



Port Sustainability as a Service: The Design of Bespoke Service Level Agreements (SLAs) to Improve Operational Efficiency at Harbours by Prioritising Social Satisfaction

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OPEN ACCESS

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Specialty section:

This article was submitted to
Sustainable Consumption,
a section of the journal
Frontiers in Sustainability

Received: 26 April 2022

Accepted: 19 May 2022

Published: 16 June 2022

Citation:

Peoples C, Moore A and Georgalas N
(2022) Port Sustainability as a Service:
The Design of Bespoke Service Level
Agreements (SLAs) to Improve
Operational Efficiency at Harbours by
Prioritising Social Satisfaction.
Front. Sustain. 3:928994.
doi: 10.3389/frsus.2022.928994

The maritime industry is a complex ecosystem which is important to manage carefully given the role it plays in handling global trade. Effective operation at a port is dependent on a timely passage of goods, involving multiple competing objectives, one of which is sustainability. Unsurprisingly, given the extent of a port's operations, it is a significant contributor of emissions. A port is a physically demanding industry in which to work, and any degradation in workforce productivity can have a detrimental effect on the port's effective running. Slow operations, combined with dependencies between port stakeholders, can further amplify unsustainability. There are some efforts to explore the digitalization of ports, including the creation of green and smart ports. However, there is general widespread resistance to the introduction of technology in this domain. There are therefore a number of areas in which to make technical contributions to improve the efficiency of port operations. In this paper, we propose using the satisfaction of staff at a port to influence the efficiency of its operations. In recognition of widespread low staff morale at ports in general, we recognize that staff become dissatisfied as operations move out of their control and the resulting consequences of interruptions to performance can lead to disruptions unable to be rectified quickly or easily, with staff motivation remaining low. Once low and unmotivated, there is a possibility that motivation will remain low even for operations which staff are in control of, with a detrimental effect on the efficiency, and therefore sustainability of the port. We believe that measuring and improving the satisfaction of staff for the efficiency it can bring will be possible through the roll-out of sensors supporting an Internet of Things (IoT) architecture across a port. With satisfied staff, they are likely to be motivated to work in an efficient manner, which will carry through to situations when unexpected circumstances outside their control occur. It is therefore through increased IoT use that port sustainability will be supported in our proposal. Enabling this, staff efficiency and satisfaction can be tracked using a connected service made available using Service Level Agreements (SLAs). The cost of the service and subsequent extent to which staff can be monitored and managed

for sustainability objectives can be agreed with a service provider in advance. When staff are satisfied, the port will be operated to sustain low costs. When staff satisfaction begins to decline, however, operation will become focused on the performance of the port to identify where bottlenecks exist in inefficient operations and staff output. While simultaneously managing both cost and performance through the satisfaction of staff, the goal is an overall positive contribution to a port's efficiency and sustainability.

Keywords: autonomy, Internet of Things (IoT), maritime industry, port, sensor-driven operations, Service Level Agreement (SLA), sustainability

INTRODUCTION

The maritime industry is one of the major contributors against and beneficiaries of a sustainability agenda (Wang et al., 2020): More than half of the sulfur dioxide emissions in Hong Kong, as one example of a significant port, are related to shipping (OECD Port-Cities Programme, 2010). Despite this however, the shipping industry was not included within the 2005 Kyoto Protocol (United Nations Climate Change, 2020). More recently, further unbalanced efforts at ports are evidenced by the UK Government's reported non-committal to green ports, fair work, or "net zero" principles (Scottish Government, 2021; UK Government, 2021). Without a uniform global application of such schemes, there are therefore gaps in the ways that sustainability is approached, and, from a port perspective, cannot be assumed a priority.

A sustainable port is considered by Sheu et al. (2013) to be a product of "social environmental responsibility", "economic impact", and "performance of enterprise and distribution network" (Sheu et al., 2013). With economic investment, people with a social responsibility, and a well-performing network, sustainable operations are possible. Concerns around the sustainability of the port industry, however, have been growing, as evidenced in recent research e.g., (Bergqvist and Monios, 2019; Lai et al., 2019). The United Nations Department of Economic and Social Affairs on Sustainable Development¹ has contributed Goal 14 to "Conserve and Sustainably Use the Oceans, Seas and Marine resources for Sustainable Development"². It might be noted, however, that while the ports have a role to play in support of this agenda, due to the levels of pollution which they emit³, the concerns of Goal 14 are not specific to optimizing the quality and operational approach at ports, and the priority lies in "life below water" (Cicin-Sain, 2022) – this is a significant gap, given that pollution arises from a variety of angles at ports, and there are several opportunities to promote sustainability at this level (Figure 1).

¹United Nations Department of Economic and Social Affairs. Available online at: <https://sdgs.un.org/> (accessed 23 April 2022).

