

Complexity and Paradox in Smart Port Transformation: Evidence From Sines' Port Case

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Abstract: Smart Ports are increasingly required to pursue digitalisation and decarbonisation simultaneously while maintaining operational continuity. Although these transitions have attracted growing academic attention, existing studies generally examine technological innovation or sustainability independently and provide limited theoretical explanations of how organisations manage both transformations concurrently. This study addresses this gap by investigating how organisations navigate digital and green transitions within complex operational environments through the complementary perspectives of Complexity Theory and Paradox Theory. A qualitative single-case study was conducted at the Port of Sines, Portugal, combining a semi-structured interview with the senior manager responsible for innovation and digital transformation with documentary evidence from institutional reports and strategic documents. An abductive research design and thematic analysis were employed to interpret the empirical material. The findings indicate that Complexity Theory explains Smart Port transformation as an adaptive and evolutionary process characterised by emergence, interdependence and continuous organisational learning. Paradox Theory complements this perspective by explaining how managers continuously balance persistent tensions, including efficiency versus sustainability, innovation versus operational continuity, and stability versus organisational change. The empirical evidence suggests that neither theoretical perspective alone fully explains the observed organisational dynamics. Accordingly, the study proposes an *Integrated Complexity–Paradox Framework*, demonstrating that adaptive system evolution and paradox management jointly enable digitalisation and decarbonisation within Smart Ports. The study contributes to innovation literature by providing a more comprehensive conceptual explanation of sustainability-oriented transformation and offers practical implications for managers responsible for leading complex infrastructure transitions.

Keywords: Smart Ports; Complexity Theory; Paradox Theory; Sustainable Innovation

1. Introduction

Smart Ports are becoming central actors in the digital and green transformation of global maritime logistics. Increasing competitive pressure, technological advances and ambitious environmental objectives require ports to modernise their infrastructures while simultaneously reducing environmental impacts and maintaining high levels of operational performance. Consequently, digitalisation and decarbonisation have become two of the principal drivers of contemporary Smart Port transformation (Belmoukari, Audy and Forget, 2023).

Digitalisation enables ports to improve operational efficiency through technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), big data analytics and digital platforms that support real-time decision-making and stakeholder coordination (Del Giudice et al., 2022). At the same time, decarbonisation requires significant organisational and technological changes, including the electrification of equipment, renewable energy integration, cleaner logistics chains and low-carbon industrial infrastructures (Yang and Ge, 2020). Although both transformations are frequently presented as complementary, their implementation creates considerable organisational complexity because ports must introduce substantial technological and environmental innovations without compromising operational continuity.

Existing research has substantially improved understanding of Smart Port technologies and sustainability initiatives. However, much of the literature examines digitalisation and decarbonisation separately or adopts a single theoretical perspective, providing only a partial explanation of how organisations manage the interaction between adaptive transformation and competing strategic priorities. Consequently, there remains limited understanding of how organisations simultaneously navigate technological change, environmental sustainability and operational reliability within highly interconnected socio-technical systems.

This paper addresses the following research question:

- How can organisations achieve digitalisation and decarbonisation in Smart Ports while maintaining operational continuity during periods of organisational transformation?

To address this question, the study adopts an integrated theoretical perspective combining *Complexity Theory* (Anderson, 1999; Arthur, 2021) and *Paradox Theory* (Smith and Lewis, 2011; Berti and Cunha, 2023). A qualitative

single-case study of the Port of Sines, Portugal, provides the empirical context for examining how these complementary theoretical perspectives explain Smart Port transformation.

The study makes three principal contributions. First, it advances theoretical understanding by integrating Complexity Theory and Paradox Theory to explain digital and green transformation within Smart Ports. Second, it provides empirical evidence from one of Europe's leading ports, strengthening the connection between conceptual development and organisational practice. Third, it proposes an *Integrated Complexity–Paradox Framework* demonstrating how adaptive organisational evolution and paradox management jointly support digitalisation and decarbonisation while maintaining operational continuity.

Unlike previous studies that primarily examine digitalisation and decarbonisation independently or through a single theoretical perspective, this study demonstrates that Smart Port transformation is more comprehensively explained by integrating Complexity Theory and Paradox Theory. This integrated perspective provides a richer explanation of how adaptive organisational evolution and paradox management jointly enable digital and green transitions while maintaining operational continuity.

