, and cranes, (4) manufacture and placement of concrete armor units on the breakwater, (5) environment (wind, waves, tides, sea level), and (6) health, safety, and environment (Table 5).

Reclaimed Land: Design

Phase 1 of the project required 72 ha of reclaimed land. The reclaimed land would be used for paving the container yard as well as for siting all port buildings. Risks related to the layout and design of the reclaimed land were identified (Table 6).

Reclaimed Land: Construction

Reclaim material was dredged from a sandbank approximately 20 km from the project site. Construction on the reclaimed land entailed either dynamic compaction or vibroflotation to prepare the soil for container yard paving and building construction. Risks involved (1) dredging and supply of reclaim material, (2) discharge of reclaim material on-site, (3) soil improvement using dynamic compaction, (4) health, safety, and environment (Table 7).

Table 6. Reclaimed land: design risks

Level 3: risk category	Level 4: individual risks
Site conditions	• Existing shoreline/underestimation of work to prepare project site • Position and extent of existing services for relocation unknown
Geotechnical conditions	• Unknown geotechnical conditions for implementation of temporary works

Table 8. Entrance canal and basin: design risks

Level 3: risk category	Level 4: individual risks
Dredging design	• Dredging depth disagreement • Dredging volume uncertainty
Equipment	• Navigational aid specifications unclear/late

Table 7. Reclaimed land: construction risks

Level 3: risk category	Level 4: individual risks
Dredging of reclaim material	• Dredging permitting and approval delays • Dredging starts late (dredger not available) • Dredger production rates lower than expected • Sand borrow royalties exceeding budget • Contaminated reclaim materials • Sand location further than planned • Heritage finds underwater • Damage to existing underwater pipelines and communication cables • Disruption of commercial shipping lanes by dredging activities
Discharge or reclaim material	• Bund wall collapsing • Bund weir overflow • Standing/stinking water onsite
Soil improvement	• Ineffective compaction methodology • Settlement repairs during construction • Backfill compacting and settlement not in specification • Compaction rates not sufficient
Health, safety, and environment	Same as identified under "Breakwater construction: health, safety, and environment," with addition of following land-based risks: • Safe operation of dynamic compacting equipment • Impact of reclamation on existing public buildings • Damages to existing and new infrastructure during compaction • Unidentified graves on-site Additional marine risks: • Turbidity caused by dredging exceeding approval limits • Dredger damaged by debris/wrecks

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Table 9. Entrance canal and basin: construction risks

Level 3: risk category	Level 4: individual risks
Dredging of sand and rock	Same as identified under "Reclaimed land construction: dredging of reclaim material," with following additional risks: • Overdredging (outside specification) • Cutter suction dredger required and not available
Natural environment	Same as identified under "Breakwater construction: natural environment," with following additional risks: • Seabed changes (siltation) • Harder rock requiring underwater blasting
Health, safety, and environment	Same as identified under "Breakwater construction: "health, safety, and environment"

Entrance Canal and Basin: Design

The project required extensive dredging (up to −19 CD) to create a safe entrance channel, turning circle, and basin inside the breakwater. The risks related to the design of the dredged area are summarized in Table 8.

Table 10. Quay wall: design risks

Level 3: risk category	Level 4: individual risks
Design	• Caisson quay wall design delays • Capping beam design delays • Design and construction tolerance alignment • Efficiency of concrete plug between caissons
Geotechnical conditions/seabed	• Stability in design/movement of quay wall • Seabed changes requiring design changes

Entrance Canal and Basin: Construction

Risks related to construction of the entrance canal and basin involved (1) dredging of sand and rock by grab as well as cutter-suction dredgers, (2) natural environment, and (3) marine health, safety, and environment (Table 9).

Quay Wall: Design

Design of the 1,000-m quay wall called for more than 50 concrete caissons, each weighing more than 2,500 t. The design risks involved are summarized in Table 10.

Quay Wall: Construction

After the quay wall trench was dredged to −19 CD, it was leveled to create a stable foundation for the caissons on the prepared seabed. To place them at sea, individual caissons were rolled onto

