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Enhancing Container Terminal Performance through Lean Six Sigma: A Case study from a Moroccan Mediterranean Port

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Abstract

This case study explores the application of Lean Six Sigma (LSS) as a structured framework for diagnosing operational inefficiencies and designing performance improvement initiatives in container-handling operations at a Moroccan Mediterranean port. The research adopts a pragmatic abductive single case design based on the DMAIC framework and draws on evidence from all 54 consecutive calls of container vessels recorded during 2023 and 2024, complemented by operational documents, direct observations, and Kaizen workshops involving key port operators and managers. Data analysis was conducted using Microsoft Excel and Minitab. The findings indicate that only 31.48% of vessel calls met the target productivity, defined as a range of 14 to 18 containers per hour, in accordance with the port's operational performance standards. This suggests that the process exhibited substantial variability and was incapable of consistently meeting the performance targets, as evidenced by the very low Cp (0.13) and Cpk (−0.01) values, indicating inadequate process capability and poor process centering relative to the specified performance limits. While five main stoppage categories accounted for nearly 80% of total downtime. The analysis phase of the DMAIC framework further revealed that equipment reliability, inter-organizational coordination, and deficiencies in operational control and organizational learning constituted the principal mechanisms explaining performance variability. The Define, Measure, and Analyze phases were fully completed, whereas the Improve and Control phases were partially completed; instead, the study culminated in the development and participants validation of an action and monitoring plan for future implementation and performance monitoring. These findings provide both theoretical and managerial contributions by showing that sustainable performance improvement in container terminals requires integrating Lean Six Sigma tools with effective coordination among multiple organizational actors, while offering a transferable framework that can support improvement initiatives in comparable port environments.

Keywords: Lean Six Sigma; DMAIC; container terminal; Moroccan port; operational performance
JEL Classification: M11; L91; R41
Paper type: Case study

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1. Introduction

Maritime transport plays a crucial role in the development of global supply chains, with nearly 80% of goods transported by sea (UNCTAD, 2024). Containerization has been a major innovation in this sector, promoting international trade through the standardization of container dimensions. This revolution has reduced logistics costs and transit times, while facilitating the handling and intermodal transport of goods (Notteboom & Rodrigue, 2008).

Chinese ports topped the world rankings for TEU volume handled in 2024, with Shanghai and Singapore leading the pack. Moroccan ports also stand out, with Tangier Med ranking 17th globally with over 10 million TEUs and 5th in terms of efficiency (Word Bank Group & S&P Global Market Intelligence, 2025). At the national level, containers account for 56.4% of total port traffic, confirming the predominance of containerization (Ministère de l'équipement et de l'eau, 2024). During the same year, Morocco ranked as the second African country and third Arab country according to the Regular Maritime Transport Connectivity Index developed by UNCTAD and MDS Transmodal (Ministère de l'Equipement et de l'Eau, 2024). This achievement reveals the country's potential to become a major logistics hub in the Mediterranean Sea and the Atlantic Ocean. However, maintaining and improving this strategic position depends strongly on the quality of port services, an essential element for strengthening national attractiveness and competitiveness. In this context, the National Ports Agency (Agence National des Ports, ANP) recently initiated an overhaul of its management system, signaling a clear commitment to modernization (Raqui, 2025).

In this context, Total Quality Management (TQM) and, more specifically, the Lean Six Sigma (LSS) approach are relevant tools for the continuous improvement of port operations (Patil et al., 2025; Pillet, 2013). LSS combines two philosophies: Lean Management, which originated from the Toyota Production System (1960s), aims to eliminate the seven wastes (MUDA) (transportation, inventory, motion, waiting, overproduction, overprocessing, defects, as well as unused skills (Gijo et al., 2019)) while promoting teamwork, customer satisfaction (Pereira et al., 2019) and economic performance with respect for the environment (Molina-Azorín et al., 2009); whereas Six Sigma, developed by Motorola in 1987, uses statistical tools to reduce variability and production errors (Praharsi et al., 2021; Singh & Rathi, 2018), with the goal of not exceeding 3.4 defects per million opportunities (Volck, 2011) and striving for zero defects to meet customer needs (Pyzdek, 2001).

This methodology has proven effective in manufacturing and service companies (Raja Sreedharan & Raju, 2016). In the healthcare sector, it has improved service quality and patient satisfaction (Heuvel et al., 2006; Yaduvanshi & Sharma, 2017). In banking institutions and insurance companies, it has increased profitability and improved customer relationships (Vashishth et al., 2017). In logistics, near of 67% of firms in Singapore have controlled their costs and enhanced their productivity due to LSS methodology (Zhang et al., 2016). A latest systematic review confirms that the deployment of LSS in the maritime sector is thriving, with increasing integration of Industry 4.0 (Hia, 2025). Recent case studies also show that Lean and TQM tools can improve the operational performance of ports (Gonzalez et al., 2025). In Africa, LSS is beginning to be implemented in container terminals, particularly in Nigeria (TICT, 2025).

In the port sector, Ridwan & Noche (2014) applied Six Sigma to three Indonesian ports, identifying low capability indices and proposing improvements. Nooramin et al. (2011) used Six Sigma to reduce container truck congestion in Iran, highlighting the importance of monitoring operator efficiency. However, these studies did not incorporate Lean principles, and none applied Lean Six Sigma jointly in a Moroccan port terminal. Research in this context remains limited due to the complexity of supply chains, difficulties in accessing data, and a lack of involvement from on-site teams.