2. Theoretical Background

2.1 Complexity Theory

Complexity Theory conceptualises organisations as *complex adaptive systems* characterised by non-linearity, emergence, self-organisation and continuous adaptation (Anderson, 1999). Within such systems, organisational outcomes emerge from the interactions among multiple interconnected actors, technologies and institutional conditions rather than from linear cause-and-effect relationships. Organisational change is therefore understood as an evolutionary process in which adaptation results from experimentation, learning and feedback across multiple system components (Arthur, 2021).

This perspective is particularly relevant for understanding Smart Port transformation. Ports constitute highly interconnected socio-technical systems involving port authorities, terminal operators, shipping companies, logistics providers, technology suppliers, regulators and energy infrastructures. Consequently, digitalisation and decarbonisation evolve through continuous interaction among organisational, technological and institutional elements rather than through isolated implementation projects.

From a complexity perspective, successful transformation depends less on implementing predefined technological solutions than on developing adaptive organisational capabilities that enable continuous learning, experimentation and adjustment under changing environmental conditions. This interpretation provides an appropriate theoretical lens for analysing how Smart Ports evolve while responding simultaneously to technological innovation, environmental sustainability and operational challenges.

2.2 Paradox Theory

Whereas Complexity Theory explains organisational transformation at the system level, *Paradox Theory* focuses on how organisations respond to persistent competing demands that cannot be permanently resolved (Smith and Lewis, 2011). Rather than interpreting contradictions as temporary problems requiring either/or choices, Paradox Theory argues that organisations achieve long-term performance by simultaneously accommodating apparently contradictory objectives through both/and approaches (Berti and Cunha, 2023).

Within Smart Ports, several paradoxes emerge throughout digital and green transformation. Organisations must simultaneously improve operational efficiency while investing in environmental sustainability, introduce technological innovation without compromising operational continuity, and promote organisational change while maintaining reliability and safety. These competing objectives remain strategically important over time and therefore generate persistent rather than temporary tensions.

Managerial effectiveness consequently depends on developing capabilities that enable continuous balancing instead of definitive resolution. Mechanisms such as organisational learning, temporal balancing, capability development and strategic reframing allow organisations to accommodate contradictory demands while maintaining long-term performance.

Paradox Theory therefore complements Complexity Theory by explaining the managerial processes through which adaptive organisational transformation is governed in practice.

2.3 Integrating Complexity Theory and Paradox Theory

Although Complexity Theory and Paradox Theory originate from different theoretical traditions, they provide complementary explanations of organisational transformation.

Complexity Theory primarily explains *how organisational systems evolve*, emphasising emergence, adaptation and interdependence. In contrast, Paradox Theory explains *how managers govern transformation*, emphasising the continuous balancing of competing strategic objectives.

This complementarity is particularly relevant within Smart Ports, where digitalisation and decarbonisation simultaneously reshape technologies, organisational routines and stakeholder relationships while generating persistent operational tensions. Neither theoretical perspective independently captures the full organisational dynamics associated with these large-scale transformations.

Accordingly, this study adopts an *Integrated Complexity–Paradox Framework* in which Complexity Theory explains adaptive system evolution while Paradox Theory explains managerial responses to persistent organisational tensions. Together, these complementary perspectives provide the conceptual foundation for interpreting the empirical findings presented in the following sections.

The following methodology was designed to investigate how these complementary theoretical perspectives are reflected in the organisational transformation of the Port of Sines.

3. Methodology

This study adopts a qualitative single-case study design to investigate how organisations simultaneously pursue digitalisation and decarbonisation while maintaining operational continuity within a Smart Port context. A qualitative approach is appropriate because the research seeks to understand organisational processes, managerial interpretations and contextual dynamics rather than test predetermined causal relationships (Yin, 2018).

The research follows an *abductive logic*, characterised by an iterative dialogue between theoretical concepts and empirical observations (Dubois and Gadde, 2002). Rather than applying theory deductively or generating theory exclusively from empirical data, the analysis continuously moved between the conceptual perspectives of Complexity Theory and Paradox Theory and the evidence obtained from the Port of Sines, progressively refining theoretical interpretations.