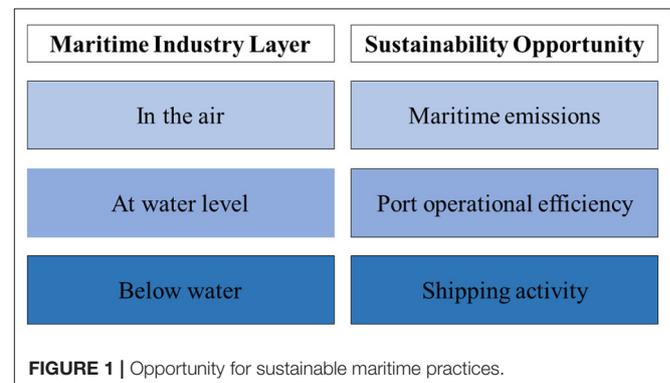
²United Nations Department of Economic and Social Affairs. SDG Goals. Available online at: <https://unstats.un.org/sdgs/report/2017/goal-14/#:~:text=SDG%20Goals-,Goal%2014%3A%20Conserve%20and%20sustainably%20use%20the%20oceans%2C%20seas%20and,for%20their%20livelihoods%20and%20prosperity> (accessed April 23, 2022).

³United States Environmental Protection Agency. Ports Primer: 7.1 Environmental Impacts. Available online at: <https://www.epa.gov/community-port-collaboration/ports-primer-71-environmental-impacts> (accessed April 23, 2022).

Overlaps also exist across the layers in Figure 1, which comprises the maritime industry in its entirety, and we believe that they should not be considered in silos when developing technical solutions in support of sustainability. Decisions both at and below the water level will contribute to emissions in the air, and our belief is that an integrated, multi-stakeholder approach is necessary.

From a multi-stakeholder perspective, the opportunities for optimizing port efficiencies include transportation (trucks, marine vessels, locomotives, cargo handling equipment) and stationary sources (refineries, oil and gas storage facilities, power generation, and storage of open piles of coal). Enlisting the support of multi-stakeholder collaboration within ports, considered by some to be a fundamental strategy e.g., (Bergqvist and Monios, 2019), is challenging however, due to, as one restrictor, the range of languages which might be spoken at a port (Alexakos and Konstantinopoulos, 2012). Furthermore, wide variation in the resources available at ports and skills of the staff (Islam and Olsen, 2011) who work there further complicates the achievement of a united approach to sustainability. Reliance on manual operation on a per port basis is therefore common, however, this is unlikely to be the most efficient approach and is a contributor to the problem observed today.

Moving from a manual to a more automated operational approach places requirements on the availability of context data to support this process (United Nations, 1976; Rajabi et al., 2018). "Context" within the perspective of our work refers to data metrics which reveal actions happening in and around the port, such as crane state (active or idle) and berth occupation (occupied or not occupied). The generation and use of context to support automated decision-making has increasingly been a



priority in ports in recent years (United Nations Conference on Trade Development, 2020), but since the Covid-19 crisis, many maritime research vessels have returned to their home country, therefore suspending ongoing investigation (United Nations, 2021) and limiting research data collections. While this change may be more related to efficiencies below the water and, as a by product, the air, there are therefore now further gaps to fill in the creation of sustainable ports. We argue that the current situation presents a prime opportunity to propose an integrated approach in support of sustainability across the **Figure 1** layers of the maritime industry.

With a need to collect context data to drive intelligent and efficient decisions, and the variable skillsets and resource availabilities across ports on an international basis, there is demand for new technical solutions. We propose that the sustainability agenda in and around ports can be influenced using Service Level Agreements (SLAs), applied to influence the ways in which ports are operated, with a subsequent positive reaction on the satisfaction of staff. SLAs, in general, refer to the assurance of guaranteed service levels in return for a pre-agreed cost. Specific to our consideration of SLAs, Internet of Things (IoT) services can be purchased from a series of tiers, each of which influences the sophistication of the service provided. Any deviation from the service delivered by an Internet Service Provider (ISP) will result in compensation being paid to the customer – the port in this case. At present, SLAs are commonly offered according to a few basic tiers, such as gold, silver, and bronze, and are primarily for a measure of platform uptime. Through our research, we advocate the use of a greater range of service metrics, which can support personalization for the domain in which the service is being used. Through offering SLAs in a bespoke manner, there are opportunities to respond more closely to the needs of the domain, which can include optimizing the carbon footprint of the network. While we appreciate that the deployment of technology in itself brings an environmental impact – the GSMA estimates a contribution of mobile networks of 0.4% to global emissions – the use of technologies enables an overall reduction in GHG emissions ten times greater than the footprint generated (anon, 2022c). Indeed, the Chief Executive of the Carbon Trust has previously encouraged the use of mobile telecommunications to this end (The Enablement Effect, 2019).

We consider using SLAs to influence the collection, storage, and processing of context data across ports to support automated decision-making for sustainability, performance and cost objectives. The SLA tier which a port buys into will influence the volume of context that can be collected and therefore the range of evaluations and decisions which might be made. Furthermore, port behaviors can be influenced by the SLAs in use, in the sense that an SLA allows customers to use a network to support certain activities, which can be focused toward ultimately being for sustainability goals.

