Empirical Decision-Making Tools as Applied to Seaports in the Industry 4.0 Paradigm

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"Remember always to dream. More importantly, work hard to make those dreams come true and never give up". Dr Robert D. Ballard.

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This research project is the end product of blood, sweat, tears, and love.

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LIST OF ABBREVIATIONS

ABP	Associated British Ports
AI	Artificial Intelligence
AIS	Automatic Identification System
BDA	Big Data Analytics
BD	Big Data
BIA	Business Intelligence and Analytics
BI	Business Intelligence
BPM	Business Process Management
BPR	Business Process Redesign
BSC	Balanced Score Card
CDP	Career Development Plan
CIM	Centralised Information Model
CLSC	Closed-Loop Supply Chain
CSR	Corporate Social Responsibility
CPS	Cyber-Physical Systems
CY	Container Yard
DDD	Data-Driven Decision Making
DIM	Decentralised Informational Model
ELM	Electronic Logistics Marketplace
EMAS	Eco-Management Scheme and Audit Scheme
EMSA	European Maritime Safety Agency
EMS	Environmental Management System
EDMTs	Empirical Decision-Making Tools
EPI	Environmental Performance Indicator
ERP	Enterprise Resource Planning
eSW	Electronic Single Window
EU	European Union
FMCG	Fast-Moving Consumer Goods
GLS	General Logistics Service
GPO	Global Port Operator
GPS	Global Positioning System
GRT	Gross Registered Tonnes

GTO	Global Terminal Operator
HPA	Hamburg Port Authority
ICT	Information Communication Technology
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organisation
IoE	Internet of Everything
IIoT	Industrial Internet of Things
IoT	Internet of Things
IPCSA	The International Port Community System Association
IPC	Information Processing Capacity
IPR	Information Processing Requirements
ISO	The International Organisation for Standardisation
IS	Information Systems
IDSS	Integrated Decision Support
ISM	Intelligent Ship Management
ISPS	International Ship Port Security Code
ISWE	International Single Window Environment
IT	Information Technology
JIT	Just in Time
KPI	Key Performance Indicator
LTC	Lead – Time
MCC	Mobile Cloud Computing
MIT	Massachusetts Institute of Technology
MSC	Maritime Supply Chain
M2M	Machine-to-Machine Communication
NBP	Net Berth Productivity
NRT	Net Registered Tonnes
NSW	National Single Window
OPAL	On-Line Analytical Processing Systems
OPC	Output
PA	Port Authority
PAM	Process Activity Mapping
PDC	Productivity
PERS	Port Environmental Review System

PES	Port Eco-System
PI	Performance Indicator
PSP	Port Single Window
RDT	Resource Dependence Theory
RFID	Radio Frequency Identification
RM	Risk Management
RMG	Rail – Mounted Gantry
ROI	Return of Investment
RTG	Rubber – Tired Gantry
SA	Supporting Activities
SC	Supply Chain
SCADA	Supervisory Control and Data Acquisition
SCM	Supply Chain Management
SDM	Self-Diagnosis Method
SDMP	Strategic Decision-Making Process
SCU	Service Costs
SG	Sustainable Growth
SME	Small and Medium Enterprises
SMS	Safety Management System
SOA	Service Oriented Architecture
SOSEA	Strategic Overview of Environmental Aspects
SRM	Supplier Resource Management
SSCM	Sustainable Supply Chain Management
SSCPs	Sustainable Supply Chain Practices
SW	Single Window
TESCI	Terminal Supply Chain Integration
TEU	Twenty-foot Equivalent Unit
TLSP	Total Logistics Service Provider
TSP	Technology Service Provider
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
5V's	Volume, Velocity, Veracity, Value, and Variety
VAL	Value Added Logistics
VAS	Value Activity Mapping

VAST	Value–Added Services
VRIN	Valuable, Rare, Imperfectibly Imitable and Non-Substitutable
WSN	Wireless Sensor Networks

ABSTRACT

Purpose:

Seaports are regarded as vital nodes within maritime supply chain operations that represent 80% of globalised trade by volume when compared to other nodes of transportation. They represent logistical hubs that constitute as the interface between land and sea transportation, facilitating the processing and storing of a variety of diverse cargoes; break-bulk, liquid, containerised, refrigerated, passenger, and roll-on/ roll-off for on-ward delivery to suppliers and end users.

By their operating nature, seaports and container terminals are characterised by conservatism, fragmentation, complexity, and uncertainty making them ideal candidates for strategic decision-support tools that underpin the sustained competitive advantages facilitated by Industry 4.0 embedded technologies.

Method:

A range of data mapping techniques have been surveyed and the author proposes an observational modelling approach adapted from an existing visualisation technique (Value Stream Mapping/ VSM) as the route to improved strategic decision-support capabilities. The suitability of these techniques to map seaport operations was underpinned by a series of semi-structured interviews, in-depth interviews, and a process walk-through.

Research Implications:

This approach values practitioner-led, direct measurement and data collection with a process of considered planning for potential future states focused upon digital technologies and automation. The research integrates academic and practitioner literature, facilitating the development of a new mapping technique (Empirical Decision-Making Tools). integrated as part of a decision-support framework.

Practical Implications

The EDMTs represent a dynamic range of visualisation tools (Process-Flow Mapping, Supply Chain Data Matrix, Decision-Point Analysis, Accuracy Completeness Amplification Mapping, and Key Characteristics of a Seaport) that are applicable to seaports that vary in size, capacity, handling specification, location, and Industry 4.0 readiness. The increased demand for time-critical decision support is addressed by their adaptability to deliver real-time visualisations of the current operational state that underpin a method of continuous improvement within a future representation of an ideal operating state.

This facilitates an enhanced understanding in terms of both asset management and situational awareness of disparate and scarce resources of the seaport (berth occupation duration, labour allocation, crane capacity, throughput rate, and vessel turnaround time).

Keywords:

Supply Chain Management (SCM), Data Visualisation, Big Data Analytics (BDA), Industry 4.0, Port Community Systems (PCS), Smart Seaports, Value Stream Mapping (VSM), Empirical Decision-Making Tools (EDMTs).

CHAPTER 1: INTRODUCTION

1.0 Introduction

Traditionally, seaports were viewed in the literature as an interface between the functions of land and sea transportation modes. The concept of globalisation and free trade agreements has transformed the role of seaports into logistical hubs (Total Logistical Service Providers TLSP) that facilitate a range of value-added services, in a flexible, visible, standardised, and coordinated format. The unique characteristics of seaborne transportation also enhance its appeal to a diverse range of customers (containerisation, bulk cargo, petrol-chemical, and dry cargo), dependent on high volume capacity at relatively low operating costs per mile (Olesen et al., 2015). Efficient performing seaports are vital supply chain nodes to local, national, and global economic prosperity, reflected by the most publicised fact that 80% of global trade is transported by sea (Olesen et al., 2015; Bălan, 2018; Gkerekos et al., 2019; González-Sánchez et al., 2019). The growth in international seaborne trade is exemplified by Figure 1 which depicts volume (1980 – 2017 per million tons loaded) by container, dry cargo, main bulk, and oil/ gas.

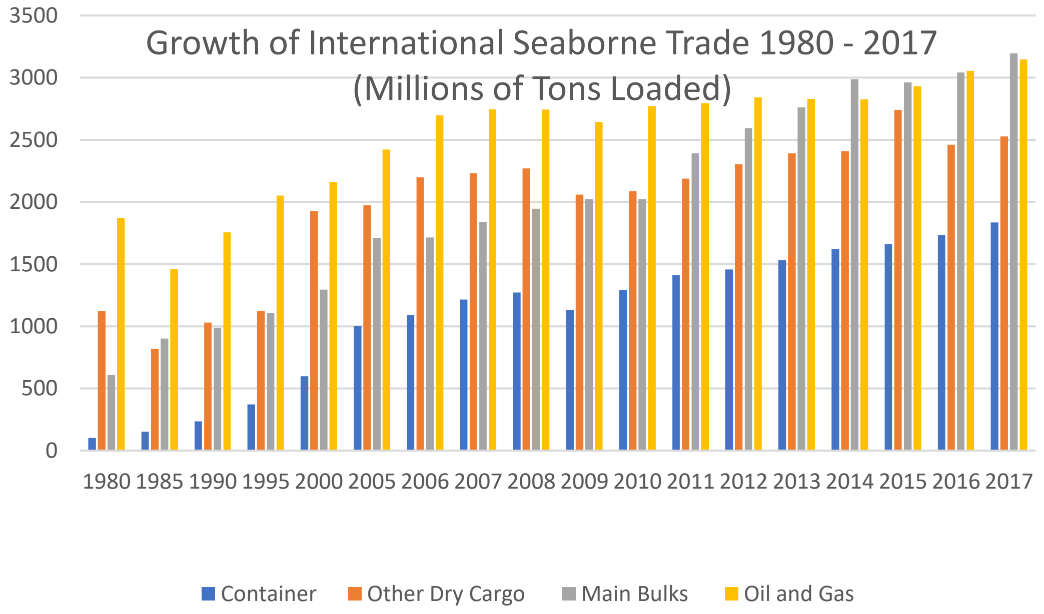


Figure 1: *Growth of International Seaborne Trade*

Adapted from UNCTAD (2017)

Seaports are subjected to increased user demand that is underpinned by a growing global population and industrialisation of nations that intensifies market competitiveness (Loyd et al., 2009). Increasing seaport throughput capacity is extremely problematic and complex: constraints on land, inter-modal split imbalances, congestion of the hinterland, cost implications, political and economic uncertainty, environmental regulation compliance, and stakeholders who have differing visions (Loyd et al., 2009).

Seaports operate in extremely hostile, complex, fragmented, conservative, and competitive markets, customers demand value-added services at the lowest possible cost. Competition from emerging economies, China, India, Malaysia, and Singapore is rapidly reducing the throughput volume of the main European Seaports that previously dominated the global containerised market (Jinxin, Qixin, and Lee, 2010).

Seaports are also viewed as possessing a culture that is resistant to both technological and operational changes (risk-averse), making accessibility for purely academic research questionable and necessary to drive operational change (Chen and Chen, 2014; Cepolina and Ghiara, 2013; Gkerekos et al., 2019; Kamble, Gunasekaran, and Dhone, 2019; Roh, Kunz, and Wegener, 2019). To address these unique operational challenges, seaports need access to real-time information flows that are facilitated by sharing, planning, and managing cargo throughput in a networked and collaborative format. This is realised by utilising Port Community Systems (PCS) as inter-organisational information architectures. The functionalities of a PCS now transcend the traditional physical and electronic boundaries of a seaport and connect both inter and intra-organisations in a secure digitalised network.

Fundamentally, seaports must develop a knowledge management culture that provides value-added services to their customers, in the form of supply chain traceability, visibility, transparency, and connectivity. However, seaports are not optimised for the implementation of new digital technology. Many seaports still operate traditional forms of EDI that were first introduced in the 1960s, resulting in scalability and interoperability issues between heterogeneous systems. It is inferred that the maritime sector is lagging behind in the implementation and exploitation of Industry 4.0 technology when compared to the manufacturing, automotive, and financial sectors (Gkerekos et al., 2019; Sanchez-Gonzalez et al., 2019). The maritime supply chain generates a large volume of data sets, although the majority remain unutilised in the form of strategic operating decisions. The unique operating conditions of seaports infer that current academic research may not have adequately addressed all the specific requirements of the sector in relation to the exploitation of Industry 4.0 embedded technologies.

To fulfil the purpose of this PhD study this thesis presents a novel and fundamental redesign of the traditional VSM technique that is applied within the paradigm of Lean Management (LM). This is leveraged by the development of the Empirical Decision-Making Tools (EDMTs) that consist of the following: Process Flow Mapping, Supply Chain Matrix, Decision-Point Analysis, Accuracy Completeness Amplification Mapping, and Key Characteristics Mapping. This will enhance decision-support by facilitating system integration and data visibility that understands the current position of the seaport with regard to Industry 4.0 technological readiness and maps operations for continuous improvement.

1.1 Research Aims and Objectives

Development of systematic techniques for industrial decision support relating to the investment in sustainable supply chain technologies & virtual infrastructure. The techniques developed will be based upon the adoption of Industry 4.0 capabilities from the wider supply chain sectors and viewed through the prism of seaport operations.

RO1. What are the existing barriers to digitalised seaports in the Industry 4.0 era?

- How does a seaport understand its current position? This research sets out to identify tools and techniques to clarify these challenges and barriers for seaports to assist decision-making.
- What are the potential impacts of new innovations and technologies?
- How does a seaport plan a roadmap to a digitalised seaport?

RO2. Determine the relevance of traditional Value Stream Mapping (VSM) tools and the means by which they can be adapted for seaport data collection and mapping.

RO3. Develop an innovative range of data visualisation tools that are more relevant for seaports. These tools are used to determine both their current Industry 4.0 readiness and implementation plans to leverage an ideal operating future state and the roadmap to "realise" it.

1.2 Statement of the Problem

The widespread adoption of the Internet of Things (IoT), Industry 4.0, and Big Data Analytics (BDA) is profoundly transforming global manufacturing, financial services, and the automotive sector. The automotive and manufacturing sectors have benefited from a strategy of flexible automation that deploys intelligent robotics to precisely automate repetitive manual processes. Myriads of real-time data are collected from automated processes in each of the production stages; Press Shop, Body Shop, Paint and Final Assembly Shop are analysed to populate contextual information monitor and improve operational performance by optimising production flow and reducing losses that are incurred from passive inventory management (Konstantinidis, Mouroutsos, and Gasteratos, 2021). Industry 4.0 facilitates the sensing processing and integration of technologies across the production stages and the wider supply chain.

Blockchain technology was introduced in 2008 and it may be applied to overcome potential cybersecurity threats to achieve intelligence in Industry 4.0 (Javaid, Haleem, Singh, and Suman, 2021). It is regarded as a distributed always available, irreversible, temper-resistant, replicated public repository of data (Chowdhury et al., 2018). This approach has attracted significant business and academic interest covering a range of functions, document verification and financial transactions (Demirkan, Demirkan, and Mckee, 2020). Blockchains utilise sophisticated mathematics and innovative software technologies that are extremely difficult to manipulate due to the success of cryptographic techniques (Demirkan, Demirkan, and Mckee, 2020). Blockchain software packages are commercially available from a range of Information Technology service providers.

Blockchain is defined in the literature as a *'defined database of records or public ledger of all transactions or digital events that have been executed and shared among participating parties'* (Demirkan, Demirkan, and Mckee, 2020, p. 190). Blockchain technology facilitates secure cryptographic functions to share data in a secure format, preventing any form of editing by other parties in the blockchain network. The advantages of blockchain technology are based on its distributed and immutable characteristics and cryptographic functions. This provides proof of the authenticity of any particular document stored within the confines of the blockchain network (Chowdhury et al., 2018). The two most commonly utilised forms of blockchain, are public or private in scope.

A public blockchain is when each participant can read the content, and populate transactions, and everybody is involved in creating the consensus algorithms by the issuing of Proof-of-Work (PoW) and Proof of Stake (PoS). A public blockchain does not require a central register, or a trusted third party (Chowdhury et al., 2018).

The private blockchain is regarded as private in scope if the consensus process can be actioned by a determined number of participants. Private blockchains are more complex in scope (Demirkan, Demirkan, and Mckee, 2020). The write function is authorised (individual/ organisation authentication) by the issuing organisation and the read permission can be public or restricted in scope (Chowdhury et al., 2018). This internal verification process speeds up the communications and transaction process (persistency, validity, and auditability) an essential consideration in sectors that are governed by time-critical decision-making constraints (Demirkan, Demirkan, and Mckee, 2020). This may potentially manifest itself as a sustained competitive advantage.

However, there are some disadvantages to implementing blockchain technology, most noticeably the cost and complexity of implementation (Demirkan, Demirkan, and Mckee, 2020). This operational scepticism has arisen from issues relating to time inconsistency and bias that may occur in existing blockchain consensus mechanisms (Demirkan, Demirkan, and Mckee, 2020). This may limit the suitability of blockchain technologies to small companies and SMEs that are governed by economies of scale constraints.

IoT is widely regarded as a disruptive technology that necessitates its own operational rules. Information itself is becoming an integral part of the value-added services and products offered by a seaport to its customers. The literature suggests that seaports are usually lagging behind in terms of advanced information technology (IT) and fail to fully exploit applied IT/IS for addressing current and future operational challenges (Heilig and Voβ, 2017a).

The scope of these challenges in terms of constraints that assist in explaining the slow pace of innovation is diverse and it is depicted by Figure 2 which is divided into Academia (knowledge creation), Government and Economic Growth, and Industrial Practitioner (profit-orientated).

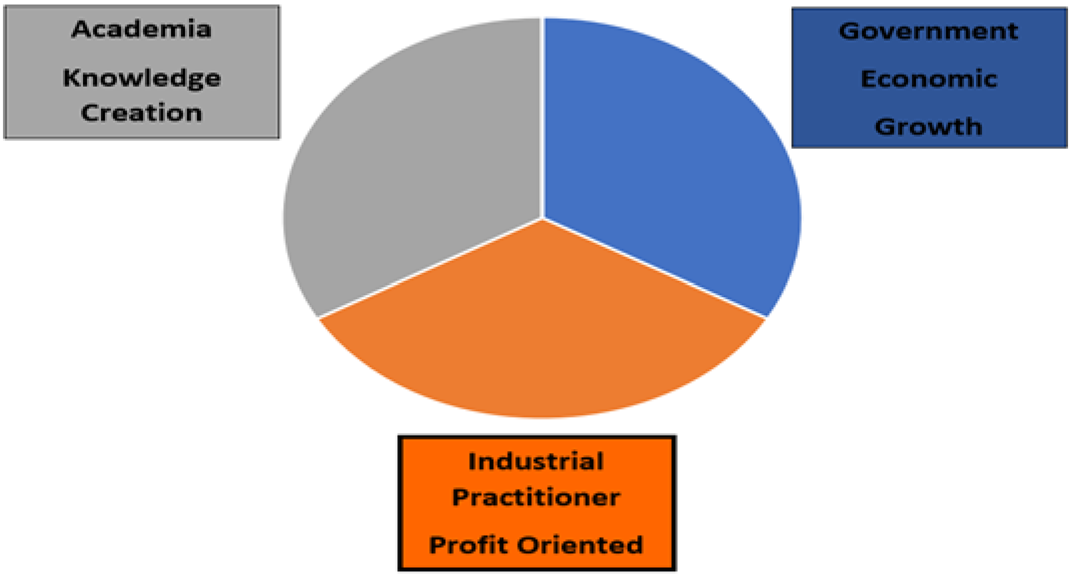


Figure 2: The Innovation Constraints

Increasing volume trade throughput, larger vessels, fluctuating production cycles and peak demands, growing intermodal volumes, and continuous urbanisation (Heilig and Voβ, 2017a). Therefore, change and uncertainty are too prevalent in the maritime sector and greatly hinder long-term strategic decision-making (Wamba and Akter, 2019).

Seaports and container terminals are complicated due to the variety of modes of transportation and their routine operation is impaired by a number of issues: Geographical constraints, infrastructure capacity and information bottlenecks, and accessibility limitations (Heilig and Voβ, 2017a). They are also regarded as fragmented due to the participation of diverse actors: shippers, seaport authorities (PA), terminal operators, import-export companies, carriers, and consignees, who operate in a decentralised manner and make decisions independently (Jacobsson, Arnἂs, and Stefensson, 2020). Seaports are addressing this issue by introducing infra-inter collaboration projects that facilitate communication. They are universally identified as PCS and they have attracted considerable interest from the maritime logistics sector and academia (Heilig and Voβ, 2017a). However, there remain some issues to address that relate to the dynamics of the collaborative relationship, technological maturity and operational relevance, power imbalance, lack of standardisation, and overall willingness to share and participate (data ownership). Seaports by their operating nature are often viewed as conservative and resistant to change due to largely repetitive system processes and an ageing workforce demographic that is limited in its desire to develop an understanding of emerging technologies (Heilig and Voβ, 2017a).

Manual intervention points contribute to more errors and stress for the involved seaport actors, emphasising the need for automatic information exchange between interoperable platforms (Jacobsson, Arnӓs, and Stefensson, 2020). Knowledge extraction and model development from Big Data (BD) and Industry 4.0 is regarded as a major challenge for organisations. Raw data sets are composed of various formats: Text documents, Excel spreadsheets, JPEG files, MPEG images, and statistical models. This new paradigm is termed as data-rich and represents a dramatic transformation from a data-poor paradigm (Venkatasubramanian, 2009). Data warehouses that store vast quantities of raw data sets are termed as data graveyards, lacking human and autonomous integration to populate insightful strategic decisions that potentially deliver a market competitive advantage (Venkatasubramanian, 2009).

BD is characterised by large and high-speed data accumulation that is dependent on new processing methods to transform vast raw data sets into human-readable information, generating actionable insights (Wamba and Akter, 2019).

One of the limitations of Traditional VSM is that addressed process flows are captured at a point in time and are predominantly used around value/waste. Therefore, in cases where the progress has changed, these changes are not documented, meaning that the mapping has limited value within highly dynamic environments. For these types of environments, this adaptation to change is regarded as process flexibility where it adapts to market and product fluctuations (Forno et al., 2014). The viewpoint taken within this thesis is that the modelling framework used in VSM methods can be leveraged to enable deeper insights beyond waste to be mapped.

Value stream maps may be considered too static to be compatible with Industry 4.0 technologies, as the modelling of information flows is quite simplistic. This research proposes the capture of more complicated flows of information within a value stream in order to understand the handling of data across processes. Mapping information flows in this way enables simple models of real-time data handling to be created. This improves traditional static VSM as process-related data visibility is regarded as a fundamental advantage of the implementation of a digitised supply chain (Wang and Wei, 2007; Heilig and Voβ, 2017a).

Information is data that can lead to less operational uncertainties and increased understanding. Information that is timely, accurate, and collated in a relevant and meaningful format is regarded as a fundamental strategic asset. It may facilitate actions, decisions, or results that are either short-term or long-term and influence all facets of the seaport operation. Real-time data is viewed in the literature as a key success factor in determining the level of seaport efficiency and represents a significant concept for future research (Jacobsson, Arnäs, and Stefensson, 2020). Variations in geographical locations, volume, cargo handling, and capacity of seaports are driving the need for additional research in the literature.

The concept of learning to understand has never been so important for the seaport operator. This PhD thesis focuses on addressing the challenges faced by the seaport sector in bridging the gap between applied sector solutions, promising theoretical ideas, and academic literature, thus leveraging a sustained competitive market advantage based on data-driven operational decisions that are time-critical (visualisations of container throughput, information bottlenecks, process integration, information sharing, and measurement of seaport key characteristics).

1.3 Justification of the Research and Research Novelty

The purpose of this study is to develop a new methodology for mapping the current and ideal future state of seaport system operations to facilitate enhanced decision support that is populated by emerging Industry 4.0 embedded technologies (combinations of computer hardware and software designed for a specific function). The novelties of this study are as follows; developing a range of techniques for enhanced data visualisations to populate time-critical decision-support strategies for seaports (berth-allocation, crane availability, vessel turnaround time, container and information flow, and container duration). This will enhance the sustained competitive advantage of seaports that are regarded as lagging behind other sectors in the application of Industry 4.0 technologies to deliver added value to their customers (shippers and end-users). This range of tools has developed in conjunction with insight from global practitioners who provided a critique of their structure, ensuring their relevance to their current operations. It is envisioned that the mapping tools would also fulfil a dual functionality in clarifying a seaport's position in terms of Industry 4.0 readiness, subjected to both digitalisation, automation, and human capital.

1.4 Scope of the Thesis

This thesis is structured into nine interrelated chapters as depicted by Figure 3 on page 15 which highlights the chapter name and a concise overview of its contents.

Chapter 1 Introduction

This chapter introduces the research aims, motivation and objectives in a systematic format. It also provides a background of the research subject and also introduces the structure of the thesis, in terms of a summary of the chapter contents and its novelty.

Chapter 2 Literature Review – The Evolution of Smart Seaports

This chapter delineates the UNCTAD model of seaport evolution from isolated cargo loading and unloading functions to integrated and digitalised logistical hubs that facilitate a total supply chain solution from shipper to end-user. This scope of seaport evolution is further extended to incorporate the concepts of intellectual copyright and cybersecurity, organisational culture, sustainability, competitive advantage, Port Community Systems (PCS), interoperability of heterogeneous systems, and Terminal Operating Systems (TOS).

Chapter 3 Literature Review – The Emergence of Value Stream Mapping, Industry 4.0, and Big Data Analytics

This chapter reviews the current state-of-the-art of VSM tools in terms of descriptive, predictive, prescriptive, and diagnostics analytics in a variety of sectoral applications. This also details the limitations of the VSM method and how previous studies have mitigated these limitations to facilitate impactful research. Due to the limited number of publications regarding the adaptation of VSM methods to map Industry 4.0

readiness states in the seaport sector, the literature review addressed the use of the VSM framework for use in flexible modelling of current state operations and the leverage of an implementation plan that drives improvement activities. The lack of a comprehensive framework to study the Industry 4.0 issues and challenges faced by seaport actors in emerging markets is acknowledged by Sanker, Shankar, and Kumar Kar (2023).

The emerging Industry 4.0 paradigm is reviewed in relation to its historical trajectory, academic definition, and pillars. The key pillars of the Internet of Things (IoT), Cyber-Physical Systems (CPS), are subsequently reviewed in detail.

Chapter 4 Research Methodology

This chapter discusses the subjects of methodology, philosophy, research approach, strategies, and selection that were embedded in the foundations of the research approach. After detailing the research design logic, this chapter offers a justification for the methodological selection to address the research objectives, by systematically reviewing the data collection and analytical methods employed.

Chapter 5 Data Collection and Initial Insights

This chapter details the initial data collection; semi-structured interviews and in-depth interviews of the EDMTs. It also details the seaports, NGOs, and service providers who populated the research sample in terms of management position, experience, and their response rates, whilst justifying the selection of global participants as opposed to local practitioners. A synopsis of their current and future state readiness of Industry 4.0 embedded technology is provided from information contained within the volumes of the semi-structured interviews, through the prism of organisational culture and confidence.

The selection and willingness of the Seaport Authority of Virginia and the North-West Seaport Alliance to participate in further research collaboration are advocated by a concise overview of their operation in terms of its significance to the research aims and objectives. This was reviewed against the concepts of financial investment, employment, capacity, infrastructure, and communication.

Chapter 6 The Application of Empirical Decision-Making Tools (EDMTs)

This chapter underpins the evolutionary and novel nature of the EDMTs, Process Flow Mapping, Supply Chain Data Matrix, Decision Point Analysis, Accuracy Completeness Amplification Mapping, and Key Characteristics. This facilitates a reconsidering of value away from traditional VSM perceptions of waste and efficiency to a more seaport-centric approach that is based on the visualisation of the current and future operating states to enhance integration, visibility, and transparency of systems that convey physical and digital throughput.

Chapter 7 Case Studies Virginia Seaport Authority and the North-West Seaport Alliance

This chapter details a refinement of the EDMTs to adhere to real operational issues experienced by the Seaport Authority of Virginia and the North-West Seaport Alliance (Seattle and Tacoma). The opinions of two senior managers with considerable experience in the seaport sector were ascertained by a detailed process walk-through of the EDMTs. Their recommendations were incorporated into the prototype versions of the EDMTs, enhancing their relevance to real-world scenarios.

Chapter 8 Discussion

This chapter delineates the overall observations and results obtained from the previous chapters in response to the research aims and objectives outlined in Chapter One. This constitutes a review of the barriers identified by the research to Industry 4.0 exploitation within the seaport sector and discusses the applied method of the EDMTs to bridge the gap between current and futures states. It also reviews the future direction of the research by focusing on the impact of the emerging Industry 5.0 and Made in China 2025 initiatives that are underpinned by human collaboration with technology.

Chapter 9 Conclusion and Future Research

Chapter 9 concludes the work in this PhD thesis by summarising the academic contributions subject to the research aims and objectives, detailing the limitations of the research, and suggesting of new aspects that may constitute future research projects.

References

This section follows the Harvard System of referencing that is required by Liverpool John Moores University's academic registry. It provides an inventory of all references utilised throughout the chapters contained within this PhD thesis.

Appendices

A number of appendices are also provided, offering a range of support materials: Examples of the covering letter and informed consent to participants, questions to practitioners, data collection templates, case study proposals, NVivo code casebook, and academic publications.

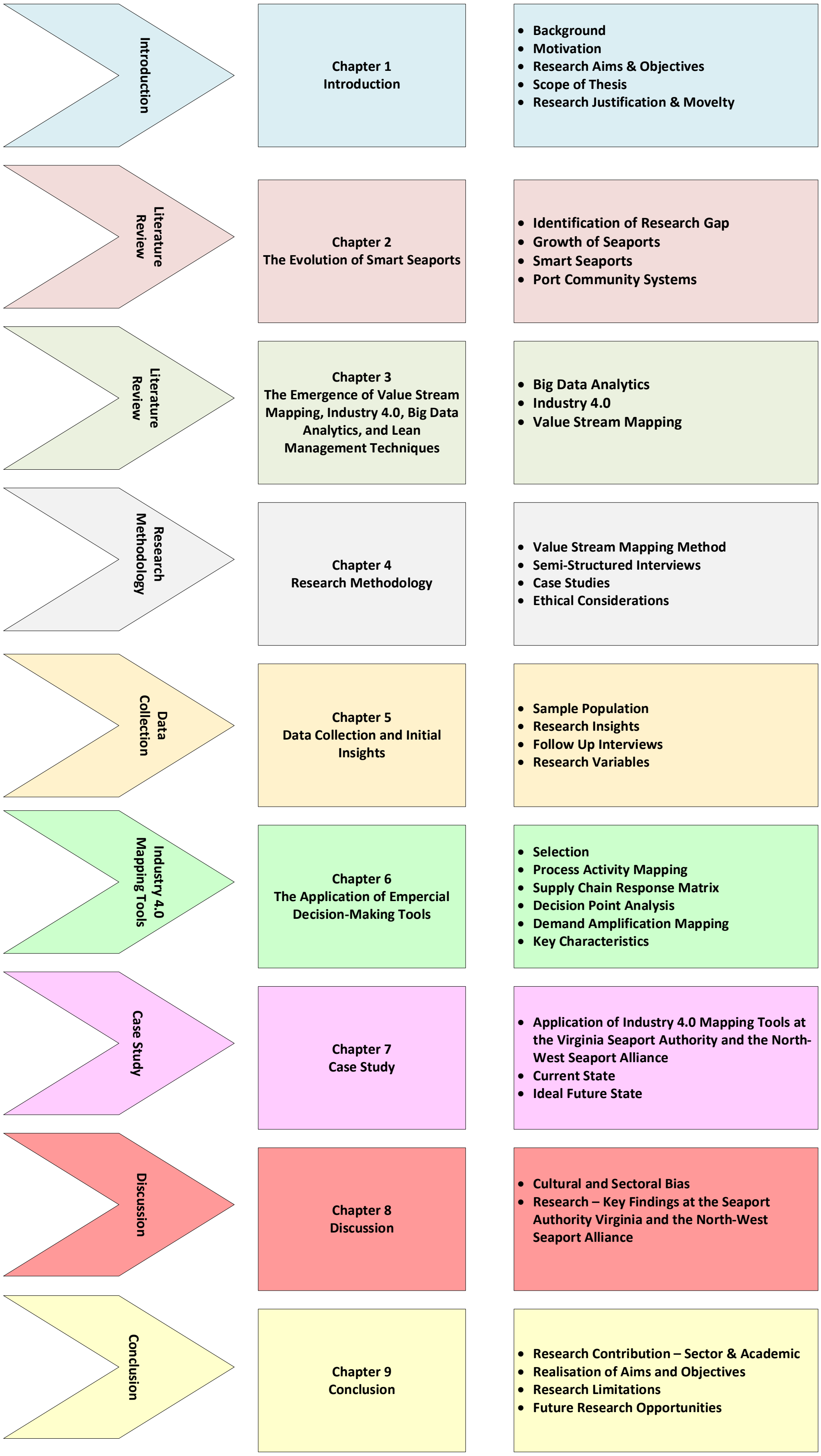


Figure 3: *Scope of the PhD Thesis*

1.5 Insights & Summary

This chapter introduces the scope of the PhD research thesis in terms of its justification from the perspective of both the practitioners and academia, reflected by the wider contribution in terms of a conference paper to the development of research aims and objectives. The structure of the thesis is delineated by chapter content and their relevance in addressing the research objectives. The justification for the research and its novel contribution to the literature and is underpinned by enhanced data visualisations of seaport system processes to support time-critical decision support tools. The next chapter (Chapter 2: Literature Review – The Evolution of Smart Seaports) will set out the current state-of-the-art to determine any potential gaps in the literature.

CHAPTER 2: LITERATURE REVIEW – THE EVOLUTION OF SMART SEAPORTS

2.0 Introduction

It is essential that seaports understand their current state with regard to the Industry 4.0 paradigm and its future application to enhance service levels. This requires a clear understanding of their existing infrastructure, knowledge base, market orientation, service provision, customer satisfaction, and functionality (traditional cargo handling, fully and semi-automated, and smart seaport). There is a growing interest in the smart seaport concept in both academic and professional literature, however, it is limited in terms of a definition (Belmoukari, 2023). The early mapping exercises utilised the structured approach that advocated the UNCTAD model which categorised seaport development based on prescriptive stages. However, this model is limited in that it fails to take into account the evolution of working cultures, health, safety, environment, ownership, and governance (Belmoukari, 2023). This chapter attempts to delineate a seaport's current state operations from the perspectives of evolution from traditional cargo handling methods to smart operations, organisational culture, sustainability, and data governance and ownership that drive strategic decision-making.

2.1 Background to Seaport Operations

A seaport is regarded as *"a geographical area where ships are brought alongside land to load and discharge cargo – usually, a sheltered deep-water area such as a bay of river mouth and often comprise multiple terminals devoted to a particular type of cargo handling"* (Stopford, 2019, p.81).

Seaports operate in extremely conservative, complex, fragmented, hostile, and volatile trading markets that are being slowly driven by processes of innovation, continuous development, and intra/inter seaport competition, ensuring a market competitive advantage through sustainable growth and quality of key value-added logistical, port-centric, and JIT services (Marlow and Paixâo- Casaca, 2003; Bichou and Gray, 2004; Paixão-Casaca, 2005; Pettit and Beresford, 2009; Mondragon et al., 2012; Bisogno et al., 2015; El-Sakty, 2016; Botti et al., 2017; Lee et al., 2018; Irannezhad, Prato, and Hickman, 2020). The complexity of the seaport may also relate to its operating environment which consists of a national and globalised socio-economic-political system, with diverse national and international legislative requirements (Perego, Perotti, and Mangiaracina, 2011; Lee et al., 2018). Fragmentation of operations limits cooperation between actors and the sharing of knowledge (Irannezhad, Prato, and Hickman, 2020). According to Baron and Mathieu (2013), a typical French seaport will require the involvement of 11 diverse actors when processing a single consignment through the maritime supply chain. Seaports are not a stand-alone phenomenon as they present an important platform and node in the international maritime supply chain network and act as an economic catalyst that stimulates trade and economic growth in the form of GDP (McLaughlin and Fearon, 2013; Bălan, 2018; Chen et al., 2019).

It is widely reported that 80% of international trade, by volume and 70% in terms of value is transported by sea, given its unique ability to carry bulk consignments at a relatively low cost per mile (González - Sánchez et al., 2015; Olesen et al., 2015; Bălan, 2018). Table 1 presents the growth of seaborne trade from 1970 and concludes in 2016 when the total volume of seaborne trade reached a record high of 287 million tons UNCTAD (2017 cited in Bălan, 2018).

Table 1: *Growth of Seaborne Trade 1970-2016 (Per Millions of Tons Loaded)*

Source Bălan (2018)

Years	**Oil and Gas Cargo**	**Main Bulk**	**Dry Cargo**	**Combined Total of Cargo**
1970	1440	448	717	2605
1980	1871	608	1225	3704
1990	1755	988	1265	4008
2000	2163	1295	2526	5984
2005	2422	1709	2978	7109
2006	2698	1814	3188	7700
2007	2747	1953	3334	8034
2008	2742	2065	3422	8229

2009	2642	2085	3131	7858
2010	2772	2335	3302	8409
2011	2794	2486	3505	8785
2012	2841	2742	3614	9197
2013	2829	2923	3762	9514
2014	2825	2985	4033	9843
2015	2932	3121	3971	10023
2016	3055	3172	4049	10287

The competitiveness of a seaport is fundamentally dependent on the following variables: cost, efficiency, productivity, reliability, availability, security, safety, and quality of the logistical services offered to their customer base (Marlow and Paixão-Casaca, 2003; Heilig and Voβ, 2017a). To leverage sustained competitive advantages major seaport operators are beginning to utilise smart technological platforms that consist of Big Data (BD) and Industry 4.0, offering the potential to formulate insightful decisions that are disseminated through real-time communications (Bălan, 2018). Seaport Authorities (PAs) are increasingly utilising the functionalities of Information and Communication Technology (ICT) to facilitate, coordinate, and synchronise the operation of the diverse seaport actors (Paixão-Casaca, 2005; Notteboom et al., 2015). However, it is argued by Harris, Wang, and Wang (2015) that the adoption of advanced ICT platforms/smart technology is relatively a slow progress when reviewing the operation of multi-modal transport in Europe. This is further emphasised by González-Sánchez et al., (2015) and de la Pēna Zarzuelo, Soeane, and Bermúdez (2020) who suggest that the maritime sector is substantially lagging behind with regard to the implementation and sustained operation of Industry 4.0 embedded technologies and that it is sporadic in terms of its implementation, being confined to major seaport operators.

The quality of transport links between the hinterland and the foreland, as well as collaborative relationships within terminal operators and shipping lines, are also viewed very highly by existing and potential new customers (Paixão-Casaca, 2005; McLaughlin and Fearon, 2013; Heilig and Voβ, 2017b). Customer demands have increased the pressure on seaport operators to reduce costs and profit margins, whilst increasing service performance, offering an integrated functionality of visibility and traceability, in a real-time format (Marlow and Paixão-Casaca, 2003; Baron and Mathieu, 2013; Bălan, 2018). The increase in demand is referenced within a study conducted by the European Union (EU) which reported that the inward movement of goods increased by 1.4% and outwards by 1.3%, in the fourth quarter of 2016 (Sarabia-Jácome et al., 2013). It is suggested that seaports are essential components of sustainable supply chains and are vital to the economic well-being and growth of their regional and national urban locations (Cullinane and Song, 2002; Lam and Song, 2013).

The evolving nature of seaport operations is shaping an emerging academic discipline, largely due to the vital role they play as a facilitator of international trade and logistical services, in the era of trade liberalisation and globalisation (Woodburn, 2007; Lam and Song, 2013; González-Sánchez., 2015). There is a significant lack of empirical studies that document the current position of the seaport to Industry 4.0 readiness and the road map required to leverage an ideal future operating state, despite the realisation that ICT now represents a critical success factor in determining seaport competitiveness that is underpinned by real-time strategic decision-support capabilities (Min, 2022).

2.2 Smart Seaports

The term "Smart" may be systematically traced back to the origins of sustainability and the utilisation of green concepts to regulate and manage industrial output. This term has been coined by the sector as the "*greening of ports"* (Hollen, Bosch, and Volberda, 2015). Smart seaports have systematically evolved and are in correlation with the development of innovative technological platforms. This justification for investment in the development of smart seaports relates to the gaining of a sustained market competitive advantage, it is currently referred to as a key strategic policy within the confines of seaport management (Cepolina and Ghiara, 2013). Therefore, the concept of a smart seaport is currently viewed as a trend for the future and a long-term strategic goal of the maritime sector (El-Sakty, 2016). A smart seaport is deemed to offer the operator the functionality of real-time communication between actors ultimately enabling a process of dynamic collaboration (Wu et al., 2013; Gnimpieba et al., 2015). The multitude of real-time communication functionality between seaport actors is a data-rich environment that underpins process integration this is further advocated by Figure 4 depicting a range of devices; sensors, smart containers, RFID tags, and autonomous front-gate process control.

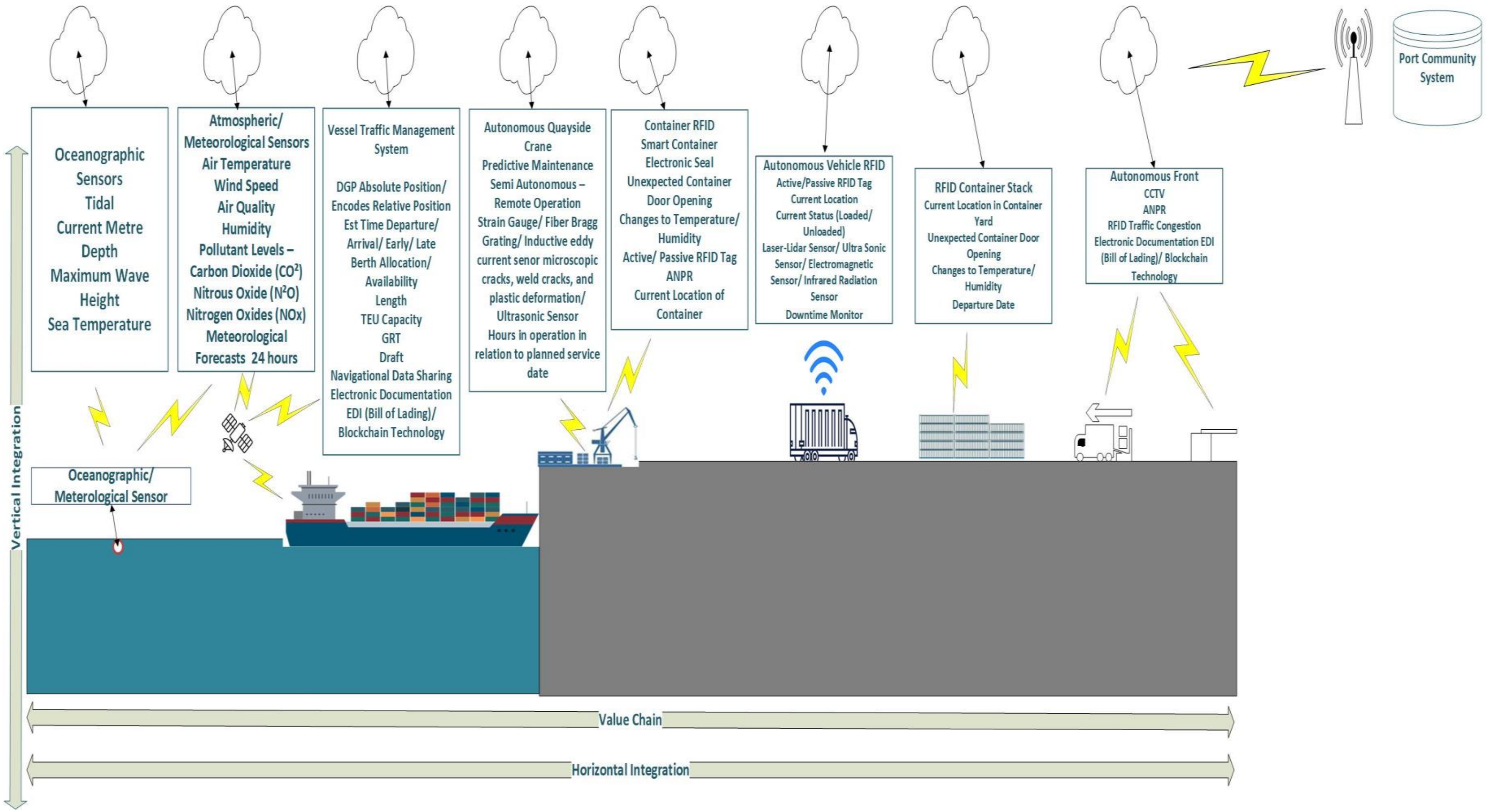


Figure 4: *Smart Seaport Integration*

2.3 Evolution of the Smart Seaport Concept

Seaports are viewed as a transport and logistics infrastructure that acts as a catalyst for regional, national, and international economic growth (Sarabia-Jácome et al., 2013; Lee et al., 2018). This is reflected by the suggestion that major cities and industrial centres have developed adjacent to coastal areas to take advantage of international maritime trade (Woodburn, 2007; Lam and Song, 2013).

The smart seaport concept is defined as "*all parts of the smart terminal operations, warehousing, logistics, yard, and seaport transportation are closely connected through the wireless network or special network, providing all kinds of daily information for production supervision, related government departments and seaport shipping enterprises*" (Jović, et al., 2019, p. 1386).

An automated seaport refers to a process whereby manual labour is fully outsourced to autonomously operating technology (Clemente et al., 2023). Seaport automation exists in two formats; fully automated where the container is automatically handled from the dockside to the pickup point and semi-automation where the operation is automated at the stacking area (Notteboom, Pallis, and Rodrigue, 2022).

The interrelationship of the drivers of innovation (Organisational Culture, Efficiency, KPIs, Health and Safety, Regulation, Standardisation, and Technology) are depicted in Figure 5, they are egarded as the most important aspects of a cultural and technological revolution that a seaport will encounter in a cycle of continuous development. This process of continuous development attempts to meet the increasing interrelated demands of their customer base for efficiency, economic growth, and security (Sarabia-Jácome et al., 2013).

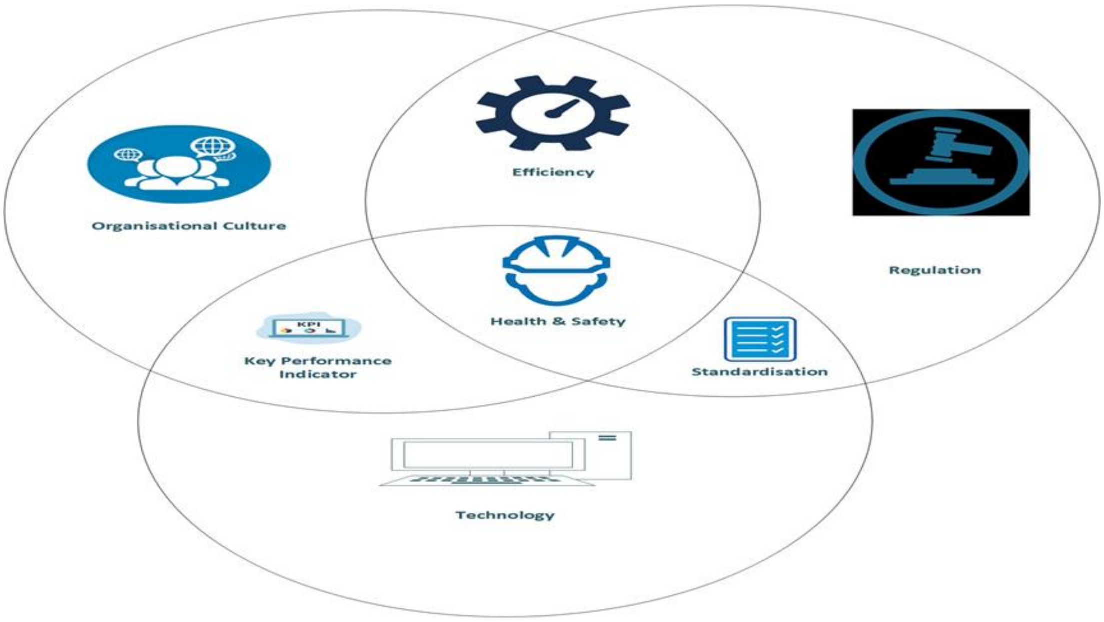


Figure 5: *Interrelationship of Innovation at Seaports*

It is concluded that seaports must continue to evolve to meet future throughput forecasts that are expected to continue in the upward trend of unprecedented economic growth (Woodburn, 2007; Sarabia-Jácome et al., 2013). The synergy of emerging technology in the form of IoT, cloud computing, and BD will assist seaports in the evolution process to a smart operation and integrated network (Sarabia-Jácome et al., 2013; Fernández et al., 2016).

A comparison of traditional and automated/ smart container terminal operations is provided in Table 2, it focuses on the transitional characteristics from manual to semi-automated operations (reduced human integration within the physical movement of cargo and the flow of information).

Table 2: *Comparison of a Traditional and Smart Seaport Container Terminal*

Adapted from Yang et al., (2018)

Container Terminal		
Characteristics	**Traditional Operation**	**Automated/Smart Container Terminal**
Operating Subjects	Humans and Machines	Autonomous Systems and Equipment
Quay Side Operations	Quayside Cranes	Semi-Automatic

		Fully Automatic Quay Side Cranes Controlled Remotely
Horizontal Transportation	Container Trucks Straddle Carriers	Container Trucks Straddle Carriers Automatic Guided Vehicles
Yard Operations	Rubber-Tyre Gantry Cranes	Automatic Rail Mounted Gantry Cranes
Operation Efficiency	Labour Intensive Operation Limited Efficiency Potential for Human Error Low Dispatching Efficiency/ Vessel Turnaround Time	Techniques/Information-Based Operation High Automation and Intelligence Improvable Efficiency and Productivity Intelligent and Coordinated Dispatching Efficient Asset Management
Economic Efficiency	Low Construction Costs Low Maintenance Costs High Labour Costs Potential for Industrial Unrest/ Resistance to Change Mentality High Transportation Costs High Administrative Costs Low Economic Costs (Economies of Scale benefits)	High Infrastructure Construction Costs High Maintenance Costs/ Up-Skilling of Employees High Implementation Costs Potential of Technology Becoming Obsolete Low Labour Costs Improved Health and Safety Management Low Transportation Costs (Cost per Mile)

		Low Administration/ Utilisation of Digital Documentation High Economic Benefits (Economy of Scale Benefits)

The smart seaport concept is essentially based on two fundamental processes: The automation and digitalisation of seaport operations and equipment and the systematic interconnection of the diverse key stakeholders/actors involved in the seaport/ supply chain operation (Sarabia-Jácome et al., 2013).

The division of seaports into defined stages of evolution was undertaken by UNCTAD (1992a) and led to the development of a conceptual model that is adapted in Figure 6 on page 29 (Beresford et al., 2004; Lee et al., 2018). It has been criticised in the literature due to the perceptions of oversimplifications and the dependency on discrete steps relating to the evolution of the seaport operation (Kaliszewski, 2018; Lee et al., 2018). It is argued by Beresford et al., (2004 cited in Kaliszewski, 2018) that the UNCTAD models fail to acknowledge factors that determine the overall level of commercial facilities provided by the seaport.

- **First Generation Isolated Seaport Pre-1960s**

It is viewed that a first-generation seaport is solely engaged in the provision of basic services, consisting of stevedoring of freight between land and sea modes of transportation (Marlow and Paixão-Casaca, 2003; Kaliszewski, 2018; de la Pēna Zarzuelo, Soeane, and Bermúdez, 2020). This was also perceived as an isolated function with limited cooperation between the seaport management and the surrounding municipality (Beresford et al., 2004). This is also advocated by de la Pēna Zarzuelo, Soeane, and Bermúdez (2020) that integration is only prevalent within the confines of the seaport terminal, prior to the era of globalised supply chain and the erosion of physical barriers to market penetration.

- **Second Generation Expanded Seaport Post 1960s**

The advent of containerisation and intermodal transport in the 1960s has revolutionised the concept of international trade and logistics, facilitating the demand for efficient cargo and information flows, while driving a process of continuous modernisation (Heilig, Voβ, and Stahlbock, 2019). Initially, this put added pressure on the infrastructure of seaports as they struggled to manage increasing levels of containerised throughput (Heilig, Schwarze, and Voβ, 2017). This, in turn, was a significant factor in the development of early EDI systems and it is frequently regarded as the catalyst of digitalisation in the maritime industry (Heilig, Schwarze, and Voβ, 2017). Early versions of EDI and IT support were characterised by systems that delivered isolated functionality that was restricted to the basic administrative requirements of internal stakeholders (Tijan, Aksentijević, and Čišić, 2014; Heilig, Schwarze, and Voβ, 2017).

- **Third Generation Container Seaport 1980s**

The advent of smart technology has impacted on the role of PCS, enabling the development of a third-generation PCS that attempts to service coproduction and enhance the process of value cocreation for both stakeholders and consumers (Tijan, Aksentijević, and Čišić, 2014; Zhang, Xue, and Dhaliwal, 2016; Nota, Bisogno, and Saccomanno, 2018). A single mode of raw data submission will enable a faster response to the demands of fluctuating and uncertain trading markets, reducing the complexity of seaport networks, and enhancing their competitive advantage in relation to other modes of logistical services (Nota, Bisogno, and Saccomanno, 2018).

- **Fourth Generation Integrated Seaport 1990s**

A fourth-generation seaport is based on the development of mutually beneficial partnerships that are flexible in terms of their duration, short, medium, or long. They enable the sharing of knowledge/expertise, and technological transfers, and provide access to additional sources of capital, connected by a network of Internet-based platforms (McLaughlin and Fearon, 2013; Tijan, Aksentijević, and Čišić, 2014). It is advocated by Lee et al., (2018) that this concept resembles the functions of a knowledge hub, enabling the dissemination of information to all interested seaport actors. However, it must be acknowledged that achieving mutual benefits for diverse seaport actors/stakeholders is often problematic and complex due to differing interests, and security considerations (McLaughlin and Fearon, 2013). There is a consensus within the literature that the Fourth Generation Model had failed to reflect the contemporary seaport functions and the latest technological advancements that are perceived as being implemented at a rapid rate, requiring the continued refinement of the UNCTAD seaport evolution model (Lee et al., 2018).

- **Fifth Generation Smart Seaports**

A PCS is viewed as an enabler in the development and deployment of smart technology that is agile in its performance, altering the role of the seaport actor to that of an organisation providing services and value to other organisations (actors) in an interrelated network (Nota, Bisogno, and Saccomanno, 2018). This process may be viewed as a Service Oriented Architecture (SOA) that facilitates the highest level of integration and implementation of smart technologies in the management of a PCS (Tijan, Aksentijević, and Čišić, 2014; Nota, Bisogno, and Saccomanno, 2018). At this stage, the administration of the seaport is undertaken in a digitalised format with the eradication of paper documentation (Tijan, Aksentijević, and Čišić, 2014). The role of the Fifth Generation Smart Seaport is viewed by Flynn et al., (2010 cited in Lee et al., 2018) as being a customer-centric seaport, managed in relation to the environmental, social, and economic concerns of the local community. It is advocated by Lee et al., (2018) that a Fifth Generation Smart Seaport may ultimately become a benchmark within the seaport sector in terms of determining the level of evolution and development that underpins sustainability and commercialisation.

First Generation – Isolated Seaport Pre 1960s

- An interface between land and sea
- Mechanical operations and labour intensive
- Limited commercial activity – No value added services
- No cooperation with surrounding municipality to support actors diverse operations
- No nodal connectivity transport and trade operations

Second Generation Expanded Seaport Post 1960s

- A transport, industrial, commercial service centre
- Commercial activities
- Closer relationships between seaport actors and municipalities
- Utilisation of early versions of EDI systems

Third Generation Container Seaports Post 1980s

- Global containerisation
- Dynamic nodes in intermodal production/ distribution networks
- Integrated transport centres and logistics platforms

- **Fourth Generation Container Seaport Post 1980s**

- Worldwide alliances of containership owners
- Centralised administrative office
- Servicing the international market (globalisation)
- Application of Information Communication Technology (ICT)

Fifth Generation Smart Seaport Post 2010

- Skilled and well-educated workforce – upskilling
- Intelligent infrastructure – Automatisation, Big Data Analytics (BDA), Internet of Things (IoT), Cloud Computation, and Cyber Physical Systems
- Knowledge development and sharing – Port Community Systems
- Optimised operations
- Maximisation of resources
- Enhanced resiliency economic – political – market uncertainty
- Strengthening the decision-making process

Figure 6: *The Evolution of the Seaport Container Terminal*

Adapted from Molavi, Lim, and Race (2019)

2.3.1 Intellectual Copyright and Cybersecurity

Seaports by their very nature are conservative and are viewed as being reluctant to disclose confidential and sensitive information that relates to their business model and operations (Marlow and Paixão-Casaca, 2003; Sarabia-Jácome et al., 2013; Vanelslander, Sys, and Carlan, 2016). The issue of data ownership is considered extremely political and controversial and has been defined as the data sovereignty concept. This concept relates to the ability of the data owner to decide how to disseminate their data and how it is utilised (Sarabia-Jácome et al., 2013). There is a wide range of cybersecurity threats posed in a digitalised and smart seaport operation and they are summarised in Table 3.

Table 3: *Review of Cybersecurity Threats*

Adapted from Heilig and Voβ (2016)

Area of Smart Technology	**Nature of Security Threat**	**Implementation of Possible Countermeasures**	**Source in Academic Literature**
Radio Frequency Identification (RFID)	Unauthorised Tracking/Monitoring of Status Tampering/ Physical Removal of Tags Counterfeiting Cloning of Tags Replay Attacks Denial of Service	Privacy Protection/ Authentication of User Control of Access (Passwords) Data Encryption Encryption of Tag Identification Detection of Foreign Devices Temporary Deactivation of Tag	Juels (2006 cited in Heilig and Voβ, 2016) Riebeck (2006 cited in Heilig and Voβ, 2016)
Wireless Sensor Network (WSN)	Transmission Disruption/ Interference/ Jamming of signal Denial of Access Communication Attacks Unauthorised Commands/Control Network Attacks	Anti – Fraud Software Authentication and Identification Control/ Password for Remote Access System Monitoring Cryptographic of Sensitive/ Confidential Data Intrusion/ Unlawful Access Detection	Wang et al., (2006 cited in Heilig and Voβ, 2016)
Internet of Things	Eavesdropping/ Unlawful Access and Control	Detection of Foreign Devices	Weber (2010 cited in Heilig and Voβ, 2016)

(IoT)	Restriction of Access Tampering of Nodes		Roman et al., (2013 cited in Heilig and Voβ, 2016)
Cloud Computing (CC)	Eavesdropping/ Unlawful Access and Control Restriction of Access Unlawful Access by Third Party	Authentication and Identification Control/ Password for Remote Access System Monitoring Cryptographic of Sensitive/ Confidential Data Intrusion/ Unlawful Access Detection Detection of Foreign Devices Attempting to Gain Access	Takabi et al., (2010 cited in Heilig and Voβ, 2016) Sabashini and Karitha (2011 cited in Heilig and Voβ, 2016) Zissis and Lekkas (2012 cited in Heilig and Voβ, 2016)
Mobile Cloud Computing (MCC)	Data Breaches/ Sensitive/ Confidential Data Impersonations/ Unlawful Access Man-In-The-Middle Attacks Unlawful Use by a Third Party Eavesdropping – Interception of Signal Application Tampering	Authentication and Identification Control Restriction of Access (Management Level) Cryptographic Measures Anti-Fraud Software Data Masking/ Anonymous Referencing of Data	Khan et al., (2012 cited in Heilig and Voβ, 2016)

Location-Based Services (LBS)	Unlawful Data Disclosure to Third Party	Need to know Principle/ Access by Level of Management Policy Verification/ Statement of Use Data-Centric Access Control	Duckham and Kulik (2006 cited in Heilig and Voβ, 2016) Krumm (2009 cited in Heilig and Voβ, 2016)

2.3.2 Organisational Culture of Seaports

Established actors and organisations that are satisfied with the status quo may be uncomfortable with the flow of sensitive and confidential information. A process that requires a shifting of organisational cultures and deregulation of boundaries (Hollen, Bosch, and Volberda, 2015).

The deregulation of boundaries may be addressed by the flow of information between all interested seaport actors, highlighting the goals and aims of the smart seaport project, documenting the perceived benefits, and the underlying logic behind the integration of the project (Petrikina et al., 2017). It is argued by Kotter (1997 cited in Petrikina et al., 2017) that it is essential to justify the necessity for change and understanding through the shared ownership of the vision, mission, and strategy of the smart project. This concept is extended by Rogers (2003, cited in Petrikina et al., 2017) who suggests that potential disadvantages of the smart seaport project should also be addressed in the form of full disclosure, contained within a precise implementation plan.

However, the implementation of advanced ICT infrastructure (IoT, BD, CC, and autonomous vehicles) may have the potential for a disruptive impact on seaports and maritime transport (Bălan, 2018). The business functions that are deemed most likely to be susceptible to disruption under this scenario are productivity increase, overall cost reduction, and service quality improvement (Bălan, 2018). It is commonly regarded that the size of the organisation will influence the level of ICT implementation, with larger enterprises experiencing a high level of ICT when compared to SMEs (Perego, Perotti, and Mangiaracina, 2011).

The role of education and training is viewed as a fundamental concept in the innovation and deployment of smart technology in the maritime sector, providing that it is adapted to match fluctuating skill attributes and manage challenges and opportunities. It is also inferred that the dissemination of education will be as important as the technological innovation itself, suggesting a shift of emphasis and focus is required (Alop, 2019). The first three Industrial Revolutions were subjected to a tolerable pace of innovation that was sustained by industry, in terms of managing its perceived challenges and opportunities. However, the Fourth Industrial Revolution is characterised by a different set of attributions, most noticeably a fast pace of innovation. This implies that the seaport sector is struggling to accommodate the challenges and opportunities provided by smart technological platforms, limiting the ability of the educational system to exploit its potential (Alop, 2019).

2.3.3 Sustainability of Smart Seaports

Seaports are not static in their evolutionary process and their operating strategy was originally dominated by a focus on productivity and service levels (Marlow and Paixão-Casaca, 2003; Chen et al., 2019). This strategy neglected issues such as climate change and environmental pollution, clearly lacking the ethos of sustainable development. It is estimated that approximately 70% of the world's marine emissions are produced within the confines of coastal waters, adversely damaging the local environment (Chen et al., 2019). However, it is argued by Lam and Notteboom (2014 cited in Lee et al., 2018) that this approach is no longer prevalent in the seaport sector, with the management strategy now focusing on environmental performance, social-sustainable development, security, safety, and operational efficiency that represent suitable variables to be monitored by remote sensor technologies, producing real-time decision support. The range of data-driven decision support variables is further elaborated by Table 4 and suggests a strategy based on social, economic, and environmental considerations.