3.1 Research Design

A single-case study was selected because the objective was to obtain an in-depth understanding of organisational transformation within a strategically important Smart Port rather than to achieve statistical representativeness. Consistent with Yin (2018) and Eisenhardt (1989), the study seeks *analytical generalisation* by contributing to theoretical understanding through rich empirical analysis rather than statistical inference.

The Port of Sines was selected as a *critical case* because it combines three characteristics directly relevant to the research question: large-scale logistics operations, advanced digital transformation initiatives and ambitious decarbonisation projects. These characteristics provide an appropriate empirical setting for examining the interaction between adaptive organisational processes and persistent managerial tensions.

The interview participant was selected through purposive sampling (Patton, 2015). The respondent occupies a senior management position with direct responsibility for innovation and digital transformation, providing comprehensive knowledge of strategic priorities, organisational decision-making and implementation challenges. Although relying on a single key informant represents a methodological limitation, the participant was uniquely positioned to provide an organisation-wide perspective spanning both digitalisation and sustainability initiatives. Furthermore, interview evidence was systematically triangulated with documentary sources to strengthen the credibility of the findings.

Table 1: Overview of the research design

Research Element	Description
Research strategy	Qualitative single-case study
Research logic	Abductive
Case	Port of Sines (Portugal)
Sampling strategy	Purposive sampling
Interview participant	Senior manager responsible for innovation and digital transformation
Interview duration	Approximately 60 minutes
Documentary sources	Institutional reports, strategic plans and official publications
Data analysis	Thematic analysis
Validation strategy	Triangulation of interview and documentary evidence
Type of generalisation	Analytical generalisation

Source: Author's own elaboration

3.2 Data Collection

Three complementary sources of evidence were employed.

First, a focused literature review established the conceptual foundations regarding Smart Ports, digitalisation, decarbonisation, Complexity Theory and Paradox Theory.

Second, primary empirical evidence was obtained through a semi-structured interview lasting approximately 60 minutes with the senior manager responsible for innovation and digital transformation at the Port of Sines. The interview protocol included open-ended questions concerning digital transformation initiatives, sustainability strategies, organisational governance, operational continuity, stakeholder coordination and managerial challenges associated with organisational change. This flexible interview format enabled the participant to provide detailed explanations and concrete examples drawn from organisational practice.

Third, documentary evidence was collected from publicly available institutional reports, strategic plans and official publications relating to the Port of Sines. These documents were used to corroborate factual information, contextualise organisational initiatives and support the interpretation of interview evidence.

Interview data and documentary evidence were analysed jointly through triangulation (Lincoln and Guba, 1985; Yin, 2018), thereby reducing dependence on a single source of evidence and enhancing the credibility of the empirical interpretations.

3.3 Data Analysis

The empirical material was analysed using thematic analysis following the procedures proposed by Braun and Clarke (2006).

The analysis comprised four iterative stages.

Initially, the interview transcript was read repeatedly to achieve familiarity with the empirical material and identify meaningful organisational episodes related to digitalisation, decarbonisation and organisational transformation.

Subsequently, *open coding* was conducted to identify recurring concepts and organisational practices. Initial codes included adaptation, experimentation, operational continuity, organisational learning, efficiency, sustainability, stakeholder coordination, capability development and technological implementation.

The resulting codes were progressively grouped into broader analytical themes representing recurring organisational patterns. Throughout this stage, emerging themes were continuously compared with the conceptual assumptions of Complexity Theory and Paradox Theory. Rather than imposing predetermined theoretical categories, the analysis followed an abductive process through which empirical observations and theoretical concepts informed one another iteratively.

Finally, the themes were organised into a comparative analytical framework identifying areas where Complexity Theory and Paradox Theory converged, diverged or complemented one another in explaining Smart Port transformation.

Coding and interpretation were conducted jointly by the authors through repeated discussion and iterative comparison between empirical evidence and theoretical constructs. Although independent multiple coding was not employed, analytical rigour was strengthened through systematic documentation of coding decisions, continuous peer discussion and repeated verification against the original interview transcript.

Several additional measures contributed to the trustworthiness of the study. Credibility was strengthened through triangulation between interview and documentary evidence (Lincoln and Guba, 1985). Transparency was enhanced by explicitly documenting the research design, data collection procedures and analytical process. Finally, the findings should be interpreted as providing *analytical rather than statistical generalisation* (Yin, 2018). Future research employing multiple-case and longitudinal designs could further examine the broader applicability of the proposed *Integrated Complexity–Paradox Framework*.