Digitalization, in general, has been encouraged in ports due to the efficiencies it can bring to process optimization. As one example, the International Maritime Organization (IMO) have been supporters of electronic and automated data exchange between ships (Acciaro et al., 2014). However, the literature also captures the challenges with general digitalization in ports e.g.,

(Acciaro et al., 2014). Despite some advancements in the creation of smart ports e.g., (United Nations, 1976), this opportunity is relatively underexplored.

To examine a few of the reasons why digitalization efforts may have been resisted so far, the use of technology in ports can result in a need to recruit more workers and pay a wage higher than typical levels (United Nations Conference on Trade Development, 2019). This can be preventative from the perspective of some ports. From a contrasting angle which also hinders digitalization in ports, increased use of technology in the maritime industry can lead to a reduced need for workers, if we consider the introduction of automatic operations. Autonomous ships, as one example, could take away the need for a crew. Coupled with such technologies are the further risks of errors without human decision-making, in addition to the risk of piracy. Given the general low motivation and morale across ports already (Webber, 2020), it is possibly not an attractive opportunity for ports to consider further ways of increasing technology. Nonetheless, some larger ports are making moves in this direction.

Current smart port projects include the Ports of Hamburg⁴ and Rotterdam⁵, both of which focus on using technology to improve logistical operations. This is worthwhile activity, with Ericsson acknowledging that operations at ports are typically slowed down by vessel and truck congestion (anon, 2022b). Rotterdam port considers itself to be a leader in smart logistics, influenced by digitalization and automation. Their strategy involves predicting traffic flow using logistical data, and have proposed Freight Traffic Management as a Service. Historical data supports traffic predictions, combined with logistical data from transport companies for a more rounded perspective. They posit that accurate planning leads to a more continuous flow of traffic, with plans dynamically adjusted where necessary based on historical data and future predictions. The Port of Hamburg, like Rotterdam, has smart logistics at its core. It uses sensor technology, combined with data analysis and forecasting to improve the efficiency of operations. A PortTraffic Center links ship, rail, and road traffic with one another for an overall perspective⁶, allowing real-time navigation and dynamic response. However, from the descriptions provided, it can be appreciated that these are piecemeal solutions, and ones which are not necessarily integratable with the activities at other ports. Response to the sustainability challenge, even at the most sophisticated of ports, is therefore under-explored and under-developed.

Taking into account the general resistance to digitalization and some roll-out of smart technology at selected ports, we believe that social satisfaction is particularly relevant in the port context in general, and particularly in relation to efficiency and therefore sustainability concerns, given the long working hours

⁴Hamburg Port Authority. Available online at: <https://www.hamburg-port-authority.de/de/hpa-360/smartport> (accessed April 23, 2022).

⁵SmartPort. Available online at: <https://smartport.nl/en/> (accessed April 23, 2022).

⁶Hamburg Port Authority. The HPA Traffic Tower. Available online at: <https://www.hamburg-port-authority.de/en/info-port/traffic-tower> (accessed April 24, 2022).

and generally poor working environments (OECD, 2022a). The maritime trade union, Nautilus, conducted a survey, and found that a quarter of workers felt “down, depressed or hopeless” for several days within the last 2 weeks, while a fifth felt hopeless and depressed every day (Shell, 2020). Factors affecting their feelings include fatigue, working environment, role, socialization, and leadership (Webber, 2020).

We therefore consider it a priority to factor the satisfaction of staff into the management decisions made. In this vein, we correlate the influence of social efficiency on people behaving in a manner which supports and promotes overall sustainability across a port. We suggest that social efficiency is equivalent to a productive port minus any detriment caused by logistical delay or, poorly operated or non-functional equipment which ultimately introduces processing delay. In saying this, we refer to the assumption that a port is productive when people operate in an efficient manner and there are no delays to their progress. Social efficiency is characterized by the balance between marginal social benefit and marginal social cost:

Social benefit may be achieved when staff are satisfied with the roles in which they are involved, they are working at maximum capacity, they have the tools available to complete their job, they are free from interruption, and they have adequate physical ability to complete work.

Social cost, on the other hand, may be incurred in the reverse of these circumstances, when staff feel discontent, they are not working at maximum capacity, the tools are unable to support the work being completed, and there may be physical impacts preventing or slowing the completion of work.

We recognize that, when an employee is working at maximum capacity, they may be exposed to delays as part of their day-to-day work, however, the significant factor here is that the delays are expected. Such delays may be incurred, for example, when powering up a crane or moving a pallet truck into the necessary position to receive load. In such situations we believe that staff will continue to experience social benefit from the role they play at work. Social cost, on the other hand, will accumulate when unexpected delays or inefficient operations occur, at which point staff will become more stressed and their satisfaction will begin to decline.

