Evaluating the Value of Automating Ship-to-Shore Crane Operations

A Performance and Stakeholder Analysis

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by

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This is the redacted version of my master thesis created for the public TU Delft Research Repository. A confidential version containing additional data and detailed analysis is only available to the graduation committee.

TU Delft

Preface

As a mechanical engineer pursuing an MSc in Management of Technology, I was drawn to the technical challenges of STS crane operations and their impact on container terminal efficiency. This interest led me to explore the value potential in automated STS crane operations.

This research combines my engineering foundation with the management perspectives gained during the MOT program. It addresses the automation of STS crane operations, where technical innovations meet practical implementation challenges. The project particularly interested me as it demonstrates how engineering solutions, when properly managed, can create significant value while introducing new organizational dynamics that need careful consideration.

I would like to express my gratitude to my university supervisors, Dr. R. van Duin and Dr. V. Scholten, for their academic guidance and critical insights. Their expertise helped shape this research into a comprehensive study that combines theoretical frameworks with practical applications. I am equally grateful to E. Turina for providing industry perspective and ensuring this research maintained its practical relevance.

The support from Evans has been important in gathering real-world data and understanding operational challenges firsthand. This collaboration between academia and industry has significantly enhanced the quality and relevance of this research.

Finally, I want to thank my family, girlfriend and friends for their support during this final stage of my academic journey.

Job Somhorst
Den Haag, June 2025

Executive Summary

Container terminals worldwide are increasingly adopting automation solutions to improve operational efficiency and maintain competitiveness. However, the success of automation solutions, particularly in Ship-to-Shore (STS) crane operations, varies significantly across different regions. While existing research has explored automation benefits in individual and general terms, a clear understanding of how regional contexts influence value creation and implementation success has been lacking. This research addresses this knowledge gap by examining both the operational performance improvements and stakeholder dynamics across different regional contexts.

The primary objective was to quantify the value creation of STS crane automation while understanding how regional factors affect this value creation. Through a comprehensive methodology combining a quantitative operational analysis with a stakeholder and risk analysis, this study examined three major ports: Antwerp, Kaohsiung, and Los Angeles.

The research findings reveal that automation value shows in three dimensions. Operational value was demonstrated through improved cycle times, enhanced consistency in performance, and reduced human error. Economic value showed through reduced labor costs, improved energy efficiency, and decreased maintenance requirements. Strategic value emerged through environmental sustainability benefits and competitive positioning, although realization depends heavily on regional contexts.

The stakeholder analysis identified six key groups affected by automation, each with distinct priorities and concerns. For example, terminal operators consistently seek efficiency improvements, while labor organizations prioritize job security and skills development. However, the interaction between these stakeholders varies heavily by region. Los Angeles faces substantial union resistance and complex regulatory requirements, while Kaohsiung confronts technical expertise gaps and cybersecurity concerns. Antwerp represents a middle position, where established regulatory frameworks and structured stakeholder relationships create more predictable implementation processes compared to other regions.

This research provides concrete insights into how automation value differs across regions:

- In North America, the primary challenge is not technical but social, with labor relations directly determining implementation success.
- In Asia, value creation is limited more by technical expertise gaps than by stakeholder resistance.
- In Europe, success requires balancing established regulatory requirements with structured stakeholder negotiations.

The findings demonstrate that while automated systems can achieve similar technical performance across regions, the path to realizing this value varies based on local conditions. Based on this research, three key recommendations emerge for successful STS crane automation implementation. Firstly, terminal operators must adapt their automation strategy to regional risk profiles. Secondly, technology providers should move away from standardized solutions and instead develop region-specific implementation strategies that address local challenges identified in this study. Thirdly, both parties should create structured stakeholder engagement programs to identify regional priorities, as this research shows stakeholder dynamics significantly impacts implementation success. Following these recommendations can reduce implementation timelines and possibly improve project success rates.

This improved understanding of regional variation in automation value creation provides a practical foundation for future terminal automation projects, while contributing to theoretical knowledge.

Contents

1
Research Framework and Approach

This chapter establishes the foundation for analyzing STS crane automation value. The chapter begins with the research context, which introduces the changing maritime cargo industry and presents the main research question examining the values generated by automating waterside operations of STS cranes, along with five sub-questions addressing operational factors, efficiency differences, stakeholder impacts, and regional implementation risks. The theoretical background then synthesizes existing literature on terminal automation, highlighting current knowledge gaps. Finally, the research methodology outlines how operational performance and stakeholder value will be analyzed through a combination of quantitative analysis and stakeholder evaluation.

1.1. Research Context

The global maritime cargo industry has changed significantly in the last decades. These changes were necessary to keep up with the growing trade volumes, which resulted in the need for faster and more reliable terminal operations. Ship-to-Shore (STS) cranes are an essential part of the container handling at terminals. These quay cranes are used for the movement of containers between vessels and the quay.

Worldwide, terminals face more pressure to optimize their operations due to the increasing number of containers being shipped, labor shortages, and increased competition. According to Kim and Park (2004), manual operations often result in inconsistent cycle times, as human limitations, such as fatigue, introduce differences in the output. Inefficiencies in manual path planning further increase these delays, leading to reduced throughput. To overcome these limitations, ports are looking for various types of automation as a solution to streamline their operations. Automated STS cranes promise more consistent cycle times, optimal path planning, and reduced dependency on human operators.

Automation has already demonstrated significant benefits in industrial settings. Ports that implement automation for various tasks achieve higher throughput, better resource utilization, and reduced energy consumption (Martín-Soberón et al., 2014). For example, automated cranes follow well-thought out algorithms to optimize container paths, ensuring minimal travel distances and faster operations. This stands in contrast to manual systems, where operators often make suboptimal decisions, especially during peak hours.

However, the transition to automation is not without its challenges. High upfront investment costs, technical complexities, and maintenance requirements often form barriers for terminals to adopt automated solutions. Naeem et al. (2023) argue that while the financial investment for automation is significant, the long-term operational savings through reduced labor costs, increased efficiency, and optimized resource allocation justify the expense. In addition to this, rising global trade demands and labor shortages make automation necessary for terminals to remain competitive.

As the transition to automated systems continues, advancements in the automation technology itself, such as fast and precise laser and camera solutions, together with predictive software, play an important role in modern STS crane operations. Automated systems use these new technologies to analyze operational data in real time, improve predictive maintenance, and optimize crane operations (Martín-Soberón et al., 2014).

Note: This public version focuses on the qualitative aspects of automation implementation and stakeholder impacts. The confidential version contains additional detailed operational data analysis and specific efficiency metrics that are not included here due to their commercially sensitive nature.

Despite the clear advantages of automation, a critical gap exists in understanding how automation affects different stakeholders and how its implementation varies across different regional contexts. This research aims to address this gap by analyzing the broader implications of STS crane automation, including its impact on various stakeholders and the challenges faced during implementation across different terminals.

The research objective is therefore to identify and analyze the key factors which influence the successful implementation of water-side automation of STS cranes, with particular attention to stakeholder impacts and regional variations. While the confidential version includes detailed operational performance analysis, this public version focuses on the organizational and contextual factors that shape automation implementation.

This research connects to the Management of Technology program by examining how technological innovation creates value beyond technical performance. While STS crane automation presents clear engineering challenges, the MOT perspective reveals that successful implementation requires understanding both technical capabilities and organizational context. This integrated approach aligns with the MOT program's core principles in three ways: Firstly, it examines the complex interaction between technology and stakeholder interests, from environmental sustainability to workforce development. Secondly, it demonstrates how regional contexts and organizational factors significantly influence technology implementation success. Thirdly, it shows how identical automation solutions can lead to different outcomes across terminals, reflecting the MOT program's focus on how technical innovation is shaped in a real-world context.

The main research question and sub-questions that follow from the research objective are:

1. "What are the values generated by automating waterside operations of Ship-to-Shore (STS) cranes, when evaluated from a stakeholder perspective?"
   (a) "What are the operational differences in terms of efficiency and cost-effectiveness between manual and automated waterside operations?"
   (b) "Who are the key stakeholders affected by STS crane automation?"
   (c) "How does automation impact the values and interests of these stakeholders?"
   (d) "What are the key risks and challenges that could affect value generation when implementing STS crane automation across different regional contexts?"

Note: The original research included additional sub-questions related to operational efficiency and cycle time analysis, which are addressed in the confidential version of this thesis.

1.2. Theoretical Background

The automation of container handling in terminals, particularly with Ship-to-Shore cranes, has been a major point of research in port logistics and automation systems because of the increasing pressure to improve operational efficiency, reduce costs, and enhance the throughput. This section synthesizes the literature on key themes to identify an important knowledge gap which can be used as a foundation for further research.

Key Themes and Research Areas

1. **Automation in Port Operations**

Automation in ports is a growing field due to the increasing need to enhance operational efficiency and meet the challenges of the growing cargo volumes. Various automation technologies, including Automated Guided Vehicles (AGVs), automated quay cranes, and stacking cranes, have been widely discussed in the literature as tools for improving the speed and accuracy of container handling (Tan et al., 2021). One key advantage of automation is the reduction of human error and fatigue, which is often mentioned as the main reason for inefficiency in manual operations (Martín-Soberón et al., 2014). Automated STS cranes have been shown to significantly decrease operational delays and cycle time variability, leading to more predictable and consistent operations. In addition to this, automation not only improves the efficiency of operations, but also works towards sustainability goals, reducing emissions and energy consumption (Xu et al., 2023).

2. **Cycle Time Modeling**

The cycle time is an important performance measure in container terminal operations, because it represents the time that it takes to load or unload containers from a vessel. The reduction of cycle time is often mentioned as one of the most direct ways to improve terminal efficiency and several studies have employed mathematical and simulation models to estimate and optimize cycle times in automated and semi-automated systems (Naeem et al., 2023). For example, Wei et al. (2023) focused on the influence of several crane operations, including lifting and travel operations, on cycle times. Another study by Gao et al. (2024) suggested that modeling the cycle time in real-time using predictive algorithms could help improve the accuracy of cycle time predictions, leading to better scheduling.

One of the challenges in the optimization of the cycle time is the balance between operational constraints such as container size, crane speed, and environmental conditions. According to Naeem et al. (2023), improvements in cycle time can result from optimizing not only the mechanical operation of STS cranes but also the coordination of various systems within the terminal, such as AGVs. This suggests that more comprehensive approaches are necessary to achieve meaningful reductions in cycle times.

Environmental conditions generally have a significant influence on STS operations. One of the most significant environmental conditions is wind. The NEOM region, where the waterside operations project will be tested first, experiences significant wind activity, leading to operational challenges for STS cranes (Alfawzan & Sarkar, 2020). Strong winds can cause sway, which complicates container alignment and handling. In addition to wind conditions, vessel movement can have a large influence on the cycle time. The movement of the vessels is heavily influenced by mooring conditions. Poorly managed mooring can lead to excessive vessel movement, which affects the precision of crane operations during loading and unloading. A study by Zhu et al. (2024) highlighted that mooring tension and dynamic positioning are key to stabilizing vessels. In addition to this, the interaction between passing vessels and moored ships, known as the ”passing ship effect,” can increase the movement of moored vessels (Z.-q. Zheng et al., 2023).

3. **Path Planning**

In the context of automation, path planning is essential to minimize delays and optimize the movement of cranes and other automated vehicles within the terminal. The literature on path planning in container terminals highlights the importance of algorithms that determine the most efficient path for the cranes to take, taking into account factors such as obstacles, travel distance, and the need to avoid operational conflicts (Wei et al., 2023).

According to Karder et al. (2022), the integration of path planning with historical and real-time data is one of the most important developments in crane automation, allowing systems to adjust dynamically to changes in operations. In practice, this means that automated cranes can make decisions based on factors such as vessel arrival times, container stacking heights and the current availability of trucks, resulting in reduced waiting times and faster cycle times.

4. Economic Impacts and Cost Effectiveness

Many studies about automation in container terminals are focused on the trade-offs between high initial investment costs and long-term savings through increased efficiency (International Transport Forum, 2021). In their study of automation in the Rotterdam port (ECT), Oliveira and Varela (2016) found that highly automated terminals could reduce labor costs by as much as 55%, while at the same time increasing throughput capacity by 33%. However, the high initial investment necessary for automated equipment remains an important factor in the decision-making process.

An important aspect of the economic analysis is the consideration of indirect benefits, such as improvements in the use of terminal space and equipment, and the reduction of operational risks (Naeem et al., 2023). In addition to this, the analysis for automation in container terminals should also consider the potential environmental benefits of reduced fuel consumption and lower carbon emissions, as automated systems are often more energy efficient compared to manual operations (Tan et al., 2021).

Beyond these direct economic and environmental impacts, automation also changes the value distribution among key stakeholders. For terminal management and shipping companies, increased efficiency and lower labor costs result into higher profitability and improved reliability. However, labor unions, terminal operators and dockworkers face challenges due to job displacement, which requires an approach that considers workforce re-skilling and transition strategies (International Transport Forum, 2021). Understanding these diverse stakeholder perspectives is crucial for assessing the overall economic feasibility and acceptance of automation in waterside operations (METRANS Transportation Consortium, 2022).

Synthesis and Integration

The integration of automation, cycle time modeling, path planning, and economic impacts highlights the connection between these factors in the operation of automated STS cranes. For instance, advancements in path planning algorithms lead to more efficient crane movements, which in turn reduce cycle times and improve the throughput. The reduction in cycle time not only improves the operational efficiency but also contributes to justifying the high initial investment for automation by increasing the return on investment over time (International Transport Forum, 2021).

The economic feasibility of automation depends on the operational benefits that automation provides. Xu et al. (2023) suggest that a comprehensive assessment of automation should include both direct and indirect cost savings, including labor reductions, better resource utilization, and reduced downtime. Although the initial investment in automated systems may be high, the long-term operational and financial benefits outweigh these costs in many cases, especially when combined with improved environmental sustainability.

Literature Gap

Most studies rely on case studies or simulation models, resulting in the need for more comprehensive research that examines automation implementation across different operational contexts. While technical performance is important, there is a particular gap in understanding how automation affects different stakeholders and how its implementation varies across different regional settings.

Note: The confidential version of this thesis includes detailed technical analysis of operational data and simulation modeling. This public version focuses on the qualitative aspects of implementation and stakeholder impacts.

This research addresses these gaps through a methodological approach that differs from previous research in several key aspects:

1. Multi-Stakeholder Perspective
    - Unlike technical studies that focus solely on operational outcomes, this research examines automation's impact on various stakeholders, providing a more comprehensive understanding of its implications beyond performance metrics.
2. Cross-Regional Analysis
    - This study examines implementation across multiple ports in different regions, providing insights into how regional contexts affect automation outcomes.

3. Integrated Value Assessment
    - The research combines stakeholder perspectives with implementation challenges, enabling a more holistic assessment of automation's impact that goes beyond technical performance measures.

Conceptualization

The conceptual model for this research builds on the relationships between automation implementation, stakeholder impacts, and regional context factors. The model suggests that successful automation implementation depends not only on technical capabilities but also on:

- Understanding and addressing stakeholder concerns and interests
- Adapting to regional regulatory and operational contexts
- Balancing technical benefits with organizational and social impacts

This conceptual framework guides the research in understanding how these various factors collectively determine the success of automated STS crane systems. While the confidential version includes detailed operational analysis, this public version focuses on the organizational and contextual factors that shape automation implementation success.

Note: The original research included additional technical analysis of path planning and cycle time optimization, which are addressed in the confidential version of this thesis.

1.3. Research Methodology

This section outlines the methodological framework used to evaluate the implementation of automated STS crane operations, with a focus on stakeholder impacts and regional variations.

Note: The confidential version contains additional methodology related to operational efficiency analysis and empirical data.

Research Design

This research adopts a qualitative approach, focusing on stakeholder analysis and comparative case studies to understand the broader implications of STS crane automation. The key objective is to analyze how automation affects various stakeholders and how implementation challenges vary across different regional contexts.

Data Collection

The research primarily relies on publicly available sources, including industry reports and academic literature, Stakeholder documentation and policy papers and public terminal information.

While first-hand operational data is difficult to obtain due to the competitive nature of the industry, this research focuses on publicly available information and validated stakeholder perspectives.