Furthermore, Lean Six Sigma has been widely adopted in manufacturing and service sectors, but its application in port logistics is limited, especially in developing ports in emerging economies. Also, the existing studies have targeted quantitative assessments and descriptive DMAIC applications, but there is little use of comprehensive case study approaches that combine operational data, field observations and stakeholder participation. This study fills the contextual and methodological gaps by investigating the application of Lean Six Sigma in container operations of a Moroccan port via an in-depth empirical case study.
To address these gaps, the following research question is proposed: how can the integrated application of Lean Six Sigma, using the DMAIC approach, enhance the overall quality and operational performance of container traffic in a Moroccan port that has recently opened its doors to this type of traffic? The originality consists in the joint application of Lean and Six Sigma in this unexplored context, following the five DMAIC steps (Define, Measure, Analyze, Improve, Control) based on operational field data. Scientific research in this sector remains limited in the Moroccan context, and this study aims to fill this contextual and methodological gaps while adopting a participatory approach rooted in field practice. Four objectives are pursued: (1) diagnose current container traffic performance using capability and waste analysis; (2) identify technical and organisational root causes of variability; (3) propose and validate improvement measures with port operators and managers, and (4) to extend the understanding of Lean Six Sigma application in port logistics operations within emerging economy contexts.
The article is organized as follows. The next section presents the research methodology (DMAIC framework, data collection and analysis tools). The third section presents and discusses the results obtained. The last section presents the main conclusions of the study.

2. Methodology

2.1 Research design

This study adopts an empirical case study approach to investigate the application of Lean Six Sigma (LSS) in improving the operational performance of container traffic processes within a Moroccan Mediterranean port. The case study method was selected because it allows an in-depth examination of operational phenomena within their real organizational setting, while capturing the complexity of interactions among processes, stakeholders, and performance drivers (Gavard-Perret et al., 2012; Eisenhardt, 1989; Yin, 2018).
The research follows a problem-solving and improvement-oriented perspective, combining principles of Lean and Six Sigma. Within this framework, the DMAIC (Define–Measure–Analyze–Improve–Control) methodology serves as the main analytical structure guiding the identification of inefficiencies, the analysis of root causes, and the implementation of corrective actions.

2.2 Research context and case selection

Several operational, strategic, and scientific reasons justify the choice of a Moroccan port as the case study. Firstly, containerized traffic has emerged as one of the most strategic activities in today's ports, given its direct influence on service quality, processing times, logistics costs, and the overall competitiveness of the port. Therefore, enhancing the performance of container related processes is a significant challenge for port operators who aim to improve operational efficiency and customer satisfaction. Secondly, the chosen port has recently consolidated its position on the containerised cargo market, which has led to the implementation of new operational procedures and management systems. This development phase is generally associated with process variability, coordination difficulties among stakeholders and large potential for performance improvement. The case in question offers a particularly relevant context for examining the application of the Lean Six Sigma approach. Third, preliminary assessments inside the port identified some operational inefficiencies (e.g., long processing times, bottlenecks, non-value-added activities, and large variations in operational performance). The issues confirmed the appropriateness of the selection of this case to evaluate the effectiveness of a structured continuous improvement approach based on Lean Six Sigma. Finally, the choice of this case is also justified by its scientific relevance. While the Lean Six Sigma literature remains largely concentrated on manufacturing environments, studies addressing its application in port operations, particularly within emerging economies, remain relatively scarce. Therefore, this case study contributes to enriching the existing body of knowledge on performance improvement mechanisms in port logistics systems and provides valuable insights for other ports facing similar operational challenges.

The selected port is not disclosed for confidentiality reasons. The decision was made to safeguard the organization's identity and the confidentiality of the operational data provided for the study, some of which is deemed commercially and operationally sensitive. The study provides sufficient information about the port context, data, and research procedures to ensure methodological transparency, while also maintaining the anonymity of the case organization.

2.3 Data collection

To develop a comprehensive understanding of the container process under investigation, data were collected from multiple complementary sources over a four-month field study covering 54 consecutive port calls. The limited number of 54 port calls is due to the relatively low volume of container traffic at this port, which primarily handles other types of cargo. The analysis focuses on container ship calls recorded during 2023 and 2024, based on available historical data, while data collection and field analysis were conducted over a four-month period. The use of different sources of evidence enabled data triangulation and enhanced the credibility and robustness of the analysis.

The collected data was operational data of the container handling operations, internal documentation and descriptions of the workflows, direct observations of the activities carried out at different stages in the handling process, and Kaizen sessions held with the operational managers. Historical performance indicators were also analysed in order to evaluate the efficiency of the process and to identify the major sources of dysfunction.

The Kaizen workshops involved ten participants representing both managerial and operational functions within the container terminal. The participants included the Port Call Manager, the Head of Operations, the Head of Infrastructure and Equipment, as well as truck drivers, equipment operators, warehouse staff, and warehouse supervisors. Their selection was based on their direct involvement in the processes under investigation and their operational knowledge. A total of five Kaizen workshops were conducted over the study period, with one workshop held approximately every two weeks. Each workshop lasted approximately 1.5 hours and focused on validating the identified root causes, discussing operational constraints, and developing and assessing appropriate improvement actions.

Data collection was mostly during the diagnostic phases of the DMAIC (Define, Measure, Analyse) process. The goal was to gain a deep understanding of the operation of the process, to identify sources of variability, non-value-added activities and the main reasons for the observed inefficiencies. This step contributed to the building of a solid factual basis for the formulation of improvement actions adapted to the context under study.

The improvement proposals generated in this research were discussed and validated with the relevant participants in order to verify their feasibility. But the full implementation and evaluation of long-term effects was outside the scope of this study. So, the research is mainly focused on the process diagnosis, improvement opportunities, and solution design based on the Lean Six Sigma principles, rather than on measuring performance after their implementation.

2.4 Lean Six Sigma implementation procedure

The DMAIC methodology provided a structured way of analysing and improving processes. The Define phase was used to create the project charter, which consisted of identifying the project team, defining the problem, setting project objectives, and planning the implementation timeline. The Measure phase was focused on quantifying the current state of the process by measuring performance levels and the extent of the problems identified through relevant operational indicators. The Analyze phase was to identify the root causes of inefficiencies and performance gaps identified in the process. The Improve phase was the proposal and design of appropriate improvement actions based on the analysis findings. Finally, the Control phase was centered on monitoring the evolution of the process after implementation and ensuring the sustainability of the improvements achieved (Citybabu & Yamini, 2023; Drohomeretski et al., 2014).