Table 4: *Challenges Impacting Sustainability on Seaport Management*

Adapted from Molavi, Lim, and Race (2009)

Challenges Impacting Sustainable Seaport Management	
Operations	Congestion, Delays, Operating Errors, and Lack of Information Sharing amongst Diverse seaport Actors.
Environmental	Air, Water, and Noise Pollution, Waste Disposal, Construction, and Expansion of Seaport Infrastructure.
Energy	Increasing Energy Consumption, Increasing Energy Costs, and Energy Disruption Impact on Seaport Operations,
Safety	Berthing Impacts, Vessel Collision, and Striking While at Berth.
Security	Armed Robbery, Cybersecurity Issues, Unlawful Acts – Insider Theft, Stowaways – People Trafficking, Smuggling of Illegal

	Substances, Conduit for Moving of Weapons, and Terrorist Attacks.

2.3.4 The Competitive Advantage of Smart Seaports

The sharing of operational seaport data is fundamental in improving the overall effectiveness of the decision-making process and it is regarded as a tangible asset that ultimately creates value-added services (Perego, Perotti, and Mangiaracina, 2011; Sarabia-Jácome et al., 2013; Zerbino et al., 2018; Heilig, Voβ and Stahlbock, 2019). It is suggested by Panayides and Song (2008) that value-added services are a measure of the seaport's ability to add service that it provides in the wider context of facilitating further objectives (data or physical assets) of the supply chain partners. The smart seaport concept allows data to be generated, collected, analysed, and converted into meaningful information. This may be disseminated by the functionalities offered by the operation of a PCS network. The corporate image of the organisation may be improved by the implementation of smart technology, resulting in an increased market reputation in terms of sustainability, innovation efficiency, productivity, and lower perceived security risks (Perego, Perotti, and Mangiaracina, 2011). The concept of supply chain visibility and traceability is also enhanced by the introduction of smart technology (RFID tags), enabling more effective and efficient management of cargo throughput (Perego, Perotti, and Mangiaracina, 2011). In many respects, the collection and organising of data enable the formation of new conceptual knowledge that may potentially be regarded as a market competitive advantage in terms of adapting business models improving customer services, operational processes, and costs (Heilig, Voβ and Stahlbock, 2019).

2.4 Port Community Systems

The EU Directive 2010/65 EU consists of a recommendation for the adoption of digital procedures concerning documentation and information relating to the throughput of goods and services in the seaport operation (Bisogno et al., 2015). The fundamental aim is to facilitate the relationship between the diverse actors that operate within the seaport hinterland by the process of information flow, whilst systematically improving the efficiency of the PCS, to leverage cost savings in terms of transactions and duplications, and faster throughput rates (Baron and Mathieu, 2013; Bisogno et al., 2015).

A PCS is defined as a neutral open electronic platform that connects the various forms of systems utilised by the seaport actors (public and private stakeholders) in a secure environment that is exemplified by Figure 7 (Baron and Mathieu, 2013; Bisogno et al., 2015; Carlan, Sys, and Vanelslander, 2016; Nota, Bisogno, and Saccomanno, 2018; Zerbino et al., 2018).

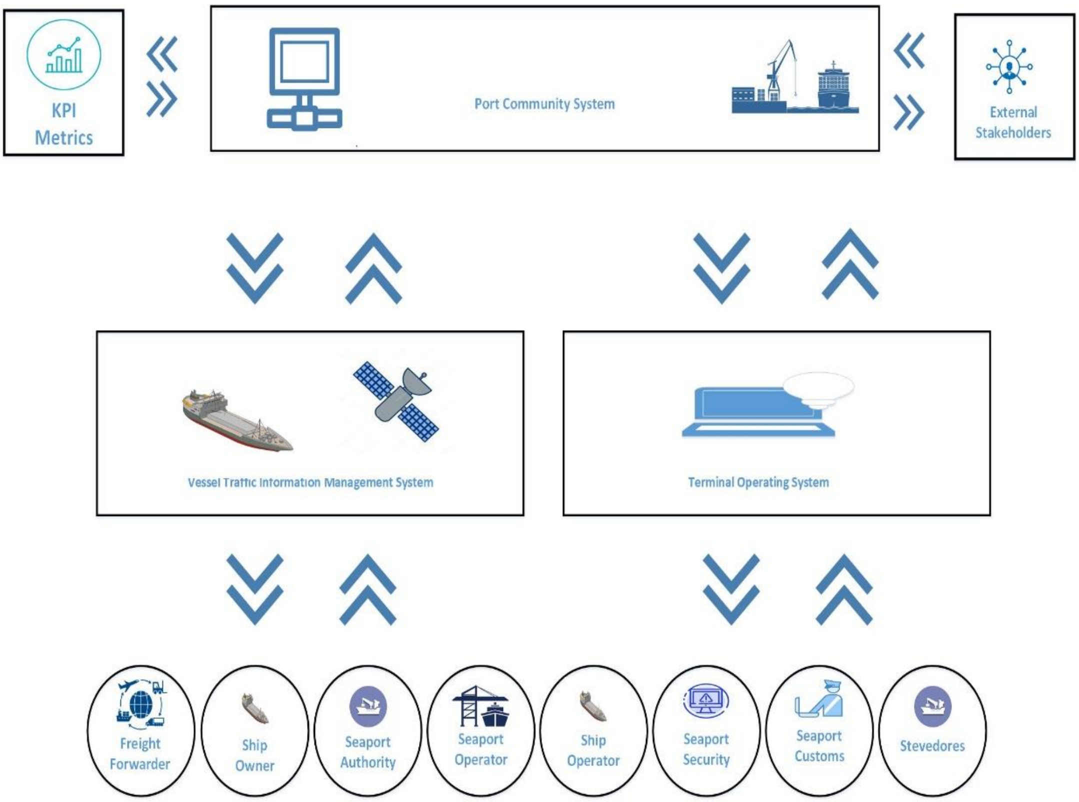


Figure 7: *The Digitalised Seaport Operation*

The membership of a PCS is depicted in Figure 7, and it generally consists of the following diverse groups, ship-owners, handlers, road, rail, inland waterway carriers (intermodal transport operators), warehouse owners, trading partners (customers), and government organisations (customs and immigration enforcement). The availability, accessibility, and overall quality of a PCS are still viewed by the maritime industry as essential for achieving increases in market growth, efficiency in terms of asset management, faster response times, agility, visibility, continuous flows of secure information, and traceability (system integration) (Baron and Mathieu, 2013; Heilig, Schwarze, and Voβ, 2017).

2.5 Evolution of Port Community Systems

The functionality of a PCS has evolved from connecting multiple information systems under the governance of a bilateral network, serving as a central information hub, to providing a tool that facilitates the exchange of information to generate added value within the supply chain (Baron and Mathieu, 2013; Carlan, Sys, and Vanelslander, 2016; Nota, Bisogno, and Saccomanno, 2018). Table 5 indicates that the utilisation of a PCS is now widespread across Europe's major seaports, based on their increased multi-stakeholder complexity and drive towards enhanced digital supply chain traceability and visibility.

Table 5: *An Overview of Current Port Community Operators*

Adapted by Baron and Mathieu (2013)

Country	System	Company /PCS Operator	Number of Seaports	Organisation/ Ownership
UK	PCS	MCP Felixstowe Port Net	11 Ports (Destin 8)	Port Community
UK	PCS	CNS	2 Ports	Port Community
France	PCS	Soget Le Havre	10 Ports	Port Community
France	PCS	MP1	3 Ports (AP)	Port Community
Belgium	PCS	Seagha (Decartes Group Canada)	Antwerp/ Zeebrugge	Port Community, Then Private

Germany	PCS	BHT (Formerly DBh)	Bremen	Private
Germany	PCS	CCS Dakosy	Hamburg	Port Community
Italy	PCS	SeT (Elasg Group)	Genova	Port Community, Then Private
The Netherlands	PCS	Portbase Infolink	2 Ports Amsterdam/ Rotterdam	Port Community
Spain	PCS	Portic INTTRA	Barcelona Valencia	Port Community

2.6 Challenges to Port Community Systems

The management of information flow and exchange in a modern seaport or container terminal is a complex and time-consuming undertaking due to the interaction of diverse public and private actors that is depicted in Table 6 (Srour et al., 2008; Perego, Perotti, and Mangiaracina, 2011; Tijan, Aksentijević, and Čišić, 2014; Olesen et al., 2015; Carlan, Sys, and Vanelslander, 2016).

Table 6: *Observed Coordination Problems at the Seaport of Rotterdam*

Adapted from Van der Horst and De Langen (2008)

Seaport Coordination Problems	**Seaport Actors Involved**
Insufficient information exchange of container data between multiple seaport actors, creating inadequate transportation planning	Container Shipping Company, Container Terminal Operator, Freight Forwarder, Road Haulage Company, Inland Waterway Operator, and Rail Operator
Insufficient intermodal transport planning and storing of loaded and empty containers, in the terminal storage yard (Hinterland)	Container Shipping Company, Container Terminal Operator, Freight Forwarder, Road Haulage Company, Inland Waterway Operator, and Rail Operator

Limited integrated planning for physical and administrative customs clearance, potentially creating delays and bottlenecks	Customs Clearance Regulators
Insufficient information/ documentation on customs clearance of the container	Freight Forwarder, Customs Clearance Regulators, Shippers, and Customers

PCS functionalities evolve due to the continuous innovation of enabling smart technological platforms. This represents a continuous demand for PCS upgrades and the inclusion of new bespoke services to suit the operations requirements that underpins a continuous improvement culture (Carlan, Sys, and Vanelslander, 2016; Nota, Bisogno, and Saccomanno, 2018). A PCS may offset its innovation and operation costs by marketing its software packages and services via a subscription fee, levelled against all seaport actors who utilise the functionalities of the system. Therefore, addressing concerns in relation to the perceived lack of return on investment (ROI) income (Tijan, Aksentijević, and Čišić, 2014).

Seaport stakeholders/actors must adhere and conform to the various regulatory requirements of internationally enforced legislation, as exemplified by the requirements of the International Ships and Port Security (ISPS) Code and the International Maritime Dangerous Goods (IMDG) Code (Tijan, Aksentijević, and Čišić, 2014). Research undertaken by De Langen and Pallis (2007 cited in Baron and Mathieu, 2013) suggested that legislative constraints and inaccessibility to knowledge and networks still represented significant barriers to entry of a PCS. However, Carlan, Sys, and Vanelslander (2016) argued that cost is a significant barrier to the implementation of PCS and concluded that academic literature has focused on reviewing the perceived benefits of operating a PCS, rather than on the issue of cost. The multitude of costs involved in the operation (developmental, procurement, training, and accessibility) of a PCS are summarised in Table 7.

Table 7: *Cost of Operating a Port Community System*

Adapted from Carlan, Sys, and Vanelslander (2016)

Responsibility	Cost	Reference in Literature
PCS Administrator	Platform Development Cost (Hardware/ Software Acquisition/ Development Costs/ Payroll/ Training) Investment Costs	Carlan, Sys, and Vanelslander, 2016 Zerbino et al., 2018
	Data Governance/ Information Storage/ Security Costs	Baron and Mathieu, 2009
PCS User	Connection Costs	Carlan, Sys, and Vanelslander, 2016
	Hardware/ Software/ Acquisition/ System Upgrades Costs	
	Training/ Education Costs/ Access to Knowledge/ Recruitment Costs	Srour et al., 2008
	Subscription Fee	Baron and Mathieu, 2013

A SWOT analysis framework of a PCS is contained within Figure 8. It analyses and identifies the perceived strengths, weaknesses, opportunities, and threats of a PCS. This SWOT analysis draws upon the findings of the literature in the advocation of a PCS to leverage enhanced supply chain visibility and agility, rather than analysing the issues of high operational costs as argued by Carlan, Sys, and Vanelslander (2016).

Strengths

Independent Operator

Direct Reporting to regulatory Authorities

Reduced Operating Costs

Increased Supply Chain Visibility

Integrated Operations

Input Validation – Data Confidence

Elimination of Informal Reporting

Standardisation of Data Format – Interoperability of Heterogeneous Systems

Weaknesses

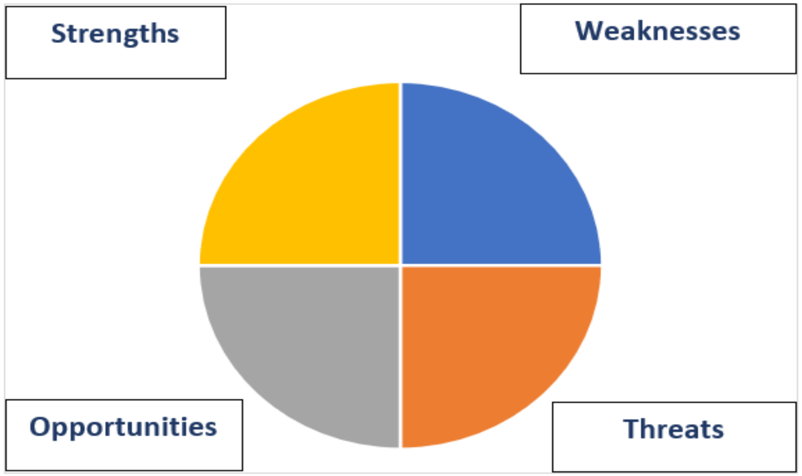
Localised Network Solution – Limitation of Coverage

Indirect Nature of Operating benefits – ROI Concerns

Difference in Governance Models – PCS Architecture

Unwillingness to Share Data – Trust Management

Conservative Nature of Seaports – Resistance to Change Mentality



Opportunities

Extension Maritime Supply Chain – Single Submission Window

Intensified Cooperation within the PCS Market

Extension of Value-Added Service Portfolio

Threats

Possible Integration of PCS and Supply Chain IOS to Provide Complete ICT Solution – Technology Obsolete – Short Product Life

Figure 8: *SWOT Analysis of PCS Function*

2.7 Interoperability of Heterogeneous Systems

It is suggested by Cepolina and Ghiara (2013) that ICT platforms are strong enablers of networking activities, by promoting secure data sharing and information flows, amongst diverse seaport actors. Therefore, reducing concerns about the secure handling and storage of information that is deemed as sensitive and confidential by seaport management. The advent of new paradigms in digitalisation (BD and Industry 4.0) have systematically increased the volume of structured and unstructured data that is produced by heterogeneous systems (Zerbino et al., 2018). The interoperability of stakeholder/actor (such as freight forwarders, multimodal transport operators, and intermodal terminal operators) information systems is a fundamental challenge to the evolution of the smart seaport concept (Sarabia-Jácome et al., 2013; Harris, Wang, and Wang, 2015). The adoption of a National Single Window (NSW) is widely advocated as an enabling platform that reduces the dependency of seaport actors to utilise a variety of heterogeneous systems. An NSW is defined as *"a facility that allows parties involved in trade and transport to lodge standardised information and documents with a single-entry point to fulfil all import and export regulatory requirements"* (Heilig and Voβ, 2017a, p.188).

2.8 Terminal Operating Systems

Container terminals generally utilise a Terminal Operating System (TOS) as depicted in Figure 9 to administer the throughput of containers (Tijan, Aksentijević, and Čišić, 2014). TOS is a dated approach to container terminal management that is considered robust and resilient, although it is subjected to frequent upgrades and modernisation programmes (Tijan, Aksentijević, and Čišić, 2014). A TOS is regarded as an essential platform that facilitated an increase in the levels of automation utilised by the seaport in its routine supply chain operations. The first automated container terminal was the *ECT Delta Terminal Maasvlakte Rotterdam*, it became fully operational in 1993 (Heilig, Voβ and Stahlbock, 2019).

A generalised definition of the operational functionalities of a TOS is provided by Min et al., (2017, p. 428) who conclude that:

> *"A TOS is referred to as a computer system that is designed to plan, track, and manage the movement and storage of all cargo, the use of assets, and the deployment of people in and around the seaport terminal or the port (including the hinterland) on a real-time basis. It can comprise a broad range of technologies including software features, handling yard planning, berth planning, stowage planning, carrier/vessel traffic control, document transmission, record keeping, accounting, Enterprise Resource Planning (ERP), Radio Frequency Identification (RFID), Electronic Data Interchange (EDI), Optical Character Recognition (OCR), and Differential Global Positioning Systems (DGPS)".*

A Big Data (BD) platform is utilised to manage TOS strategic decision-making, in the context of crane position, capacity, status, and GPS positional data of assets and resources as represented by Figure 9 (Baştuğ et al., 2017). However, it is suggested by Heilig, Voβ, and Stahlbock (2019) that existing data from TOS is still both under-processed and analysed to be of real value in the formulation of strategic decisions, reducing the concept of transparency and visibility that is disseminated by the PCS.

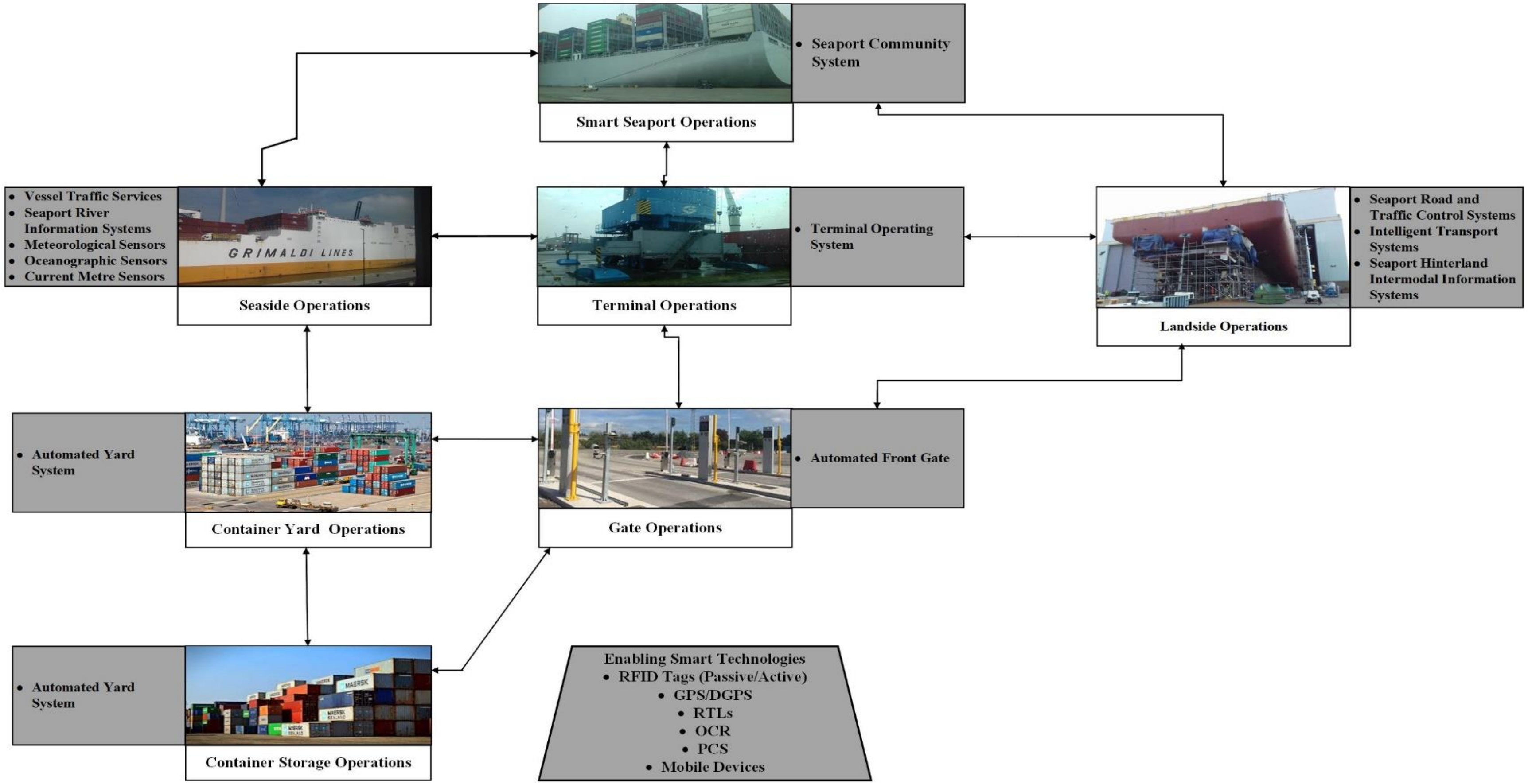


Figure 9: *Seaport Container Terminal: The Interface Between Land and Sea*

Adapted from Molavi, Lim, and Race (2019)

2.9 Insights & Summary

This literature review chapter has identified gaps in the literature that relate to a significant lack of empirical studies that document the current position of the seaport sector to smart/ Industry 4.0 implementation and application. The need for seaports to adopt a more rigorous understanding (experience, knowledge, and skill set) of the Industry 4.0 paradigm is advocated by the literature due to their importance to regional, national, and international economic growth as facilitators of globalisation. Seaports also operate in competitive (increasing customer demand for supply chain efficiency, transparency, and agility at the lowest possible cost), fluctuating and volatile markets that are characterised by economic and political uncertainty, necessitating the need for effective strategic decision support that exploits Industry 4.0 technologies. The reasons behind the sporadic sectoral acceptance of Industry 4.0 and the slower pace of infrastructure modernisation are considered as barriers, relating to conservative/risk-averse operating attitudes, investment constraints, interoperability of heterogeneous systems, concerns of data ownership/ accessibility and the disruptive nature of its implementation. The next chapter (Chapter 3: Literature Review - The Emergence of Value Stream Mapping, Industry 4.0, and Big Data Analytics) delineates the emerging concepts of Industry 4.0, VSM, and Big Data Analytics to determine if they are relevant and adaptable in the seaport sector.

CHAPTER 3: LITERATURE REVIEW – THE EMERGENCE OF VALUE STREAM MAPPING, INDUSTRY 4.0 AND BIG DATA ANALYTICS

3.0 Introduction

Decision-making in the seaport is undertaken in a vast geographical operating area. This has also been intensified by the continuous increase in throughput rates as seaports have evolved into logistical hubs at the centre of the globalised supply chain (Olesen et al., 2015; Heilig and Voβ, 2017a; Bălan, 2018; Gkerekos et al., 2019; González-Sánchez et al., 2019). The advent of the Industry 4.0 paradigm presents an unprecedented opportunity for seaport operators to develop their decision-support to facilitate data visualisations of their current and ideal future state to systematically identify aspects of the operation that require continuous improvement to achieve a sustained competitive advantage. The concept of Industry 4.0 is further delineated to provide clarification of its functions and subsequent barriers to sector-wide implementation. This chapter also considers the suitability of existing Value Stream Mapping (VSM) tools to be adapted to complement strategic decision-making in the form of data visualisations that are underpinned by descriptive, predictive, prescriptive, and diagnostic representations. This would assist the seaport sector in catching up with other sectors that are leading the way in terms of Industry 4.0 implementation and application to drive process efficiency.

3.1 Decision-Making

Decision-making has been defined in the literature as a process that involves an individual, group, or organisation that reaches conclusions relating to what future actions should be pursued in achieving organisational objectives (goals, values, and desires), efficiently and effectively subject to economic and resource constraints that originate from internal and external environments (Schoemaker and Russo, 2017; Kozioł-Nadolna and Beyer, 2021). In Figure 10 the inputs originate from an internal environment that is influenced by the seaport's governance and an external environment which is subjected to influences from independent organisations i.e., legislation regulators. These inputs underpin the decision that is additionally subjected to customer demands, process, and operation constraints, and KPI measurement/ analysis. The output is the decision that is formulated in response to the dynamic internal and external environments.

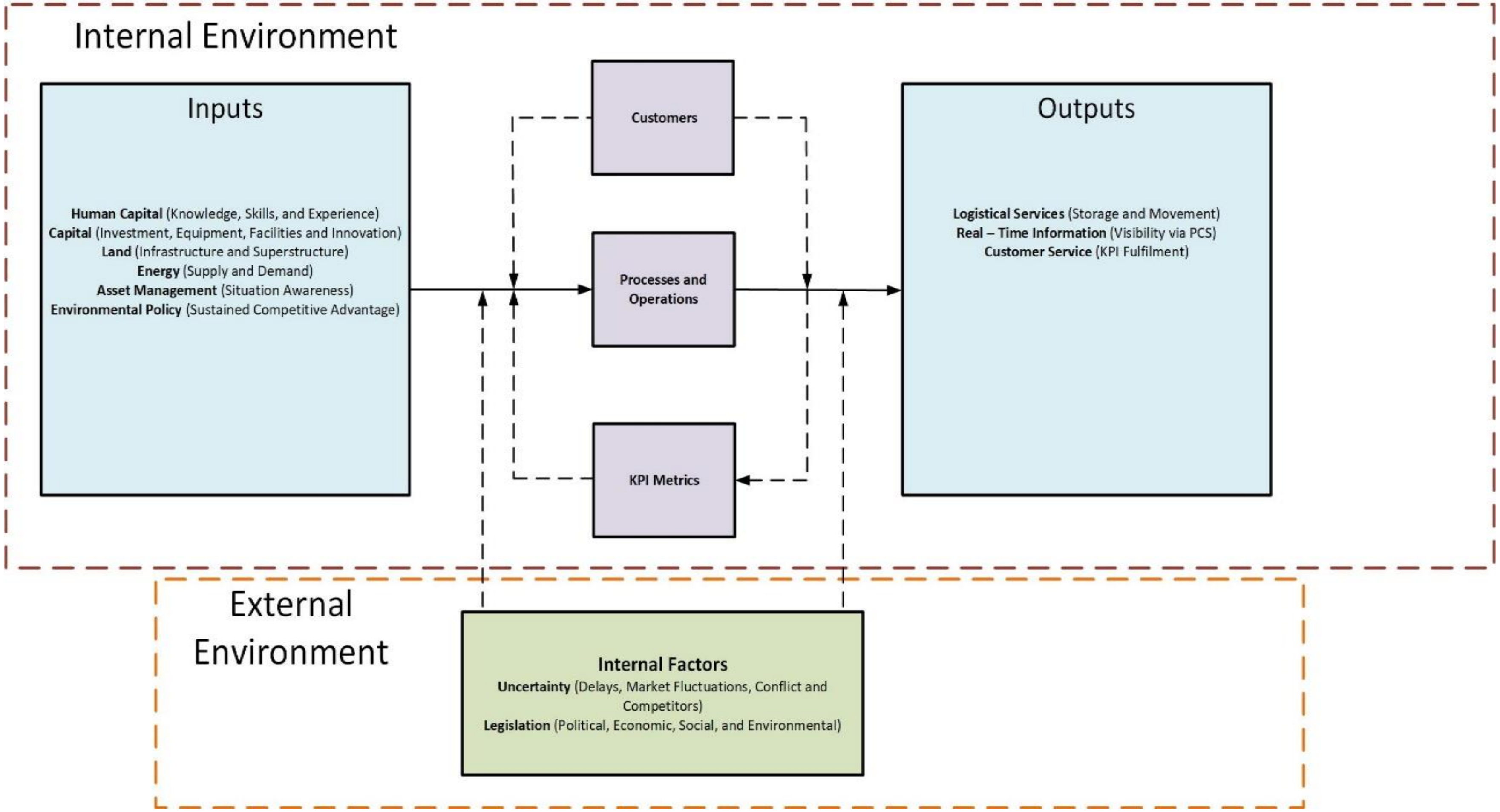


Figure 10: *The Decision-Making Inputs and Outputs in Internal and External Environments*

Decision-making processes as presented in Figure 11 can be regarded as a critical success factor for an organisation as they determine the achievement of short- and long-term goals and in many respects the success or failure of an entity. Decision-making occurs at every level of the management structure and impacts on all employees within the organisation, and it is influenced by a variety of inputs (human, situational, and data quality).

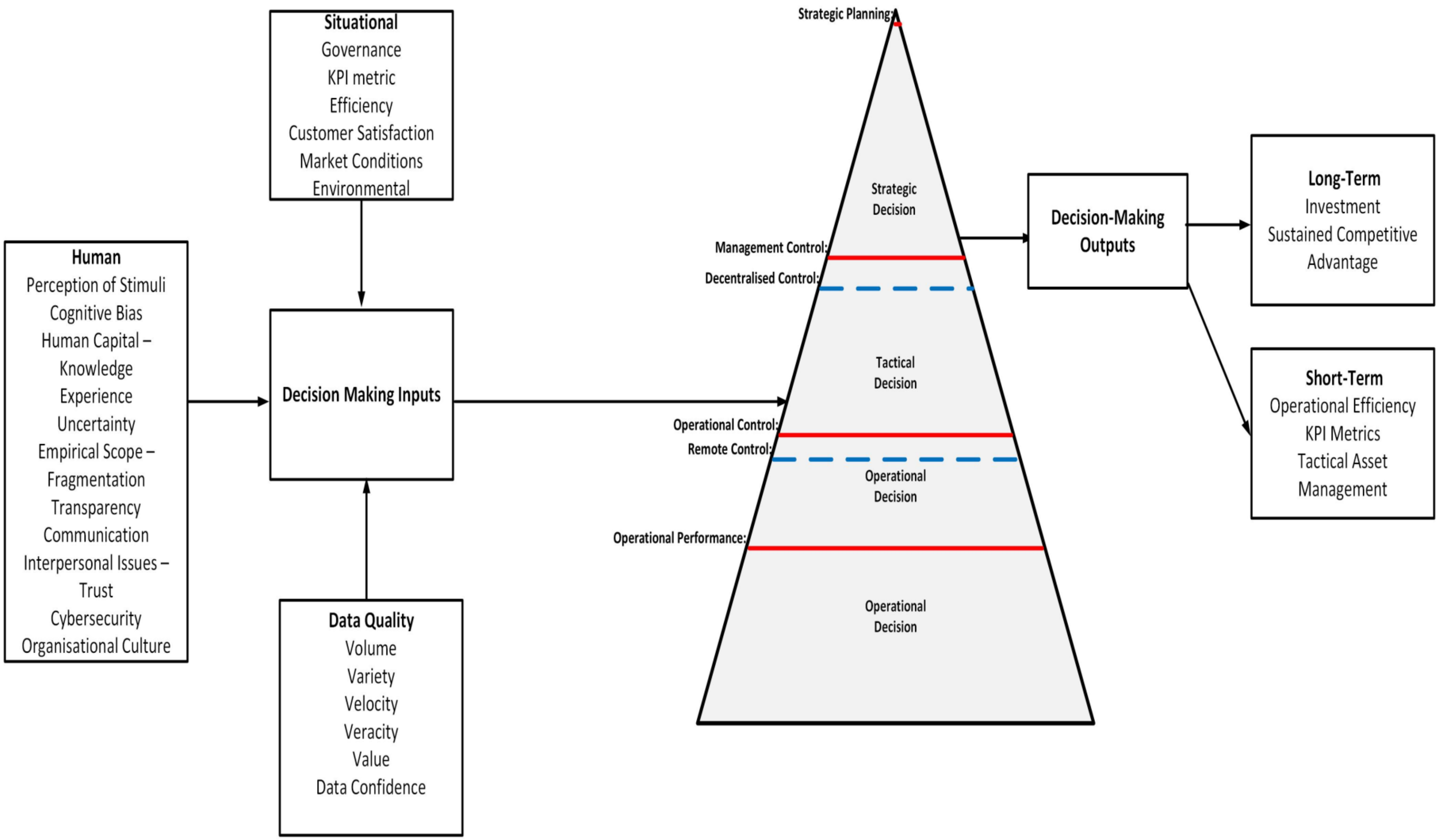


Figure 11: *The Decision-Making Process*

Seaports are viewed as complex, dynamic, and volatile decision-making structures with three classical levels: strategic, tactical, and operational (Huang, Mamatok, and Jin, 2021). Complexity is underpinned by an idiosyncratic range of input factors (economic, environmental, sociocultural, organisational, personal, and psychological) that are subjected to fluctuations within a dynamic and uncertain operating environments (Kozioł-Nadolna and Beyer, 2021). The time frame to formulate decisions is rapidly decreasing which pressures organisations to issue high-risk and long-term decisions, without access to real-time data from multiple sources. A decision-maker as depicted in Figure 11 can no longer depend on just their experience and competencies (intuition-driven decision-making), requiring situational awareness (data and evidential-driven decision-making) of internal and external supply chain factors (based on a seaports evolution into logistical hubs) (Kozioł-Nadolna and Beyer, 2021).

The quality of the data collated is measurable by determining its volume, variety, velocity, and veracity. This will systematically increase the decision-maker's confidence in the data that is utilised to formulate the operational, tactical, and strategic decisions (Kozioł-Nadolna and Beyer, 2021). When under time constraints the application of visual representations will facilitate a quicker/real-time interpretation of the data.

This facilitates an operational need for systematic visualisation tools to underpin insightful decisions that contribute to the efficient operation by underpinning favourable trading conditions within the prism of a sustained competitive advantage (Kozioł-Nadolna and Beyer, 2021). The visualisation tools would facilitate a variety of data-driven analytical functionalities, which are depicted in Figure 12. This analysis would allow the decision-maker to consider the impact of their decision on the operation, based on a range of data visualisations that offer an immediate assessment.

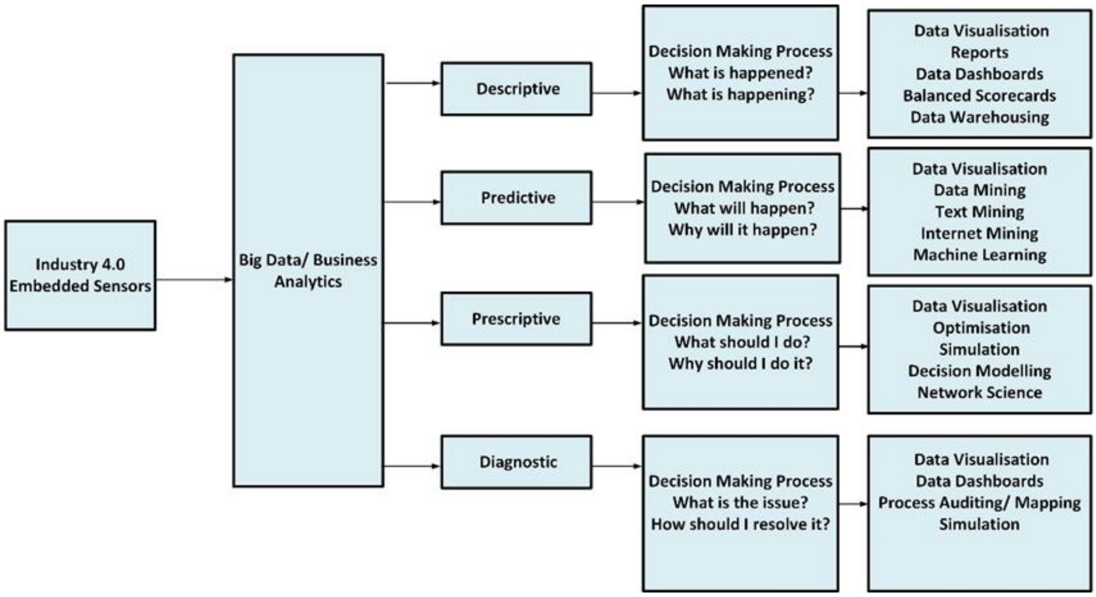


Figure 12: *Data-Driven Decision-Making*

This range of techniques has formed the core of the emerging Business Analytics discipline and underpins the critical examination of complex supply chain components at a granular level, generating a more perceptive understanding of the operation.

Strategic decision-making in the maritime sector represents an emerging topic for research with little academic focus when integrated with infrastructure extension (Woo et al., 2011). Tactical-level decision-making research consists of transportation network planning, inter-modal selection, and asset management. Operational decision-making research has predominantly focused on container storage space allocation. Strategic-level decision-making research has explored the relationship between commercial activities and sustainable development that underpins long-term policy (Huang, Mamatok, and Jin, 2021).

It is perceived from the literature that both lean and agile seaports would offer an efficiency improvement and enhance the integration of seaports into a multi-modal supply chain; to meet the increasing demands of today's globalised consumer markets (Marlow and Paixão-Casaca, 2003). It is argued by Hicham – Hakam and Solvang (2012) that the seaport industry is under tremendous pressure to streamline the transportation process while delivering improvements in the quality of service and a reduction in operational costs. However, it is argued by Olesen et al., (2015) that the application of lean principles within the intermodal transport sector is rather limited.

This contrasts with the automotive and manufacturing sectors which embraced lean principles in the 1990s to eliminate efficiency issues in information and material flows. The origins of the LM concept are based on the Toyota Production System (TPS) and in simplistic terms relate to the systematic elimination of waste within a value stream (Olesen et al., 2015).

3.2 The Origins of Value Stream Mapping (VSM)

The VSM method was initially devised in 1995 and it was popularised by the research of Rother and Shook in their publication *"Learning to See"* (Huang et al., 2019). The VSM technique is perceived as a concept within lean philosophy, based on the Toyota Production System (Hines et al., 1998). A Toyota Production System House diagram is a commonly applied visualisation tool which is detailed in Figure 13 and depicts the fundamental elements of a lean system (See Section 4.2 Lean Methodology). It also displays the foundations in the bottom section and the pillars in the middle section that represent both the core activities and the goals of the Toyota Production System within the top section (roof). This adds credence to the assumption that traditional VSM has been focused extensively on the rigid environments of standardised process manufacturing that limits its flexibility to map dynamic environments (Hines et al., 1998).

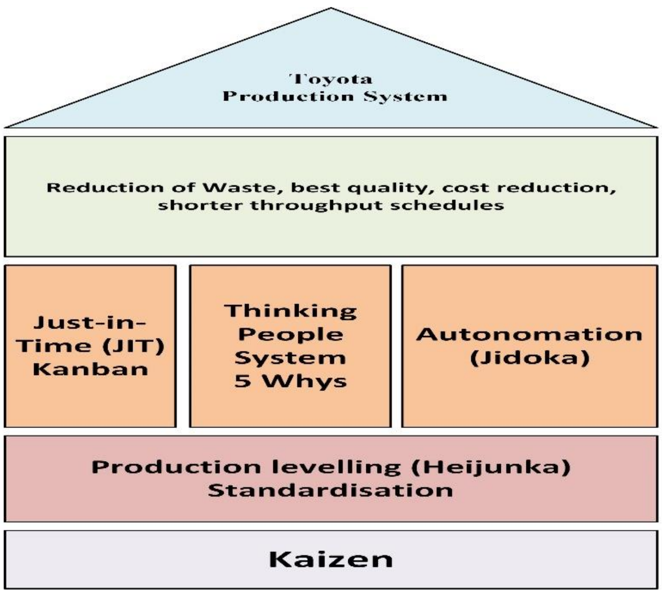


Figure 13: *A Toyota Production System House*

As previously noted, the fundamental objective of a Toyota Production System is the avoidance of waste within a process. There are two elements that need to be addressed in the elimination of waste. Firstly, an improvement must leverage a cost reduction as a direct result of its implementation. This suggests that only goods and services are authorised to be produced if they are really required. This task must be accomplished with the minimum utilisation of resources. Secondly, the efficiency of the resources applied to the production system needs to be continuously analysed to identify waste reduction opportunities. This is commonly captured by current state VSM to map and identify waste and non-value-adding activities in the value stream of a current state manufacturing process as depicted in Figure 14.

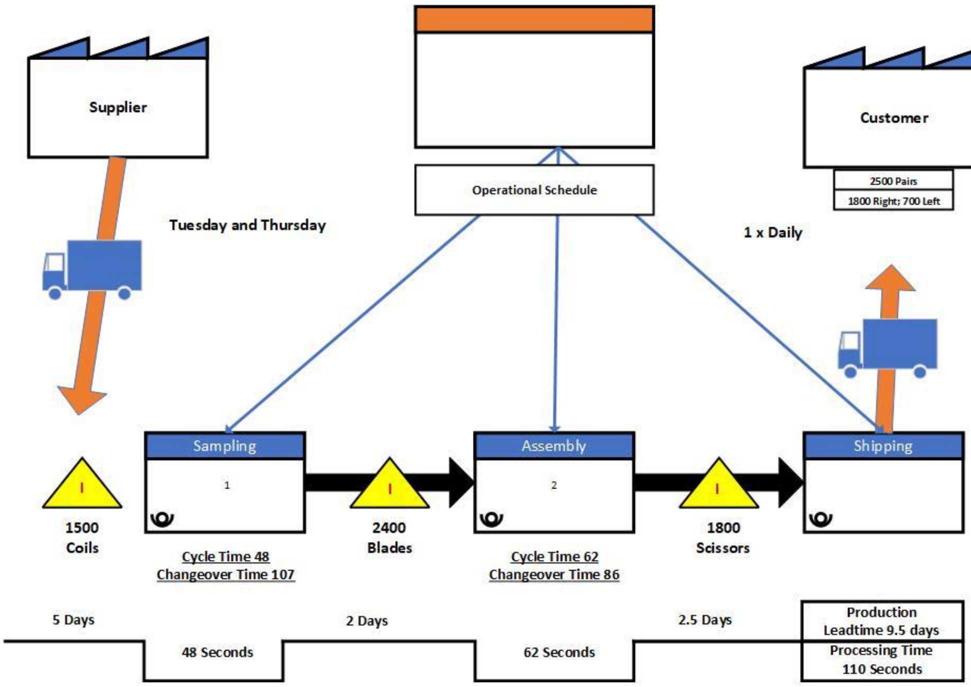


Figure 14: *VSM Mapping of Process Flows in the Current State of a Simplistic Manufacturing Process*

The foundations of a Toyota Production System consist of three core elements: Kaizen, Production Levelling (Heijunka), and Standardisation. The advantage of applying Production Levelling is the precise visualisation of orders that facilitates an integration of production processes. The standardisation of processes is achieved by the documentation of standard operations that are undertaken by the workforce.

The pillars of the Toyota Production System House refer to the concept of Just-in-Time (JIT) and are customer focused in terms of adhering to service levels. This is further elaborated into the lean principle: the right amount, at the right time, at the right place, in the right quantity, and free from defects. The underlying principle is the reduction in unnecessary stock and inventory levels, eliminating waste and non-value-adding activities from the value stream. The realisation of JIT also generates fiscal benefits in the reduction of current assets held by the business and their subsequent charges (Thun, Drüke, and Grübner, 2010).

However, Romanowski, Nadolny, and Sutowski (2017) acknowledge the pioneering research of Charles E. Knoeppel who submitted diagrams that depicted the flow of materials and information, within his 1918 publication "*Installing Efficiency Methods*". The origins of VSM were predominantly in the analysis and improvement of discontinuous flow line processing environments (Lasa, de Castro, and Laburu, 2009). VSM may be defined in simplistic terms as a simultaneous visual management tool that records, analyses, and attempts to understand the sequence of a single product family, including the flow of information and materials throughout a value stream in the context of a graphical interface (Lasa, de Castro, and Laburu, 2009; Chen, Li, and Shady, 2010; González - Sánchez et al., 2015; Romanowski, Nadolny, and Sutowski, 2017; Huang et al., 2019).

3.2.1 Descriptive Analytics

Data-oriented approaches detail all procedures, methods, and applications that generate knowledge from raw data sets collected from processes and system infrastructures. For many companies, the generation, storage, and processing of large amounts of data represents a significant operational challenge. The most fundamental challenges relate to a lack of a centralised data storage due to the heterogeneous system infrastructure, inconsistent data formats, and an inherently inhomogeneous structure that necessitates an enormous amount of effort in data processing (Muehlbauer et al., 2022). Prevention of data inconsistencies, although very challenging, has the potential to leverage significant amounts of savings in time and money, a vital consideration for a seaport that operates in globalised and highly competitive markets (Muehlbauer et al., 2022). Data-oriented approaches such as machine learning and data mining enable process data to be utilised in identifying opportunities for transparency and aspects for improvement and increasing the performance of the supply chain. Therefore, the conversion of unstructured data into structured data is considered to be an essential component of data-oriented approaches.

VSM generates a graphical visualisation that serves as a remarkably effective diagnostic tool that populates a descriptive representation of a current state (Marin-Garcia, Vidal-Carreras, and Garcia-Sabates, 2021). Antonio et al., (2023) advocated VSM as a Lean analytical tool to describe processes in current states that are suitable for continuous improvement in future states. This constitutes all production and logistics processes from the supplier to the customer. When drafting the initial VSM it is necessary to record the actual status of the process, subject to their process constraints, process parameters, and Key Performance Indicators (KPIs) (Muehlbauer et al., 2022).

This descriptive representation of VSM graphically utilises standardised symbols to structure the information and material flows that are required to complete a project, a product, or a service (Marin-Garcia, Vidal-Carreras, and Garcia-Sabates, 2021). A descriptive representation of the current state will also identify relationships between material and information flows, communications, collaborations, and potentially altering existing working practices (Lasa, de Castro, and Laburu, 2009; Romanowski, Nadolny, and Sutowski, 2017).

3.2.2 Predictive Analytics

Ali, Petersen, and Nicolau de França (2015) proposed an adaptation of traditional VSM methods to combine predictive diagnostics in the form of software process simulation modelling. The utilisation of simulation as proposed in their framework led to realistic process improvements with a high likelihood of implementation (Ali, Petersen, and Nicolau de França, 2015). Faisal (2018) applied predictive simulation analytics for the realisation of future state VSM representations. This was underpinned by discrete event simulation and automation software that was utilised to construct models of the VSM mappings. It is argued by Faisal (2018) that predictive simulation analytics of VSM is an appropriate analytical tool for the implementation of lean manufacturing in SMEs to improve competitiveness.

Narasimhan and Parthasarathy (2007 cited in Vikraman and Kumar, 2017) devised a new approach that integrated the concept of simulation to VSM (Simulation-aided/ saVSM) to increase the flow of data analysis and to facilitate the process of continuous mapping. Thulasi et al., (2022) apply simulation to mitigate the limitations of traditional VSM to map dynamic behaviour. They also applied discrete event simulation and automation software to leverage an understanding of the factory dynamics.

It is suggested by Huang et al., (2019) that a multi-agent system may populate an innovative multi-layer dynamic value stream mapping (DVSM), identifying multi-material and information flows. A multi-agent system is a cluster of autonomous devices representing physical or logistical units connected by a network that possesses the capacity to sense and regulate autonomously in a complex and dynamic operating environment. DVSM is viewed as an enhancement of the concepts utilised in traditional forms of VSM in its capability to monitor devices in near-real time than rather as a snapshot. This facilitates a measure of flexibility to document the changing state of process control within a value stream (Vikraman and Kumar, 2017; Huang et al., 2019). VSM is not suited to map rapid and dynamic manufacturing environments, complex flow of materials, or the efficiency of machine or labour performance (Huang et al., 2019). They regarded these as the most important resources of the manufacturing process that leverage transparency for the decision-maker. They developed a multi-agent system of several cost-effective Arduino systems as agents and a Raspberry Pi as a core agent (Arduino is an open-source electronics platform based on easy-to-operate hardware and software. Arduino can read inputs - sensors and turn them into an output - activating an LED) (Huang et al., 2019).

Barenji and Hashemipour (2014) infer that multi-system agents act in a similar capacity to an intelligent manager that interacts with the physical objects within the networked community. This process will also foster value-added benefits that account for reduced operating costs, lower allocation of labour resources, and reduced maintenance and downtime. It may be inferred that information dissemination is fundamentally vital to the overall success of Cyber-Physical Systems and multi-agent systems within the confines of a dynamic environment that is subjected to fluctuations in supply and demand (Huang et al., 2019). The functionalities of simulation and VSM facilitate a measure of flexibility to document the changing state of process control within a value stream.

3.2.3 Prescriptive Analytics

Prescriptive approaches to traditional VSM employ the utilisation of data-oriented approaches to expand the understanding of dynamic and data-rich environments. Horsthofer-Rauch et al., (2022) applied data-mining techniques to mitigate mapping issues surrounding process complexity and increasing production demand in order to realise digitalised VSM.

Lu, Liu, and Min (2021) investigated the feasibility and validity of a digital twin-enabled VSM approach for manufacturing SMEs. They applied a data-driven approach to mitigate data accuracy limitations that were deemed insufficient to leverage production process reengineering tasks. Faroukhi et al., (2020) adapt the concept of traditional value chains to mitigate new data-related challenges, such as high volume, velocity, and variety. This approach adapted the concept of a Big Data Value Chain that is exploited to generate data monetisation and populate prescriptive analytical tools that facilitate business growth (Faroukhi et al., 2020).

3.2.4 Diagnostic Analytics

Traditional VSM methods represent a diagnostic technique of a process's current state that is underpinned by the lean principle of leveraging continuous process improvement (Marin-Garcia, Vidal-Carreras, and Garcia-Sabater, 2021). They conducted a scoping of VSM research in the healthcare sector which inferred that most applications of VSM focused on tertiary levels of care. It is advocated by Marin-Garcia, Vidal-Carreras, and Garcia-Sabater (2021) that more standardisation of VSM methods in the healthcare sector is required with a renewed focus on primary care, including operational and social sustainability indicators.

Zhu, Zhang, and Jiang (2020) proposed a green-modified value stream mapping model (GMVSM) that used carbon efficiency (flow of all types of waste) and carbon emission as evaluation indicators. The application of the model was multi-faceted in diagnostic terms that gravitated towards carbon efficiency, budgeting, and reduction measures.

3.2.5 Sectoral Value Stream Mapping (VSM) Approaches

There are a number of research papers in the literature that discuss the emergence of lean technology with ICT solutions, which may be summarised by (Marlow and Paixão-Casaca, 2003); Houy (2005); Ward and Zhou (2006); Riezebos, Klingenberg, and Hicks (2009); Loyd et al., (2009); Powell and Skjelstad (2012); Maguire (2016); and Meudt, Metternich, and Abele, (2017). The traditional VSM approach is robust and has been adapted and utilised by a number of diverse sectors and disciplines which is depicted in Table 8 & Figure 15 (Hines et al., 1998).

Table 8: *Cross-Section Application of Value Stream Mapping Techniques*

Industrial Sector	Reference
Construction	Choromokos and Mckee (1981); Matt, Krause, and Rauch (2013)
Information Technology/ Industry 4.0	Houy, (2005); Ward and Zhou, (2006); Narasimhan, Parthasarathy and Narayan, (2007); Tabanli and Ertay, (2013); Almada-Lobo, (2016); Meudt, Metternich, and Abele, (2017); Vikraman and Kumar (2017); Sony (2018); Huang et al., (2019); Kamble, Gunasekaran, and Dhome, (2019); Roh, Kunz, and Wegener, (2019)
Healthcare	Kaale et al., (2005); Synder, Paulson, and McGrath, (2005); Carter et al., (2012); Sampalli et al., (2015); Bhat Gijo, and Jnanesh, (2016); Bal, Ceylan, and Taçoğlu, (2017); Tecihgräber and De Bucourt, (2012); Tortorella et al., (2017)
Environmental Management/ Sustainable Development	Lummus, Vokurka, and Rodeghiero, (2006); Rigot-Muller et al., (2013); Faulkner and Badurdeen, (2014); Brown, Amundson, and Badurdeen, (2014); White and James, (2014); Campos and Vazquez-Brust, (2016); Alvandi et al, (2016); Vinodh, Ruben, and Asokan, (2016); Carmignani, (2017); Garza-Reyes et al., (2018)
Service Sector/ Quality Management	Piercy and Rich, (2015)
Product Development/	McDonald, Van Aken, and Rentes, (2002); Braglia, Frosolini, and Zammori (2009); Schulze et al., (2013); Seyedhosseini, Taleyhani, and Makini (2013): Matt, (2014); Schmidtke, Heiser, and Hinrichsen, (2014); Tyagi et al., (2015); Satish et al., (2015)

Innovation Management	
Seaport Management	Marlow and Paixão-Casaca (2003); Loyd et al., (2009); González-Sánchez et al., (2015); Amrina, Kamil, and Rahmad, (2019)
Manufacturing Sector	Lugert, Batz, and Winkler, (2018)
Architecture	Lima, Rolim, and Alves (2010)
Mining	Roisienkiewicz, (2012); Kumar, Garza-Reyes, and Saboo (2014)
Maintenance	Kasava et al., (2015)
Tourism	Vlachos and Bogdanovic (2013)
Transport	Villareal (2012); Romanowski, Nadolny, and Sutowski (2017)
Lean Engineering	Pavanaskar and Gershenson (2004)

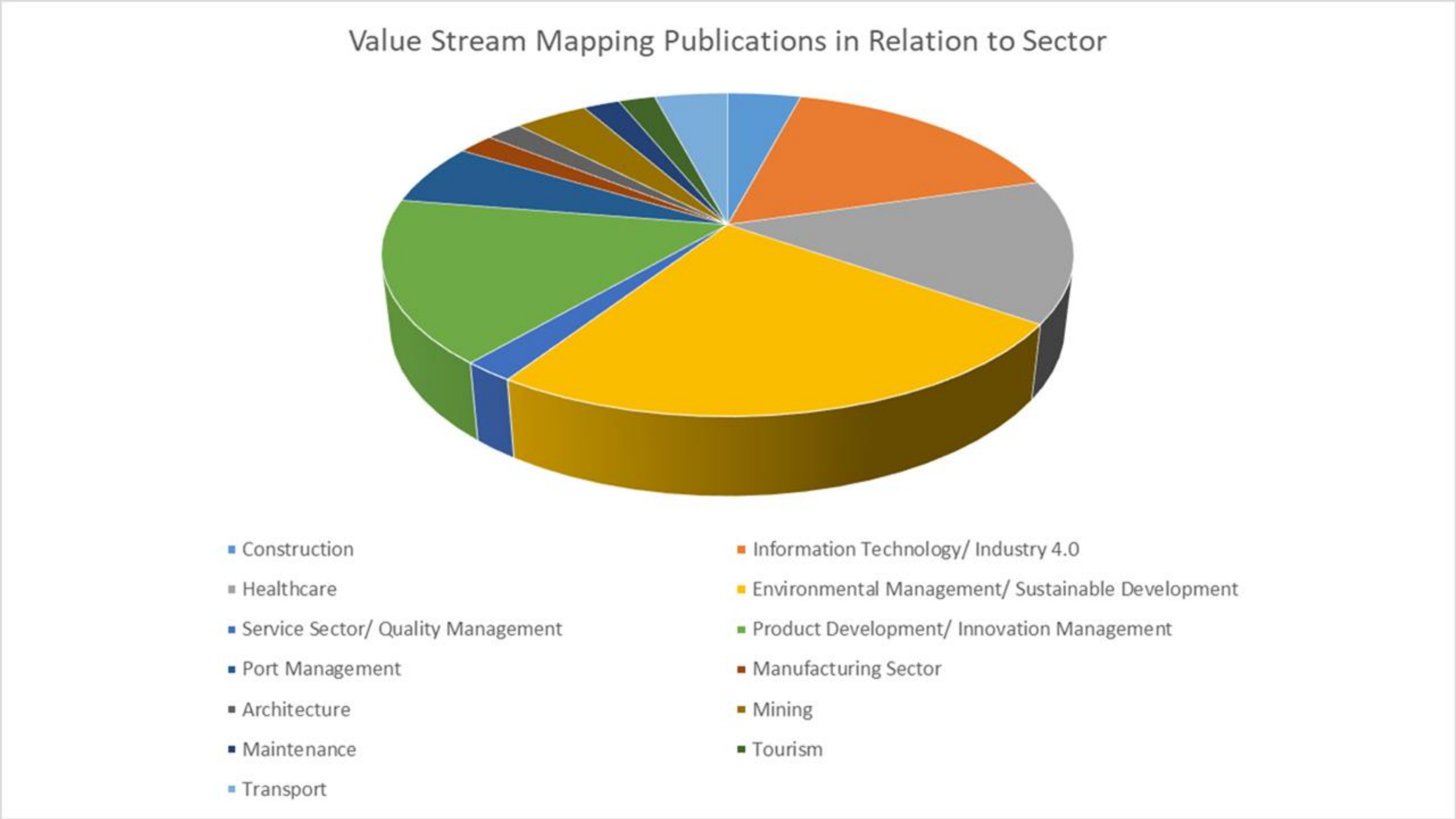


Figure 15: *VSM Publication in Relation to Sector (Sample Population of 49 Journal Papers)*

It is suggested by Marlow and Paixão-Casaca (2003) that VSM will be extremely important for time and sequence management within the seaport operating environment. They also advocated the application of VSM to measure the performance of a seaport operation that has endeavoured to transform its management strategy from a lean perspective to a more customer-focused seaport that is agile in the services it provides. They measure a seaport's evolution in relation to the generation model that was devised by UNCTAD (Marlow and Paixão-Casaca, 2003). However, this research is now rather dated and justifies adaptation and revision in relation to the increasing growth of the seaport sector and the impact of economic and political uncertainty. Loyd et al., (2009) utilised a traditional VSM approach at the Seaport of Mobile (Alabama, USA) in a project that was designed to increase the throughput capacity at the McDuffie Coal Terminal. The project concluded that the philosophy of LM can be successfully applied to seaports in order to elevate throughput capacity limitations (Loyd et al., 2009). Meudt, Metternich, and Abele (2017) integrated VSM and Industry 4.0 into the Value Stream Mapping 4.0 model that aimed to identify the location of information logistics waste (ILW) within the supply chain operation. A similar approach was conducted by Franzén and Streling (2017) who conducted four case studies at seaport container terminals (APM Terminals Gothenburg, Noatum Container – Valencia, Seaport of Helsingborg, and Seaport of Norrköping) to identify eventual inefficiencies through traditional VSM techniques. They concluded that seaport operations in the short term need enhanced situational awareness of their operational assets. A long-term strategy should leverage the implementation of automated container handling and technology to systematically reduce human error, increase throughput rates, and promote procedural standardisation (Franzén and Streling, 2017).

3.3 The Problematic Nature of Value Stream Mapping

The traditional concept of VSM is subjected to a number of criticisms that relate to its inability to cope with a multi-product manufacturing process and its subsequent lack of process integration (Alvandi et al., 2016). It is argued that this conceptualisation represents a rather static environment that fails to effectively determine the dynamic system behaviour of the manufacturing operation, potentially producing a misleading representation of the actual system behaviour (Alvandi et al., 2016). This static limitation is further acknowledged by Forno et al., (2014) who argue that VSM struggles to map precisely in dynamic and complex environments that are fluctuating in relation to international market volatility and production uncertainty. VSM is a paper and pencil exercise that is populated by a limited number of observations and subsequently a limited level of process accuracy. The unconsidered information in the operating environment may contain useful insights for waste management and process improvements that would otherwise be disregarded. The scope of VSM is limited to the identification of waste in the value stream and lacks quantifiable economic mapping of profit, throughput, operating costs, and inventory expenditure (Forno et al., 2014).

Braglia, Frosolini, and Zammori (2009) argue that the issue of complexity is most apparent in high-variety, low-volume processes, where the value streams consist of numerous components. Stadnic and Litwin (2019) also conclude that VSM enables only a static analysis of a manufacturing system within a dynamic environment that is subjected to a variety of problems.

This simplistic overview also limits the application of the what-if-analysis that ultimately determines the future state map’s structure and its ability to operate within a dynamic environment (Lasa, de Castro, and Laburu, 2009). Many researchers have adapted traditional VSM techniques to incorporate the functionality of multi-product complexity, by utilising the concept of discrete event simulation (Alvandi et al., 2016). McDonald, Van-Akens, and Rentes (2002) developed simulation models of manufacturing systems to analyse and visualise the dynamic states of both unit processes and the entire process, enabling a holistic overview of the manufacturing system. This view is also advocated by Alvandi et al., (2016) who conclude that a holistic perspective is essential when utilising VSM in dynamic environments, centred on the manufacturing of multi-products with a series of complex machines and process interactions.

It is generally perceived that VSM is a very simplistic task. A mere pen-and-paper exercise that requires a predetermined number of visits to the process site to be mapped, leaving a straightforward data collection task, and then drafting the map on paper (Liker and Meier, 2005). However, if VSM is not applied correctly the identification of waste and non-value-adding activities may become compromised and result in a misinterpretation of the process and undermine the implementation of improvement strategies (Liker and Meier, 2005). To mitigate the representation of bias it is recommended that a cross-functional team should be selected to walk the shop floor, analyse the physical flow, gather the required information, and then subsequently draft the map (Rother and Shook, 1998).

VSM is regarded as a time-consuming process that requires continuous monitoring of a value stream to observe the effects of changes and implementations (Lian and Van Landeghem, 2007). Hines and Rich (1998) suggest that it may take a few months of continuous monitoring to observe the effects of process changes and improvements of the VSM exercise.

3.3.1 Mitigation of Value Stream Mapping Shortfalls

One of the first steps in the VSM process is to define the value stream that ultimately generates value for the customer in the product or service delivered. Define the scope of the process that requires mapping, determine the boundaries (start and the end point), and clearly state the goals and objectives (Hines and Rich, 1998). This task is potentially problematic as stakeholders have differing perceptions and expectations of what value means to their operation. If there is not a clear and shared understanding of both the value proposition and customer demands, the VSM representation may be subsequently inaccurate and irrelevant to the operation. To mitigate this potential issue, the VSM process should involve the participation of all the relevant stakeholders in aligning their goals and objectives. Further validation of the value stream may be obtained from customer feedback, facilitating additional revisions of the VSM.

It is essential that the right data is collated to measure and evaluate the efficiency of the current state of the process. The data should generally include the following, cycle and lead times, inventory and defect levels, customer demand, and value-added activities.

In addressing the issues surrounding process complexity and dynamic environments, it is advocated that the VSM method should be simplified and standardised. Lain and Van Landeghem (2007) proposed a simulation adaptation of VSM to mitigate issues surrounding the dynamic behaviour of production processes and complexity. It is also emphasised that a standardised format that is populated by VSM methods and guidelines should be applied, ensuring its ease of understanding and comparison to the real-world observation (Rother and Shook, 1998).

The ultimate aim of the VSM exercise is to identify and implement process improvements that enhance value to the customer and eliminate waste and/ or non-value activities. Therefore, VSM managers should systematically prioritise process improvements in relation to their operational impact, feasibility, or perceived urgency. This approach will mitigate an implementation policy for low-value or high-risk changes that lack focus and direction.