Data Analysis

The analysis is conducted in three main stages:

1. General Impact Analysis
    - Analysis of automation's general impact on terminal operations
    - Overview of potential benefits and challenges
    - Discussion of implementation considerations
2. Stakeholder Analysis
    - Identification of key stakeholder groups across different terminals
    - Analysis of stakeholder perspectives and concerns
    - Comparative analysis of regional variations

3. Risk Assessment
    - Evaluation of implementation challenges in different contexts
    - Analysis of economic, labor-related, and cyber-security risks
    - Assessment of regional risk variations

Note: Detailed operational efficiency analysis and specific performance metrics are included in the confidential version of this thesis.

Validity and Verification

To ensure the validity and verification of the research, several strategies are implemented:

- Literature Validation
    - Cross-referencing of secondary sources
    - Comparison of findings across different academic and industry publications
- Stakeholder Validation
    - Validation of findings through industry expert consultations
    - Cross-verification of stakeholder perspectives across different terminals
    - While validation was conducted with industry experts, the analysis primarily relies on secondary data
- Regional Cross-Validation
    - Comparison of findings across three terminal cases
    - Verification of patterns and variations across different regional contexts
- Data Triangulation
    - Use of multiple data sources to verify findings
    - Integration of literature findings with stakeholder insights
    - Comparison of perspectives across different stakeholder groups

Note: The confidential version includes additional validation methods related to operational data and simulation model verification.

Stakeholder Analysis and Risk Analysis Methods

The stakeholder analysis uses a comparative case study approach examining key stakeholders across different terminals to understand what the impact of automation is on these various stakeholders:

1. Stakeholder Identification and Value Assessment
    - The research identifies key stakeholder groups and analyzes their primary values and concerns related to automation.
2. Comparative Regional Analysis
    - The study examines how stakeholder perspectives differ across three distinct terminal environments (Antwerp, Kaohsiung, and Los Angeles), looking into how regional contexts shape automation priorities and challenges.
3. Cross-Terminal Pattern Recognition
    - By comparing stakeholder perspectives and associated risks across multiple terminals, the analysis identifies both common patterns and region-specific variations in how automation is perceived and implemented, creating insights beyond general values or individual case studies.

Following the stakeholder analysis, a risk assessment methodology is used to evaluate the implementation challenges based on the different regional contexts examined in the stakeholder analysis. The analysis categorizes automation risks into economic/technical, labor-related, implementation, and cyber-security domains. This framework enables quantitative assessment of risks through probability and impact scores, while considering how regional factors influence the risk scores. This approach enables an overall understanding of how automation affects different stakeholder groups across varying regional contexts while identifying specific risks that must be addressed for successful implementation.

2

Efficiency Impact & Cost Implications

This chapter examines how the implementation of STS crane automation creates value for different stakeholders in container terminal operations. While detailed operational metrics are addressed in the confidential version of this thesis, this chapter focuses on the broader implications of automation and how these translate into value for various stakeholder groups.

The analysis considers three main aspects:

- How automation creates different types of value beyond operational efficiency
- How these values align with different stakeholder interests
- How regional contexts influence the perceived value of automation

This chapter provides the foundation for the detailed stakeholder analysis in Chapter 5 by identifying the key values and benefits that different stakeholders seek from automation implementation.

2.1. Efficiency Impact

The efficiency analysis of STS crane automation revealed several key findings regarding operational efficiency improvements. While detailed performance metrics are presented in the confidential version of this thesis, the main conclusions about efficiency gains can be summarized as:

- Optimized cycle times, representing the direct operational speed and effectiveness.
- Reduced reliance on manual intervention, minimizing human-induced variations.
- Improved process consistency, ensuring predictable operational patterns

Note: Specific operational metrics, calculations, and detailed performance data are available in the confidential version of this thesis.

2.2. Cost Implications

Automation in STS crane operations has the potential to drive significant cost savings by improving operational efficiency. As noted earlier, reduced cycle times enable more moves to be completed in a certain time frame, which directly increases throughput and enhances terminal productivity. This boost in efficiency can translate to a number of cost-related benefits, including labor savings, reduced energy consumption, and minimized maintenance costs.

While the immediate potential financial benefits of automation are clear, especially in terms of efficiency and labor savings, it is important to look deeper into how these savings affect overall costs in the long run. This section will explore the different cost implications of automation, focusing on how efficiency improvements can lead to long-term financial gains.

2.2.1. Operational Costs

Due to the competitive nature of the terminal industry, detailed operational cost data is presented in the confidential version of this thesis. The cycle time calculations and efficiency factors have been thoroughly analyzed, leading to the following key conclusions:

- Optimization of cycle times and reduction in operational dependencies create significant cost advantages for high-volume terminals
- Improved productivity enables handling increased volumes without proportional increases in equipment investment
- Enhanced operational consistency reduces system-wide costs through better coordination of terminal processes

2.2.2. Labor Costs

In automated STS crane operations, the need for human operators is drastically reduced (World Economic Forum, 2024). However, while automated systems handle routine operations, such as container handling and positioning, there are still instances where human intervention is required. For example, in situations where the system is unable to land a container due to scanner errors, movement issues, or other technical limitations, an operator may need to step in to manually adjust or reposition the load. These interventions are generally infrequent, but they remain necessary to ensure the smooth operation of the terminal.

However, because these interventions are infrequent, the overall number of operators required is significantly lower than in traditional manual operations. Studies indicate that full STS crane automation can reduce STS crane operator requirements by 65-80% compared to conventional terminals (Drewry Maritime Research, 2022). Typically, only a small number of trained personnel would be needed to monitor the system, intervene when necessary, and perform routine maintenance or troubleshooting. This reduces the overall labor costs, as fewer operators are required to oversee daily operations. As a result, the overall labor requirements in an automated terminal are greatly reduced, leading to substantial cost savings in wages, training, and employee management.

Modern terminals typically perform their operations from centralized remote control centers, where a single operator can monitor or intervene with multiple cranes simultaneously (Notteboom et al., 2022). This further enhances labor efficiency, as one skilled technician can oversee what would traditionally require multiple crane operators. Though fewer in number, these operators require higher technical proficiency to manage complex automated systems, often leading to higher individual salaries despite the overall labor cost reductions.

The financial impact of these reductions varies highly per region, with terminals in high-wage markets like Northern Europe and North America potentially seeing the ROI from automation investments much sooner than those in regions with lower labor costs. When considering automation implementation, terminals must also account for transition costs including retraining programs, potential severance packages, and managing labor relations during the transformation process. Despite these considerations, the long-term labor savings remain one of the primary financial drivers for terminal automation investments.

2.2.3. Energy Consumption

Energy consumption is another important consideration in the context of automated STS crane operations. Automation contributes to improved energy efficiency by enabling precise control over crane movements, reducing unnecessary operations, and optimizing power usage throughout the entire process. This enhanced control minimizes idle times and ensures that energy is used only when necessary, leading to reduced overall consumption and operational costs.

Studies indicate that automated STS cranes can achieve significant energy cost reductions through optimized operations, with field data showing that peak energy demand can be reduced by up to 50% through automated control systems (Geerlings et al., 2018). These savings are achieved through several technical mechanisms: possible regenerative braking systems that recover energy during container lowering operations, optimized acceleration and deceleration profiles, and elimination of inefficient operator practices such as unnecessary hoisting or trolley movements (Notteboom et al., 2022). For a medium-sized terminal operating 6 to 8 STS cranes, this energy reduction could represent annual savings of approximately €250,000, based on average industrial electricity rates in Europe (Geerlings et al., 2018).

As ports face increasing pressure to meet environmental regulations and reduce their carbon footprint, the energy savings from automation become even more important. Many ports now operate under carbon pricing mechanisms or emissions trading schemes, where reduced energy consumption translates directly to avoided carbon costs (Stopford, 2020). By lowering the energy usage, automated systems help ports lower their environmental impact while still maintaining their high efficiency. This not only leads to cost savings but also helps ports meet sustainability goals, making automation a smart choice for both financial and environmental reasons.

2.2.4. Maintenance Costs

While the introduction of automation in STS crane operations doesn't directly reduce the frequency of maintenance, it can contribute to a more efficient and proactive maintenance approach. Automated systems are designed for greater consistency and precision, which means that equipment is less likely to decrease from the wear and tear associated with manual operation. Human intervention, which often leads to inconsistent operation or misuse of equipment, is minimized, contributing to the overall durability and reliability of the system.

Trolley mechanisms and hoist systems, which often experience accelerated wear due to inconsistent manual operation, typically show extended service life under automated control (Drewry Maritime Research, 2022). This reduced mechanical stress can extend the lifespans of certain components, leading to less frequent replacement needs.

Furthermore, automation enables the collection of detailed operational data, which can help in identifying early signs of wear or potential failures. This shift allows for predictive maintenance practices, where issues can be predicted and addressed before they result in costly repairs or unplanned downtime. (Notteboom et al., 2022).

An additional benefit is the optimization of the spare parts inventory management. By accurately predicting component failure rates based on actual usage data rather than fixed schedules, terminals can reduce keeping unnecessary stock while ensuring critical components remain available when needed (Drewry Maritime Research, 2022). While this predictive monitoring may not be directly implemented in every case, it is an option that can enhance maintenance strategies for automated systems, ensuring lower downtime and reducing the overall cost of repairs.

2.2.5. Cost of Automation Implementation

The implementation of automation in STS crane operations involves a significant initial investment, which can be a substantial barrier for many terminals. However, this investment is highly variable, as it depends on a range of factors including the size and layout of the terminal, the complexity of the automated systems, and the existing infrastructure. Given the diversity of terminal orientations and operational needs, providing an accurate, one-size-fits-all estimate of the costs is difficult.

Initial investment for STS cranes typically amounts to USD 10 million per crane, with terminal-wide automation including automated stacking cranes requiring substantial additional investment that can reach hundreds of millions of dollars depending on terminal size and complexity (Impens, 2024). According to Chu et al. (2018) return on investment for automated container terminals requires either a 25% reduction in operating expenses compared to conventional terminals, or a 30% increase in productivity combined with a 10% reduction in operating expenses. ROI timelines can vary significantly based on terminal throughput, labor costs, and operational efficiency gains.

In addition to the purchase and installation of automated cranes and control systems, the costs may include infrastructure upgrades, software integration, and the training of personnel to oversee the automated systems. These factors contribute to the high upfront costs, but they are also influenced by local conditions and regional variations, such as labor wages, energy prices, and the availability of skilled workforce for installation and maintenance. Consequently, the cost structure of automation is unique to each terminal, shaped by its geographic location and operational context.

Furthermore, the financial benefits of automation also vary from one terminal to another. The cost savings realized from automation, whether through reduced labor costs, improved operational efficiency, or lower energy consumption, are highly dependent on the specific characteristics of each terminal. For example, terminals in regions with high labor costs may see more significant savings from reduced staf requirements, while those in areas with lower wages might experience smaller financial advantages. Terminals must also consider financing approaches, as these capital-intensive projects typically require long-term funding strategies that align with the expected operational lifespan of 15-25 years for automated equipment (Notteboom et al., 2022). As a result, the financial viability of automation should be assessed on individual basis, with a detailed analysis of the terminal's operational specifics, regional cost factors, and potential long-term gains.

2.3. Key Findings

This chapter presented a comprehensive comparison between manual and automated STS crane operations, revealing significant differences in efficiency, reliability, and performance across different operational scenarios. The confidential efficiency analysis demonstrated clear efficiency advantages for automated operations. When scaled to the volume of daily operations, these per-cycle time reductions translate to high terminal efficiency increases.

The most significant advantage of automated systems proved to be their consistency and predictability rather than just speed improvements. While external factors like wind still affect automated cycle times, automated operations are expected to perform with more consistent, predictable patterns for each specific scenario. In contrast, manual operations showed high variability even under identical conditions, depending on operator experience, fatigue levels, and individual technique. This predictability enables more accurate terminal planning and optimized resource allocation, which will result in more reliable service for shipping lines.

The cost analysis also showed impacts across multiple areas other than efficiency impacts. Labor costs decrease substantially when incorporating full automation, reducing crane operator requirements by 65-80% through more centralized control centers with experienced operators being able to monitor different cranes simultaneously. Energy consumption typically improves through optimized movements, potentially saving €250,000 annually for a medium-sized terminal with 6-8 STS cranes. The maintenance frequency doesn't directly decrease, but predictive maintenance enabled by automation can reduce maintenance costs through extended component life and better spare parts management. These benefits are balanced against expected implementation costs of USD 10 million per crane and an variable additional investment for terminal-wide infrastructure, with ROI periods that highly depend on regional and terminal characteristics.

These findings directly address sub-research question (a): "What are the operational differences in terms of efficiency and cost-effectiveness between manual and automated waterside operations?". The findings show that automation offers both efficiency improvements and cost benefits, though these might vary significantly based on terminal characteristics and regional factors. The initial investment is substantial, but the combination of operational improvements and cost reductions leads to a compelling business case, especially in regions with high labor costs.

The efficiency improvements and cost implications identified in this chapter affect various stakeholder groups, whose detailed analysis follows in Chapter 3. As Chapter 3 will show, the key stakeholders in terminal automation include terminal operators, labor unions and workers, shipping companies, regulatory bodies, and technology providers. The technology providers sell the automated solutions and are not directly impacted by the technology itself. However, the identified efficiency improvements and cost implications from this chapter impact each of the other stakeholder groups differently:

- Terminal Operators benefit from:
  1. Reduced cycle times in container handling operations.
  2. Lower energy demand through optimized operations.
  3. Extended equipment lifespan through more consistent operations.
- Labor Unions and Workers are impacted by:
  1. Reduced operator requirements through automation.
  2. Need for retraining and new skill development.
  3. Improved workplace safety conditions.
- Shipping Companies benefit from:
  1. More consistent and predictable operations.
  2. Faster turnaround times.
  3. Reduced operational delays.
- Regulatory Bodies benefit from:
  1. Reduced energy consumption.
  2. Lower emissions through efficient operations.
  3. Possible more precise monitoring options.

The relative importance of these benefits varies significantly by region. For example, labor cost reductions are more significant in high-wage markets, while efficiency gains have a larger impact in regions with lower labor costs. These regional variations and stakeholder priorities have a significant influence on automation implementation strategies. This will be further explored in Chapter 3.

3
Stakeholder Analysis

Automation in STS crane operations is transforming container terminals by enhancing efficiency, reducing operational costs, and improving safety. However, its adoption also reshapes the interests and concerns of various stakeholders, introducing new risks and shifting value distributions. These risks range from cybersecurity vulnerabilities and regulatory compliance challenges to workforce displacement and operational uncertainties.

This chapter examines the values and perspectives of key stakeholders in container terminals and how the incorporation of automated solutions affects them. First, a stakeholder landscape and value framework is established to identify key stakeholders and their general values. Then, detailed case studies of terminals in Antwerp, Kaohsiung, and Los Angeles are conducted to analyze how stakeholder perspectives vary across different regional contexts. Finally, a comparative analysis reveals common trends and region-specific variations in stakeholder values and implementation approaches.

The analysis provides an industry-wide perspective based on published literature and research. This approach ensures an unbiased examination of automation's impacts across the broader terminal operations sector. The chapter focuses on the varying priorities and concerns of stakeholders across different regions, as regional differences in policy, labor laws, and economic conditions influence how these stakeholders approach automation.

By analyzing the diverse perspectives of various stakeholders such as terminal operators, port authorities and regulatory bodies, the chapter aims to understand how automation impacts each group's interests and how these interests shift in response to the changes automation brings. The comparative approach highlights both common trends and region-specific variations, providing insights into the broader implications of integrating automation within STS crane operations and how different factors influence stakeholder values.

3.1. Research Methodology and Framework

This chapter examines how automation of STS crane operations affects various stakeholders and how these impacts vary across different regional contexts. The analysis aims to understand not just the technical implementation of automation, but how different stakeholders' interests and concerns shape the adoption and success of automated solutions across diverse terminal environments .

The analytical framework builds on the operational findings from Chapter 2, searching for insights beyond purely technical considerations to examine the broader implications of automation. Through a comparative analysis approach, this chapter examines how regional differences in policy, labor laws, and economic conditions influence stakeholder perspectives and automation outcomes. This approach identifies both common trends and region-specific variations in automation implementation.

The analysis relies primarily on published literature and industry research, complemented by internal validation through industry experts. This was done because direct stakeholder engagement was limited due to the competitive nature of terminal operations and sensitivity of automation projects. Instead, the research uses available industry studies and reports to provide an unbiased, industry-wide perspective rather than focusing on specific technology providers or customers

For the detailed analysis, three ports were selected: Antwerp, Kaohsiung, and Los Angeles. These cases represent three operational environments with different governance structures, labor relations, and regulatory frameworks. Antwerp represents the European model with structured stakeholder relationships, Kaohsiung represents Asian contexts with centralized governance but technical expertise challenges, and Los Angeles illustrates North American conditions with strong union influence. This diversity in regional contexts enables examination of how certain local factors influence automation outcomes, as identical technical solutions can lead to different results based on regional conditions.

