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Asset lifecycle approach to port infrastrucutre sustainability

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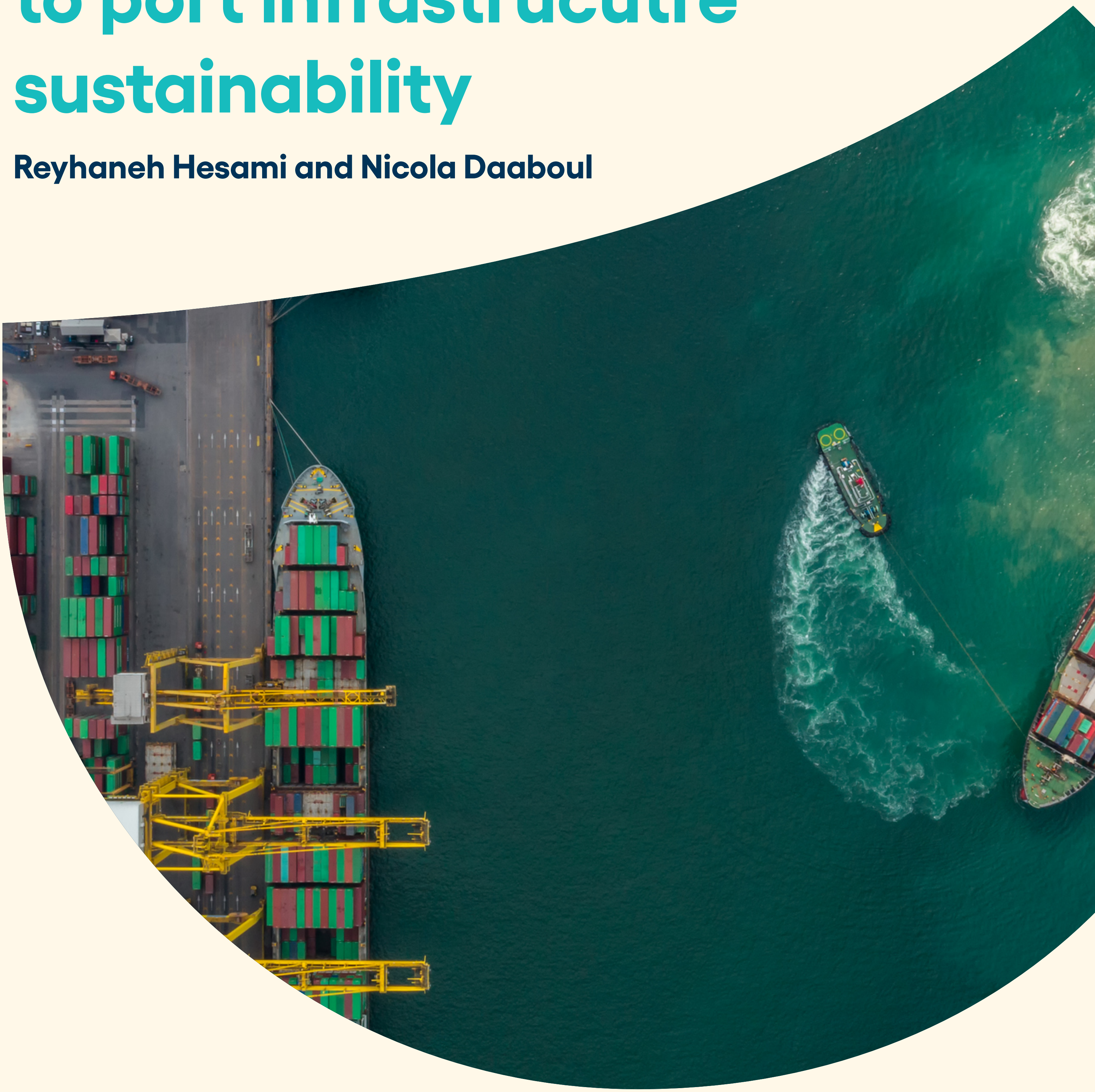

Abstract

Port sustainability is a challenging subject to address. Port authorities worldwide are striving to find ways of operating and managing sustainably in terms of economic, social and environmental factors. With a desire to encourage more research on port sustainability in economic performance terms, this paper discusses a predictive asset lifecycle approach for evaluating, comparing, and improving port infrastructure sustainability.