The application of VSM methods should be regarded as a continuous process that is underpinned by the monitoring or measurement of the process improvement, the benefits that they leverage, and its dissemination to all interested stakeholders. This will ensure that the momentum and accountability instigated by the VSM exercise will be sustained to drive the lean philosophy of continuous improvement. It is advocated by both Rother and Shook (1998) and Hines and Rich (1998) that VSM managers should implement KPI metrics to monitor and evaluate operational performance and feedback mechanisms to disseminate achievements and best working practices. This would allow all interested stakeholders a further opportunity to identify any additional gaps in the VSM, discuss any issues and incorporate revisions to the future state visualisation.

The increasing pressure on seaports to deliver increased throughput capacity that is subjected to infrastructure and economic constraints is a very complex issue (Loyd et al., 2009; Olesen et al., 2015). The process of VSM mapping in relation to the implementation of smart technology is a viable solution to this issue. This approach is advocated by Olesen et al., (2015) who suggest that further research should examine the combination of innovative Information Technology platforms with lean management concepts, contributing to the literature.

3.4 Industry 4.0

The emerging globalised market competition and the rapid development of technological advancements in industry have forced companies to reconsider the effectiveness and efficiency of their processes and systems (Liao et al., 2017; Dalaklis et al., 2022; Razmjooei et al., 2023). The Industry 4.0 concept was initiated at the Hannover Messe in 2011 to address the challenges faced by companies in response to globalisation. It is regarded as a new paradigm that aims to fulfil globalised market needs for more reliable, flexible, and efficient industrial processes by utilising digital technologies (Liao et al., 2017). Academic and practitioner literature are presently struggling to devise a universally acceptable definition of Industry 4.0. This is exemplified by Table 9 which provides an overview of the numerous definitions of Industry 4.0 that are published in the literature. It is argued by Tjahjono et al., (2017) that the features of Industry 4.0 (Vertical Networking, Horizontal Integration, BD, and acceleration of Industry 4.0 through exponential technologies) are also lacking in a conclusive definition. It is suggested by Zhou, Liu, and Zhou (2015, cited in Ben-Daya et al., 2017, p.2) that the concept of Industry 4.0 is "*the integration of information communication technologies with industry technology"*. Its most fundamental application has been within the manufacturing sector, with limited research conducted within the discipline of Supply Chain Management. Industry 4.0 has attracted different labels: Smart Factories, Smart Industry, Advanced Manufacturing, Logistics 4.0, Port 4.0, or Industrial Internet of Things (IIoTs) (Tjahjono et al., 2017; de la Pēna Zarzuelo, Soeane, and Bermúdez, 2020).

Table 9: *Definitions of Industry 4.0*

Definition of Industry 4.0	**Reference**
A New level of value chain organisation and management across the lifecycle of products	Henning and Johnnes (2013, cited in Lu 2017, p. 2)
A collective term for technologies and concepts of value chain organisation	Hermann et al., (2016, cited in Lu 2017, p.2)

Industry 4.0 is the sum of all disruptive innovations derived and implemented in a value chain to address the trends of digitalisation, transparency, mobility, modularisation, network collaboration, and socialising of products and processes	Crnjac et al., (2017)
Industry 4.0 is focused on creating a “smart” environment within production systems. Features of Industry 4.0 are horizontal, vertical, and digital integration of the entire system	Crnjac et al., (2017)
The transformation of production processes from separate automated processes into a fully integrated, optimised, and automated manufacturing/service environment	Nafchi and Mohelská (2020)

Fruth and Teuteberg (2017) suggest that Industry 4.0 facilitates the networking of the many diverse actors who coordinate the flow of goods and services within the supply chain, achieving greater levels of transparency, efficiency, and customer satisfaction (sustainable competitive advantage).

It is suggested by Oztemel and Gursev (2018) that Industry 4.0 will generate €78 billion for the German GDP by 2025. However, current financing of research and development on Industry 4.0 and related technological platforms is assumed to reach €200 billion by 2020, indicating that ROI calculations (payback considerations) are still a major issue for SMEs who are considering the possible implementation of Industry 4.0 embedded technologies (Oztemel and Gursev, 2018). An embedded system is determined as a combination of computer hardware and software that is configured to perform a specific function. Embedded systems may also function within a large system that is either programmable or undertakes a fixed functionality (Bosch and Olsson, 2020).

The possible utilisation within generic business models has been published in the United States, in the form of a framework guide to the implementation of Industry 4.0. However, at present, it does not relate to the discipline of Supply Chain Management which still lacks a quantified definition and scientific artefact (Gružauskas, Baskutis, and Navickas, 2018). The *European Commission* reported in 2013 that the economic and social potentials of Industry 4.0 are far greater than what is currently anticipated, suggesting that the maritime sector is a viable aspect for further research in relation to environmental, economic, and social sustainability (Gružauskas, Baskutis, and Navickas, 2018). This view is also advocated by Pang et al., (2015 cited in Birkel and Hartmann, 2019) who suggest that the full potential of Industry 4.0 needs to be unlocked, with the creation of income-centric values instead of traceability-centric values. It is suggested by Calatayud, Mangan, and Christopher (2019) that the onus is on practitioner literature to advocate the potential of the "self-thinking" supply chains of the future and that current research is rather limited. They advocate a multi-disciplinary approach that incorporates a variety of subjects, Supply Chain Management, computer science, engineering, and economics to systematically review future research trends (Calatayud, Mangan, and Christopher, 2019). By 2014, there were a total of 32 automated container terminals operational in a global context, indicating that the advent of Industry 4.0 is still in its infancy.

3.4.1 Evolution of Industry 4.0

The concept of Industry 4.0 is widely regarded as the Fourth Industrial Revolution and Figure 16 represents that it is underpinned by the following pillars: autonomous robotics, cloud computation, IoT, system integration, BDA, cybersecurity, addictive manufacturing, simulation and modelling, and 3D printing (Sarabia-Jácome et al., 2013; Fruth and Teuteberg, 2017; Hováth and Szabó, 2019; Stanley and Hensher, 2019). IoT is applied to harvest BD from the physical operating environment, and it is processed by an AI model to create a creation of a digital twin. The system integration allows CPS to interact between physical and digital environments by the application of computation and physical processes (Hováth and Szabó, 2019).

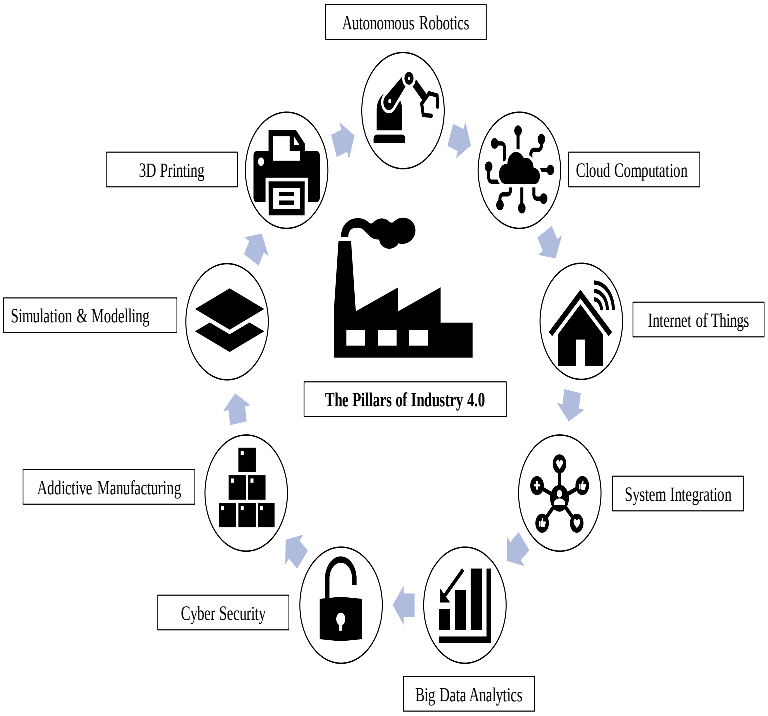


Figure 16: Pillars of the Industry 4.0 Paradigm

According to Gattullo et al., (2019), there are six principles of the Industry 4.0 paradigm: interoperability, virtualisation, decentralisation, real-time monitoring, service orientation, and modularity.

Interoperability relates to the level of communication between machines, technical documentation and humans that can be simplified using standardisation for both text information and visual elements (symbols). In addition, to how they can communicate and connect with each other over the Internet of Things (IoT) in the Industry 4.0 paradigm (Gattullo et al., 2019).

Virtualisation is the capability to create a digital version of technical documentation in order to monitor the physical processes of the system and provide the system with the necessary information for humans in case of failure. It represents a virtual copy of the physical environment that is facilitated through the connection of the Cyber-Physical Systems to virtual environments and simulation models (Gattullo et al., 2019).

Decentralisation is in response to the demand for customised products, as it is increasingly difficult to control the systems centrally. This principle allows the system to move to components rather than a central computer to enable unlimited scalability and flexibility. Therefore, embedded computers allow Cyber-Physical Systems to make decisions on their own as exemplified by the following scenario. Embedded computers on the machines can function when the operator asks for production. In this case, tasks would be assigned to a higher level if there is a system failure. Therefore, even if the whole technical documentation must be retained and eased access to the technical documentation should be provided locally. For example, when a failure occurs the system should provide just the exact solution to solve that problem without any need to look through it manually. This can be considered as the automation of manual and repetitive functions and reduces the time taken for manual interaction (Gattullo et al., 2019).

Real-time Data is needed to be collected, cleansed, and analysed in a real-time format, allowing the status of processes to be constantly tracked and analysed in order to react to failures and changes in production levels simultaneously. One of the advantages of the availability of real-time information throughout the process is the reduction of risk. A digitalised system can make the potential risks visible to the operator and allow various stages such as Supply Chain Management to monitor material flows in real-time in order to improve the future outcome (Gattullo et al., 2019).

The future of manufacturing industries is based on a service-oriented design. Cyber-Physical Systems, humans, and services of other companies are arranged as a service that is accessible over the Internet of Service. In the end, the process operations on a product can be created based on the customer's individual requirements. As exemplified by maintenance processes, which involve most of the technical documentation produced in a manufacturing industry which is subsequently administered as a service (Gattullo, et al., 2019).

A modular system is a flexible system that can adapt to the demands of dynamic environments. As exemplified by seasonal fluctuations in product demand or changed product characteristics by the customer or company. These changes may be implemented by reducing, replacing, or expanding individual modules based on standardised software and hardware interfaces. Technical documentation should be modular and with the integrations of new procedures and new technologies considered to be effortless (Gattullo et al., 2019).

In Figure 17 it is depicted that the origins of the industrial age began in the late 18th century with the development of the steam engine and the water wheel that powered mechanical production operations (Hováth and Szabó, 2019). The second industrial revolution commenced in the early 20th century when Henry Ford pioneered the concept of mass production which exploited the supply of electricity and the division of labour (Hováth and Szabó, 2019).

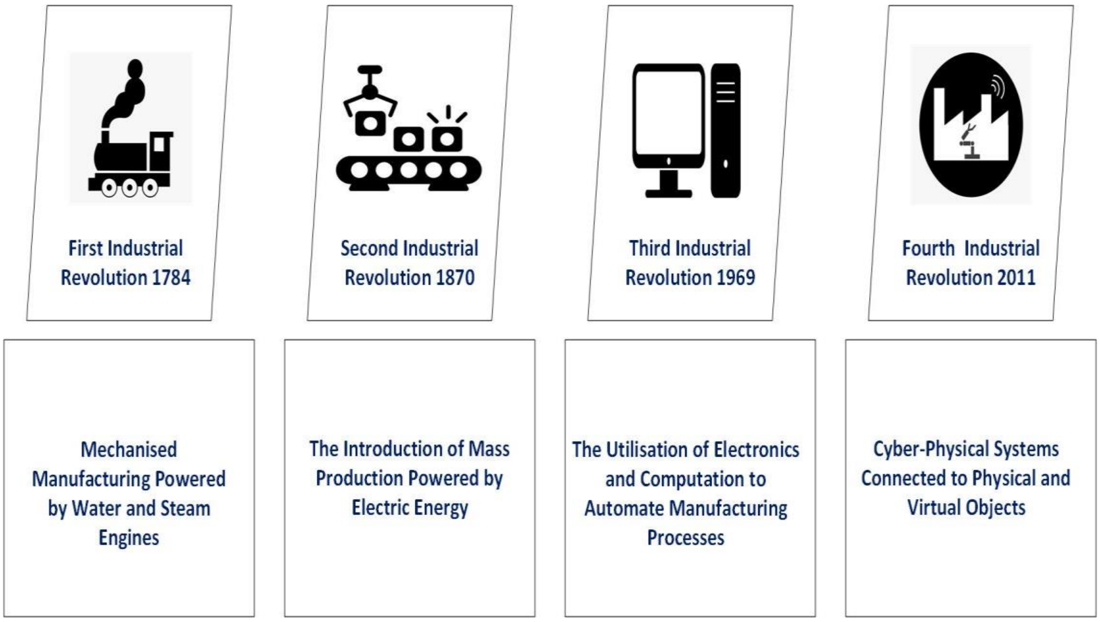


Figure 17: *Timeline of the Industrial Revolution*

It is argued by Hováth and Szabó (2019) that the Third Industrial Revolution is still in progress, and it is underpinned by the utilisation of electronics to automate the manufacturing processes. The Fourth Industrial Revolution utilises information and communication technologies in a more extensive way through the integration of physical and virtual objects. This is found at varying degrees in all spheres of human activity, business, government, and everyday life (Hováth and Szabó, 2019).

Hováth and Szabó (2019) conclude that the implementation of Industry 4.0 constitutes a technological and socio-economic phenomenon that is continuously evolving and difficult to forecast. It is suggested by Alop (2019) that the Fourth Industrial Revolution is developing exponentially rather than linearly, based on the principles of speed, scope, and systemic impact. However, it is argued by Maynard (2015 cited in Liao et al., 2017) that there is no universal agreement on what constitutes an industrial revolution. This infers that this term is applied to catch the public’s attention when reporting on the perceived benefits offered by the application of Industry 4.0 to industry and society. A commonality is identified by Alop (2019) as all four Industrial Revolutions have a similar underlying logic, based on the simplistic principle of producing more goods and ultimately consuming more goods.

The digitisation of the maritime supply chain may be traced back to the 1960s and the introduction of Electronic Data Interchange (EDI), involving a sending and receiving device that acted as a standalone form of communication. Developments in the 1970s witnessed the utilisation of Material Requirement Planning (MRP) and Manufacturing Resource Planning (MRP) in the 1980s, in an attempt to holistically manage the complete supply chain network. This trend continued in the 1990s with the application of Enterprise Resource Planning (ERP) which focused on the complete process of manufacturing and Supply Chain Management (Kakhki and Gargeya, 2019). It is argued by Stanley and Hensher (2019) that the maritime sector is set for the next technological revolution in the form of the advent of Industry 4.0, consisting of IoT, automation, digitalisation, the proliferation of remote applications, and the development of electric propulsion systems for all modes of transport.

The futuristic paradigm of Industry 5.0 is envisioned to reintroduce human technicians to the factory floors, increasing process efficiency. This integration will combine the creativity and brainpower of humans and machines (Leng et al., 2022). While Industry 4.0 primarily focuses on the pillar of process automation, Industry 5.0 will seek to involve human and machine cooperation. This will facilitate the evolution of a Super–Smart Society 5.0 concept (Leng et al., 2022, p. 282).

> *"Through the high degree of merging between cyberspace and physical space, will be able to balance economic advancement with the resolution of social problems by providing goods and services that granularly address manifold latent needs regardless of locale, age, sex, or language".*

Society 5.0 is characterised by four interrelated concepts, a human-centric society, a convergence of cyberspace and physical space, a knowledge-intensive society, and a data-driven society (Leng et al., 2022). The desired outcome of this collaboration is envisioned as a highly effective manufacturing process that leverages both added value and decreased levels of waste and cost (Leng et al., 2022). The next generation of robots will be highly flexible and able to quickly learn new processes in dynamic environments. The learning process will be underpinned by robots watching and emulating a person's movement and techniques. They will ultimately become cobots who act like an apprentice who learns by watching and applying their newly acquired knowledge and skill sets (Leng et al., 2022). The necessity of safety and risk management is adhered to as the robots will be aware of human presence, being perceptive of their environment and able to comprehend the objectives and expectations of the human operators (Leng et al., 2022).

3.4.2 Internet of Things

Figure 18 presents the view that the Internet of Things (IoT) permits a continuous visualisation of complex and multi-stakeholder seaport, city, and global supply chain integrations. IoT is defined as a physical object that is digitally connected through a remote network, enabling its capacity to sense, monitor and communicate with the supply chain actors, suppliers, factories, distributors, retailers, and customers (Birkel and Hartmann, 2019). The networked requirement for IoT is stressed by Zhou et al., (2015 cited in Calatayud, Mangan, and Christopher, 2019) that its ability to optimise and communicate with heterogeneous devices is dependent on the function of wired, wireless, or hybrid systems. However, Gnimpieba (2015 cited in Calatayud, Mangan, and Christopher, 2019) acknowledged that the value-added concept of IoT is precisely its capacity to integrate contrasting sensors, data transmissions, and storage. In a platform that is widely accessible to the Supply Chain Management who seek accurate data to formulate insightful management decisions. The ability of heterogeneous devices to communicate with others is viewed as an enabler in establishing the element of visualisation (Olesen et al., 2015; Gružauskas, Baskutis, and Navickas, 2018). It is now possible to access visualisation platforms in a remote setting through the advent of cloud computing, a concept that facilitates the fast and secure transfer, storage, processing, and sharing of data. A more holistic definition is advanced by Ben-Daya, Hassini, and Bahroun, (2017 cited in Calatayud, Mangan, and Christopher, 2019) who focused on the interrelationship between IoT and the discipline of Supply Chain Management, in formulating, controlling, and coordinating processes. An integrated approach is also advocated by Rai, Patnayakuni, and Seth (2006 cited in Kakhki and Gargeya, 2019) who argue that supply chain performance improvement could not be generated by merely utilising ICT applications; they emphasise the suitability of an ICT platform and enabling process.

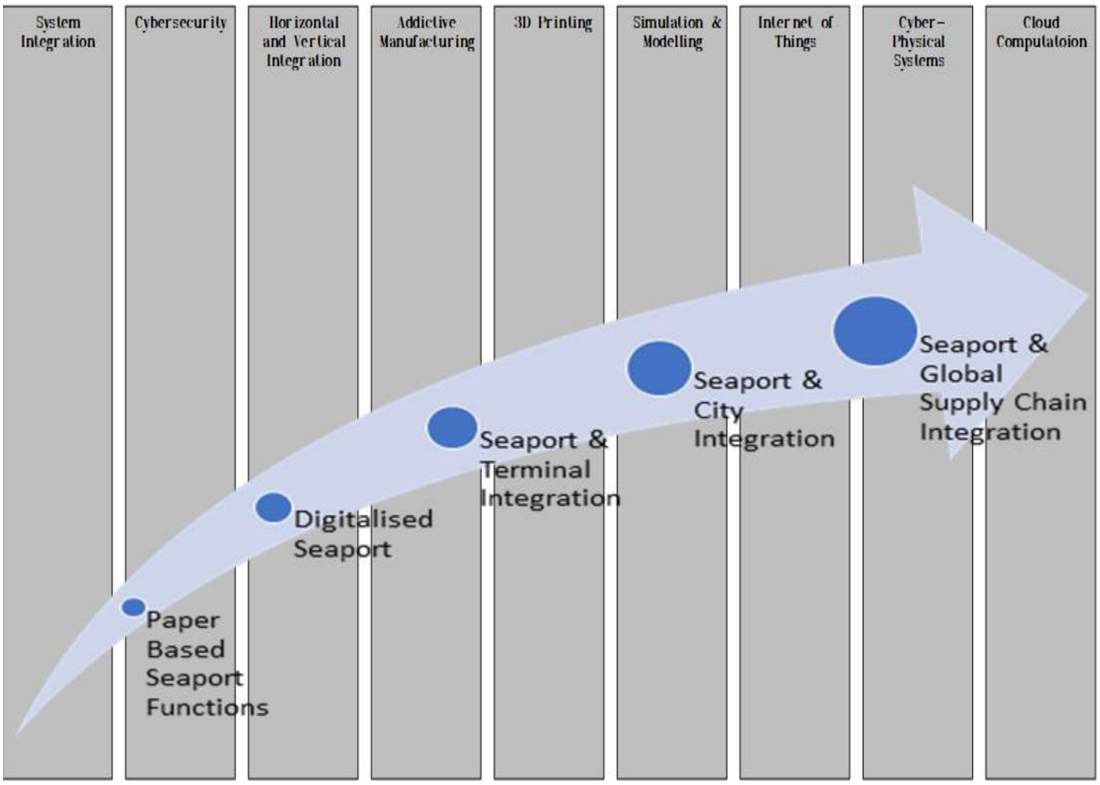


Figure 18: *Evolution of the Seaport Operation in Relation to the Pillars of Industry 4.0*

The IoT concept was devised by Kevin Ashton in 1999 to describe his concept of connecting Radio Frequency Identification (RFID) technology with the Internet, to gather, collate data, and visualise data in real-time without the need for any human intervention as depicted in Figure 19 (Birkel and Hartmann, 2019). His project was in collaboration with Proctor and Gamble (P&G) who provided access to their supply chain network. A number of positive advantages have been identified in the literature regarding the application of IoT and Industry 4.0: increases in product durability, higher customer satisfaction, improved build quality at lower management costs, and reduced waste (Birkel and Hartmann, 2019). This limits the requirement of continuous human interaction in terms of predictive maintenance, enhancing asset reliability as sensors will determine variations in the standardised operating parameters, (alerting the operators and arranging service support. Integrating the functions of asset records (work history), and sensor data (temperature, humidity, and consumable levels) into data dashboards that are able to be monitored remotely.

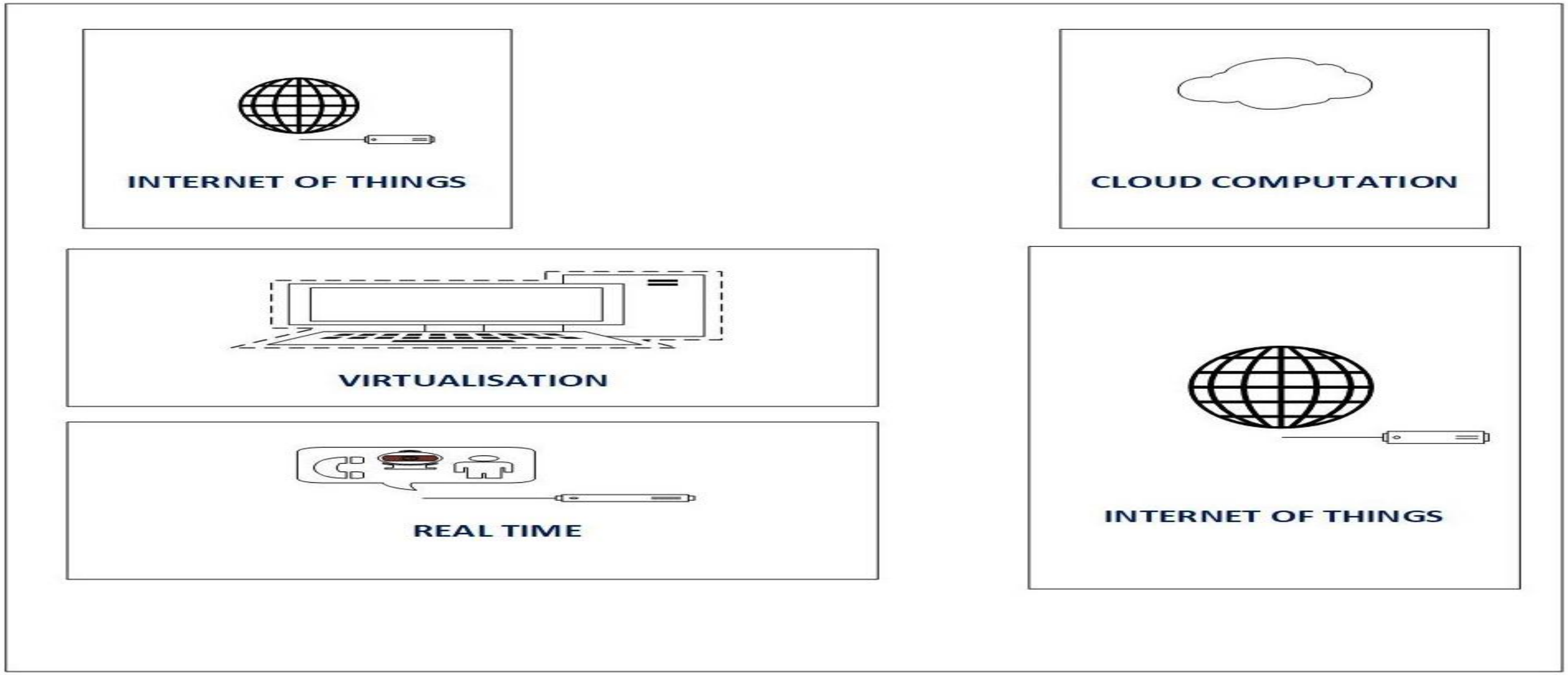


Figure 19: *Interconnected Concepts of Industry 4.0 - Without an overarching structure*

Adapted from Sangnahachai (2015 cited in Oztemel and Gursev, 2018)

3.4.3 Cyber-Physical Systems

The systematic exploitation of Cyber-Physical Systems has provided the concept of Industry 4.0 with an immense opportunity to transform the process of identifying and enhancing industrial value creation in the manufacturing sector (Huang et al., 2019). Cyber-Physical Systems are regarded as transformative technologies employed to monitor, coordinate, control, integrate, map, and collate information on the physical resources and the computational capabilities utilised in the routine operation of the supply chain or manufacturing process in near-real-time (Sarabia-Jácome et al., 2013; Lee, Bagheri, and Kao, 2015). Cyber-Physical Systems technology is utilised to perform repetitive activities and it is proposed to reduce the level of human involvement, making the activities more automated (Barreto et al., 2017).

Lu (2017) states that Cyber-Physical Systems are underpinned by the emergence of IoT, cloud computation, and BDA. Gilchrist (2016) advocated that IoT had digitalised the functionalities of Cyber-Physical Systems through integration, cooperation, and communication of the diverse actors engaged in a manufacturing process (production, Supply Chain Management, and resource planning). Equipped with Cyber-Physical Systems technology these actors can reflect the non-linear material flow, by modelling the process or requiring RFID tags. The sensors installed in each machine and the realisation of the operator ID, facilitate the actors to transmit the data in the form of a Dynamic Value Stream Map (DVSM) in near real-time for subsequent storage, analysis, and process visualisation (Huang et al., 2019).

3.4.4 Industry 4.0 Adoption Barriers

Approximately, 80% of global seaports still operate manual, legacy management systems, including whiteboards or spreadsheets to coordinate basic processes. Therefore, it is suggested that the advancement of the Industry 4.0 paradigm is in its nascent stage when considering universal seaport sector implementation and application (Heikkilaä, Saarni, and Saurama, 2022). This underpins a manifold of barriers to universal seaport sector application and implementation that were formulated when reviewing the literature. These barriers are reviewed subject to operational impact on the pillars of the Industry 4.0 paradigm. These barriers are delineated in the following Table 10.

Table 10: Barriers to Industry 4.0 Adoption

Operational Challenges	Pillar of Industry 4.0	Industry 4.0 Implications	Reference
Lack of knowledge relating to Industry 4.0 implications	IoT Augmented Reality Simulation Additive Manufacturing System Integration Cloud Computing BDA	Seaports lag behind and fail to fully integrate Information Communication Technology to manage current and future operational challenges. The digitalisation process is slow in the maritime sector, especially in seaports. The economic and social potentials of Industry 4.0 are far greater than what is currently anticipated. The full potential of Industry 4.0 needs to be unlocked – the creation of income-centric values instead of traceability-centric values. Transformation of the concept of Data Warehousing from a data graveyard to a data-rich environment utilised to populate insightful data-driven decisions.	Heilig and Voβ (2017a) Gružauskas, Baskutis, and Navickas (2018) Birkel and Hartmann (2019) LaValle et al., (2011 cited in Hazen et al., 2014)
Lack of skills and competencies	IoT Augmented Reality Simulation Additive Manufacturing System Integration Cloud Computing Cybersecurity	Human capital issues – scarcity of skilled workers. Lack of training and education.	Harris, Wang, and Wang (2015)

	BDA		
Low management support	IoT Augmented Reality Simulation Additive Manufacturing System Integration Cloud Computing BDA	Limited investment in digitalisation. Loss of Confidence in advanced ICT application.	Philipp (2020)
Resistance to change mentality	IoT Augmented Reality Simulation Additive Manufacturing System Integration Cloud Computing BDA	Personnel reluctance to change or to learn new technology relating to SME and traditional family-owned organisations. Job Destruction. The unwillingness of seaport actors to cooperate with each other.	Harris, Wang, and Wang (2015) Xu, David, and Kim (2018) Harris, Wang, and Wang (2015) Sarkar and Shankar (2021)
Spiritual and Ethical Concerns	IoT Augmented Reality Simulation	Relating to the Replication of human cognitive processes.	Xu, David, and Kim (2018
Lack of both academic and practitioner research on Industry 4.0 implementation	IoT Augmented Reality Simulation Additive Manufacturing	The onus is on practitioner literature to advocate the potential of the 'self-thinking' supply chain.	Calatayud, Mangan, and Christopher (2019)

	System Integration Cloud Computing Cybersecurity BDA		
Financial Constraints	IoT Augmented Reality Simulation Additive Manufacturing System Integration Cloud Computing BDA	Size of organisation constraints on human resources and level of expertise. SMEs usually conduct short-term, informal, and ad hoc practices. High investment and high running costs. Rapid obsolescence of technology – ROI concerns. Long-term projects requiring significant levels of investment.	Harris, Wang, and Wang (2015) Shah, Logiotatopouloh, and Menon (2019)
Data Security	Cybersecurity System Integration	Data sovereignty is defined as the ability of the data owner to decide how to disseminate and use its data. Data ownership and use are complex and controversial issues – especially relating to personal data. Cybersecurity has demanded the highest attention of seaport and maritime leaders in recent years. Lack of trust in online transactions. The large number of actors engaged in the seaport operation offers manifold opportunities for cyber-criminals to pursue. This increases the vulnerability of the seaport's assets to cyber-attacks, Representing	Sarabia-Jácome et al., (2013) Milne and Watling (2019) de la Pēna Zarzuelo, Soeane, and Bermúdez (2020)

		a genuine security risk, just a hypothetical or theoretical risk.	
Data Quality	Simulation Cybersecurity BDA	Seaports are regarded as hostile environments for wireless communications, requiring functionality to network vast distances with a wireless signal, in addition to the capacity of containers to inhibit radio signals as they continuously transit around the terminal.	Lundgren 2019 cited in de la Pēna Zarzuelo, Soeane, and Bermúdez (2020)
Interoperability	System Integration	Lack of standardisation may potentially isolate actors in the seaport. Low compatibility between heterogeneous systems. Lack of data transmission interoperability. Integration of customer and partner applications problematic – interconnectivity and data bottlenecks.	Sarabia-Jácome et al., (2013) Harris, Wang, and Wang (2015)

3.5 The Nature of Big Data (5V's)

Table 11 suggests that there is limited consensus in the academic literature relating to the terminology utilised in providing a definition of the structure of BD (Jeble et al., 2018). The BD model was formulated by the pioneering research of McAfee and Brynjolfsson (2012, cited in Richey et al., 2016) who originally based their conceptualisation in terms of volume, variety, and velocity. It was recently extended to incorporate the concepts of veracity, and value to provide a greater understanding.

Table 11: *Definitions of Big Data*

Adapted from Milne and Watling (2019)

Reference of Source	Definition of Big Data
Batty (2013 cited in Milne and Watling, 2019)	Any data that cannot fit into an Excel Spreadsheet
Laney (2001 cited in Milne and Watling, 2019)	3V = Volume, Velocity, & Variety
GSR (2016 cited in Milne and Watling, 2019)	5V + C = 3V Variability, Veracity, & Complexity
Kitchin (2013 cited in Milne and Watling, 2019)	3V + 2R + E + F = 3V Resolution, Relational, Exhaustive, & Flexible
Boyd and Crawford (2011, cited in Milne and Watling, 2019)	Big Data is notable not because of its size, but because of its relationality to other data
Anderson (2008 cited in Milne and Watling, 2019)	The end of theory

3.5.1 Volume

Volume relates to the magnitude of the data set generated by the various sources that monitor the life cycle of the supply chain network (Richey et al., 2016). This creates additional concerns that relate to the high degree of undesired transparency that is generated through the process of information disclosure, between collaborating supply chain partners (Harris, Wang, and Wang, 2015; Birkel and Hartmann, 2019). The flow of information exchange amongst supply chain partners is usually unbalanced in its cycle, leading to an operating perception of asymmetry and the dominance of one particular partner. It may result in the weakening of bargaining power, information advantages, and the skipping of supply chain linkages (Birkel and Hartmann, 2019).

3.5.2 Variety

The data collated from a complex supply chain originates from numerous heterogeneous sources of data sets, requiring a cross-function capacity of interoperability throughout the operation (Nguyen et al., 2018). It is estimated by Ilie-Zudor et al., (2015, cited in Barbosa et al., 2018) that supply chain networks generate approximately 1.6 billion raw data sets during each month of their operation. A fundamental challenge for BDA is the very nature of the data produced: structured, semi-structured, and unstructured (Raman et al., 2018). It is suggested by Harris, Wang, and Wang (2015) that 80% of all data collated within the supply chain environment is classified as unstructured, creating compatibility issues due to its heterogeneous nature. The accumulation of this unstructured data originates from a variety of diverse sources: radio-frequency identification (RFID), sensory information, and tracking devices (Raman et al., 2018). Uncoordinated implementation of Industry 4.0 devices may ultimately impede the continuous orchestration of the supply chain network when considering the issues of heterogeneous devices and their interoperability limitations (Harris, Wang, and Wang, 2015; Birkel and Hartmann, 2019).

BD generated by RFID platforms also results in the accumulation of large data sets, often created sporadically within the operation of the supply chain. This suggests that frequent mining of trajectory knowledge is significant for determining decision support models (Zhong et al., 2017). The transformation of embedded RFID platforms into Smart Manufacturing Objects (SMO) is attributable to the increasing accumulation of raw data sets, based on the continuous process of sensing, interacting, and reasoning (Zhong et al., 2017). In retrospect, the implementation of IoT technology may be viewed as merely accenting to the issue of interpreting vast amounts of data sets, to formulate effective business insights. A number of academic papers have published research findings that holistically model the collation of raw data sets from IoT platforms. It is suggested by Zhong et al., (2017) that this issue still poses a great challenge to the implementation of BDA, in terms of the ultimate aim of knowledge discovery and identification of data patterns.

3.5.3 Velocity

The terminology used to define the concept of velocity in BDA is regarded as a defining characteristic, which is largely based on the rate at which a data set is created and the frequency at which it should be analysed and incorporated into the decision-making process (Richey et al., 2016; Mishra et al., 2018). Hofmann (2017 cited in Calatayud, Mangan, and Christopher, 2019) suggested that to maximise the full potential of BD in Supply Chain Management, data needed to be captured, analysed, and transferred in the quickest time possible. It is implied by Richey et al., (2016) that velocity is a measurement of the machine-to-machine exchange of data sets that are calculated at increasing rates. According, to the research of Moradpour and Bhaptani (2005 cited in Calatayud, Mangan, and Christopher, 2019) the real value of data sets is in leveraging insights to monitor operational performance, discover data correlations, ask new questions, and formulate insightful decisions. However, the collation of vast data sets will not automatically result in a detectable improvement in supply chain throughput and performance. Velocity is often viewed within Supply Chain Management as representing both a challenge and an opportunity for operational management (Richey et al., 2016).

3.5.4 Veracity

A study conducted by Lavalle (2011 cited in Hazen et al., 2014) surveyed a population sample of over 3,000 business executives who perceived that data quality was their primary barrier to implementing more robust data analysis-based strategies. This problematic nature of BD quality is enhanced when subjected to the functions of the smart technological platforms, Industry 4.0 and IoT. It is referred to as a generic term of "noise" that relates to the quality and nature of the data sets: incomplete, redundant, and inaccurate records. These would ultimately impinge on the reliability and relevance of the decision formulated (Zhong et al., 2017; Birkel and Hartmann, 2019). The financial cost of poor data quality has been estimated by Redman (1998 cited in Hazen et al., 2014) to equate to between 8% and 12% and may result in up to 40% to 60% of service organisations operating expenses. Poor quality data sets may also adversely impact on less tangible areas of the business operation, potentially influencing the perception of job satisfaction, the formulation of the long and short-term strategy, and the levels of mistrust between diverse departments in the supply chain (Hazen et al., 2014). The process of frequent data mining is deemed highly significant in managing the function of BDA, with regard to Industry 4.0, IoTs and RFID smart platforms. However, the process of generating data is extremely sporadic in a complex supply chain that transcends international borders under the trading phenomena of globalisation (Zhong et al., 2017).

3.5.5 Value

The concept of value should not be considered in purely economic terms when discussing the composition of BDA. It refers to the process of extracting previously underexploited correlations and patterns of data sets, to provide a logical rationale in the formulation of a decision-making strategy in real time (Nguyen et al., 2018; Calatayud, Mangan and Christopher, 2019). This ultimately leads towards a process of optimisation within supply chain functions, increasing KPI performance, risk management, traceability, and visibility (Calatayud, Mangan and Christopher, 2019).

3.5.6 Big Data Analytics in Seaport Management

A complex and fragmented operation will generate a significant volume of raw data that requires analysis to determine both short- and long-term decision support. Many organisations fail to exploit the benefits offered by BD and it is accumulated as a by-product (Power, 2014). Data volume measures the units of data collection from various forms of media. Data from multiple sources is difficult to interpret in terms of linking, matching, cleansing, and transforming across inter/intra-organisational systems as depicted in Figure 20 (Power, 2014).

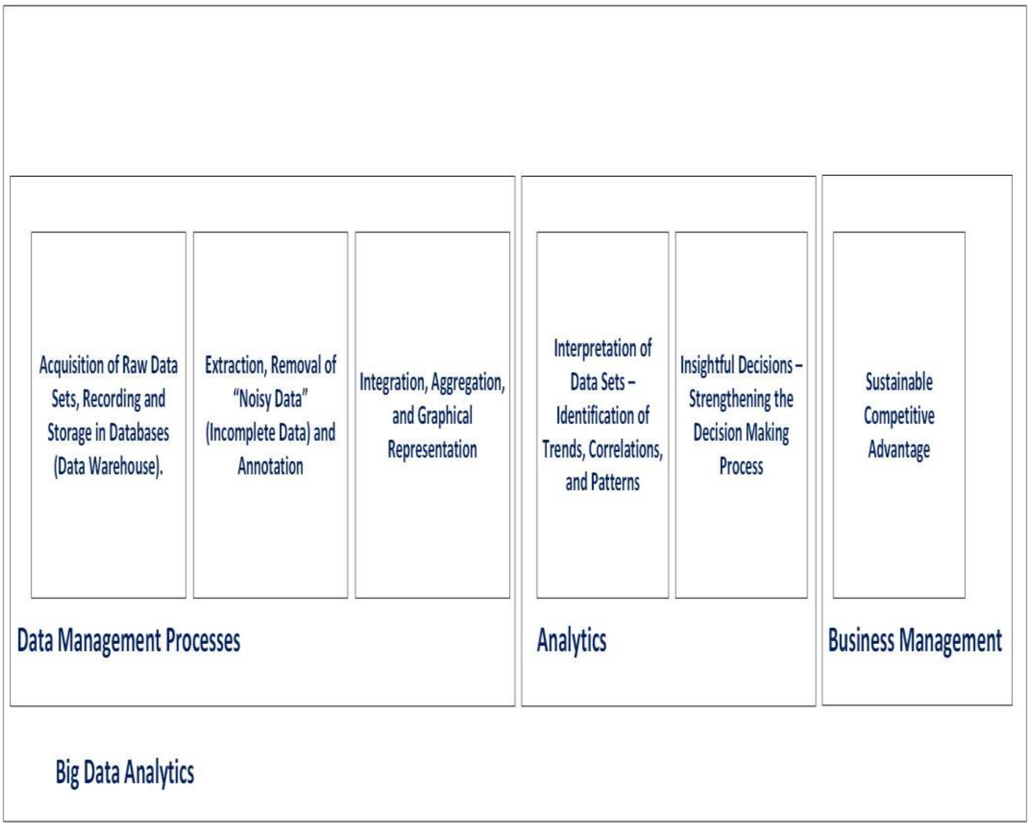


Figure 20: *BDA and the Formation of Strategic Decisions*

Adapted from Zaman et al., (2017)

Seaports are under increasing pressure from their customers to disclose real-time tracking information within dynamic systems, identified as transparency, traceability, and efficiency of their consignments (Chopade et al., 2015; Zerbino et al., 2018). Despite the critical importance of BD to enhance both decision-making and operational efficiency, many small-scale seaports are drowning in data and fail to utilise it effectively (Ferńandez et al., 2016; Zerbino et al., 2018). As can be seen from Figure 21 foresight and optimisation are fundamental in formatting a representative future vision of operational performance, which is difficult to ascertain and of more strategic value to a seaport.

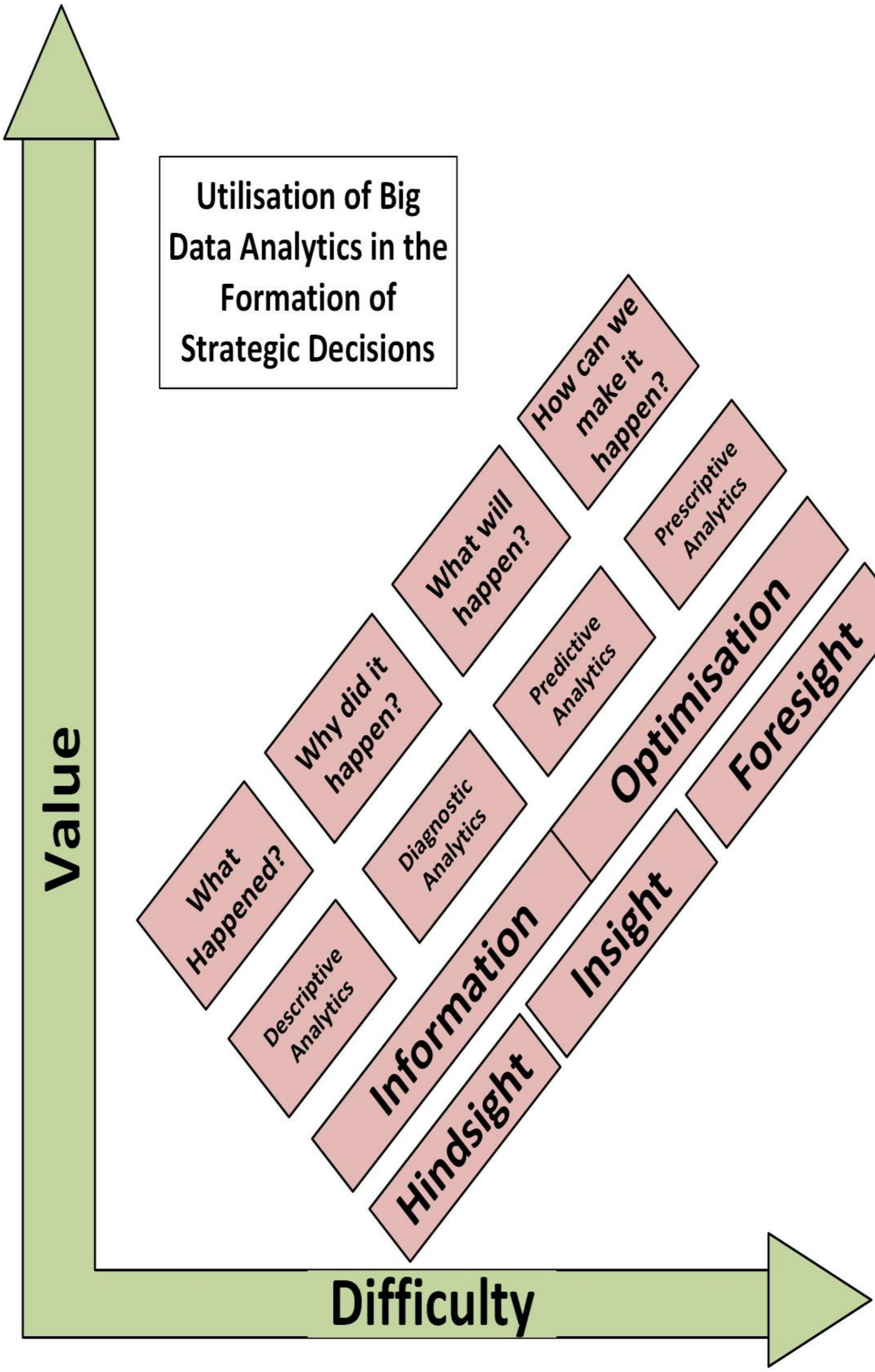


Figure 21: *Big Data and Business Analytics*

Adapted from Power (2014)

3.5.7 Data – Mining

The concept of Data Mining is underpinned by a methodology that is primarily discovery-driven (Laudon and Laudon, 2002). Data Mining provides insights into corporate data sets that cannot be generated by traditional analytical methods (OLAP) by identifying obscure patterns and correlations in extremely large databases and infers logic from their structure that facilitates the prediction of future behaviour (Laudon and Laudon, 2002). The patterns and logic are also utilised to assist decision-makers in relation to forecasting the effects of their decisions. The forms of information that are determined from Data Mining are depicted in Table 12 and include associations, classifications, clusters, forecasts, and sequences (Laudon and Laudon, 2002). Data Mining has been applied to Supply Chain Management in a variety of diverse applications: pricing and inventory management, demand prediction, and risk management (Nguyen et al., 2020).

Table 12: *Information Generated by Data Mining*

Adapted from Laudon and Laudon (2002)

Information Generated from Data Mining	Nature of the Information
Associations	Assumptions
Classifications	Similarity
Clusters	Partitioning Hierarchical Agglomerative Density Grid Model
Forecasts	Patterns
Sequences	Patterns

3.6 Insights & Summary

This literature review provides insights into the foundations of the current state-of-the-art research. It also assists in the identification of gaps in the literature, providing both challenges and opportunities for the continued development of the smart seaport concept, in relation to the monitoring and synchronisation of insightful digitised information from physical processes. It has become apparent that the maritime sector has yet to fully embrace the new technological platforms of BDA, Industry 4.0, IoT, and Cyber-Physical Systems when compared to the automotive and manufacturing sectors. The increasingly complex and dynamic operations of the seaport, system interoperability, cybersecurity, data quality, resistance to change mentality, and lack of competencies are hindering the widespread sectoral exploitation of Industry 4.0 technologies. However, the growth in throughput and demands of customers who now require highly customised products (value-added services), transparency, visibility, and supply chain agility are slowly changing this mindset amongst larger seaports, as they attempt to achieve sustainable competitive advantages. In many respects, these value-added services become tailored according to the fluctuating expectations of the customer. The future challenge for the maritime sector is to leverage operational benefits from conventional supply chain networks (response planning, warehouse management systems, transportation management systems, and information security) for implementing smart technological platforms to offset their running costs, achieving a sustainable ROI as justification for their continued development. To assist seaports in exploiting Industry 4.0 technologies it is advocated that VSM provides a robust method, populating current data visualisations of current state operations, leveraging an ideal future that is underpinned by the lean management principles of continuous improvement. The next chapter (Research Methodology) provides a justification of the research methodology employed in terms of VSM visualisations and the research strategy for data collection and subsequent coding.

CHAPTER 4: RESEARCH METHODOLOGY

4.0 Introduction

The methodological stance of the research is interpretivistic in its philosophy. The reliability of the semi-structured interviews in depicting the current state-of-the-art with regards to the seaport sector's perception of Industry 4.0 implementation and application, inferred an interpretivistic approach. The data collection method deployed was qualitative through the use of semi-structured, in-depth interviews, and process walk-throughs to ascertain the operational benefits of current and future state visualisations of Industry 4.0 embedded technologies as decision support tools. This methodological approach was also conducted in accordance with the ethical guidelines of Liverpool John Moores University (LJMU).

4.1 Research Design

The formulation of research design relates to the "Research Onion Model" as depicted in Figure 22, within the *Research Methods for Business Students* by Saunders, Lewis, and Thornhill (2016). The structure of the research onion depicts the methodological components that are applied to the research project. The Research Onion consists of five contrasting layers: Research Philosophy, Research Approach, Research Strategy, Time Horizon, and Data Collection Methods (Saunders, Lewis, and Thornhill, 2016).

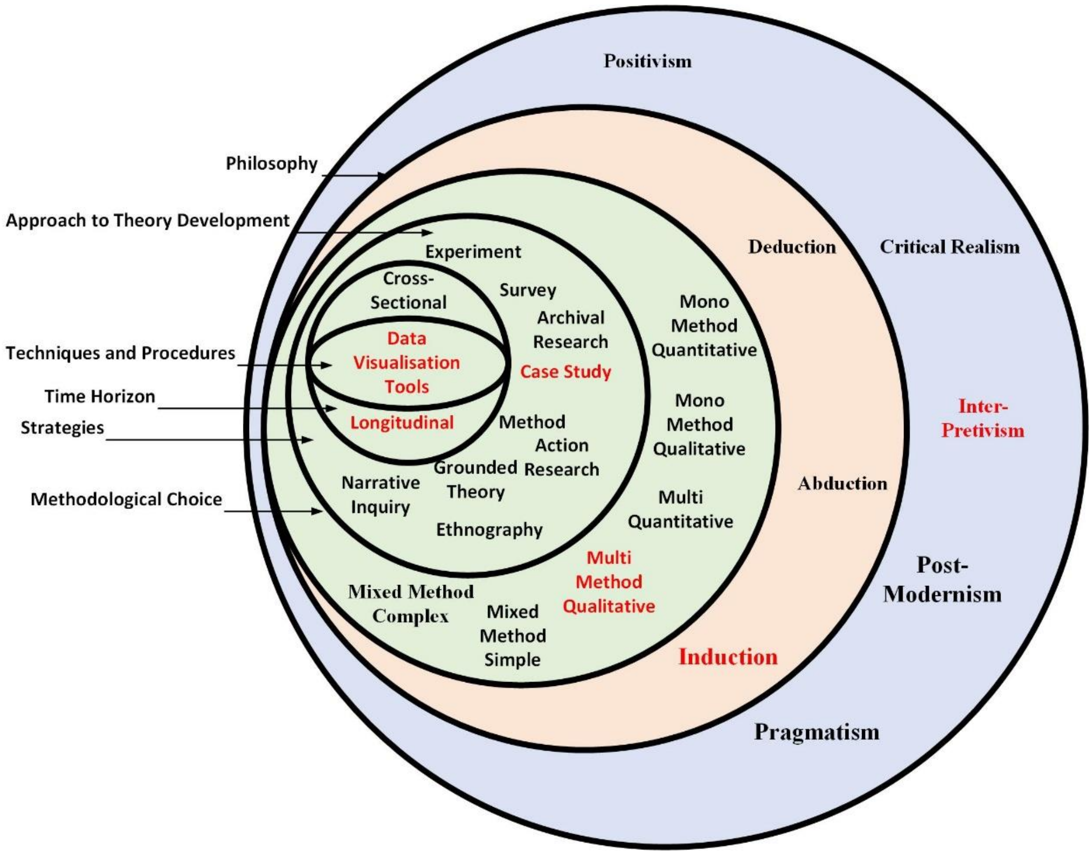


Figure 22: *The Research Onion - The Road Map of the Applied Research Methodology*

Interpretivism emphasises the influences that social and cultural factors can exert on an individual organisation. When implementing an interpretivistic philosophy the researcher has an active role in the study, populating a holistic view of the participant's actions, thoughts, and meaning. The concept of the research paradigm (philosophy) was popularised by the research of Thomas Kuhn in the early 1960s (Gummesson, 2000). Both research paradigms and their subsequent philosophical manifestations on the justification and accountability for their implementation in the natural and social sciences are viewed as a fundamental methodological procedure (Mangan, Lalwani, and Gardiner, 2004). Research paradigms consist of a basic set of beliefs that guide human interaction (Mangan, Lalwani, and Gardiner, 2004). They facilitate a general philosophical orientation about the world, and research attributes, and indicate what the researcher contributes to the overall study (Creswell and Creswell, 2018). It is advocated by Wittgenstein (1961 cited in Mangan, Lalwani, and Gardiner, 2004) that research philosophy is akin to a “worldview” and acknowledges the contrasting application of diverse philosophical approaches. There are various forms of epistemological positions that underpin research methodologies: Positivism, Post-positivism, Interpretivism, Constructivism, Transformative, and Pragmatism (Creswell and Creswell, 2018).

An inductive approach is applied in the study of isolated communities, where little preconceived knowledge exists. Research is subsequently conducted to gain information and insights on the community, underpinning the formulation of new theories (Saunders, Lewis, and Thornhill, 2016). Inductive approaches are typically applied when limited previous research has been undertaken (Saunders, Lewis, and Thornhill, 2016).

The data collection is Qualitative in its nature and focuses on textual, visual, and/ or audio-based data sets (Saunders, Lewis, and Thornhill, 2016). Gilbert (2001) argued that Qualitative research is akin to the researcher viewing human phenomena through another's eyes, in discovery and exploratory cycles that are both deeply and subjectively experienced.

A case study approach has been applied to this research project and it facilitated an opportunity to conduct an in-depth study of a seaport operation, in a real-life setting (See section 4.6.3 Case Studies). A longitudinal time horizon was selected to conduct a series of semi-structured interviews, in-depth interviews, and a process walk-through of the adapted VSM tools. This suited the seaports due to their limited time availability as the interviews and process walk-throughs had to fit around their busy schedules and make allowances for the time differences. It also allowed for a global search and selection of potential seaport participants, in addition to studying changes in responses and progression of the transcribing over time.

A methodological overview is provided in Table 13, which details the research philosophy, approach, and data collection methods deployed. It concludes that research philosophy is interpretivism as depicted in Figure 23 and it is regarded as a sociological method of research in which an action/ event is analysed subject to the beliefs, norms, and values of the culture of society where it is undertaken (Bryman and Bell, 2015).

Table 13: *Methodological Overview of the Research Project*

Methodological Overview	
Philosophy	Interpretivism
Research Approach	Inductive
Research Strategy	Multiple Case Studies
Research Design	Multi-Method Qualitative
Length of Study	Longitudinal
Data Collection Methods	Semi-Structured Interviews and In-Depth Interviews (Qualitative) Observation (Process Walk-through) Case Studies (Qualitative)
Data Analysis	Qualitative Data Analysis (NVivo Enterprise Software)

The techniques and procedures are the final layer in the Research *Onion*, and this facilitated the development of the data visualisation tools (Empirical Decision-Making Tools) that constitute a novel adaptation of traditional VSM methods. The data collected by the initial semi-structured interviews will be subsequently coded by NVivo Enterprise software into a series of themes, allowing a more considered approach to understanding the data. This will enhance the relevance of the data visualisation to accommodate the operational requirements of the seaport operators (See section 4.3 Value Stream Mapping and 4.6.2 Coding the Semi-Structured Interviews). Table 14 aligns the research philosophy and the applied research methods to adhere to the operational requirements of seaports in their natural operating environments.

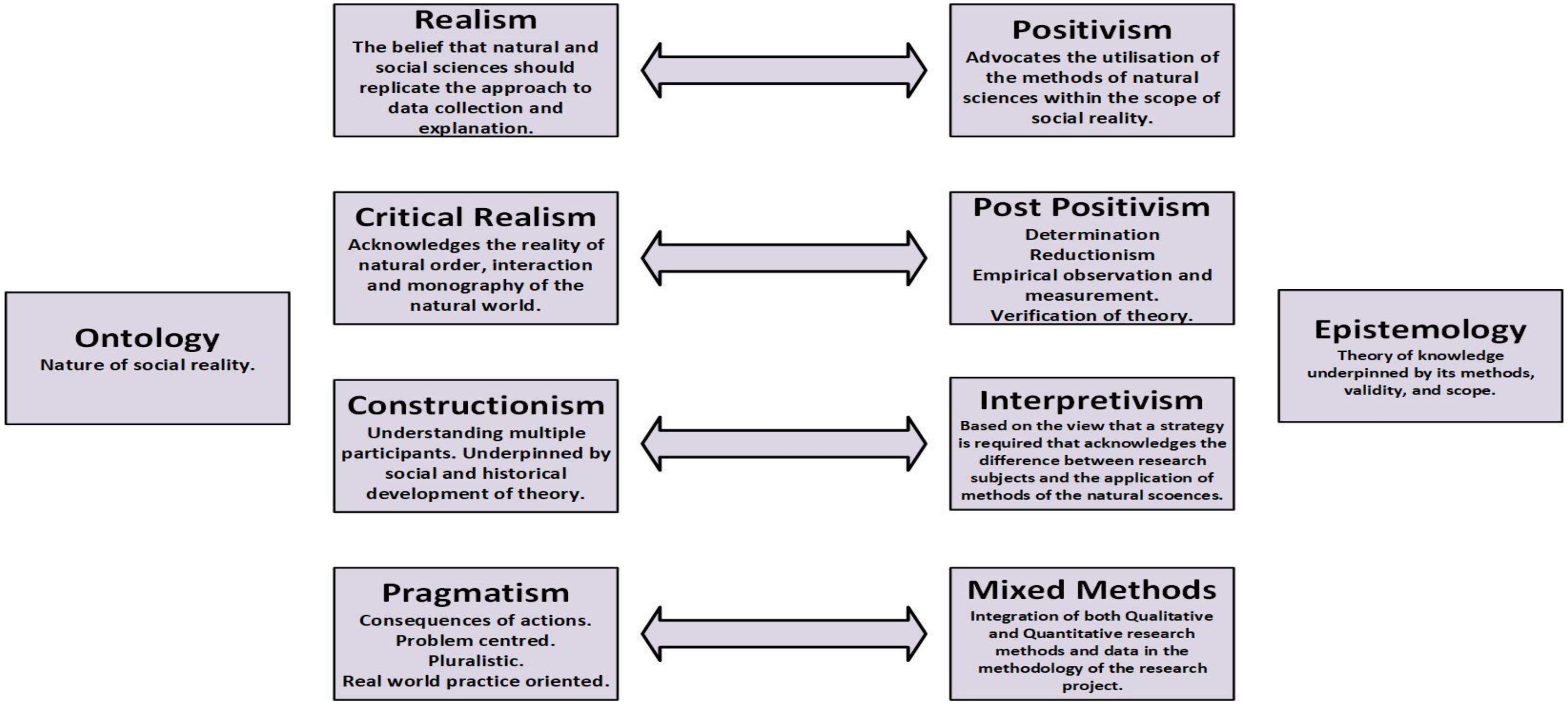


Figure 23: *The Philosophy of Research Methods*

Adapted from Denscombe (2010); Bryman and Bell (2015); Creswell & Creswell (2018)

Table 14: *The Relationship Between Research Objectives and Methodological Approach*

<table>
<tr><th>Research Objectives</th><th>Keyword(s)</th><th>Research Philosophy</th><th>Research Method Applied</th></tr>
<tr><td>RO1. What are the existing barriers to digitalised seaports in the Industry 4.0 era?
• How does a seaport understand its current position? This research sets out to identify tools and techniques to clarify these challenges and barriers for seaports to assist decision-making.
• What are the potential impacts of new innovations and technologies?
• How does a seaport plan a roadmap to a digitalised seaport?</td><td>Challenges and Barriers</td><td>Interpretivism</td><td>Systematic Literature Review Confirmation by Semi-Structured Interviews</td></tr>
<tr><td>RO2. Determine the relevance of traditional Value Stream Mapping (VSM) tools and the means by which they can be adapted for seaport data collection and mapping.</td><td>Relevance and Adapted</td><td>Interpretivism</td><td rowspan="2">Literature Review/ Semi-Structured Interviews Follow-Up Interviews Process Walk-Through</td></tr>
<tr><td>RO3. Develop an innovative range of data visualisation tools that are more relevant for seaports. These tools are used to determine both their current Industry 4.0 readiness and implementation plans to leverage an ideal operating future state and the roadmap to “realise” it.</td><td>Visualisation Tools, Industry 4.0</td><td>Interpretivism</td></tr>
</table>

4.2 The Lean Methodology

Lean philosophy is derived from either a philosophical (Liker and Meier, 2005) or a practical perspective (Womack and Jones, 1996). When lean philosophy is implemented, it reduces the time taken from order placement to the delivery of the product through the identification and elimination of waste in the production flow (Liker and Meier, 2005). A practical perspective of lean philosophy is defined as an alternative production model that combines equipment, methods, and strategies in product development, Supply Chain Management, and operations management into a complete service (Womack and Jones, 1996).

4.3 Value Stream Mapping

Value Stream Mapping has been developed from the Lean Methodology and it has been extensively used as a waste reduction technique, however as part of this research the applicability of the approach to be used for broader improvement initiatives has been identified (Rother and Shook, 1998). The core framework of VSM to undertake direct collection of data, followed by visualisation or mapping activities to establish progressive improvement or future states has been kept as the methodological core of the approach employed in this research as depicted in Figure 24.