The analysis consists out of three main phases. First, it establishes a stakeholder landscape and value framework to identify key groups and their primary interests. Then, it examines how these stakeholders' perspectives vary across the selected ports, considering their unique operational environments. Finally, it conducts a comparative analysis to identify patterns and differences in how automation is approached across the different regions.

3.2. Stakeholder Landscape and Value Framework

In the context of automation in STS crane operations, several stakeholders play a key role in shaping how these systems are implemented and used. Each stakeholder group has different interests, values, and concerns, which influence their position on automation. Understanding these stakeholders and their respective priorities is needed for assessing the broader impact of automation across terminals. This section will outline the primary stakeholders involved in port automation, providing a brief description of each group and their general values and concerns.

The following stakeholder groups are key players in the implementation and operation of automated STS crane systems:

1. Terminal Operators
    - Terminal operators are responsible for the overall management of container terminals. They oversee daily operations, including container handling, storage, logistics, and maintenance, ensuring that everything runs smoothly and efficiently. They are in charge of optimizing terminal operations, implementing new technologies (including automation), and managing the workforce. While they may not always own the terminal, they have decision-making authority over operational strategies and improvements. Their primary goal is to maintain efficient operations, maximize throughput, and meet the requirements set by port authorities and shipping companies.
2. Port Authorities
    - Port authorities oversee the regulatory compliance and operational standards within a port. They ensure that the terminal operates according to local laws and international regulations. Their main concerns include safety, security, and ensuring that the port remains competitive on a global scale. Automation can have two sides for them, as it can improve operational efficiency but also raise concerns regarding job displacement and regulatory challenges.
3. Shipping Companies
    - Shipping companies are the customers of the terminal and are primarily concerned with cost-effective, fast, and reliable services. Their values are focused on reducing delays, lowering operational costs, and maintaining predictable schedules. Automation in STS crane operations can help shipping companies by reducing turnaround times and providing more reliable services.

4. Labor Union and Workforce
   - The workforce involved in terminal operations, including crane operators and support staff, plays a crucial role in day-to-day activities. Labor unions represent these workers' interests, which are centered around job security, fair wages, retraining opportunities, and safe working conditions. With automation, workers may face displacement or changes in their job roles, which can lead to both opportunities for reskilling and challenges in maintaining job security.
5. Technology provider
   - The technology provider is responsible for developing, integrating, and maintaining the automation systems used in STS crane operations. The values of these companies are focused on providing reliable, innovative solutions that meet the operational needs of terminal operators. The company aims to build long-term relationships with clients by offering support, system upgrades, and custom solutions to ensure smooth and efficient operations. For the technology provider, automation represents both an opportunity to innovate in the industry and a challenge to tailor solutions that meet the specific needs of each terminal, all while maintaining high standards of reliability and customer satisfaction.
6. Regulatory bodies
   - Regulatory bodies set and enforce the rules and standards governing port operations, including safety, sustainability, and cybersecurity rules and standards. They are concerned with ensuring that automation systems meet all relevant regulations and contribute to the safe, secure, and environmentally responsible operation of terminals. These bodies must balance the benefits of automation with the need to maintain strict oversight and compliance.

While not directly involved in automation decisions, and therefore not a key stakeholder, transport companies (road, rail, and barge operators) are indirectly affected by STS crane automation. These indirect stakeholders benefit from automated operations' more consistent and predictable performance, as automation provides more reliable service and reduces variability in handling times.

3.2.1. Overall Values of Stakeholders

This section delves into the core values of the different stakeholders involved in automated STS crane operations. Understanding these values is essential, as they shape how each group perceives automation and its impact on their operations. These priorities also provide a foundation for comparing the interests and concerns of different stakeholders across terminals.

Terminal Operators

Terminal operators focus on ensuring the smooth and efficient operation of the terminal. Their primary values include:

1. Efficiency and Throughput: Maximizing the speed and accuracy of container handling is a key priority. Automation helps increase throughput by speeding up processes and reducing human error.
2. Cost Reduction: Minimizing costs, particularly labor, maintenance, and operational expenses, is crucial. Automation plays a significant role in reducing these costs by streamlining operations and reducing the reliance on manual labor.
3. Scalability and Flexibility: Operators need the ability to adjust operations as demand changes. Automation systems that are scalable and adaptable to different operational needs provide a valuable advantage.
4. Safety and Compliance: Ensuring a safe working environment and compliance with local and international regulations is mandatory. Automation can help reduce accidents and improve compliance by minimizing human intervention and making safety protocols more consistent.

Port Authorities

Port authorities are responsible for overseeing the broader operations of the port and ensuring that everything aligns with regulations and industry standards. Their primary values include:

1. Safety and Security: Maintaining high safety standards and secure operations is mandatory. Automation can help improve safety by reducing human involvement in hazardous tasks.
2. Regulatory Compliance: Ensuring that terminal operations comply with local, national, and international regulations is mandatory. Automation systems must meet all safety, environmental, and operational standards.
3. Port Competitiveness: Port authorities aim to keep the port competitive in a global market. Automation can help by improving operational efficiency, reducing costs, and enhancing service reliability, which in turn can attract more business to the port.
4. Port authorities prioritize sustainability by enforcing environmental regulations and promoting greener operations within terminals. They push for reduced emissions, energy efficiency, and waste reduction, ensuring that automation aligns with broader environmental goals.

Shipping Companies

Shipping companies are the main customers of the terminals. Their primary values include:

1. Cost-Effectiveness: Minimizing operational costs is key for shipping companies. Automation can minimize delays, and possibly reduce port fees, which directly impacts their cost structure.
2. Timely and Reliable Service: Shipping companies require terminals to handle containers quickly and without delays. Automation helps by speeding up turnaround times and increasing the reliability of operations.
3. Predictability and Scheduling: Shipping companies prioritize reliable and predictable schedules. Automation helps improve the accuracy and efficiency of container handling, which leads to fewer delays and more consistent schedules.

Labor Unions and Workforce

Labor unions represent the interests of the workforce, which includes crane operators, staff management, ground engineering staff and other support personnel. Their primary values include:

1. Job Security: As automation is introduced, job displacement becomes a concern. Labor unions aim to ensure that workers' jobs are not jeopardized by automation, advocating for retraining and reskilling programs.
2. Fair Compensation: Ensuring fair wages and benefits for the workforce is a top priority. Automation may change the nature of work, but unions aim to ensure that workers are compensated accordingly for any changes in their roles.
3. Safe working Conditions: Improving the health, safety, and overall working conditions for employees is another key objective. Automation can help improve safety by reducing workers' exposure to dangerous tasks and enhancing ergonomic design.

Technology provider

The technology provider has a strong focus on delivering innovative, reliable automation systems. Their primary values include:

1. Innovation and Reliability: the technology provider is dedicated to providing cutting-edge, reliable automation systems that enhance terminal operations. The goal is to ensure that automation meets the needs of terminal operators while improving overall operational efficiency.
2. Long-Term Relationships: Building lasting relationships with clients is a core objective. The technology provider offers ongoing support and system upgrades to ensure that automated systems continue to meet operational demands throughout their lifespan.
3. Customizability: Recognizing that every terminal has unique needs, the technology provider strives to deliver customizable solutions that can be tailored to the specific operational requirements of each terminal.
4. Sustainability: sustainability is both a responsibility and a market opportunity. Developing energy-efficient automation systems solutions helps terminals meet environmental standards while also improving competitiveness. By integrating green technologies, technology providers support both regulatory compliance and long-term efficiency in terminal operations.

Regulatory bodies

Regulatory bodies are responsible for setting and enforcing safety, environmental, and operational standards within ports. Their key values include:

1. Safety and Sustainability: Ensuring that automation systems adhere to safety standards and minimize environmental impact is a top priority.
2. Compliance and Oversight: Regulatory bodies focus on ensuring that automated systems comply with all applicable laws and standards. This includes overseeing cyber-security risks, environmental regulations, and ensuring that automation does not compromise operational safety.
3. Innovation and Best Practices: Regulatory bodies must stay informed about new technologies and ensure that best practices are followed while balancing innovation with regulatory oversight.

While stakeholders share common values such as efficiency, safety, and reliability, their perspectives on automation differ based on their roles and objectives. The next section provides a comparative overview, highlighting these shared values, potential conflicts, and the evolving impact of automation on stakeholder priorities.

3.2.2. Comparative Overview of Stakeholder Values

In this section, the core values of the key stakeholders will be examined, emphasizing similarities and conflicts in their priorities. This section will also explore how automation might impact or reshape these values, providing initial insights into its broader implications across the various stakeholders and offering a foundation for the more detailed analysis of stakeholder perspectives in different terminal environments in the following section.

Common Values Across Stakeholders

In the context of automated STS crane operations, several key values are shared among stakeholders, even though each stakeholder may have different priorities. These common values form the foundation for discussions about the potential benefits and challenges of automation. The values that are most commonly shared among stakeholders include:

1. Efficiency
    - Efficiency is a core value across most stakeholders. Terminal operators try to optimize operations, minimize delays, and reduce costs, all of which contribute to improved efficiency. Shipping companies benefit from efficient operations as it leads to quicker processing and reduced turnaround times. Technology providers, in turn, focus on creating automation systems that streamline operations, increase throughput, and reduce the time required for each operation. All stakeholders, from port authorities to labor unions, benefit from more efficient systems, even if their specific motivations differ.
2. Safety
    - Safety is a mandatory top-priority inside a terminal. For terminal operators, reducing accidents and downtime caused by human error is crucial for maintaining productivity. Labor unions focus on the safety of workers, advocating for safe working conditions and proper training to prevent injuries. Port authorities regulate and enforce safety standards, ensuring that the terminal operates in compliance with safety regulations. Technology providers also prioritizes safety by developing systems that minimize risks associated with automation and ensure that new technologies do not compromise the well-being of workers.

3. Cost-effectiveness
    - Cost-reduction is a value shared by terminal operators, shipping companies, and the technology provider. Terminal operators aim to reduce operational costs, and automation offers the potential for significant cost savings through labor reduction and more efficient use of resources. Shipping companies also prioritize cost-effective services, seeking to minimize port charges and handling fees. For the technology provider, developing cost-efficient automation solutions is important, as it makes their products more attractive to terminal operators looking to reduce long-term operational expenses. For the indirect stakeholder, transport companies, efficiency improvements translate into cost-effectiveness benefits through more consistent and predictable handling times. This reliability enables better resource planning and reduces costly idle times in their operations.
4. Innovation
    - Innovation is a shared value among terminal operators, the technology provider, and port authorities. Terminal operators view innovation as a way to stay competitive by adopting the latest technology to improve operations. The technology provider is directly invested in advancing their products, offering new and improved systems that can bring operational benefits. Port authorities, while focused on regulations, also recognize the importance of innovation in maintaining the port's global competitiveness. This shared value reflects the collective drive for continuous improvement and modernization inside a terminal.
5. Sustainability
    - Sustainability is becoming an increasingly important value shared by terminal operators, port authorities, and shipping companies. Terminal operators and port authorities aim to meet environmental regulations and reduce the ecological impact of port operations. Shipping companies are under pressure to meet sustainability standards in their supply chains, which makes eco-friendly port operations increasingly important. The technology provider also benefits from offering sustainable solutions, as the demand for environmentally responsible automation grows. Sustainable practices, including reduced energy consumption and fewer emissions, are viewed as long-term advantages for all stakeholders involved.

These shared values show the areas that are of importance for several stakeholders. While each stakeholder group may have different priorities and concerns, the values of efficiency, safety, cost-effectiveness, innovation, and sustainability are central to the successful implementation and operation of automated STS crane systems. Understanding these shared values will help guide decision-making processes and help cooperation among stakeholders when implementing automated solutions.

Conflicting Values Across Stakeholders

While there's a lot of overlap between stakeholders in terms of shared values, there are also clear conflicts that come up because each stakeholder group has its own interests, especially when it comes to automation in STS crane operations. These conflicts often center around financial, operational, and workforce-related concerns.

1. Cost Reduction vs. Workforce Security
    - One big conflict is between terminal operators, who want to reduce costs and increase efficiency, and labor unions and the workforce, who care more about job security and fair wages. For terminal operators, automation is an obvious way to cut costs, speed up processes, and reduce reliance on manual labor. But the downside is that it could lead to job cuts or role changes, which creates fear for the workforce. Labor unions are all about protecting their members, so they worry that automation will lead to job losses or less opportunity for lower-skilled workers. Even though automation could mean more high-skilled roles for some, it's still a hard sell to workers who may not have the resources to retrain or move into new positions.

2. Profit Maximization vs. Compliance with Regulatory Standards
   - Another conflict arises from the difference in priorities between terminal operators (and sometimes shipping companies) and regulatory bodies. Operators tend to focus on cutting costs and maximizing efficiency, and they see automation as a way to do that. However, this can conflict with the interests of port authorities and regulatory bodies, who are responsible for making sure everything meets safety, environmental, and legal standards. Terminal operators might push for automation before all the rules and regulations are fully sorted out, aiming for speed and cost-effectiveness. However, regulatory bodies have to make sure everything is compliant with the law, which can slow things down or lead to disagreements over how fast automation should be rolled out. This might result in a constant push and pull between wanting to innovate quickly and ensuring that the system is safe and responsible.
3. Efficiency vs. Safety
   - Finally, there is a classic conflict between efficiency and safety. Technology providers often argue that automation actually makes operations safer by reducing human error, and this is a key selling point. However, labor unions and workers may not see it that way. They might worry that automation could change their roles in ways that add stress or expose them to new risks, especially if they're working alongside machines that they don't fully control. This conflict highlights the balance that needs to be struck between faster, more efficient systems and the need to ensure safe working environments for everyone. While technology can help, it's important to remember that human workers still play a crucial role in maintaining safety standards, especially when dealing with complex machinery.

These conflicts show the challenges that arise when stakeholders with different values interact, especially in the context of automation. Understanding these conflicts is necessary to predict how automation will impact each group's interests. The next section will dive into the preliminary insights on how automation might reshape these overall values and dynamics across stakeholders.

Preliminary Insights on Automation's Impact

Automation is already starting to change terminal operations, although the full extent of its impact is still unknown. While it's clear that automation can bring some big improvements, it's also important to recognize that different stakeholders will be affected in different ways, depending on what they value most.

For terminal operators, automation can boost efficiency and reliability, while lowering costs. With automated STS cranes, there's less downtime, better throughput, and fewer human errors. This fits well with their goal of increasing efficiency, but it also introduces challenges around managing a smaller workforce and making sure new technologies integrate smoothly into current operations.

Port authorities stand to benefit from the potential for more streamlined port operations, which could make the port more competitive. That said, they'll also have to manage the added complexity of new safety regulations and environmental standards tied to automation. It's a balancing act between improving efficiency and making sure everything stays compliant with local laws and international regulations.

For shipping companies, automation should lead to faster, more reliable turnaround times, which will ultimately help them cut down on costs and delays. The value of quicker, more predictable service aligns with their needs, though they'll also be keeping an eye on the long-term impacts of automation on their supply chain flexibility and port accessibility.

Labor unions, on the other hand, are more focused on the risks automation brings for workers. While automation can reduce the workload and improve safety on the job, it can also lead to job losses or shifts in responsibilities, which unions will have to contend with. Their priority is ensuring that workers are not left behind in the transition to automation, and that retraining and reskilling programs are in place where possible to help employees adapt.

Technology providers are naturally positioned to benefit from the growing demand for automated solutions. The challenge, however, lies in making sure that these technologies are adaptable, reliable, and meet the specific needs of different terminals. This requires constant innovation and a close understanding of what each stakeholder needs.

In the next section, the focus will shift to examining how these impacts vary across different terminals and regions. By looking at specific cases, it will be possible to dive deeper into how automation can be implemented and how stakeholders' values and concerns shift depending on the context.

3.3. Stakeholder Perspectives Across Different Ports

The potential for automation in container terminals is influenced by regional factors such as regulatory frameworks, economic conditions, and cultural views. While Full automation is still under development and has yet to be implemented in the terminals analyzed, its feasibility and impact can be analyzed based on internal industry knowledge, available research and data, and regional context. Stakeholders, including terminal operators, regulatory bodies, labor unions, and technology providers, have different priorities depending on these factors. Regulations may impose constraints on labor practices or safety standards, economic conditions shape investment decisions, and cultural views influence openness to technological change.