Figure 1. Adopted DMAIC approach

Source: By authors

2.5. Data analysis

The data analysis used a comparative and descriptive approach to assess how well the container handling process works and to find the main factors that cause inefficiency. The data collected were first analyzed to characterize the current state of the process, focusing on operational indicators like processing times, sources of variability, and bottlenecks. We then performed a gap analysis, comparing the observed performance against the expected levels or best practices identified in the literature and within the operational context of the port. The analysis also included quality tools such as Pareto analysis and Ishikawa diagrams to identify and prioritize the causes of malfunctions at their source.

The statistical and graphical analyses were conducted using Microsoft Excel and Minitab software, and the graphical representations were generated using these tools, which was selected for its suitability for Lean Six Sigma applications and its dedicated tools for calculating process capability indices. The qualitative data collected during the Kaizen workshops were organized and analyzed by grouping the main problems, causes, and areas for improvement identified by the participants, in accordance with the principles of qualitative data analysis, in particular, the synthesis, organization, and interpretation of data in order to identify the main factors explaining the phenomenon under study (Miles et al., 2014).

Finally, the interpretation of the results allowed us to connect the observed inefficiencies with organizational and operational factors of the process, thus providing a basis for formulating improvement proposals based on Lean Six Sigma principles.

2.6. Reliability and validity

A triangulation procedure was implemented to increase the reliability and validity of the

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findings by systematically comparing evidence gathered from multiple data sources, such as operational performance indicators, internal documents, direct observations, and Kaizen workshops. The analysis of operational data revealed the quantitative findings, which were then compared with documentary evidence and field observations. The causes identified and the opportunities for improvement were subsequently discussed and confirmed in the Kaizen workshops that brought together key operational and managerial participants. This process allowed the researchers to determine how consistent the evidence was across the various sources and to pinpoint where there was agreement or disagreement. The process of triangulation used on the study's main findings is summarized in Table 1.

Table 1: Triangulation of data sources for key findings

Key findings	Operational indicators	Internal documents	Direct observations	Kaizen workshops	Validation
Productivity performance below the target level	X	X	X	X	Confirmed
Cycle Time Exceeds the calculated Takt Time	X	X	X	X	Confirmed
Major sources of downtime	X	X	X	X	Confirmed
Process incapability	X	X	X	X	Confirmed
Root causes of operational inefficiencies		X	X	X	Confirmed
Improvement actions		X	X	X	Participants validation
Monitoring requirements		X	X	X	Plan validated

Source: by authors

3. Results and discussion

This section develops and presents results across all five DMAIC phases, with discussion linking empirical findings to the literature at each stage.

3.1. Overview of the container process

This stage consists of presenting the scope of this investigative project, which has been validated by field team and formalized in a document known as the project charter or project mandate. This document contains a clear and precise definition of the project's scope, the main objectives, the team field involved in the project's implementation, and a timeline for the various phases (Murmura et al., 2021). Figure 2 illustrates the details of the project charter developed as part of this study.

A Kaizen session was organized with the project team to establish this project charter and to define the critical to quality (CTQ) factors of the process under study, which directly affect customer satisfaction and the operational performance of this traffic (Kumar et al., 2006). Indeed, the use of the CTQ tree will better illustrate the critical quality characteristics of this process (Figure 3). Customers primarily desire rapid container handling with an hourly volume of between 14 and 18 containers. Meanwhile, the port aims for stability and continuous improvement in the efficiency of the various port calls.

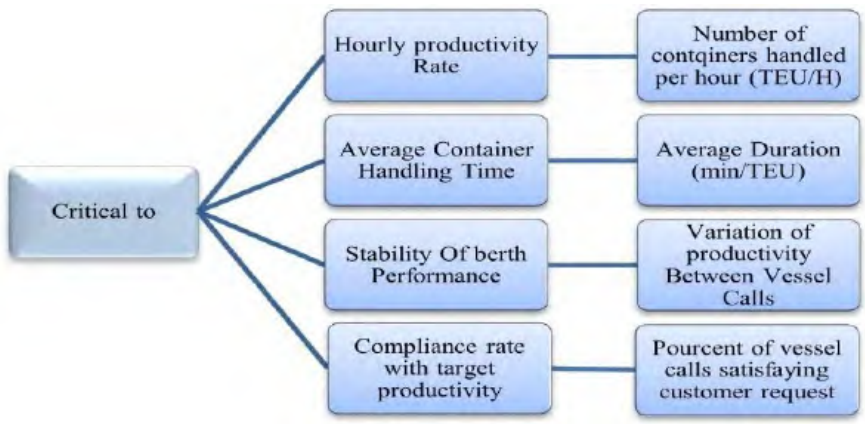
A visual representation of the containerized freight process is necessary to identify all the elements essential to initiating the process (inputs) and their suppliers, to determine the key stages in the utilization of these elements, and to specify the customers for the outputs generated. The SIPOC (Supplier, Input, Process, Output, Customer) diagram was developed to provide a systemic representation of the containerised freight process, identifying inputs, suppliers, key stages, and output customers, thereby delimiting the scope of improvement interventions (Trubetskaya et al., 2023).