In this paper, we posit that situations of higher social cost than benefit lead to inefficient and unsustainable operation in a port, and that IoT technology can be deployed to support the efficiencies with which a port operates – this is the significant deliverable of IoT capability, and staff satisfaction and subsequent efficiency is a by-product of this. We believe that the SLAs which drive the way in which IoT technology is operated and managed can be used to increase staff satisfaction, providing a mechanism through which staff and management at the port are bound by contracts that are agreed in advance. By prioritizing staff satisfaction, this is intended to control the efficiency of operations and therefore the overall performance of the port. It is with this approach that the work is presented in this paper.

Ideally, we would like to be able to make a comparison between our proposal and related academic state-of-the-art solutions. However, to the best of our knowledge, SLAs are not offered to support sustainable port operations through the products and technologies made available in support of operating as being “green” or “smart”. It is therefore not possible to provide a comparative academic analysis with other SLAs. We identify our proposed approach to respond to the sustainability challenges in ports as being one which is novel, and provides a solution in a unique way to a prominent challenge in this domain. Furthermore, we are seeking to provide an implementable solution to the port efficiency/sustainability problem by working directly with Belfast Harbour, and there is a need to ensure that the solution is competitive in relation to the others available; these are not widely discussed in academic literature, and rather, come from industry bodies deploying practical solutions. Ports, in general, are not rapid to digitalize, and as a result of this, there are few specific case studies to base our research on. We therefore hope that our research makes a positive contribution to sustainability in a relatively under-examined domain from the academic perspective.

The remainder of the paper continues as follows: In Section State-of-the-Art in Smart & Sustainable Ports, a literature review of the state-of-the-art in smart and sustainable ports is presented, with a view to expanding upon the context provided in the introduction and setting the scene for our research proposal. In Section Review of the Conflicting Priorities of Multiple Port Stakeholders & Impact on Staff Efficiency, we review the conflicting priorities of multiple port stakeholders and the impact that this can have on staff efficiency at a port. Our research proposal of using SLAs to support port sustainability through efficient operations is presented in Section Research Proposal: Using SLAs to Support Port Sustainability Through Efficient Operations, and the paper concludes and presents our further work in Section Conclusions & Future Work.

STATE-OF-THE-ART IN SMART AND SUSTAINABLE PORTS

According to the Review of Maritime Transport 2021 (United Nations Conference on Trade Development., 2021), technology will play an important role in supporting environmental sustainability. Heilig et al. (2017) describe the three phases of a port’s technical evolution: The first phase is the paperless phase, the next phase uses automated procedures, and the final phase is the emergence of the smart port (Heilig et al., 2017). Acciaro et al. (2014) note that innovation in this domain is often met with resistance (Bergqvist and Monios, 2019). This can be due to the complexity of the digitalization process, and the problems which emerge when making this move (Brunila et al., 2021). It can also be dependent on the size of the port and the diversity of resources, with larger ports being more able to support digital processes than smaller ones. Furthermore, there is a parallel with the economic worth of the country in which the port is placed, with developing countries prioritizing economic growth rather than the use of green strategies. Green strategies, nonetheless, are

significant, given recent criticism of the UK Government's lack of attention to the goal of net zero in Scottish ports (Scottish Government, 2021), giving the impression that this is an area of interest today.

Green Ports

There is limited research in the field of green ports (Acciaro et al., 2014). A green port is one which encourages environmentally friendly operations, including those which reduce emissions (Bergqvist and Monios, 2019). The Ports of Brunswick and Savannah in the USA are green ports and reduce emissions by transitioning rubber-tired gantry cranes (RTGs) from diesel to electric power. A RTG is the crane used to move containers to the ground or to stack them, when inbound at a port for pickup by a truck and when outbound, for loading onto a shipping vessel. The stochastic behavior of RTGs, leading to unpredictable needs to power up and move into position, makes RTGs inefficient devices. RTGs are significant contributors to carbon dioxide and nitrogen oxide emissions (Alasali et al., 2018). The Georgia Ports Authority is also using electrified ship-to-shore cranes which generate energy as they lower containers⁷. In this case, usable energy is created through gravity, with the gravitational energy being converted into kinetic energy as the body is moved from a higher to a lower altitude (Ambade et al., 2014).

These are piecemeal approaches to implementing sustainability at these ports, and respond to individual areas of concern in relation to specific inefficient practices. It is generally recognized that operating in a sustainable manner can be more about the responsibility of the organization as opposed to fully engaging with the complete picture of sustainable operation (Barasti et al., 2022). This is evidenced in instances where localized efficient approaches have been rolled out. This finding is further supported by Anastasopoulou et al. (2011), who acknowledge that many adopt the conventions of the International Maritime Organization (IMO) (e.g., safety, the environment, legalities, and security, among other concerns), however, they do not follow recommended practices in their everyday operations (Anastasopoulou et al., 2011). Non-compliance with this can result in a port being fined. anon (2020), for example, specifies the limit on sulfur content in fuel oil used on board ships (Puig and Wooldridge, 2021). However, the IMO works under the United Nations, and has no authority to enforce their regulations. Enforcing a fine for non-compliance is therefore difficult, however, there are signs of pressure coming from the market itself, with Ikea and Walmart, as two examples, requiring shipping firms to comply with regulations (anon, 2020).