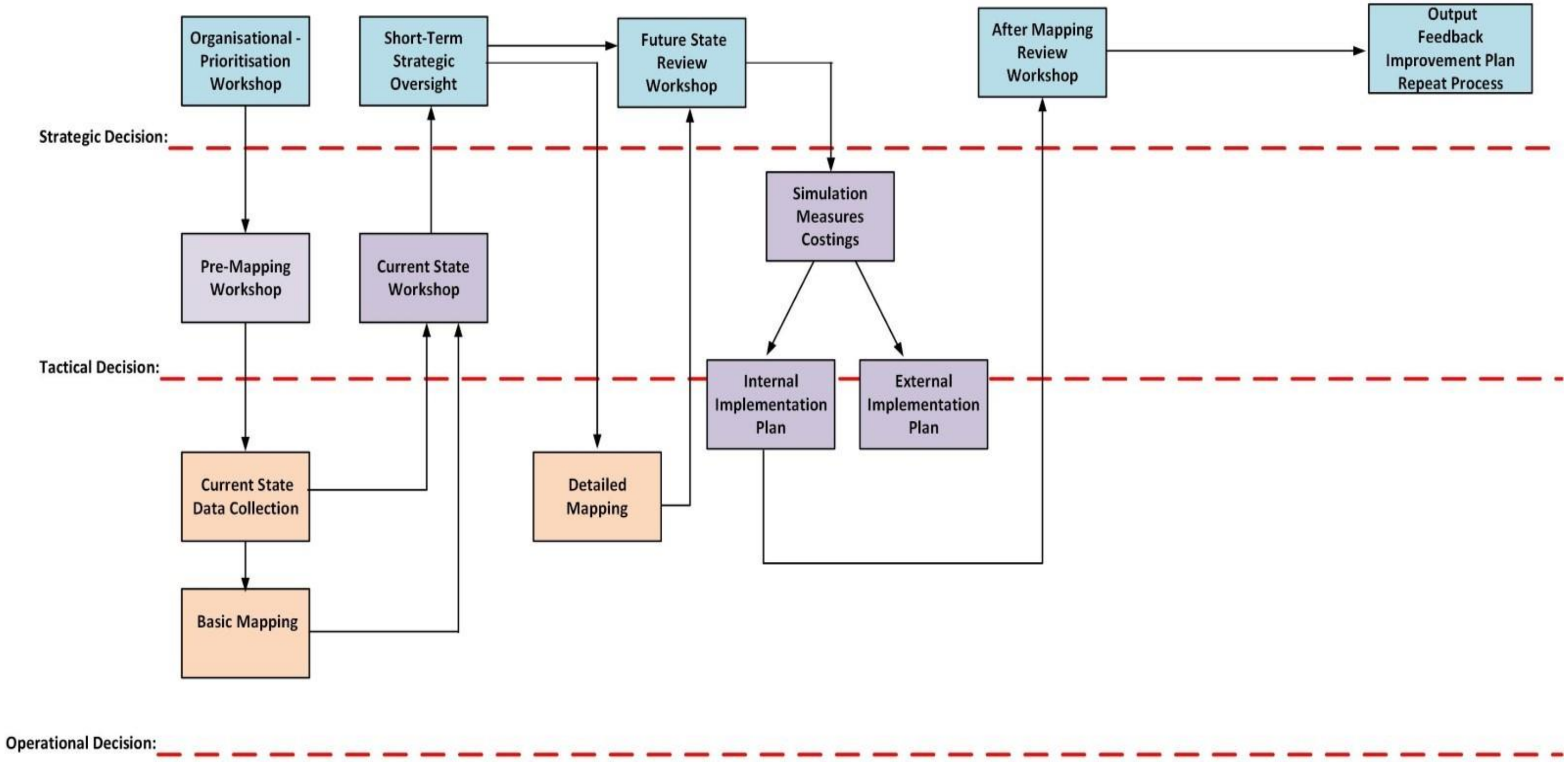


Figure 24: *The Traditional Lean Methodology*

Adapted from Womack and Jones (1996)

The novelty employed in this study around the application of this methodology to other objectives (such as data handling or intellectual capital) rather than just product movements and waste; means that this method when removed from Value Streams offers a structure by which organisational improvement across a broad spectrum of measures may be implemented. The range of application areas already described by VSM literature has been limited to waste reduction and flow improvements as depicted by Figure 25 (Rother and Shook, 1998), this study has proposed the use of that methodological core to radically improve many other aspects of seaport operations. In recognition that the technique no longer singularly focuses on Value Streams, the author has described the method in conjunction with other bespoke visualisation tools collectively as Empirical Decision-Making Tools (EDMT) tools.

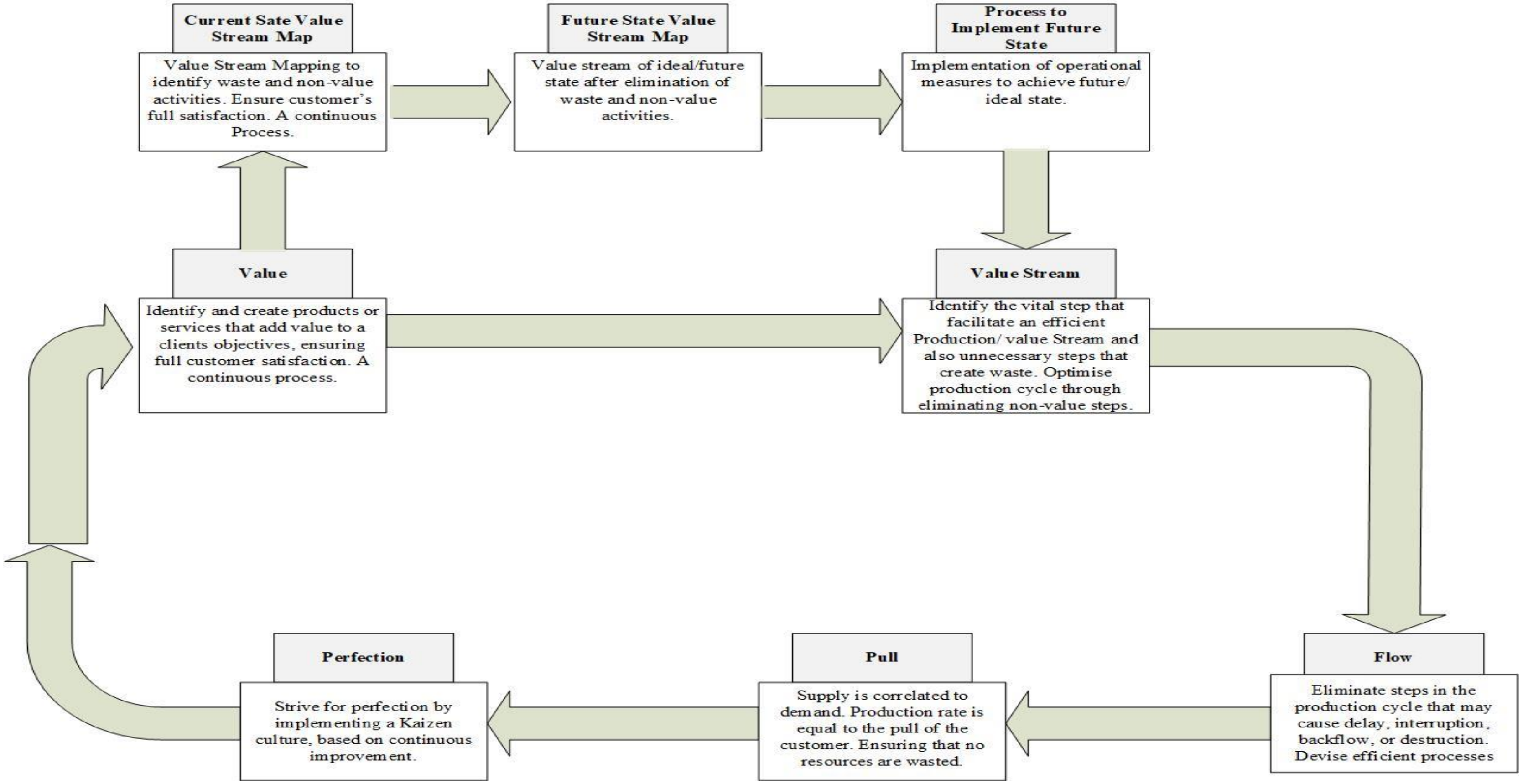


Figure 25: *Five Principles of Lean Management and the Implementation of VSM*

Adapted from Olesen et al., (2015)

4.3.1 Traditional Value Stream Mapping (VSM) Tools

VSM consists of seven tools: Process Activity Mapping, Supply Chain Response Matrix, Production Variety Funnel, Quality Filter Mapping, Demand Amplification Mapping, Decision Point Analysis, and Physical Structure Mapping (Hines and Rich, 1997). VSM tools are extensively applied to identify waste and non-value-adding activities in a value stream. The following Table 15 provides an overview of the VSM tool's suitability to map waste/ non-value-adding activities within the value stream.

The processes mapped by traditional VSM tools are recorded by a range of standardised symbols and figures which are presented in Figure 26. They are subsequently applied to map the process from raw material acquisition to finished product. The VSM symbols depicted in Figure 26 are not an exhaustive list and allow the inclusion of symbols to best represent the specific requirements of the process under observation.

VSM symbols are categorised as process symbols, material symbols, informational symbols, and general symbols. Process symbols are related to the working functions of different processes, an example being manufacturing, or supply chain driven (Rother and Shook, 1998). Material symbols represent the flow within the value chain and usually constitute the functions of inventory between two processes and shipments from suppliers or finished goods transiting to customers/ end users.

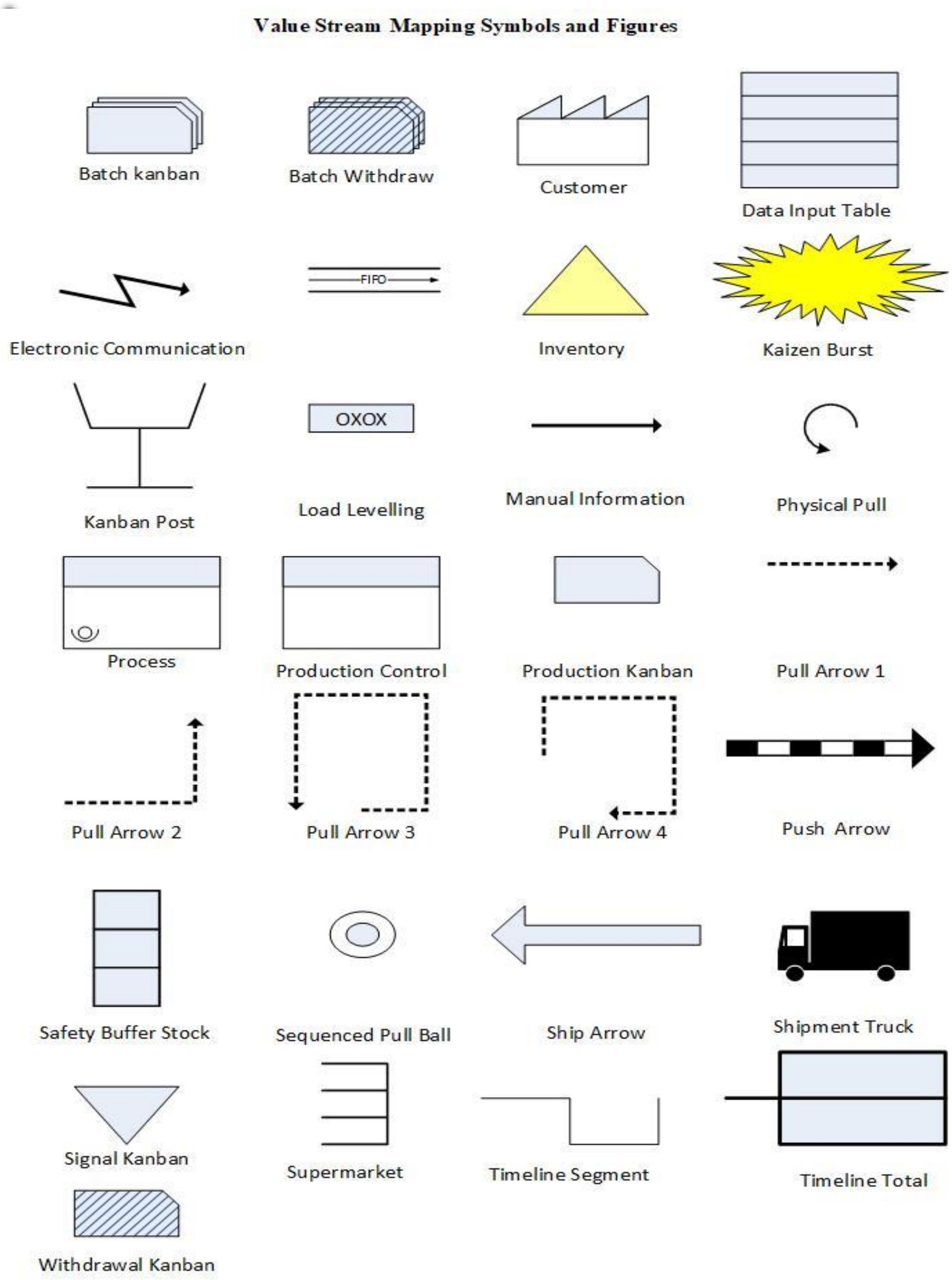


Figure 26: *Traditional VSM Symbols and Figures*

Table 15: *Suitability of VSM Tools to Identify Waste in the Value Stream*

VSM Tool	Waste/ Non-Value Adding Activity								
	Overproduction	Waiting	Defects	Unnecessary Inventory	Transport	Unnecessary Motion	Over Production	Inappropriate Processing	Overall Structure
Process Activity Mapping	Low	High	Low	Medium	High	High	Low	High	Low
Supply Chain Response Matrix	Medium	High	n/a	High	n/a	Low	n/a	n/a	Low
Production Variety Funnel	n/a	Low	n/a	Medium	n/a	n/a	n/a	Medium	Medium
Quality Filter Mapping	Low	n/a	High	n/a	n/a	n/a	n/a	Low	Low
Demand Amplification Mapping	Medium	Medium	n/a	High	n/a	n/a	n/a	n/a	High

Decision Point Analysis	Medium	Medium		Medium	n/a	n/a	n/a	Low	High
Physical Structure (Volume/ Value)	n/a	n/a	n/a	Low	Low	n/a	n/a	n/a	High

Process Activity Mapping originates from industrial engineering and applies a range of techniques to eliminate waste, inconsistencies, and irrationalities in the workplace (Ishiwata, 1991). Process Activity Mapping requires that a preliminary analysis is undertaken, followed by a detailed recording of all the items required to fulfil each process. Each process is categorised by its activity type, such as transport and storage. The machine or area utilised in each process is documented in terms of the machine or area allocated, transit time, and number of workers engaged (Hines and Rich, 1997). A simplistic process flow chart that represents the types of activity being undertaken at a particular moment in time can be drafted as depicted in Figure 27 (Hines and Rich, 1997). The total amount of distance transited, time taken, and the number of employees required can then be calculated and documented. This representation can then be utilised to underpin further analysis and process improvement initiatives, such as the 5W1H approach (Why does an activity occur? Who does it? On which machine? Where? and How?) (Hines and Rich, 1997). The objectives of this approach are to try and eliminate activities that are deemed to be unnecessary and wasteful (non-value adding), enabling the identification of lead times and productivity (physical flow and information flow). In addition to simplifying, combining processes, and implementing sequence alternations (Rother and Shook, 1998). Multiple approaches may be mapped until a consensus is reached regarding the most beneficial process improvement option (Hines and Rich, 1997).

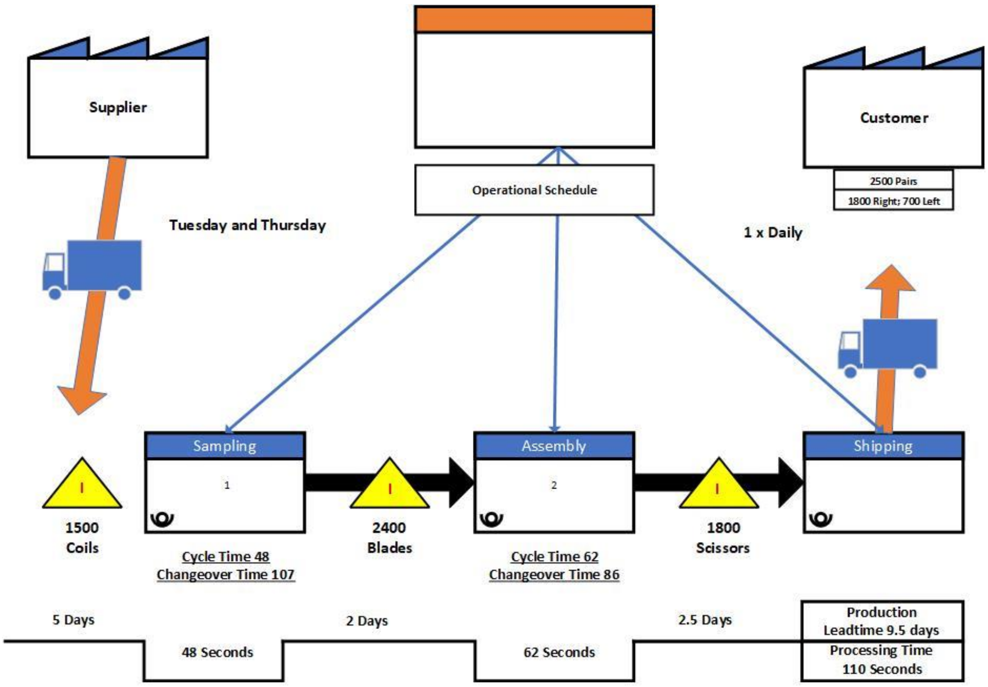


Figure 27: *Process Flow Mapping – Current State of a Simplistic Manufacturing Processes*

The Supply Chain Data Matrix tool originates from the textile supply chain sector and portrays the critical lead time for process completion (New, 1993). It is represented in a graphical and text format and illustrates the relationship between lead times and inventory on channel distribution as depicted in Table 16. The horizontal axis shows the lead time for the product in both external and internal environments. The vertical plot shows the average amount of standing inventory (in days) at specific nodes in the supply chain (Hines and Rich, 1997). The total response time leverages an understanding of each individual process lead-time and inventory amounts that facilitate improvement initiatives, as previously advocated by the Process Activity Mapping tool (Rother and Shook, 1998; Hines and Rich, 1997).

__Table 16:__ A Supply Chain Matrix – Bottle Filling Production Line

Number	STEP	**FLOW**	**MACHINE**	**DISTANCE (M)**	**TIME**	**OPERATIVES**	**OPERATION**	**TRANSPORT**	**INSPECT**	**STORE**	**DELAY**	**COMMENTS**
1	Raw Material	S	Reservoir	n/a	n/a	n/a	O	T	I	**S**	D	
2	Kitting	O	Warehouse	10	5	1	**O**	T	I	S	D	
3	Delivery to Lift	T	n/a	120	n/a	1	O	**T**	I	S	D	
4	Off-load from Lift	T	n/a	n/a	0.5	½	O	**T**	I	S	D	
5	Wait for Mix	D	Mix Area	n/a	20	n/a	O	T	I	S	**D**	

6	Put in Cradle	T	n/a	20	2	½	O	T	I	S	D	
7	Pour Mix	O	Mix Area	n/a	0.5	1	**O**	T	I	S	D	
8	Mix	n/a	n/a	n/a	20	½	**O**	T	I	S	D	
9	Test 1	I	n/a	n/a	30	2	O	T	**I**	S	D	
10	Pump to Storage Tank	T	Storage Tank	n/a	n/a	1	O	**T**	I	S	D	
11	Mix in Storage Tank	O	Storage Tank	100	10	1	**O**	T	I	S	D	
12	I.R Reset	I	n/a	n/a	10	2	O	T	I	S	D	
13	Await Filling	D	n/a	n/a	15	n/a	O	T	I	S	D	

14	Move to Filter Head	O	n/a	n/a	0.1	1	O	**T**	I	S	D	
15	Fill/ Top/ Tighten	O	Filler Head	20	1	2	**O**	T	I	S	D	
16	Stack	T	Pallet	n/a	0.1	1	O	**T**	I	S	D	
17	Delay to Fill Pallet	T	n/a	3	30	n/a	O	T	I	S	D	
18	Stack/ Secure Pallet	O	n/a	n/a	2	1	**O**	T	I	S	D	
19	Transfer to Storage Area	T	n/a	n/a	2	1	O	**T**	I	S	D	
20	Await Truck	D	Store	80	540	n/a	O	T	I	S	D	
21	Fork Truck Pick Up and Movement	T	n/a	n/a	3	1	O	**T**	I	S	D	

22	Waiting to Fill Up HGV Trailer	D	HGV	90	30	1	O	T	I	S	D	
23	Await Shipment to Customer	D	HGV	n/a	60	1	O	T	I	S	D	
	Total	**n/a**	**23 Steps**	**443**	**781.2**	**25**	**6**	**8**	**2**	**1**	**n/a**	
	Operators	**n/a**	**n/a**	**n/a**	**38.5**	**8**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	
	% Value Adding	**n/a**	**n/a**	**n/a**	**4.93%**	**32%**	n/a	n/a	n/a	n/a	n/a	

Production Variety Funnel originates from the operations management discipline (New, 1974). Figure 28 depicts a brewing industry representation of the Production Variety Funnel (Hines and Rich, 1997). It is regarded as a visual mapping technique that identifies both the number of product variations in each stage of a manufacturing process and potential bottlenecks in process design. This enables an understanding of how the company, or the supply chain operates and the management of its complexity (Hines and Rich, 1997).

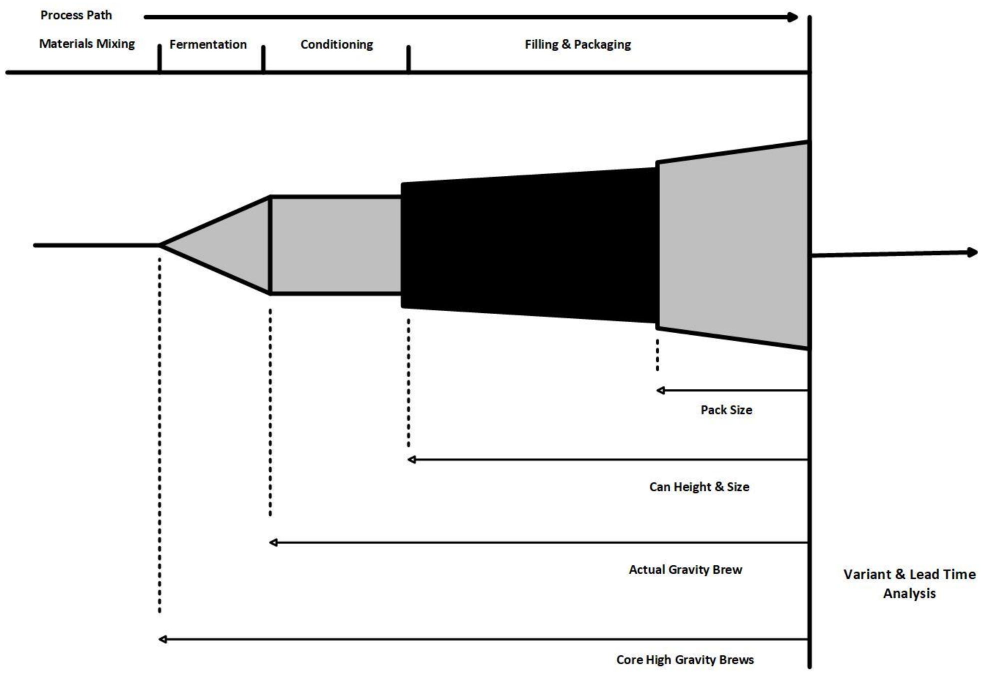


Figure 28: *Production Variety Funnel (Hines and Rich, 1997)*

Quality Filter Mapping is depicted in Figure 29 it is designed to identify where quality issues exist in the supply chain, and they are defined as product and quality defects, and internal scrap. Product defects relate to the quality of the product that has not been detected by in-line or end-of-the-line inspections and this is subsequently passed on to the end user (Hines and Rich, 1997). Service defects are issues passed on to the end user that are not directly related to the product. They relate to the accompanying service levels that reflect their experience. One of the most fundamental service defects relates to inappropriate delivery scheduling (early or late), including incorrect documentation. Internal scrap refers to defects in the company's operation that have been detected by in-line and end-of-the-line inspections, statistical process controls, and poke-yoke (an automatic device or method to detect or eliminate defects) devices (Hines and Rich, 1997). Each of these defects is subsequently mapped latitudinally across the supply chain. A clear advantage of this approach is the identification of the location where the defects are occurring, and it underpins process improvement strategies.

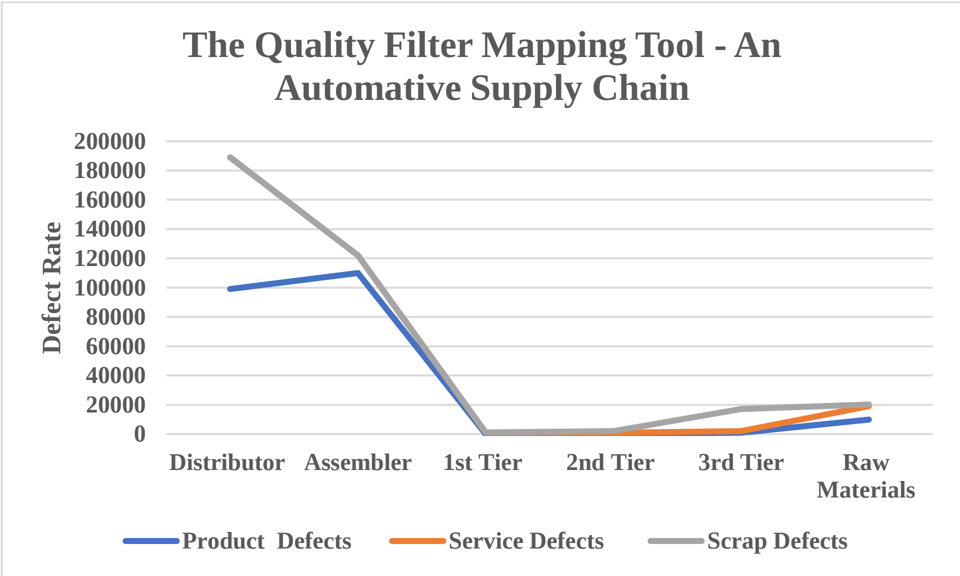


Figure 29: *The Quality Filter Mapping Tool – An Automotive Supply Chain (Adapted from Hines and Rich, 1997)*

Demand Amplification Mapping as depicted in Figure 30 originates from the dynamic systems research of Forrester (1958). Demand Amplification Mapping is an analytical tool that indicates how demand fluctuates along the supply chain in varying time periods (Hines and Rich, 1997). The information displayed may be utilised in formulating decisions, managing, and reducing fluctuations, and populating dual-mode solutions where regular demand can be managed in one way and exceptional or promotional demand can be managed in a separate way (Hines and Rich, 1997).

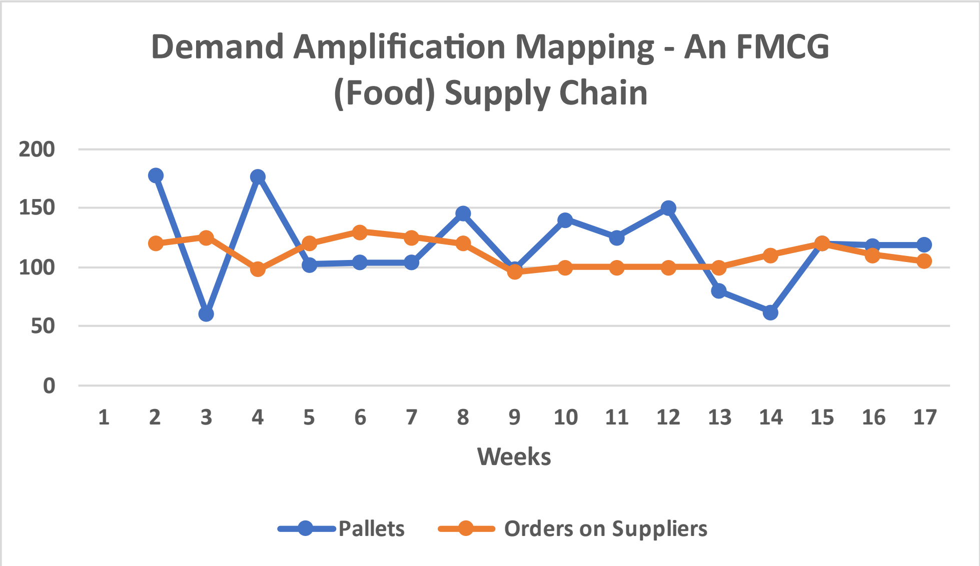


Figure 30: *Demand Amplification Mapping of an FMCG Food Supply Chain (Hines and Rich, 1997)*

Decision Point Analysis is of relevance for supply chains that exhibit similar functionalities of the Fast-Moving Consumer Goods (FMCGs) sector as depicted in Figure 31. The decision point in the supply chain is where the actual demand pull gives way to forecast-driven pull. This is defined as the point at which products stop being manufactured according to actual demand levels and are manufactured in response to forecast volumes (Hines and Rich, 1997). Understanding the location of a decision point in the supply chain is useful for two purposes; assessing the processes that function both downstream and upstream from the decision point. This ensures that they are aligned with the relevant pull or push philosophy (Hines and Rich, 1997). It is also possible to design what-if scenarios to visualise the operation of the supply chain if the decision point is moved.

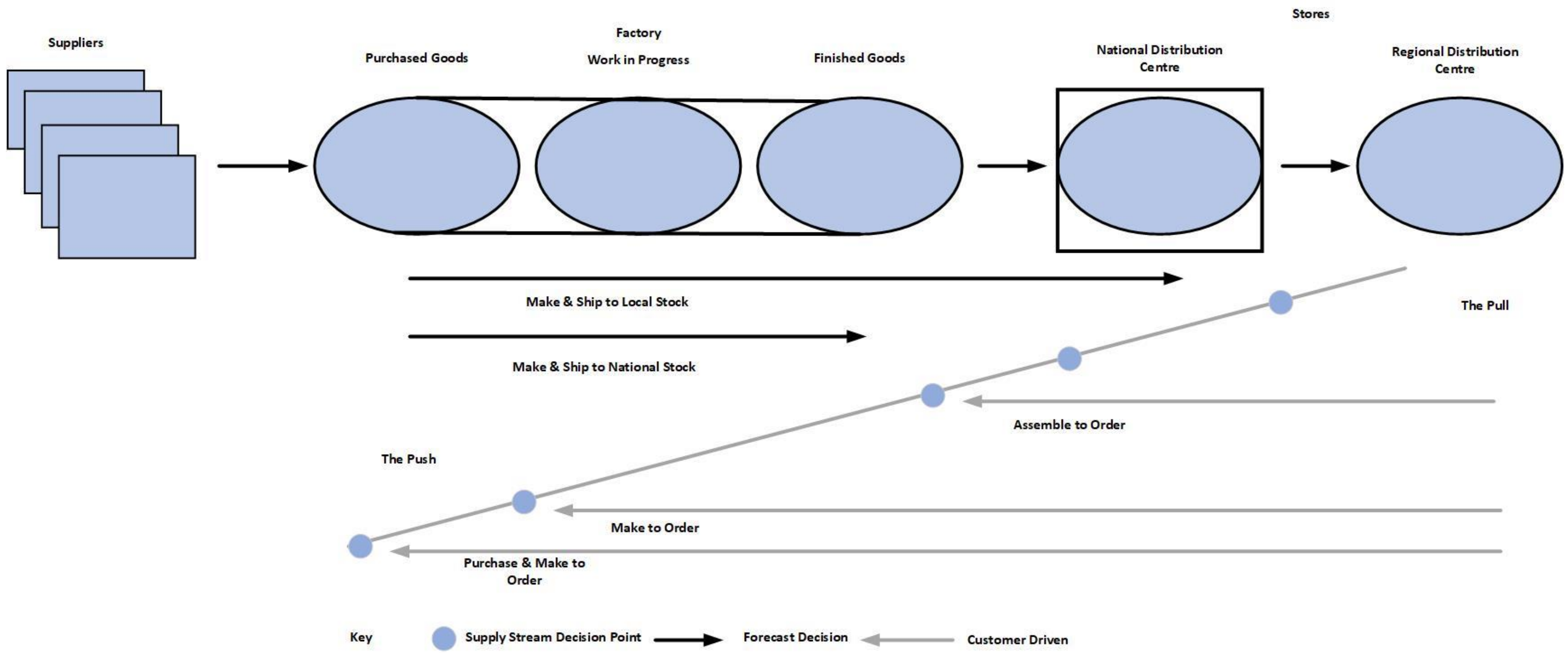


Figure 31: *A Decision Point Analysis of a Fast-Moving Consumer Goods Operation (Adapted from Hines and Rich, 1997)*

Physical Structure is regarded as a new mapping tool that facilitates an understanding of what a particular supply chain looks like from an overview or industry level. It directs attention to areas that may not be receiving adequate developmental focus (Hines and Rich, 1997). Figure 32 depicts the structures of the sector in relation to the various tiers that operate in the supplier and distribution tiers (Hines and Rich, 1997).

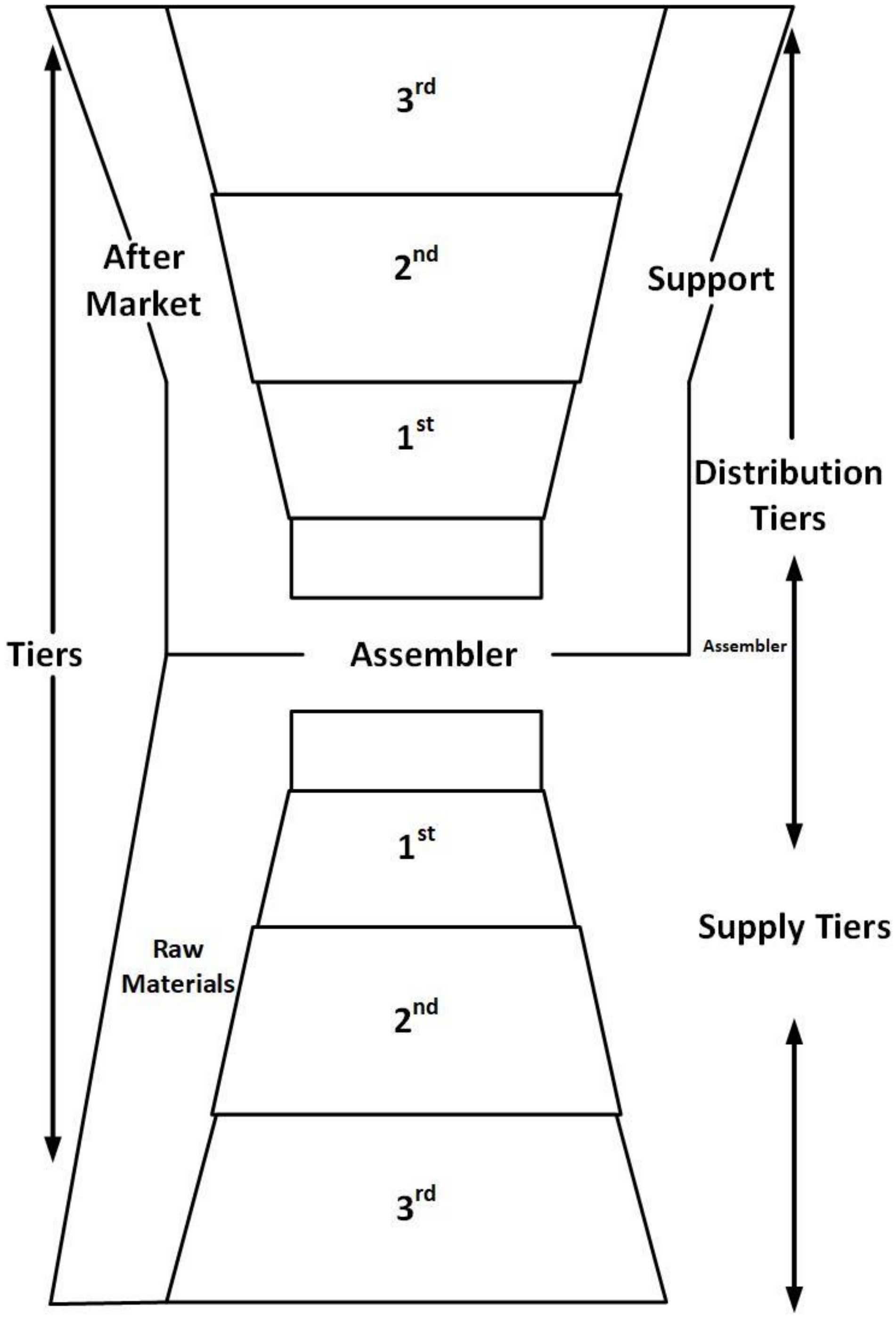


Figure 32: *Physical Structure of the Firms Involved in the Operation (Adapted from Hines and Rich, 1997)*

Figure 33 maps the industry in a similar format that includes the same set of organisations.

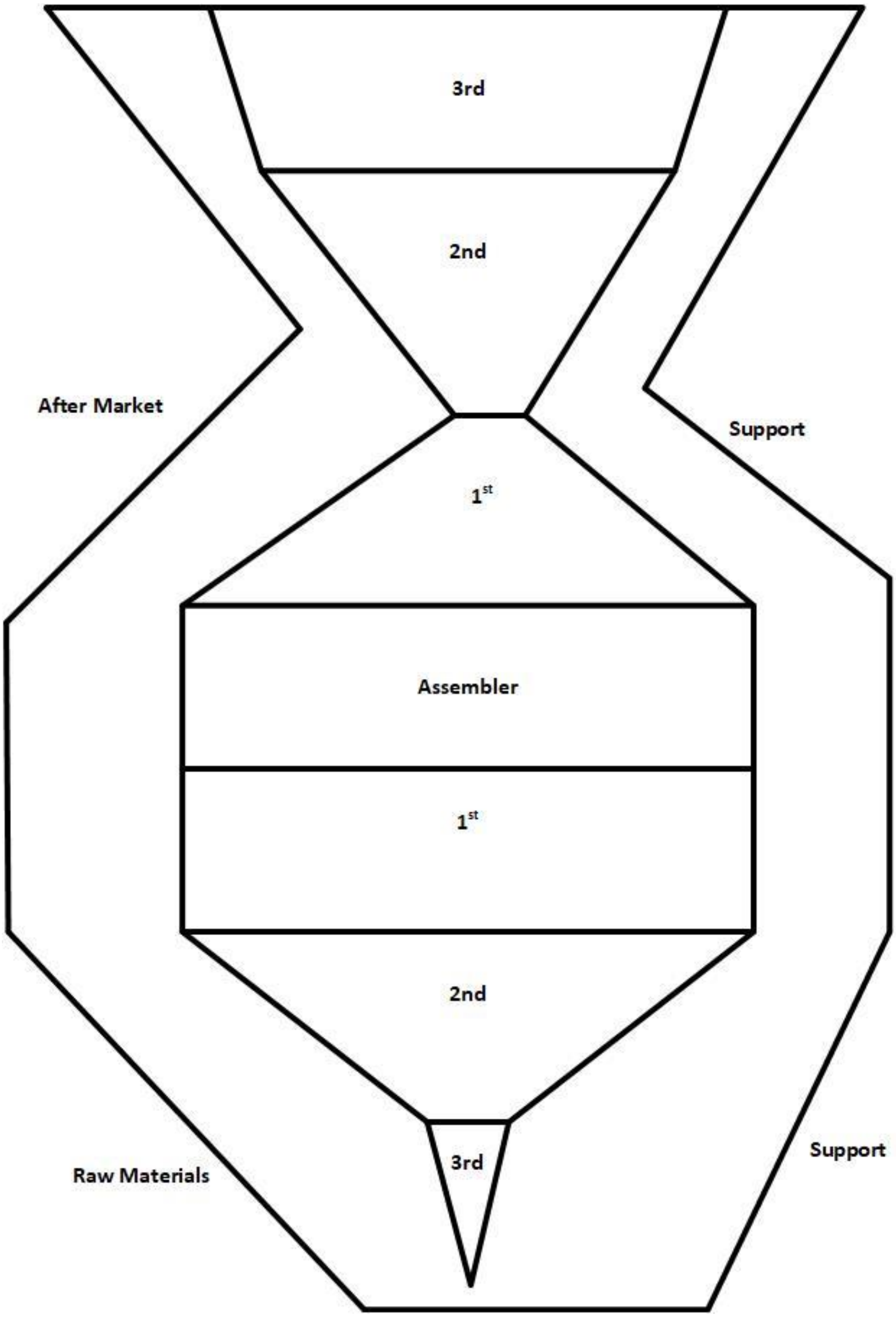


Figure 33: *Physical Structure by Cost-Adding*

However, Figure 33 is directly associated with value-adding processes. It may be inferred that in the automotive example developed by Hines and Rich

(1997) that the major cost-adding is incurred by the raw material suppliers, the first-tier suppliers, and the assembling process. The distribution channel is not regarded as a major cost-adding process. Figure 33 facilitates an analysis of the value-adding required in the final product as it is subsequently marketed to the customer (Hines and Rich, 1997). The value analysis may be focused on the complete industrial process or the supply chain structure. This will underpin opportunities to eliminate processes that are deemed as unnecessary, introduce process simplification, integrate processes, and implement sequence alterations to reduce waste (Hines and Rich, 1997).

4.3.2 Classification of Waste and Non-Value-Adding Activities

VSM produces a descriptive representation of a current state that is utilised to identify areas of the operation that are subjected to varying levels of waste and non-value-adding activities (disturbances) that prolong the supply chain/ value chain (Vikraman and Kumar, 2017; Romanowski, Nadolny, and Sutowski, 2017; Shou et al., 2017). The value stream is based on the set of all the specific processes that are required to bring a particular product or product family through the three critical management tasks of any manufacturing organisation: problem-solving, information management, and physical transformation (Romanowski, Nadolny, and Sutowski, 2017). The concept of waste is utilised to indicate any form of activity that does not add value and incurs a cost that is levied against the operating budget of the operation (González - Sánchez et al., 2015). It is stated in Table 17 that waste is predominant in seven formats: overproduction, over-processing, unnecessary motion, waiting, excessive transportation, defects, and unnecessary inventory (Olesen et al., 2015). This may serve as the catalyst for a strategic improvement plan that has a common language, utilising a range of integrated lean management concepts and techniques (Lasa, de Castro, and Laburu, 2009).

Table 17: *The Various Forms of Waste*

Adapted from Sullivan, McDonald, and Van Aken (2002)

	Classifications of Waste in the Value Stream
Over-Production	Production levels are too high or poorly scheduled in terms of rate. Indicative of issues with information flow and poor communication between the supplier, shipper, and consumer.
Over Processing	Restricted best working practices, utilising inappropriate procedures or systems. Underpinned by a resistance to change mentality, unwilling to embrace simpler approaches that may be more effective.
Unnecessary Motion	The Poor structural layout of the organisation results in poor levels of ergonomics. Includes human physical motion such as bending and stretching, and frequently dealing with misplaced items.
Waiting	Extended periods of inactivity for staff, raw materials, goods, and information flow. Resulting in reduced throughput capacity and longer-than-anticipated lead times.
Excessive Transportation	Excessive transportation of people, information, goods, or services. Resulting in increased lead times, transhipment costs, and other related logistical costs.
Defects	The frequency rate of errors in the fulfilment of administration, raw material, and poor finished goods quality. Defects usually require a process of recap to eliminate their impact within the value stream. Recap may constitute high levels of scrap, damaged, or reworked products. Double handling of products may adversely affect delivery scheduling and their KPI monitoring measures.

Unnecessary Inventory	Excessive storage of finished goods and/or raw materials, potentially creating bottlenecks in the value stream or the supply chain. Limited storage space will ultimately limit the capacity of goods in to accept new deliveries.

4.3.3 Current State Mapping

The approach of a Value Stream Map (VSM) is depicted in Figure 34 and it aims to eliminate waste and minimise the effect of processes that are deemed necessary but do not add any value to the operation, such as transportation and inventory (Romanowski, Nadolny, and Sutowski, 2017). Waste is also identified by the term friction costs, viewed as a concept of seaport functionality and the provision of customer service (Paixão-Casaca, 2005).

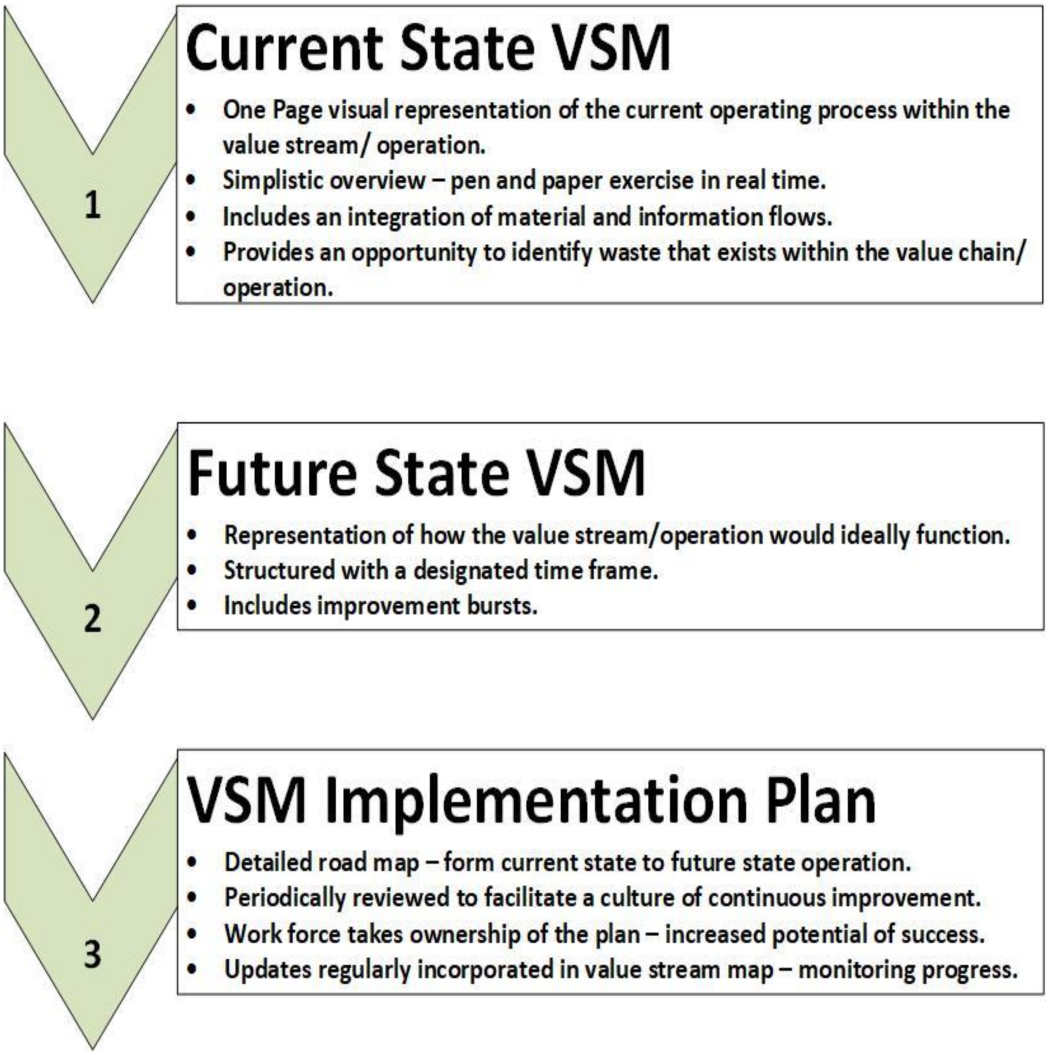


Figure 34: *The Process of a Traditional VSM Exercise*

The current state map is formulated under the principle of "go and see" which facilitates direct contact between shop floor employees and management (Manos, 2006; Lasa, de Castro, and Laburu, 2009). Data may be captured by utilising a variety of sources: process observation, interviews, surveys, measurements, and VSM software (Hines and Rich, 1997). Managers can access the knowledge of their employees regarding the functionality of their processes which is fundamental in the identification of waste/non-value-adding activities and their causes. To avoid the mistake of turning the current state VSM into a flow chart that tracks all of the different paths of the process it is advantageous to work backwards, ensuring the focus remains on one product (Rother and Shook, 1998; Manos, 2006). Each basic step of the process should be defined in the value stream, enabling the waiting times (queue) times between each process to be populated (Rother and Shook, 1998). Traditional VSM focuses on the Process Cycle Time (the amount of time taken to complete one task, production, service, or process from its start to finish) (Rother and Shook, 1998; Manos, 2006). Process Cycle Time is required to be separated between non-value-adding time and value-adding time. Process data is required to populate data boxes beneath each main process step. Process data considers the following: Process Cycle Times, Changeover Times, Pace TAKT Time/ Rate, Defects, Problems per Shift/Day, First Pass Yield, Batch Size, and Shifts. TAKT time refers to how frequently a part or component must be produced to meet the customer's demands (Manos, 2006). The value-added percentage (%NA) represents all the data in the value-added section and it is divided by the total Process Cycle Time. To provide additional representation it is necessary to multiply by 100, determining the percentage of value-added activities (%VA) (Rother and Shook, 1998). The completed VSM will facilitate an overview of the process and depict what has subsequently occurred as the product or family of products transits the value stream. This will include the following non-value-adding activities: bottlenecks, long process times, poor uptimes, excessive start-up times, and poor quality requiring rework (Rother and Shook, 1998; Manos, 2006). Processes identified for improvement are denoted by a Kaizen burst (star symbol) that details the recommended measure.

4.3.4 Future State VSM

A Future state VSM is an interim stage between the current state map and the ideal future state. Its objective is to identify where non-value-adding activities occur, waste, the generation of waste, non-value adding activities and how they can be subsequently mitigated or eliminated from the value stream (Rother and Shook, 1998; Manos, 2006; Ramani and Lingan, 2021). The implementation of the proposed process improvements does not necessitate immediate integration, commencing with the critical processes until reaching the ideal future state representation (Ramani and Lingan, 2021).

To formulate an ideal future state by VSM it is necessary to determine the TAKT time (Rother and Shook, 1998; Manos, 2006). The formula for TAKT time is the time available per shift divided by the demand per shift. If the cycle time or processing time is greater than the TAKT time there is an indication of a bottleneck or constraint within the value stream (Manos, 2006). This may result in overproduction waste or extra processing time (overtime) to adhere to customer demand.

A VSM ideal future state map will determine if queue time is a viable option for improvement, by focusing on logically reducing inventory volumes: raw materials, work in progress, buffer stocks, safety stocks (preventing production line stoppages), and finished goods (Rother and Shook, 1998). VSM ideal future state maps also visualise the flow of inventory documentation, identifying bottlenecks in batching processes. This acts as a catalyst for discussion relating to where can the operator improve the flow, by adding extra material into a process, eliminating materials from stopping and waiting. This scope of improvement is further expanded by an ideal future state map. In terms of the level of equipment reliability (maintenance and downtime duration). This is underpinned by analysing the number of defects/ reworks per shift (Rother and Shook, 1998; Manos, 2006). An ideal future state map reflects the operator’s vision for the next six or 12 months (Rother and Shook, 1998).

4.3.5 VSM Implementation Plan

The implementation plan details all the actions required to transform the current state to the desired future state. The implementation plan should provide a clear strategy, responsibility, timeline, and a budget. In addition to clear and actionable aims and objectives, a clear understanding of the resources and human capital (employee training, development, and recruitment) required in order to achieve them (Rother and Shook, 1998). Project milestones, events and deliverables may be monitored by a Gantt chart, allowing members to take ownership of their designated responsibilities (Manos, 2006).

The overall success of the implementation plan is dependent on its dissemination to all stakeholders (employees, suppliers, and customers) and their full collaboration/ engagement (Rother and Shook, 1998).

4.4 Research Approach

A collaborative relationship was established with the two principal seaport participants, the Northwest Seaport Alliance, and the Virginia Seaport Authority as depicted in Table 18 which shows how this approach was developed to adhere to the scope of the research aims and objectives.

Table 18: *Collaborative Levels to the Research Project*

Host Organisation	Control Measure	Format	Collaborative Relationship
The Northwest Seaport Alliance Virginia Seaport Authority	Initiation	Collaborative	Introductory Semi-Structured Interview In-depth Semi-Structured Interview Empirical Decision-Making Tools (EDMT) Presentation Agreed to follow up mapping exercise

The selection of 11 research participants represented a small-scale research population, when in comparison to the number of approaches made to the globalised seaport sector. This population does not represent seaports from the vast majority of coastal countries, which constitute a diverse culture, location, human capital, investment, governance, size, or market share. The data collected from the semi-structured interviews were applied to the insights obtained from the literature review and underpinned the development of the Empirical Decision-Making Tools (EDMTs) to address the operational needs of the participants. In terms of their lagging behind other sectors in terms of Industry 4.0 implementation and application, and the academic need for enhanced scope of observation in the literature.

4.5 Research Strategy and Decisions

The term research strategy relates to a general plan of how the researcher will formulate answers to the research questions posed in chapter one.

Figure *35* represents the methodological link between research objectives and the subsequent selection of data collection techniques and analysis. Research in the social sciences deals with human beings and real-world situations that develop in diverse, dynamic, and complex environments in the form of organisations, businesses, and institutions (Yin, 2014). These represent important opportunities to observe, understand, and formulate theoretical models of employee communities, networks, and hierarchical structures (Gray, 2014). In contrast to natural science disciplines, there is no singular methodological application to conducting social science research. As a more humanistic approach is advocated in order to structure and ask questions of the participant, and influence the nature of the research by political and/ or value considerations (May, 2011). In many respects, social science may be interpreted as an overarching framework for mixed methods research. The social science approach is considered as flexible in presentation, constituting a number of approaches that include literature reviews, as a conceptual model, or as a theory.

4.6 Methodology for Data Collection and Analysis

The methodology employed in the data collection and subsequent analysis to address the research objectives consisted of the following qualitative approaches: semi-structured interviews and case studies as outlined in

Figure *35* Miles (1979 cited in Bryman and Bell, 2015, p. 579) has viewed Qualitative data as an "*attractive nuisance because of the attractiveness of its richness, but the difficulty of finding analytic paths through that richness*".

Research Objectives	Research Methods
RO1. What are the existing barriers to digitalised seaports in the Industry 4.0 era? • How does a seaport understand its current position? This research sets out to identify tools and techniques to clarify these challenges and barriers for seaports to assist decision-making. • What are the potential impacts of new innovations and technologies? • How does a seaport plan a roadmap to a digitalised seaport?	Literature Reviews – Chapters 2 & 3 Current State of the Art • Impact of IoT and Cyber-Physical Systems • Barriers to Industry 4.0 implementation and application • Adaptation of the VSM approach to leverage a road to a digitalised seaport • Semi-Structured Interviews to collaborate the literature review in relation to challenges faced by seaports (As detailed in Appendix 6)
RO2. Determine the relevance of traditional Value Stream Mapping (VSM) tools and the means by which they can be adapted for seaport data collection and mapping.	Research Methodology – Chapter 4 • Traditional VSM tools – Adaptability from waste identification to seaport data collection and mapping exercises for Industry 4.0 awareness.
RO3. Develop an innovative range of data visualisation tools that are more relevant for seaports. These tools are used to determine both their current Industry 4.0 readiness and implementation plans to leverage an ideal operating future state and the roadmap to "realise" it.	Multi-Method Qualitative Chapters 5, 6,7,8, and 9 • Data Collection and initial insights relating to current state operations. • Semi-structured interviews and In-depth Interviews to discuss current state perceptions • Process Walk Through of EDMTs to evaluate potential mapping exercises and implementation plan to achieve an ideal future state

Figure 35: *Alignment of Research Objectives and Research Method*

4.6.1 Semi-Structured Interviews

Semi-structured interviews are regarded as a wide-ranging category that enables the interviewer to vary the order in which the questions (Appendix Four) are presented to the participant, therefore deviating away from the original set of interview themes that had been predetermined (Saunders, Lewis, and Thornhill, 2016). This allowed the formulation of a new set of questions based on the context of the research situation and the answers obtained from the participants. It offers a measure of organisational flexibility as some questions may be omitted or added in relation to the nature of the operation and the position of the participant (Bryman and Bell, 2015; Saunders, Lewis, and Thornhill, 2016). The participants were predetermined based on their knowledge and experience in managing Industry 4.0-enabled technology in a Supply Chain Management operating environment. The semi-structured interviews lasted for approximately one hour due to the seaport's time constraints.

In many respects the application of semi-structured interviews enables the interviewer to gain a deeper insight into a subject matter, permitting a more reasoned understanding of the answer obtained (Bryman and Bell, 2015; Saunders, Lewis, and Thornhill, 2016). This resembles the format of probing questions that are designed to relate answers with established theory and usually, they precede the answer obtained in response to an open question (Bryman and Bell, 2015). Each semi-structured interview was recorded in accordance with the participant's prior permission and subsequently, they were transcribed for detailed analysis (Ralston and Blackhurst, 2020). It is argued by Barrett and Barrett (2011) that the recording of the semi-structured interviews would allow the researcher to format additional notes and observations, systematically increasing their understanding of the subject matter.

4.6.2 Coding the Semi-Structured Interviews

Braun and Clarke (2006) advocate the following method as an iterative process that consists of the following stages: becoming familiar with the data, generating the codes, generating themes, reviewing themes, defining, and naming themes, and locating examples as depicted by Figure 36.

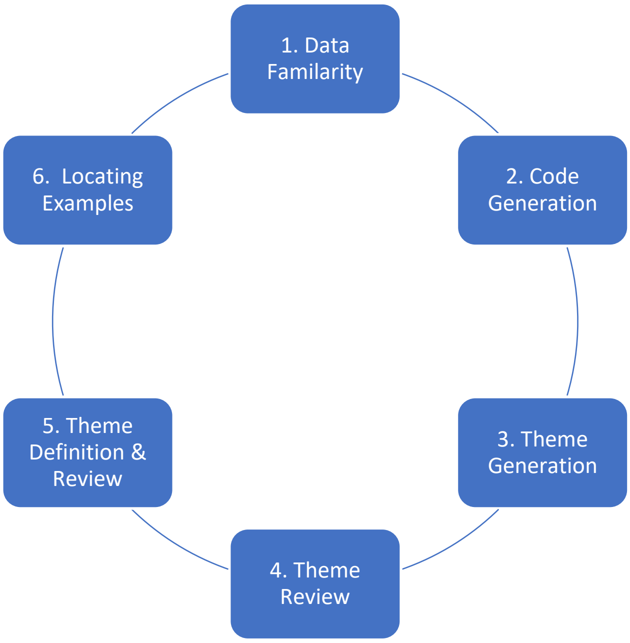


Figure 36: *Braun and Clarke - Thematic Analysis Method (2006)*

The Braun and Clarke Thematic Analysis method was applied to the semi-structured interviews in the following format as presented in Table 19. The theme generation was undertaken by NVivo Enterprise Software as depicted in Figure 37.

Table 19: *Braun and Clarke Thematic Analysis Method (2006)*

Thematic Analysis Stage	**Action**
Data Familiarity	Transcribing and reading the 11 semi-structured interviews Formulating initial codes
Code Generation	Coding of interesting features in the semi-structured interviews in a systematic manner

	Collecting data relevant to each code
Theme Generation	Collecting codes into potential themes – gathering data relevant to each theme
Theme Review	Confirming that the themes are suitable for the coded extracts and the entire semi-structured interviews
Theme Definition & Review	Continued analysis to refine each theme; generation of clear names for each theme
Locating Examples	Final analysis Selecting of themes Discussion of analysis Relate to the research objectives in Chapter One Introduction and the Literature Reviews Chapters Two and Three

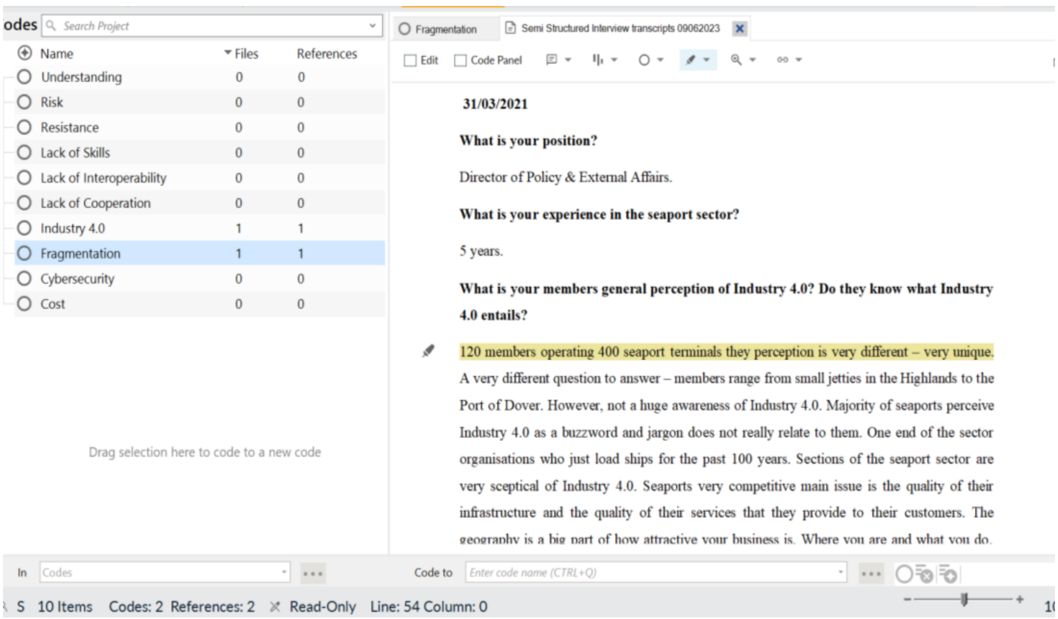


Figure 37: *The NVivo Coding Process*

The NVivo Code Case book is presented in Appendix Six. It constitutes a list of the thematic nodes and their descriptions, and it was subsequently exported from the NVivo software.