Figure 2. Project chart

<table>
<tr><th colspan="6">Project Charter : Improving the Operational performance of Container Traffic</th></tr>
<tr><td colspan="2">Problem statement (What?)</td><td colspan="4">The actual hourly yield of container handling operations fluctuates markedly from one vessel call to another, revealing increased variability and instability in the operational process.</td></tr>
<tr><td rowspan="3">Who?</td><td>Project Sponsor</td><td colspan="4">Port Operations Director and Head of Port Services</td></tr>
<tr><td>Project Leader</td><td colspan="4">Head of Operations Division, QHSE Manager and Lean Projects Coordinator</td></tr>
<tr><td>Team Member</td><td colspan="4">Container Handling Supervisors, Warehouse Supervisor, Equipment Operators, Maintenance Department and IT Department</td></tr>
<tr><td colspan="2">Where?</td><td colspan="4">Container Teminal / On-board container handling process</td></tr>
<tr><td colspan="2">How?</td><td colspan="4">Applying the Lean Six Sigma approach using the DMAIC methodology (Define, Measure, Analyze, Improve, and Control).</td></tr>
<tr><td rowspan="6">When?</td><td></td><td>Start date</td><td>Due Date</td><td>Progress</td><td>Note</td></tr>
<tr><td>Define</td><td>01/04/2025</td><td>12/04/2025</td><td>100%</td><td>Completed</td></tr>
<tr><td>Measure</td><td>13/04/2025</td><td>07/05/2025</td><td>100%</td><td>Completed</td></tr>
<tr><td>Analyze</td><td>08/05/2025</td><td>28/05/2025</td><td>100%</td><td>Completed</td></tr>
<tr><td>Improve</td><td>29/05/2025</td><td>26/06/2025 Partially completed</td><td>50%</td><td>Validated collectively by the participants in the Kaizen sessions</td></tr>
<tr><td>Control</td><td>28/06/2025</td><td>in progress</td><td>50%</td><td>In progress</td></tr>
<tr><td colspan="2">Why?</td><td colspan="4">To reduce deviations in container yield and improve operational performance.
To enhance stakeholders satisfaction.
To reduce operational errors, delays, and rehandling rates.</td></tr>
</table>

Source: Authors own work

Figure 3. Critical to quality tree



Source: Authors own work

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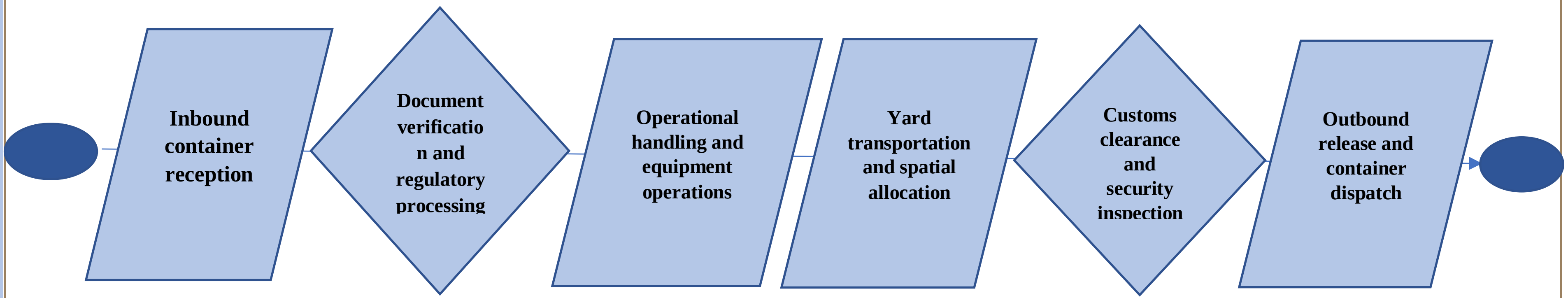
Table 2: SIPOC diagram

SUPPLIERS	Shipping companies; Freight forwarders; Shipper; Port authorities; Equipment suppliers; Customs services
INPUTS	Containers; Loading manifest; Shipping documents; Loading plans; Lifting equipment; Qualified personnel; Trailers/Chassis; Computer systems
PROCESS	
OUTPUTS	Loaded/unloaded containers; Correctly positioned containers; Quality control reports; Repaired containers; Delivery documents; Tally sheets; Departed vessel; Containers delivered to customers
CUSTOMERS	Shipping companies; Importers; Exporters; Freight forwarders; Final consignees; Logistics services; Warehouses

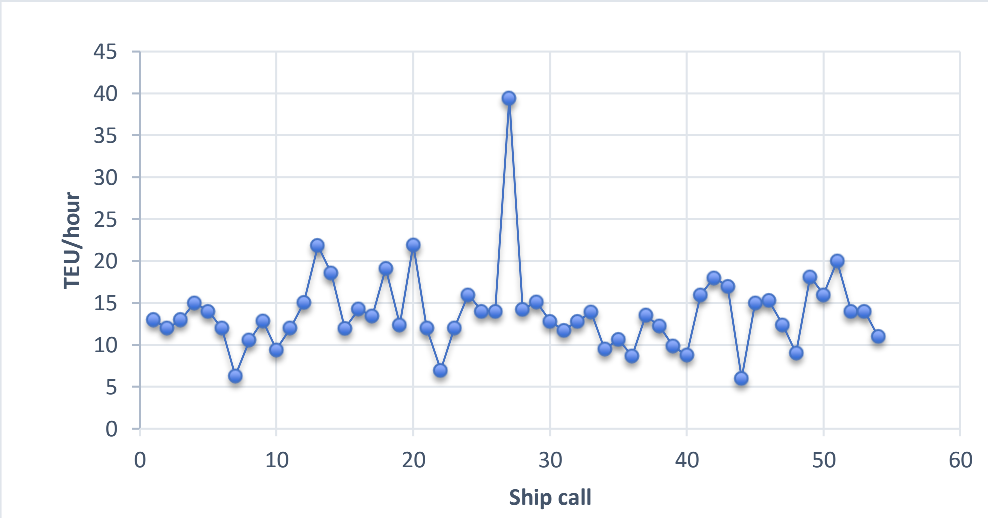
Source: Authors own work

3.2. Current performance and operational diagnosis

3.2.1. Descriptive data analysis

An initial observation of the collected data on the actual hourly throughput of container ship calls, as well as the targeted productivity range (14–18 container/hour), reveals that 31.48% of calls fall within this range. Furthermore, a descriptive analysis of this data shows increased variation around the mean. The standard deviation is 4.93 ($\sigma = 4{,}9287$) for a mean of 14 Container/hour, corresponding to a coefficient of variation (CV) of 0.3520. These figures indicate that the actual hourly throughput varies by 35.2% around the mean, suggesting significant dispersion in hourly throughput from one port call to another. Figure 5 illustrates the variability level of current process. It markedly exceeds benchmarks from comparable container terminal studies (Nooramin et al., 2011; Weerasinghe et al., 2023), confirming that the process is out of control.