The key outcome of this research is to establish initial evaluation criteria for port economic sustainability that have been tested using real-world sample data as a proof of concept. The KPI is derived from the risk, condition and cost-benefit rating of each predicted investment strategy for port capital works over a given lifecycle. These investment strategies will allow asset custodians to understand the year-on-year condition and associated risk of the assets, as well as the cost-benefit ratio of each budget strategy. This will facilitate informed investment decisions by port infrastructure managers that consider and analyse economic sustainability.

The method is developed based on an adaptive heuristic genetic search algorithm of the degradation profile of port infrastructure components using a Gaussian-based degradation strategy. The model predicts the port's infrastructure condition and provides options for the capital works investment forecast for the given period (e.g. whole of asset lifecycle) based on the indicative available budget. The model also provides the optimised budget forecast to achieve or maintain a level of service while maximising benefit and minimising risk. In order to demonstrate the proposed approach, a commercially available predictive modelling tool is used to analyse and model data from the Port of Hobart, one of the key ports in Tasmania, managed by TasPorts.

While further study is required to fine-tune and benchmark the evaluation criteria and set realistic targets towards economically sustainable port infrastructure, this paper establishes an initial baseline for that further research using a lifecycle approach.

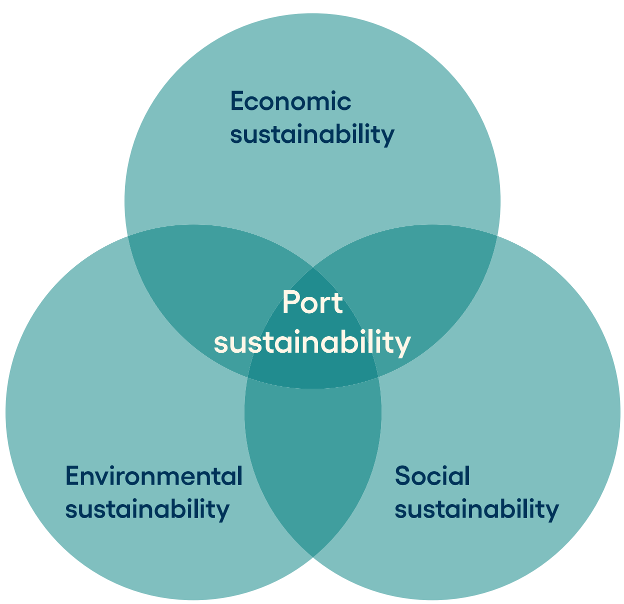

Figure 1 Three key pillars of port sustainability adopted from [1]

2. Definitions

Sustainable Infrastructure: In brief, it refers to infrastructure that is 'green', 'smart' and 'efficient'. More broadly, it encompasses infrastructures that are designed, constructed, operated, and decommissioned to optimise environmental, social and economic outcomes over the entire lifecycle of the infrastructure [9] [3]. It can also refer to existing infrastructure retrofitted, rehabilitated, redesigned, and reused [8].

Economic Sustainability: Maximising the financial performance resulting from implementing sustainable development initiatives and minimising risk without adversely affecting social and environmental development [12]. On the other hand, an economically sustainable infrastructure generates a positive net economic return over the asset lifecycle or, at minimum, maintains the infrastructure financial capital over a long time.

Infrastructure Risk: The risk due to the failure of the functionality of the infrastructure. The ranking of the infrastructure risk is estimated by the impact that the specific failure may have on the operation of the business, including the financial impact as a result of the service disruption.

Risks must be evenly distributed to the entire asset portfolio while they can be controlled, or their impact can be absorbed over the life of the assets.

Asset Sustainability Index (ASI): The ratio of the amount of available funding considered for servicing, renewing and upgrading the asset divided by the amount of funding needed to adequately sustain assets at a targeted condition or level of service over a long period [13]. In other words, assets with a lower forecasted backlog are considered to be more sustainable.