The following section introduces the Port of Sines as the empirical context within which these theoretical propositions are examined.

4. Case Study: Port of Sines

The Port of Sines is Portugal's largest deep-water port and one of the country's most strategically important logistics infrastructures. Located on the southwest Atlantic coast, it serves as a major gateway connecting Europe with international maritime trade routes linking Europe with Asia, Africa and the Americas. Its deep-water conditions enable the operation of large container vessels, oil tankers and liquefied natural gas (LNG) carriers, positioning the port as a critical node within European and global supply chains.

The port comprises specialised terminals handling containerised cargo, liquid bulk, solid bulk and general cargo while supporting major industrial and energy-related activities. Beyond its operational importance, the Port of Sines has assumed a leading role in Portugal's digital and energy transition through investments in digital technologies, renewable energy integration and low-carbon industrial projects.

These characteristics make the Port of Sines an appropriate empirical setting for investigating how organisations simultaneously implement digitalisation and decarbonisation while maintaining operational continuity within a highly interconnected socio-technical system.

4.1 Digitalisation Initiatives

The Port of Sines has progressively implemented a broad portfolio of digital transformation initiatives intended to improve operational efficiency, coordination and decision-making.

These initiatives include:

- real-time operational monitoring platforms;
- Internet of Things (IoT) sensors supporting equipment monitoring;
- Artificial Intelligence (AI) applications for predictive maintenance;
- digital platforms integrating multiple organisational stakeholders.

Rather than representing isolated technological investments, these initiatives form part of an integrated transformation programme designed to increase organisational responsiveness while simultaneously supporting long-term sustainability objectives.

As explained by the interview participant:

“A digital transformation plan involves several actions.”

This statement indicates that digitalisation is understood as a coordinated organisational transformation process rather than as the implementation of individual technological projects

4.2 Decarbonisation Initiatives

Digital transformation has been accompanied by an equally ambitious decarbonisation strategy.

Current initiatives include:

- electrification of port equipment and operational vehicles;
- integration of renewable energy sources;
- development of green hydrogen projects;

- carbon capture and storage initiatives;
- promotion of cleaner logistics chains.

Importantly, the interview indicates that digitalisation and decarbonisation are organisationally interdependent rather than independent strategic programmes.

As the interview participant stated:

“Digital transformation can be a means towards sustainability.”

This evidence suggests that digital technologies are not pursued exclusively to improve efficiency but also function as enabling capabilities supporting environmental objectives.

4.3 Organisational and Operational Challenges

The simultaneous implementation of digitalisation and decarbonisation generates significant organisational challenges.

Interview evidence identifies four principal challenges:

- maintaining uninterrupted port operations during transformation;
- coordinating multiple organisational stakeholders;
- managing interdependencies among digital, logistics and energy systems;
- reconciling short-term operational efficiency with long-term sustainability objectives.

Rather than occurring sequentially, these challenges emerge simultaneously throughout the transformation process, requiring continuous organisational adjustment and managerial coordination.

The empirical findings therefore suggest that Smart Port transformation should be understood as an ongoing organisational process rather than a sequence of discrete technological implementation projects.

The following section analyses these empirical observations through the complementary perspectives of Complexity Theory and Paradox Theory.

5. Analysis

The empirical findings indicate that the transformation of the Port of Sines is characterised by the simultaneous presence of adaptive organisational dynamics and persistent managerial tensions. This section analyses these findings through the complementary lenses of Complexity Theory and Paradox Theory before integrating both perspectives into a unified conceptual explanation.

5.1 Complexity Theory Perspective: Transformation as Adaptive System Evolution

The interview evidence strongly supports the interpretation of the Port of Sines as a complex adaptive system.

The respondent repeatedly described organisational transformation as an evolutionary process driven by continuous adjustment to changing operational and environmental conditions:

“The organisation adapts to challenges and to the dynamics of the context, changing and evolving.”

This observation illustrates one of the central assumptions of Complexity Theory: organisational adaptation emerges through continuous interaction between the organisation and its environment rather than through predetermined linear planning (Anderson, 1999).