Figure 5. Actual hourly productivity of container traffic



Source: Authors own work

3.2.2. Cycle time and Takt Time

Takt Time (TT) is an indicator that establishes the theoretical unit processing time that a system must maintain in order to fulfill customer demand (Adeodu et al., 2021). In the present context, with an average daily throughput demand of 350 container and a net daily available time (T) of 1185 minutes . the Takt Time is calculated as follows:

$$TT = \frac{1185}{350} \cong 3{,}39\ min/container$$

T = Operating time (3 shifts × 8 hours) – Scheduled downtime (255 minutes for all shifts) = 1185 min

So, the time required to handle a single container under optimal conditions and in accordance with customer demand (Takt Time) is 3.39 min/container.

When this indicator is set against observed cycle times across port calls, pronounced failures become apparent. Figure 6 shows that the vast majority of cycle time of studied port calls considerably exceed the calculated theoretical time (3,39 min/Container) threshold, a pattern that aligns closely with findings throughout the Lean literature. The progressive accumulation of waste and bottlenecks are the primary mechanisms through which cycle times become inflated beyond what the process inherently requires (Shingo, 1989). The deviation between actual cycle time and Takt Time serves as a direct, quantifiable index of process inefficiency and the extent to which non-value-added activities have taken hold within the operational flow.

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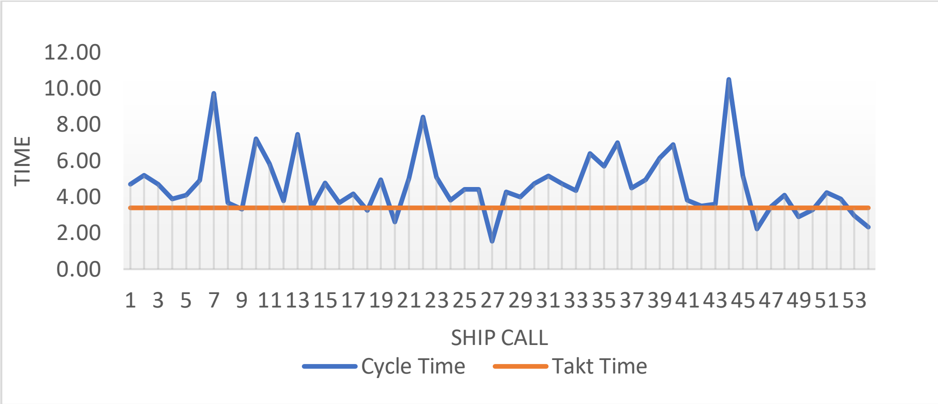
Figure 6. Takt Time and Cycle Time



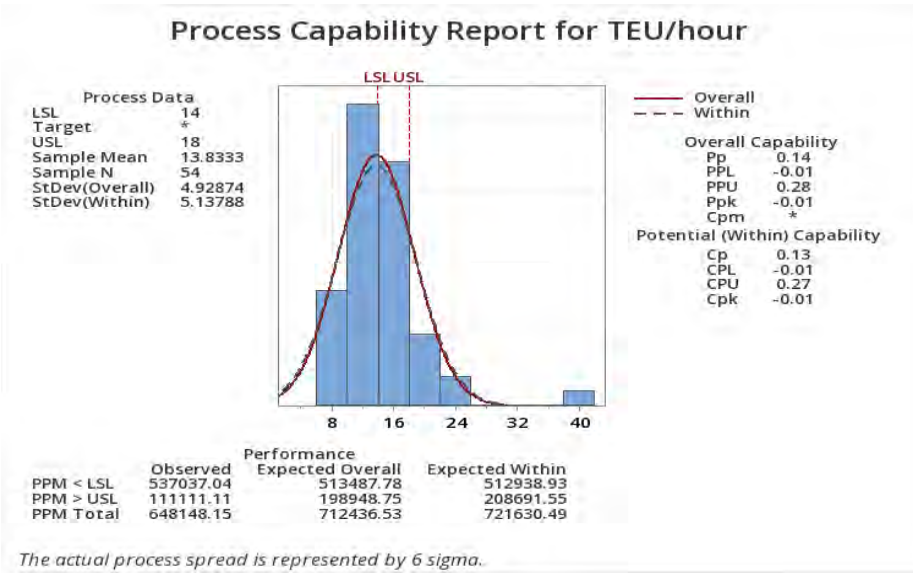
Source: Authors own work

3.2.3. Process capability

Kane (1986) defines process capability as the intrinsic ability of a process to generate results that meet defined criteria, assessed by the ratio of the specified tolerance range to the natural variation of the process. It is measured by two main indices, Cp and Cpk (Mogatusi et al., 2025). The first verifies whether the process naturally varies within the specification limits. The second takes into account the centering of the process relative to the predefined limits. This involves assessing whether the actual mean is close to the center of the specifications.

In this study, the process under investigation is unable to meet customer requirements (LSL = 14 container per hour; USL = 18 container per hour) since $Cp = 0{,}13$ and $Cpk = -0{,}01$, which are well below 1.33 (Figure 7) (Mogatusi et al., 2025). These indices reconfirm that the process is unstable and out of control, requiring immediate and urgent intervention. The mean of the distribution lies outside the specified limits (Mean = 13.83), indicating a significant left-skew of the curve. A truly capable process targets less than 3.4 PPM. However, the total defect rate in the studied process is 648148.15 PPM (defects per million opportunities), representing over 64% of values outside, which is incompatible with Six Sigma capability standards specifications.