Table 11. Quay wall: construction risks

Level 3: risk category	Level 4: individual risks
Fabrication of caissons	• Cranes for caisson fabrication arrive late • Late start of caisson casting • Suitability of ordered caisson formwork • Caisson concrete mix design confirmation delays • Caisson-casting quality • Caisson production rates
Dredging and preparation of quay wall trench	• Trench-leveling machine late • Trench tamping and leveling quality problems • Dredging of quay wall trench starts late • Dredging of quay wall trench taking longer than planned
Placement of caissons	• Caisson semisubmersible barge not on-site in time • Caisson semisubmersible barge stability during loading • Quay trench filled by sand from reclamation activities • Caisson-loading delays onto semisubmersible barge • Caisson abortive work/placed caisson needs to be repositioned • Caisson placement delays at sea (wave action/inclement weather) • Caisson settlement and displacement • Caisson backfilling quality • Quay wall stability after dredging • Late completion of breakwater
Geotextile	• Backfill geotextile specification and placement method • Damage to geotextile during piling
Capping beam	• Improper concrete curing • Position of cast-in items • Pouring risks • Corroding rebar
Crane rails	• Crane rail steel pile load capacity • Crane rail steel pile position • Delays in unloading of cranes • Crane rails not ready when cranes arrive
Health, safety, and environment	Same as identified under "Breakwater construction: health, safety, and environment," with addition of following land-based risks specific to construction of quay wall: • Caisson crane accidents • Safety supervision during moving of caissons Additional marine risk: • Ship-to-shore crane delivery ship draught too deep

a semisubmersible barge that moved them close to their placement position; the barge then submerged, allowing each caisson to float. The floating caissons were positioned by tugboats and filled with water to make them sink. They were then backfilled with sand. To prevent reclaimed land from leaking through gaps between the caissons back into the sea, a geotextile was placed between the reclaimed land and the caissons.

The risks related to quay wall construction involved (1) fabricating the caissons, (2) dredging and preparing the quay wall trench, (3) moving the caissons onto the semisubmersible barge and placing them in the prepared trench, (4) placing the geotextile between the reclaimed land and the quay wall, (5) installing the quay wall capping beam, (6) installing crane rails, and (7) health, safety, and environment (Table 11).

Table 12. Container yard and buildings: design risks

Level 3: risk category	Level 4: individual risks
Scope definition	• Seismic design requirements • Container terminal design assumptions • Scope definition clarity • Late design changes by client and port authorities • Military/Coast Guard requirements and approvals • Pavement design rework due to incorrect rainfall data
Design interfaces	• Admin building/services design alignment • Port gate/road interchange alignment • Communication systems alignment • IT-ducting design delays/changes • Scanner and other electronic equipment alignment • Unknown electrical loading requirements of container-handling equipment • Pavement stormwater pipe alignment with quay wall design • Rear crane beam/services alignment • Ship-to-shore crane power supply turnover pits alignment

Container Yard and Buildings: Design

The entire 80 ha of reclaimed land was designed to be paved. Three major buildings (port authority, port management, and port equipment workshop) as well as other structures (port access gates, interchange, and power supply) were part of the project scope. As mentioned earlier, extensive risk identification work took place regarding design and operational interfaces between various parts of the WBS. The risks identified are summarized in Table 12.

Container Yard and Buildings: Construction

Container yard and building construction involved (1) procurement and logistics, (2) paving-block manufacture and installation, (3) commissioning and operational readiness, and (4) land-based and health, safety, and environment (Table 13).

Power Supply: Design

Part of the design of the port included a separate power plant that could be used if the bulk power supply were delayed, and deployed during power failures. The design risks are summarized in Table 14.

Power Supply: Construction

Power supply construction risks involved (1) procurement and logistics, (2) commissioning and operational readiness, and (3) land-based health, safety, and environment risks (Table 15).

Project Management Office

Several categories of risk were identified that could be grouped as project management office risks. They involved (1) permitting

Table 14. Power supply: design risks

Level 3: risk category	Level 4: individual risks
Equipment design	• Equipment design and specification clarity • Electrical loading interface mismatch • Power supply late design changes • Transformer oil sump design
Civil design	• Concrete plinth weight-bearing capacity

Table 13. Container yard and buildings: construction risks

Level 3: risk category	Level 4: individual risks
Procurement and logistics	• Building, pavement contractor award delays • Ineffective procurement/logistics plan management • Cable and ducting materials availability and supply delays • Pavement material availability and supply delays • Contractor cashflow management • Steel and electrical equipment availability and supply delays
Paving block manufacturing and installation	• Paving block production and placement delays • Equipment breakdown during construction • Construction quality/rework • Incorrect ducting installed
Commissioning and operational readiness	• Ship-to-shore cranes late • IT infrastructure installation delays • Late start to commissioning and operational readiness plans • Operational readiness delays • Late completion of public-access roads to new terminal • Construction and container traffic interaction during commissioning (port goes live when construction is not complete)
Health, safety, and environment	Same as identified under "Breakwater construction: health, safety, and environment," with addition of following risks specific to construction of container yard and buildings: • Commissioning safety • Fire during construction of pavement and buildings • Damage to completed buildings and other assets during construction

and site access, (2) planning and schedule management, (3) scope management, (4) commercial management, (5) quality management, (6) human resource management, and (7) health, safety, and environment management (Table 16).