A second empirical illustration concerns the implementation of new technologies.

Rather than introducing innovations simultaneously across the organisation, the Port of Sines deliberately follows an incremental implementation strategy.

As explained by the interview participant:

“Drones are being introduced gradually because change also needs to be managed.”

This quotation demonstrates that technological innovation itself is treated as an adaptive organisational process. Incremental implementation enables experimentation, organisational learning and continuous adjustment while reducing operational disruption.

A further observation concerns the coordination of transformation initiatives.

The respondent emphasised that:

“A digital transformation plan involves several actions.”

This evidence reinforces the complexity perspective by illustrating that organisational transformation results from the interaction of multiple interconnected initiatives rather than from isolated technological investments.

Overall, the empirical findings indicate that digitalisation and decarbonisation emerge through cumulative adaptation, organisational learning and systemic interdependence, fully consistent with the assumptions of Complexity Theory.

5.2 Paradox Theory Perspective: Managing Persistent Organisational Tensions

Whereas Complexity Theory explains how transformation evolves, Paradox Theory provides a stronger explanation of how managers govern transformation in practice.

The interview reveals that organisational decision-making is characterised by persistent tensions requiring simultaneous rather than sequential management.

One of the clearest examples concerns operational continuity.

The interview participant stated:

“The main difficulty is maintaining port operations while, at the same time, implementing these changes.”

This quotation illustrates the coexistence of two equally legitimate organisational priorities: maintaining uninterrupted operations while simultaneously introducing substantial organisational transformation.

Rather than resolving this tension, management continuously balances both objectives.

A second paradox concerns the relationship between operational efficiency and environmental sustainability.

The respondent explained:

“Our competitiveness comes first from efficiency, and digital transformation will increase efficiency.”

Later, the same participant added:

“Digital transformation can be a means towards sustainability.”

Taken together, these statements indicate that efficiency and sustainability are not viewed as mutually exclusive organisational goals. Instead, digitalisation functions as the mechanism through which both objectives can be pursued simultaneously.

A third paradox concerns technological innovation and human capability development.

The respondent emphasised:

“People need to be empowered and trained.”

This observation highlights that successful technological transformation depends not only on technological investment but also on continuous organisational learning and workforce development.

Finally, the interview participant explicitly recognised the coexistence of apparently contradictory organisational realities:

“The organisation sometimes lives with situations that seem irreconcilable and ultimately manages them.”

This quotation provides particularly strong empirical support for Paradox Theory because it explicitly describes paradox management rather than merely illustrating competing organisational objectives.

Overall, the findings indicate that Smart Port transformation depends on the continuous balancing of persistent organisational tensions rather than their elimination.

5.3 Comparing Complexity Theory and Paradox Theory

The empirical findings reveal considerable complementarity between the two theoretical perspectives.

Both theories recognise the importance of organisational adaptation, innovation and the simultaneous pursuit of operational performance and sustainability. However, they differ in their principal analytical focus.

Complexity Theory primarily explains how organisational transformation emerges through adaptive interactions among interconnected organisational components.

Paradox Theory primarily explains how managers respond to the persistent tensions generated by that transformation.

Table 2 summarises the principal similarities and differences identified through the empirical analysis.

Table 2: Comparison between Complexity Theory and Paradox Theory

Analytical Dimension	Complexity Theory	Paradox Theory
Adaptation	Continuous organisational evolution	Continuous balancing of competing organisational
Efficiency and	Adaptive improvement of organisational	Simultaneous pursuit of both objectives
Innovation	Gradual implementation, experimentation	Innovation balanced with operational continuity and
Primary analytical focus	Evolution of the organisational system	Managerial decision-making
Transformation logic	Emergence, adaptation and	Persistent paradox management

Source: Authors' own elaboration.

The comparison demonstrates that neither theory independently explains all dimensions of Smart Port transformation. Instead, each perspective illuminates different but complementary aspects of the same organisational phenomenon.

To strengthen the transparency of the analytical process, Table 3 links representative interview quotations directly to their corresponding theoretical interpretation.