Figure 7. Process Capability



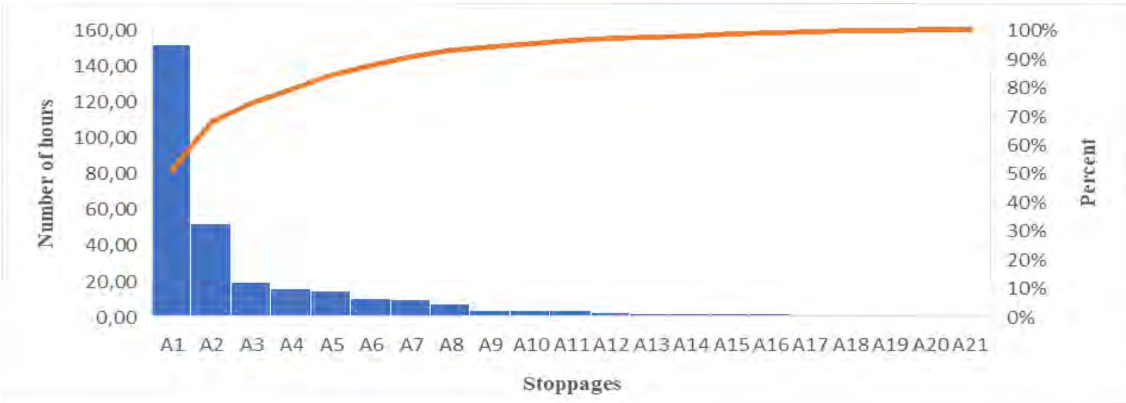
Source: Authors own work

3.3. Identification of operational inefficiencies

3.3.1. Critical stoppages affecting container traffic performance

The stoppages recorded at the various port calls are listed in Appendix A and presented in Figure 8 by the Pareto chart. This graphical representation allows for the identification of critical stoppages causing the major deviation in container traffic performance (Hackman & Wageman, 1995; Shingo, 1989), in accordance with the Pareto law (20/80). Figure 8 shows that stoppages A1 (recovery/adjustment of misaligned containers), followed by A2 (waiting for empty container inspection), A3 (delay in docking), A4 (waiting for administrative documents), and A5 (waiting for customs approval), are the most potential stoppages in the process, accounting for 80% of the variation in process yield. Therefore, it is recommended to address these five stoppages in order to significantly reduce the observed variation and improve the performance of the container traffic process.

Figure 8. Pareto Chart of Critical stoppages



Source: Authors own work

3.3.2. Root causes of detected variations

To identify the root causes of instability in container traffic performance, brainstorming sessions were organized with project team to deepen the analysis and identify systematic issues in this process. To this end, the use of the fishbone diagram will help visualize the main problems, classified around five dimensions: Material, Human, Machine, Environment, and Method (Gupta et al., 2018).

Figure 9 illustrates the various failures identified in organized sessions. Analysis of this diagram demonstrates that the instability in container traffic yield is attributed to several factors, notably human factors related to a lack of investment in continuing training for operational staff to improve their soft and hard skills regarding new industry trends. Technical factors related to the aging and wear of handling equipment, leading to recurring breakdowns, repeated downtime, and a decline in the lifting capacity of cranes and machinery. Organizational weakness also affect the productivity of this process, such as inconsistent implementation of the preventive maintenance plan by technical teams, overloading of containers beyond the lifting capacity of cranes, and improper securing of cargo within containers, leading to an increase in breakdown rates and significant time waste. A lack of administrative formalities and delays in customs inspections of containers destined for export exacerbate the inefficiencies in the containerized traffic process. Insufficient lighting and limited space at the container terminal also undermine operational efficiency, especially during the third shift.

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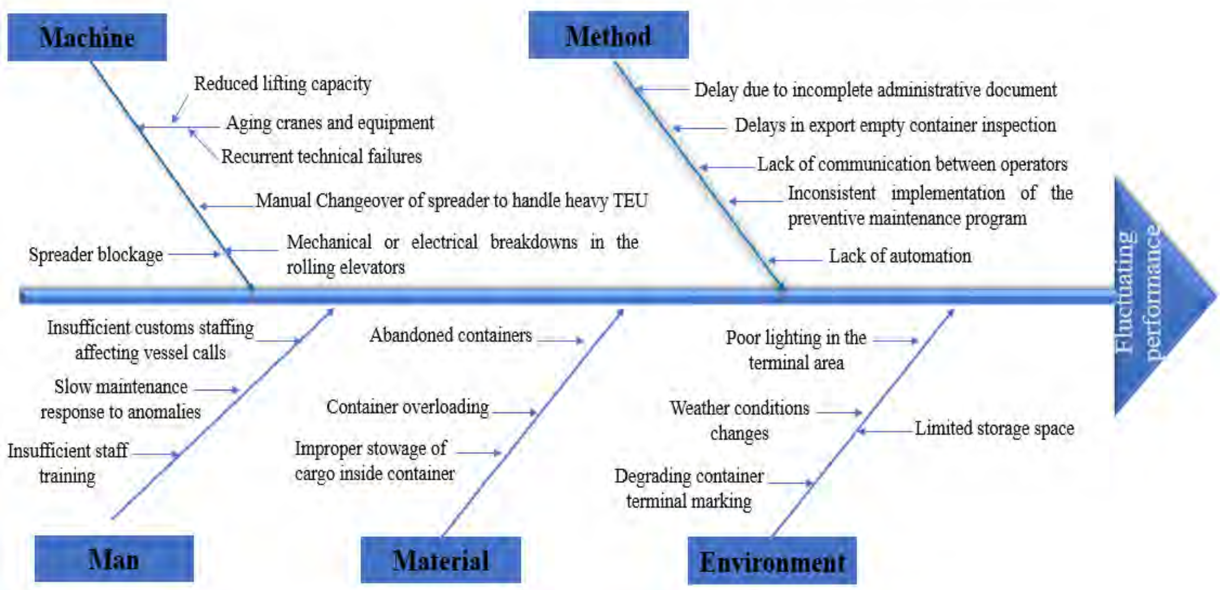
Figure 9. Ishikawa diagram of root causes



Source: Authors own work

This analysis of the root causes of the container traffic process issues identifies critical areas for improvement and provide a solid foundation for the next step in the DMAIC process.