The piecemeal approach to green operations is also seen in ports across Greece (Puig and Wooldridge, 2021). The port authority of Patras for example, does not allow hazardous merchandise to be transported because of insufficient infrastructure to handle it. The port of Igoumenitsa, as another

example, uses a Building Management System to control energy consumption. The ports, however, have limited ability to collect and treat wastewater, with the consequence of lost opportunities of reusing waste products.

Ports are reluctant to enforce action to become green, as there is a cost associated with doing so (Woo et al., 2018). Indeed, in parallel with improving the pollutant efficiency of ports, there is a drive to similarly develop a profitable business model to encourage port authorities to commit. Magginas et al. (2018) consider viable approaches in the creation of a multi-agent port business model, with a view to responding to multi-stakeholder needs at ports. They examine the improvements possible through a landlord management model and a partial privatization management model, before concluding that the landlord approach is the most cost effective. It is significant to note, however, that the priorities used to influence the cost model do not include operational efficiency. The authors of (Mjelde et al., 2019), on the other hand, discuss how the fees of a port can be based on the environmental performance of vessels. A shipowner has been found to be more likely to commit when the fee rebate is large. The rebate reveals the financial incentive to invest in green technology.

The Environmental Port Index (EPI)⁸ is a reporting tool for ship owners and port operators to influence better sustainability practices. The EPI Baseline, as one measure, determines a ship's environmental impact while at a port. The EPI Portal captures a ship's utility data while docked at a port, including its fuel consumption, emission levels, and power levels. The EPI Score compares the Baseline and the Portal, with a higher score for a Portal which is higher than the Baseline. The Report supports a ship owner in identifying areas where they can exploit better efficiency. The EPI is used, however, only at 19 ports at the time of writing, which are located across Norway and Iceland (EPI, 2022).

Smart Ports

Smart ports are generally deployed for the improved logistical opportunities they can introduce (Douaioui et al., 2018), considering as specific examples the Ports of Rotterdam and Hamburg. The Port of Rotterdam is a significant port on an international scale, given that it is the largest deep-water port in Europe, and it is one of the top ten worldwide (anon, 2022a). In February 2021, it was described as having sensors installed to improve asset management (Maundrill, 2021a). The Port of Rotterdam has also recently become digitally connected to Teesport port in the UK, with a view to improved data exchange between the two ports, which act as important transport routes between Europe and the UK (Maundrill, 2021b).

While more efficient logistics, such as those aimed for between Rotterdam and Teesport ports, will ultimately contribute to more sustainable operations in some regard, this approach does not specifically create a more humane environment or prioritize the needs of the individuals who work there. This is important, given

⁷United States Environmental Protection Agency. Georgia Ports Authority Reduces Diesel Emissions, Improves Efficiency, and Saves Costs. Available online at: <https://www.epa.gov/ports-initiative/georgia-ports-authority-reduces-diesel-emissions-improves-efficiency-and-saves> (accessed April 24, 2022).

⁸Environmental Port Index Homepage. Available online at: <https://epiport.org/> (accessed May 17, 2022).

the general low motivation and morale evident across ports e.g., (Munyiva and Wainaina, 2018).

There are also wider benefits to be achieved beyond a port itself from the social perspective as a result of contributing to operational efficiencies (Gurzhiy et al., 2021). Wang et al. (2020) discuss the social aspects of improved maritime sustainability, including the benefit to coastal residents, seafarers, and cities and communities who depend on the global logistics system (Wang et al., 2020). This is considered from the social entrepreneurship perspective, although there is less focus on how sustainable operations in this manner might be achieved from the port. It is therefore to this gap that we contribute in this paper.

Port Internet of Things Management Frameworks

Technology deployed in support of the Internet of Things, which is essentially what we are considering with the use of sensors at a port, requires management. There are a few, but not many examples of IoT port management solutions in the academic literature, and all of them are published recently, within the last couple of years. Barasti et al. (2022), describe an IoT framework which has been deployed at the Port of Livorno. The framework is organized in terms of the infrastructure, platform and software layers. The infrastructure and platform resources are shared so that the applications can use the collected data. Min (2022) considers the essential elements of a smart port architecture, which include end-point automation, network communication, security and surveillance, analytics, and performance monitoring. There is very much a lack of a standardized approach to managing IoT technology at ports, and experimental testbed roll-outs are few.

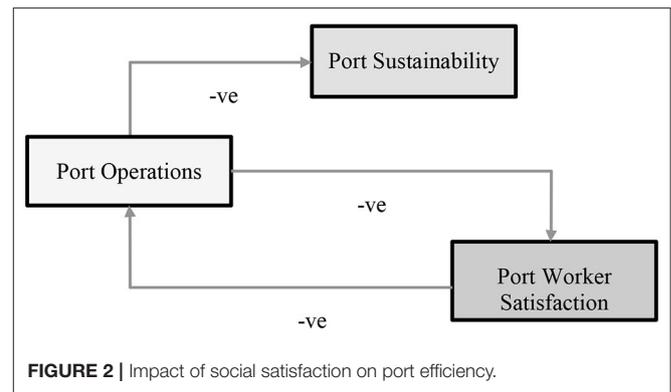
Port Service Level Agreements (SLAs)

There are even fewer examples of SLA use in ports. As noted by Barasti et al. (2022), it may be considered that the Port Authorities would be the providers of digital innovation services, however, they are, so far, the final users of them. Our research has not uncovered any use of SLAs to manage online service provision in ports. This is therefore a key research gap to which our work responds.