Table 3: Summary of empirical evidence and theoretical interpretation

Representative Empirical Evidence	Complexity Theory	Paradox Theory
<i>"The organisation adapts to challenges and to the"</i>	Adaptive system evolution	—
<i>"Drones are being introduced gradually because change"</i>	Incremental adaptation and	Innovation versus operational
<i>"The main difficulty is maintaining port operations while"</i>	Organisational interdependence	Operational continuity versus
<i>"Our competitiveness comes first from efficiency."</i>	Adaptive performance	Efficiency versus sustainability
<i>"Digital transformation can be a means towards"</i>	Co-evolution of digitalisation and	Simultaneous pursuit of
<i>"People need to be empowered and trained."</i>	Organisational learning	Capability development for
<i>"The organisation sometimes lives with situations that"</i>	—	Explicit paradox management

Source: Authors' own elaboration.

The systematic relationship between empirical evidence and theoretical interpretation strengthens the credibility of the findings and demonstrates how the two theoretical perspectives complement one another in explaining Smart Port transformation.

5.4 Integrated Complexity–Paradox Framework

The comparative analysis indicates that Complexity Theory and Paradox Theory should not be interpreted as competing explanations but as complementary analytical perspectives operating at different organisational levels.

Complexity Theory explains the adaptive evolution of organisational systems through emergence, experimentation and continuous learning. Paradox Theory explains the managerial mechanisms through which competing strategic priorities are continuously balanced during this adaptive process.

Accordingly, this study proposes an *Integrated Complexity–Paradox Framework*, which conceptualises Smart Port transformation as the result of the interaction between adaptive system evolution and paradox management.

Within this framework, digitalisation and decarbonisation are understood as mutually reinforcing transformation processes supported simultaneously by adaptive organisational capabilities and managerial capability to balance persistent tensions.

Figure 1 illustrates the proposed Integrated Complexity–Paradox Framework, demonstrating how adaptive organisational evolution and paradox management jointly enable Smart Port transformation while maintaining operational continuity.

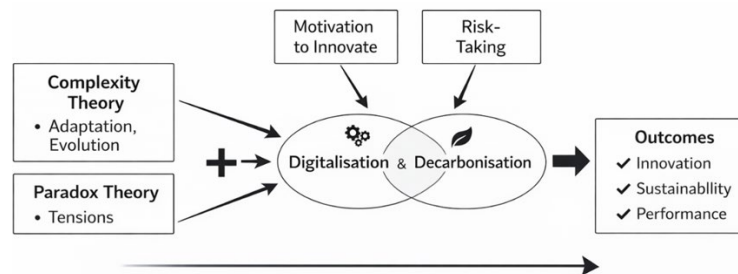


Figure 1: Integrated Complexity–Paradox Framework explaining Smart Port transformation through the complementary interaction between adaptive system evolution (Complexity Theory) and paradox management (Paradox Theory).

Source: Authors' own elaboration.

6. Discussion

The findings provide a more comprehensive understanding of how digitalisation and decarbonisation unfold within complex, asset-intensive environments such as Smart Ports. By integrating Complexity Theory and Paradox Theory, this study moves beyond linear explanations of organisational change and demonstrates that successful transformation depends simultaneously on adaptive system evolution and continuous management of competing organisational demands.

From a *Complexity Theory* perspective, the Port of Sines illustrates how transformation emerges through iterative adaptation rather than predetermined implementation. Digital technologies, sustainability initiatives and organisational routines evolve together through continuous interaction among multiple actors, infrastructures and institutional conditions. The empirical evidence indicates that organisational change is characterised by experimentation, gradual implementation and learning rather than by discrete technological projects. These findings reinforce previous complexity-informed interpretations of organisational transformation (Anderson, 1999; Arthur, 2021).

From a *Paradox Theory* perspective, the study demonstrates that organisational transformation is accompanied by persistent tensions requiring continuous managerial balancing. Rather than resolving contradictions, managers simultaneously pursue operational continuity and innovation, efficiency and sustainability, and technological development and workforce capability building. The interview evidence suggests that organisational effectiveness depends on developing capabilities to accommodate these competing priorities over time, consistent with the paradox perspective advanced by Smith and Lewis (2011) and Berti and Cunha (2023).

Importantly, the empirical analysis indicates that neither theoretical perspective independently captures the full organisational dynamics observed at the Port of Sines. Complexity Theory explains how transformation evolves through adaptive interactions, whereas Paradox Theory explains how managers govern that transformation by balancing persistent tensions. The complementary application of both theories therefore provides a richer explanation of Smart Port transformation than either perspective could offer independently.