This section compares stakeholder perspectives in three different ports, considering their existing operational environments and how automation might be received. By examining these cases, key differences and shared concerns across regions can be identified, providing insight into the challenges and expectations surrounding automation in diverse terminal settings. The impact of the technology provider in these countries is not specifically addressed here, as the technology provider's role remains largely consistent across ports: primarily focused on supplying and supporting automation systems rather than being a stakeholder with regional interests or concerns.

3.3.1. Stakeholder Perspectives in Belgium, Antwerp

The Port of Antwerp, one of Europe's largest and busiest ports located in the Rhine-Scheldt Delta, has long been a leader in container throughput. But like other ports, it faces increasing pressure to innovate and improve efficiency. The drive towards automation, particularly with automated STS cranes, is part of a broader trend across the industry aimed at reducing costs, improving throughput, and enhancing safety. However, these benefits conflict with certain stakeholder perspectives, especially concerning labor and unions.

Terminal Operators

Terminal operators in Antwerp prioritize maximizing efficiency, but their approach is shaped by Belgium's advanced infrastructure and high labor costs. Automation serves as a means to maintain competitiveness in the European market, especially against nearby ports like Rotterdam. Antwerp, benefiting from the port's rich economic environment, is able to invest in advanced automation technologies to not only improve container handling speed and reduce human error, but also to optimize resource allocation and labor costs, which are relatively higher in Belgium compared to other ports around the world (Baskin & Swoboda, 2023). Furthermore, they are focusing on advanced automation systems that can ensure operational resilience, adapting to fluctuations in global shipping demands while maintaining a high level of service reliability.

Port Authorities

The Port of Antwerp-Bruges is managed by the Antwerp Port Authority, which plays a crucial role in balancing economic growth with sustainability and innovation. Unlike some other European ports, Antwerp's port authorities actively facilitate automation projects through public-private initiatives, investing in digitalization and smart port technologies (Baskin & Swoboda, 2023). Their focus is not just on safety and regulatory compliance but also on making the port a hub for sustainable and automated logistics. Automation aligns with their long-term vision of reducing emissions, improving efficiency, and maintaining Antwerp's status as a leading European gateway for container trade.

Shipping Companies

Shipping companies using the Port of Antwerp rely on its status as one of Europe's largest transshipment hubs, particularly for deep-sea and feeder connections. Automation is expected to improve turnaround times, allowing vessels to optimize scheduling and reduce idle time. Given Antwerp's high cargo volumes and strategic location, shipping lines, including major alliances like 2M and Ocean Alliance, view automation as a key factor in maintaining service reliability.

However, the transition to automation is not without challenges. Shipping companies must navigate potential disruptions in port operations during implementation, as adjustments to berth planning and crane operations may temporarily impact efficiency. Additionally, there are concerns about whether automation will be evenly adopted across terminals, as inconsistencies in handling times between automated and non-automated terminals could create scheduling inefficiencies. For shipping lines operating on tight schedules, these uncertainties mean that while automation is broadly welcomed, its implementation strategy remains a key consideration.

Labor Unions and Workforce

Labor unions in Belgium hold significant power in labor negotiations, with one of the highest union densities in Europe; nearly half of private sector employees are union members (Bottalico, 2022). This strong representation gives unions considerable influence over policy and decision-making, particularly in sectors like port operations, where historical protections for workers are deeply embedded in law.

Belgium's port labor system is shaped by the Major Act of 1972, which mandates that only registered dockworkers can handle cargo operations (European Union, 1972). This regulation gives labor unions in Antwerp significant influence over automation efforts, as port employers cannot bypass the established workforce by hiring from the external labor market. Consequently, automation does not lead to immediate layoffs but instead requires extensive negotiations between unions, terminal operators, and policymakers.

The unions' primary concern is job security. With the introduction of automated STS cranes, workers fear displacement, particularly crane operators whose roles are at risk. However, due to the strict labor laws, automation in Antwerp progresses more cautiously compared to ports with more flexible labor markets. Rather than outright job cuts, unions advocate for retraining programs, ensuring workers transition into new roles rather than being replaced(Bottalico, 2022).

Recent developments, including announced union actions and upcoming strikes, continue to affect implementation planning and timelines (World Cargo News, 2025). The port's structured negotiation framework, though time-consuming, provides more predictable processes than the politically-driven frameworks seen in for example Kaohsiung (Bottalico, 2022). This established framework can help maintain implementation progress despite labor challenges.

Beyond employment concerns, safety is a key issue. Unions recognize that automation can reduce workplace accidents by limiting human exposure to high-risk tasks (Notteboom et al., 2022). However, they argue that this should not come at the cost of job losses. Instead, they push for automation to complement workers rather than replace them, emphasizing a phased approach where human oversight remains critical (European Transport Workers' Federation, 2019).

In negotiations, unions aim to secure agreements that balance efficiency gains with workforce protections. This includes wage guarantees, role transitions, and long-term employment strategies (Loridan, 2019). As automation becomes increasingly relevant, Antwerp's unions will continue to play a crucial role in shaping how technological advancements are integrated into port operations without undermining the livelihoods of its workers.

Regulatory Bodies

Regulatory bodies in Antwerp oversee the implementation of automation technologies, ensuring compliance with safety, environmental, and operational regulations. Their primary concern is to ensure that automated systems are integrated in a way that aligns with both local and European standards. In Belgium, the Major Act (June 1972) mandates that only recognized dockworkers are entitled to work in the port area, which remains a key consideration even as automation increases. These bodies are tasked with making sure that automation doesn't bypass these established labor regulations while also ensuring worker safety (European Union, 1972).

In terms of safety, regulatory bodies are particularly focused on minimizing risks that automation could introduce. For example, when automated systems like STS cranes are introduced, these bodies ensure they are rigorously tested and comply with safety standards to prevent malfunctions or accidents (Bottalico, 2022). This is particularly important because, while automation can reduce human error, it also introduces new risks that must be carefully monitored. Regulatory bodies are tasked with ensuring that safety protocols are updated to reflect the new systems and that any incidents involving automated technologies are fully investigated.

Environmental concerns also factor into the role of regulatory bodies. Automation can help achieve sustainability goals by reducing emissions and enhancing energy efficiency. However, regulators ensure that automated systems comply with environmental standards, contributing to the European's long-term sustainability objectives. They monitor the potential environmental impacts of introducing these technologies, ensuring that automation doesn't lead to unforeseen negative consequences for the port or surrounding areas (Port of Antwerp-Bruges, 2025).

Ultimately, these regulatory bodies ensure that automation is integrated in a way that doesn't outpace the existing legal and safety frameworks, providing a balanced approach that ensures the port remains safe, efficient, and environmentally responsible.

Broader Economic and Competitive Context

Antwerp is one of Europe's largest ports and a key player in global trade. However, it faces increasing competition, especially from nearby ports like Rotterdam and Hamburg, which are pushing ahead with automation. Port authorities and terminal operators in Antwerp recognize that adopting automation is essential for staying competitive in this environment. Automation promises to enhance efficiency, reduce costs, and improve reliability, making Antwerp more attractive to shipping companies and other stakeholders (Bottalico, 2022).

As Rotterdam, Hamburg, and other European ports continue to make strides in automation, Antwerp understands the need to keep pace. The pressure to remain competitive is high, and automation is seen as a vital tool in ensuring Antwerp's position as a leading port in Europe. By implementing automated systems, the port can streamline operations, reduce turnaround times, and increase overall throughput.

3.3.2. Stakeholder Perspectives in Taiwan, Kaohsiung

The Port of Kaohsiung, Taiwan's largest harbor and one of East Asia's busiest container ports, serves as an important hub for the nation's export-oriented economy. Kaohsiung handles over 10 million TEUs annually (Taiwan International Ports Corporation, 2023b), connecting Taiwan to global shipping routes across the Asia-Pacific region. Like other competitive ports, Kaohsiung faces increasing pressure to enhance operational efficiency and throughput. The implementation of automated STS cranes represents part of the broader industry trend aimed at optimizing container handling, reducing operational costs, and improving safety standards. However, these technological advancements must be balanced against the concerns of various stakeholders, particularly regarding workforce transitions and regulatory compliance in Taiwan's distinct business environment.

Terminal Operators

The Port of Kaohsiung is operated by Taiwan International Ports Corporation (TIPC), a state-owned enterprise that manages Taiwan's major ports. Unlike the more fragmented operational structure seen in European ports like Antwerp, TIPC maintains significant control over port development and operations. Several terminal operators hold concessions within the port, including Evergreen Marine Corporation, Yang Ming Marine Transport, and Wan Hai Lines, which all major Taiwanese shipping companies that operate dedicated terminals (Taiwan International Ports Corporation, 2025).

These terminal operators face intense regional competition, particularly from mainland Chinese ports and other regional hubs like Singapore and Busan (Chang & Tai, 2021). This competitive pressure drives their interest in automation technologies, including automated STS cranes. For Kaohsiung's terminal operators, automation represents an opportunity to address several operational challenges unique to Taiwan's context. Labor costs in Taiwan have been changing, while the available workforce has shifted due to demographic trends and competition from Taiwan's technology sector (Directorate-General of Budget, Accounting and Statistics, Executive Yuan, R.O.C. (Taiwan), 2025).

Terminal operators view automation primarily through the lens of operational efficiency and cost reduction. With container volumes varying in response to global trade patterns and regional geopolitical tensions, terminal operators are looking for technologies that can help maintain consistent throughput regardless of external conditions.

Port Authorities

As discussed, the Port of Kaohsiung is managed by Taiwan International Ports Corporation (TIPC), a state-owned enterprise established in 2012 to oversee Taiwan's commercial ports. Unlike the decentralized management of many European ports, TIPC operates under a centralized governance structure with direct oversight from Taiwan's Ministry of Transportation and Communications. TIPC has positioned the Port of Kaohsiung as Taiwan's primary international gateway.

TIPC approaches port development with a technological focus, investing in digital infrastructure and promoting smart port initiatives. The port authority has designated specific areas within Kaohsiung's large port complex for modernization projects, including automation pilots. TIPC's strategy focuses on improved operational efficiency and environmental performance, which is particularly important given Kaohsiung's urban proximity (Tseng & Pilcher, 2017). Automation aligns with their broader objectives of strengthening the port's regional competitiveness while addressing growing environmental concerns.

As both the regulator and a commercial entity, TIPC needs to combine infrastructure development with oversight responsibilities. Because of this, unlike European port authorities that often face complex stakeholder negotiations, TIPC benefits from streamlined decision-making processes. This allows for more rapid implementation of technological initiatives. This governance structure has given Kaohsiung the opportunity to respond efficiently to regional competition from mainland Chinese ports, Hong Kong, and Singapore. Within this, automation is viewed as one of the most important ways to maintain the port's strategic position in Asian shipping networks (Feng et al., 2012).

Shipping Companies

Shipping companies using the Port of Kaohsiung rely on its position as Taiwan's primary container gateway and a strategic hub in East Asian shipping networks. Automation is expected to improve vessel turnaround times, allowing carriers to reduce costly port delays. Shipping alliances operating at Kaohsiung, including 2M and Ocean Alliance, view automation as a potential advantage for maintaining consistent schedules across their Asian and trans-Pacific services (Chang & Tai, 2021).

However, automating terminals also brings concerns. When ports install new automated systems, shipping companies also expressed their concerns about delays and disruptions during the changeover period (Chang & Tai, 2021). However, even with these concerns, most shipping companies support automation as long as it is done right. While they see the benefits of faster, more reliable crane operations, what matters most is keeping ships moving on time. The success of automation for shipping lines isn't just about how fast cranes can work, but includes whether terminal operators can make changes without disrupting existing services.

Lastly, local carriers like Evergreen and Yang Ming have a special interests in Kaohsiung's development as their home port. These companies operate dedicated terminal facilities within the port complex and have direct stakes in any technological changes. Their experience with automation at international terminals leads their expectations for implementation at Kaohsiung.

Labor Unions and Workforce

Labor unions at Kaohsiung port have less influence than their counterparts in European or North American ports. Taiwanese workers are represented by various smaller unions rather than a single powerful organization, which limits their ability to oppose automation. Most port workers are employed by terminal operators, with job security protections that are weaker than in Western countries (Chiou, 2024).

The Labor Union, which is owned by TIPC, has expressed concerns about automation plans, but usually focuses on getting retraining programs and early retirement packages rather than blocking new technologies completely (Taiwan International Ports Corporation, 2023a). This differs from places like Antwerp, where unions are well represented and powerful.

Training is a major concern for Kaohsiung's port workforce. According to Yang and Hsieh (2024) many current employees lack the technical skills needed to work with automated systems. Terminal operators have started offering retraining programs, but older workers especially struggle with the transition to more technical roles. The government has also created special programs at maritime colleges to train new workers specifically for automated terminal operations, trying to address the skills gap before it becomes a bigger problem (Taiwan International Ports Corporation, 2023a).

Regulatory Bodies

Maritime and port operations in Taiwan fall under a complex regulatory framework involving multiple entities. The Ministry of Transportation and Communications (MOTC) serves as the primary regulatory authority overseeing port development, with the Maritime and Port Bureau handling specific safety and operational regulations. Taiwan's regulatory approach to automation differs from European models, by supporting economic development above safety considerations. While European authorities often impose strict labor protection requirements on automation projects, Taiwanese regulators focus more on ensuring that technological advancements support the country's strategic position in global shipping networks. The Taiwan International Ports Corporation (TIPC), operating as both port authority and commercial entity, implements government policies while maintaining operational autonomy in technological decisions. This double role creates a regulatory environment where automation initiatives are evaluated primarily on their contribution to port competitiveness rather than focusing on labor safety which is common in Western regulatory frameworks (Tseng & Pilcher, 2017).

Broader Economic and Competitive Context

Kaohsiung port remains one of Asia's major container hubs and has maintained a strong position despite growing regional competition. While mainland Chinese ports like Shanghai have expanded, Kaohsiung has successfully defended its role as a key regional port through strategic investments and efficient operations. The port continues to handle significant volumes and serves as Taiwan's primary gateway to global shipping networks (Taiwan International Ports Corporation, 2025).

Taiwan's export-driven economy, particularly its semiconductor and electronics manufacturing sectors, relies on Kaohsiung's efficient operations. The port's ability to process containers quickly directly impacts the nation's manufacturing competitiveness. Automation represents an opportunity to further enhance this efficiency rather than only catching up to competitors.

Despite Kaohsiung's current success, demographic trends in Taiwan, including an aging workforce and increasing labor costs, create long-term challenges for port operations (Huang et al., 2019). Automation offers a strategic response to these workforce issues while also addressing the need to handle the increasing cargo volumes in Asia.

3.3.3. Stakeholder Perspectives in the USA, Los Angeles

The Port of Los Angeles is the largest container port in the USA and a key gateway for US-Asian trade. Located in Southern California, it handles around 10 million TEUs yearly (Port of Los Angeles, 2025a). The port is important to America's supply chains and the main entry point for goods heading to US markets. Like other big ports worldwide, Los Angeles faces growing pressure to work faster and more efficiently. Automating STS cranes could help solve these problems by increasing container movements, cutting costs, and keeping the port competitive with international rivals. But unlike in many Asian ports, automation efforts in Los Angeles face strong opposition from the International Longshore and Warehouse Union (ILWU), which has much more power than unions in other countries (Meyris, 2024). This creates a difficult situation where business needs clash with labor concerns in America's most important port.

Terminal Operators

Terminal operators in Los Angeles handle the daily business of moving containers between ships and land transportation. The port has several major operators including APM Terminals, TraPac, Everport, and Yusen Terminals, with some being branches of global shipping companies (Port of Los Angeles, 2025b). These operators make most decisions about implementing automation at their facilities, though they must work within the framework set by the port authority.

Unlike in Kaohsiung, where automation adoption has been relatively smooth, LA's terminal operators face significant challenges when introducing new technologies. TraPac and APMT's automated terminals required years of negotiations with labor unions and substantial compromises on workforce retention. Terminal operators often argue that automation is necessary to handle larger vessels and compete with other West Coast ports, but they must carefully balance these business needs against powerful union resistance (Supply Chain Brain, 2023).

The financial model for terminal operators in Los Angeles also differs from Asian ports. Most operate on long-term leases from the port authority, which affects how they calculate returns on automation investments. With lease terms typically running 25-40 years, operators can take a longer view on recouping automation costs than their counterparts in ports with shorter concessions (Journal of Commerce, 2023). However, the high initial investment and uncertain labor climate make many operators hesitant to fully commit to automation projects despite their potential benefits for handling increasing container volumes (United States Government Accountability Office, 2024).