REVIEW OF THE CONFLICTING PRIORITIES OF MULTIPLE PORT STAKEHOLDERS AND IMPACT ON STAFF EFFICIENCY

Before thinking about how to support staff efficiency using IoT technology and its associated SLAs, it is relevant to consider the multi-stakeholder operations at a port which can affect efficient operations:

1. *Cargo ship*: If a ship is unable to dock due to a backlog or staff not being available to support the docking, noise and particle emissions will continue for longer than they would otherwise.
2. *Lorry*: With a backlog of cargo ships waiting to dock, a backlog of lorries waiting to load goods will also build up.



3. *Warehouse*: If lorries are waiting to receive good from ships which are unable to dock, lorries arriving to receive goods from the warehouse will be delayed.

Social efficiency in this case is considered to be influenced by the delay of the ship being unable to dock, the cargo being unable to be unloaded, a congested yard, and a congested warehouse. As staff are unable to work at maximum capacity, their day-to-day role is interrupted. We posit that, in this situation, the social cost will begin to increase, the social benefit will decline, staff will become less efficient overall, and the sustainability of operations at the port will suffer (Figure 2).

Any operations which might therefore have a potentially negative impact on port operations are beneficial to identify in advance of occurrence, and staff efficiency should not have an opportunity to decline. The goal of this proposal is therefore to provide a technical solution which supports this.

Social Dimensions of Port Sustainability

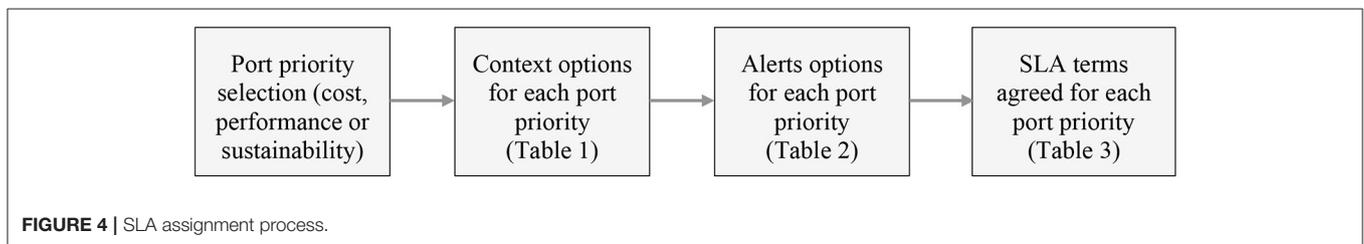
It is relevant to consider the social dimensions of port sustainability given the involvement of humans across many port operations. The Organization for Economic Cooperation and Development (OECD) describes that port pollution arises from three core areas which include: port activity, ship emissions, and hinterland transportation (OECD, 2022b). Each of these areas involve manpower and its coordination for efficient operations. For example:

- Port activity:
 - Hauling mooring ropes off large ships.
- Hinterland transportation:
 - Being available in the port to receive container loads.
- Ship emissions:
 - Responding to port call processes for docking.

Ports are particularly vulnerable to the efficiencies of staff, given the negative health impacts a port can bring, including hypertension, cardiovascular disease and mental stress

Tier	SLA Services	Objective
1	Port critical / emergency services	Sustainability
2	Port operational & efficient	Cost
3	Port operations and efficiencies impacted	Performance
4	Port all services (constantly monitoring in comfort)	Performance

FIGURE 3 | Port SLA service tiers.



(The Editorial Team, 2018). By focusing on the people operating the port, we argue that operations will become more optimized and efficient, and therefore sustainable. It is our belief that the scheme proposed, through harnessing both IoT capability which are managed using SLAs, can contribute to supporting both social efficiency in addition to equipment and logistical efficiency. The goal is to achieve this by monitoring staff efficiency and any factors which might cause their effectiveness to decline, in addition to monitoring and taking proactive intervention in the event of potential delays, caused by equipment failure or human error. In this way, the goal is to assure staff efficiency through achieving a social benefit which exceeds the social cost.

METHODOLOGY

The SLA tiers which we propose to promote sustainable operations at a port are presented below. These are based on the comparisons with typical home-based SLA offerings, and the priorities which we hope to encourage with port operations. A policy-based SLA assignment process is then defined, based on the metrics we advise are collected from an IoT deployment across a port, such that the appropriate alert conditions can be triggered, and the necessary operational priority responded to. This paper does not present any results as our proposal is not yet implemented. Instead, we have proposed ideas around the ways in which SLAs may be used to promote effective and efficient human behavior across ports. To the best of our knowledge, there are no equivalent deployments of SLAs across ports. Therefore, there are no other studies with which to compare our proposal.