Proposed Risk Breakdown Structure

Based on the checklist derived from this research, the RBS depicted in Fig. 1 is proposed for similar port and container terminal design and construction projects.

Discussion

Checklist and Proposed RBS Validity

The checklist of 215 risks is deemed appropriate and valid because (1) it was obtained and refined during an actual construction project case study using either one-on-one interviews or structured workshops, (2) it was developed in collaboration with experienced subject matter experts, and (3) it contains various categories of project risks, such as technical, delivery/logistics, contractor/supplier,

Table 15. Power supply: construction risks

Level 3: risk category	Level 4: individual risks
Procurement and logistics	• Power supply equipment availability • External power late • Standby generators late
Commissioning and operational readiness	• Power tie-in delays between construction phases • Power supply–commissioning delays
Health, safety, and environment	• Same as identified under "Breakwater construction: health, safety, and environment," with addition of following risk specific to construction of container yard and buildings: • Commissioning safety

Table 16. Project management office risks

Level 3: risk category	Level 4: individual risks
Permitting and site access	• Site access at project start • Construction traffic congestion • Sufficient site access for construction traffic • Building permit delays • Building plan approval delays • Certificate and permit requirements incomplete
Schedule management	• Late start of near-critical path activities • Marine contractor ambitious schedule • Marine contractor schedule dependencies • Misaligned schedule and equipment • Late handover by marine contractor to land contractor • Project phasing not aligned with client go-live and operational requirements
Scope management	• Design interface management • Design and cost estimate not aligned • Design reviews late • Uncoordinated design changes • Bulk services (sewerage, water, electricity) late for terminal operations • Design changes required due to owner requirements • Construction site layout and capacity
Commercial management	• Contractor tax exemption compliance • Corruption in supply chain • Delayed payments • Large contractor liquidation • Small contractor liquidation • Project owner cashflow • Local content plan compliance • Incorrect measurement of rock and reclamation sand before payment
Quality management	• Insufficient contractor quality control • Specialized testing and laboratory equipment availability
Human resource management	• Labor force/strikes • Community objections/complaints • Project team continuity • Contractor underestimating site supervision requirements
Health, safety, and environment management	• Compliance with environmental protection agency requirements • Compliance with international financier environmental management requirements • Compliance with report submission dates to international financier • Incomplete wording of environmental management plan