3. Case Study

The case study selected for this research is Port of Hobart, located in Tasmania and managed by TasPorts. The port was initially constructed in 1951 and, throughout the years, has been expanded to include 11 wharves, docks, piers, and low-landing point.

Figure 2 Aerial view of Port of Hobart (image obtained from Google Earth)

4. Scope

The scope of this paper corresponds to the lifecycle analysis of a major port in Tasmania. Port infrastructure components incorporated in this study include piles, beams, deck, deck soffits, fenders, and bollards. The data used for the analysis in this paper is an extracted sample data from the entire port. Figure 3 shows a typical wharf configuration utilised at the Port of Hobart.

The key focus of this paper is to measure the economic or financial sustainability of port infrastructure using the asset sustainability index.

While the economic sustainability measure has indirect impacts on environmental and social sustainability, this paper will not assess those sustainability indicators of the port infrastructure.

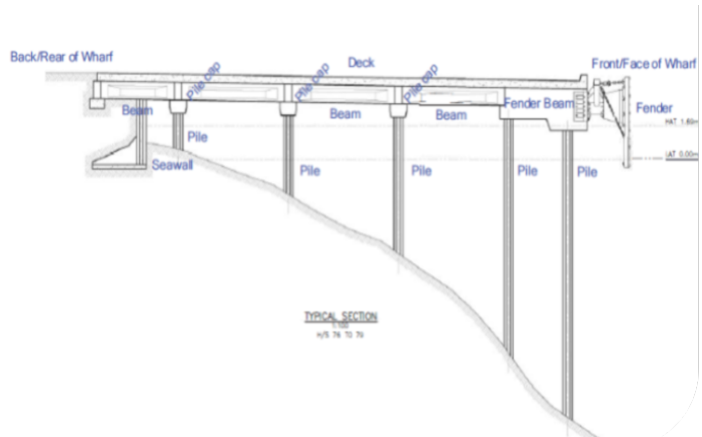

Figure 3 Typical cross-section of wharf and its key components (obtained from TasPorts)

5. Methodology

This section discusses a methodology that uses a comprehensive lifecycle cost analysis and what-if scenarios to help decision-makers assess infrastructure sustainability, considering risk.

The method is developed based on an adaptive heuristic genetic search algorithm of the degradation profile of various port infrastructure components using a Gaussian-based degradation strategy. The model consumes a combination of infrastructure renewal, and upgrade expenditure (CAPEX), together with maintenance, operational, user and environmental expenses (OPEX) required for managing the asset over its lifecycle. The model predicts the port's infrastructure condition and provides options for the capital works investment forecast for a given period (e.g. whole of asset lifecycle) based on the indicative available budget and expenditures.

Risk name	LoF	CoF	Score
Wharf surface or decking drainage's failure	Almost certain	Severe (<$10M)	Extreme
Bollard's failure	Almost certain	Moderate (<$1M)	High
Fender's failure	Almost certain	Moderate (<$1M)	Moderate

Table 1 Example risk identification and rating

Infrastructure risks are mostly overlooked in conventional lifecycle analysis. In order to incorporate infrastructure risks, the first step is to conduct a risk assessment to identify and rank the possible risks and assign a Consequence of Failure (CoF) value versus Likelihood of Failure (LoF). The below table shows examples of infrastructure risks that we identified as potential risks.

Asset importance, wharf utilisation (revenue), location and significance are key drivers determining CoF and risk ranking (e.g. revenue score = no of vessel calls/ revenue). For instance, failure of a pile component in a high utilisation or large wharf causes a significantly greater financial impact than a failure of a fender asset in low utilisation or small harbour.

Figure 4 and Figure 5 shows the typical risk rating we used to model the port infrastructure.

		Likelihood of failure (LoF)				
		1	2	3	4	5
Consequences (CoF)	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	16	20	25

Figure 4 Risk assessment matrix

Risk rating	Min	Max
Low risk	1	4
Moderate risk	5	10
High risk	11	19
Extreme risk	20	25

Figure 5 Risk rating values

The model interprets the costs of risks of infrastructure failure in the form of a benefit variation percentage. By setting the benefit variation, the model will choose and prioritise the assets and appropriate treatments with higher Consequences of Failure (CoF). This is particularly useful when port management operates under a constrained budget and yet tries to deliver optimum asset performance.