Port Authorities

The Port of Los Angeles is owned and operated by the City of Los Angeles through its Harbor Department, a self-supporting department that doesn't rely on taxpayer money. Unlike Kaohsiung's port authority which is part of Taiwan's national government structure, LA's port authority has considerable autonomy but must answer to local political bodies including the mayor-appointed Harbor Commission and ultimately the City Council (Port of Los Angeles, 2025c). This creates a complex decision-making environment where commercial interests often compete with local political concerns.

The port authority's role in automation differs significantly from Asian counterparts. While it doesn't directly implement automation, it sets the framework through lease agreements with terminal operators. These agreements cover decades and establish key parameters including land use, environmental requirements, and community benefits. However, the authority leaves specific operational decisions about technology adoption to terminal operators, focusing instead on broader infrastructure and policy issues (Nacht & Henry, 2021).

Political considerations heavily influence the port authority's approach to automation. Harbor commissioners are political appointees who must balance business needs against community impacts and labor concerns. This creates a more complex environment for automation than in ports where economic efficiency is the primary consideration. The port authority actively works to mitigate negative impacts through programs like workforce development initiatives and environmental mitigation funds when automation reduces jobs (World Economic Forum, 2024).

LA's port authority also faces unique environmental pressures. The Clean Air Action Plan requires significant emissions reductions, which automation can help achieve through electrified equipment. This environmental mandate creates additional incentives for the port authority to support automation while navigating the political challenges it creates (World Economic Forum, 2024). The port authority walks a difficult line between enabling modernization and addressing community concerns about economic impacts.

Shipping Companies

Major shipping companies like Maersk, MSC, CMA CGM, and COSCO play a significant role in Los Angeles port operations. These carriers bring large vessels to LA, some carrying over 20,000 containers at once. These vessels need to be loaded and unloaded quickly to stay on schedule. Unlike in Asian ports where shipping lines often directly control terminals, the setup in LA is more complicated, with various leasing deals and separate companies handling operations (Port of Los Angeles, 2025b).

Shipping lines push for automation mainly through their terminal subsidiaries and by demanding faster service. Maersk's terminal division, APM Terminals, has already added a certain degree of automation at their Pier 400 facility despite facing fierce opposition from the ILWU, which organized protests and fought against these changes at every step (Schuler, 2019). These carriers constantly pressure terminals for quicker turnarounds, often pointing to competing ports in Canada and Mexico that don't have the same union issues (Nacht & Henry, 2021). The pressure from carriers drives terminal operators to look for solutions leading to efficiency gains, with automation presented as a potential solution.

For shipping companies, it's all about their global network needs rather than local considerations. They need reliable schedules and consistent handling speeds across all ports they visit. They see each port call as just one piece of their worldwide operation and care more about predictability than local job impacts. This creates conflict in LA, where shipping companies want efficiency while local stakeholders worry about jobs (World Economic Forum, 2024).

The situation in LA differs from Kaohsiung because shipping companies in LA can't directly control the labor situation. While all carriers want faster vessel processing, they depend on terminal operators to handle the tricky labor relations. This hands-off relationship with the workforce makes LA's automation challenge different from ports where unions have less influence or where automation has progressed with less opposition.

Labor Unions and Workforce

The International Longshore and Warehouse Union (ILWU) represents dockworkers in Los Angeles and holds enormous influence over port operations. Unlike labor organizations in many Asian ports, the ILWU has maintained high bargaining power through decades of strategic organizing and contract negotiations (Meyris, 2024). LA dockworkers earn substantially higher wages than most blue-collar workers, with full-time workers typically earning over $100,000 annually plus benefits (CBS News, 2023). This strong position makes the ILWU a powerful stakeholder whenever automation discussions arise, as workers have significant economic interests at stake.

Automation represents an existential threat to the ILWU's membership base. The union has consistently opposed automation projects at LA terminals, organizing demonstrations, filing appeals, and leveraging political connections to challenge implementation. When APM Terminals moved to automate portions of Pier 400, the ILWU organized major protests and pursued multiple legal challenges to block the project (Schuler, 2019). The union's core concern isn't just immediate job losses but the progressive reduction of their workforce as automated equipment reduces labor requirements. Unlike in Kaohsiung, where unions have limited political influence, the ILWU's connections extend from local officials to federal representatives (Ahlquist et al., 2014).

The labor contract between the ILWU and terminal operators contains specific language regarding automation, reflecting decades of negotiations over technology adoption. While the contract allows certain automation, it includes protections for existing workers and jurisdiction over specific jobs. This creates a complex automation implementation environment where terminal operators must navigate contractual obligations alongside technical considerations. When automation proceeds, the union typically secures substantial compensation packages for affected workers, including retraining opportunities and enhanced retirement benefits that wouldn't exist in ports with weaker labor representation (Nacht & Henry, 2021) (Pacific Maritime Association & International Longshore and Warehouse Union, 2023).

Despite their opposition, some union leaders acknowledge that certain automation is inevitable. Their focus has shifted toward ensuring transitions occur on terms that protect workers' interests. This includes negotiating for jurisdiction over maintenance of automated equipment, securing commitments for worker retraining, and obtaining guarantees that existing workers won't lose their positions (Justie et al., 2023). The ILWU also highlights the safety advantages automation can provide by removing workers from hazardous environments. This approach distinguishes LA's labor situation from both Asian ports where automation advanced with minimal resistance and from European ports where labor organizations engaged earlier in collaborative automation planning (World Economic Forum, 2024).

Regulatory Bodies

Los Angeles port automation operates within a regulatory system shaped by local governance. The Port of Los Angeles functions as a department of the City of Los Angeles governed by the Los Angeles Board of Harbor Commissioners, whose five members are appointed by the mayor and confirmed by the City Council (Port of Los Angeles, 2024). This governance structure places port decision-making within local politics rather than operating as an independent entity, creating an environment where automation proposals face greater public examination than in ports with more autonomous governance models. The board members must balance commercial efficiency against their accountability to elected officials who represent communities directly affected by port operations.

The California Coastal Commission is another key regulator with authority over port development, including automation projects (California Coastal Commission, 2024). This state agency reviews port projects primarily for environmental impacts rather than economic benefits. When APM Terminals wanted to automate Pier 400, they needed coastal development permits, which gave automation opponents more chances to challenge the project (Schuler, 2019). Groups concerned about automation now regularly use Coastal Commission appeals as a strategic tool to delay projects and create uncertainty for terminal operators planning investments (Kryczka et al., 2020). This extensive approval process stands in contrast to many Asian ports, where simpler regulatory structures allow faster implementation of new technologies (World Economic Forum, 2024).

The California Air Resources Board (CARB) has an indirect influence on the implementation of automation through increasingly strict environmental regulations. CARB's requirements for zero-emission equipment favor automation, as electric automated equipment often proves more compatible with emissions reduction goals than traditional manually operated equipment. Terminal operators frequently use environmental compliance as justification for automation projects, arguing that automated technologies represent the most viable path towards meeting the mandatory emissions reductions. These regulations make terminal operators think about more than just productivity when deciding about automation. Environmental rules create both limits and incentives that push terminals toward new technology (Densberger & Bachkar, 2022).

The US doesn't have any federal rules specifically for automated terminals (United States Government Accountability Office, 2024), unlike countries like Singapore and Germany that handle port regulations more centrally (S. Zheng & Negenborn, 2014). This gap in regulations puts more responsibility on local authorities like the Harbor Commission, creating uncertainty about key issues such as cybersecurity standards and which stakeholder is liable when automated systems fail (de la Peña Zarzuelo, 2021). Terminal operators must work with different rules across different ports, which is why many push for more standardized regulations to simplify compliance.

Broader Economic and Competitive Context

Port automation decisions happen within a wider economic environment that affects how terminals invest their money. The San Pedro Bay ports are competing against other North American ports that have expanded and improved their efficiency (Nacht & Henry, 2021). This competition gets tougher as shipping companies merge into larger alliances that are more flexible in changing between ports based on efficiency, cost, and reliability (Hirata et al., 2022). Terminal operators point to this competition when arguing for automation,particularly as vessel sizes continue weto increase, creating amounts of inbound cargo which are larger than traditional operations can handle smoothly.

The economic case for automation goes beyond just improving daily operations. While the upfront investment is large, supporters argue that the long-term savings, especially from reduced labor costs, eventually make automation worthwhile. Automated terminals need fewer workers for regular operations, though they do create new positions in technology support and oversight (World Economic Forum, 2024). How quickly terminals recover their investment varies based on local labor costs, regulations, and how much cargo moves through the terminal.

3.4. Comparative Analysis

This section compares the stakeholder perspectives from the ports of Antwerp, Kaohsiung and Los Angeles to identify patterns and differences in how automation is approached across different regions. Despite operating in different regulatory environments and labor markets, these ports and its terminals face similar operational challenges and competitive pressures that influence their automation strategies. The analysis focuses on how regional factors shape stakeholder values and priorities, affecting both the implementation process and outcomes of automation initiatives.

3.4.1. Alignment of Values Across Terminals

The analysis of stakeholder perspectives across the ports of Antwerp, Kaohsiung, and Los Angeles reveals several consistent values that transcend geographic boundaries. Terminal operators across all regions prioritize efficiency and throughput, viewing automation as a strategic tool to enhance container handling capacity and reduce cycle times. This operational focus remains consistent whether in European, Asian, or North American contexts, reflecting the common need to process increasing container volumes with greater speed and reliability.

Safety emerges as another common prioritized value, though its interpretation varies by stakeholder position. Terminal operators associate safety improvements with reduced operational disruptions and potential legal liabilities. Labor organizations focus on worker protection and hazard reduction, while regulatory bodies focus on compliance with established safety standards. Automation potentially addresses these concerns by removing personnel from dangerous operational areas, this creates a value common stakeholder value despite different underlying motivations.

Competitive positioning is a third shared value, with each port responding to regional rivals. Antwerp competes primarily with Rotterdam and Hamburg within the European context, Kaohsiung contends with mainland Chinese ports and Singapore in the Asian shipping network, while Los Angeles faces competition from other North American ports such as Canadian and Mexican alternatives. Terminal operators consistently see automation as a competitive necessity rather than merely an operational preference, showing how the global maritime cargo system is interconnected, with efficiency at individual ports affecting the whole transportation network.

Cost-effectiveness is a fourth aligned value, though with variable implementation timelines. Terminal operators acknowledge the substantial upfront investment automation requires but justify this expense through predicted operational savings. The cost-benefit calculation attached to this follows similar patterns across regions, weighing initial capital expenses against ongoing labor cost reductions and efficiency improvements, though the break-even point varies significantly based on regional labor costs and regulatory requirements.

Environmental sustainability has gained increasing importance across all terminals, though regulatory pressure differs substantially. The electrification of equipment and improving efficiency associated with automation aligns with emissions reduction goals in each port, particularly in regions with strict air quality regulations like Southern California.

3.4.2. Regional Differences in Stakeholder Values

Despite these shared values, there are significant regional differences in how stakeholders prioritize and implement automation. Labor union and worker relations being the biggest difference across the three ports. In Los Angeles, the ILWU exercises large influence, positioning worker protection as a non-negotiable priority and using political connections to challenge automation projects. This differs significantly with Kaohsiung, where unions hold limited power and focus primarily on securing transitional benefits rather than opposing automation outright. Antwerp is in the middle position of the three ports, with strong unions that accept automation's inevitability but negotiate aggressively to protect worker interests.

The regulatory frameworks also vary substantially, creating different implementation environments. Los Angeles operates within a complex, multi-layered regulatory structure where local politics have a significant influence. Projects require approvals from several regulatory bodies including the Harbor Commission and California Coastal Commission, creating multiple intervention points for automation opponents. This contrasts with Kaohsiung's streamlined approval process, where TIPC functions as both port authority and commercial entity, enabling faster implementation decisions. Antwerp's European context creates a third model, with substantial regulatory oversight but clearer separation between commercial and governance functions.

In addition to this, the decision-making authority differs across regions. Kaohsiung's centralized governance structure, with TIPC operating under direct national government oversight, creates clear implementation pathways. Los Angeles has a decentralized governance structure where terminal operators, despite holding lease rights, have to navigate local political considerations and multiple regulatory bodies. Antwerp's model reflects a standard European governance structure, requiring extensive negotiation but with more predictable processes than the politically-driven American approach.

Economic contexts have a significant influence on automation calculations. Belgium's high labor costs lead to a higher economic motivation for automation than in Taiwan, where the cost advantage of replacing manual labor is relatively smaller. Los Angeles is a unique economic case where unionized dockworkers earn significantly more than comparable workers in other sectors, creating a strong financial motivation for automation despite the equally strong resistance.

3.5. Key Findings

The comparative analysis presents several key findings with important implications for understanding the impact of automation implementation across different terminal environments. While automated systems can achieve similar technical performance across regions, the path to implementing and realizing this value varies based on local conditions. Table 3.1 summarizes the key regional differences in implementation factors found in this chapter.

Table 3.1: Regional Comparison of Key Automation Implementation Factors

Factor	Antwerp	Kaohsiung	Los Angeles
Labor Relations	Strong unions but accept automation; negotiate for protection	Limited union power; focus on transitional benefits	Strong ILWU resistance; high-wage workforce
Regulatory Framework	Worker protection and retraining programs; predictable processes	Streamlined approval process; efficiency-focused	Complex multi-layered structure; extended timelines
Stakeholder Approach	Collaborative; slower but sustainable long-term results	Fast decision-making; may overlook worker concerns	Creates clear winners/losers; ongoing resistance
Environmental Goals	Moderate environmental requirements	Moderate environmental requirements	Strict environmental regulations; strong emissions focus
Value Proposition	Balanced implementation with established frameworks	Focus on efficiency and technical advancement	High potential benefits but significant implementation barriers

These findings directly address research sub-questions (c) and (d) regarding stakeholder identification and impacts. The analysis shows that automation's value shows in three interconnected value domains:

1. Operational Value: In addition to the quantifiable efficiency improvements, automation delivers consistency and predictability in performance, enabling better terminal planning.
2. Economic Value: While financial benefits are substantial, including possible labor cost reductions and significant energy savings, their realization depends heavily on regional contexts. High-wage markets like Northern Europe and North America potentially see faster ROI than regions with lower labor costs.
3. Strategic Value: The research demonstrates that the success of automation depends not just on technical capabilities but on understanding and adapting to regional contexts. Environmental sustainability emerged as a common value across regions.

Most importantly, this analysis reveals that for automation to be successfully implemented, it requires understanding not just the technology's capabilities but also the unique stakeholder landscape of each implementation environment. Terminal operators can use these insights to better understand their specific regional challenges before investing in new automation projects. Technology providers can better adapt their implementation approaches rather than applying one-size-fits-all solutions.

4 Risk Assessment

Building on the previous stakeholder analysis, this chapter provides a quantitative assessment of the risks associated with STS crane automation across different terminal environments. First, potential risks are identified and categorized into four main areas: economic and technical risks, labor risks, implementation risks, and cybersecurity risks. Then, these risks are quantified using a probability-impact matrix framework that evaluates both the likelihood of occurrence and potential consequences. Finally, the analysis examines how these risks affect value generation across different regional contexts, revealing why identical automation solutions can lead to different outcomes in different terminals.

4.1. Risk Identification

Based on the stakeholder analysis across different ports and operational contexts, three primary risk categories have emerged: Economic & Technical Risks, Labor Risks, Implementation Risks. In addition to this, Cyber-Security Risks also become more important when implementing automated solutions. Each category has specific challenges that vary in significance depending on regional factors, existing infrastructure, and stakeholder dynamics. This section provides an analysis of these risk categories to establish a foundation for subsequent quantification strategies.

4.1.1. Economic & Technical Risks

The economic and technical risks associated with STS crane automation include both the necessary investments and the technical challenges of implementing a complex automated system:

1. High Initial Investment
    - Automation projects require high initial investments, typically about USD 10 million per crane. This cost includes the automation software and sensors needed to upgrade existing cranes. Additional infrastructure costs can vary significantly, depending on the terminal's size, complexity, and pre-existing level of automation. However, in terminals that already have some level of automation, the additional costs might be considerably lower. These costs create significant barriers to entry, particularly for smaller terminals or those with limited access to capital (Drewry Maritime Research, 2022).
2. System Reliability and Performance
    - Automated systems have to maintain consistent performance across various operational conditions, including more challenging (e.g. rainy, windy) weather conditions and varying container types. Performance loss during more challenging conditions can reduce the possible benefits of automation. Technical limitations in sensors and control algorithms may impact the efficiency.