4.6.3 Case Studies

A case study method is defined as *"a research strategy which focuses on understanding the dynamics present within single settings"* (Eisenhardt, 1989, p.534). Yin (2014, p.209) defines a case study as "*an empirical enquiry that investigates a contemporary phenomenon within its real-life context especially when the boundaries between phenomenon and context are not clearly evident".* However, Stake (1995) suggests a method that is expected to reveal the complexity of a single case, with an emphasis on understanding its context and interactions in its natural environment. This definition is also advocated by Piekkari, Welch, and Paavilainen (2009, p.569) who conclude that case studies are indicative of "*a research strategy that examines, through the use of a variety of data sources, a phenomenon in its naturalistic context, with the purpose of confronting theory with the empirical world".*

It is argued by (Yin, Stecke, and Li (2018) that many aspects relating to Industry 4.0 are unknown or uncertain and they call for a case-based research approach to enhance understanding of Industry 4.0 implementation and utilisation. The utilisation of the case study approach is well documented in business management disciplines and now represents an important Qualitative method (Lee, Collier, and Cullen, 2007; Bryman and Bell, 2015). Knights and McCabe (1997); Eisenhardt (1989); and Yin (2014) advocate case studies as a vehicle that facilitates the combination of multiple Qualitative methods, such as interviews, observations, and archival documentation as presented in Table 20, in order to devise and test new theoretical approaches. This reduces the over-dependency on one single Qualitative approach (Knights and McCabe, 1997; Ravenswood, 2011). This may potentially facilitate a more in-depth understanding of phenomena and enable further statistical analysis (Lee, Collier, and Cullen, 2007). The case study methodological approach is considered appropriate for conducting exploratory research on a phenomenon's nascent stages (Ralston and Blackhurst, 2020). It is argued by Ralston and Blackhurst (2020) that Industry 4.0

within a supply chain operation fulfils this condition due to its evolutionary implementation and application.

Table 20: *The Data Collection Dimensions*
Adapted from Yin (2014)

Source of Evidence Presented Within Case Studies	**Strength**	**Weakness**
Direct Observation	Real-time data collection methods Correct contextual content – set in the natural operating environment of the subject matter	Susceptible to observer bias Time-Consuming Validity Issues
Participate Observation	An insightful lens into interpersonal behaviour, relationships, and motives	Bias due to participants/ observer's manipulation of stimuli
Documentation	Accessible Researchers were able to review its contents repeatedly, enabling a deeper insight of the subject matter Longitudinal in the scope of inventory (times and locations) High level of detail, accuracy, and reference Qualitative in structure	Retrievability/ accessibility concerns in light of confidential agreements Restriction on publication time frame/ Accessibility may be deliberately withheld Biased selectivity – gaps in the report Report bias of author/ source of documentation

Archival Documentation	High level of detail, accuracy, and reference Qualitative in structure	Accessibility concerns relating to data protection legislation and copyright ownership
Physical Artefacts	In-depth understanding of cultural content Insightful perceptive into technical operations - unscripted	Selectivity and Availability concerns
Interviews	Targeted source of data collection – directly related to case study aims and objectives Insightful provision of explanations – personal and professional in the form of perceptions, attitudes, meanings, experiences, and knowledge	Biased scope of the interviewer – poorly formulated questions Response bias – reluctance to disclose the true opinion Reflexivity – The interviewee has apathy toward the interviewer and their research aims and objectives.

There has been considerable debate over the issue of case studies and their external validity/generalisability, based on the representation of their findings in relation to mutually exclusive cases. It is essential that research does not infer that it is possible to identify standardised cases that may be utilised in the representation of samples (Bryman and Bell, 2015). Both Eisenhardt (1989) and Yin (2014) have indicated a preference for the utilisation of multiple case studies due to their strength in presenting the concept of analytical generalisation, indicating that the robustness of case study findings is determined by its systematic replication in contrasting situations. It is advocated by Lee, Collier, and Cullen (2007) that a case study has a source of validity that relates to the realisation of particularisation rather than the conceptualisation of generalisation. Therefore, the objective of case study research and analysis should be engineered to focus on the uniqueness of the case, enabling deeper insights and understanding of its dynamic and complex nature (Knights and McCabe, 1997; Lee, Collier, and Cullen, 2007; Bryman and Bell, 2015). It is argued by Eisenhardt (1989) and Lee, Collier, and Cullen (2007) and Lasa, de Castro, and Laburu (2009) that a case study approach has various objectives: to facilitate insight/description, test established theory, or devise new theory after a period of refinement. It is further argued by Dangayach and Deshmukh (2001, cited in Lasa, de Castro, and Laburu, 2009) that the application of case study research may enhance the academic skill set of the researcher. It is suggested by Vieira, Neto, and Amaral (2014) that seaport management research is undertaken by a predominantly Qualitative approach, underpinned by case studies and conceptual endeavour. Case studies have also been extensively applied to discuss the utilisation of VSM within an industrial sector, although there is a perceived lack of research based on VSM implementation in diverse sectors that are not predominantly based on the identification of waste/non-value-adding activities (Shou et al., 2017).

It is stressed by Bryman and Bell (2015) that a combination of research methods, in the form of triangulation as represented in Figure 38, is a prerequisite to obtaining a more reliable and valid representation of the dynamic phenomenon under investigation.

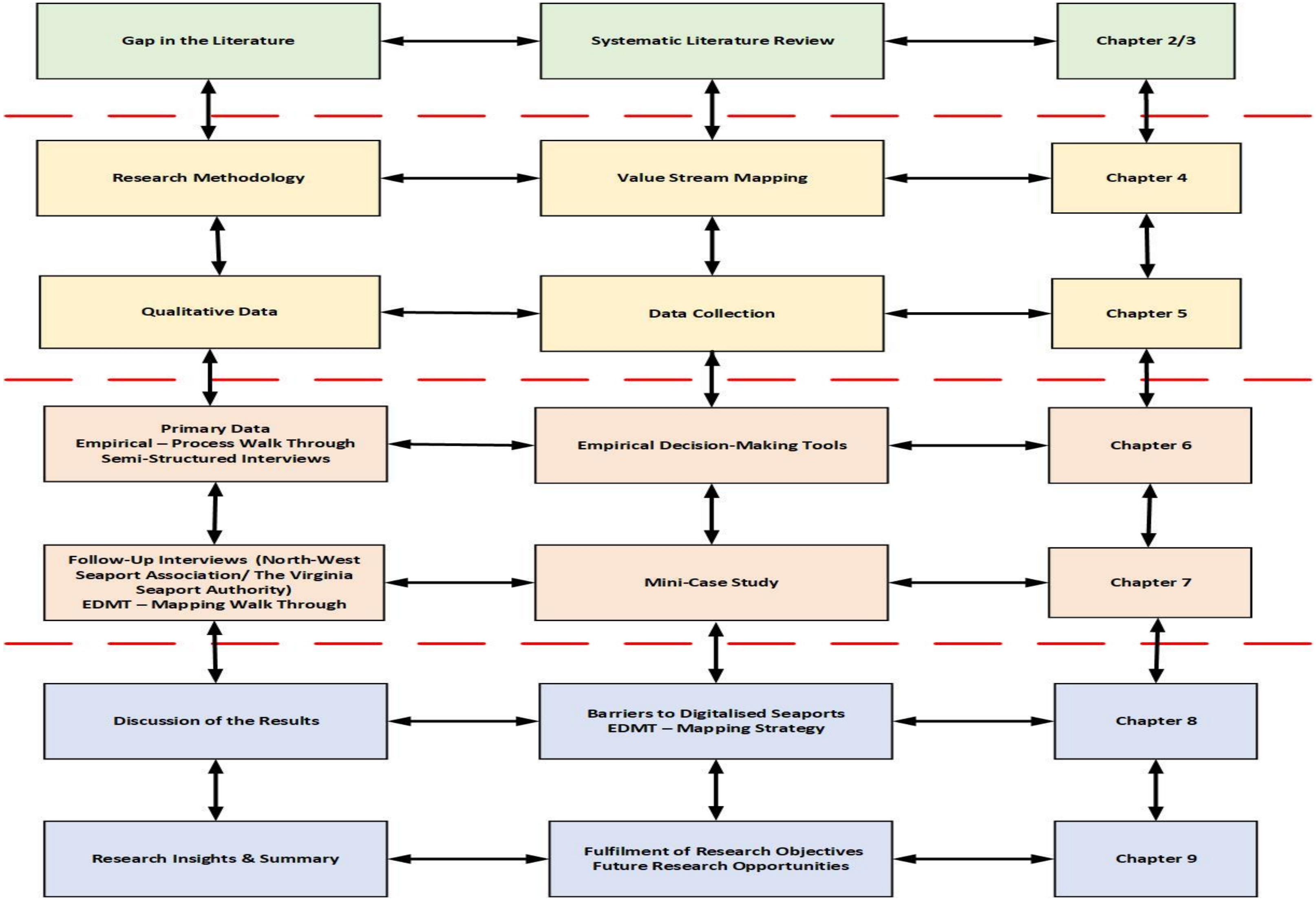


Figure 38: *Triangulation of Research Methods*

4.7 Research Ethics

Prior to the application of adapted VSM methods, full acceptance was obtained from the Liverpool John Moores University (LJMU) Research Ethics Committee (Favourable Ethical Opinion & Approval 15th March 2021 – Registration Number 21/MME/001), in relation to primary data collection that consisted of case studies, observations, and semi-structured interviews. The Liverpool John Moores University Guidelines were strictly adhered to throughout the prosecution of this research project, safeguarding the physical and mental well-being of both the researcher and the participants. Ethical issues in research projects now command increased attention and due diligence (Creswell and Creswell, 2018). Issues relating to ethical considerations were also safeguarded by cross-referencing the utilisation of four ethical principles depicted in Table 21 and advocated by Diener and Crandall (1978 cited in Bryman and Bell, 2015).

Table 21: *Ethical Principles and Considerations*

Ethical Principles	**Ethical Concerns**	**Safeguarding Measures**
Harm to participants	Potential harm to personal and professional reputation	Confidentiality and anonymity of the participant's personal information. Included in the provision of the Informed Consent Declaration (Appendix Three) All collected data will remain protected by the researcher and will not be made accessible to any third party. Data collection was anonymised and kept strictly separate from the dataset. Systematically limiting any age, gender, disability, or race discrimination concerns.
Lack of Informed Consent	Right to refuse or withdraw from the research project	Issue of Informed Consent Documentation to all participants before their involvement in the research project. Informing the participants that they have the right to refuse or withdraw from the research project at any time (verbal and written notification). Participation in the research project is voluntary. Participants are not obliged to answer all questions.

LJMU ethical research guidelines and data protection legislation require that research subjects must be provided with a covering letter that details the purpose of the research and acknowledged that they may withdraw at any time (Appendix Two). Additional information (justification for research, participant confidentiality, and researcher contact details) was contained within the Informed Consent Declaration for Research Participation (Appendix Three and Appendix Five) and it was issued prior to the commencement of the data collection methods.

4.8 Insights & Summary

This chapter has precisely outlined the methodology applied to this thesis. The justification for applying VSM methods is also reasoned, including the merits of alternative forms of research methods. With respect to the scientific principle of subject objectivity. The methodological decisions formulating the research strategy were ultimately selected as the most advantageous form of conducting the research and answering the aims and objectives outlined in Chapter One of this thesis. These research decisions may be concisely reviewed as a philosophy that is underpinned by Interpretivism, with the application of Qualitative methods, in the format of semi-structured interviews, in-depth interviews, and case studies. Enabling a reliable and valid interpretation of the natural phenomenon of seaport operations in the digital age. The next Chapter Five delineates the application of the data collection methods that were employed by the research project: semi-structured interviews and in-depth interviews.

CHAPTER 5: DATA COLLECTION AND INITIAL INSIGHTS

5.0 Introduction

This chapter details the initial data collection methods to confirm the barriers to seaports as outlined in RO1 and support a more deeper understanding of current state perceptions underpinning RO3. The data collection was conducted in two stages, and it provides a detailed view of the initial findings from the semi-structured interviews. The first stage was a series of semi-structured interviews that had a limited sample global population of 11 seaports, NGOs and a service provider. The semi-structured interviews and in-depth interviews provided the opportunity to discuss the current state of seaport operations from the perspective of Industry 4.0 implementation and application subject to barriers that impede their sectoral utilisation. They also underpinned the development of the EDMTs in terms of sectoral relevance to mapping current state operations, identifying and mitigating these barriers by formulating an implementation plan to achieve the desired ideal future state. The second stage was a more in-depth series of two interviews that had a more structured approach that underpinned the seaport prior to data visualisation knowledge/ experience and the drivers of Industry 4.0 readiness to be mapped.

The global COVID-19 pandemic and subsequent national lockdowns in the United Kingdom necessitated a systematic redesign of the data collection method from a localised scope to an international scope in terms of participant identification, engagement, and selection. As presented in Table 22. Therefore, an international focus was pursued through online video conferencing platforms. A systematic search of seaport databases (Searates) facilitated the identification of potential participants to be approached. This process included both seaports and container terminals, as well as international associations, service providers, and NGOs (British Port Association, International Port Community Association, and Intercargo) who provided additional context on the motivation and drivers of seaports to upgrade their existing infrastructure to be Industry 4.0 ready. It was deemed that all seaport operations are not mutually exclusive in their functionality, and they are generators of vast amounts of structured and unstructured data in their own right. Some additional clarification was necessary as seaport operators questioned if this research opportunity was only targeted toward containerised operations.

Table 22: *Overview of the Research Participants*

Organisation	**Position of Participant**	**Experience**	**Location**	**Date of Engagement**
UK Seaports NGO	Policy & External Affairs	5 Years	United Kingdom	31/03/2021
US East Coast Seaport Authority 1	Market Analyst	2 Years	USA	06/04/2021
International Port Community NGO	Secretary	10 Years	United Kingdom	19/04/2021
Irish Seaport Authority 1	IT and Projects Manager	17 Years	Republic of Ireland	21/04/2021
Irish Seaport Authority 2	Commercial	10 Years	Republic of Ireland	30/04/2021
US North-West Seaport	Operations Service	30 Years	USA	06/05/2021
Seaport Service Provider	Head of Sales	2.5 Years	Brazil	07/05/2021
International Cargo NGO	Operations Manager	30 Years	NGA/ IMO	10/05/2021
Australian West Coast Seaport	IT	20 Years	Australia	12/05/2021
US East Coast Seaport Authority 2	Manager Port Business, Planning, and Policy	30 Years	USA	25/05/2021
US East Coast Seaport Authority 3	Senior Vice President of Technology and Projects	21 Years	USA	10/06/2021

An introductory email facilitated initial contact with the target population. This email contained the rationale that underpinned this research project (Appendix Two and Three). A generic email was sent to the major seaports, potentially reducing their impact in terms of obtaining a positive response. A range of experience was obtained from the sample population with a range from 2.5 years to 30 years as depicted in Figure 39, facilitating a range of opinions regarding the readiness of seaports to exploit Industry 4.0. However, some positive responses were based on the networking and influences of governmental agencies. Most noticeably the US Maritime Commission who forwarded the research proposal to the seaport authorities of New York/New Jersey and Virginia. These seaport authorities have both significantly contributed to the research project and emphasised the importance of finding direct contacts, rather than just generic ones.

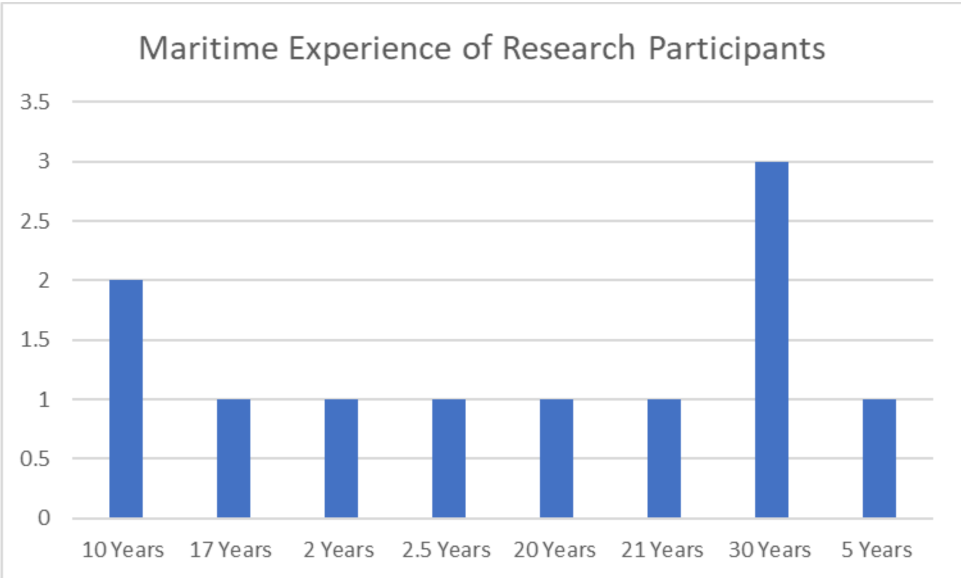


Figure 39: *Maritime Experience of Research Participants*

An interview was scheduled with the author to work through the semi-structured interview process as depicted in Figure 40 and it presents the development of collaborative sector relationships.

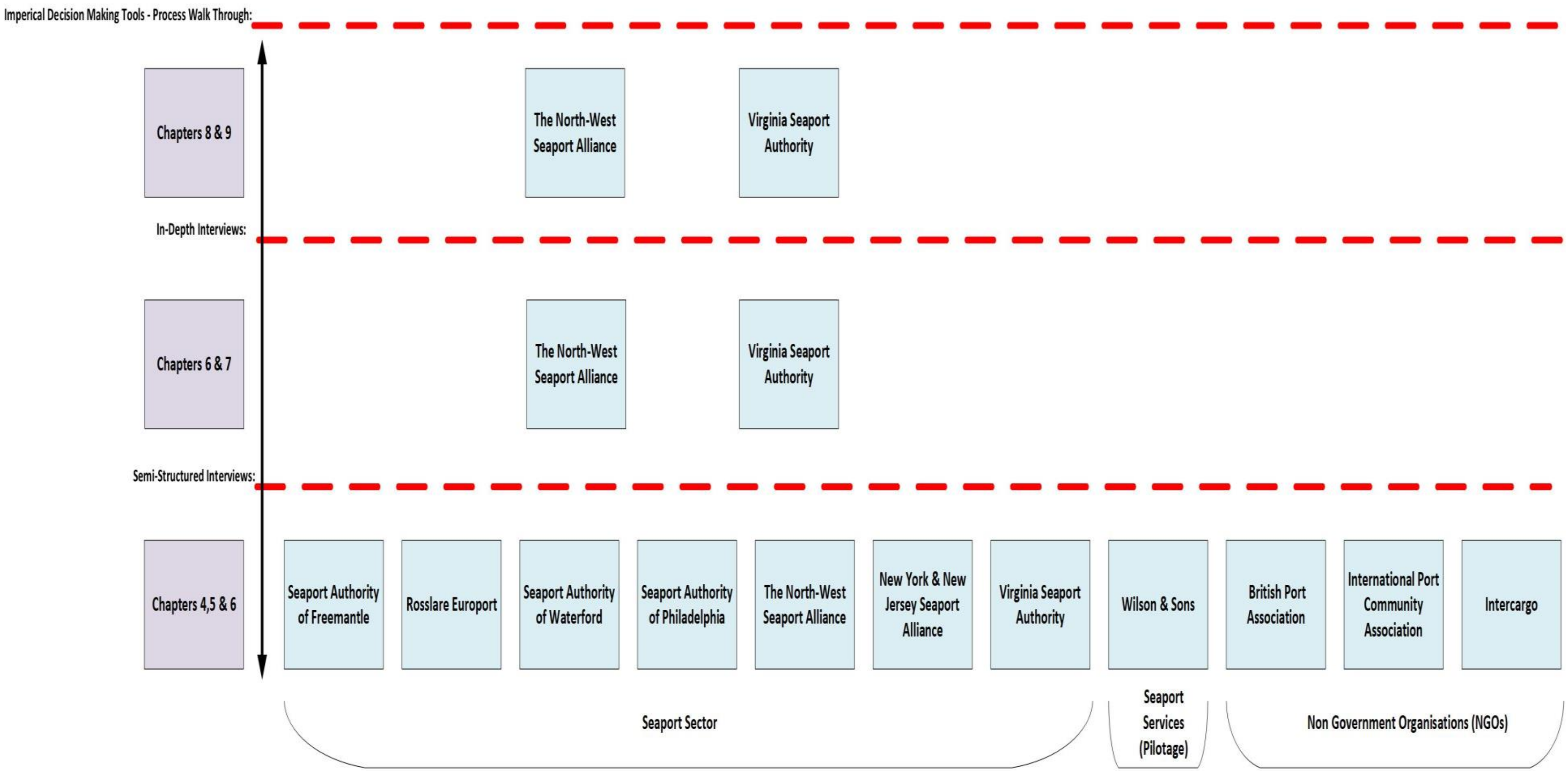


Figure 40: *The Applied Data Collection Method*

5.1 Participant Response Rates

Figure 41 depicts the number of positive responses obtained from the United Kingdom seaport sector from emails (including a covering letter, informed consent, and research synopsis) requesting if the organisation would be willing to participate in the PhD research, in relation to negative responses. The negative responses constituted a refusal to participate, no acknowledgement, and an incorrect email address.

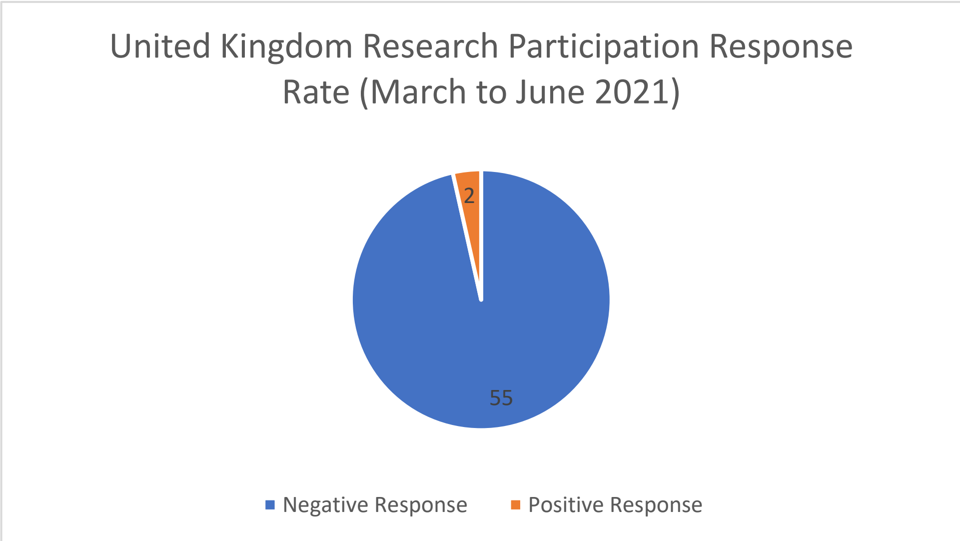


Figure 41: *United Kingdom Research Participation Response Rates - March to June 2021*

Figure 42 depicts the number of positive responses obtained from the United States seaport sector from emails (including a covering letter, informed consent, and research synopsis) requesting if the organisation would be willing to participate in the PhD research, in relation to negative responses. The negative responses constituted a refusal to participate, no acknowledgement, and an incorrect email address.

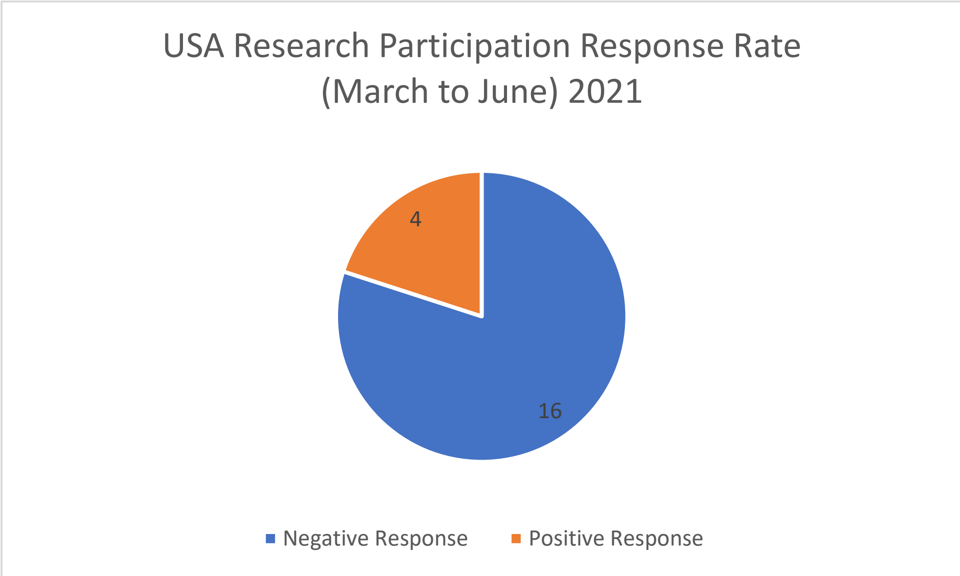


Figure 42: *USA Research Participation Response Rates - March to June 2021*

Figure 43 depicts the number of positive responses obtained from the Australian seaport sector from emails (including a covering letter, informed consent, and research synopsis) requesting if the organisation would be willing to participate in the PhD research project, in relation to negative responses. The negative responses constituted a refusal to participate, no acknowledgement, and an incorrect email address.

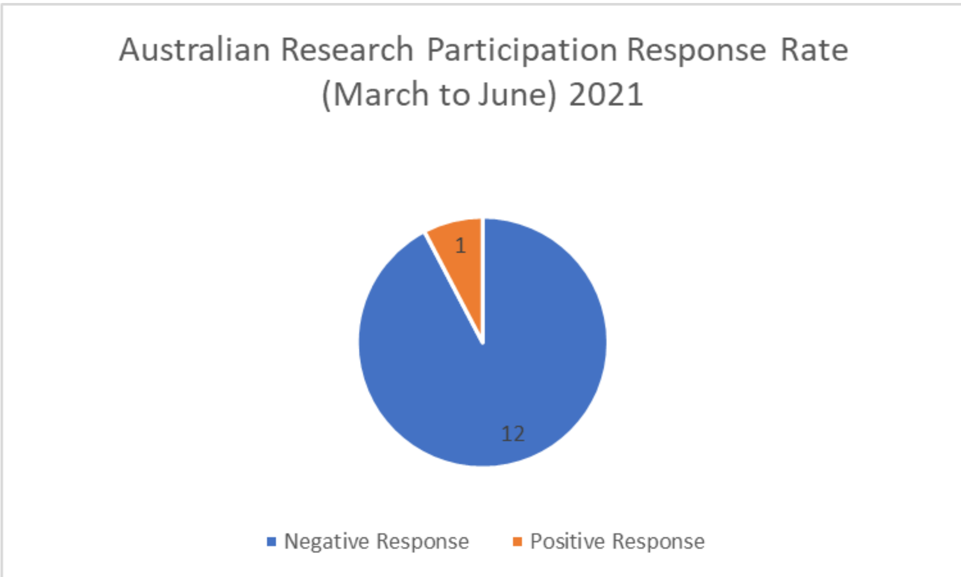


Figure 43: *Australian Research Participation Rate - March to June 2021*

Figure 44 depicts the number of positive responses obtained from the Brazilian seaport sector from emails (including covering letter, informed consent, and research synopsis) requesting if the organisation would be willing to participate in the PhD research, in relation to negative responses. The negative responses constituted a refusal to participate, no acknowledgement, and an incorrect email address.

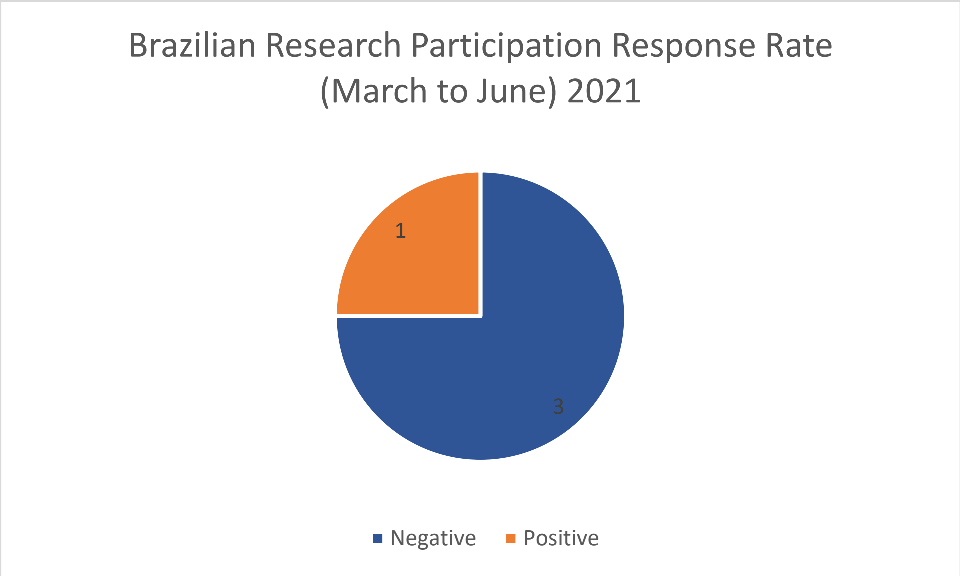


Figure 44: *Brazilian Participation Response Rate - March to June 2021*

Figure 45 depicts the number of positive responses obtained from the Republic of Ireland seaport sector from emails (including covering letter, informed consent, and research synopsis) requesting if the organisation would be willing to participate in the PhD research, in relation to negative responses. The negative responses constituted a refusal to participate, no acknowledgement, and an incorrect email address.

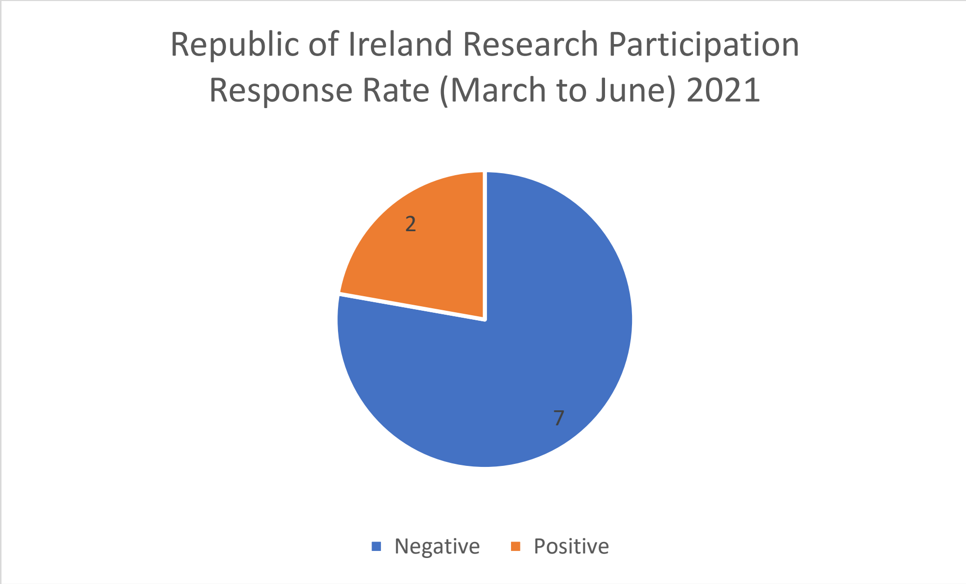


Figure 45: *Republic of Ireland Research Participation Response Rates - March to June 2021*

$$\text{Total Response Rate} = \frac{\text{Total Number of Responses}}{\text{Total Number in Sample} - \text{Ineligible}}$$

$$\frac{11}{200 - 9} = \frac{11}{181} = 6.07\ \%$$

$$\text{Active Response Rate} = \frac{\text{Total Number of Responses}}{\text{Total Number in Sample} - (\text{Ineligible} + \text{Unreachable})}$$

$$\frac{11}{155 - 9} = \frac{11}{146} = 7.53\%$$

The poor response rate from UK seaports as depicted in Figure 41 was attributed by the British Ports Association to the disruptive impact of the global COVID-19 pandemic on trade flows that developed with unprecedented velocity and scale, post the national lockdowns.

5.1.1 Initial Insights from the Semi-Structured Interviews

The flexible nature of the semi-structured interview method allowed for a detailed overview of the drivers and barriers to Industry 4.0 embedded technological implementation and application in the seaport sector (RO1) and they assisted in confirming the findings of the literature review chapters. These barriers are present in a seaport's current state of operation and provide a starting point for the development of a range of visualisation tools as per the requirements of RO3. These tools will map the current state of Industry 4.0 readiness, and underpin an internal and external implementation plan, to achieve the ideal future operating state.

The process facilitated a comparison with the literature of the seaport sector's perception of its current and future state strategy with regard to Industry 4.0 embedded technologies as presented in Table 23 and their adaptation as a decision-support facilitator in terms of future strategic policy. It also assisted in the formulation of the EDMTs to identify and recommend process improvements that also mitigate barriers experienced by seaports in Chapters Six and Seven, enhancing their operational relevance to seaports who are embarking on Industry 4.0 technological implementation and application.

Table 23: *Current and Future State Industry 4.0 Perspectives*

Seaport	**Current State Perspective**	**Future State Perspective `**
British Port Association	Innovation to support Net Zero/ Sustainability and the facilitation of bespoke services.	Sector cultural change – Innovate to become more competitive in national and international markets. Increased communication and collaboration to systematically reduce the fragmented operation of the seaport.
Seaport Authority of Philadelphia	Tentative steps towards vessel tracking, financial (Blockchain) transactions, and semi-automated terminal (containerisation/ break bulk) capabilities. Not very technologically developed in terms of infrastructure. Employees are hesitant to embrace change and a culture of risk aversion is prevalent.	Cultural change underpinned by the new CEO. Increased sales pitch based on the KPI metric of ship turnaround time – to market service efficiency. Increased competition from the seaports of New York/ New Jersey and Virginia.

	Exemplified by the transition from hard-copy documentation to digitalised versions.	
International Port Community Association	An advocate of interoperable communications that is facilitated by the membership of a PCS. Lack of sector awareness of sustainable competitive advantages offered by PCS.	Driving cultural change in the maritime logistics sector that is underpinned by a resistance to change mentality expressed by a legacy workforce.
Seaport Authority of Waterford	Restricted in development of Industry 4.0/ Smart technology due to economies of scale constraints. Republic of Ireland currently does not operate a PCS, due to economies of scale constraints.	Data-driven decisions. Development of their seaport traffic system for the benefit of their own seaport community. It would not have the system integration to share its data amongst external supply chain partners.
Rosslare Europort	The realisation is that the seaport needs to invest in its infrastructure to secure and enhance its market position. This is driven by the development of ships in terms of their tonnage and length.	Early stages of Industry 4.0 implementation - €35 million digitisation of seaport infrastructure as per seaport Masterplan.

The Northwest Seaport Alliance	To update existing seaport infrastructure. Limited PCS based on a universally accessible IT system.	Facilitating data sharing amongst seaport actors to facilitate enhanced levels of transparency and visibility in the supply chain and its subsequent dissemination to intra-organisations.
Wilson & Sons	High-level managerial support for the implementation and application of Industry 4.0 embedded technologies.	Research into market augmentation underpinned by Industry 4.0 embedded technologies.
Intercargo	Lack of awareness amongst members in relation to the potential sustained competitive advantages that exploitation of Industry 4.0 technologies offers.	Promote the widespread application of Industry 4.0 embedded technologies via presentation at the IMO.
Seaport Authority of Freemantle	Started on the journey to becoming a smart seaport. Developing supply chain partner integration to mitigate data-sharing issues. Based on the value of shared data as opposed to the value of hidden data.	Willing to participate in a PCS – attempting to change the culture to promote data sharing amongst actors and shareholders.

New York & New Jersey Seaport Authority	Require a clear understanding of their current state in relation to Industry 4.0/ smart technology implementation.	Investment in ageing seaport infrastructure despite funding constraints due to other projects i.e., the Lincoln Tunnel upgrade and the redevelopment of the World Trade Centre site.
Virginia Seaport Authority	State of the Art – Fully Automated Seaport – Upskilling of employees to operate semi-automated technology.	Continued development of over-the-road automated vehicles to deliver economies of scale benefits.

5.1.2 Organisational Size of Seaports

It is regarded in the literature that the inclusion of small and medium seaports is fundamental to achieving the sectoral-wide application of Industry 4.0 embedded technologies (Philipp, 2020). However, the consensus of the research population indicates that small and medium seaports are not convinced of the potential of Industry 4.0 embedded technologies to deliver improvements in efficiency, effectiveness, and supply chain visibility/transparency. This is evidenced by the following question and answer from the semi-structured interview with the British Port Association:

Would you say that the innovation drive is linked to the size of the organisation – reflected in the literature? Concerns about return on investment.

> *"I would say yes, but even some of the biggest are not that interested. The ones at the forefront tend to be the bigger seaports. They have more money to invest. There is also another factor that is also starting to change is that the people in the industry have traditionally been seafarers coming ashore and they picked things up this is how it is done".*

It is further argued in the semi-structured interviews that the size of the seaport in terms of cargo throughput will determine the level of technological implementation. The larger seaport operations will be able to sustain the high front-end purchasing costs of continuing to upgrade their technology and the subsequent installation and training costs. However, the vast majority of small and medium-sized seaports are usually constrained in their investment strategy and must maximise their returns on investment. The following extract from the semi-structured interview with the North-West Seaport Alliance emphasises this statement.

> *"That huge investment on the first generation of automation with the Automatic Stacking Container (ASC) when you build that, you are not unbuilding that, you are sunk in. When something better comes along you are kind of stuck with what you have got".*

However, at Wilson & Sons (regarded as a large company in the semi-structured interview) which provides pilotage services, it is argued that the smaller organisations have a distinct operational advantage in implementing Industry 4.0 embedded technologies. This relates to their streamlined decision-making processes that have systematically removed unnecessary bureaucratic steps to facilitate a more agile approach to dynamic market requirements, in addition to cooperation between seaports to share knowledge and a responsive learning curve that tolerates failure. The following response advocates their Industry 4.0 current position in relation to organisational size.

> **Would you say that innovation is linked to the size of the organisation? The literature suggests that larger organisations invest more capital in the research and development of smart technologies. Have more tolerance to see a project through to its conclusion and to sustain the costs of the project.**
>
> *"But they are more bureaucratical as well. Being big but not huge I think makes a lot of difference here. From my understanding, for instance, we have the perfect size at Wilson & Sons to be a first mover in this market. Why, because we are big, but not as huge as Maersk or DP World and for this reason I mean we can take decisions faster and we can learn faster and if we make any mistakes, we can adjust the action faster as well. I do not believe that being big will prevail, but I mean of course being big it is good because it gives us the proper money to invest in what we believe, while we are running the day-to-day business. What can happen is maybe in the future 2/3 years ahead if we did not invest, I do not know if we would remain competitive in the market. It is quite difficult to separate big companies from start-ups. I believe in cooperation between organisations to share knowledge".*

5.1.3 Culture

It is suggested that seaports are very sceptical of the perceived competitive advantages offered by Industry 4.0 implementation and application. However, there appears to be a gradual change in this attitude as the larger seaports are seeking means of innovation that are underpinned by economies of scale, environmental/ sustainable development issues, service cost, market share, and competition. This is evidenced by the following extract from the semi-structured interview with the British Ports Association.

"*The drivers of what causes an industry to innovate have always necessarily been there. However, I am now starting to see this change. In the last couple of years, things are changing, and companies are more interested in innovation and a big driver of that is decarbonisation and the environment/ sustainability more generally. This is starting to make seaports think about how they are going to address these challenges. Seaport sector is a mature industry never been at the forefront of technological change and innovation".*

A number of employees are former seafarers who are often viewed as displaying a resistance to change mentality with regard to the implementation and application of innovative technology to enhance operational capability. Many smaller seaports and harbour authorities identify themselves as SMEs with a clearly defined operating strategy consisting of dredging and disposing of waste and piloting vessels in and out of restricted coastal waters. This relates to a rigid overreliance on previous successful practices that are often inflexible in their application and management of uncertainty. Tijan et al., (2021) expanded on this view by arguing that a lack of awareness, proper strategies, and initiatives are prevalent in the seaport sector, limiting the exploitation of digital technologies.

The drivers of innovative change emphasised the need to shift away from passive asset management to a more active mode that accesses real-time data to formulate strategic decisions that are responsive to the fluctuating dynamics of their management structure which is depicted by Figure 46. It is suggested that education is a suitable driver to change the culture based on the management of anticipated expectations, subject to the need to demonstrate a clearly defined ROI time frame. This view is advocated from the following extract from the semi-structured interview with the Freemantle Seaport Authority.

"In terms of the cultural phase, we need to educate the organisation around innovation. Yes, you cannot expect a return on investment in 5 minutes and that there is a need to have an innovation strategy of some description and support for that. Part of that support is checking that expectation against the timeline which it might be done by. So, there needs to be flexibility basically".

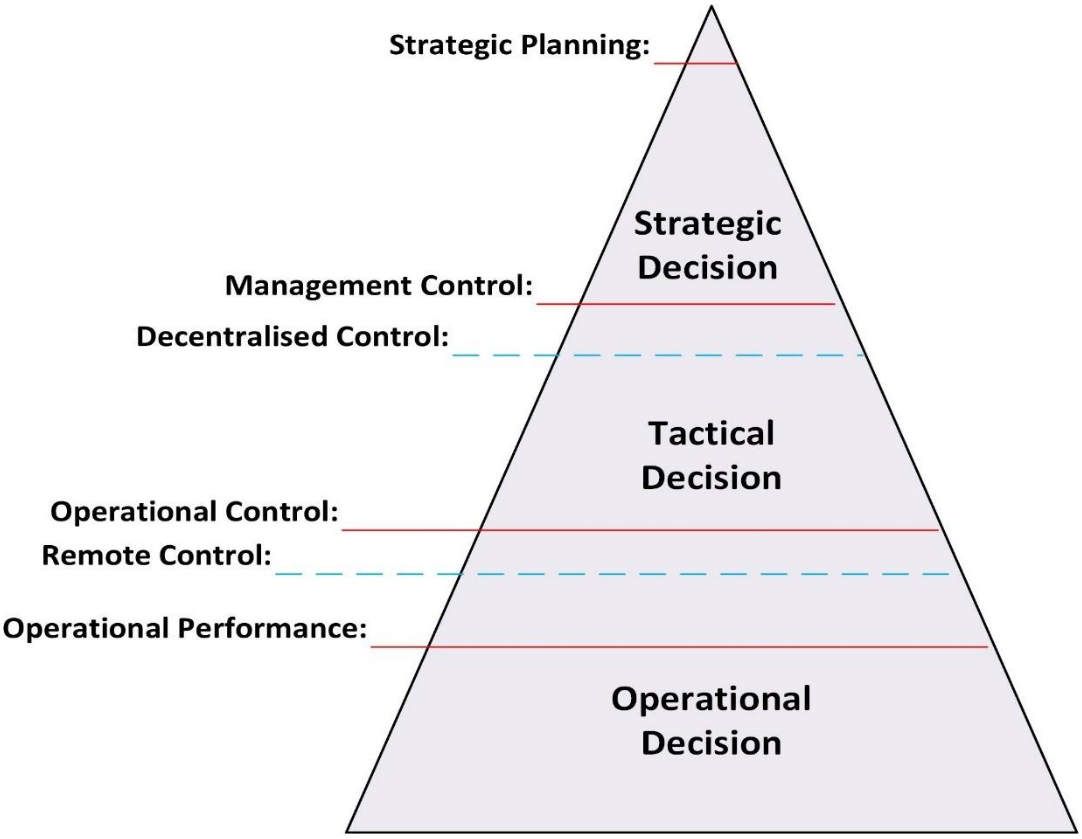


Figure 46: *The Organisational Culture*

A risk appetite is considered by the Seaport Authority of Freemantle to be a driver of cultural transformation that cascades down through the management hierarchical structure as depicted in Figure 46 (executives, managers, and supervisors). This risk appetite will embrace the learning and lessons that arise from failure and leverage a willingness to try innovative realisation projects again, underpinned by existing baseline data. This is revealed by the following extract from the semi-structured interview with the Seaport Authority of Freemantle.

> "*I think also there is a cultural element to that and part of that is embracing and the learning and lessons that you can gain from that failure and the willingness to try again. So, it is around risk aversion and risk appetite, but also a very good understanding that innovation does not just happen. You know – you fail – you succeed*".

A tolerance must also be exercised that is based on the principle that innovation is not an instantaneous process that delivers immediate returns, and it is underpinned by the circle of failure and success. This is advocated by Inkinen, Helminen, and Saarikoski (2021) who stress the need for continuous planning and a proactive attitude from seaport management. This is also reflected by Chandra and Hillegersberg (2018) who argue that governance and management of a seaport is elemental for digitalisation adaption, as exemplified by the success of the Seaport of Rotterdam.

To derisk any proposed capital investment in Industry 4.0 embedded technologies many smaller-scale seaports are seeking collaborative relationships with larger seaports that are more advanced in their implementation strategy. This is exemplified by the following question and answer from the semi-structured interview.

> **Do you ever collaborate with other seaports?**
>
> **‘***We are starting to. We have a few connections, bits and pieces. I must admit that we have been very busy to lock ourselves internally to understand what we want to do first before we go on the global stage, or the national, or the state stage. We have presented a bit because not many people have done. What we do, therefore, they can use it as a good use case. But we are starting to get a few connections with those larger seaports and learn from them. Because there is so much to learn. So, it would be a great advantage for us to have a more tighter connection with them, But you know we are in a different league. We are a small seaport when you look at the grand scale of things. We have an advantage. We are small and compact. We are very agile in what we do. I mean Rotterdam has got 44 km of seaport. An entire city of participants. Whereas us we have got 8 cranes and 2 stevedores. They have got 88 wharves. So it is a different size. Probably the only thing we would want to talk to them about is more from a strategic point of view. From a technology platform they use. The scalability has no comparison.*

However, collaborative relationships are constrained by scalability and the focus is on the strategic utilisation of Industry 4.0 platforms to achieve improvements in operational efficiency.

5.1.4 Confidence

A consistent theme of no confidence in technological innovation was also identified during the transcribing of the semi-structured interviews. Most predominantly by the British Ports Association which advocated that their members are continuously offered innovative technology that does not enhance their capacity to operate under a sustained competitive advantage. This is reflected by their comment that *"sections of the seaport sector are very sceptical of Industry 4.0. Seaports main issue is the quality of their infrastructure and the quality of their services that they provide to their customers"*. Scepticism of innovative technology is also found amongst operational staff who fear for their future employment position. However, this is viewed by seaports as a misconception with their focus on providing real-time to add value to decision-making and improve overall operational performance.

It is argued by the NGO Intercargo that the issue of confidence in Industry 4.0 technologies is to exploit supply chain efficiency and it is underpinned by "*different images or visions of their next level of the shipping industry*". Limiting consensus on the future strategic direction of the maritime sector should undertake to implement Industry 4.0 embedded technologies to enhance supply chain resilience, agility, and efficiency. It is suggested by Inkinen, Helminen and Saarikoski (2021) that collective standardised solutions may facilitate long-term digitalisation planning. As exemplified by the IMO-driven e-navigation action plan that attempts to integrate seaport information systems with e-navigation systems. A clear vision of the future is considered by Tijan et al., (2021) to be a prerequisite for the first stage of seaport digital transformation.

5.2 Follow-Up Interviews

Two seaports were selected for a more detailed investigation: The Virginia Port Authority and the North-West Seaport Alliance. These two seaports were very enthusiastic about being further involved in this PhD research project; in part, this was recognised in terms of engagement with Industry 4.0 developments already. While this means they were not typical seaport authorities, they had insights from the practicalities of implementing smart technology. A data collection template was designed to collect the data that was transcribed from digital recordings of the follow-up interviews as presented in Table 24.

Table 24: *In-Depth Semi-Structured Interview - Data Collection Template*

Process	Comments	KPI
Attendees .		
The Brief		
Seaport Authority Objectives Any previous research and/ or marketing? Future objectives data analytics, data handling, reliability issues, downtime (planned and unexpected) response time, continuous training, Industry 4.0/ 5.0 Interoperability, Human intervention, Skill Sets, and Cybersecurity considerations		
Marketing Audit External Audit Internal Audit		
Value Chain function to be mapped and its location: This requires us to walk through (flow-chart level) the process to leverage a functional-level understanding Seaside Operations Terminal Operations Landside Operations Container Yard Operations Front Gate Operations		
Selection of Industry 4.0 concept to be mapped: Mapping Variables Mapping the level of implementation and/or application to Industry 4.0 embedded technologies within the desired value chain – What is their priority?		

Autonomous Robotics Simulation/ Communication/ Training/ Human and Machine Interaction/ Perception/ Deliberation/ Autonomy **Cloud Computation** Interoperability of Heterogeneous Platforms/ Decentralised Control/ Remote Access/ Digitalisation/ Cloud-Based Servicelisation **Internet of Things** Software/ Platform/ Infrastructure **System Integration** PCS/ Collaborative Networks/ Vertical and Horizontal Integration/ Cyber-Physical Systems (CPS) Real-time Communication **Big Data Analytics** Sensors/ Data Collection/ Processing Data/ Data Analytics/ Decision Points/ Data Quality (5Vs) **Cybersecurity** Identification of threats/ Data loss Prevention/ Data Access/ Blockchain **Addictive Manufacturing – (Value Added Seaport Logistics)** Software/ Materials/ 3D Printing **Simulation & Modelling** Products and Processes/ Digital Twins/ Training		
Timescales: Selection of a time and date for the virtual walk-through		
Anticipated time required for the mapping process		
Requirement of a Non-Disclosure Agreement (NDA)		
Summary		

5.3 The Barriers of Industry 4.0 Strategic Investment

Figure 47 depicts the drivers of Industry 4.0 strategic investment in the seaport sector. These factors are suitable to be mapped in the current state operation of a seaport to determine their readiness to implement the pillars of the Industry 4.0 paradigm. They represent potential opportunities for improvement within the ideal future state map. The macro-environment will impact decision-making, strategies, and business growth and comprises of a range of external factors, demographic, physical, natural, economic, technological, political, legal, and socio-cultural conditions. The microenvironment is specific to the seaport and is close to the operation, influencing its day-to-day performance, and the management's ability to reconcile the objectives of the business. The internal environment consists of the seaport's infrastructure in the form of tangible assets (equipment and property) and intangible assets (knowledge, experience, and skills) that are unique to the workforce.

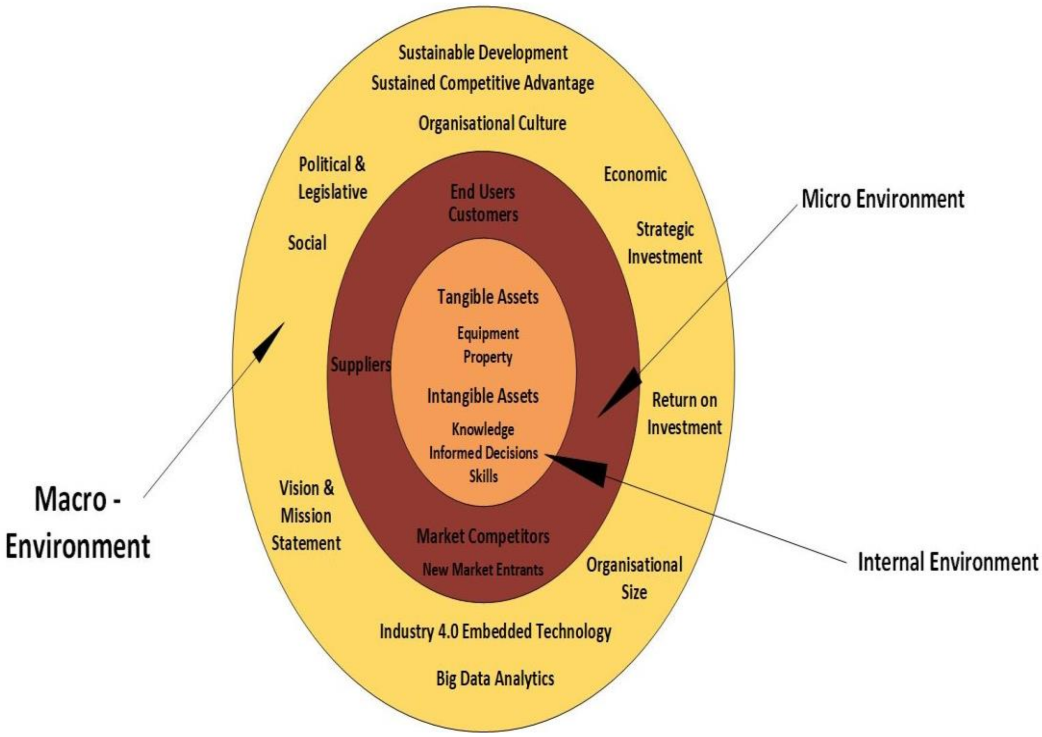


Figure 47: *The Environmental Drivers of the Industry 4.0 Paradigm*

5.3.1 Financial Investment

The capacity to sustain investment in innovative technology is problematic for many smaller seaports when calculating anticipated ROI time scales. The North-West Seaport Alliance suggests that financial investment is proportionate to the size of the operation; *"Including the scale of the problem. Bigger seaports will have bigger issues – getting bigger ships in, but also a bigger hinterland. More parties/ stakeholders, potential hindrances to change. It is very similar, but everybody is different".* This view is supported by the British Port Association (within the semi-structured interviews) when the author commented that smaller seaports still operate dated EDI systems to undertake inter-organisational communications between stakeholders that constitute a range of dynamic functions; automated invoicing, data entry, tracking updates, cargo manifesting, ship arrival and departure times, inbound cargo movements, and status notifications. They concluded that smaller seaports are resistant to updating robust EDI due to its "*comparatively large investment costs, maintenance costs, and its limited data transmission capability*" that still accommodates the needs of the business.

It was argued in the follow-up meetings that there needs to be a clearly defined roadmap of those returns, enhancing inter-organisational confidence. It is necessary to articulate the value of the investment in a clearly defined metric, exemplified as operational cost reduction. Evidenced by the following extract from the North-West Seaport Alliance*: "You have to get technology to suit your problem, rather than applying technology for the sake of it. There is a perception that, maybe, within Industry 4.0 you are creating/ applying technology in areas that may not need or be in drastic need of it. Like demonstrations of companies of the seaport digital twin".* This approach is further evidenced by the North-West Seaport Alliance which also applies a systematic analysis of the operational problem involving all interested key stakeholders to resolve operational issues with the implementation of Industry 4.0 embedded technologies. *"To try and manage the assets and to figure out where we are going to make our investments. Work with all the stakeholders, whether it is the trucking community or the cargo owners, about issues they are having getting in and out of the seaport".*

5.3.2 Employment

The access to state funds provided by the Commonwealth of Virginia was dependent on the Virginia Seaport Authority creating employment positions. Approximately 300,000 positions were created under this agreement. This commercial focus of the seaport was directed towards increasing capacity, appeasing trade union concerns, rather than automation for the purpose of employment reduction. This is evidenced by the following extract.

> "*We were building this facility in Virginia and what we do not like, what we feel was a problem is despite the fact they had been in use for 10 years, their productivity rates were low. They were doing 22-23-24 moves an hour against each vessel crane and we did not think that was good enough. So, we were looking for 35-40 and we thought if we are fully automated, we have a problem because we will not get to where we want to go because the state of the art is not there. The other problem was that the union had to agree to a deal, and they were just not going to agree a deal for eliminating all those jobs. So, the win-win situation was we took some jobs out. First, of all, nobody lost their job. So, we did not get rid of anybody".*

The relationship with the US trade unions is considered to be a barrier to the sectoral implementation and application of automated technologies to undertake process-driven repetitive work patterns as reflected by the North-West Seaport Alliance which concluded that.

> *"So, we have got a very strong union here on the West Coast. Even on the East Coast in Charlestown, there is a new terminal that they have opened up. The port authority did not use union labour and has just sued the port authority for I think $300 million. So, unions do not like automation. Unions do not like efficiency improvements. So. Let me explain myself. I have got no problem with unions but that is what a union does it protects its workers and pushes for a worker-focused agenda. Automation unfortunately when you are talking about repeatable work like in the automotive sector where robotics they can do a lot of what a human being can do and then in combination with artificial intelligence and machine learning can do an incredible amount of work. The*

same is possible on the docks and there are terminals that are fully automated and there is not a lot of people on those terminals. That is the reality of it. So, you have got unions here in this country that are looking at what has happened in other countries and the fact that it is getting easier and cheaper".

The New York and New Jersey Seaport Authority is implementing a policy that advocates automation as an aid to workers in developing new IT skill sets that prolong their careers, limiting their exposure to adverse weather conditions and health & safety risks. This statement is reflected by the following extract from their semi-structured interview:

"One of our container terminals is semi-automated and another hat that I wear is workforce development. I think that it is an individual thing, but we are marching forward with innovation to support our workforce. We are looking for innovative ways that help workers, not eliminate workers first and foremost. So, in GCT they have a semi-automated situation, and their longshore persons work inside at desks with computer monitors and they love their jobs. If you go in and tour their facilities, they will tell you I am not outside in the wind. I am not outside in the rain, not out in the snow. I am doing everything. I've got computer skills that I did not have before. So, that I think is a perfect example of where innovation and technology is supporting the workforce".

The financial considerations are also a barrier to automating the cargo handling processes at the North-West Seaport Alliance which still operates quayside cranes from the 1980s and 1990s and relies on a high number of employees. This is evidenced by their answer to the following questions.

Does it still entail a labour-intensive business? *"We have new cranes at the lumber facilities. However, other terminals have cranes from the 80s and 90s".*

If it is still economically viable to operate them – they are not going to change them. *No, and the auto terminal is very labour-intensive people are still needed to get into them and drive. No desire to automate the process due to cost considerations'.*

5.3.3 Capacity

The apparent success of globalisation and trade liberalisation has adversely impacted on existing maritime supply chains, limiting their long-term ability to handle market fluctuations in international trade. The recent global COVID-19 pandemic has also exacerbated fluctuations in seasonal demands and reduced lay times, merely publicly highlighting the seaport's capacity constraints that were previously identified in Seaports Masterplans as requiring systematic investment. It has been suggested that this overcapacity is also now impacting on all national and international supply chains regardless of the mode of transportation utilised. The Virginia Seaport Authority advocates a careful approach to increases in seaport capacity, mitigating the disruptive impact on the operation.

> *"It has to be planned carefully. Let's assume you are building capacity. You do something live off the terminal, and you figure out a way to operate. Maybe, you can divert cargo to another facility, or it diverts temporary and that 1/3 online as quickly as possible, and when you do that, it results in 2/3 of your capacity. Now you can move cargo from there and do another 1/3. By the time you have finished that you have got 33% more of what you previously had. Then you do the last one and now you have doubled your capacity. The problem is doing it that way is more costly them just saying ok let's just flatten it all and start all over again. So, what are the dynamics associated with having to operate on the existing footprint, while you are making an enhancement. You do not want to kill yourself in the operation. You want to survive and get better. In this business, there are some opportunities to just do technology upgrades and not have to upgrade the equipment. They tend to not yield as much of a result. It is almost like you do this and the equipment properly has to change to get the real benefit".*

The solution advocated by the North-West Seaport Alliance is to integrate their management of the whole supply chain solution, offering a bespoke logistical service, without focusing on the individual components of the supply chain. It is envisioned that this approach will systematically reduce the current fragmented management of the various seaport actors and stakeholders, facilitating a seamless flow of goods, services, and information. A similar approach has been undertaken by the Seaport Authority of Virginia which is driving its own pace of innovation rather than passi*vely* responding to market conditions and acting as trade facilitators of the state.

5.3.4 Infrastructure

The solution of increasing infrastructure capacity to leverage enhanced efficiency and throughput rates has two fundamental drawbacks. The first issue relates to the significant levels of capital investment required to increase the number of terminals in operation, subject to geographical constraints. Seaports operate under a strategic and highly structured budget, limiting sustained investment in infrastructure (berths, quay crane and labour allocation, road networks and container yard storage capacity). This issue has become more pronounced due to the recent global COVID-19 pandemic that has witnessed an unprecedented influx of seaport throughput within a confined time frame, leading to physical and administrative bottlenecks in the maritime supply chain.

The North-West Seaport Alliance has an ageing infrastructure at both of their seaports (Seattle and Tacoma) that was upgraded in the 60s and 70s to meet their operational requirements, within the confines of a seaport-centric infrastructure. However, the continued growth and success of globalisation have led to increased activity around the site of the seaports, in addition to the growth of cities adjacent to the seaport's infrastructure. This has subsequently led to a shared utilisation of the seaport's existing infrastructure with the general public, most noticeably in terms of road traffic volume. It is advocated that a more active response (populated by real-time information) to manage finite assets is required to determine, traffic flow prediction, congestion and accident alert systems, security monitoring, vehicle emission profiles, travel time estimation, optimisation of vehicle routing, and parking control (Dogo et al., 2021). These insights are generated by a range of sensors that include GPS, ultrasonic sensors, inductive loops, piezo-electric strips, pneumatic tubes, cameras, infrared sensors, passive acoustic, microwave, and RFID tags (Dogo et al., 2021). This may then be utilised to underpin decisions, such as the temporary introduction of variable speed restrictions, traffic light signalling and rolling roadblocks to ease congestion around the container terminal.

This statement is evidenced by the following extract from the in-depth interview with the North-West Seaport Alliance.