RESEARCH PROPOSAL: USING SLAs TO SUPPORT PORT SUSTAINABILITY THROUGH EFFICIENT OPERATIONS

Efficient and smart port operations will evolve from a multi-stakeholder approach, therefore, we seek to examine strategies to optimize the stakeholder cost. When we consider SLAs, we typically think about a response which provides a service to a target user group. The provisions made in the SLA respond to user needs, and deviations from the ability to provide the service requested by the customer should be compensated for. Given not only the human resistance to but also the practical barriers of the integration of modern technology into the port, the use of SLAs goes some way to limit the ways in which humans need to explicitly interact with the technology, but instead, benefit from the services provided. We suggest that SLA services are offered on the basis of prioritizing sustainability, cost or performance in a tiered offering (**Figure 3**).

At the most basic level of service, a port will be operated for sustainability. This will involve the collection of a minimum of context attributes, with minimal SLA configuration options. The assumption is that the port will be performing as expected, staff are satisfied, and sustainability can therefore be prioritized. This assumes that sustainability will be optimized when staff are satisfied. There are also opportunities to collect more information around the port to influence the management decisions. Such service plans can be offered with cost as a priority, or performance. When the service plan prioritizes performance, an increased volume of sensor data will be collected to support more informed decision-making around operations.

The SLA provisioning process is presented in **Figure 4**.

TABLE 1 | Context metrics collected per SLA priority.

Context options			
Staff satisfaction priority	Sustainability priority	Cost priority*	Performance priority
timeToHaulRopeOffLargeShips	nitrogenOxideEmission	warehouseCapacityEmpty	warehouseCapacityEmpty
timeToBreakOutPre-packedOrPallettedLoads	sulphurOxideEmission	lorryTurnaroundTime	warehouseCapacityFull
timeToLift/ManoeuvreLashingBars	ghgEmission	shipTurnaroundTime	delayInExpectedArrivalTime
	decibelEmission		lorryTurnaroundTime
			shipTurnaroundTime
			numberOfLorriesInYard
			oxygenLevelInConfinedSpace
			shipQuantityOfCargoWorkedPerShipHour
			toxicOrFlammableGasesInConfinedSpace

*Basic Health & Safety service offered, not under the advice of the SLA

TABLE 2 | SLA alert options.

SLA alert options		
Sustainability priority	Cost priority	Performance priority
oxygenLevelInConfinedSpace – above/below threshold	lorryTurnaroundTime – above threshold	shipTurnaroundTime – above threshold
decibelEmission – above threshold	warehouseCapacityEmpty – above threshold	
latencyToHaulRopeFromShip – above threshold		

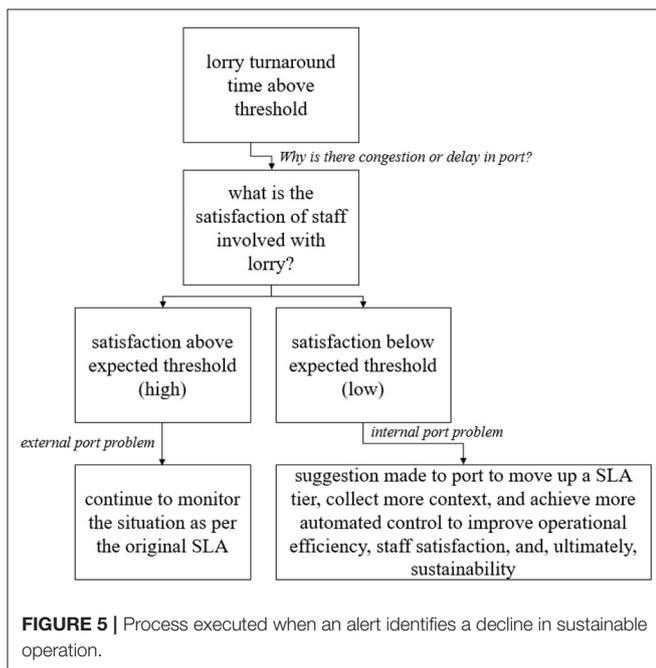


FIGURE 5 | Process executed when an alert identifies a decline in sustainable operation.

Once a port makes a decision on their operational priority, they will be able to consider the context metrics when can be collected for greater awareness around port operations, including staff satisfaction (Table 1).

Staff satisfaction can be assessed according to the time it takes staff to execute their operations, and comparing this value against

TABLE 3 | SLA metrics for sustainability, cost and performance service tiers.

	Sustainability priority	Cost priority	Performance priority
Time to repair			x
Minimum link throughput			x
Disk read errors		x	
Storage space		x	x
Storage space utilization		x	
Uptime			x
Service availability			x
Services offered	x		x
Number of alerts	x	x	x
Number of metrics collected		x	x
Staff satisfaction	x		x

a threshold (which may be calculated through monitoring over time). When the value begins to increase above the threshold, it can be concluded that staff satisfaction is declining, and preventative action can be taken.