In order to understand the cost-benefit trade-offs of different budget strategies and to be able to prioritise the infrastructure works based on their sustainable lifecycle, we simulated and analysed various funding scenarios, including:

- Level of Service (LoS) driven strategy with risk mitigation:
- The model provides an optimised budget forecast to achieve or maintain a level of service while maximising benefit and minimising risk.
- LoS driven strategy without risk mitigation:
- The model provides an optimised budget forecast to achieve or maintain a level of service.
- Constraint budget strategy with risk mitigation
- Constraint budget strategy without risk mitigation.
- No budget and unconstraint budget scenarios for control and comparison

Then, for each of the above funding strategies, we calculated the asset sustainability index (ASI) over the given lifecycle period (20 years in this case study) using the following formula:

$$\text{ASI} = \frac{\text{Net strategy cost}}{\text{Required budget to maintain LoS}}$$

6. Outcome

Where "Net Strategy Cost" is equal to "total treatment cost" plus "maintenance cost" plus "change in backlog"; and "Required Budget to Maintain LoS" is equivalent to "renewal treatment cost" plus "maintenance cost".

Suppose the net cost of managing port assets is equal to or more than the proposed budget (ASI >=1). In that case, the strategy is financially sustainable, whereas ASI< 1 indicates the strategy is not as economically sustainable.

In order to demonstrate the proposed approach presented in this article, a commercially available predictive modelling tool is used to analyse and model the sample case study data.

Figure 6 shows a year-on-year risk comparison between the funding strategies for high and extreme risk events. The line graph represents the value of assets in high and extreme risk for a period and strategy.

Figure 7 illustrates the year-on-year net strategy cost comparison followed by the threshold backlog comparison shown in Figure 8.

Table 2 summarises the funding strategy comparison by various financial and non-financial parameters, including net strategy value and funding allocation for each strategy. It also includes the overall condition of the port assets in the current year compared to the predicted state at the end of the modelling period (20 y); and the calculated asset sustainability index for each funding scenario.

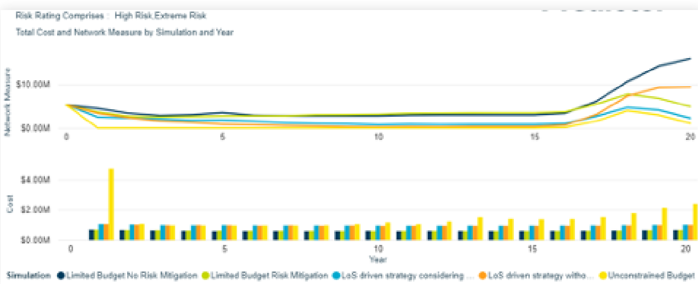

Figure 7 Year-on-year risk comparison of asset value and treatment costs for assets in high or extreme risk.

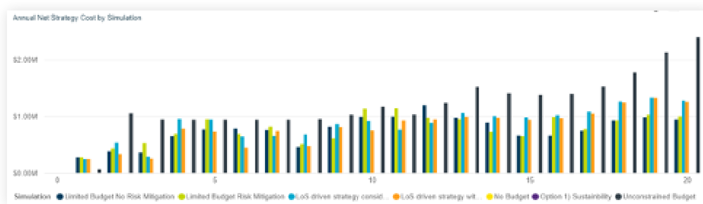

Figure 8 Year-on-year comparison of threshold backlog by funding strategy

Strategy	Net strategy cost	Total funding allocation over 20Y	Workbank backlog value (Y20)	% Assets in High + Extreme risk (Y20)	Condition index (Y1)	Condition index (Y20)	ASI (Y20)
Limited budget: No risk mitigation	$15,209,055	$15,050,964	$7,832,359	30.16%		3.35	0.54
Limited budget: Risk mitigation	$15,783,490	$15,169,005	$8,288,752	9.39%		3.47	0.56
LoS driven strategy: No risk mitigation	$16,157,415	$21,867,042	$1,964,640	17.83%	2.87	3.07	0.58
LoS driven strategy: Risk mitigation	$17,372,801	$21,974,683	$3,072,385	4.32%		3.18	0.62
Unconstrained budget	$24,779,454	$32,445,002	$8,720	2.08%		2.98	0.89