> *"It has been an organic evolution. But really for us what we have seen over time is that our facilities which were mostly built at the start of the last century. In the 60's and 70's, we brought more activity into both Seattle and Tacoma. These seaports were built for the activity of the time, and it is 50 years later. The amount of container traffic is expansionary larger than what it was. Obviously, the 70's and 80's, our roadways were very seaport centric. There was not a lot of activity around our seaports. Today, we have got cities that have grown up completely around our seaports, and so we share those roadways with the general public. With other transportation, with other kinds of freight traffic. Wherever, that is the final mile, UPS trucks, or a plumber to fix a sink. The way it used to get done was you build as an asset, like a bridge or roadway and you turn it loose to whoever wants to use it. Today, there is so much pressure on that system in total. We have got to shift from passively managing it to actively managing it and the only way to actively manage something is if you have got information coming from that thing. So, that means getting a lot of digital inputs. That means lots of sensors out on the roadway that catch when things are slowing down or identify through data choke points in the system. Identify how all of these different groups are using these assets, and then using that information to be able to pinpoint this is where we need to put finite resources. Right, we cannot just build the whole highway – make it 10 times bigger. No one has the money for that. So, we have got to be smarter about how to manage those finite assets and share those assets with all the other people that need to use them. The only way you are going to do that is by heading towards a digital future".*

The objective of the Virginia Seaport Authority was to systematically expand its seaport infrastructure as they were operating at full container capacity and to create 300,000 employment positions. The latter justification was also a prerequisite of the Commonwealth of Virginia who agreed to fund the infrastructure expansion project to generate economic growth for the state. The operators at the Virginia Seaport Authority advocated that their infrastructure expansion projects also adhere to the concept of social justice in creating employment opportunities in economically disadvantaged areas, improving the quality of life for the local community who reside in the surrounding areas. This is evidenced by the following quote.

> *"There is a social justice side. By that I mean you are not building your terminal next to your most important and biggest property. We are operating in areas where economically disadvantaged people live, and the building of the terminal will improve and certainly not reduce the quality of life in the surrounding areas. So, there is a social justice element".*

This payback is also measured by the metric of GDP creation. It is reported that the Virginia Seaport Authority drives $34 billion of other business activity that is related to seaport operations. This is evidenced by the following extract from the in-depth interview which emphasises the advantage of being a public entity and accessing state funds to leverage upgrades in infrastructure.

> *"So, at the time that these projects were justified. The seaport was full. There was no room for more business and the goal was to grow. So, a five-year strategic plan showed that if we had more capacity, it would eventually grow and fill the seaport and make the facility bigger. What you have to understand now – this is really hard if you are not a public government-type operation. We are a government entity. We are not a private company. So, what is the payoff here? So, the goal for the politicians was that the money had to increase capacity and drive employment higher. There is a metric related to GDP. I think we drive $34 billion of other business related to the seaport operation. It was an economic growth problem created by the politicians. Grow seaport resources and the state would grow".*

Another value-added benefit of upgrading the infrastructure is that it operates in a more efficient and environmentally friendly manner. This is evidenced by the following extract from the in-depth interview with the Seaport Authority of Virginia.

"Let me tell you about another side benefit that we have started doing recently. One of the benefits of doing this infrastructure upgrade that we have not talked about at all is typically that the new equipment is much more environmentally friendly. We

converted one of our facilities from being a conventional terminal to being an automated terminal. The reduction in CO_2 was over 40%".

5.3.5 Communication

The development of effective partnerships is not just confined to the actors within the seaport operation. This should include interested stakeholders from the city, county, and state, evolving from a purely seaport-centric approach. An effective partnership will leverage an understanding of what the seaport's operational needs are in terms of capital investment to address both infrastructure capacity constraints and supply chain bottlenecks, relating to throughput rates and the flow of value-added information between seaport actors. In terms of information fluidity, the North-West Seaport Alliance is trying to catch up, with regard to real-time data generation, collecting, sharing and its subsequent analysis to underpin sustainable decision-making that is disseminated by PCS. This is reflected by the following extract:

> *"Yes. There is an unimaginable amount of data. Trying to figure out what data you truly need. Once again as a landlord seaport authority, I do not want to hold onto any data. So, what I do is provide general visibility of how things are going that are within my realm, and then facilitate business connections. So, I am sure over on your side, it is like here. There are lots of tech startup companies that are coming into this logistics – not just the maritime space, but the logistics space in general. Who are looking to solve problems? They have got tons of venture capital behind them. So, that is the best-case scenario. As a seaport authority, I want to try and facilitate those business-to-business connections. To provide visibility to all of my stakeholder users of these new tools that are out there. That is cool if you have got that kind of control. It is just not where we are at. That is not something we have the ability to do. So, when we have to figure out a different way – leveraging technology".*

The communication network of seaports is regarded as a vital component of the Industry 4.0 paradigm. However, the research suggested that seaports are still hindered by fragmentation and the perceived necessity to safeguard hidden data as opposed to the value of sharing their data with interested seaport stakeholders and/or actors. This is advocated by the following extract from the in-depth interview with the North-West Seaport Alliance.

> "*We look at what the future holds in terms of digitalisation, 5G, smart edge computing where you are getting that hidden information out and pushing it back in. So, I think from me personally that ha-ha moment was when I shifted from the private sector where I was really just looking at my terminal because that was my focus. I was getting paid for making sure that a particular terminal was running as efficiently as possible and having all these external factors that I could not do anything about. Coming to the seaport and really beginning to see how interconnected all of this is in that you cannot just fix one part of it. You could make the terminal as efficient as it could be. But if all of those inputs that are around it are complete garbage, you will never make that thing as efficient as it could be. This is where this drive to figure out our communication backbone is vitally important. So, that is a fibre optic network. Your communication you have connecting your terminal internal operations with the outside world by sharing previously hidden and restricted data. Is that good enough? All terminals, all business, the two most critical things are power and communication".*

The vital importance of real-time communication to enhance customer service levels by facilitating a frictionless flow of information between employees who operate at different levels and location is advocated by the Seaport Authority of Virginia, who regard its functionality as a strategic asset. This is evidenced by their response to the following question.

> **In terms of seaports: What is the main advantage that shipowners want from seaports? Is it vessel turnaround time, operational efficiency, and/or value-added services that are cost-competitive?**

> *Yes, shipper-terminal interface there are quite a few issues, safety – a vessel approaching a seaport. Is the seaport arranging for safe anchorage? Does the seaport have an adequate berth available? The second part does the seaport have advanced notification about congestion or no congestion. To allow the vessel to adjust to their journey schedule, and also their loading and unloading*

efficiency. The vessel can go in and quickly load and unload. I think they are the different layers'.

5.4 Insights & Summary

This chapter first reviewed the sample population who participated in the series of semi-structured interviews in terms of their management level, sectoral experience, and length of service. The response rates were also highlighted in relation to their geographical and operating regions. Their initial insights into the questions posed were also discussed in relation to organisational size, culture, and confidence. Revealing the importance of ownership, size of operation, and cultural acceptance of the risks and barriers to Industry 4.0 sectoral implementation and application. This chapter concluded with a review of the insights collated from the series of in-depth interviews that were held with the North-West Seaport Alliance and the Seaport Authority of Virginia. Chapter Six The Application of the Empirical Decision-Making Tools (EDMTs) will delineate the development of a range of Industry 4.0 mapping tools that present a novel adaptation of traditional VSM that focuses on the drivers of Industry 4.0 (rather than the identification of waste/non-value adding activities). In preparation of the case studies presented in Chapter Seven Case Study: Virginia Seaport Authority and the North-West Seaport Alliance, it also detailed the operations of the Virginia Seaport Authority and the North-West Seaport Alliance and their current state processes that require Industry 4.0 mapping.

CHAPTER 6: THE APPLICATION OF THE EMPIRICAL DECISION-MAKING TOOLS (EDMTs)

6.0 Introduction

This chapter presents the Empirical Decision-Making Tools (EDMTs) that facilitate an enhanced understanding of the seaport's current position (situational awareness) with regard to Industry 4.0 embedded technologies as drivers of strategic decision support. The EDMTs will provide seaport operators with a range of visualisations that will depict the current and ideal future state of the operation. They will capture data sets that are specific to the seaport zone as the managed asset is deployed. A different range of mapping techniques and data visualisations were investigated to explore data that is either structured or unstructured. These included the following, Process Flow Mapping, Supply Chain Data Matrix, Decision Point Analysis, Accuracy Completeness Amplification Mapping, and Key Characteristics Mapping. In addition to the ability to map a multitude of operations; vessel loading time, vessel unloading time, berth waiting time, crane availability, container storage capacity, throughput rate monitoring, and human capital awareness (identification of gaps in skills, knowledge, expertise, and training). This chapter also identifies how the EDMTs may be applied to mitigate the barriers to Industry 4.0 implementation that were presented in Table 10 on page 78.

6.1 Reconsidering Value

A wide range of traditional VSM tools to map the value and non-value-adding activities in a value stream has been extensively described in previous literature. VSM tools are a robust method and are ideally suited to mapping, analysing, and developing value streams to limit operational waste under a Lean Production methodology within a variety of diverse sectors that have been systematically identified in the literature review (Chapter Three). This research has identified an opportunity to harness the strength of VSM in identifying value and non-value adding activities, but to broaden the scope of the value proposition following concepts of integration of inter (cross-boundary) /infra digitalised information flows, to improve real-time agility and transparency. The benefit of this shift in value-focus can be seen by the range of mapping opportunities presented to even include mapping human capital and organisational culture as drivers of Industry 4.0 technology acceptance. The EDMTs will develop well-understood and tested VSM methods into a decision-making support tool to facilitate enhanced situational awareness that impacts KPI metrics that regulate efficiency, effectiveness, and process agility. This will facilitate a broader research contribution that is applicable to a range of sectors that operate complex operations and require a representation of their current and ideal future state which is underpinned by the EMDTs. This will also enhance the robust methodology of VSM by incorporating metrics of improved decision-making that are leveraged by Industry 4.0 embedded technologies as the overall aims of digitalisation do not require the same focus on value streams as in traditional VSM contexts. As such this research proposes a different blend of visualisation and mapping tools to enable operators to prioritise decisions around digitalisation strategies.

6.2 Empirical Decision-Making Support Structure

Below is a review of the salient steps identified in the Empirical Decision-Making Support Structure which is depicted in Figure 48. The Empirical Decision-Making Support Structure has been adapted from Figure 24 (Section 4.3 Value Stream Mapping) and is utilising the robust and widely applied structure that underpins traditional VSM. However, it proposes an alternative method that is underpinned by data visualisations of the Industry 4.0 current and ideal future state to facilitate enhanced decision support, regarding investment and operating strategies.

Due to time and funding constraints, the Empirical Decision-Making Support Structure has not been undertaken with a seaport operator. This stage has not been undertaken in practice during the PhD research project due to funding constraints, COVID-19 disruption, and time limitations. This PhD is fully self-funded, and it was not financially possible to travel to Virginia or Seattle/ Tacoma. This stage would require a significant amount of time to complete, and in-person involvement, and the seaports did not have the operational time to make such a commitment.

Another difference between the EDMT and traditional VSM techniques relates to the inclusion of strategic thrusts that drive the process of continuous improvement. The theory of strategic thrusts was developed by Wiseman (1985) (Bergeron, Buteau, and

Raymond, 1991). It utilises a grid known as a generator of strategic options that enables a manager to analyse three strategic targets of the seaport sector: suppliers, clients, and competitors (Bergeron, Buteau, and Raymond, 1991). The grid facilitates awareness of strategic direction that can be undertaken in pursuit of competitive advantage: differentiation, cost reductions, innovation, growth, and alliance. It constitutes an interface between each stage of the EDMT support structure.

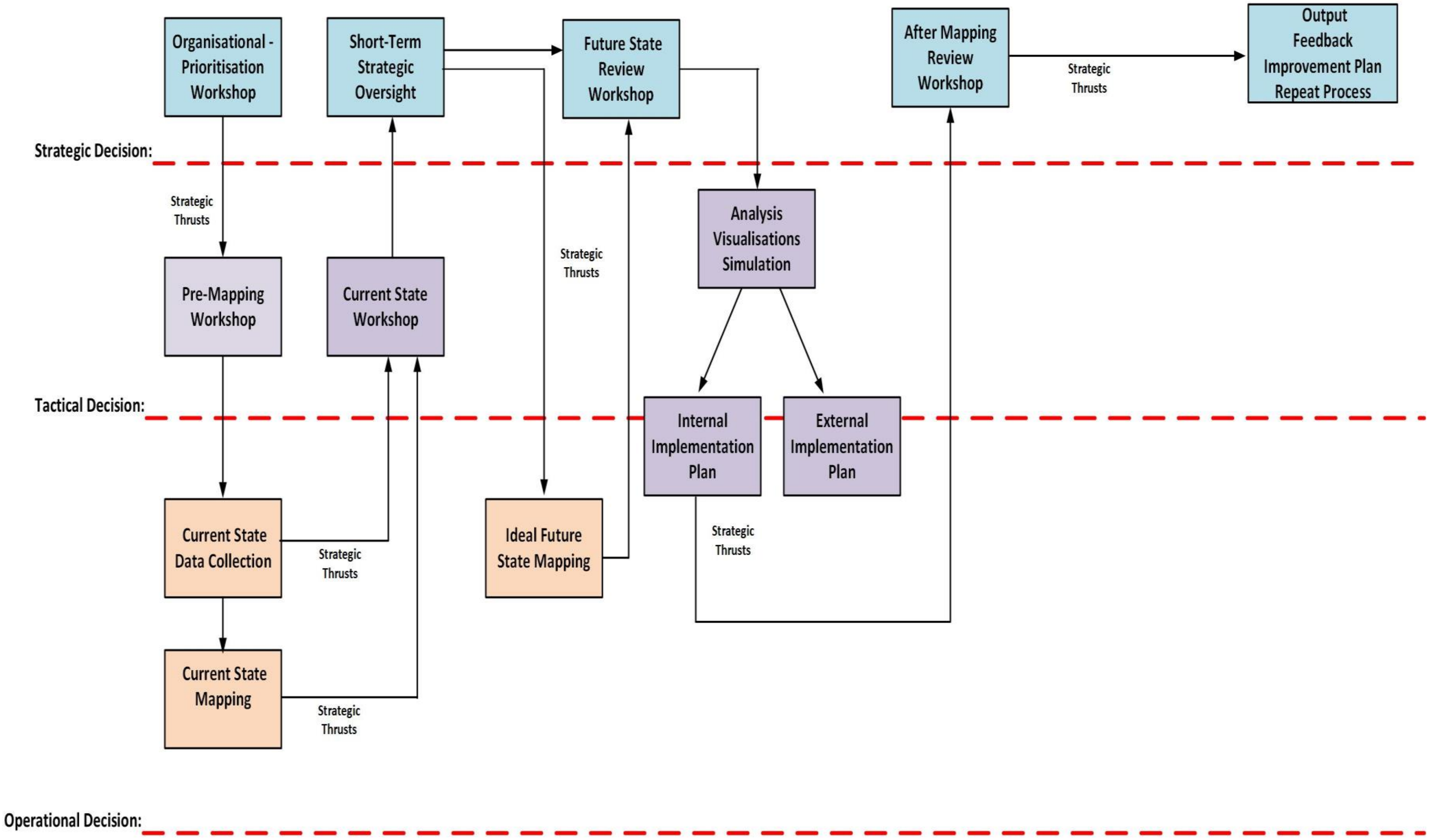


Figure 48: *The Empirical Decision-Making Structure*

6.2.1 Organisational Priorisation Workshop

The Organisational Priorisation workshop as depicted in Figure 48 would enable a systematic understanding of the seaport's mission, detailing the customer environment and their expectations (evaluated for priority and importance), in addition to the strategic direction set by the senior management team. The following stakeholders presented in Table 25 would be expected to attend this workshop, eliminating organisational boundaries, lack of communication and the fragmentation of operations. This will also ensure the project has a representative mix of the appropriate skills, knowledge, and experience, especially when one considers the current state of operation.

Their insight would be fundamental in the series of informal discussions that would facilitate a perception of the seaport's current state in relation to Industry 4.0 readiness. The pillars of Industry 4.0 discussed in Chapter Three (Section 3.4 Industry 4.0) will facilitate a benchmark for the seaport to measure its existing competencies and technological infrastructure. A review of the seaport's current KPIs would be cross-referenced against the perceptions of Industry 4.0 readiness to delineate a seaport operation to be mapped in its current state and then it's ideal future state. This would ensure that the EDMTs is of commercial relevance to the seaport, enhancing the commitment of both management and the operatives.

Table 25: *Seaport Stakeholders*

Adapted from Wagner (2017)

Classification of Stakeholder	Position of Stakeholder
Internal Stakeholder	Seaport Authority, Employees, Trade Unions, Shareholders, and Board Members
External Stakeholders	Transport Operators (Shipowners, Railway companies, trucking

	companies), Terminal Operators, Forwarding Agencies, Shipping Agencies, and Industrial Partners
Legislation and Public Policy Stakeholders	Customs Enforcement

6.2.2 Pre-Mapping Workshop

A pre-mapping workshop as depicted in Figure 48 would facilitate a direct observational process walk-through that is conducted in person at the site of the predetermined operation. However, the pre-mapping workshop is also ideally suited to be conducted remotely by utilising video conferencing tools, highly applicable in operations that are undertaken in various locations. It is an opportunity to observe processes, gather structured and unstructured data and interact with employees to obtain functional and unbiased insights on the operation, underpinned by the concept of a continuous improvement methodology. All interested stakeholders should be invited to participate in the mapping process to enhance insights, improvement opportunities and summaries of the operation. It is highly recommended that the operatives receive prior notification that the pre-mapping workshop is scheduled to take place, mitigating the likelihood of any atypical or forced actions. This also underpins an understanding of the purpose of the pre-mapping workshop. Participants of the pre-mapping workshop are there to learn about the processes under observation and are invited to ask questions, and engage with the employees to ascertain their opinions; What problems do they encounter? What works well? However, the members of the pre-mapping exercise should resist dissimilating feedback to operatives regarding continuous improvement opportunities, or visualisations of the ideal future state until the Empirical Decision-Making Support Structure has been completed.

6.2.3 Current State Mapping

The current state map as depicted in Figure 48 is a transparent process and not a closed-loop exercise that is produced by gathering baseline data from the process to be mapped. It represents a snapshot of how the operation is undertaken and identifies opportunities to implement Industry 4.0 embedded technologies to populate strategic decision support. The integration of the pillars of Industry 4.0 will facilitate a representative indication of the seaport's current position i.e., Industry 3.0 (robotic processes), Industry 4.0 (semi or full automation, vertical and horizontal system integration, and smart data collection processes), or leading to Industry 5.0 (collaborative robotic functions).

The following concepts offer a baseline for the current state mapping visualisations; system integration (manual, semi-automated, or full automation), digitalisation, interoperability of data (inter/infra organisational), location of sensors, data collection (manual, semi-automated, or fully automated), data quality (5Vs – Volume, Variety, Velocity, Veracity, and Value) as delineated in Chapter Three section 3.5 (The Nature of Big Data 5Vs). One of the fundamental benefits of the EDMTs is its flexibility and adaptability to map the spectrum of Industry 4.0 concepts that are not just confined to the maritime and seaport sectors.

The completed data visualisations will need to be verified by a team member who has detailed knowledge of the operation. Further verification may be obtained from the supply chain partners, shippers, and end-users who integrate with the seaport's existing information platforms. A range of data visualisations may be deployed (see 6.2.7 Selection of Empirical Decision-Making Tools – EDMTs a Seaport Perspective) to capture data.

6.2.4 Ideal Future State Mapping

The objective of the future state map as depicted in Figure 48 is to produce a visualisation of what the future state could be based on improvements being quantified through the observable gaps between the current and ideal future state operation. The same visualisation (EDMTs) is applied to ideal future state mapping, facilitating a quick and standardised approach that is intrinsically suited to the dynamic and time-critical seaport environment.

6.2.5 Ideal Future State Review Workshop

In order for the ideal future state project to progress and transform into reality it is fundamental that all involved stakeholders are fully committed to ensuring its successful completion. The Ideal Future State Review Workshop as depicted in Figure 48 is an opportunity to discuss the feasibility of the project in terms of current operational commitments, budgetary/ investment constraints, improvements to operations (increased capacity, throughput, visibility, and transparency), the desire of the stakeholders, and alignment of the seaports culture to achieve the projects aims and objectives.

6.2.6 Internal and External Implementation Plan

One of the primary functions of the internal and external implementation plan is to determine the scheduling of the recommendations identified by the current state map and their subsequent implementation by the ideal future state map. As reflected by Table 26 which depicts the roles and responsibilities that are subjected to budgetary constraints. It represents a communication for the identified stakeholders to address any concerns that relate to how the seaport will advance from its current operational state to the visualised ideal future state.

This would consist of the employees responsible for the execution of tasks and the deadlines for their successful completion, facilitating a more metric-orientated monitoring of progress. A Gantt chart is suitable to provide a visualisation of the critical deadlines and the required tasks to be successfully completed. A list of resources would be required for both the internal and external implementation plan. The internal implementation plan would constitute the following actions: recruitment and training/ upskilling if the current and ideal future state mappings identified any perceived gaps in the knowledge of existing employees. The external implementation plan would source capabilities and equipment that are not currently accessible within the seaport's operation or network. This may constitute specialist IT support for the interoperability of data into the seaport's existing information systems. A budget would ensure that the internal and external implementation plan would conform to the investment levels predetermined by the seaport management.

Table 26: *Provisions of Internal and External Implementation Plans*

Implementation Plan	
Internal	**External**
Budgetary constraints	
Clarification of roles and responsibilities Timeline (Time critical completion dates – Gantt charts) Lines of communication to stakeholders/ project participants	
Provision of training Recruitment (Full Time – Fixed Contract, Part-Time, or Agency Staff) Procurement (Sensors, IT Technology, Equipment, Hardware, and Software) Liaison with supply chain partners (Customs, Shippers, End-Users, Community)	Specialist IT support
Risk management plan (Identification of anticipated barriers/obstacles – contingency plans)	

6.2.7 Selection of Empirical Decision-Making Tools (EDMTs) in a Seaport Perspective

Indicators are utilised in a variety of sectors and for various purposes. The three main functions of indicators are quantification, simplification, and communication. They can also underpin decision-making by assisting in setting targets and tracking and monitoring progress on service performance. See Table 27 for a range of seaport KPI metrics that are formulated by financial and operational indicators.

Table 27: *Summary of Seaport Financial and Operational Performance Indicators*

Financial Indicators	**Measurement Unit**
Tonnage Worked	Tons
Berth occupancy revenue per ton of cargo	Monetary units/Tons
Cargo-handling revenue per ton of cargo	Monetary units/Tons
Labour expenditure per ton of cargo	Monetary units/Tons
Capital equipment per ton of cargo	Monetary units/Tons
Total contribution	Monetary units
Financial Indicators	**Measurement Unit**
Arrival time	Ships/ day
Waiting time	Hours/ ship
Service time	Hours/ ship
Turnaround time	Hours/ ship
Tonnage per ship	Tons/ ship

Fraction of time berthed ships worked	Hours/ ship
Number of gangs employed per ship per shift	Gangs
Tons per ship hour in seaport	Tons/ hour
Tons per ship hour at berth	Tons/ hour
Tons per gang hour	Tons/ hour
Fraction of time gangs idle	Gangs/ hour

The origins of Key Performance Indicators (KPIs) are in business administration. KPIs enable a seaport to compare their current state performance and communicate the evolution of performance levels over time. They are usually applied to target formulation, monitoring, benchmarking, ranking purposes, and most fundamentally insightful strategic decision-making. The application of the EDMTs will assist the seaport management in visualising its operation subject to the following unit's lapsed time/ KPIs and resources utilised. In addition to assisting in the identification of Industry 4.0 implementation barriers as depicted in Table 28, underpinning a visualisation of improvement opportunities.

Table 28: *Selection of Empirical Decision-Making Tools (EDMTs) and the Identification of Industry 4.0 Implementation Barriers*

Barrier	**Industry 4.0 Mapping Tool**	**Lapsed Time/ KPIs Resources**	**Performance Measures**	**Section**
System Interoperability – Information Bottlenecks Lack of Knowledge Limited Visualisation Scope	Process Flow Mapping	Vessel Loading Time	Total Elapsed Time of the Loading Process	Section 6.3
	Process Flow Mapping	Vessel Unloading Time	Total Elapsed Time of the Unloading Process	Section 6.3
Data Quality System Interoperability - Information Bottlenecks Limited Flow of Information Cybersecurity – Electronic Seal Tampering	Supply Chain Data Matrix	Berth Waiting Time	Total Elapsed Time of Berth Availability Waiting	Section 6.4
Resistance to Change Mentality Low Management Support – Financial Constraints	Decision Point Analysis	Crane Availability	Number of Cranes Utilised per Ship	Section 6.5
Limited Visualisation Scope System Interoperability	Demand Amplification Mapping	Capacity	Container Storage Yard	Section 6.6
	Demand Amplification Mapping	Throughput Rate	Number of Containers handled per Hour	Section 6.6
Data Quality System Interoperability Lack of Skills & Competencies	Key Characteristics	Human Capital	Knowledge of Industry 4.0 Embedded Technology to Leverage Efficiency, Integration, Agility, and Transparency in the supply chain mechanics	Section 6.7

The novel adaptation of VSM tools will also assist the seaport in formulating insightful decisions in an efficient, effective, standardised, and timely manner which adds value to the logistical services provided to the shipper and the end user as represented by Table 28 in its leveraging of KPIs and continuous process improvements. The lack of understanding of the Industry 4.0 paradigm has been implicitly identified in the semi-structured interviews and the literature as representing a fundamental barrier to the seaport sector utilisation of Industry 4.0 embedded technologies. This range of mapping tools is a response to market demands that expect the following service levels as standard, sharing of real-time information, transparency, higher processing speeds, automation of the process, and the avoidance of human errors. These essential services will be mapped in a faster more efficient manner allowing their inclusion in the day-to-day decisions by visualisations of EMDTs that are measured in relation to KPI metrics, providing a current state representation of the supply chain and a methodology to achieve an ideal future state operation.

6.3 Process Flow Mapping

Process Flow Mapping constitutes the following steps. Firstly, a preliminary analysis of the operation to be mapped is undertaken with the execution of a process walk-through. This is subsequently followed by a detailed data capture of all activities in the integrated fulfilment of each process. This will include the location or area of deployment for each semi or fully-automated machine, distance transited, time taken, duration of operation, number of sensors deployed, and downtime, in addition to the identification of barriers relating to information flow, and interoperability, data structure, static and remote decision points, level of human intervention/ interaction, data dissemination, and storage. The collated data will be populated into a walk-through flow chart depicted in Table 29 (Page 186) that is flexible to meet the unique operating requirements of the seaport.

As previously discussed in the literature review contained within section 3.2.5 Sectoral Value Stream Mapping Approaches in Chapter Three; VSM tools were primarily focused on the identification of wastes contained within the value stream. However, this chapter proposes an alternative use of Process Flow Mapping to facilitate a deeper understanding of the interoperability of Industry 4.0 technologies engaged in maintaining and enhancing the throughput capacity of the seaport to adhere to KPI targets, capacity optimisation, and efficient utilisation of valuable resources and land, and shipper/ end-consumer expectations. An example of a Process Flow Map is depicted in Figure 49 it has been constructed utilising insights collated from the literature (container handling procedures), the literature review chapters (Industry 4.0 pillars) the series of semi-structured interviews (Chapters Five and Six), and the EDMT walk-through case study (Chapter Seven). The process walk-through facilitated a step-by-step demonstration and explanation of a seaport process by the practitioner, such as loading and unloading a container from a ship using their internal processes.

The EDMTs walk-through was consulted in the development of the Process Flow Map as it revised the process to reflect the actual operation of the Seaport Authority of Virginia. This produced a more intuitive map that was based on their internal operating procedures as depicted by Figure 57 in Chapter Seven Section 7.4.1 Process Flow Mapping rather than a theoretical concept that was formulated from insights from both the literature, semi-structured and in-depth interviews.

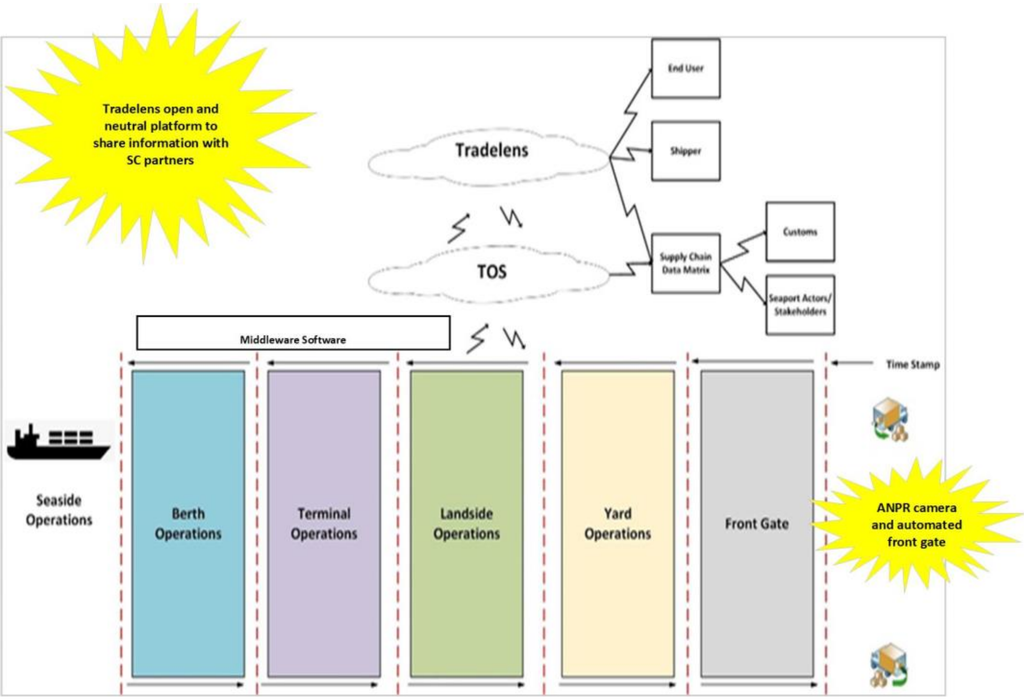


Figure 49: *Mapping the Time Gates for the Supply Chain Data Matrix*

To map the flow of containers and data through the seaport, Figure 49 has been divided into the following sections: Seaside Operations, Berth Operations, Terminal

Operations, Landside Operations, Yard Operations, and Front Gate Operations. When the container enters the seaport/ or is unloaded from a ship it is issued with an active RFID tag. An active RFID tag is more suited to the operating environment of a seaport where the container stacks reduce the signal strength of passive RFID tags. RFID tags are considered to be extremely durable and are able to withstand harsh operating environments (Heilig, Voβ, and Stahlock, 2019). An RFID reader receives the tag data in each seaport section and then subsequently transmits the information to middleware software. The reader will transmit the following data as tags are suitable to be integrated with sensors to capture other telemetric data: tag ID, receive time, location, electronic seal status, motion status, humidity, and temperature. The middleware software (sits in the middle between the RFID readers and the PCS application) will translate the data into a standardised format by the process of filtering, cleansing, and aggregation for integration into a PCS application.

The mapping of the information flow of Industry 4.0 embedded devices/ smart assets is integrated into the following mapping constructs; capacity, and infrastructure previously identified in Sections 5.3.3 and 5.3.4 of Chapter Five. This facilitated a comparison of the traditional VSM variable of the physical flow of the container as it transits from the container storage yard to the seaside zone where it is subsequently loaded aboard the ship. The frictionless flow of information between inter-organisational departments is an essential component of the Industry 4.0 paradigm and underpins the concept of supply chain transparency (visibility across multiple seaport facilities and asset management), a value-added service that is highly desired by competitive global markets. Interoperability is deemed as the interconnection of physical and digital technologies and unstructured information produced by a variety of different sources within the context of a cyber-physical environment. The mapping exercise will also offer the identification of bottlenecks in the flow of information in the supply chain and facilitate the tracking of high-value/ bonded cargo as it transits the seaport. Disrupting the functionality of the seaport to generate insightful BD to formulate decisions in relation to throughput KPIs and service level forecasts. A current state Process Activity Map as depicted by Figure 49 provides an excellent opportunity for the identification of aspects that require improvement, under the traditional Lean Methodology of continuous improvement and it also signifies a strategy to bridge the perceived gap in the maritime sector's Industry 4.0 competencies.

This form of improvement is regarded in VSM literature as a Kaizen burst and it is denoted by a yellow star in Figure 49. A Kaizen Burst is a Lean Manufacturing tool that is applied to generate a specific improvement aim during the process of developing the ideal future state map, emphasising the relevance of the improvement to enhance supply chain efficiency, effectiveness, agility, transparency, and visibility.

Table 29: *Walk-Through Flow Chart - Traditional Seaport Loading of a Container Ship in the Current State*

Step Number	Location	KPI Metric	Human/ Machine – Full or Semi-Automation	Decision Point	Interoperability	Data Structure	Human Interaction/ Intervention	Data Dissemination/ Storage
1	Container Storage Yard	Selection of the correct undamaged container	Manual Confirmation	Straddle Carrier Operator	Manual Integration – Hard Copy Documents	Open Data	Radio Communication	Container Movement Recorded in Hard Copy
2	Container Storage Yard	Straddle Carrier transits to the desired container	Driver Perception	Visual Recognition	Human - Observation	Open Data	Physical Motion	Container Movement Recorded in Hard Copy
3	Container Storage Yard	The Straddle Carrier lifts the container	Driver Controlled	Straddle Carrier Operator	Manual Operation of Straddle Carrier	Open Data	Physical Motion	Manual Straddle Carrier Time Sheet Entered into TOS after completion of the shift Excel Spreadsheet updated – Container Yard inventory via confirmation from Straddle Carrier Operator
4	Container Storage Yard	Straddle Carrier transits to the Quayside	Driver Controlled	Straddle Carrier Operator	Manual Operation of Straddle Carrier	Open Data	Radio Communication Physical Motion	Manual Straddle Carrier Time Sheet. Entered into TOS after

								completion of the shift
5	Quayside	Quay Crane Starts Up	Driver Controlled	Straddle Carrier Operator	Manual Operation of Straddle Carrier	Open Data	Physical Motion	Manual Straddle Carrier Time Sheet Entered into TOS after completion of the shift
6	Quayside	Quay Crane confirms container number/ identification and physical condition	Driver Perception	Quay Crane Operator	Human – Observation	Open Data	Radio Communication	A hard copy of the ship loading plan is consulted and annotated to confirm compliance
7	Quayside	Quay Crane lowers the container onto the ship	Driver Controlled	Quay Crane Operator	Manual Operation of Quay Crane	Open Data	Radio Communication Physical Motion	Container loaded as per hard copy ship loading plan

The ideal Industry 4.0 future state in Figure 50 depicts a representation of where the seaport would like its operation to function. This assists in representing realistic and feasible visions of the process as it should be and aligning it to the business strategy and customer needs. It is envisioned that this tool will identify and mitigate the barriers that were previously discussed in Chapters Three and Five relating to Industry 4.0 awareness, financial investment, employment concerns, culture, organisational size, capacity, communication, and infrastructure. The implementation and application of the EDMTs is an innovative approach that assists operators to learn to understand the capability of Industry 4.0, to leverage potential process improvements that enhance supply chain efficiency, effectiveness, agility, transparency, and visibility. In terms of visualising their current position towards Industry 4.0 readiness, exploiting the potential of new innovative technologies, and formulating a roadmap to leverage an ideal future operating state. This adds to the lack of empirical literature identified in Chapters Two and Three. This adaptation differs from the traditional VSM method which has focused on the identification and elimination of waste and non-value-adding activities in the value stream, prompting a refining of the concept of waste identification.

The Process Activity Map's ideal future state as depicted in Figure 50 is not a wish list. It will be drafted by the process mapping team with guidance from senior management, enhancing the likelihood of its successful completion. It is a shared visualisation of prioritised improvements that may be applied to the current state of operation, leveraging improvements in supply chain efficiency, effectiveness, visibility, transparency, and agility. As improvements are successfully completed, both the current and future state maps should be systematically revised. The future state map is a visualisation that is underpinned by a time frame of 12 months, reflecting a realistic representation of what is expected to be achieved subject to funding, expertise, and resource constraints.

In Figure 50 the focus of the continuous improvement strategy is centred around the implementation of an Automated Guided Vehicle (AGV) network to horizontally handle and transport containers to their required location. The improvements offered by AGVs are manifold for seaport operations and include the following increases: productivity, reliability, consistency, predictability (underpinned by BD analytics), and security. AGVs that operate within open navigational paths are extremely flexible and require accurate real-time locational information. An AGVs position is estimated by utilising radio frequency identification (RFID) sensors, laser sensors, cameras, and global navigation satellite systems (GNSS) (Torsoli et al., 2023). However, they are limited in the provision of flexible and accurate positional information in highly dynamic and congested seaport environments. This is exemplified by both cameras which are restricted in their scope of visual observation and GNSS which is unable to provide accurate positional tracking in indoor environments (warehouses) (Torsoli et al., 2023). To mitigate these issues the application of private 5G networks for determining positional and communication tracking is gaining sectoral importance, producing high levels of flexibility and scalability (Torsoli et al., 2023).

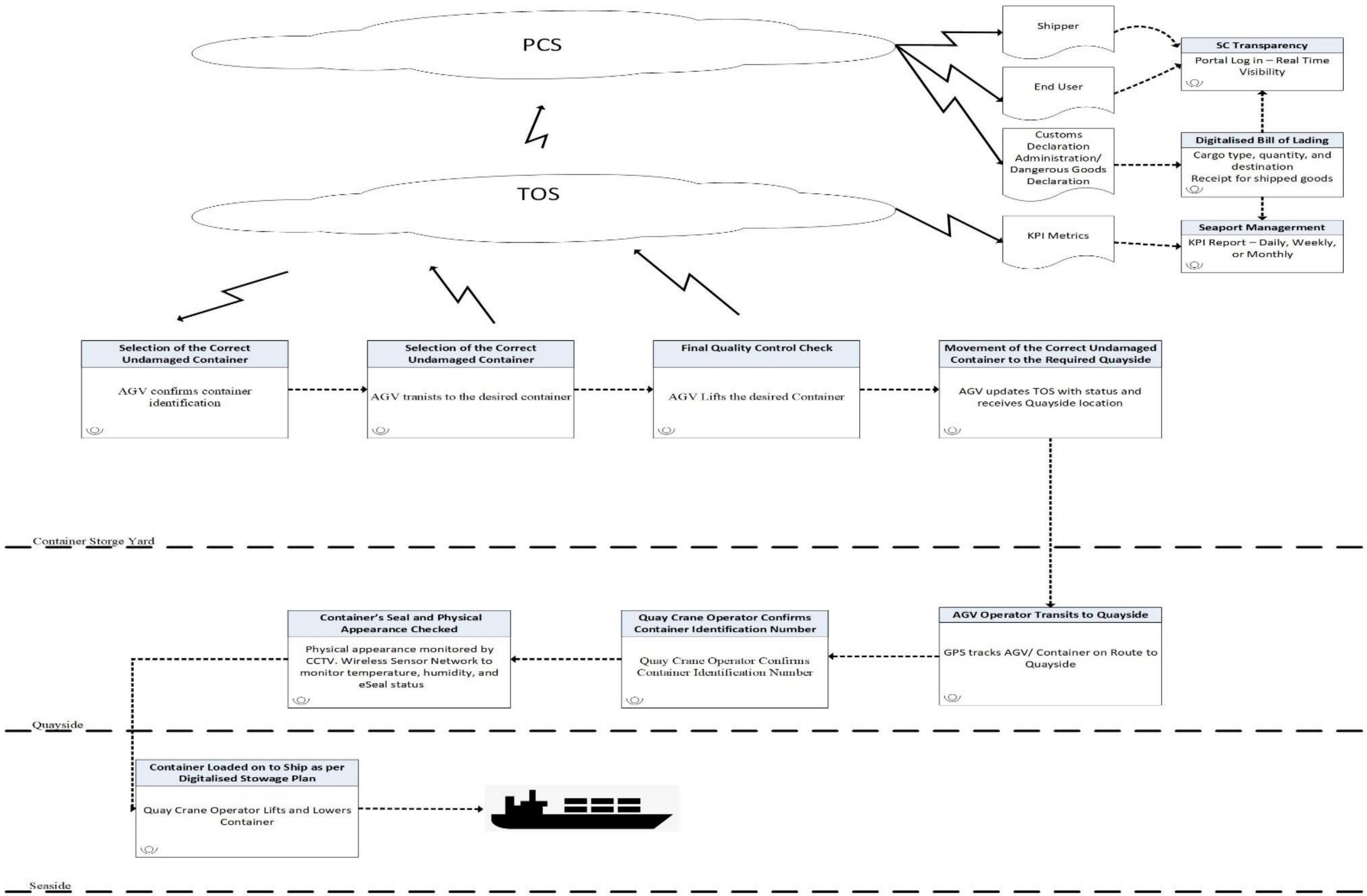


Figure 50: *Process Activity Mapping - The Future State*

Process Activity Mapping is a good first step towards understanding the current state as the processes are identified but without the requirement to capture lots of time-populated data (value-added and non-value-added) to each process. This increases the flexibility of its scope of application within complex environments and the likelihood of completion.

6.4 Supply Chain Data Matrix

The Supply Chain Data Matrix is depicted in Figure 51, and it is applied to simultaneously map the flow of information as it follows the physical movement of containers throughout the supply chain. Figure 51 displays the time taken for the container to enter the storage yard and then the time taken to load it aboard a ship. This is displayed in terms of cumulative inventory days. The cumulative lead time relates to the ship turnaround time (the time taken to load/ unload the ship in the seaport). An RFID reader will receive the data from an active tag that is assigned to the container at arrival at the seaport gate. An active tag is ideally suited to the demands of the Supply Chain Data Matrix as its internal power source enhances its RF communication range. This will address the barrier of data quality that is regarded as a barrier for seaports in the implementation of Industry 4.0 embedded technologies as presented in Table 10 on page 78. This is fundamental in the vast container storage yards of modern seaports where accurate time-critical identification is required. Real-Time Location Systems provide for real-time or near real-time tracking that utilises triangulation techniques to determine the tag location. The middleware software will translate the data into a standardised format that is displayed through the TOS platform. This will monitor the location of the container as it transits the seaport and alert the operator to any unscheduled delays in its progress. Each stage is mapped and displayed in graphical and text format, facilitating its monitoring and the subsequent documentation is digitally attached. The purpose of the Supply Chain Data Matrix is to graphically display any bottlenecks and/or electronic seal tampering in the physical pull of the container and the flow of information within the supply chain that may be regarded as inter-organisational barriers in the seaport that are defined by their geographical location and function (Seaside, Quayside, Container Terminal, Container Storage Yard, and the Front Gate). Therefore, the Supply Chain Data Matrix will add to a seaport's resilience in relation to the early detection of cybersecurity risks that arise from electronic seal tampering.

The data populated by the Supply Chain Data Matrix would also map and identify hotspots within the terminal structure by recording historic security-related events and comparing this with real-time data flows. The Supply Chain Data Matrix will contribute to the issue of determining Industry 4.0 readiness as it underpins the pillar of IoT that requires the collection of information from anything, anytime, and anywhere (Katayama et al., 2012).

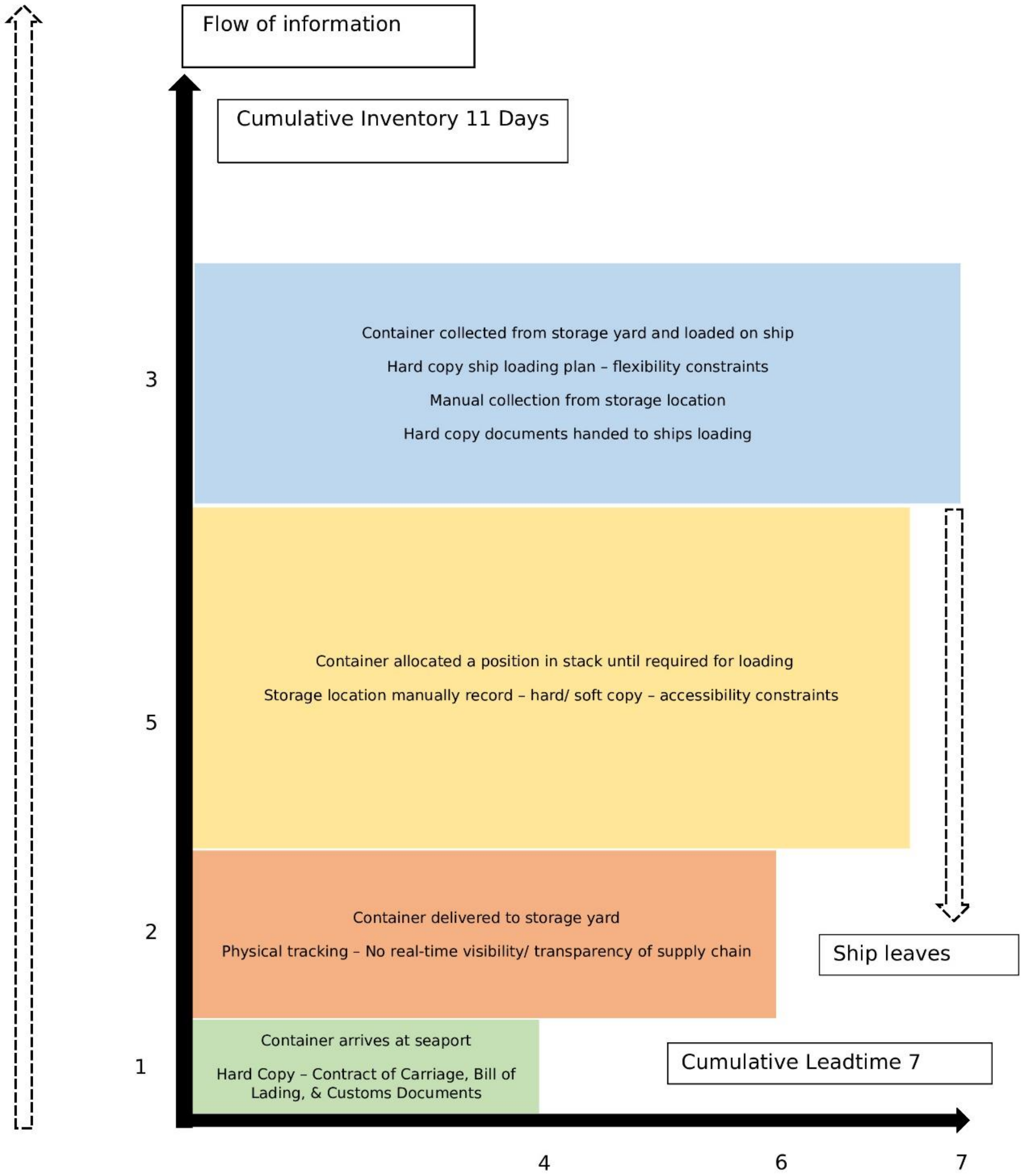


Figure 51: *A Supply Chain Data Matrix of a Traditional Seaport Loading Process*

6.5 Decision Point Analysis

Decision Point Analysis as depicted in Figure 52 is a suitable method to identify the applied Industry 4.0 technologies that form part of the decision-making process. Decision points as depicted in the top of Figure 52 are seamlessly integrated into the movement of the container from the ship's arrival until it is collected by the third-party logistics provider. These decision points are forecast-driven in terms of asset and resource management and/or customer-driven by the terms of the service agreement. They are defined by the pillars of the Industry 4.0 paradigm (Chapter Three) as system integration that are either static or fluid in the supply chain. Decision Point Analysis in Figure 52 allows the seaport management to develop hypothetical 'what if' scenarios that impinge on the operation of the decision point that is moved within the supply chain. This is of fundamental importance when considering the concept of asset management and resource allocation to adhere to customer service levels and KPI targets. These decision points are forecast-driven in terms of asset and resource management and/or customer-driven by the terms of the service agreement. The Decision Point Analysis in Figure 52 will also allow the seaport management to visualise the flow of information (information value chain) and the physical movement (physical value chain) that pulls the container through the supply chain, following the execution of a particular decision.

The mapping of decision points within a seaport is of fundamental importance when determining the efficient utilisation of limited assets within a fragmented, dynamic, complex and data-intensive environment that constitutes devise stakeholders and actors as depicted in Figure 53 (Franzén and Streling, 2017). The application of the Decision Point Analysis will also mitigate any instances of resistance to change amongst the workforce as the benefits generated by the change in the operation/ process will be abundantly clear. This will also enhance the likelihood of the proposed change in operation/ process that is driven by the decision being successful as the workforce becomes fully invested due to flexible and joint learning exercises. Despite this view, it is interesting to note that when analysing the semi-structured interviews, it has become apparent that decisions made by seaports have been predominately based on external factors, such as overloaded and shared seaport infrastructure (road network) and state funding acquisition to act as a catalyst for economic growth. The Decision Point Analysis will map the decisions formulated in relation to their location in the supply chain, the nature of the process, and the Industry 4.0 technology utilised to underpin the decision-making process.

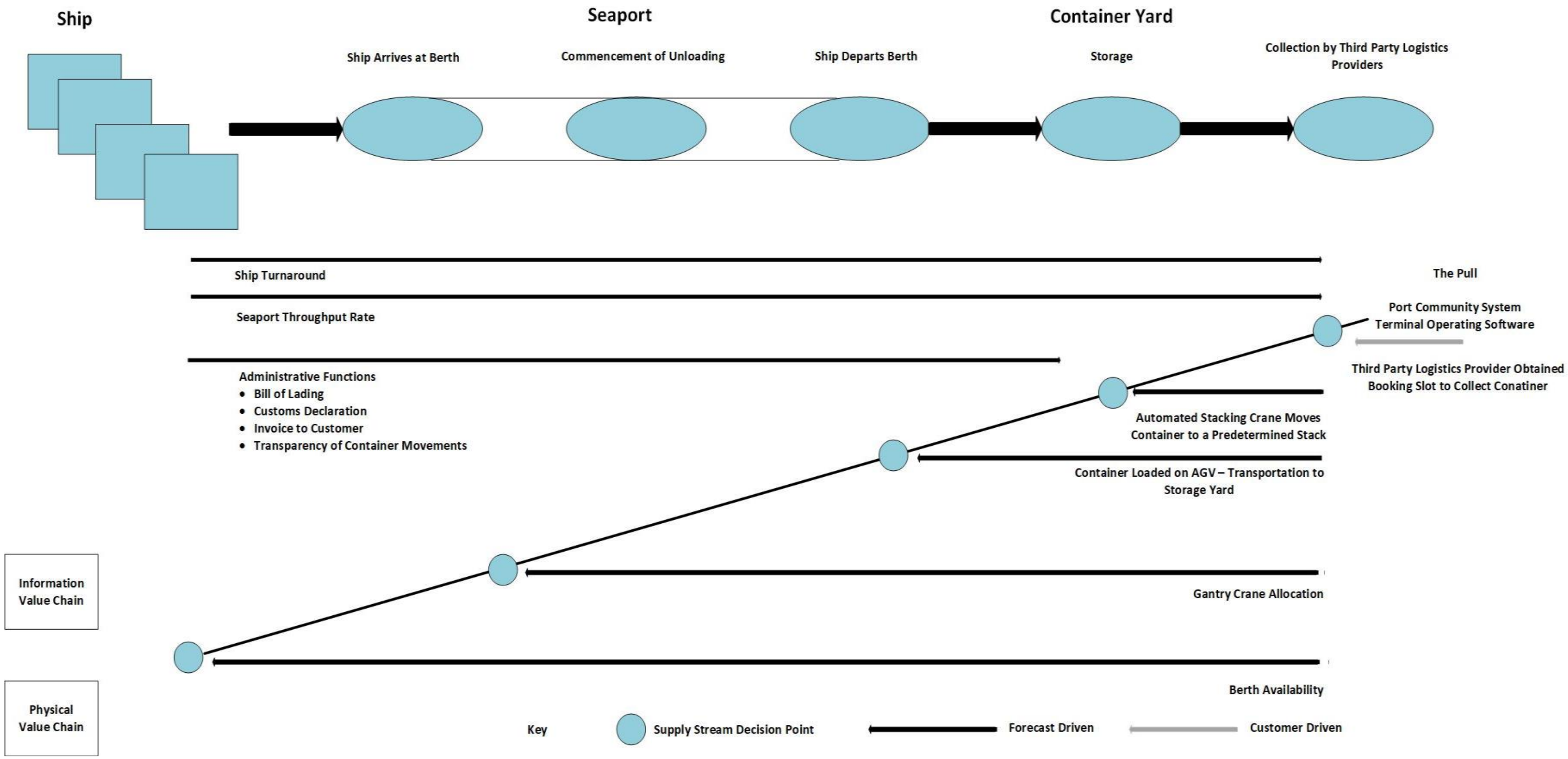


Figure 52: *Decision Point Analysis*

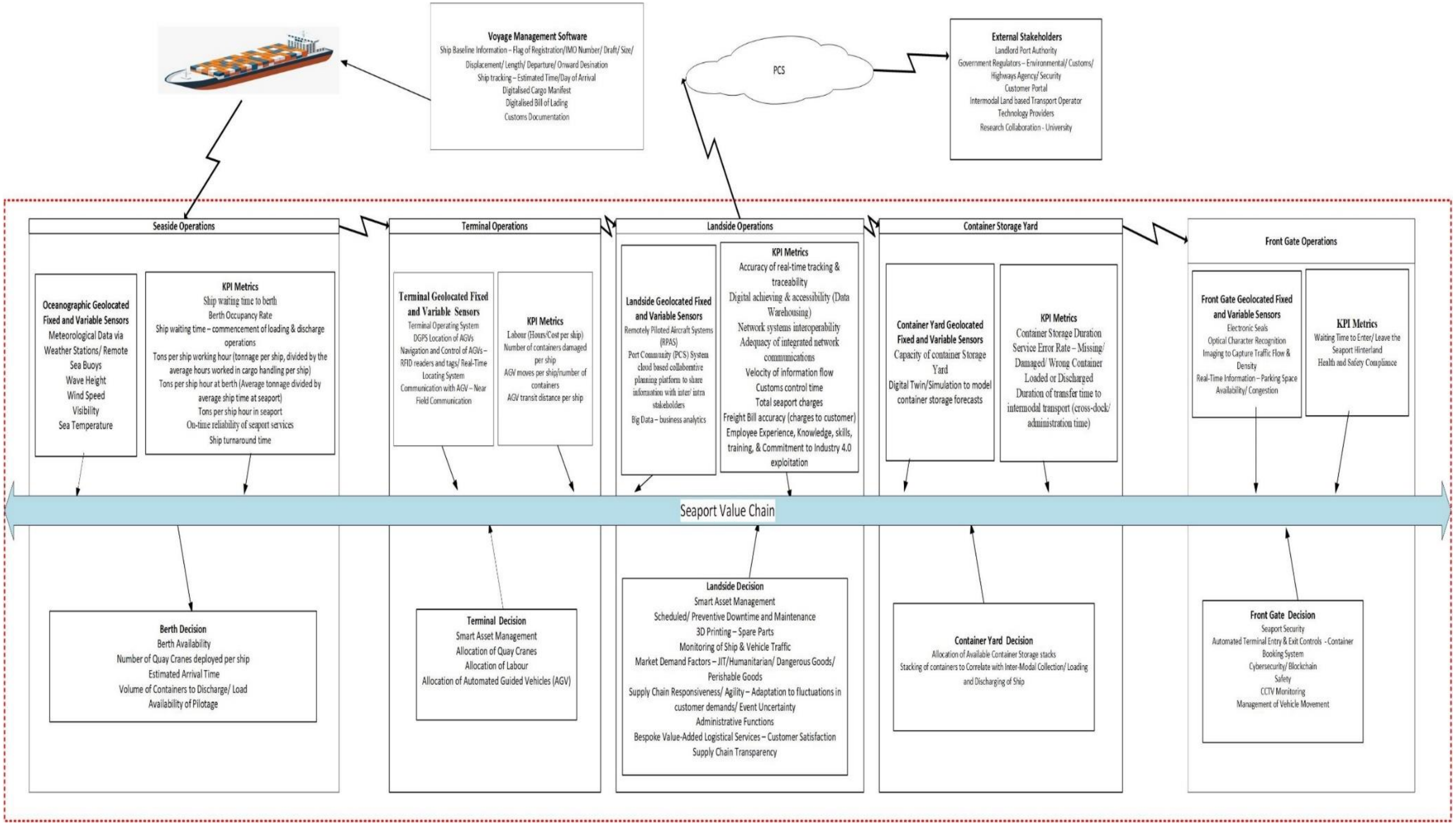


Figure 53: *The Multitude of Decisions in a Seaport Operation*

6.6 Accuracy Completeness Amplification Mapping

The accuracy of data can be verified in a variety of ways, including manual interventions, direct measurements, or sampling techniques. Where processes run sequentially without verification then sources of error can create inaccuracies that may be problematic for automation implementation.

By mapping the points at which data is transferred and verified then a mapping can be constructed to enable a better understanding of the sources of inaccuracies, and potential improvement areas can be planned. The mapping construct itself allows modellers the ability to track sources of error, the accuracy/completeness metric at a point, actors responsible for the process/verification and traceability of where the data is held/stored for example. This will stimulate a more systematic utilisation of operational data, driving the seaport from a data graveyard to a data-rich environment, where decisions are formulated utilising real-time data. The Accuracy Completeness Amplification Mapping tool will mitigate the barriers surrounding the knowledge to successfully apply Industry-embedded technologies to deliver meaningful actions. An example accuracy completeness amplification mapping tool is presented in Figure 54.

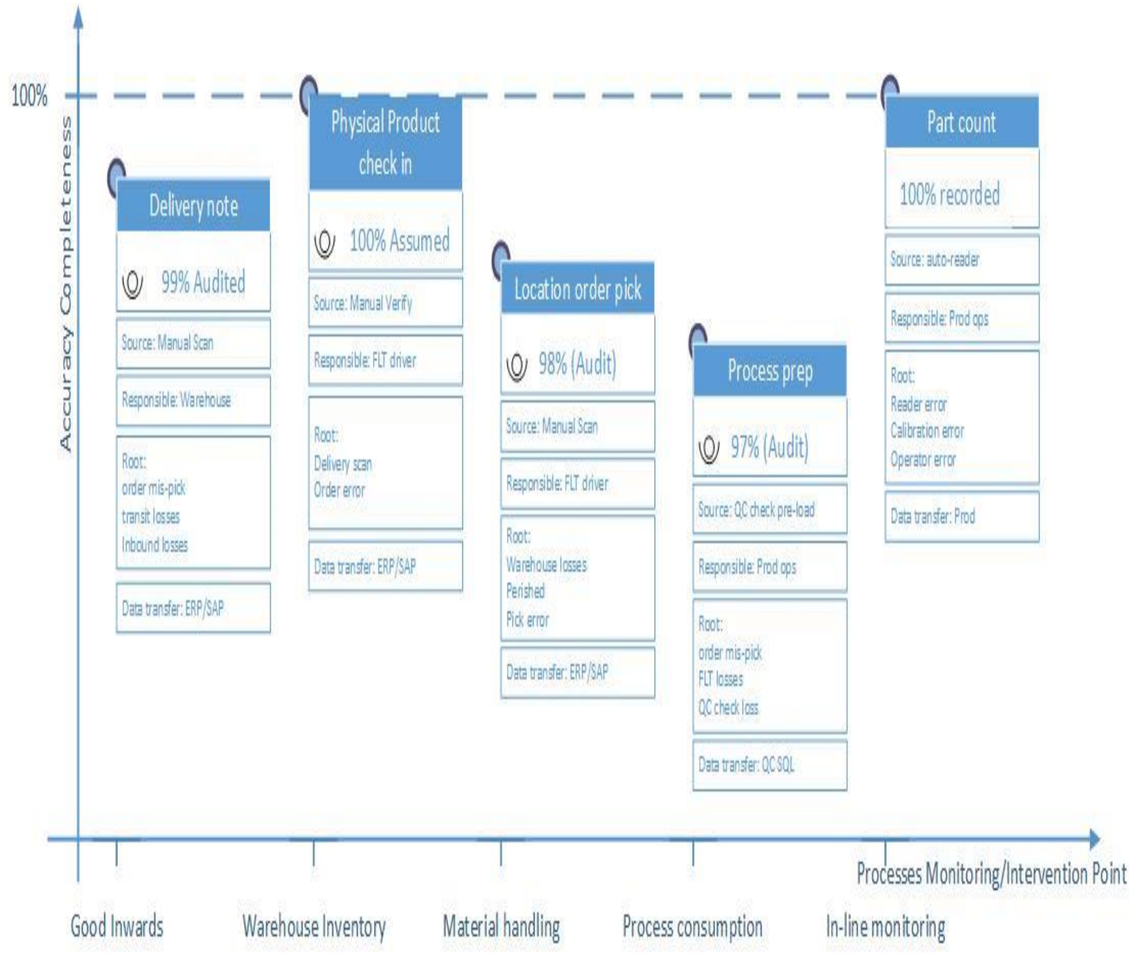


Figure 54: *Accuracy Completeness Amplification Mapping*

This example follows the material flow of a product through a production system and the associated logistical data linked to the material in the system. Data inaccuracies occur where physical material counts differ from the planned volumes. These differences could be accounted for by various sources including human or system errors, physical losses, and process efficiencies calibration errors. As can be seen from the example, where process steps include multiple stages without verification (picking materials from a warehouse location for an order, and then processing these materials) then the inaccuracies can be amplified, with several sources of data error potentially compounding the accuracy at a point in the process flow.

6.7 Key Characteristics of a Seaport

The concept of key characteristics has been applied in several sectors and has been extensively applied to control of product features that can be tracked over time

(Whitney, 2006). Key characteristics were originally defined as dimensions at the assembly level that are important for safety, performance, and quality KPI fulfilment and that are at risk of not being achieved due to variations in the fabrication or assembly process (Whitney, 2006). Rather than focusing on the tolerances of a component; this principle of understanding is based on what are the features of a system that allow it to perform as it was designed and documents their monitoring over time to ensure the system continues to perform as designed.

As previously delineated in Section 2.2 (Chapter Two) a seaport is a multidimensional system that is combined between the key characteristics of governance (organisational culture), land-based logistics, seaport infrastructure, maritime logistics, operational KPIs, smart seaports, shipowners, and seaport customers as depicted in Figure 55. These characteristics are features of the products and services that the seaport provides to its customers and frequent monitoring is required to ensure that the KPI targets are achieved, based on the functions performing as they are intended.