3.4. Proposed improvement actions and monitoring phase

The analyses conducted throughout the collected data have shown that the containerized traffic process requires significant improvements to correct the identified failures, which exacerbate performance variability. Meetings with the field team were organized to discuss these anomalies, identify those requiring priority attention, and propose effective and feasible solutions to eliminate these malfunctions or reduce their impact on the productivity of the container traffic.

From an operational and technical standpoint, it is recommended that the Equipment and Infrastructure Division reinforce its staff's commitment to ensure the ongoing implementation of the preventive maintenance program and to anticipate potential failures and unscheduled downtime. This measure will ensure safer and more reliable equipment operation, preventing machinery failures and automatic spreader blockages, which are the primary factors affecting the operational performance of container traffic. Furthermore, the wear and aging of handling equipment, in a context where automation and robotization are now widespread, require the port in question to rethink its strategies in order to evolve toward a more modern model aligned with international trade trends (Belmoukari et al., 2023). This recommendation involves the use of new technologies such as AGVs (Automated Guided Vehicles), ASCs (Automated Stacking Cranes), digital twins, the IoT, artificial intelligence, and cybersecurity, among others. These innovative technologies have been the subject of several scientific studies to analyze their effects on port performance. They have demonstrated the significant and positive impact of these digital systems on the operational efficiency of container terminals, on the optimization of energy consumption, and on the improvement of port quality services (Chandra et al., 2024; Heikkilä et al., 2022; Tsagkaris & Moschovou, 2025). Zulfiqar et al. (2023) add that top management support is an essential factor for Lean Six Sigma projects and technology integration.

Similarly, the port still uses diesel-powered thermal equipment, such as forklifts and lift trucks. This equipment has become less efficient and emits more greenhouse gases, which negatively impacts the port's environmental performance. These vehicles are slated for future upgrades as part of the National Port Strategy for 2030, with the aim of replacing the existing fleet with more effective and efficient vehicles having a low environmental impact. The gradual modernization and transition toward more efficient and lower-emission port equipment are increasingly recognized as important levers for improving the environmental performance of port operations (Paulauskas et al., 2025). Therefore, this port is examining how to integrate this new equipment into all terminals in order to strengthen its position in terms of traffic volume handled and ensure the sustainability of its operations. These conclusions build on previous research work focused on sustainability issues in Moroccan ports, highlighting the growing need to optimize processes to achieve sustainable performance (Aakaou & Lahrach, 2025).

Conversely, improper stowage of cargo inside containers, as well as overloading, constitutes a major risk that must be addressed as a priority, as it can cause serious accidents during handling operations, damaging the vessel, port infrastructure, and equipment, as well as menacing the health and safety of operational team. Consequently, shippers are required to comply with cargo securing and weighing standards, in accordance with international standards and port capacities, prior to transport, in order to avoid any risk of damage.

It should also be noted that the inspection of empty containers intended for export leads to significant delays during on-board handling operations, due to the insufficient number of customs officers assigned during container ship calls. Therefore, it appears necessary to request the relevant authorities to increase customs staffing levels and ensure a smooth export process.

Added to this is the problem of communication, both among operators during cargo handling operations and among the various operators in the port logistics chain. For example, during cargo handling, the crane operator and the forklift operator have no direct means of communication to exchange essential information, which could negatively impact the smooth running of different workflows. In this regard, it has been recommended to implement the use of walkie-talkies to facilitate communication among operators and improve operational coordination. Another example in the same line highlights the A1 stoppage (adjustment of a mispositioned container), which accounts for the highest amount of lost and non-productive time. This downtime is primarily due to a lack of communication with the shipping lines, since the list of containers intended for export (export manifest) is prepared by the shipping lines without coordination with the warehouse managers. The shipping lines arbitrarily designate the containers to be loaded without taking into account their actual location in the yard, which leads to prolonged downtime while searching for the relevant containers.

The short-term solution that was implemented involved reorganizing the yard before the ship's arrival to sort the containers for export. However, this solution proved ineffective, as it resulted in excessive fuel consumption by forklift operators when repositioning the containers, thereby generating more greenhouse gas emissions.

Another recommendation proposed by the warehouse manager is to entrust the preparation of the list of containers intended for export to the port organization responsible for handling and managing the container yard. This recommendation must be discussed and approved by all relevant stakeholders.

Nevertheless, ongoing employee training plays an essential role in enhancing the sustainability of any organization. Hosen et al. (2024) confirm the significant relationship between training and job performance in the hotel sector in Bangladesh. Erregui (2024) emphasizes, for his part, that training practices implemented within Moroccan companies have a significant impact on the development of employees' skills and on their individual productivity. Bucci et al. (2026) highlight the central role of human competencies within Industry 5.0 principles, quality dimensions and digital tools. Consequently, the current port must strengthen its human

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resources training programs to improve its operational efficiency. More comprehensive training programs, such as those implemented in ports in collaboration with advanced Moroccan container terminals, such as Tanger Med, would enable employees to acquire new techniques, expand their knowledge of contemporary challenges in the national port sector, and foster a climate of complementarity and cooperation among the various Moroccan ports. Beyond formal training, these initiatives could also strengthen organizational learning by facilitating knowledge sharing, systematic feedback, and the capitalization of lessons learned from recurring operational problems. Establishing mechanisms to capture and disseminate operational knowledge across teams would help transform individual learning into organizational capabilities and support the sustainability of future improvement actions.

All the proposed solutions were discussed and validated by the boards of directors. Subsequently, an implementation plan was developed for the deployment of these solutions and to monitor or track the effectiveness of the corrective actions implemented. This plan aims to define the scope or critical control points, the person responsible for monitoring, the necessary resources, and the frequency of monitoring (Murmura et al., 2021).