Table 2 Funding strategy comparison

7. Discussion

Comparison of the budget strategies presented in Table 2 shows:

- Unconstrained and optimised or LoS-driven budget strategies for managing port assets have a higher sustainability ratio than the limited budget strategy, indicating a sustainable asset renewal approach.
- Strategies that incorporated risk mitigation in their budget have less percentage of assets in high or extreme risk at the analysis period.
- For the case study presented in this paper, the higher range of asset sustainability index is 0.89 based on the unconstrained budget strategy analysis. The lower range is always 0, where no budget is spent.

The method and parameters presented in this paper help decision-makers, government and investors to be able to compare the options by considering all quantified variables to make informed and optimised decisions about their capital expenditure. By using the described ASI method, decision-makers can evaluate how financially sustainable a port authority is. Furthermore, to utilise and employ this KPI, Port authorities need to possess data regarding condition, risk, and accurate replacement costs to configure the predictive models, which will then optimise future infrastructure behaviour patterns. The decision is based on a holistic valuation of risks that contribute to fulfilling national development priorities, reducing climate change impact, addressing its effects, and achieving the UN Sustainable Development Goals [14][1].

8. Conclusion and future direction

Ports are an essential part of global manufacturing and distributions systems. Key requirements for commercial ports are accessibility and economic viability. The challenges are accommodating very large ships and the competition from new and modernised ports in the smart cities.

In addition, in recent years, ports are under increasing pressure from world regulators to become more environmentally and socially integrated and friendly. Ports face environmental issues such as pollution from ships, transport traffic for the movement of goods, raw materials, and port construction wastes. Simultaneously, port operators and their related businesses need to remain viable, competitive, and profitable.

The lifecycle analysis of port infrastructure helps ports respond to such economic challenges by making informed decisions about infrastructure investment and ensuring their competitiveness in a resource-constrained world while fostering innovation and reducing environmental impacts. Unfortunately, research on the economic performance in ports is limited, although there are a few practical examples within Australian ports. This paper builds on port lifecycle literature to present a case study demonstrating how the lifecycle approach can help secure a sustainable future for one of the Australian commercial ports.

Technology and innovation play a key role in the switch to sustainable infrastructure. For example, the Internet of things (IoT), drones and artificial intelligence (AI) are transforming infrastructure condition measurement. The sophisticated lifecycle models consume the condition data obtained from the intelligent measuring tools to predict the investment required to achieve a certain level of service (asset performance) within a defined annual budget over a whole life of the assets (economic performance) while minimising risk.

1 UN Sustainable Development Goals 9 & 11 are the most relevant sustainability goals to this article

However, there are challenges in this field include achieving consistency among the ports in how economic sustainability is measured. In addition, more case studies are required to set a benchmarking platform to be able to evaluate economic sustainability performance in Australia and worldwide.

In addition, further research is required to set KPIs that incentivise improvements in port management practice and encourage self-examination in order to reprioritise activities considering sustainability.

In addition, further study is required to fine-tune and benchmark the evaluation criteria for financial performance and set realistic targets towards economically sustainable port infrastructure. The KPIs that encourage improvements in port management practice by self-examination of financial performance in order to reprioritise activities considering sustainability.

In addition, the authors hope that setting a consistent economic performance measure leads to a step-change in government policy and infrastructure investment decisions so that infrastructure sustainability and climate resilience becomes an automatic and critical investment

9. Acknowledgement and declaration

The authors would like to thank the asset management team of the Tasmanian Port Authority for providing data and background information for the case study presented in this paper.

Since this project is in an early stage of its development and to protect TasPorts' data privacy, we extracted sample data from the entire port. We made some changes to the financial and non-financial figures.

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