6.1 Theoretical Contributions

This study makes three principal contributions to innovation research.

First, it contributes to the Smart Port literature by demonstrating that digitalisation and decarbonisation should be analysed as mutually reinforcing organisational transformations rather than as independent technological or environmental initiatives.

Second, it advances theory by integrating Complexity Theory and Paradox Theory within a single analytical framework. Previous studies have generally relied on one theoretical perspective to explain organisational transformation. In contrast, this study shows that combining adaptive systems thinking with paradox management provides a more comprehensive explanation of organisational change in sustainability-oriented contexts.

Third, the proposed *Integrated Complexity–Paradox Framework* extends innovation theory by conceptualising transformation as the interaction between adaptive organisational evolution and continuous management of competing strategic priorities. This integrated perspective may also inform future research examining digital and green transitions in other complex infrastructure systems beyond the maritime sector.

6.2 Managerial Implications

The findings also generate practical implications for managers responsible for leading digital and green transformation.

First, organisations should recognise transformation as an adaptive process requiring continuous experimentation and organisational learning rather than rigid implementation plans. Incremental deployment of technologies enables organisations to learn from experience while minimising operational disruption.

Second, managers should anticipate that digitalisation and decarbonisation will generate persistent organisational tensions rather than temporary implementation challenges. Developing capabilities to balance efficiency, sustainability and operational continuity therefore becomes a strategic capability rather than a short-term project management activity.

Third, the findings indicate that technological investment alone is insufficient. Successful transformation also depends on organisational capability development, stakeholder coordination and workforce training. As illustrated by the Port of Sines, digital technologies become effective enablers of sustainability only when embedded within broader organisational transformation processes.

Finally, the proposed *Integrated Complexity–Paradox Framework* provides managers with a conceptual tool for understanding how adaptive organisational evolution and paradox management jointly support long-term transformation in complex infrastructure systems.

7. Conclusion

This study examined how organisations can simultaneously pursue digitalisation and decarbonisation while maintaining operational continuity, using the Port of Sines as an empirical case.

Drawing upon Complexity Theory and Paradox Theory, the study demonstrates that Smart Port transformation is characterised by both adaptive organisational evolution and persistent managerial tensions. Complexity Theory explains how transformation emerges through continuous adaptation, organisational learning and interaction among multiple interconnected elements. Paradox Theory complements this perspective by explaining how managers continuously balance competing organisational priorities such as efficiency and sustainability, innovation and operational continuity, and technological change and workforce capability development.

The principal contribution of this study is the development of an *Integrated Complexity–Paradox Framework*, which demonstrates that adaptive organisational evolution and paradox management jointly explain Smart Port transformation more comprehensively than either theoretical perspective alone. By integrating these complementary perspectives, the study contributes to innovation literature through a richer explanation of how organisations manage simultaneous digital and green transitions within complex operational environments.

From a practical perspective, the findings suggest that managers should approach digital transformation as an ongoing organisational capability rather than a discrete technological project. Successful transformation requires adaptive organisational learning, continuous stakeholder coordination and sustained capability to manage competing strategic priorities.

The study is subject to several limitations. As a qualitative single-case study, the findings are intended to provide *analytical rather than statistical generalisation* (Yin, 2018). Furthermore, the primary empirical evidence relies on a single senior informant, although credibility was strengthened through documentary triangulation and systematic analytical procedures. Future research could extend the proposed framework through multiple-case

studies, longitudinal designs and comparative analyses across different Smart Ports and other complex infrastructure systems.

Overall, this study demonstrates that digital and green transitions should be understood as interconnected organisational processes requiring both adaptive evolution and continuous paradox management. The proposed *Integrated Complexity–Paradox Framework* therefore provides a theoretically grounded and practically relevant explanation of how organisations can navigate sustainability-oriented transformation within increasingly complex operational environments.

Ethics Declaration

No ethical approval was required for this study. Participation in the interview was voluntary, informed consent was obtained from the participant, and the data were analysed and reported in accordance with accepted academic research standards.

AI Declaration

Artificial Intelligence (AI) tools were used exclusively to support language refinement, editing and manuscript structuring. All conceptual development, interpretation of findings and final content remain the responsibility of the authors.

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