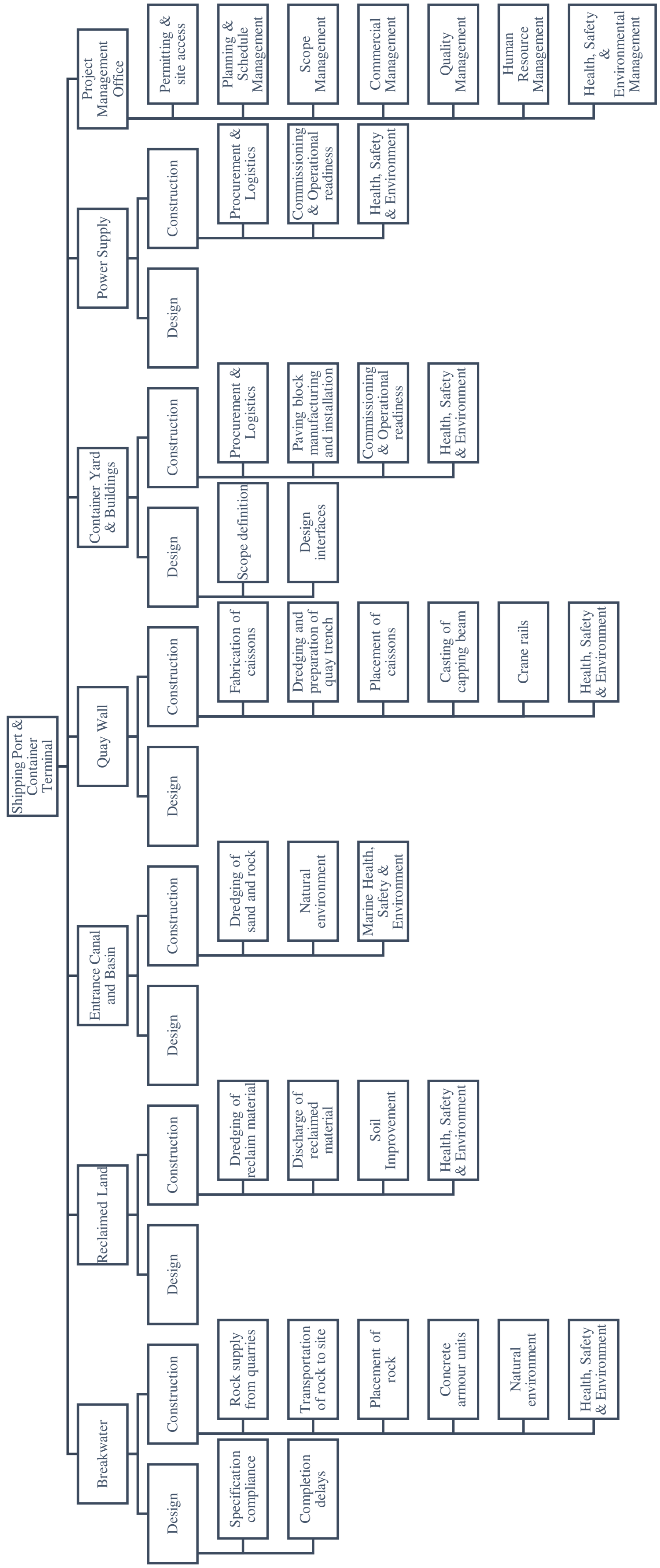

Fig. 1. Proposed risk breakdown structure for shipping port and container terminal project.

quality, and out-of-area location. Although not at the level of detail described in this research, similar risks can be found in research published by Chan et al. (2011), Karim et al. (2012), Rezakhani (2012), Zou et al. (2006), and Tam and Shen (2012). This should promote confidence in the checklist because it is at least in part based on reviewed literature.

Differences between Construction Project and Port Project Risks

When reviewing the list of 215 risks, it was possible to identify 83 (38.6%) generic design and construction risks specifically related to the Table S1, Shipping port and container terminal: specific design and construction risks, in the Supplemental Data. These are risks that generally have some kind of interface with the sea and related marine conditions.

Benefits

The benefits and applications of the checklist of 215 risks and the RBS include the following:

- Since the checklist covers breakwater, reclaimed land, entrance canal and basin, quay wall, container yard and buildings, and power supply, it can be used for projects with similar scope or during the risk identification process in projects with smaller scope, where, for example, only a breakwater is constructed.
- The RBS may be useful in risk identification, risk assessment, and risk reporting for similar shipping port projects. According to Hillson (2002b), it can be used (1) in the tender phase for similar projects to present risks in a consistent format and (2) in the analysis of risk-related information in port project reviews.
- The list of risks created here relates to marine construction. It can be be used in risk identification to ensure that the appropriate risks are identified.

Shortcomings

The main shortcoming of the checklist is that, for the following reasons, it makes no claim to completeness:

- Since the risk register is limited to the scope of the EPMC's tasks, it excludes the project owner's commercial, project, and operational risks.
- The risk register used in creating the checklist was developed only after appointment of the EPMC by the port project management team and therefore excludes some design and execution risks identified by other parties and dealt with before the EPMC appointment.
- The checklist excludes risks from the EPMC's project implementation risk register. These risks mainly relate to the EPMC's commercial objectives, which include issues such as (1) additional specialist contractor costs, (2) staff mobilization costs, and (3) continuity of project staff until project completion. Many of these are included in a list of out-of-area risks (Cooper et al. 2014).
- Although the risk register includes project-specific external natural events, such as wave action and inclement weather, it contains no similar risks (earthquakes/tsunamis) that might be associated with building a port and container terminal elsewhere.
- The checklist excludes any opportunities that were subsequently identified but which were highly context-specific.

Conclusions

This paper presented positive lessons learned from risk identification. These lessons mainly relate to (1) use of appropriate checklists in preparing for initial risk identification sessions, (2) initial risk workshop structure, (3) risk-naming conventions, (4) shortcomings of MS Excel for managing project risks, and (5) structured identification of interface risks between parts of the WBS.

Shortcomings in initial risk identification relate to (1) a gap in the initial risk register where production and placement risks (rock, concrete armor units, and caissons) were not included in all packages, (2) missing risks related to procurement management, and (3) mismatches between equipment and schedule. The case study supports Hillson (2002a) in that there is no "best method" for risk identification and that an appropriate combination of methods should be used.

Using checklists (megaprojects, construction projects, out-of-area risks, and technical risks), initial risk identification sessions, and subsequent risk reviews, the case study produced a valid list of 215 design and construction risks for a shipping port and container terminal project.

Since the checklist of 215 risks (1) was obtained and refined during an actual construction project using either one-on-one interviews or structured workshops, (2) was developed in collaboration with experienced subject matter experts, and (3) contains various categories of project risks (technical, delivery/logistics, contractor/supplier, quality, and out-of-area location), it represents an appropriate, valid set of risks that may be used in risk identification for similar projects. The RBS created as an outcome of this research can be useful in risk identification, assessment, and reporting as well as in postproject reviews on similar projects.

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Supplemental Data

Table S1 is available online in the ASCE Library (www.ascelibrary.org).

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