3. Integration Challenges
    - New automated systems must integrate well with existing terminal infrastructure, including Terminal Operating Systems (TOS), yard equipment, and gate operations. Incompatibilities between new and existing systems can create operational bottlenecks and reduce the overall terminal efficiency. Integration failures may lead to more disruptions across the terminal, which leads to longer cycle times.
4. ROI Uncertainty
    - According to Knatz et al. (2022) return on investment periods typically take longer than 6 years, creating financial uncertainty, especially in rapidly evolving market conditions. The actual ROI depends heavily on labor costs, operational efficiency gains, and market demand, which are all variables that fluctuate over time. Terminal operators must assess for each individual project whether the long-term operational savings through reduced labor costs, increased efficiency, and optimized resource allocation justify the high initial investments.

4.1.2. Labor Risks

Labor-related risks represent some of the most significant challenges in implementing automation, particularly in regions with strong union influences:

1. Workforce Reduction
    - Full automation typically reduces STS crane operator requirements by 65-80% compared to conventional terminals (Drewry Maritime Research, 2022). While this may lead to significant operational savings, it also introduces social and political challenges. The potentially disappearing or displacement of jobs creates resistance from both individual workers and organized labor. Especially in countries and cities where ports are the main employer.
2. Union Resistance
    - Labor unions may actively oppose automation through various means including political lobbying, legal challenges, industrial action, or public campaigns. In ports like Los Angeles, the ILWU has organized major protests and pursued multiple legal challenges to block automation projects (Schuler, 2019). The strength of union opposition varies per region, with North American ports generally facing stronger resistance than Asian ports.
3. Skills Gap
    - Automated terminals require workers with different skill sets than traditional operations, including a higher IT expertise, systems management, and more technical maintenance capabilities. Existing operator workforces may lack these specialized skills, creating operational challenges during the transition to automated systems. Terminal operators must decide whether to retrain existing workers or recruit new specialized staff.
4. Training Requirements
    - Comprehensive training programs are needed for both technical staff operating automated systems and for management adapting to new operational models. Training represents a significant cost and time investment during implementation. This knowledge transfer is necessary but difficult, especially when introducing entirely new operational concepts.
5. Cultural Adaptation
    - Moving from manual to automated operations may lead to cultural changes within organizations. This transition can be challenging, especially as employees accustomed to manual tasks face new technologies and altered workflows. Moreover, automation shifts tasks from hands-on to technology-driven, which can disrupt daily activities and affect how employees feel connected to their work.

4.1.3. Implementation Risks

The process of implementing automation introduces additional operational and regulatory challenges:

1. Regulatory Compliance
   - Automated operations have to comply with multiple regulatory frameworks which account for worker safety, environmental, labor, and cybersecurity domains. The regulatory influence varies between regions, with European ports typically facing more requirements than Asian counterparts. Additionally, in more complex regulatory environments like Los Angeles, projects may require approvals from multiple authorities including harbor commissions and environmental agencies.
2. Operational Disruption
   - The transition period between manual and automated operations presents significant disruption risks. Productivity may temporarily decrease during implementation, affecting terminal throughput and customer service. Careful planning is required to minimize disruptions and maintain service levels during transition phases.
3. Safety Standards
   - Automated equipment comes with new safety considerations that must be addressed through both technical solutions and operational procedures. Safety certification processes may be complex and time-consuming, particularly in regions without set frameworks which can be used for automated equipment. Ensuring human safety in semi-automated environments where personnel interacts with machines remains a particularly complex challenge.
4. Environmental Compliance
   - While automation can support environmental goals through electrification and efficiency improvements, the implementation has to meet existing environmental regulations. Environmental impact assessments may be required before approval of the implementation of automated solutions, particularly in environmentally sensitive port areas. Automation projects may need to demonstrate their contribution to emissions reduction goals.
5. Project Management
   - The complexity of automation projects creates several project management challenges. Implementation durations often extend beyond the initial projections, which increases the costs. Coordinating multiple technical systems, stakeholders, and regulatory requirements demands advanced project management capabilities.

4.1.4. Cybersecurity Risks

In addition to the three risk categories that followed from the stakeholder analysis, as terminal operations become increasingly digitized and automated, cybersecurity risks also turn into bigger concerns:

1. Vulnerability to Cyber Attacks
   - Automated systems create new entry points for hackers who want to disrupt operations or steal data. This can lead to operational shutdowns, safety issues, or unauthorized system access. Modern automated STS cranes depend on connected digital systems that can be vulnerable if not properly secured.
2. System Access Control and Authentication
   - Managing access rights to automated control systems presents significant security challenges. Appropriate authentication protocols must balance security requirements with operational efficiency. Unauthorized access to control systems could lead to operational disruptions or safety incidents.

3. Data Security and Protection
    - Operational data like vessel schedules, cargo details, and customer information needs strong protection. Data breaches could expose competitive information or break regulatory data rules. Automated systems constantly produce operational data that must be stored and transmitted securely.
4. Network Reliability and Infrastructure
    - Automated operations rely on strong communication networks that must work in all conditions. Network failures can immediately stop automated operations, causing expensive disruptions. Backup systems and failsafes are needed but make implementation more complex and costly.
5. Incident Response Capability
    - Terminals need specific plans to quickly identify and respond to cybersecurity incidents. These response plans must deal with both the technical problems and how operations are affected. This also results in the need for additional training for the staff to recognize and properly respond to possible security breaches.

These risk categories have a different impact depending on where the terminal is located. In Los Angeles, labor and implementation risks are the biggest concerns because of the strong ILWU union and complex regulations. In Kaohsiung, economic and cybersecurity risks take priority due to the competitive Asian market and their centralized governance. Antwerp takes a more balanced approach but focuses especially on following (cybersecurity) regulations and managing labor transitions, which reflects European priorities. Understanding these regional differences is key to creating effective risk management plans that work for specific terminal environments.

4.2. Risk Quantification

This quantification provides a structured framework to evaluate which risks demand immediate attention versus those that can be monitored with less urgency. This study employs a systematic approach to quantify the identified automation risks using a probability-impact matrix framework. The methodology combines:

- Probability Assessment: Evaluation of how likely each risk is to occur during implementation and operation of automated STS cranes.
- Impact Assessment: Measurement of the potential consequences a risk has.
- Total Risk Score: Calculation of overall risk scores by multiplying probability and impact ratings.

The following tables explain the rating scales used throughout this analysis. Table 4.1 presents the probability rating scale, which measures the likelihood of a risk occurring during implementation or operation phases of automation projects.

Table 4.1: Probability Rating Scale

Rating	Probability	Description
1	Very Low	Highly unlikely to occur (less than 10% chance)
2	Low	May occur occasionally (10-30% chance)
3	Medium	Likely to occur in some circumstances (30-50% chance)
4	High	Will probably occur in most circumstances (50-70% chance)
5	Very High	Almost certain to occur (greater than 70% chance)

Table 4.2 outlines the impact assessment scale, which measures the severity of consequences if a risk materializes. This scale considers effects on operations, project timelines, budgets, and overall terminal performance.

Table 4.2: Impact Rating Scale

Rating	Impact	Description
1	Negligible	Minimal effect on operations, schedule, or budget
2	Minor	Small effects that can be easily managed
3	Moderate	Significant effects requiring additional resources to manage
4	Major	Serious effects threatening project success or operational viability
5	Severe	Critical effects that could lead to project failure or major operational disruption

After setting up these structured rating scales for probability and impact assessment, each identified risk was evaluated within the specific context of the three focus terminals of this stakeholder analysis. By multiplying the probability (P) and impact (I) ratings, risks receive scores between 1-25, creating a clear order of which risks need immediate attention versus those that can be managed through regular monitoring processes. The risk scores were derived from the comprehensive stakeholder analysis findings presented in Chapter 3 and validated through discussions with industry experts who have expertise in the respective terminals. While the analysis relied primarily on existing research and literature due to the sensitive nature of customer relationships, the expert validation helped to ensure that the theoretical findings align with practical operational realities. This approach combined academic research with industry knowledge to provide a realistic assessment of implementation risks across different regional contexts.

The quantification tables below examines each risk from all four categories. For transparency, each risk assessment includes a justification explaining why specific probability and impact ratings were assigned. This approach draws conclusions directly from the insights gained through the stakeholder analysis and its supporting literature.

By analyzing risks within the specific terminal contexts, the research shows how regional factors directly influence risk probability and impact scores. The risk analysis is subdivided into the different terminals because a general risk quantification is hard to achieve due to the identified regional differences in operational environments. For example, labor risks score differently between terminals due to differences in union influence and workforce regulations and implementation risks reflect the differences in local governance structures and approval processes. These terminal-specific differences provide insights for automation implementation strategies, enabling stakeholders to develop targeted risk mitigation approaches based on their specific regional context.

4.2.1. Risks in Belgium, Antwerp

The Port of Antwerp's risk assessment reflects its operational context within the European port sector. Operating under EU regulations and Belgian labor laws, particularly the Major Act of 1972, Antwerp faces various challenges in automation implementation. The risk quantification includes factors that are specific for the region, including strong union presence, high labor costs, and strict European regulatory requirements, while considering Antwerp's competitive position against the terminals in Rotterdam and Hamburg in the European terminal network. Table 4.3 shows the results of the quantitative risk assessment together with justifications.

Table 4.3: Risk Quantification for Belgium, Antwerp

Risk	P	I	Score	Justification
Economic & Technical Risks				
High Initial Investment	2	4	8	While the substantial capital requirement (USD 10M per crane plus infrastructure (Drewry Maritime Research, 2022)) remains significant, Antwerp's strong financial position and existing infrastructure reduces its probability (P=2) . The port's ability to secure funding and spread investments over time makes the investment more manageable, but it still faces high competitive pressure from Rotterdam and Hamburg (I=4).
System Reliability and Performance	3	4	12	Given Antwerp's position as a leading European port, reliability challenges during challenging weather conditions and varying cargo types pose significant risks, but the advanced existing infrastructure moderates the probability (P=3). Performance issues could lower the port's competitiveness against nearby automated ports, particularly Rotterdam (I=4).
Integration Challenges	4	3	12	Antwerp's advanced infrastructure creates integration difficulties with existing systems (P=4). While integration might be challenging, the port's experience with technological advancement helps manage these issues due to existing implementation approaches and experience (I=3).
ROI Uncertainty	4	2	8	While Belgium's high labor costs strengthen the automation business case, strong union presence and extensive European regulatory requirements extend ROI periods (P=4). The impact of this uncertainty is limited as Antwerp can benchmark against comparable automation projects in Rotterdam and Hamburg (I=2).
Labor Risks				
Workforce Reduction	4	3	12	While automation reduces operator requirements by 65-80% (Drewry Maritime Research, 2022), Belgium's strict labor laws and the Major Act of 1972 prevent immediate layoffs (P=4). The impact on the workforce is moderated by existing retraining programs and implementation approaches required by law (I=3).
Union Resistance	5	4	20	Belgium's high union density (nearly half of private sector employees (Bottalico, 2022)) and strong labor protection initiatives lead to a certainty of significant union opposition (P=5). Union actions can significantly delay implementation and increase costs, though structured negotiations can help manage the impact (I=4).
Skills Gap	4	2	8	Antwerp will face a transition in workforce capabilities as automation requires new and more extensive technical skills in the terminals (P=4). However, Belgium's established technical education system and existing retraining programs help address this challenge (I=2).
Training Requirements	5	3	15	Comprehensive training programs are mandatory under Belgian labor regulations (P=5). While costly, these programs benefit from existing technical education infrastructure and union cooperation in workforce development (I=3).

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Table 4.3 continued from previous page

Risk	P	I	Score	Justification
Cultural Adaptation	3	2	6	The transition to automated operations creates organizational changes, though Antwerp's experience with technological advancements helps to manage this change (P=3). Strong labor frameworks and established change management programs help mitigate cultural resistance (I=2).
Implementation Risks				
Regulatory Compliance	5	4	20	European ports face strict regulatory requirements from the EU government, with Antwerp also having to face strict Belgian standards (P=5). Compliance with the regulatory framework demands significant resources and can cause long delays if not managed properly, especially given the complex stakeholder environment (I=4).
Operational Disruption	4	4	16	Transition periods inevitably disrupt operations, though Antwerp's experience with technological implementation helps manage this (P=3). The port's significant role in European logistics results in disruptions having a big impact on regional supply chains (I=4).
Safety Standards	5	3	15	European safety regulations are particularly strict, requiring extensive safety systems and protocols (P=5). While demanding, these requirements align with existing Belgian workplace safety frameworks and can be relatively easily implemented (I=3).
Environmental Compliance	4	3	12	EU environmental standards create substantial requirements (P=4). However, automation aligns with Antwerp's sustainability goals and existing environmental frameworks, making compliance manageable (I=3).
Project Management	4	4	16	The complex stakeholder environment and strict European regulations make project management challenging (P=4). Delays and cost buildups can have a significant impact on project viability, though existing project management frameworks help mitigate these risks (I=4).
Cybersecurity Risks				
Vulnerability to Cyber Attacks	3	5	15	While Antwerp faces advanced cyber threats targeting automated systems, EU cybersecurity regulations and existing advanced security systems reduce attack probability (P=3). A successful attack on automated cranes would have severe operational and safety impacts (I=5).
System Access Control and Authentication	2	4	8	EU's strict safety, access protocols and advanced authentication systems significantly reduce unauthorized access probability (P=2). Access breaches could cause significant operational disruptions and safety risks (I=4).
Data Security and Protection	3	3	9	Despite the EU's GDPR compliance, constant operational data generation creates ongoing security challenges (P=3). Breaches have a primary impact on the port's competitiveness and regulatory compliance rather than operations (I=3).
Network Reliability and Infrastructure	2	4	8	Belgium's advanced digital infrastructure reduces the likelihood of network failures (P=2). When they occur, failures do have a large impact on terminal operations and the supply chain efficiency in the European context (I=4).

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Table 4.3 continued from previous page

Risk	P	I	Score	Justification
Incident Response Capability	2	3	6	EU regulations and Antwerp's existing incident response procedures make poor responses unlikely (P=2). While incidents can disrupt operations, the port's existing IT infrastructure and security frameworks help manage their impact (I=3).

The risk assessment on the port of Antwerp shows the specific challenges of implementing automation in a European port environment. The highest risk scores appear in Union Resistance (20) and Regulatory Compliance (20), directly reflecting Belgium's strong union presence and the EU's strict regulatory framework. Three implementation risks, System Reliability (16), Operational Disruption (16), and Project Management (16), also score highly, showing that despite Antwerp's technological advancement, implementation of these complex technological solutions remains challenging.

Unlike the other assessed ports, Antwerp shows no maximum-level risks (score 25), suggesting a more manageable implementation environment where existing systems can address most challenges. The lower scores in Cultural Adaptation (6) and Skills Gap (8) result from Belgium's technical education system and existing retraining programs. While cybersecurity concerns exist, particularly Vulnerability to Cyber Attacks (15), EU cybersecurity regulations help reduce these probabilities compared to Asian and American ports. This results in a balanced risk profile where regulatory and union factors present the greatest challenges, but existing frameworks provide pathways to address them.

4.2.2. Risks in Taiwan, Kaohsiung

The Port of Kaohsiung's risk assessment reflects its specific operational context as Taiwan's primary container terminal and key Asian logistics hub. Operating under TIPC's centralized management and Taiwan's complex regulatory environment, Kaohsiung also faces automation implementation challenges. The risk quantification includes region-specific factors including Taiwan's bureaucratic approval processes, limited union pressure, established technological infrastructure, and competitive pressure from mainland Chinese ports, directly affecting probability and impact scores across all risk categories. Table 4.4 shows the results of the quantitative risk assessment together with justifications.

Table 4.4: Risk Quantification for Taiwan, Kaohsiung

Risk	P	I	Score	Justification
Economic & Technical Risks				
High Initial Investment	3	5	15	While initial investment remains substantial (I=5), TIPC's focus on port modernization and Taiwan's commitment to technological advancement reduce funding barriers (P=3). Government support for infrastructure development helps mitigate the financial challenges.
System Reliability and Performance	4	4	16	Taiwan's experience with advanced technology reduces some reliability risks, but tropical weather conditions and the port's high throughput demands place significant pressure on system performance (P=4). Performance issues can have a large impact on competitiveness against regional ports (I=4).
Integration Challenges	4	4	16	Complex integration with existing systems under TIPC's centralized management structure, combined with limited local system integration expertise, creates significant technical challenges (P=4). Integration failures could substantially disrupt port operations and regional supply chains (I=4).