Furthermore, the control chart is an effective tool for monitoring changes in container traffic performance relative to the specifications established by the client ($\text{LSL} = 14 \text{ container per hour}; \text{USL} = 18 \text{ container per hour}$) (Trubetskaya et al., 2023). It is advisable to periodically develop a control chart in order to regularly evaluate the operational performance of the process under study. It is also recommended to recalculate the process capability to monitor its variability and its ability to produce services that meet predefined requirements.

The limited duration of this study did not allow for the evaluation of the effectiveness of the corrective actions. However, the restricted implementation of this phase should not be interpreted solely as a methodological limitation, but also as a reflection of how Lean Six Sigma is put into practice in complicated port settings. In practice, especially in ports where operations are dynamic and involve coordination among multiple stakeholders, the DMAIC cycle cannot always be fully implemented due to time constraints, limited data, and competing organizational priorities.

This suggests that in such contexts, Lean Six Sigma is not always strictly implemented as a fully sequential and comprehensive cycle. Instead, the methodology serves as a structured framework for diagnosis, analysis, and the design of improvement actions, while long-term control and sustainability assessment can be conducted as a separate managerial process.

Theoretically, this discovery underlines that Lean Six Sigma needs to be regarded in a context that is not merely demarked as a set improvement cycle, but as a flexible methodology for problem resolution suited to the constraints offered by real life operations environment settings. This perspective is particularly relevant in the case of complicated logistics systems in developing economies, where systems of continuing control may not always be in place after improvement designs have been made.

4. Conclusion

This research studied the applicability of the Lean Six Sigma methodology in the Moroccan port sector. The findings demonstrate that the integration of Lean Six Sigma principles and improved community intelligence can be an important factor in reducing unplanned downtime and improving hourly throughput of a small container terminal. Quantitative analysis showed that the process is out of control (Cpk = -0,01; 648148 PPM) justifying the need of corrective actions.

However, this study provides a practical framework for practitioners who intend to implement Lean Six Sigma to improve handling services at container terminals. The five DMAIC phases

(Define, Measure, Analyse, Improve, Control) have been rigorously followed, using tools like SIPOC diagram, Ishikawa diagram and capability mapping. It points out the inefficiencies that negatively impact the performance of container traffic, and it offers recommendations for dealing with them, while ensuring that there is constant improvement in operations. The study also indicates the necessity to optimise the use of material and human resources, underlining the environmental challenges and the necessity to develop a sustainable culture of continuous improvement.

This study contributes to the enrichment of national and international scientific literature on the application of Lean Six Sigma in the port context. It provides empirical evidence on the application of the DMAIC framework to container terminal processes in an emerging-economy context. The study extends previous research by combining quantitative process performance analysis with direct observations and team field participation to identify the main sources of operational inefficiency. It also highlights the importance of considering not only technical and logistical factors, but also organizational learning, knowledge sharing, and employee competencies when seeking to sustain process improvements. In this respect, This study opens up new avenues for future research on the integration of Lean Six Sigma with environmental and digital approaches in port operations (Gholami et al., 2021; Pongboonchai-Empl et al., 2023).

From a managerial perspective, the findings provide port managers with a structured approach for diagnosing operational inefficiencies and prioritizing improvement opportunities. The results highlight the importance of addressing equipment reliability, operational coordination, employee training, and knowledge sharing to improve container-handling performance. The proposed improvement and monitoring framework can support managers in translating the identified root causes into future improvement actions and performance-monitoring mechanisms. However, these recommendations remain prospective, as the improve and control phases were not fully implemented during the study period.

However, the study was conducted in a single port, which restricts the generalizability of the findings to other Moroccan or international ports. Furthermore, the qualitative evidence collected through Kaizen workshops may be subject to social desirability bias. Implementing a control plan (control charts, periodic capability monitoring) is essential to sustain the improvements resulting from the control phase. The absence of a post-implementation quantitative assessment during the control phase can be also considered us a limitation. But the recommendations were formulated based on a rigorous analysis of process inefficiencies and were validated by the management team, ensuring their operational relevance.

In summary, this research deepens the scientific understanding of continuous improvement in port processes and offers a tangible practical framework for enhancing the efficiency and excellence of container terminals in Moroccan ports.

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Appendix A. Operational stoppages in container traffic

	Delays	Number of hours	Percent
A1	Recovery/adjustment of misaligned container	151,50	50,78%
A2	Waiting Empty container inspection	51,50	17,26%
A3	Delay in docking	18,75	6,28%
A4	Waiting for documents or administrative formalities	15,17	5,08%
A5	Waiting for customs approval	14,42	4,83%
A6	Breakdown of rolling stock	9,67	3,24%
A7	Preparation of goods on board and at the dock	9,25	3,10%
A8	Handling equipment breakdowns	7,17	2,40%
A9	Hauling	3,50	1,17%
A10	Completed ship	3,25	1,09%
A11	Accessory handling changes	3,00	1,01%
A12	Movements of lifting equipment (excluding wedge changes)	2,00	0,67%
A13	Crane operator break	1,67	0,56%
A14	Lifting equipment failure	1,50	0,50%
A15	Stop between import and export	1,50	0,50%
A16	Change of wedge	1,50	0,50%
A17	Handling by the edge	1,08	0,36%
A18	Opening/closing of automatic wedges	0,92	0,31%
A19	Stop before the end of the shift	0,50	0,17%
A20	Delay in shift start due to stevedores	0,33	0,11%
A21	Delayed start at the beginning of the shift	0,17	0,06%
	Total	298,35	100%

Source: by authors

Use of artificial intelligence

Artificial intelligence tools were used solely to support language editing, text revision, and translation of portions of the manuscript through DeepL. The authors reviewed, validated, and take full responsibility for the final content of the manuscript. No artificial intelligence tool was used to generate, analyze, interpret, or modify the research data, results, figures, or scientific conclusions presented in this study.