Metrics to facilitate the cost-based SLA, which has the aim of reducing operational cost at the port, include:

- *warehouseCapacityEmpty*
- *lorryTurnaroundTime*
- *shipTurnaroundTime*

Both the lorry and ship turnaround time indicate effectiveness of port operations. Detail on the how and why of any delay is not

collected to support an overall more sustainable technical system, but indicates to management that intervention may be required.

With the goal of performance, the desire is to improve operational throughput at the port. Metrics to facilitate this include:

- *delayInExpectedArrivalTime*
- *numberOfLorriesInYard*

The aim with performance measures is to therefore gain an appreciation for the reasons why a delay is occurring. If *lorryTurnaroundTime* is above a threshold, for example, there is a need to assess if this has been impacted by the *numberOfLorriesInYard*.

Our model builds upon the fact that context will already be collected to support health and safety in general at a port, in a manner equivalent to what is achieved already. Taking this further, there are opportunities to offer workers the option for additional services to support their health in a more specific and bespoke way, with a view to increasing their satisfaction and therefore overall performance efficiency, and subsequently sustainability, across the port (Table 2).

An alert will occur in the event that any of these metric values exceed an acceptable threshold. Consider the situation of *lorryTurnaroundTime* being greater than the registered threshold (Figure 5).

Once alerted, the satisfaction of staff working with the lorry will be assessed, with a view to understanding if this delay may have been influenced by the efficiencies of lorry workers. If prior to this interruption satisfaction has been high and above the expected threshold, this indicates a problem which is external to the port. The SLA therefore need not be adapted in this case, with operations beyond the port being unable to be influenced by adapting SLA configuration and application within the port. On the other hand, if staff satisfaction prior to the delay is below the expected threshold, this indicates an internal port problem. In this case, a suggestion will subsequently be made to move up a port tier and to collect more context data from a wider range of activities across the port with a view to returning operations to a more efficient mode, and staff satisfaction at or above the threshold.

Once the metric and rules options are decided for the port, the service tier can be selected, and the SLA terms agreed (Table 3).

With the sustainability option, a minimum of SLA terms are agreed, seeking the less intensive configuration process and supporting a minimum of services which might offer performance with least cost. When cost is the priority of the SLA, more aspects will form the SLA contract, with a view to ensuring that operations are efficient, and cost is therefore minimized as a result. When performance is the target, further metrics again are considered in the SLA contract terms, prioritizing the quality of service delivered as opposed to cost minimization or sustainability. In relation to the specific resource allocations made, this will be influenced by the size of the port. For example, the average number of ships passing annually through a port will influence the storage space and the minimum link throughput.

CONCLUSIONS AND FUTURE WORK

One of the arguments around challenges with port operations and their ability to be integrated with the activities at other ports is the divergence between operational approaches, technical solutions, and therefore their interoperability. The largest ports and therefore those with the most resources are likely to have the greatest levels of digitalization. Without equity across all ports, however, solutions are unable to interact with one another. Given this multi-stakeholder environment, there is a need for a collaborative and willing approach. In the event that sustainability is measured through staff satisfaction, the ability to support this is dependent on workers being willing to communicate satisfaction with staff, and even having their day-to-day efficiencies observed. Given the complexity of the port ecosystem, it is difficult to argue from a paper-based perspective that any single goal – performance, cost, sustainability, or staff/passenger satisfaction – will be improved. However, we are now working with Belfast Harbour⁹ to examine the suitability of our proposals.

In response to the wider project with which our research is involved, the BT-Ireland Innovation Center (BTIIC)¹⁰, sensors are currently being deployed across the Harbour in the creation of an IoT testbed. The SLA proposal described in this work will subsequently be deployed and examined for the contributions it can make in support of facilitating efficient and sustainable operations. As this is taking place, we will continue to examine the opportunities for ensuring that our proposal will support interoperability with future port IoT management solutions internationally.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

CP devised the idea with the support of AM and NG. AM and NG were involved in planning and supervised the work. CP drafted the manuscript and AM designed the figures and tables. All authors discussed the contributions and commented on the manuscript.

FUNDING

This research was supported by the BTIIC (BT Ireland Innovation Center) project, funded by BT and Invest Northern Ireland.

⁹Belfast Harbour. Available online at: <https://www.belfast-harbour.co.uk/> (accessed April 24, 2022).

¹⁰BTIIC. Available online at: [https://www.ulster.ac.uk/research/topic/computer-science/btiic#:~:text=BTIIC%20is%20a%20five%2Dyear,Things%20\(IoT\)%20and%20Telecommunications](https://www.ulster.ac.uk/research/topic/computer-science/btiic#:~:text=BTIIC%20is%20a%20five%2Dyear,Things%20(IoT)%20and%20Telecommunications) (accessed May 17, 2022).

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Conflict of Interest: NG was employed by BT Group PLC.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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