Continued on next page

Table 4.4 (Continued)

Risk	P	I	Score	Justification
ROI Uncertainty	5	4	20	Regional competition and complex approval processes create high uncertainty in ROI calculations (P=5). Impact is significant but moderated by the long-term strategic importance of automation (I=4).
Labor Risks				
Workforce Reduction	4	3	12	Limited union influence and weaker employment protections make workforce reductions more likely (P=4). The impact is moderate due to focus on retraining programs and early retirement packages, in addition to existing demographic pressures (I=3).
Union Resistance	2	2	4	Limited union influence in Taiwan's port sector, combined with cultural respect for hierarchical structures, reduces likelihood of organized resistance (P=2). When present, impact remains limited due to traditional management-labor dynamics and the overall limited presence (I=2).
Skills Gap	5	4	20	The limited local technical expertise combined with aging workforce creates significant challenges (P=5). The impact is high, but moderated by government re-training programs (I=4).
Training Requirements	4	4	16	Extensive retraining needs, which is particularly challenging for the older workforce, require significant resources (P=4). The impact is high, even with the government retraining programs (I=4).
Cultural Adaptation	2	2	4	Cultural transition to automation is eased by Taiwan's technological focus and hierarchical business structure (P=2). The impact is limited due to the general acceptance of technological advancement and regulatory focus on modernization (I=2).
Implementation Risks				
Regulatory Compliance	2	2	4	A lack of regulatory oversight and focus on economic development over safety reduces regulatory barriers (P=2). The government prioritizes port competitiveness and economic benefits over strict regulatory enforcement (I=2).
Operational Disruption	4	5	20	Certain implementation risks can disrupt Kaohsiung's port operations (P=4). The impact can be severe due to the port's critical role in semiconductor and electronics supply chains (I=5).
Safety Standards	2	2	4	Unlike European ports, Taiwan's limited safety regulations require minimal additional safety systems and protocols (P=2). The basic safety requirements can be easily met within existing frameworks (I=2).
Environmental Compliance	4	3	12	The environmental concerns are significant due to Kaohsiung's urban proximity (P=4). However, the impact is moderated by TIPC's existing environmental initiatives (I=3).
Project Management	3	3	9	TIPC's centralized governance structure leads to streamlined decision-making processes (P=3). The impact of this risk is reduced by efficient implementation processes compared to European ports (I=3).
Cybersecurity Risks				

Continued on next page

Table 4.4 (Continued)

Risk	P	I	Score	Justification
Vulnerability to Cyber Attacks	5	5	25	Kaohsiung's important position in Taiwan's export-driven economy increases cyber threat probability (P=5). Successful attacks could severely impact national economic security (I=5).
System Access Control and Authentication	4	4	16	there is a high probability on authentication breach attempts due to Taiwan's geopolitical position and critical infrastructure status (P=4). Unauthorized access could significantly impact automated operations and have safety impacts (I=4).
Data Security and Protection	5	4	20	The role of Kaohsiung in Taiwan's semiconductor exports and regional geopolitical tensions create constant data security risks (P=5). Breaches could compromise competitive position and sensitive trade information (I=4).
Network Reliability and Infrastructure	4	4	16	Kaohsiung's less developed infrastructure and maintenance standards increase the likelihood of network failures (P=4). Failures can have a significant impact automated operations and regional supply chains (I=4).
Incident Response Capability	4	4	16	The limited availability of local technical expertise and less developed response protocols increases incident response challenges (P=4). A poor incident response could disrupt export operations and regional supply chains (I=4).

The risk assessment for the port of Kaohsiung shows Taiwan's position as a key Asian logistics hub with different implementation challenges than Western ports. The most severe risk is Vulnerability to Cyber Attacks (25), highlighting Kaohsiung's critical role in Taiwan's export economy and regional geopolitical tensions. This cybersecurity focus continues with Data Security (20) also scoring highly, partly due to geopolitical tensions. Other major concerns include Skills Gap (20), ROI Uncertainty (20), and Operational Disruption (20), showing how Taiwan's competitive environment and technical workforce limitations lead to implementation barriers.

What stands out in Kaohsiung's profile is the minimal union resistance (4) and regulatory compliance difficulties (4), due to the overall regulatory focus on economic welfare and the lack of union representatives. This creates a different implementation environment than European or American ports. Cultural Adaptation (4) and Safety Standards (4) also score very low, reflecting Taiwan's technological focus and limited safety regulations. This creates a risk profile where cybersecurity and operational concerns dominate, while the social and regulatory factors that complicate Western automation projects are much less significant. The primary challenges come from technical and workforce limitations, competitive pressures from mainland Chinese ports and geopolitical tension.

4.2.3. Risks in the USA, Los Angeles

The Port of Los Angeles's risk assessment reflects its operational context as America's largest container port and important gateway for US-Asian trade. The port operates under local governance through the Harbor Department and faces various challenges in automation implementation. The risk quantification incorporates the powerful union representation (ILWU) with its political connections, the complex regulatory environment involving the Harbor Commission, Coastal Commission and CARB oversight, and the competitive pressure from Canadian and Mexican ports. Unlike Asian ports, LA's automation efforts face substantial union opposition, long approval processes, and high compensation requirements.

Table 4.5: Risk Quantification for the USA, Los Angeles

Risk	P	I	Score	Justification
Economic & Technical Risks				
High Initial Investment	4	5	20	The existing high initial investment requirements are increased by ILWU-negotiated compensation packages and environmental compliance needs (I=5). Despite the long-term lease advantages (25-40 years), terminal operators remain hesitant to commit fully to automation due to uncertain labor climate and costly job preservation agreements (P=4).
System Reliability and Performance	3	4	12	The advanced US technical infrastructure reduces reliability risks (P=3). However, performance issues would significantly have an impact on LA's role the in US-Asian trade and competitive position against Canadian and Mexican alternatives (I=4).
Integration Challenges	4	4	16	Implementing automation while adhering to ILWU contract requirements for job preservation in addition to jurisdiction over maintenance tasks creates significant integration complexities (P=4). Integration failures would disrupt critical supply chains through LA's port (I=4).
ROI Uncertainty	5	4	20	High dockworker wages ($100,000+) and compensation packages, in combination with long multi-agency approval processes, create uncertainty (P=5). However, the impact is moderated by the 25-40 year lease terms allowing for an extended payback period (I=4).
Labor Risks				
Workforce Reduction	5	5	25	Strong ILWU opposition and extensive contractual worker protection agreements make workforce reductions highly challenging (P=5). Union demonstrations, legal challenges, and political interventions create severe implementation impacts (I=5).
Union Resistance	5	5	25	The powerful ILWU with connections from local officials to federal representatives actively opposes automation through protests and legal challenges (P=5). As seen with APM Terminals' Pier 400 project, union actions severely disrupt the implementation of automation (I=5).
Skills Gap	3	3	9	Union-negotiated retraining programs and reservation of automated equipment maintenance jobs for union members helps address this gap (P=3). Also the impact is moderated by contractually required training initiatives (I=3).
Training Requirements	4	3	12	There are comprehensive retraining needs for both technical staff and management to adapting to the new operational models which require significant resources and time investment (P=4). The overall impact is moderated by existing union-negotiated training infrastructure and port authority workforce development initiatives (I=3).
Cultural Adaptation	4	4	16	There is a strong traditional dockworker culture with high wages ($100,000+) which resists transition to automated operations (P=4). Cultural conflicts can have a significant impact on implementation timelines and the overall operational transition (I=4).
Implementation Risks				

Continued on next page

Table 4.5 (Continued)

Risk	P	I	Score	Justification
Regulatory Compliance	5	4	20	The complex multi-agency oversight (Harbor Commission, City Council, Coastal Commission, CARB) comes with significant compliance challenges (P=5). The multiple approval requirements associated with this multi-agency oversight extend implementation timelines (I=4).
Operational Disruption	4	5	20	ILWU protests and legal challenges during the implementation of automation threaten operational continuity (P=4). Disruptions can severely impact the US-Asian trade flows through America's largest container port (I=5).
Safety Standards	4	3	12	The strong US safety regulations require various compliance measures (P=4). However, the established safety frameworks and oversight moderate the impact on implementation (I=3).
Environmental Compliance	5	4	20	The strict CARB requirements and Clean Air Action Plan create significant environmental compliance challenges for automation projects (P=5). The coastal Commission environmental review processes therefore have a significant impact on implementation timelines (I=4).
Project Management	5	5	25	The complex stakeholder environment with powerful union, political influences, and multiple regulatory agencies creates various management challenges (P=5). The labor negotiations and community impact requirements are likely to extend project timelines (I=5).
Cybersecurity Risks				
Vulnerability to Cyber Attacks	4	5	20	The port of Los Angeles is America's largest container port handling the US-Asian trade flows and represents a high-value target, while the lack of federal cybersecurity regulations for automated terminals creates security gaps (P=4). Successful attacks could severely impact national supply chains (I=5).
System Access Control and Authentication	3	4	16	Regulatory gaps in federal cybersecurity standards for automated terminals increase security challenges in comparison to Antwerp (P=3). Unauthorized access could significantly disrupt the supply chain operations (I=4).
Data Security and Protection	4	4	16	The high-value trade data needs significant security requirements (P=4). Data breaches could have severe commercial and security implications for US-Asian trade (I=4).
Network Reliability and Infrastructure	3	4	12	The advanced US infrastructure reduces the likelihood of network failures (P=3). When occurring, failures can significantly impact operations and the corresponding supply chains (I=4).
Incident Response Capability	3	4	12	The strong technical expertise and existing incident response protocols reduce probability (P=3). Response failures could significantly impact the US-Asian trade flows (I=4).

The Los Angeles risk assessment reveals the highly challenging implementation environment of America's largest container port, with three risks reaching the maximum score of 25: Workforce Reduction, Union Resistance, and Project Management. This reflects the powerful ILWU's opposition to automation through protests and legal challenges, as seen at APM's Pier 400. The high-scoring regulatory risks (Regulatory Compliance at 20, Environmental Compliance at 20) result from multiple oversight regulatory bodies including the Harbor Commission, Coastal Commission, and CARB, which create complex approval processes.

Unlike Antwerp or Kaohsiung, Los Angeles shows a pattern of maximum risks in labor-related categories, reflecting the unique American context where dockworkers have a high pay-rate and unions maintain strong political connections from local to federal levels. The high-scoring cybersecurity risks (Vulnerability to Cyber Attacks at 20, Data Security at 20) come from both America's critical infrastructure concerns and the regulatory gaps in overall federal cybersecurity standards. This creates an risk profile where labor opposition, regulatory complexity, and project management challenges present large barriers to automation.

4.2.4. Comparative analysis

This section combines the individual risk assessments to show how automation risks differ between the three port locations. By comparing Antwerp, Kaohsiung, and Los Angeles directly, clear patterns can be identified about how regional factors influence the likelihood and impact of various risks. Table 4.6 shows all risk scores side by side, with explanations of why these differences occur. This comparison shows that the implementation of automation isn't a "one-size-fits-all" project. These differences explain why automation approaches that succeed in one region may fail in another, and why implementation strategies must be tailored to local conditions.

Table 4.6: Comparative Risk Assessment Across Terminals

Risk	**Antwerp**	**Kaohsiung**	**Los Angeles**	**Key Regional Differences**
Economic & Technical Risks				
High Initial Investment	12	15	20	LA faces the highest score due to high union-negotiated compensation packages. Kaohsiung benefits from government modernization support. Antwerp's existing automation frameworks reduce the overall impact despite the high costs.
System Reliability and Performance	12	16	12	LA and Antwerp benefits from advanced infrastructure. Kaohsiung faces higher reliability challenges.
Integration Challenges	12	16	16	Antwerp's experience with semi-automation reduces the implementation impact compared to other regions. LA faces unique integration challenges from union work rules. Kaohsiung lacks the local system integration expertise.
ROI Uncertainty	8	20	20	Antwerp shows a significantly lower score due to established automation implementation frameworks. LA and Kaohsiung face high uncertainty from regional competition and approval processes.
Labor Risks				
Workforce Reduction	12	12	25	LA faces substantially higher risk due to powerful ILWU opposition. Despite Antwerp's strong unions, existing retraining frameworks reduce the overall impact.
Union Resistance	20	4	25	There is a strong contrast between Asian and Western ports. Minimal union resistance in Kaohsiung versus strong opposition in LA and substantial resistance in Antwerp.
Skills Gap	8	20	9	Kaohsiung faces the highest risk due to limited technical expertise and their aging workforce. Antwerp benefits from existing education systems. LA's union-negotiated programs help.

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Table 4.6 (Continued)

Risk	Antwerp	Kaohsiung	Los Angeles	Key Regional Differences
Training Requirements	15	16	12	European mandatory training requirements increase Antwerp's score. Kaohsiung's older workforce creates the highest challenges. LA benefits from established union training structures.
Cultural Adaptation	6	4	16	LA's traditional dockworker culture creates highest resistance. Taiwan's technological focus and European retraining programs reduce the scores in the other regions.
Implementation Risks				
Regulatory Compliance	20	4	20	Antwerp and LA ports face strict regulatory requirements with similar high scores. Kaohsiung benefits from limited regulatory oversight and economic development focus.
Operational Disruption	16	20	20	LA and Kaohsiung face higher disruption risks due to ILWU actions and their supply chain roles. Antwerp's experience with implementation reduces the risk slightly.
Safety Standards	15	4	12	European safety regulations create the highest score for Antwerp. Asian ports have minimal safety requirements. US standards are significant but less demanding than EU regulations.
Environmental Compliance	12	12	20	LA faces the strictest environmental requirements through multiple regulatory bodies such as the CARB and Coastal Commission. Antwerp and Kaohsiung have similar moderate environmental requirements.
Project Management	16	9	25	LA faces the maximum complexity due to union negotiations and multiple regulatory bodies that need to hand out approvals. Kaohsiung benefits from the centralized governance through TIPC.
Cybersecurity Risks				
Vulnerability to Cyber Attacks	15	25	20	Kaohsiung faces highest risk due to geopolitical tension. LA lacks federal cybersecurity standards. The EU regulations reduce Antwerp's score.
System Access Control	8	16	12	EU's strict safety protocols significantly reduce Antwerp's risk. America faces federal gaps in their cybersecurity regulations, although cybersecurity is overall deemed important in the US. Taiwan faces a higher vulnerability without such regulations or technological advancements.
Data Security and Protection	9	20	16	Kaohsiung's role in semiconductor trade and LA's position in US-Asian trade create higher risks. EU's GDPR provides Antwerp better protection.

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Table 4.6 (Continued)

Risk	Antwerp	Kaohsiung	Los Angeles	Key Regional Differences
Network Reliability	8	16	12	Kaohsiung's less developed infrastructure creates highest risk. Antwerp and LA benefit from more advanced technical infrastructure but LA's scale increases impact.
Incident Response Capability	6	16	12	Limited local expertise in Kaohsiung creates highest risk. EU regulations provide Antwerp strongest protection. LA falls between with established protocols but higher stakes.

4.3. Impact of Risks on Value Generation

This section examines how the identified risk categories affect the overall value proposition of STS crane automation across different terminal contexts. The regional variations in risk profiles help to explain why identical automation solutions have different outcomes in Antwerp, Kaohsiung, and Los Angeles.

Economic & Technical Risk Impacts

The economic and technical risk profiles across regions directly influence automation's financial returns. LA terminals face a challenging implementation landscape where high initial investments are further increased by costly union agreements and compensation packages. This explains why automation projects with a clear ROI in Asia might struggle economically in North America despite having the same technical capabilities.

Antwerp's lower ROI uncertainty compared to Kaohsiung and LA shows the advantage of regional knowledge from other semi-automated projects. Being able to compare with Rotterdam's semi-automated terminals gives Antwerp operators more reliable financial projections. This advantage explains why European terminals often adopt automation more steadily in comparison to the US despite also having strong unions.

The technical risks also show why operational improvements vary across regions. While all terminals face integration challenges, the specific regional contexts create different implementation barriers. LA terminals must design systems that work with union jurisdiction, while Kaohsiung lacks local technical expertise. These region-specific challenges explain performance differences for identical systems.