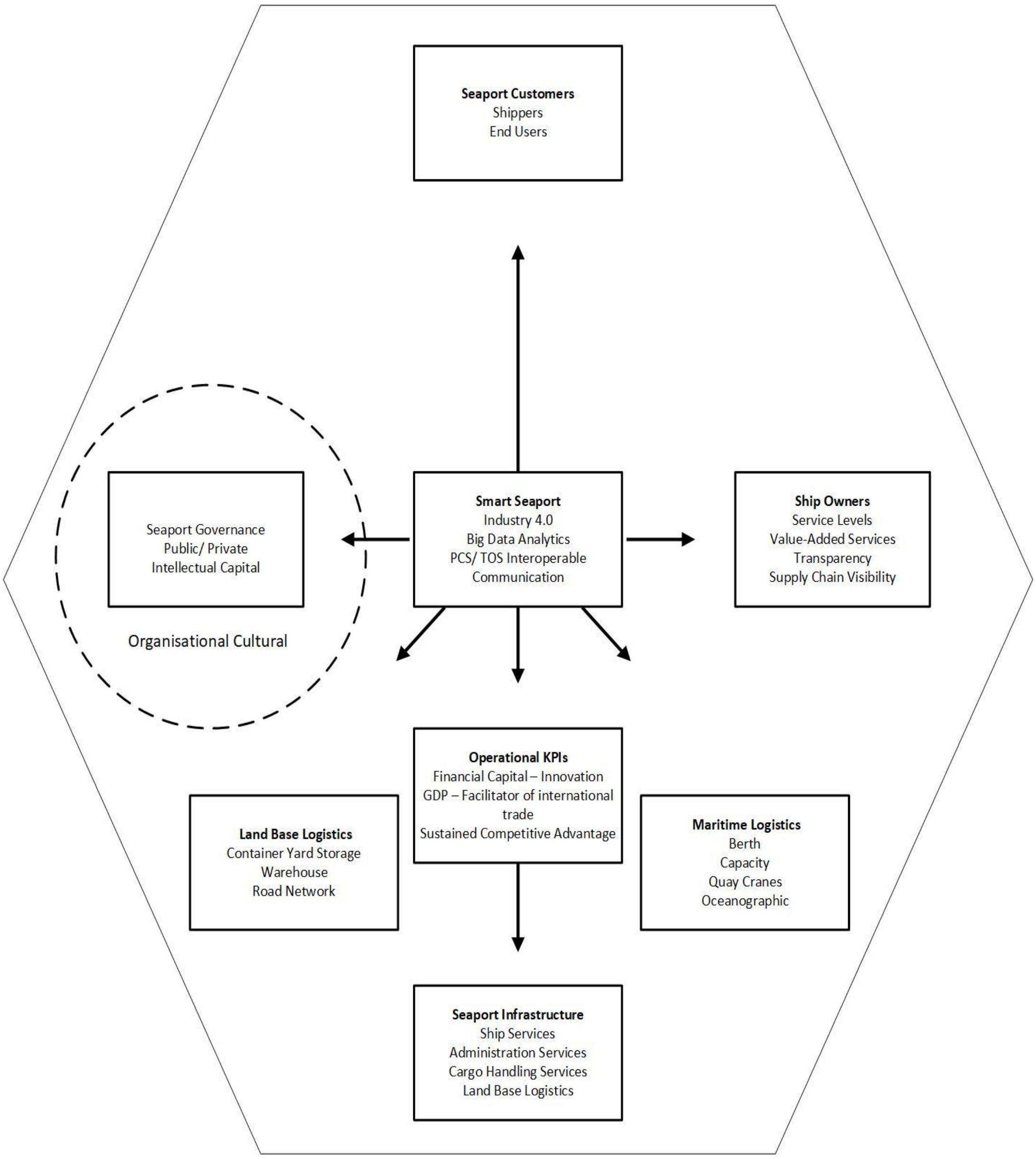


Figure 55: *Key Characteristics of a Seaport*

A review of the literature emphasised the importance of the following key characteristics of a seaport operation. The Key characteristics of a seaport are subsequently derived from the following intrinsic resources, capabilities, and competencies in Table 30 that allow it to operate as intended, adhering to contractual service levels and predetermined KPI targets.

Table 30: *The Key Characteristics of a Seaport*

Key Characteristics	Reference
Seaport Governance (Public and Private) Intellectual Capital	Roll and Hayuth (1993); Notteboom (2000); Rodrigue (2020); Pallis, and Rodrigue (2022) Hadžić, Jugović, and Perić, (2015)
Maritime Logistics (Seaport Infrastructure), Berths, Capacity, Quay Cranes, Oceanographic Data (Seaport Geography)	Cullinane et al., (2006); Hlali and Hammami (2017); Notteboom, Pallis, and Rodrigue (2022)
Seaport Infrastructure, Ship Services, Administration/ HR Services, and Cargo Handling Services	Notteboom et al., (2000); Taneja, Ligteringen, and Van Schuylenburg (2010); Notteboom, Pallis, and Rodrigue (2022)
Operational KPIs, Financial, Human Capital, Innovation, GDP Facilitator of International Trade, Sustained Competitive Advantage	Notteboom, Pallis, and Rodrigue (2022)
Smart Seaport, Industry 4.0, Big Data Analytics, Interoperable Communication	Gružauskas, Baskutis, and Navickas, 2018); Min (2022)
Ship Owners, Service Levels, Value-Added Services, Transparency, Supply Chain Visibility	Notteboom, Pallis, and Rodrigue (2022);
Seaport Customers, Shippers, End Users	Notteboom, Pallis, and Rodrigue (2022)

The Key Characteristics Map is ideally suited to monitor economic, seaport governance, human resource, and technological, fluctuations over time and highlight them to the operator who may undertake any required corrective action. This corrective action may constitute arranging (date, time, location, cost and level) training to mitigate a lack of skills and competencies that relate to Industry 4.0 embedded technologies.

Another simplistic example of a Key Characteristics Mapping exercise may relate to the monitoring of the expiry date of Microsoft software licences and their subsequent renewal processes to maintain the administrative functions of the seaport. The following sections provide an overview of the most influential key characteristics of a seaport.

6.7.1 Intellectual Capital

Intellectual capital represents the main source of the competitive ability of an organisation in market competition (Hadžić, Jugović, and Perić, 2015). The International Federation of Accountants (IFAC) classified intellectual capital as a combination of Human Capital, Relational (Customer) Capital, and Organisational (Structural) Capital that included Intellectual Property and Infrastructure Assets (Dzinkowski, 2000) as depicted in Table 31.

Table 31: *The Classification of Intellectual Capital*

Adapted from Dzinkowski, 2000)

Classifications of Intellectual Capital	
Human Capital Know-How Education Vocational Qualifications Work-Related Knowledge Occupational Assessments Psychometric Assessments Work-Related Competencies Entrepreneurial Elan Licencing Agreements Innovativeness, Proactive, Reactive Abilities, Dynamic	**Relational (Customer) Capitals** Capitals Brands Customers Customer Loyalty Company Name (Reputation) Backlog Orders Distribution Channels Business Networks (Collaborations) Favourable Contracts Franchising Agreements
Organisational (Structural) Capital	
Intellectual Property Patents Copyrights Design Rights Trade Secrets Trademarks	**Infrastructure Assets** Management Philosophy Corporate Culture Management Processes Information Systems Networking Systems

Service Marks	Financial Relations

6.7.2 Seaport Infrastructure Systems

Seaport Infrastructure Systems are presented in Table 32 and consist of the following components: Basic Seaport Infrastructure, Seaport Operational Infrastructure, Seaport Superstructures, and Seaport Equipment. The maintenance of Seaport Infrastructure Systems is of fundamental importance due to their challenging field of operation, ageing, and continuous utilisation. The importance of seaports to the global economy has been delineated in Chapter Two and demands a robust maintenance plan to ensure that the seaport operates as it was originally intended. Monitoring of Seaport Infrastructure Systems (basic and operational) by the Key Characteristics Mapping tool would assist management in scheduling preventive maintenance.

Table 32: *Seaport Infrastructure Systems*

Adapted from Taneja, Ligteringen, and Van Schuylenburg (2010)

Seaport Infrastructure Systems	
Basic Seaport Infrastructure Maritime Access Channels Seaport Entrance Breakwaters and Coastal Defences Sea Locks Rail Network between Hinterland and Seaport Inland Waterways (Seaport Area)	**Seaport Operational Infrastructure** Inner Channel Seaport Basins and Turning Cycles Roads, Tunnels, Bridges, and Locks (Seaport Area) Quay Walls, Jetties, and Finger Piers Navigational Aids, Buoys and Beacons Vessel Traffic Management System (VTMS)
Seaport Superstructures Paving and Surfaces Terminal Lighting Parking Areas Offices and Buildings for Terminals Repair Shops	**Seaport Equipment** Cargo Handling Equipment (Apron and Terminals) Tugs Dredging Equipment Line Handling Vessels Ship/ Shore Handling Equipment

6.7.3 Seaport Transparency

Seaport Transparency and easy access to data is regarded as a prerequisite for a successful seaport business and an important trend that seaports need to develop considerably in the future. Transparency of data reduces costs, facilitates real-time tracking of containers (value-added services) and business transactions, attracts new business opportunities, and enhances supply chain agility to accommodate dynamic environments.

6.7.4 Investment

Seaports by their operating nature are regarded as capital-intensive due to their infrastructure requiring continuous maintenance (Notteboom, Pallis, and Rodrigue, 2022). Investment by a seaport is calculated as - CAPEX expenditure/month. It is defined as an investment by the seaport to purchase or upgrade fixed, physical, or non-consumable assets. A CAPEX expenditure is predominantly a one-time investment in non-consumable assets, utilised to maintain operational performance, increase the scope of the operation, and to enhance future growth (investment in new technologies).

6.7.5 Seaport Governance

There are five main seaport management models that are underpinned by the responsibility of the public and private sectors. They consist of public service seaport, tool seaport, landlord seaport, corporatised seaport, and private service seaport (Rodrigue, 2020).

The seaport authority of a public service seaport undertakes a range of seaport-related services and owns all the infrastructure. A public service seaport usually consists of a government ministry and the majority of its employees are civil servants. Some ancillary services are undertaken by private companies. Due to operational inefficiencies, the number of public service seaports has declined (Rodrigue, 2020).

The tool seaport model operates a similar management model of a public service seaport. It differs only in the private handling of its cargo operations. The seaport authority still owns the terminal equipment. In many respects, a tool seaport management model represents a transition between a public service seaport and a landlord seaport (Rodrigue, 2020).

The Landlord seaport model represents the most common form of management model. The infrastructure and terminals are leased to a private company and the seaport authority retains ownership of the terminal. The most commonly applied lease is a concession agreement whereby a private company is granted a long-term lease in exchange for a rental payment. The rental payment is derived from the size of the terminal as well as the investment required to construct, upgrade, or expand the terminal operation. The private company is subsequently responsible for the provision of terminal equipment and maintaining performance levels (Rodrigue, 2020).

Under the structure of a corporatised model, the seaport has been almost entirely privatised. However, the ownership remains public, often in the form of a majority shareholder. The seaport authority functions like a private enterprise. This structure is unique as the functions of ownership and control are separated (Rodrigue, 2020).

The private service seaport model represents a complete privatisation of the seaport facility and mandates a retention of their maritime role. The vast majority of seaport functions are under private control, with the public sector retaining regulatory jurisdiction. Public entities may be regarded as shareholders who implement policies that are deemed to be of public interest (Rodrigue, 2020).

6.7.6 Seaport Geography

The geography of a seaport is derived from its site and situation. The site relates to the physical (oceanographic) characteristics, such as bay, access channel, and depth (Rodrigue, 2020). A geographical definition of a seaport relates to the specificity of location, not in relation to the functions undertaken, but in relation to the rest of the earth’s surface (Hlali and Hammami, 2017). Under this context, a seaport operation is subsequently defined as contact between two organised spaces for the transport of goods and passengers. The two spaces are land and sea, with the third being the seaport that ensures the organised logistical functions (Hlali and Hammami, 2017). These physical characteristics require continuous monitoring and dredging operations to ensure that the seaport adheres to KPI targets and service level agreements. The situation is determined by its proximity to major hinterland markets, which fluctuate in response to the type of commodity, seasonality, business cycle, technological development, and the introduction of new legislation (Notteboom, Pallis, and Rodrigue, 2022).

6.8 Continuous Improvement

The EDMT has adopted the continuous improvement methodology that is inherent in traditional VSM techniques. Kaizen is a Japanese term for continuous improvement and implements process change for the better and relates to both large and small incremental changes. It is also considered as a philosophy that strives for operational perfection, eliminating all waste that incurs cost without adding value to the product or service. The continuous improvement methodology is underpinned by the EDMTs by a repeated mapping process that is subject to insights identified previously and the strategies implemented to achieve an ideal future operating state.

6.9 Insights & Summary

It has become apparent in the literature reviews and the semi-structured interviews that VSM tools are suitable for adaptation to map the current and future state of Industry 4.0 technological implementation and application. This will assist seaport managers in the formulation of strategic master plans that forecast longitudinal investment and innovation, subject to economic and geographical infrastructure constraints. One of the most significant barriers to the adoption of Industry 4.0 in the seaport sector is the apparent lack of clarity in regard to understanding their current position. This chapter suggests a range of tools that provide qualitative answers to a seaport's current position and future strategy that is underpinned by a clear implementation plan (See Section 6.2 Empirical Decision-Making Support Structure. In Chapter Seven (Case Studies Virginia Seaport Authority and the Northwest Seaport Alliance) the EDMT tool set has been presented to the Virginia Seaport Authority and the North-West Seaport Alliance to demonstrate flexibility in underpinning empirical decision–support, within a current and ideal state of Industry 4.0 readiness.

CHAPTER 7: CASE STUDIES: VIRGINIA SEAPORT AUTHORITY AND THE NORTHWEST SEAPORT ALLIANCE

7.0 Introduction

In this Chapter, the backgrounds of the Virginia Seaport Authority and the North-West Seaport Alliance operations are discussed in regard to its governance structure, financial performance, infrastructure, market, and perception of their Industry 4.0 readiness. The Seaport Authority of Virginia regards its operation as state-of-the-art, and it is now pursuing research into over-the-road autonomous vehicles. However, the North-West Seaport Alliance regards its operation as lagging behind the leading advocates of Industry 4.0 in the seaport sector. The collection and delivery of containers is dependent on a high volume of small-scale third-party logistics providers, who are resistant to the implementation of Industry 4.0 technologies due to the high start-up costs. A comparison of the Seaport Authority of Virginia and the North-West Seaport Alliance's current operating infrastructure is presented in Table 33.

__Table 33:__ Comparison of the Seaport Authority of Virginia and the North-West Seaport Alliance

North-West Seaport Alliance	Seattle	Deepwater	1,428,567 TEU	Container Terminals T-5 179 Acres Berthing 2,900 ft T-18 196 Acres Berthing 4,400 ft T-30 71 Acres Berthing 2,685 ft T-46 88 Acres Berthing 2,930 ft. T-115 96 Acres Berthing 1,600 ft	Public Municipal Corporation	Limited system integration between supply chain partners due to size and financial constraints
	Tacoma	Deepwater	1,315,827 TEU	East Sitcum 36 Acres Berthing 900 ft. West Sitcum 135 Acres Berthing 2,200 ft. Husky 124 Acres Berthing 900 ft. PCT 184 Acres Berthing 2,087 ft, WUT 150 Acres Berthing 2,600 ft. TOTE 52 Acres Berthing 40 ft		
Seaport Authority of Virginia	Virginia	Deepwater	1,284,567 TEU	Newport News Marine Terminals 165 Acres 3,480 ft Break Bulk - RoRo	Public owned by the Commonwealth of Virginia	State-of-the-art – Continuous upgrading of smart

				Norfolk International Terminals 567 Acres Berthing 6,630 ft. Portsmouth Marine Terminal 287 Acres Berthing 3,540 ft multi-cargo handling. Virginia International Gateway 567 Acres Berthing 4,000 ft Semi-Automated Container Terminal		technology – developing new over-the-road transportation network

The process walk-through was invaluable as it facilitated an opportunity to refine the EDMT's functionality to suit the individual needs of the contrasting operations. The following EDMTs were discussed with the Seaport Authority of Virginia: Process Flow Map, Supply Chain Data Matrix, Decision Point Analysis, and Key Characteristics Map. Due to the North-West Seaport Alliance's time constraints, only the Supply Chain Data Matrix was discussed.

This chapter reviews their feedback on the structure and application of the EDMTs, it was subsequently incorporated into the redesign of the approach, increasing the tool's relevance to their routine operations. The research collaboration involved a separate presentation to each seaport that described the purpose and rationale of each step, and the participants were encouraged to make comments that underpinned their experience and knowledge within their organisation and the wider seaport sector. To allow for a period of reflection they were also requested to view the tools after the presentation had concluded. It was envisioned that this would reduce the influence of researcher bias on the participants, enhancing the refinement of the EDMTs subject to real-world operations, rather than just a theoretical/academic exercise.

7.1 The Justification for the Selection of the Seaport of Virginia and the North-West Seaport Alliance

Section 5.3 (Chapter Five) provides background information in terms of geographical location, financial investment, State and Federal support, the operational justification for Industry 4.0 embedded technologies, and market orientation of the Seaport Authority of Virginia and the North-West Seaport Alliance who both agreed to participate in the semi-structured interviews, In-depth interviews, and the process walk-through. Both seaports also play a key role in stimulating US economic growth in terms of TEU and freight handling and are ranked in the top ten in terms of TEU and general cargo throughput. This is presented in the rankings of the top ten US seaports in Table 34.

Table 34: *The Top Ten US Seaports – TEU (2023)*

Amended from Thomas (2023)

Seaport	Year	TEU	Tons of Freight
Seaport of Los Angeles California	1907	9.91 million	63 million
Seaport of New York and New Jersey	1921	9.49 million	136 million
Seaport of California Long Beach	1911	9.13 million	80 million
Seaport of Savannah Georgia	1744	5.89 million	41 million
Seaport of Houston Texas	1914	3.97 million	288 million
The Seaport of Virginia	1981	3.70 million	61 million
North-West Seaport Alliance Washington	Seattle 1911 Tacoma 1918	3.38 million	22 million Seattle 21 million Tacoma
Seaport of Charleston South Carolina	1670	2.79 million	24.5 million
Seaport of Oakland California	1927	2.79 million	19.3 million
Seaport of Jacksonville Florida	1963	1.29 million	18 million

This assists in explaining their current perception of their Industry 4.0 readiness and the driving factors behind strategic policies for future process improvement, driven by economies of scale that are underpinned by increased customer demand and infrastructure space limitations.

7.2 The Seaport Authority of Virginia

The Seaport Authority of Virginia operates as both the owner and operator. It works with a diverse range of customers as presented in Table 35 who ship cargo through the seaport facilities, ocean carriers, importers and exporters, and international freight forwarders. Other customers and partners include supply chain companies in the road haulage, railway, inland waterway, and warehouse sectors.

Table 35: *Customers of the Seaport Authority of Virginia (2018-2022)*

Adapted from The Seaport Authority of Virginia 2018-2020 Executive Progress Report

Customer/User-Defined Groups	Number Served Annually	Potential Number of Annual Customers
Shipping Lines	23	23
Importers/ Exporters	10,000	90,000
International Freight Forwarders/ Custom House Brokers	700	1,000
Consumers (General Public/ US Population)	70,000,000	150,000,000
State Agency (Federal/ State)	20	20
Members of Maritime Community	10	10
Foreign Market Consumers (Billion)	8	9

The operation is regarded as a state-of-the-art terminal in terms of investment in automation. The Seaport Authority of Virginia is currently undertaking a four-year project to implement autonomous over-the-road vehicles (driverless trucks) at a cost of $5 million. The underpinning concept of the seaport's innovative projects relates to adding value to their customers, with payback scales not at the forefront of the initial investment. This is partly due to the significant investment that the seaport authority has received from the Commonwealth of Virginia and the US Federal Government to modernise their infrastructure. Recently, the Commonwealth of Virginia pledged $800 million to renovate, modernise, and expand the existing infrastructure. This investment also delivered significant economic benefits, most noticeable was the creation of employment opportunities. The metric that assisted in employment creation was GDP and it was estimated that the seaport operation contributed $34 billion to the economy. In many respects, this investment had a dual purpose as Virginia is deemed as a right-to-work state, whereby a person’s right to work shall not be denied or abridged on account of membership or non-membership in any labour union or labour organisation. Therefore, the seaport authority focused its investment on automated container handling processes, to increase capacity rather than reducing employment. This would also increase market competition with the two nearby East Coast seaports in Philadelphia and New York.

In addition to the significant investment, the seaport in Virginia has the following geographical competitive advantages. Virginia is a mid-Atlantic seaport that is located only 2.5 hours away from the open sea. The Seaport has an extensive infrastructure that consists of:

- 6 Terminals able to process over 4,000,000 containers on an annual basis
  Norfolk International Terminal (NIT)
  Portsmouth Marine Terminal (PMT)
  Virginia Inland Port (VIP)
  Virginia International Gateway (VIG)
  Newport News Marine Terminal (NNMT)
  Richmond Marine Terminal (RMT)
- 1,864 acres
- 19,885 L.F of berths

- Up to 50 deep-water berths
- 30 Miles of dockside rail

7.3 The North-West Seaport Alliance

The North-West Seaport Alliance is a marine cargo operating partnership that operates under the jurisdiction of the Federal Maritime Commission as a seaport development agency. It incorporates the operations of both the Seaport of Seattle and the Seaport of Tacoma. Under the jurisdiction of a seaport development authority, the North-West Seaport Alliance administers containers, breakbulk, and a variety of bulk terminals in Seattle and Tacoma. The North-West Seaport Alliance was established in 2014 to mitigate competition from other local seaports and enhance collaboration between Seattle and Tacoma. The North-West Seaport Alliance views its position in terms of Industry 4.0 implementation as limited due to its position as a landlord seaport authority, without any influence on terminal strategic policies.

The North-West Seaport Alliance is vital to the economic well-being of the region (Pacific Northwest), creating more than 58,000 employment positions, contributing approximately $12.4 billion in business development, producing $4 billion in labour income, and generating $136 billion in state and local taxes. This is also reflected in the growth of the North-West Seaport Alliance which is currently ranked as the fourth-largest container terminal in the US, with over $73 billion in international trade throughput. The North-West Seaport Alliance handled 3.4 million TEUs in 2022 as reflected in Figure 56, a reduction of 9.4% when compared to the 2021 figure of 3.7 million TEUs. Import handling was also adversely affected by high retail inventories, in addition to exports which were impacted by the strong dollar exchange rate, protective trade tariffs, and reduced ship capacity arising from voided sailing schedules.

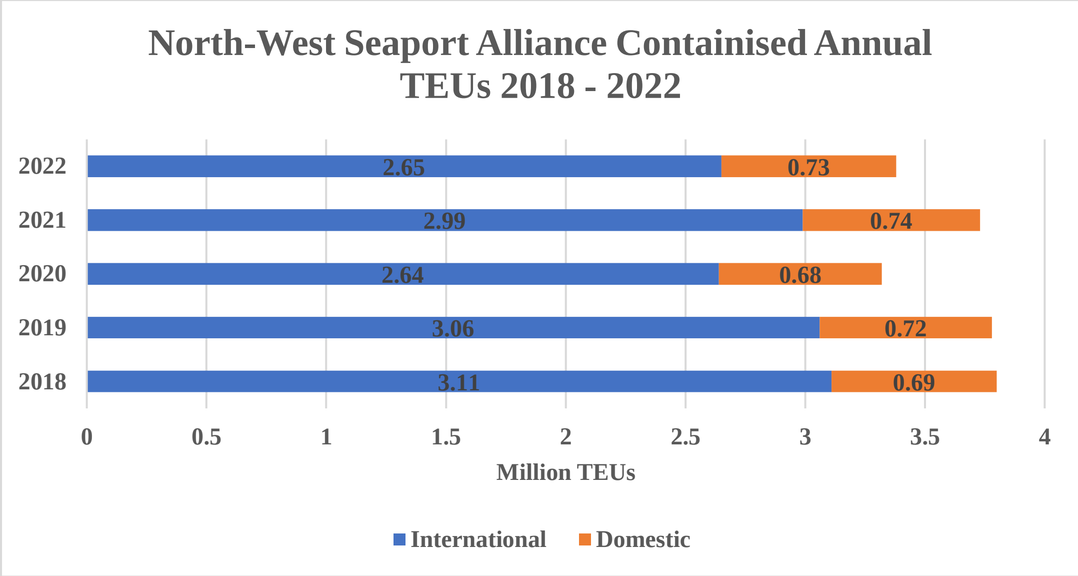


Figure 56: *North-West Seaport Alliance – Containerised Cargo Annual Handling 2018-2022*

Adapted from the North-West Seaport Alliance Trade Report for Seattle and Tacoma

The North-West Seaport Alliance offers a range of bespoke logistical services that focus on the emerging trade markets in Alaska (North-West Seaport Alliance currently has an 80% market share of trade to Alaska) and Asia. Its primary function is to enable a shorter transit between the US and Asia, leveraging sustained penetration of emerging markets. A weekly regular service is maintained by 17 international carriers who provide services to the developing markets in Asia, Europe, Central and South America, and Oceania.

7.4 The Application of the Empirical Decision-Making Tool (EDMT)

The Virginia Seaport Authority and the North-West Seaport Alliance who had previously participated in the semi-structured and in-depth interviews agreed to review the tools that have been developed in Chapter Six – The Application of the Empirical Decision-Making Tools (EDMTs). To ascertain their professional insight with regards to the tools of the EDMT it was agreed to present them as a draft version, with processes modelled from both the literature review and the series of semi-structured interviews. The processes modelled were based on simplistic logistical operational functions of a seaport, in terms of the physical and informational flow of a container through a seaport.

7.4.1 Process Flow Mapping – Current State

When discussing the development of the Process Flow Mapping tool it was suggested by the Virginia Seaport Authority that it was not intuitive to their experience of processing a container that is entering the terminal. It was recommended that the collection of the container from the warehouse outside of the seaport's jurisdiction should be included, making it more suitable to their operation. In their opinion this revision would benefit a seaport that is dedicated to handling high-value FMCGs and is subsequently dependent on high levels of traceability and visibility. This reflects their operation due to long-term contracts with Amazon and Walmart.

The following revisions have been made in relation to the feedback obtained from the Seaport Authority of Virginia during the process walkthrough who subsequently recommended the following stages as depicted in Figure 57.

1. Contract of Carriage signed between the shipper and line operator.
2. Vessel sharing agreement between the line operator and the ship operator.
3. A Third-Party Logistics provider may be involved to arrange for the goods to be stuffed into a container and transported to the seaport/ container terminal.
4. Issuing of customs clearance and preliminary import customs at the destination country.
5. Transportation of containers from the shipping point of origin to the outbound container yard.
6. On-terminal straddle carrier operation reception, validate, store, plan, and load the appropriate container ship. It was also suggested that the Process Flow Map should intermix the loading and unloading operations of the gantry crane. This function is known as cycling and systematically reduces the empty movements of the gantry crane, enhancing operational productivity and reducing ship turnaround times by approximately 50%. This also enhances berth utilisation and reduces bottlenecks of ships attempting to enter the seaport.
7. Ship transit.

8. Offloading from the ship including the functions of planning, discharge, and movement to storage location in the container yard.
9. Destination customs final clearance.
10. Intermodal transportation to Beneficial Cargo Operator (BCO)/ owner. This stage typically has another layer of systems integration (planning and services) related to moving the container to the 'last mile' in the supply chain.

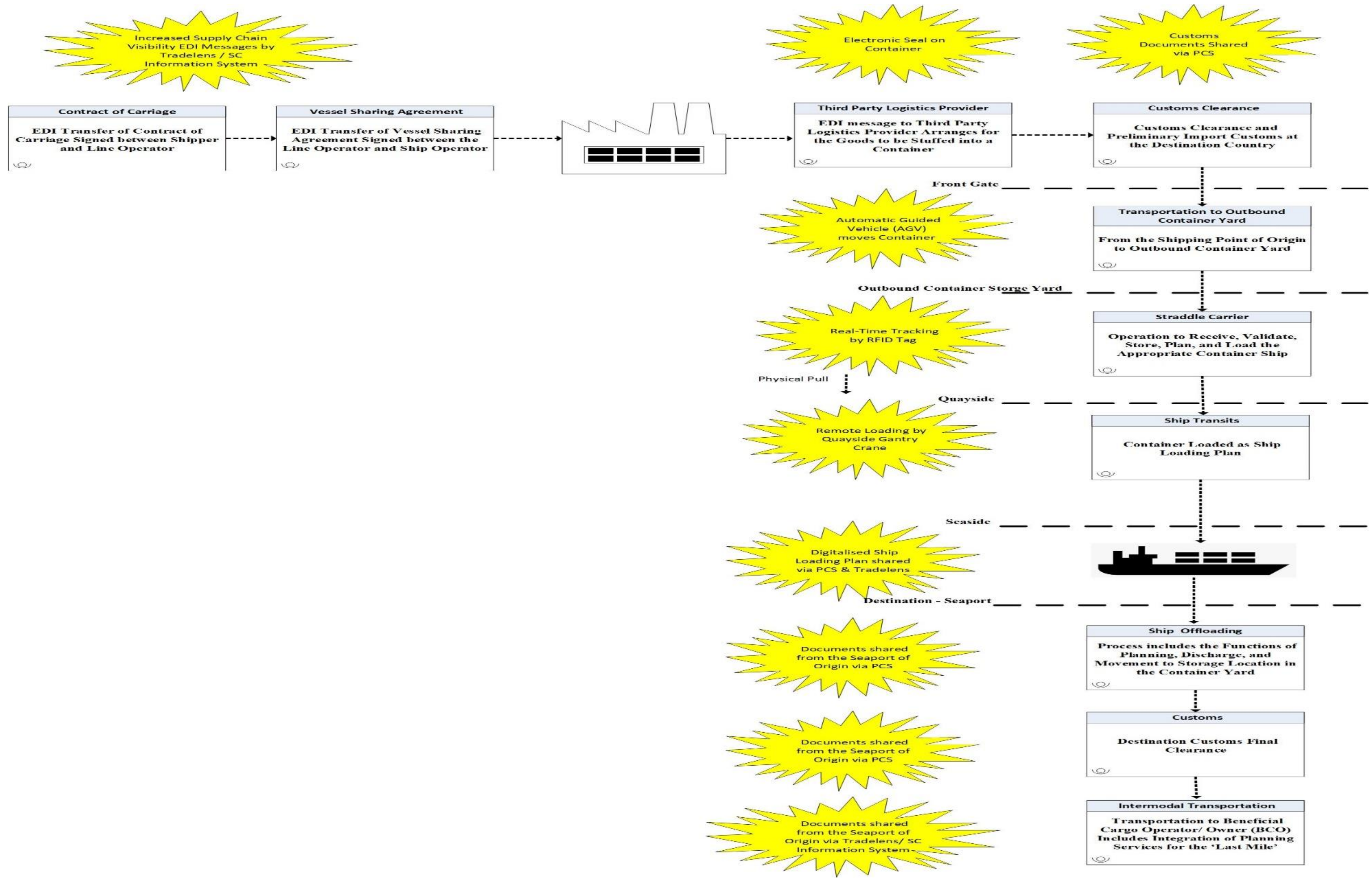


Figure 57: *Revisions Made to the Current State Map*

7.4.2 Process Flow Mapping – Ideal Future State

The formulation of a Process Flow Mapping – Ideal Future State visualisation would benefit the Seaport Authority of Virginia by recommending the following process improvements.

The application of a time stamp when a container passes through a section of the seaport would enhance both the traceability and transparency of the supply chain and simultaneously increase the value of the service provided to the shipper and end-user. This would accommodate the high-value nature of the goods handled by the Seaport Authority of Virginia in the fulfilment of the Walmart and Amazon contracts. The information is suitable to be disseminated to all interested stakeholders by a secure, neutral, and open blockchain portal that records details of cargo shipments as they leave their origin, arrive in seaports, and are shipped overseas. However, there are two barriers that are restricting the sectoral application of supply chain visibility platforms; the slow adoption of digitisation in the maritime sector and a lack of willingness to share data with potential competitors.

7.4.3 Decision Point Mapping

It was established from the literature review (Chapter Two) that the movement of a container is an extremely complex and fragmented operation that involves multiple actors and stakeholders. Therefore, the mapping of the decision points within the supply chain is designed to reduce complexity by enhancing visibility and transparency. This is of fundamental importance when considering the nature of the container, in terms of its value, contractual sensitivity, and whether or not it is classified as a dangerous good.

It was recommended by the Seaport Authority of Virginia that the function of the PCS needs further clarification when mapping the multitude of decision points (Chapter Six Figure 53). It would be beneficial to larger seaports who operate more fragmented operations, are a member of a PCS, and are seeking to facilitate a more integrated approach to Supply Chain Management.

This recommendation was applied to the following revision which is depicted in

Figure 58, where the functions of the PCS and the Tradelens/ supply chain visibility platform have been separated in their operational scope. The PCS would facilitate secure access to the informational flow of the container in the form of customs declarations and payment of duties and taxes to external partners, in addition to the dissemination of KPI metrics to internal stakeholders.

The supply chain visibility platform would increase the scope of the Process Flow Mapping tool allowing shippers and end-users to access the following information that had been previously disseminated by the PCS to its members, booking of containers or space for general cargo, monitoring of containers (e-seal status, temperature, location, duration, humidity, and motion), manifest submission, and monitoring of ship sailing schedules (ship position, arrival, and departure times). This would also resemble a Single Window platform that would standardise the data at a single point of entry to disseminate data, enhancing system integration as the data is instantly visible.

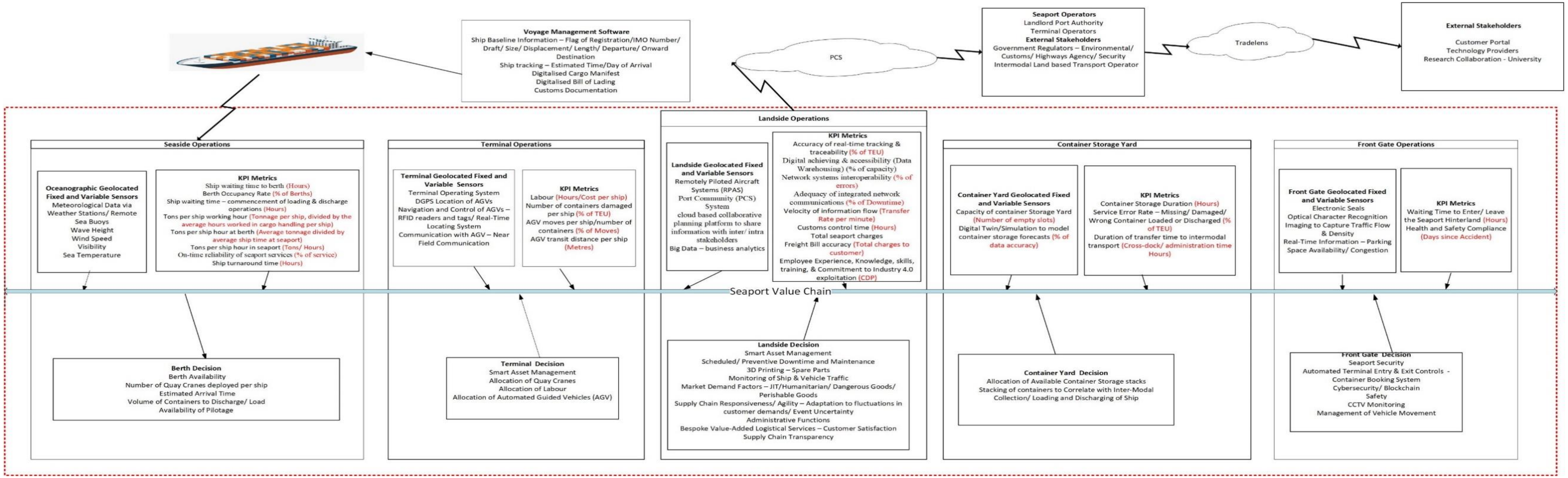


Figure 58: *Mapping Seaport Decision Points*

7.4.4 Supply Chain Data Matrix

The Industry 4.0 era facilitates a method to enhance the current levels of supply chain visibility and transparency. These concepts are regarded in the literature review (Chapter Two) as highly desirable when shippers select a seaport to handle their consignment. The utilisation of the Supply Chain Data Matrix is suitable for dissemination through the Tradelens supply chain visibility platform as it would clearly display the real-time position of a consignment in the seaport complex, as depicted in Figure 59. In addition to a continuous monitoring of the internal structure of the container that detects the tampering of the electronic security seal, door intrusion, and route deviation that populate actionable intelligence alerts for the TOS and PCS systems via email or SMS text messages. It was advocated by the Seaport Authority of Virginia that this enhanced level of holistic supply chain resilience, visibility and transparency would be ideally suited to the operational needs of their key customers Walmart and Amazon who frequently ship high-value containers. It was remarked by the Seaport Authority of Virginia that enhanced levels of real-time monitoring would potentially leverage a reduction in insurance premiums for shippers and subsequently a sustained competitive advantage for the seaport. This infers that the Supply Chain Data Matrix would benefit seaports who are engaged in the handling of value-high FMGC cargo.

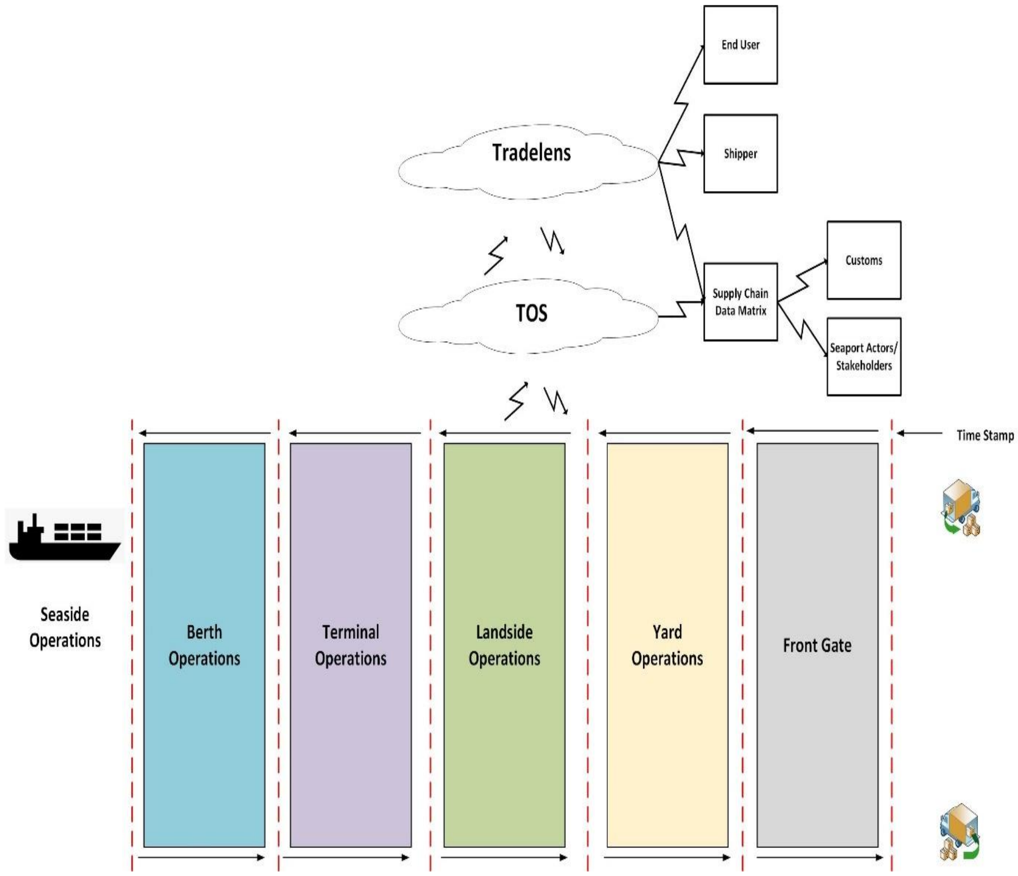


Figure 59: *Mapping the Time Gates for the Supply Chain Data Matrix*

Containers that exceed the KPI target in terms of duration will be mapped in relation to their location within the seaport supply chain; Seaside Operations, Terminal Operations, Landside Operations, Yard Operations, and Front Gate as depicted in Figure 60. This will instigate further investigation by the operator who will extract the data set from RFID readers for that particular container, in terms of arrival time and departure time, on-ward destination, customer details, contents of the container, customs documentation status, and a holistic status of the shipment.

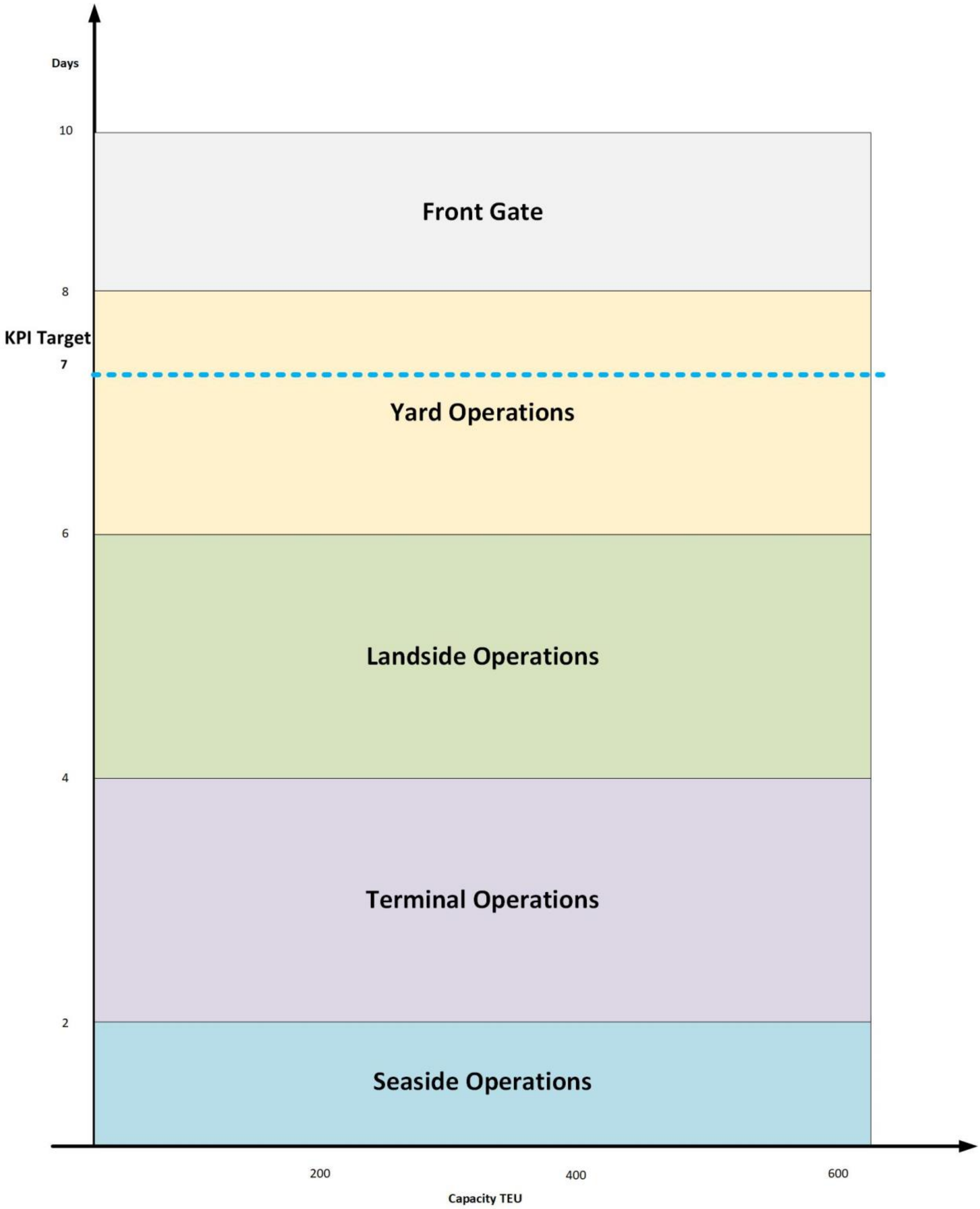


Figure 60: *The Supply Chain Data Matrix*

RFID technology deployed at focal locations in the seaport as depicted in Figure 60 will facilitate the dissemination of the container flow within the supply chain. This system is ideally suited to function in harsh environments, where nonconductive materials are prevalent.

The Supply Chain Data Matrix consists of a reader or antenna that is securely housed in the ground preventing damage arising from acts of vandalism, accidental collision, weather, and seawater penetration. It is envisioned that the RFID tags are active offering an increased range of transmission, allowing for its utilisation in larger seaport operations. Active tags also have an adequate memory capacity to store the relevant data sets that are underpinned by encrypted Blockchain technology, preventing the unauthorised reading of the RFID tags by regulating access in the PCS and the Tradelens/ supply chain visibility platform. Active tags are also able to accommodate a variety of sensors; Global Positioning Systems (GPS), satellite communications, temperature and humidity, and smart container e-seals that systematically record locking and unlocking actions. This is depicted in Table 36 which has been populated with dummy data.   This will reduce the operational necessity of physically checking the security of the container, increasing the flow of containers through the seaport complex and limiting performance bottlenecks. The impact of performance bottlenecks may be accelerated if the surrounding road network is shared with the local community. This issue is currently driving the North-West Seaport Alliance to modernise its ageing infrastructure to meet current and future throughput forecasts. This is particularly relevant to Front Gate operations when RFID tags attached to the windscreen of the Third-Party Logistics Provider trucks automatically transmit the release number which activates the automatic front gate.

The Supply Chain Data Matrix aims to facilitate more efficient and effective management of existing infrastructure by enhancing container throughput, optimising container storage capacity, and reducing road network congestion, and vehicle emissions. This offers a commercially viable alternative to infrastructure expansion which in turn will require the purchase of additional land and may potentially result in environmental objections raised by the local community. This scenario is of relevance to the North-West Seaport Alliance which is restricted in its infrastructure capacity as they share the surrounding road network with the local community. The selection of the EDMT will facilitate seaport management with an opportunity to visualise a particular aspect of their operation that is measured subject to the KPI metrics. This facilitates the identification of improvements in the current operation that are underpinned by both short- and long-term investments in Industry 4.0 embedded technologies.

Table 36: *Dummy Data for a Tradelens Supply Chain Visibility Platform*

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">RFID Battery Status</th><th rowspan="2">Time In</th><th rowspan="2">Time Out</th><th rowspan="2">Date</th><th colspan="2">Smart eSeal</th><th rowspan="2">Container Temperature & Humidity</th><th rowspan="2">Documents Disseminated by PCS & Tradelens</th></tr>
<tr><th>Time Open</th><th>Time Closed</th></tr>
<tr><td>Seaside Operations</td><td>80%</td><td>03:00</td><td>04:15</td><td>08/05/2022</td><td colspan="2">Seal Identification Number
Seal Intact</td><td>9 °C</td><td>Packing List
Bill of Lading</td></tr>
<tr><td rowspan="2">Terminal Operations</td><td rowspan="2">70%</td><td rowspan="2">04:20</td><td rowspan="2">05:18</td><td rowspan="2">08/05/2022</td><td colspan="2">Seal Open</td><td rowspan="2">11°C</td><td rowspan="2">Destination Customs Final Clearance</td></tr>
<tr><td>04:45</td><td>04:52</td></tr>
<tr><td rowspan="2">Landside Operations</td><td rowspan="2">85%</td><td rowspan="2">05:24</td><td rowspan="2">06:10</td><td rowspan="2">08/05/2022</td><td colspan="2">Seal Open</td><td>11°C</td><td>Invoice Raised</td></tr>
<tr><td>05:34</td><td>06:07</td><td>12°C</td><td>Release documentation complied</td></tr>
</table>

<table>
<tr><td colspan="2">Yard & Container Storage Operations</td><td rowspan="2">78%</td><td>06:15</td><td>23:45</td><td rowspan="2">09/05/2022</td><td colspan="2" rowspan="2">Seal Intact</td><td rowspan="2">13°C</td><td rowspan="2">Appointment made by Third-Party Logistics Provider – Encrypted release number issued via PCS</td></tr>
<tr><td>Stack Number</td><td>Position</td><td>3</td><td>14</td></tr>
<tr><td colspan="2" rowspan="2">Front Gate</td><td rowspan="2">91%</td><td rowspan="2">23:55</td><td rowspan="2">00:10</td><td rowspan="2">10/05/2022</td><td colspan="2">Seal Open</td><td>9°C</td><td>Third-Party truck RFID tag transmits encrypted release number that was issued when the appointment was made – Faster acceptance/ release of the container

Final Security Check</td></tr>
<tr><td>23:56</td><td>23:59</td><td>9°C</td><td>Driver submits digital signature</td></tr>
</table>

7.4.5 Key Characteristics Mapping

The Seaport Authority of Virginia recommended that the role of customs clearance should be incorporated into any Key Characteristics Mapping due to its strategic importance in maintaining the flow of inbound and outbound containers. The theoretical Key Characteristics of the Seaport Authority of Virginia are represented in Figure 61.

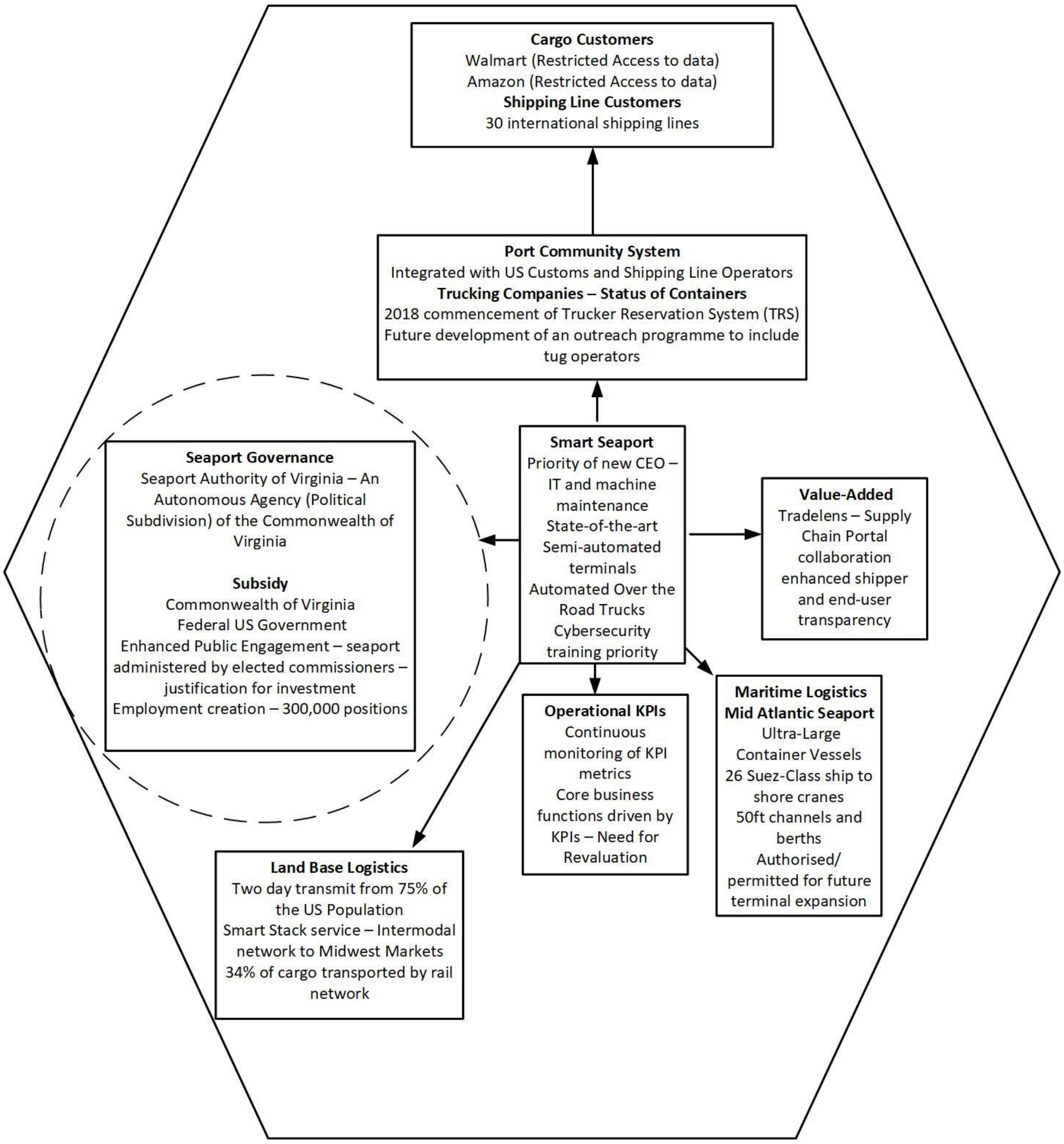


Figure 61: *Mapping the Key Characteristics at the Seaport of Virginia*

The mapping of the Key Characteristics of the Port Authority of Virginia would provide an interesting opportunity to investigate how the governance structure impacted the capability to innovate and implement Industry 4.0 embedded technologies. The Seaport Authority of Virginia receives financial support for capital projects from both the State and Federal Governments to stimulate the local economy and generate employment positions. To accommodate this requirement from the State and Federal Government the Virginia Seaport Authority has focused on the continuation of maximising its container handling capacity, rather than the reduction in employment positions due to the implementation of Industry 4.0 embedded technologies. The Virginia Seaport Authority has a semi-automatic operation that it considers as being state-of-the-art. This sustained competitive advantage is paying dividends with its container handling capacity recording an increase of more than 314,000 TEU in March 2022, an increase of more than 35,000 TEU when compared to March 2021. The Seaport of Virginia is a public entity that comprises of the seaport authority and the terminal operators as depicted in Figure 62 that operates under a not-for-profit business model. It was also determined during the process-walk through that a key characteristics map would be beneficial in monitoring the commencement (start and end date, test score, certification, and failure necessitating a retest) of simulated phishing exercises to test employee's ability to detect phishing emails and potentially malicious attachments. This would enable the operation to continue as originally intended by enhancing employee's skills (employment creation without the need for redundancies) and underpins the lean philosophy of driving continuous improvement strategies forward.

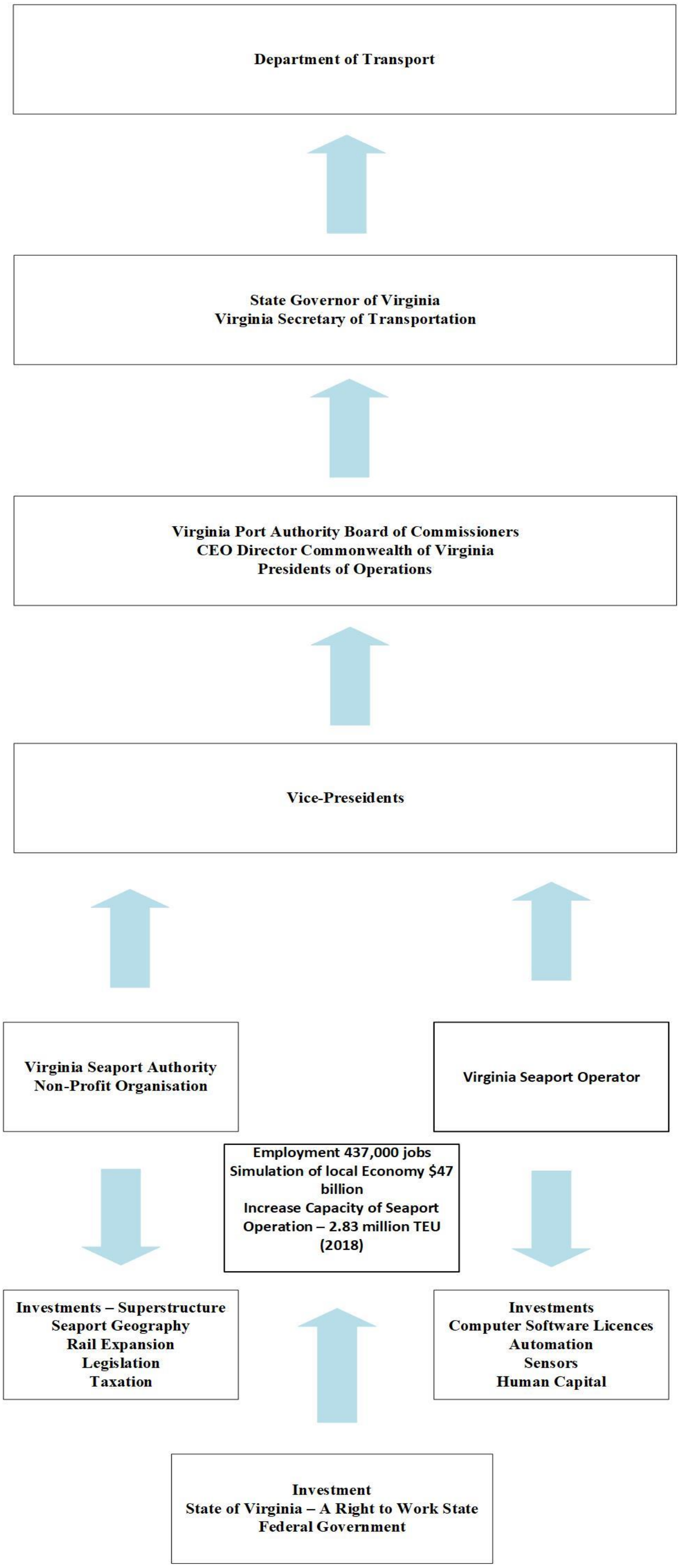


Figure 62: *Mapping the Key Characteristics of the Stakeholders at the Seaport Authority of Virginia*

7.5 The North-West Seaport Alliance and the Empirical Decision-Making Tools (EDMTs)

The North-West Seaport Alliance measures the following KPIs on behalf of their terminal operators as depicted by Table 37, monitoring variables of the rate and capacity per acre. This is fundamental for both the terminal operator to measure their efficiency and the North-West Seaport Alliance which owns the real estate in determining the profitability of that asset and calculating future terminal lease agreements.

Table 37: *KPI Metrics Utilised by the North-West Seaport Alliance*

North-West Seaport Alliance Fundamental KPI Measurements	
KPI Metric	**Action Point**
Average Turnaround Time < 120 Minutes	Average of loading/ unloading process per container ship
Turnaround Time > 120 minutes	If the turnaround time is more than the 120-minute threshold, it requires further investigation to determine the root cause
Dual Transaction	Delivery and collection of a container per intermodal transport
Percentage of Rail to Total Lifts (Dock Rail Activity)	Not front gate activity
Capacity Utilisation	Total TEU capacity compared to actual TEU capacity
Production Utilisation	Maximum lifts compared to actual lifts
Throughput TEU per Acre	Measures terminal efficiency – higher number of containers per acre

7.5.1 Supply Chain Matrix

The North-West Seaport Alliance is provided with KPIs from their terminal operators. This data is initially cleansed and processed by a third-party IT provider in a data lake and then transmitted back to the North-West Seaport Alliance for dissemination on their website. The third-party IT vendor will also cleanse and aggregate the data so that the North-West Seaport Alliance can then populate the data dashboard. The North-West Seaport Alliance does not desire a direct relationship with the terminal operators, due to their status as a public entity, which would require the data to be publicly disclosed.

At present this process lacks the dissemination of real-time data, reducing its value to the North-West Seaport Alliance in monitoring the throughput of their tenants and liaising with smaller third-party intermodal transport operators. To facilitate a real-time option, it is advocated that a Supply Chain Data Matrix as populated with the North-West Seaport Alliances KPI metrics in Figure 63, provides a user-friendly graphical overview of the current status of the operation, facilitating its dissemination to all internal stakeholders via the TOS/ PCS or to external stakeholders via a Tradelens/ supply chain platform. Third-party logistics providers would be able to access this data via a secure supply chain platform to book container collection appointments in relation to the operational status of the terminal, reducing congestion on the surrounding road infrastructure. Road congestion is an issue that the North-West Seaport Alliance is actively seeking to resolve by applying visibility tools as the road infrastructure serves both the seaports and the local community while enhancing terminal efficiency as the workflow would be evenly spread out. The facilities surrounding the seaports were mostly built during the last century and adequately met the activities of the time. However, the amount of container traffic is exponentially larger, and the seaport-centric road network does not have the capacity to handle large volumes of freight traffic, in addition to the traffic from the surrounding cities. The application of the Supply Chain Data Matrix represents a shift from passive to active management that is underpinned by real-time data that identifies potential bottlenecks within the seaport at fundamental locations, such as the Front Gate.