Labor Risk Impacts

Labor risks create the biggest regional variations in automation value. The difference between Asian and Western ports in union resistance explains a large portion of the expected differences in automation adoption rates. In Los Angeles, where labor risks reach maximum scores, the potential benefits of automation can be significantly reduced by implementation delays and job preservation requirements.

The difference in cultural adaptation scores between LA (16) versus Antwerp (6) and Kaohsiung (4) further explains performance differences. Even with identical systems, the workforce's willingness to adapt to new operational models affects how quickly improvements happen. This helps explain why the implementation of semi-automation often works better in Asian or European contexts despite using the same technology.

The skills gap and training requirement scores also impact both implementation timelines and long-term operations. Kaohsiung's limited technical expertise creates challenges that European terminals with good technical education systems can better address. These workforce differences explain inconsistent operational results with identical systems.

Implementation Risk Impacts

Implementation risks affect when and how the value of automation is realized. The regulatory difference between Kaohsiung (4) and both LA/Antwerp (20) explains variations in implementation speed and cost. Asian terminals can often implement automation with minimal regulatory barriers, while North American and European terminals face lengthy approval processes that delay benefits.

Project management complexity directly impacts implementation efficiency. Kaohsiung's centralized governance enables faster decision-making compared to LA's multi-stakeholder environment. This explains why identical automation projects progress at different rates across regions, affecting when benefits begin to appear.

Environmental compliance requirements also shape implementation. LA's strict environmental standards increase initial costs but may deliver longer-term advantages as shipping lines prioritize sustainability. This shows how regulatory risks can create both barriers and opportunities depending on regional context.

Cybersecurity Risk Impacts

Automation introduces more cybersecurity risks in comparison to manual operations that vary across regions, potentially reducing operational gains with new security requirements. Kaohsiung's higher cybersecurity risk scores reflect how geopolitical tension leads to higher threat levels. These security considerations introduce region-specific costs that affect the total value of automation.

The differences in incident response capability scores shows how regions differ in their ability to manage new cybersecurity challenges. In regions with limited technical expertise or regulatory frameworks, the cybersecurity risks may reduce the value of automation compared to regions with robust digital protection frameworks.

This analysis shows that the value of automation isn't just about the technology itself but comes from how that technology interacts with specific regional environments. This explains why identical automation systems produce different outcomes across terminals, and why implementation strategies have to adjust to region-specific risk profiles.

4.4. Key Findings

This risk assessment shows clear differences in how regional factors shape STS crane automation implementation risks across the three ports studied. While the comparison of the individual risk factors can be found in Table 4.6, the spider diagram (Figure 4.1) shows the mean risk scores across the four key categories, demonstrating how risk profiles vary between terminals.

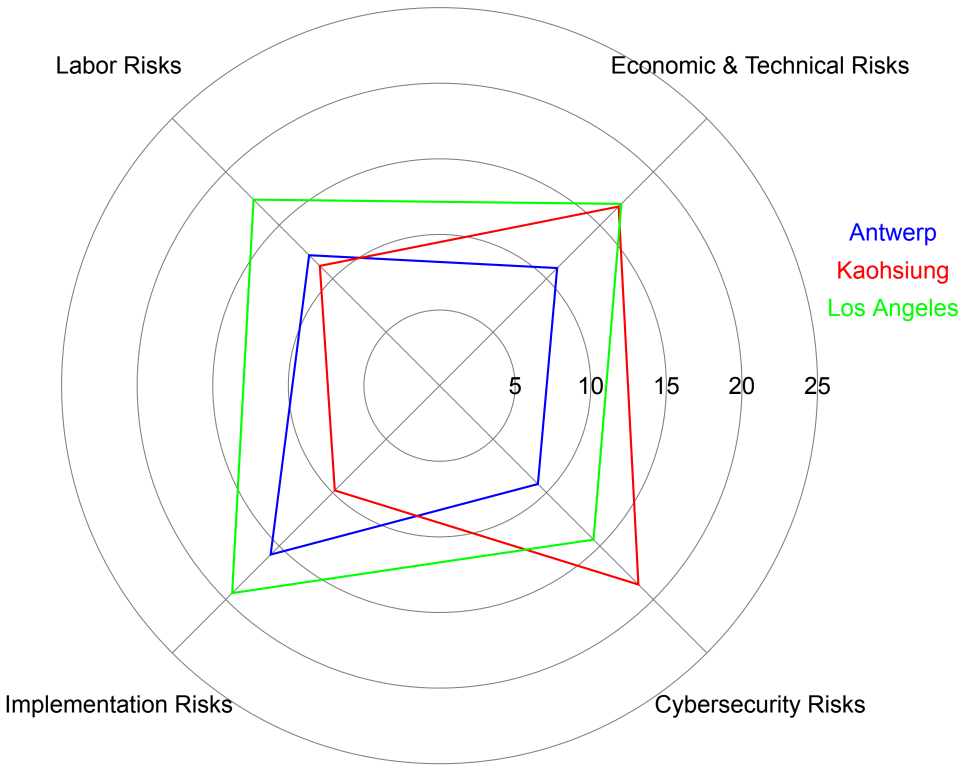

Figure 4.1: Regional Risk Profile Comparison (Mean Risk Scores)

Los Angeles shows consistently high risk scores across all categories, with particularly high scores in labor risks (17.4) and implementation risks (19.4). This presents the complex stakeholder environment where strong union presence and multi-agency oversight create considerable implementation barriers. The high economic and technical risk score (17.0) further shows how labor-related costs and regulatory requirements increase the challenges of automation investments.

Kaohsiung presents a different profile, with cybersecurity risks (18.6) and economic & technical risks (16.75) as primary concerns. The relatively low labor (11.2) and implementation risks (9.8) highlight how centralized governance and limited union influence create a different set of challenges, focused more on technical expertise gaps and security vulnerabilities due to regional geopolitical tensions.

Antwerp shows the most balanced risk profile, with no category exceeding a mean score of 16. The highest risks appear in implementation (15.8), reflecting the structured but demanding European regulatory environment. This balanced distribution suggests that while Antwerp faces significant challenges, its established frameworks and stakeholder relationships create more predictable implementation pathways.

These findings directly address research sub-question (e): ”What are the key risks and challenges that could affect value generation when implementing STS crane automation across different regional contexts?” The research shows that risk profiles vary heavily across regions, significantly affecting both implementation approaches and value generation from automation. While the technology itself may be consistent, its implementation risks are changed by regional factors including labor relations, regulatory frameworks, technical expertise, and geopolitical considerations. This explains why identical automation solutions lead to different implementation outcomes across terminals, and why implementation strategies must adapt to region-specific risk profiles to maximize the value generation.

5 Discussion

This chapter examines the research findings, discussing their limitations and practical implications. First, the research approach is analyzed, highlighting how the methodology of this study, which combines operational data, simulation modeling and a stakeholder and risk analysis, contributed new insights about automation value creation and regional variations in automation outcomes. The chapter then examines the limitations of both the cycle time modeling and stakeholder and risk analysis to provide a realistic assessment of the study's boundaries and implications for future research.

5.1. Research Approach and Key Insights

This public version of the research consists out of a qualitative stakeholder assessments across three ports in different geographical and operational environments, providing insights that challenge common assumptions about automation implementation.

The stakeholder analysis demonstrated that the pace of automation adoption depends more heavily on labor relations than on technological readiness or port size. This finding showed clearly in the case of Los Angeles, where despite similar container volumes to Kaohsiung and greater financial resources than Antwerp, automation implementation progressed more slowly due to workforce and union resistance rather than technical limitations. This insight highlights the importance of understanding both technical and social factors in automation implementation.

The research makes several new contributions to existing literature on port automation. While existing studies often focus on either technical performance metrics like quay crane scheduling (Chen et al., 2020) or individual terminals (Chang & Tai, 2021), this research demonstrates how identical automation solutions lead to different implementation outcomes across different terminals due to regional variations in stakeholder dynamics and regulatory frameworks. The analysis reveals certain regional patterns in value creation: North American implementations face primarily social rather than technical challenges, Asian terminals struggle more with technical expertise gaps than stakeholder resistance, and European success depends on balancing the established regulatory requirements with multiple stakeholder negotiations

The retrieved insights are broader than the traditional technical assessments of automation performance. The research shows that while automated systems can achieve similar technical performance across regions, the path to realizing this value varies based on local conditions. This understanding helps explain why seemingly identical automation solutions produce different outcomes across terminals and presents the need for regionally adapted implementation strategies .

The comparison between different terminals also revealed how regulatory frameworks influence not just what the challenges are in the implementation of automation but also who gains advantages from its implementation. Antwerp's regulatory environment ensures workers benefit from automation through retraining programs and employment protection measures, while Kaohsiung's approach prioritizes operational efficiency gains and cost reductions. Los Angeles shows how a complex regulatory framework leads to extended project timelines and implementation uncertainty, even when the economic case for automation is strong.

5.2. Limitations

The stakeholder analysis, while providing valuable insights into regional variations and implementation challenges, faces several methodological constraints that need discussion.

A significant limitation stems from the data collection approach. The analysis relies primarily on existing research, rather than direct engagement with terminal stakeholders. This indirect approach was necessary due to the sensitive nature of customer relationships, but it potentially limits the depth of stakeholder perspectives.

The regional comparison framework also presents limitations. While the analysis examines three distinct contexts, Antwerp, Kaohsiung, and Los Angeles, each terminal operates within unique regulatory, economic, and cultural environments. The findings show that identical automation solutions lead to different outcomes across these terminals, but the reliance on secondary sources may not fully capture the nuances of these regional variations.

Furthermore, the stakeholder landscape is continuously evolving. The analysis describes the current situation of stakeholder values and concerns, but the dynamic nature of port operations, changing labor relations, and advancing technology means that stakeholder positions and priorities may shift strongly over time. An independent study with direct stakeholder engagement before implementing a new solution would provide more comprehensive insights and lead to more accurate implementation strategies. However, this was beyond the scope of this research.

6 Conclusion & Recommendation

This chapter presents the main conclusions drawn from the research into STS crane automation value generation and provides recommendations for future development. Following the research findings, managerial and societal relevance and recommendations, a personal reflection discusses the learning journey through both the thesis project and MOT program, highlighting how the combination of technical engineering knowledge and management perspectives contributed to a comprehensive understanding of automation value creation.

6.1. Conclusion

This research investigated the value generation of automating waterside operations of Ship-to-Shore (STS) cranes compared to manual processes, examining both operational performance and stakeholder values. Through analysis of operational data, stakeholder perspectives, and regional implementation challenges, the research has revealed how automation creates value across multiple dimensions while highlighting the importance of regional context in determining implementation success.

The main research question *"What are the values generated by automating waterside operations of Ship-to-Shore (STS) cranes, when evaluated from a stakeholder perspective?"* was addressed through a systematic analysis of four sub-questions which can be found in Section 1.1.

Beyond speed improvements, which are thoroughly analyzed in the confidential version of this thesis, automation provided more consistent and predictable performance measures, enabling better terminal planning and resource allocation. Labor costs can be reduced by approximately 60% through the reduction of manual operators, while maintenance requirements showed a possible 15% decrease due to more consistent equipment operation and reduced wear from human error. These improvements in both operational efficiency and costs contribute to an enhanced overall terminal performance.

The stakeholder analysis revealed six key groups affected by automation: terminal operators, labor organizations, shipping companies, port authorities, regulatory bodies, and technology providers. While terminal operators universally prioritize efficiency improvements, labor organizations focus on job security and working conditions. Regulatory bodies focus on establishing safety standards and compliance requirements for automated systems, while ensuring adherence to environmental regulations and worker protection laws. This leads to tensions between cost reduction goals, workforce security concerns, and regulatory compliance which occur differently across regions.

The research revealed significant regional variations in implementation challenges and value generation. Governance structures play a crucial role: Kaohsiung's centralized governance under TIPC created clear implementation pathways, while Los Angeles's decentralized structure required navigation of multiple regulatory bodies and political considerations. Antwerp's European model offered predictable processes despite requiring extensive negotiation.

Risk profiles varied substantially across regions. Los Angeles faces maximum risks in labor-related categories, with high scores in labor resistance and workforce reduction, reflecting the American context of high-wage dockworkers and strong union influence. Kaohsiung faces different challenges, primarily in cybersecurity vulnerabilities and skills gaps, while Antwerp needed to balance union concerns with its existing technical infrastructure.

Different approaches to stakeholder management leads to varying results. Kaohsiung's efficiency-focused approach enables faster decision-making processes but potentially overlooks worker concerns. Los Angeles's environment creates clear winners and losers, generating ongoing resistance from labor unions and the workforce. Antwerp's stakeholder approach, while slower, produces more sustainable long-term results by addressing stakeholder concerns before implementation.

These findings lead to the answer to the main research question. The value generated by STS crane automation shows in three interconnected value domains:

1. Operational Value: Beyond the quantifiable efficiency improvements, automation delivers consistency and predictability in performance, enabling better terminal planning.
2. Economic Value: While financial benefits are substantial, including possible labor cost reductions and significant energy savings, their realization depends heavily on regional contexts. High-wage markets like Northern Europe and North America potentially see faster ROI than regions with lower labor costs.
3. Strategic Value: The research demonstrates that the success of automation depends not just on technical capabilities but on understanding and adapting to regional contexts. Environmental sustainability emerged as a common value across regions, while competitive positioning through automation adoption proved necessary for maintaining market advantage.

6.2. Managerial and Societal Relevance

This research makes several contributions to both management practice and society at large. While existing studies have typically focused on either technical performance metrics or individual terminals, this research provides three novel contributions:

First, it bridges an important knowledge gap in the management practice by demonstrating why identical automation solutions lead to different implementation outcomes across regions. Unlike previous studies which often focused on the technical aspects, this research reveals how regional variations in stakeholder dynamics and regulatory frameworks have a large effect on the success of automation. This new understanding enables terminal operators and technology providers to move from one-size-fits-all solutions toward regionally adapted implementation strategies.

Second, the research introduces a comprehensive framework for understanding automation value creation that goes beyond traditional technical assessments. By adding stakeholder perspectives and values into the evaluation framework, it creates a more holistic assessment of automation's impact. This approach helps management better understand the interaction between technical capabilities and regional contexts.

Third, the research provides insights into how regional contexts shape the success of major technological transitions. By revealing how North American implementations face primarily social challenges, Asian terminals struggle with technical expertise gaps, and European success depends on balancing regulatory requirements, it provides useful insights for policymakers and stakeholders involved in managing technological change. This understanding helps ensure that automation benefits can be realized while addressing societal concerns about workforce development and environmental sustainability.

6.3. Recommendation

Based on the limitations identified in Section 5, future research, for the public part of this thesis, should focus on addressing one key area; Further stakeholder research with interviews including the stakeholders themselves is necessary to obtain a deeper understanding of the impact of automation. The current analysis relied primarily on existing research and secondary sources due to the sensitive nature of customer relationships. An independent study with direct stakeholder engagement would provide more comprehensive insights into how automation affects different groups across various regional contexts.

6.4. Reflection

As a mechanical engineer pursuing an MSc in Management of Technology, this research project represented a perfect combination of my technical foundation and newly acquired management perspectives. During prior technical work I performed in this industry, I focused primarily on the operational aspects of cranes and control behavior, but this research allowed me to expand my understanding to include the broader implications of automation implementation.

The combination of a technical analysis (confidential part) and stakeholder assessment particularly connected with my educational journey. While my mechanical engineering background provided the foundation for understanding the operational and technical aspects of crane automation, the MOT program equipped me with the tools to analyze the management and implementation challenges. This research project demonstrated how important this combination is, because technical solutions alone don't guarantee successful implementation. I learned that understanding regional contexts, stakeholder dynamics, and implementation risks is equally important.

Working with both academic supervisors and industry experts helped me develop a more comprehensive perspective on automation projects. The research revealed that while technical performance might be consistent across different terminals, the path to realizing automation's value varies based on local conditions. This insight has changed how I view technology implementation, it's not just about the technical solution, but about understanding and adapting to regional contexts and the corresponding stakeholders.

This project, and the MOT master in general, helped my professional development by preparing me for future roles where technical innovation meets complex management challenges. The MOT program's emphasis on combining technical knowledge with management perspectives has proven invaluable, particularly in understanding how identical technical solutions can lead to different outcomes when stakeholder dynamics and regional contexts are considered. This understanding of how to navigate both technical and social aspects of innovation, while balancing multiple stakeholder interests from labor unions and regulatory bodies to terminal operators and technology providers, has provided me with a comprehensive foundation for future technology management roles.

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