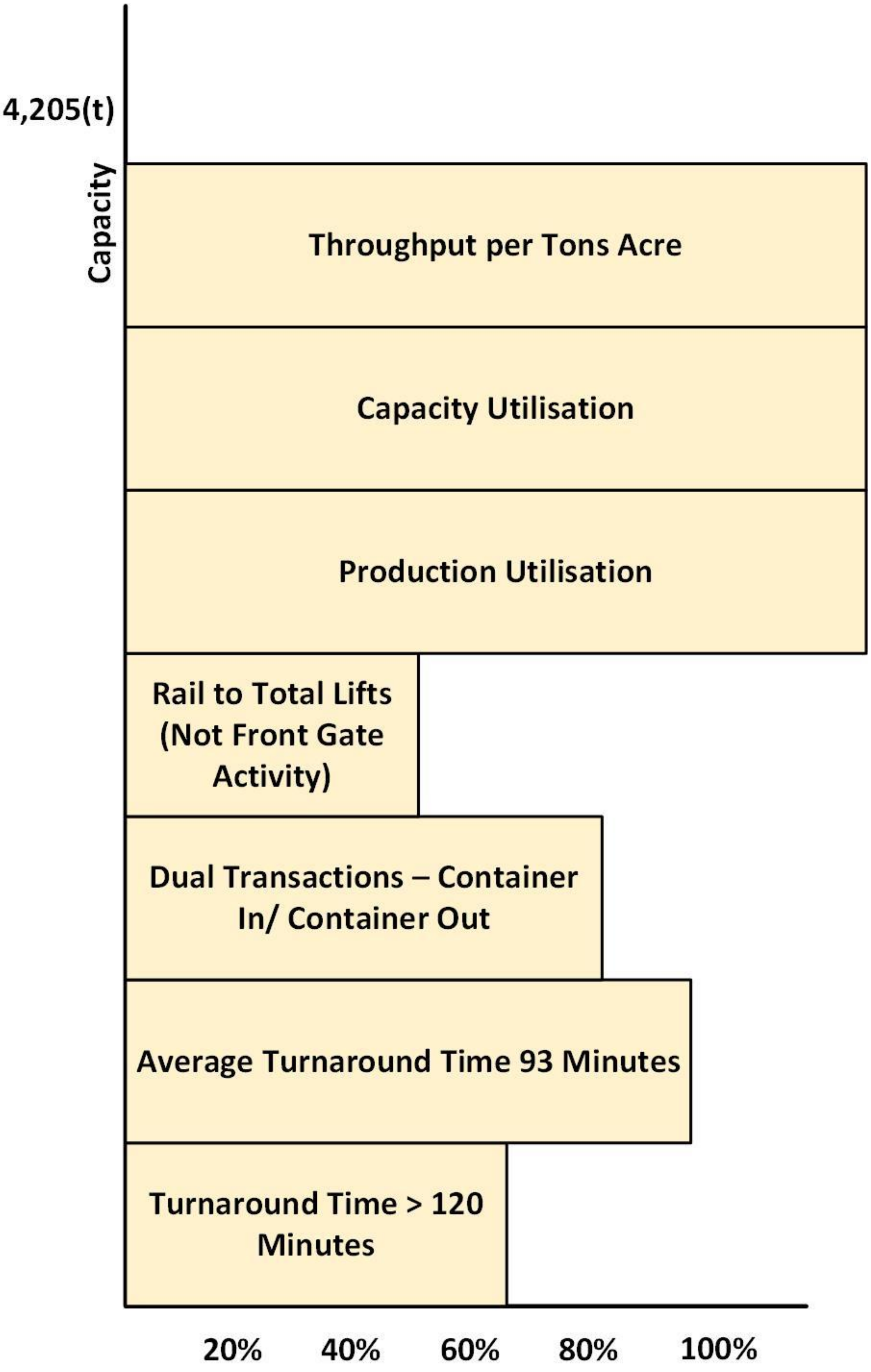


Figure 63: *Supply Chain Data Matrix of the North-West Seaport Alliance*

7.5.2 Development of a Supply Chain Visibility Platform at the North-West Seaport Alliance

The North-West Seaport Alliance does not have the infrastructure to support a dedicated PCS. This is partly due to the number of small third-party logistics providers that deliver and collect containers from the storage yard as depicted by Figure 64 and their financial constraints that prevent them from subscribing to PCS software. The advent of the EDMTs would offer a cost-effective solution for small-scale third-party logistics providers as they could access the insights populated by the EDMTs, from secure Blockchain-enabled supply chain visibility platforms that are updated in real-time. This would mitigate the need for data processing by IT service providers.

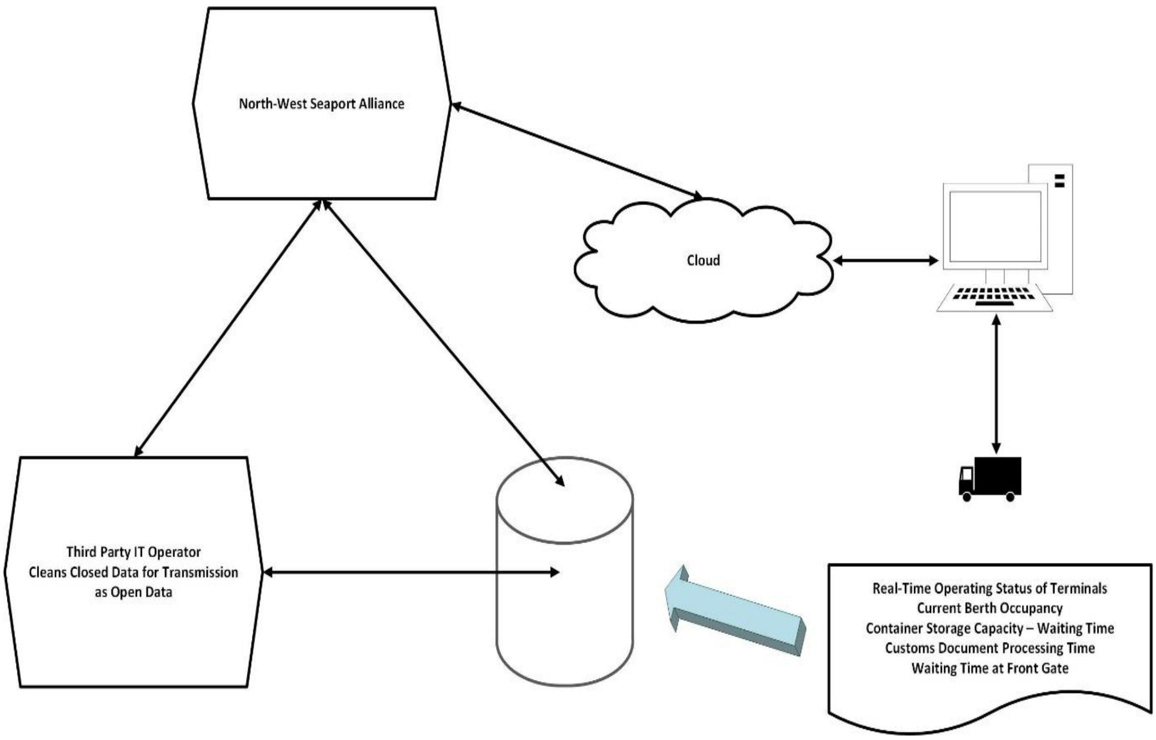


Figure 64: *Data Sharing Network of the North-West Seaport Alliance*

7.6 Insights & Summary

The opportunity to present the draft versions of the EDMTs was invaluable to the successful completion of this PhD research project and the continued evolution of the mapping technique. However, there is still a need to engage in a practical mapping exercise at a variety of seaport operations, to future refine the EDMT technique and ensure its relevance to visualise opportunities for Industry 4.0 implementation of the application in an ideal future state scenario. In terms of the Process Activity Mapping Tool, the sequencing of the processes of container loading and unloading was revised to resemble their actual operation, enhancing its relevance to map their current state operation and visualise opportunities for an ideal future state that is underpinned by continuous process improvement. The understanding of the functions of the PCS in disseminating customs information and KPI monitoring to internal and external stakeholders was extremely beneficial. This facilitated the widening of the scope of dissemination to external shippers, supply chain partners, and end-users by populating a secure supply chain visibility platform with real-time insights from the EDMTs. The integration of internal and external supply chain partners would mitigate the fragmentation and lack of data sharing that limits logistical process efficiency and system interoperability. In Chapter Eight the PhD project is discussed in relation to the findings of the research to the objectives posed in Chapter One and its contribution to the literature.

CHAPTER 8: DISCUSSION

8.0 Introduction

This chapter discusses the findings of the research in relation to the objectives detailed in Chapter One and how they contribute to the literature. The barriers to digitalised seaports are discussed in relation to how the findings of the research relate to the current position of the literature. The development of the EDMTs facilitates seaport operators with a systematic understanding of their current operating position with regard to the requirements of the Industry 4.0 paradigm. The drafting of an implementation plan will provide seaport managers with a clear roadmap to leverage their ideal future state that is underpinned by the Lean Management concept of continuous process improvement. A roadmap to leverage an ideal future state is presented by the Empirical Decision-Making Structure that is designed to mitigate the scepticism surrounding the Industry 4.0 paradigm and its relevance to seaport operations. The views of the workforce should be reflected in the ideal future state visualisation. The potential impact of new innovations and technologies is realised by the development of an ideal future state map which depicts a representation of their integration into the operation, based on the pillars of Industry 4.0 that were addressed in Chapter Three. The roadmap to a digitised seaport has been quantified by the development of the Empirical Decision-Making Support Structure that was delineated in Chapter Six. This structure was adapted to present current and future state visualisations of integrated Industry 4.0 technologies, underpinned by the robust VSM method that has been extensively applied to a variety of sectors, identifying waste and non-value-adding activities in a value chain.

The development of the EDMTs was delineated in Chapter Six and the subsequent revisions and insight from the Seaport Authority of Virginia and the North-West Seaport Alliance was incorporated into Chapter Seven. The EDMTs consist of the following tools: Process Flow Mapping, Supply Chain Data Matrix, Decision Point Analysis, and Accuracy Completeness Amplification Mapping. These tools are designed to capture the physical movement of a container through the supply chain, in addition to the flow of information. The last tool is Key Characteristics Mapping, and it captures the features of a system that allow it to perform as it was originally intended.

8.1 Barriers to Digitalised Seaports

The static nature of the VSM method is regarded as a snapshot in time of a process. This is considered as a fundamental limitation of the VSM method when mapping dynamic and time seaport environments. To mitigate this limitation, it is proposed that the EDMTs are populated with real-time data that is captured by sensors which is determined in the literature as representing a characteristic of the Industry 4.0 paradigm in terms of decentralised integration and Cyber-Physical Systems (Gattullo et al., 2019).

Seaports vary in their size, operation, market orientation, physical characteristics (water depth, access channel, and available land for redevelopment), and their digitalisation strategies are subsequently constrained by economies of scale in terms of resources and financial investment, personnel skill attributes, and a smaller number of employees per department. This supports the literature which concludes that larger seaports are more engaged in developmental programmes, collaborative research, and innovation initiatives (Brunila et al., 2019). It is further advocated in the literature that only the largest seaports are actively engaged in the implementation of digitalisation that produces specific solutions for situational awareness and scheduling (Inkinen, Helminen, and Saarikoski, 2021). This was reflected in the findings by the lack of a dedicated PCS in Ireland due to an insufficient cargo throughput volume to justify its start-up and running costs. It was argued by the Seaport Authority of Freemantle that the sector will benefit from lagging behind in terms of Industry 4.0 as it will learn from the mistakes made and employ what has worked well, subject to its operational relevance and risk appetite. The introduction of a culture that tolerates both practice and preparation is required to familiarise employees with the needs of the operation. Once the levels of Industry 4.0 knowledge, skills, and experience have sufficiently increased it will drive up the maturity level. However, this process is considered to be a slow-paced undertaking. It is argued by Heikkilä, Saarni, and Saurama (2022) that seaports anticipate a similar adoption of new technologies and new business models that are underpinned by the impact of Industry 4.0 in other sectors.

The issues concerning the relevance of Industry 4.0 embedded technologies to exploit sustained competitive advantages were a constant theme from the semi-structured interviews. A number of seaports recalled examples where they had been contacted by consultants in regard to technological solutions that provided solutions to issues that were not their responsibility and therefore of limited operational relevance. This is partially reflected in the literature which indicates that the exploitation of Industry 4.0 in the seaport sector is still in its early stages and the implementation has been less than proactive (Vanelslander et al., 2019). One of the main barriers to sectoral maritime digitalisation is the perception that it would include high implementation costs (Tijan et al., 2021). The application of the EDMTs would attempt to address this issue by its universal appeal to SMEs and global seaport operators due to its reduced cost, requiring only consultation and training of the seaport digitalisation projects staff. The fundamental driver of digitalisation by the EDMTs is the capacity to map and identify aspects of the current state processes. Another advantage of the EDMTs is its role in enhancing the sector's awareness and understanding of how Industry 4.0 embedded technologies and process digitalisation can enhance supply chain efficiency, effectiveness, agility, transparency, and visibility amongst external and internal stakeholders.

Industry 4.0 is regarded as a disruptive technology by the literature that constitutes a considerable change to the processes and roles of individual employees in the seaport. The significance of the issues concerning resistance to change mentalities within seaport operations generated the highest reference indicator of 61 (Appendix Six NVivo Code Casebook) within the semi-structured interviews. It is argued by Sarkar and Shankar (2021) that power and its redistribution based on process changes will play a decisive role in motivating seaport employees. It is possible that incentives (financial or career development) for employees to assist in mitigating the issues brought about by process disruption may potentially reduce time increases, corruption, agency problems, insecurity between economic agents, wastage, employee resistance to change, and cybersecurity risks (Sarkar and Shankar, 2021).

The engagement of all interested stakeholders in the EDMT process from its very inception (Organisational Priorisation Workshop) is fundamental to establishing shared ownership of the EDMTs project aims and objectives. The approach undertaken by the Seaport Authority of Virginia and the New York and New Jersey Seaport Authority is to offer incentives to their employees in the form of upskilling and retraining, eliminating the need for compulsory redundancies and the prolonging of careers by reducing health and safety risks, and the need to work outside in adverse weather conditions. The EDMTs would allow seaports to determine their current and identify opportunities for the application of new sensor technologies (RFID tags) that underpins an opportunity to learn how to operate and maintain its functionalities This also aligns with the interests of the US labour unions (disclosed during the collaboration with the US Seaports) which are concerned with safeguarding employment positions and the Federal and State Governments which seek to facilitate employment creation opportunities that stimulate economic growth.

Smaller seaports regard a lack of comprehensive training and domain expertise as a significant barrier to Industry 4.0 exploitation (Sarkar and Shankar, 2021). To learn additional skills and competencies takes time and this represents a significant challenge for seaports to allocate scarce resources in terms of cost and staffing levels. The familiarity with the core method of traditional VSM will potentially reduce the length of time required to understand the EDMTs approach, enhancing its relevance to smaller seaport operators who lack adequate staffing levels to cover multiple positions.

The recruitment of a consultant who is familiar with the VSM method represents a suitable alternative for seaports who lack the necessary skills and expertise. Initially, this could be a one-time engagement, subject to training of existing staff that allows them to learn and conduct the core business functions of the seaport. A consultant from outside the organisation may provide a different perspective, preventing the seaport from becoming too insular in its strategy. This approach offers a financial incentive to SME organisations as their employment is usually by a fixed-term contract and lasts for the duration of the project. A dual background in VSM/ Lean Management and maritime logistics would be beneficial to mitigate the disruptive impact of Industry 4.0 implementation. It would also mitigate any potential conflict with existing employees, as a consultant may lack detailed knowledge of in-house and Supply Chain Management procedures. It is also of vital importance that any potential consultant is able to communicate with existing employees who are involved in the mapping project. The collaborative nature is evident in the early stages of the EDMTs structure. When holding the Organisational Priorisation Workshop it is necessary to collaborate with both external and internal stakeholders; seaport authorities, terminals, customers, supply chain partners, local communities, and seaport hinterlands that extend well beyond the supply chain. It is vital to ascertain their opinion of the current level of service, recommendations for improvement, and expectations of an ideal future state. This will align the aims and objectives of the current state mapping exercise. The Pre-Mapping Workshop is also very dependent on communicating the purpose of the direct observational process walk-through, which is fundamentally designed as a learning exercise, allowing management to understand the processes.

The Seaport Authority at Waterford regards that understanding what problems need to be solved in order to get the right technology to solve the problem and the lack of trained personnel are prime concerns for smaller seaports which need to be addressed before the implementation of digitalisation strategies. It is also necessary to unlearn best working practices which underpin a resistance to change mentality within the workforce. Many seaport stakeholders perceive that their functions are rigid in terms of dredging shipping channels, loading and unloading cargos, warehousing of goods disposing of dredging waste, and piloting ships in and out of the seaport.

The unwillingness of external and internal seaport stakeholders to exchange data due to cybersecurity and data ownership concerns has been acknowledged in the semi-structured interviews by the Seaport Authority of Freemantle as a barrier that limits the application of supply chain nodal integration, based on the perception of an unequal distribution of costs and benefits. The implementation of the EDMTs would facilitate a clear understanding of the benefits generated by the data exchange, exemplified by a data-driven real-time monitoring of containerised throughput that is securely accessible by blockchain login portals for PCS and supply chain visibility platform members. This would reduce the time taken by seaport actors, shippers, and end users who require real-time supply chain traceability and visibility, enhancing the added value of the services provided.

The issue of Cybersecurity achieved a reference indicator of 18 (Appendix Six NVivo Code Casebook). This indicator may be viewed in relation to the statements expressed in the semi-structured interviews suggested that seaports are adopting a proactive approach to cybersecurity that is underpinned by regular operating system updates, stronger passwords, secure satellite communications, resilience exercises, secure

(Blockchain) information exchange, and employee awareness training. It is argued by de la Pēna Zarzuelo, Soeane, and Bermúdez (2020) that the human factor is fundamental in mitigating the risk of cyberattacks as it represents the main access point for criminals to target. The lean concept of continuous improvement is underpinned by the concept of regular security measures to mitigate cyberattacks. It is possible to monitor the scheduling of cybersecurity initiatives by utilising the Key Characteristics Map to record when employees require enrolling on training programmes or to update software security certification. This would ultimately ensure that the features of the system would be able to function as they were originally intended to do so.

8.1.1 Current Position

The implementation of Lean Manufacturing tools such as traditional VSM tools are predominately applied to the identification of waste and non-value-adding activities in the value stream. This would be an ideal precursor to the application of EDMTs to then map the supply chain reducing the scenario of a digitalisation process of non-value-adding and wasteful activities. The PhD research contributes to the knowledge that is reflected in the literature by utilising its robust Lean Management methodological approach that has been universally applied to the identification of waste / non-value-adding activities and the simplification of processes in the range of diverse sectors (Meudt, Metternich, and Abele, 2017). The EDMTs are underpinned by the Lean Management approach that introduces a culture of continuous process improvement that is embedded throughout the organisation's management structure. This method encompasses the traditional VSM approach of conducting a process observational walk-through and drafting the current state map and a systematic implementation internal/ external plan that acts as a roadmap to leverage an ideal future state map. The series of semi-structured interviews allowed the researcher to understand the challenges and barriers to the implementation and application of Industry 4.0 embedded technologies. In addition to exploring their current state from the perspectives of limited Industry 4.0 implementation to semi-automated operations.

The need for enhanced visualisations of a seaport's current state operation is apparent when considering the complexity of multifunctional seaport operations that arise from fluctuations in socioeconomic trends. This constitutes both tangible and intangible assets (infrastructure, superstructure, resources, tools, equipment, and intellectual capital) that demand careful tactical and strategic management. The overreliance on visual observations facilitated a very limited scope of the current operating state, limiting the ability to monitor and manage discrete seaport operations (handling of ships, cargo and passengers). This limits the flow of real-time information and the detection of seaport operational issues (reduced crane efficiency) that reduce the likelihood of adhering to KPI targets. Data-driven decision-making can for example assist in real-time monitoring of scarce seaport resources, such as high-value containers, tugs, pilots, and AGVs, mitigating wasteful double handling of containers and unnecessary journeys. The formulation of time-critical decision inputs (Human, Capital, Land, Energy, Asset Management, and Environmental Policy) to mitigate operational issues is also subsequently delayed due to the fragmented (incomplete) information received at a tactical management level. However, seaports at the opposite end of the Industry 4.0 paradigm that operate state-of-the-art terminals that are semi or fully automated are now acting as both informal and formal mentors for seaports, that are embarking on the transition to Industry 4.0 embedded technologies. This may potentially mitigate the risk-averse nature of some seaports that are sceptical about the relevance of Industry 4.0 embedded technologies to improve the efficiency of their current state operations. There are various forms of collaborations that constitute demonstrations of technology/ best practice, research, joint investments, secondment of personnel, training, and qualifications. This would greatly assist a seaport in determining and enhancing its current state readiness and in the formulation of an implementation plan to bridge the gap to the ideal future state. It would allow an SME seaport to derisk the proposed capital investment on the basis of lessons learned from their mentor seaport, learning from what solutions worked well and which did not. The role of mentor is being successfully undertaken by the leading seaport proponents of Industry 4.0 embedded technologies, most noticeable in this field are Rotterdam, Hamburg, and Virginia. An international partnership under the term ChainPORT has been established by the following seaports; Hamburg, Los Angeles, Antwerp, Barcelona, Busan, Felixstowe, Indonesia, Montreal, Panama, Rotterdam, Shanghai, Shenzhen, and Singapore. The main aim of the partnership is the sharing of knowledge and cooperation for the optimal application and investment in smart technologies at seaports. This reflects the findings contained within chapter five that suggest that collaboration between seaports is driven by the strategic utilisation of Industry 4.0 embedded/ smart technologies.

The Industry 4.0 paradigm is still lacking a universal definition in the literature, making it a topical, controversial and common subject. Seaports are considered to be lagging behind and lacking awareness in regard to the exploitation of Industry 4.0 embedded technologies when compared to the manufacturing, automotive, and financial sectors (Heilig and Voβ, 2017a). The semi-structured interviews revealed that the seaport sector is sceptical of the relevance of Industry 4.0 to its core function of container loading and unloading, which has experienced limited process transformations. The proposed EDMT method may allow seaports to benchmark their current position and underpin rational solutions and decisions related to investments in Industry 4.0 embedded technologies.

Many seaport operators are very sceptical of the Industry 4.0 paradigm and its buzzword tag and regard its solutions as lacking in relevance to their operational issues. The implementation of the EDMTs method is designed to address its sectoral scepticism due to its ability to map a diverse range of seaport functions, and identify, and mitigate barriers to Industry 4.0 implementation. Many seaports lack a clear understanding of their current position in regard to the Industry 4.0 paradigm, preventing the formulation of a robust internal and external implementation plan to leverage sustained process improvements (Heilig and Voβ, 2017a). The EDMTs method will facilitate a low-cost solution that determines their Industry 4.0 current state readiness in relation to its core pillars which is achievable by the drafting of an implementation plan to realise an ideal future state.

The EDMTs allow a visualisation of a future state of how changes in one supply chain node will affect other processes downstream, without the physical disruption of implementing unsuitable solutions to dynamic and time-critical operations. It is concluded that the exploitation of the Industry 4.0 paradigm in the seaport sector is not linear in terms of implementation and application due to investment constraints (payback times), skills, experience, knowledge base constraints, lack of managerial support, infrastructure constraints, and relevance to improve existing operations.

8.1.2 Future State

The application of simulation and modelling techniques would enable the refinement of the future state map and corroborate process improvements. This would mitigate the concerns of senior management relating to the relevance of Industry 4.0 embedded technologies to leverage beneficial process improvements. The ideal future map is a representation that facilitates an opportunity for the seaport management to visualise the strategic direction for their implementation plans without any impact on their routine logistical services. It also enabled a degree of flexibility with regard to the final strategic output of the EDMT continuous structure from the current state to the ideal future state. The dynamic structure of the EDMTs will mitigate the limitations of the traditional VSM method in mapping dynamic environments as it will reflect the evolution and impacts of processes over time. This will also provide the management team with a point of reference to revisit a previous current state visualisation and revert to its structure if it is viewed as providing a more efficient and effective solution. The EDMTs facilitate the opportunity to visualise the physical and informational flow within the supply chain in its entirety, in addition to focusing on specific processes to determine specific, targeted improvements that have been identified from KPI metrics or stakeholder feedback.

8.1.3 Roadmap

The development of a detailed roadmap to bridge current state operations to an ideal future state of Industry 4.0 implementation and application is scantly populated in the literature. The structure of the EDMTs contributes to the literature by advocating an internal and external implementation plan. Smaller seaports have little or no knowledge of what Industry 4.0, IoT and Blockchain are and what operational improvements they may instigate. The research on measuring the digital performance of seaports is also regarded by the literature as limited in its scope of application. Without the implementation of tools like the EDMTs, it would be extremely difficult to audit the readiness of a seaport operation to integrate Industry 4.0 embedded technologies. This process is vital in determining the scope of internal and external implementation plans in terms of investment, resource allocation, training, recruitment, and stakeholder and management collaboration. It is envisioned that the

EDMT roadmap would mitigate the resistance of the seaport's personnel that has arisen from ignorance of the Industry 4.0 paradigm. The participation of internal and external stakeholders in the initial stages of the roadmap (Organisational Prioritisation Workshop) that facilitates an opportunity to mitigate the concerns of external stakeholders, most predominately trade unions who are sceptical of automation due to the reduction in employment positions.

8.2 The Adaptation of VSM Tools to Map and Capture Seaport Data

The application of the Lean/VSM method to identify waste and value-adding activities in the seaport sector has been successfully applied in the literature (Marlow and Paixâo- Casaca, 2003; Loyd et al., 2009; Franzén and Streling, 2017). However, there is limited research on the framework and architecture of Industry 4.0 that focuses especially on the operational side of the seaports (Min, 2022). This thesis has taken the core method of VSM and adapted it to facilitate a set of novel data visualisation tools to map the current operating state of a seaport to determine its position in regard to Industry 4.0 readiness and an ideal future state to facilitate their implementation and application strategies.

However, there are a number of limitations in the method of VSM that impinge on its suitability to map dynamic environments and its static operational representation of the current state. The EDMTs will be underpinned by real-time data that is generated by remote sensors that are strategically placed within the seaport zones. This will extend the scope of supply chain visibility by facilitating a more comprehensive understanding of the seaport's current position with regard to process improvements that are leveraged by the Industry 4.0 paradigm.

8.3 Development of the Empirical-Decision Making Tools

The development of the EDMTs is applicable to seaports as they represent data visualisations of their current level of Industry 4.0 readiness and facilitate a structured road map to leverage value from an ideal future operating state. Value has transformed in response to both the aims and objectives of the Industrial Revolution that accommodate the demands of the market as depicted by Figure 65.

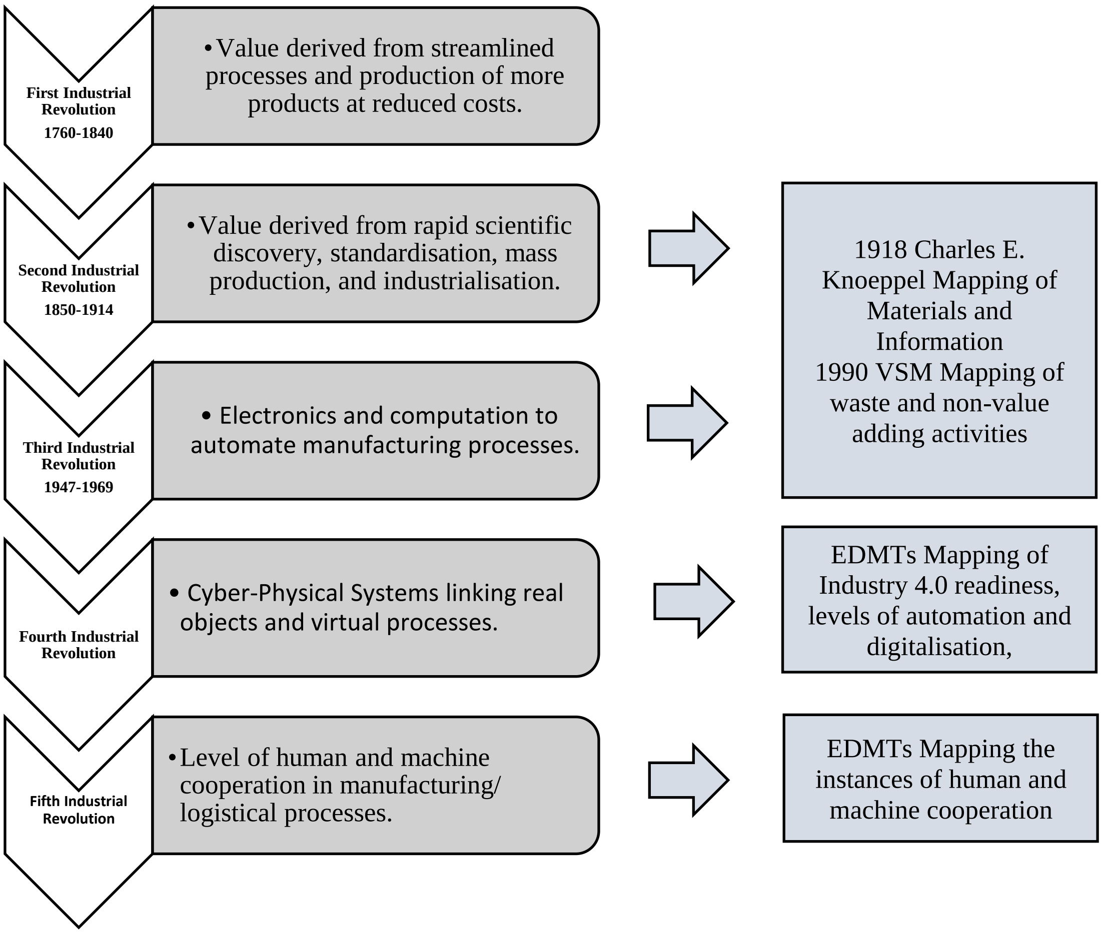


Figure 65: *The Transformation of Value*

This contributes to the literature which has advocated the scarcity of user empirical-based research relating to the integration of Industry 4.0 and VSM methods (Luggert, Batz, and Winkler, 2018). However, the contribution of this research is limited due to its small sample population and its user application is confined to a number of process walk-throughs, rather than in-person mapping exercises. It is increasingly apparent that future research should be directed to the practical application of the EDMTs in a variety of seaport operations, permitting a process of continued refinement.

The future scope of the research may incorporate the Made-in-China 2025 initiative that constitutes China's industrial development master plan for the next ten years (Li, 2018). The plan intends to transform the Chinese industrial focus from a labour-intensive production to a knowledge-intensive manufacturing that ushers in a major breakthrough at a fast developmental speed (Li, 2018). One of the common aims of Industry 4.0 and Made-in-China 2025 is to accelerate process automation and develop collaborative industrial robots as presented in Table 38. Collaborative industrial robots present a form of complex machines that support and replace the human operator, leveraging improvements in productivity, increased flexibility, reduced costs, and increased security (Li, 2018). It is advocated by Yang (2017) that collaborative industrial robots are ideally suited to the functions of small component assembly and the sorting of materials. These functions are highly applicable to the processes undertaken in both the manufacturing and logistics sectors.

Table 38: *Comparison between Industry 4.0 and Made in China 2025*

	Industry 4.0	**Made in China 2025**
Country of Origin	Germany	China
Date of Issue	April 2011	May 2015
Aim	Intelligent manufacturing – Cyber-Physical Systems applying the advanced tools of ICT to production. Increase the speed of automation implementation and development of industrial collaborative robots.	Transformation from made in China to designed in China. Increase the speed of automation implementation and development of industrial collaborative robots.
Key Pillars	Internet of Things (IoT) Cyber-Physical Systems.	Internet of Things (IoT) Cyber-Physical Systems.

	Big Data (BD) and data analytics.	Big Data (BD) and data analytics.
Implementation Period	10 – 15 years	Originally set for 10 years; extended to 2049
Implementation Phases	Not clearly defined	Three Phases
Pilot Test	N/A	The City of Ning Po was selected to be the first pilot city

The flexibility of the EDMTs method that is underpinned by the adaptation of the robust VSM technique is ideally suited to mapping the dynamics of a manufacturing process as opposed to a logistical one. Due to its functionality of direct process observation and formulating an implementation plan to leverage an ideal future state.

There is now a consensus in larger seaports that ICT represents a critical success in determining seaport competitiveness, with the largest European seaports, such as Rotterdam and Hamburg leading the way. However, the findings of this research suggest that the smaller seaports are restricted in their implementation of Industry 4.0 technologies due to economies of scale constraints. Therefore, the EDMTs method provides an opportunity for smaller seaports to ascertain their level of Industry 4.0 readiness and visualise an ideal future state, without the financial risks associated with investing in technology of little operational relevance. This issue was raised by the British Ports Association as presenting a significant barrier to Industry 4.0 exploitation for their smaller members.

Industrial revolutions are not a linear process that is characterised by dramatic and comprehensive process change. It is now considered that there is an overlapping between the Industrial Revolutions of 4.0 and 5.0. As previously stated in Chapter Three the Industry 5.0 paradigm is primarily focused on value which is of a high relevance to traditional VSM methods which identify waste and non-value adding activities, and subsequently attempt to eliminate them from the value chain. Figure 66 depicts the application of VSM and EDMT methods in the Industry 5.0 paradigm and its suitability to enhance the concept value by mapping its generators: Economic, Environmental, and Societal (Leng et al., 2022).

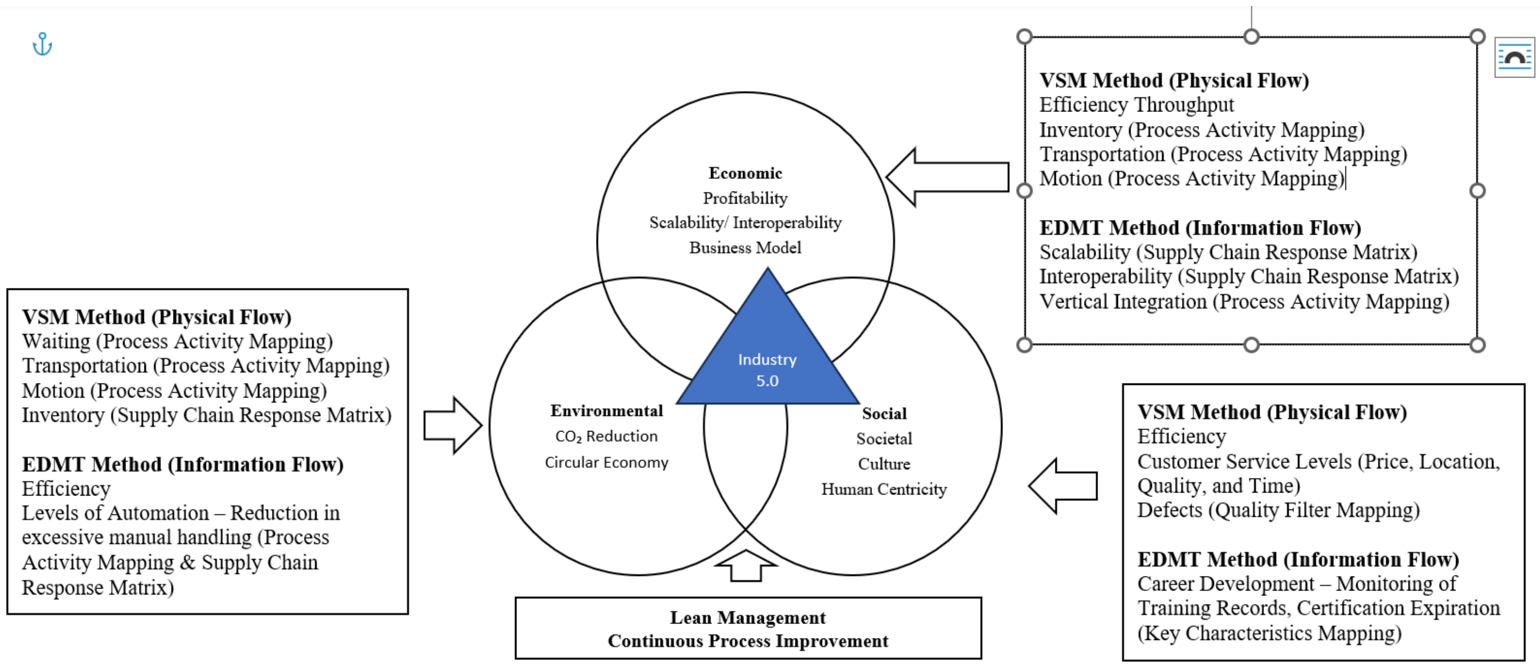


Figure 66: *Mapping the Industry 5.0 Paradigm*
Amended from Xu et al., (2021)

When considering the concept of Society 5.0, the proposed EDMTs architecture will fully enable the integration of all the different sensors by mapping information that is generated in the physical space and disseminated in the cyberspace. The movement of a container in the physical space of the seaport will generate a multitude of data entries; location, storage time, temperature, humidity, e-seal status, and motion. This will be disseminated as information by the EDMTs as a visualisation of the current state map that will underpin the evidence-based decision-making processes of the seaport operators and external stakeholders. As exemplified by real-time tracking of the location of a container, issuing alerts due to e-seal violations, and excessive storage time.

8.4 Insights & Summary

This chapter reviews the findings of the research in relation to the research objectives that were outlined in Chapter One. The lack of understanding of the very essence of the Industry 4.0 paradigm has become increasingly apparent when reviewing the literature and the content of the semi-structured interviews. The development of the EDMTs attempts to mitigate this barrier by map representations of the current state that identify short and long-term process improvements that will underpin investment decisions. A determination of the future scope of the EDMTs is also considered in relation to mapping the drivers of value in the emerging paradigms of Industry 5.0 and Made in China 2025. It is considered that the overarching method of VSM would be highly suited to accomplish the task due to direct observation of economic, environmental, and societal processes.

The next Chapter Nine – Conclusion identifies a gap in the literature, details how the research objectives were achieved, and their contribution to the literature.

CHAPTER 9: CONCLUSION

9.0 Introduction

The relationship between Lean Manufacturing methods and Industry 4.0 is an emerging research topic that is slowly attracting attention from academia and industrial practitioners. Lean Manufacturing is regarded as a prerequisite to implementing Industry 4.0 technologies to leverage operational efficiency and process improvements. This research investigated the adaptability of traditional VSM techniques to enable seaport operators to understand their current position to Industry 4.0 readiness and formulating a road map to realise an ideal future operating state.

The static capture of process data by traditional VSM methods is identified in the literature as an operational limitation. The frequent application of VSM methods to the mapping and identification of waste and non-value-adding activities was also established in the literature review Chapters. This represented an innovative research opportunity to adapt traditional VSM methods to facilitate data visualisations of current state Industry 4.0 operations to underpin a systematic implementation plan for an ideal future operating state.

The literature also expressed a lack of understanding surrounding the implementation and application of Industry 4.0 embedded technologies to leverage sustained competitive advantages for seaports. The mapping of the current state determines an evaluation of their position with regard to the implementation of the pillars of Industry 4.0 which are disseminated in Chapter Three.

Consideration is also given to the limitations of the research and recommendations for further research on Industry 4.0 mapping are provided in this Chapter. The recommendations for further research relate to conducting a current state mapping exercise in a contrasting operating environment.

9.1 Contribution of the Research

Development of a range of tools that facilitate seaport management to visualise their current operating position through enhanced empirical decision support in relation to pillars of the Industry 4.0 paradigm. This will potentially generate sustained competitive advantages that underpin the increased customer demands for enhanced levels of global supply chain integration, constituting end-to-end visibility and transparency. This level of integration is now viewed as a prerequisite for many customers and not just a value-added service, increasing the intensity of market competitiveness.

The role of the seaport is vital to an island nation that is dependent on maritime trade and the EDMTs are engineered to measure of visualisation that is currently highly desired by the seaports that agreed to participate in this research project. The need for increased efficiency, effectiveness, and supply chain agility is demonstrated by the long delays experienced at the Seaport of Los Angeles where ships had to wait outside the entrance to the seaport due to the high volumes of containerised traffic. As globalised market surged in response to fluctuations in post-COVID-19 supply and demand levels. The issue of seaport delays and congestion was raised in the semi-structured interviews with the Seaport Authority of Virginia and the North-West Seaport Alliance. See sections (5.3.4 Infrastructure and 5.3.5 Communication).

9.1.1 Academic Contribution

This PhD research adds to the literature by addressing gaps that were identified in the systematic literature review that is contained within Chapters Two and Three. The static limitation of traditional VSM methods to identify waste and non-value-adding activities in a value stream and its unsuitability to map dynamic multi-actor environments is documented in the literature. The literature also has a strong emphasis on applying VSM methods to exclusively identify and remove waste/non-value-adding activities from the value stream. This research proposes adapting the traditional and robust methodology to generate data visualisations of a seaport's current state in regard to Industry 4.0 implementation and application. This will underpin an implementation plan to leverage a representation of an ideal future state that incorporates the application of Industry 4.0 embedded technologies to facilitate process improvements. It is anticipated that these process improvements will enhance the efficiency, effectiveness, agility, transparency, and visibility of the logistical services provided by the seaport.

The seaport sector is considered by the literature to be lagging behind the manufacturing, financial, and automotive sectors in the application of Industry 4.0 technologies. There are numerous barriers to Industry 4.0 sectoral-wide application that range from a lack of understanding, financial constraints, shortage of skills, experience, and knowledge, and the manifestation of a resistance to change culture. The development of the EDMTs will assist seaports in the identification of these barriers and the application of a clearly defined implementation plan to bridge the gap from the current state to an ideal future state.

The participation of both global seaports and supply chain partners increased the research scope from a national perceptive. This is a fundamental contribution made by this PhD thesis in addition to the insights generated from the series of semi-structured interviews, in-depth interviews, and a process walk-through.

Traditional decision-making strategy is based on the robust and widely applied Dematel methods to evaluate interdependent relationships between both factors and critical factors through the application of a mathematical structural model. This research advocates a novel alternative approach to strategic decision-making that is dependent on the visualisation of the current state when time-critical factors require a faster response time. This form of empirical research is advocated by the literature as requiring additional focus, implementation, and application.

9.2 Realisation of the Research Aims and Objectives

The research aims and objectives have been realised with respect to identifying a gap in the literature reviews (Chapters 2 and 3) and are detailed in Table 39. The research objectives were reviewed from the perspective of achievement, assumptions, and weakness to leverage a balanced appraisal of the PhD research project's contribution to the literature.

__Table 39:__ Assessment of the Research Objectives in Relation to Achievements, Assumptions, and Weaknesses

Research Objective	Achievements of Research	Assumptions from Research	Perceived Weakness of Research
RO 1.	Identification of barriers to seaport sector exploitation of Industry 4.0 technologies – Chapters 2 and 3. Seaports understanding their own current position – Chapters 4, 5 and 6. The potential impact of new innovations and technologies – Chapter 6.	Understanding the seaports current position was outlined in Chapter 2 in the form of the UNCTAD model. Barriers to seaport sector exploitation of Industry 4.0 technologies were outlined in Chapter 3. The most prevalent were lack of knowledge and skills competencies across the nine pillars of the Industry 4.0 paradigm. The culture of the seaport sector had barriers that related to low management support, resistance to change, and spiritual/ ethical considerations. Existing functionalities of traditional VSM tools was outlined in Chapter 4. The application of the EDMTs would facilitate a representation of the current state of the operation with regard to the level of Industry 4.0 readiness. It would also identify aspects of the operation that are suitable for process improvement initiatives. The application of an ideal future state map would facilitate a representation of the impact of innovations and technologies on existing processes.	The industry 4.0 paradigm is in its nascent stages, limited scope of both academic and practitioner empirical research. Small research sample population. Limited to only seven seaport authorities, three NGOs, and one service provider.

	Planning a roadmap to a digitalised seaport – Chapter 6.	The structure of the EDMTs method was outlined in Chapter 6. It facilitates the involvement and ownership of all interested internal and external stakeholders – enhancing the successful transition from a current state to an ideal Industry 4.0 future state.	
RO 2.	Determining the relevance of traditional Value Stream Mapping (VSM) tools for data collection and mapping of current state operations – Chapters 6 and 7.	Adaptation of the robust VSM method to develop an innovative range of data collecting and mapping tools (EDMTs). EDMTs adaptable for current state Industry 4.0 readiness map and implementation plan to leverage an ideal future state.	Limited collaboration with seaport operators that encompassed a series of semi-structured interviews with 11 research participants and in-depth interviews with the Seaport Authority of Virginia and the North-West Seaport Alliance. Lack of insight from the larger European seaports.
RO 3.	Development of an innovative range of data visualisation for seaports to determine Industry 4.0 current state and ideal future state – Chapters 6 – 7.	Range of EDMTs adapted for current state and ideal Industry 4.0 mapping, underpinned by insights from the Seaport Authority of Virginia and the North-West Seaport Alliance.	No mapping exercise was undertaken. Limited to a process walkthrough with two seaport authorities in both the same market and country. This PhD was self-funded therefore, it was not financially possible to demonstrate the EDMTs to either the Seaport Authority of Virginia or the North-West Seaport Alliance. This would have required a sustained period of collaboration that they could not accommodate due to their operational demands. A systematic walk-through and application of the EDMTs represents a possible option for further research at seaports that operate in diverse markets.

9.3 Limitations of Research

This research represents a positive attempt, almost blue-sky research at developing EDMTs for current and ideal state visualisations to supplement and enhance strategic decision-making to leverage sustained competitive advantages. Some issues were identified throughout the research process and they could not be incorporated due to scope, funding, and time constraints. A perceived limitation relates to the inability to conduct a mapping exercise of a seaport's current operating state, in addition to the formulation of an implementation plan to realise an ideal future state. The PhD research was self-funded, and it was not financially viable to arrange a protracted visit to the North American seaport authorities to conduct a range of mapping exercises. The scope of collaboration was also dependent on the goodwill of the participants who had to accommodate the semi-structured interviews, in-depth interviews, and the process walkthrough around their busy and demanding schedules. In addition to scheduling around the international time zones, emphasising their goodwill and interest in the synopsis of the PhD research.

The lack of participation from the UK and mainland Europe seaports is regarded as a limitation in terms of ascertaining the perceptions of Industry 4.0 leading proponents, most noticeably the seaports of Hamburg and Rotterdam. The reluctance of European seaports to participate in this PhD research project was inferred by the British Port Association to be a legacy of the supply chain throughput disruption instigated by the global COVID-19 pandemic. The Made in China 2025 initiative also presents a potential future study in terms of determining its flexibility to map Chinese seaports which play a fundamental role in global supply chains in terms of manufacturing throughput and stimulating economic growth. Therefore, the final representation of the EDMTs is limited in its scope of application to the insights ascertained from the Virginia Seaport Authority and the North-West Seaport Alliance.

9.4 Recommendations for Future Research

This research has attempted to make a valid contribution to the body of literature relating to the emerging topic of empirical decision-making and seaport strategic management. This has answered the research aims and objectives, however, it has, in turn, generated a number of questions that require further research. It would be beneficial if similar research could be conducted in a different context, both geographically and in logistical sector. This could be exemplified by a study of a seaport within a developing maritime nation, offering additional insights underpinned by supply chain transparency, visibility, and agility.

The continued refinement of the EDMTs is advocated in terms of operational mapping, enhancing the insight gained from the walk-throughs with the Seaport Authority of Virginia and the North-West Seaport Alliance. This will also ensure that the EDMT is versatile to meet the diverse operational needs of the seaport sector.

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APPENDIX ONE GLOSSARY OF TERMS

Big Data Analytics	A process of examining large and varied data sets (Big Data) to leverage hidden trends, unknown positive and negative correlations, market forces, customer behaviour, and other significant information that may assist an organisation when formulating more intelligence-based business strategies.
CAPEX	A capital expenditure is capital reinvested by an organisation to fund the purchase or upgrade of a fixed, physical, non-consumable asset within the infrastructure or superstructure. It may also be related to the funding of a new business venture.
Competitive Advantage	The capacity of an organisation to deliver a high standard of service at the lowest possible management cost.
Culture	Set of stored, implicit assumptions, that the group holds as central to its identity and determines the response to various conditions.
Customer Service	A business relationship between seller and buyer that promotes or facilitates the sale or use of a seller's products/ services.
Data Mining	Is defined as the process of analysing hidden patterns displayed within raw data sets, according to contrasting perceptions for categorization into information knowledge. Data Mining is collated and categorised into common parameters, such as data warehouses, for efficient analysis, and data mining algorithms. It formulates business management

	decisions producing Key Performance Indicators (KPIs) to leverage efficiency, turnover, revenue, expansion into new markets, development of new products, and enhanced customer service experiences.
Digitisation	The process of changing from an analogue to a digital format.
Electronic Logistics Marketplace	There are three fundamental classifications of ELM, Open, Closed, and Cloud. An Open ELM is defined as the provision of on-the-spot logistical services. A Closed ELM is associated with the delivery of long-term collaborative partnerships, underpinned by knowledge and technological transfer.
Heterogeneous Networks	Operate under standard-conforming hardware and software interfaces, enabling the facilitation of different platforms by means of communication within their networked environment. The Internet is a classic example of a Heterogeneous Network.
Human Resource	A managerial function that promotes and administers organisational development, employee training/upskilling, and career development (Career Development Plans/CPD) for the purpose of maximising operational performance.
Interoperability	Describes the extent to which systems and devices can exchange data and interpret that shared data. Two systems will be deemed as interoperable if they are able to exchange data and then subsequently present the data in a

	format that allows for understanding and insightfulness.
Key Performance Indicator	An advanced statistical or graphic representation that measures and records the performance of an undertaking in terms of efficiency, health and safety, profitability, sustainability, and handling of freight/cargo (throughout measured in TEU).
Industry 4.0	Is the end product of combining the processes of Cyber-Physical Systems and the Internet of Things to the industrial automation complex.
Network Analysis Optimisation	A structured process or methodology that is utilised to maximise the operational efficiency of a network. It may involve the application of mathematical reasoning to calculate the most adventurous solution.
OPEX	An Operational Expenditure that is ongoing and occurs due to the routine operation of a product or service.
Radio Frequency Identification	Is a wireless communication platform that may identify specific targets utilising radio signals with the capacity of a read/write function for data collection, without the necessity of optical or mechanical contact.
Risk Management	The perception, evaluation, and ranking of risks that may adversely disrupt a supply chain network. Followed by sustainable control methods to reduce the impact of the unforeseen and uncertain events.

Semi-structured data	Presents a continuum between the classifications of structured and unstructured data sets. Hence the utilisation of the term semi-structured data.
Structured Data	Refers to tabular data contained in a spreadsheet database; it represents an amount of 5% of all the data that is currently generated.
Supply Chain Agility	The ability to manage, and cost-effectively adapt to fluctuating and volatile market conditions. That ultimately results in no significant disruption to the supply chain operation.
Supply Chain Collaboration	Is viewed as a measurement of collaborative projects between seaport operators and seaport users. In order to enhance the functions of reliability, punctuality, value-added services, productivity, freight throughput, and health & safety awareness. This underpins the overall KPI measure of overall supply chain performance.
Supply Chain Integration	The level to which a manufacturer strategically collaborates with its supply chain partners, and suppliers. When delivering its services or products and is reflected in the measurement of operational performance.
Sustainable Development	Defined in the *Brundtland Report* as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Sustainable Supply	Effective operational management with minimal negative environmental effects.

Takt Time	A manufacturing term that is applied to describe the required amount of product assembly duration that is needed to match customer demand. Takt Time is calculated by dividing the available production time by the levels of customer demand. It is applied to optimise the production process to deliver products on time.
Unstructured Data	Presents a collection of data that may consist of text, images, audio, and visual images.
Value Stream Mapping	A simplistic planning tool that enables a visual representation of the value stream, enabling the identification of non-value-adding activities within the production cycle.
Value Stream	All processes that are required to complete the production cycle. It includes the facilitation of material (arrival of raw materials) and information flows (a receipt of customer orders and operational instructions to employees).
Visibility	The capability of sharing on time and accurate data sets.

APPENDIX TWO LETTER OF INTRODUCTION

Email: S.A.Caldwell@ljmu.ac.uk

Dear Sir/Madam

My name is Scott Caldwell; I am currently studying for a PhD degree at the *Liverpool Logistics Offshore and Marine Research Institute (LOOM*) at *Liverpool John Moores University.*

This questionnaire is part of a PhD research project to investigate the application of smart technology in the manufacturing industry/ maritime supply chain operations. Your responses are very important in enabling me to obtain as full an understanding as possible on this topical issue. However, your decision to take part is entirely voluntary and will be safeguarded under the *Liverpool John Moores University Ethical Guidelines.* All responses will be treated anonymously, in light of any perceived operational concerns and in accordance with the LJMU ethical guidelines. You will not be expected to include your name or address on the questionnaire. Therefore, your responses can not be attributed to you or your company. The information obtained will form the bases of my primary research, leading to the completion of a PhD in Maritime and Mechanical Engineering. A copy of the informed consent form/participant information sheet will be enclosed for your reference.

If you do decide to participate in this research project, the questionnaire should take approximately 30 minutes to complete. Please answer the questions in the space provided. If you wish to add further comments, please use the space provided at the end of the questionnaire.

I hope that you find completing the questionnaire enjoyable and thought-provoking. If you have any questions or would like further clarification, please do not hesitate to email me at S.A.Caldwell@ljmu.ac.uk, or my Director of Studies Dr R. Darlington, by email at R.I.Darlington@LJMU.ac.uk.

Thank you for your assistance.

Scott A. Caldwell
PhD Candidate

APPENDIX THREE INFORMED CONSENT DECLARATION

Informed Consent Declaration – For Research Participants

This study is being conducted by ***Scott Caldwell***, PhD Student in the Faculty of Engineering and Technology, Department of Maritime and Mechanical Engineering under the supervision of ***Dr Rob Darlington*** who can be contacted via the following email address: ***R.I.Darlington@ljmu.ac.uk.***

Participation in the research project will involve **a semi-structured interview** with relevant industry stakeholders.

Participation in the study is entirely voluntary and participants can withdraw from the study at any time without giving a reason. Participants may also ask questions at any time and discuss any concerns with either the researcher or the supervisor as listed above.

The findings of the study will form part of the research assignment.

All information provided during the interview will be held anonymously so that it will not be possible to trace information or comments back to individual contributors. Information will be stored in accordance with the current General Data Protection Regulations.

Participants can request information and feedback about the purpose and results of the study by applying directly to the researcher at ***s.a.caldwell@ljmu.ac.uk***.

Scott Caldwell

23rd November 2020

PhD Researcher – Scott Caldwell Faculty of Engineering and Technology.

APPENDIX FOUR SEMI-STRUCTURED INTERVIEW QUESTIONS

Questions that populated the semi-structured interviews.

Culture

1. What is your job title?
2. What is your length of service/ experience in this sector?
3. What is your current vision and mission statement?

a) How does this relate to the day-to-day targets/ KPIs?

4. Have does your company define value?
5. Has the customer value viewpoint been gathered (reword?)

a) Customer viewpoint and how their perception of value relates to the company's KPIs.

b) Customer viewpoint and how their perception of value relates to the company's smart technology.

6. Does agility play an important role in the management of your company?
7. How could you improve your customer service department to be more responsive to customer demands?
8. How closely do you collaborate with your customers in the product developmental processes?

Classification of the Business

1. How would you define the size of your company?
2. Where do you stand in the market competition?
3. Does your company trade in international markets?
4. What sector does your company operate in?
5. How would you classify your products and services?
6. How do you receive orders from your customers?
7. Any forms of IT/Smart platforms for an invoice, purchase–ordering, and customer order scheduling?

8. What is the total number of staff employed by your company? (Full-time/ Part-time)

9. Do you provide continuous development training for your staff in relation to IT/smart technology training?

b) Do you provide Career Development Plans (CDP)?

10. Do you require a specialised labour force to operate your production systems?

11. Are you familiar with the concept of Industry 4.0?

12. Investment levels in new technology/smart technology

13. Payback periods/measures relating to investment

14. What is your average lead time and delivery time to domestic customers?

b) What are your average lead time and delivery time to international customers?

15. How does your company facilitate inter-organisational communications?

16. Is the demand for your products and services variable (peak season demand)?

17. How long in advance do you receive your orders?

18. Does your company outsource any of the manufacturing processes?

b) If so, why?

19. What is the main problem when it comes to the shortening of lead and delivery time?

20. Do you face any operational issues with logistical service providers

Smart Technology

1. How does your company view research and development in smart technology?

a) Are there any internal R&D projects currently/previously?

2. What is the main barrier to the implementation of smart technology in your industry?

3. How often do you upgrade your IT systems?

4. How often do you upgrade your smart technology?

5. What is the main barrier to the implementation of smart technology in your company?

6. Does your company collaborate with other companies within your sector to share knowledge, research and development costs, and operate smart technology?

7. If yes, how does your organisation safeguard its intellectual copyright and sensitive/ confidential information?
8. Does your company offer training in relation to the perceived implementation of smart technology?
9. Does your company provide financial investment to the development and operation of smart technology?
10. What are the main benefits to your company of smart technology? This is supported by KPI analysis.
11. What is the type of variables used to measure your organisation's KPIs?
12. Does the current economic uncertainty limit your company's commitment to the operation of smart technology?
13. Is there an integrated strategy in place for identifying/implementing industry 4.0/smart/etc? technologies?
14. To what extent are your manufacturing processes automated

APPENDIX FIVE RESEARCH SYNOPSIS

Exploiting the Potential of Industry 4.0

Reference: 21/MME/001

Introduction

Seaports and container terminals operate in extremely complex conservative, and competitive trading markets. Fragmented operations limit cooperation and the sharing of knowledge. The literature suggests that seaports usually lag behind the manufacturing, automotive, and financial sectors in terms of advanced information technology (IT) and fail to fully exploit applied IT/IS for addressing current and future operational challenges. This research explores routes by which seaports can identify strategically important areas for Industry 4.0 investment opportunities.

Challenges

Industry 4.0 is deemed as representing the 'Fourth Industrial Revolution' facilitating the digitalisation and automation of the maritime supply chain. This will leverage a sustainable competitive advantage for the operator. However, successful implementation of Industry 4.0 embedded technologies represents a major challenge, in terms of change management (cultural and operational), capital investments that are subjected to a return of investment constraints, education and training of the workforce, and knowing where to start the implementation of Industry 4.0.

This Research

To address these unique operational conditions, seaports need access to real-time information flows that are facilitated by sharing, planning, and managing cargo throughput in a networked and collaborative format, leveraging a market competitive advantage. This research supports seaports to first establish their current strategic position in relation to Industry 4.0 readiness, underpinned by KPI metrics. There is a significant lack of empirical studies that document the multi-dimensional innovation of smart technologies (technological, managerial, organisational, and cultural concepts) within a seaport terminal, despite the realisation that ICT now represents a critical success factor in determining seaport competitiveness.

The fundamental objective of the Empirical Decision-Making Tools (EDMTs) is to determine the level of Industry 4.0 readiness of a seaport terminal by measuring its current performance in relation to an ideal future state (where the organisation wishes to be in the future).

Approach

Zoom video conferences, in the form of a structured interview, to discuss the seaport's current position in regard to the implementation and application of Industry 4.0 embedded technology. This would include a discussion around the functional mapping of processes in relation to container ship turnaround time that follows both physical and information flows from different seaport actors.

Common questions

How long will it take?

Roughly 1 to 2-hour discussion of topics that are key to solving the mentioned challenges

Will you need any sensitive/restricted data?

Any data discussed will be anonymised and handled in accordance with the University's GDPR processes you can withdraw from the research at any time.

Do I have to set up Zoom?

You will be sent a link to follow at a pre-agreed time to suit your availability.

I'm not sure we have the right kind of decisions or processes to be useful

This can be clarified as part of the discussion- your input will be useful to gauge awareness of available technologies and initiatives by members of seaport operations, even if they are not utilising these tools.

APPENDIX SIX NVivo CODE CASEBOOK

Barriers to Industry 4.0 Implementation/ Application	Description	Files	References
Competitiveness of Seaports	The competitive position of the seaport is determined by the services and products provided to shippers and shipping lines for specific trade routes, geographical regions, and the interconnection of other seaports.	1	34
Cybersecurity Barriers	The barriers posed by cybersecurity on the integration of Industry 4.0 embedded technologies in seaport operations.	1	18
Fragmentation of Seaport Operations	Determination of fragmentation of seaport operations in terms of data sharing.	1	36
Industry 4.0 Investment Constraints	The barriers imposed by Investment constraints (economies of scale) on Industry 4.0 embedded implementation and application in the seaport sector.	1	44
Interoperability	The importance of system interoperability in the current and ideal future operating states.	1	9

Barriers to Industry 4.0 Implementation/ Application	Description	Files	References
Quality of their Infrastructure	The quality of infrastructure to drive seaport competitiveness and innovation of Industry 4.0 embedded technologies.	1	24
Resistance Mentality	The attitude of the seaport sector to innovation in terms of employment security and creation, upskilling, and career progression.	1	61
Risk of Industry 4.0 Implementation	The risk posed by Industry 4.0 embedded technology to achieve desired process improvements in terms of supply chain efficiency, agility, visibility, and transparency.	1	23
Skills Required Industry 4.0 Implementation	The required knowledge, experience, and training to deliver the sustained competitive advantages that are offered by the implementation and application of Industry 4.0 embedded technologies.	1	12
Sustainability of Seaports	The suitability of Industry 4.0 embedded technologies to improve the sustainable services offered by the seaport.	1	6
The Levels of Seaport Stakeholder Cooperation	The level of cooperation the between seaport governance, terminal operators, customers (supply chain platforms), and external stakeholders (customs).	1	15
Industry 4.0 Exploitation	The levels of Industry 4.0 implementation and application within the sample population.	1	59

Barriers to Industry 4.0 Implementation/ Application	Description	Files	References
Understanding of Industry 4.0	The seaport sector's understanding of the relevance of Industry 4.0 to improve the efficiency, agility, visibility, and transparency of the seaport's logistical services to exploit sustained competitive advantages.	1	18

APPENDIX SEVEN ACADEMIC PAPERS

Articles Resulting from Authorship of this PhD Thesis

The following journal and conference publications were submitted in relation to the authorship of this PhD thesis:

https://link.springer.com/chapter/10.1007/978-3-030-90532-3_56

Accepted Conference Papers

GCMM Industry 4.0 Mapping for Strategic Decision-Making

Submission of a paper to the 15th Global Congress on Manufacturing and Management, held at Liverpool John Moores University, on the 7th – 9th June 2021.

Caldwell, S. and Darlington, R. (2020) GCMM 2020 Industry 4.0 mapping strategic decision-making for seaport operations management. *In Proceedings of the 15th Global Congress on Manufacturing and Management.*

The researcher has also been accepted by the EMPORIA4KT Technology Transfer Programme which is designed to facilitate in-depth training and monitoring for Blue Economy researchers to enhance their analytical skills in innovation and technological transfer.