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ASSESSING THE FACTORS IMPACTING SHIPPING CONTAINER DWELL TIME: A MULTI-PORT OPTIMIZATION STUDY

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Abstract. Ocean transportation is the most preferred mode of transportation that represents a significant role in the global trade. Ocean transportation comprises around 80% of the aggregate worldwide cargo volume. This research paper focused on evaluating the factors that influence the dwell time of the shipping containers. Dwell time is one of the important port performance parameters which evaluates the time spent by the container in a port. In this research, the data from the fourteen major ports was collected and analysed across the variables, such as cycle, size, mode, status, delivery and tracking technology for evaluating the variation in container dwell time. OLS regression method (Ordinary least squares) along with independent sample T test was adopted for the analysis of 2.8 million container data entries utilizing python for big data analysis and SPSS. For the top three ports with lowest RMSE (Root mean square error), Port A – 15.6 %, Port G – 15.7 % and Port L – 15.86 %, a qualitative study was performed to identify the reasons for the variation in dwell time. The major reasons identified included free days period, trans-shipment port, high rail frequency, industrial hubs in the vicinity of the ports for lower dwell time. A qualitative research framework was presented as the research outcomes and reasons for variations in a multiport study.

Keywords: dwell time, port performance, optimization, container, shipping, ocean port.

JEL Classification: R41, R42.

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1. Introduction

Ocean shipping containers are the primary storage equipment of choice for ocean transit and movement. A variety of container types are transported in the marine transportation such as general-purpose, reefer, dry, oil, and tank containers. According to research, a significant proportion of global trade, specifically 80% by volume and 30% by value, is facilitated through the utilization of these containers (Muñuzuri et al., 2020; UNCTAD, 2018). These numbers are expected to further rise due to the expansion of economies and the process of globalization (Fruth & Teuteberg, 2017). The cross-border cargo transportation sector, currently valued at USD 10.9 billion in terms of industry capitalization, is seeing a steady growth rate of 8.5%. This phenomenon will lead to an increase in the quantity of containers being transported, thus resulting in a significant surge in both the volume and traffic of containers at seaports. According to a research, India, as an emerging country, has experienced a significant increase of 30% in container volume during the period of April to October 2021 (Whelan, 2021). This rise has consequently led to an escalation in freight rates. Figure 1 depicts the various components of container dwell time. The dwell time components have been classified as operational, transactional and discretionary dwell time. This research study primarily considers the dwell time between container discharge to exit from the yard. The timestamps and container specifications have been considered for research and analysis within this perspective of operations.

With such a growth witnessed in the global trade and containerization, there are certain parameters which are of utmost importance for the container operators to optimize and efficient handling for port efficiency. Logistics performance and global competitiveness are associated to each other for driving efficiency (Yildiz, 2017). Two such port

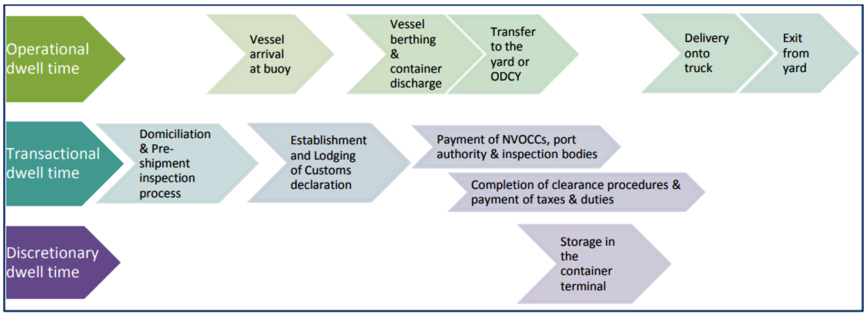


Figure 1. Components of dwell time (source: Refas & Cantens, 2011)

performance parameters are reshuffle and dwell time of container. Container reshuffle and rehandle is an inevitable process while storing and stacking inbound and outbound containers. These operational handling are complicated in transactions due to the complexity of the nature of operations and irregular demand of operations and movement of container within a defined area of yard. These erratic movement impacts the time spent by container in a terminal. The research problem addressed in this study focused on varying dwell time of containers despite the container with same standard size, weight and handling equipment's. There is a significant variability in the duration of container dwell time at the prominent Indian and International Ocean ports, Figure 2. The primary objective of this research was to evaluate the import and export procedures implemented at the major ports in India, with a specific emphasis on the time taken from the arrival of vessels to the completion of gate out processes. This research paper made a unique and valuable contribution to the academic and practice by understanding the various factors and elements that influence shipping container dwell time, with a particular focus on the role of tracking technologies. The qualitative examination of factors influencing stay duration was conducted through structured interviews with port operators.

The larger container port operations comprise of multiple terminals and berths discharging container at an ever-growing pace. Thus, port operators have to design and implement innovative strategies for operations and stacking containers to avoid handling and optimize operations. Many researchers have studied on the relation between reshuffling and time spent in a container terminal (Dwell time) by a container. However, the limitation has been around the data set from the real time operations. This research study has analysed the data for the multi-port set up and subsequently help discussion interviews with port experts to understand the varying reasons of container dwell time.

Various studies have researched on the port performance parameters and its benchmarking against each other. Performance indicators such as vessel operations time, throughput volume, number of cranes, labour productivity, vessel turnaround, vessel waiting time, truck turnaround, container dwell time have been adopted to measure port productivity (Tongzon, 1995; Brooks, 2006; Nicoll & Nicholson, 2007). There are few other indicators of the similar nature such as availability and capability of employees, capability of dockworkers, speed of stevedores' cargo loading/unloading, timeliness of maritime services used to measure service quality of a container

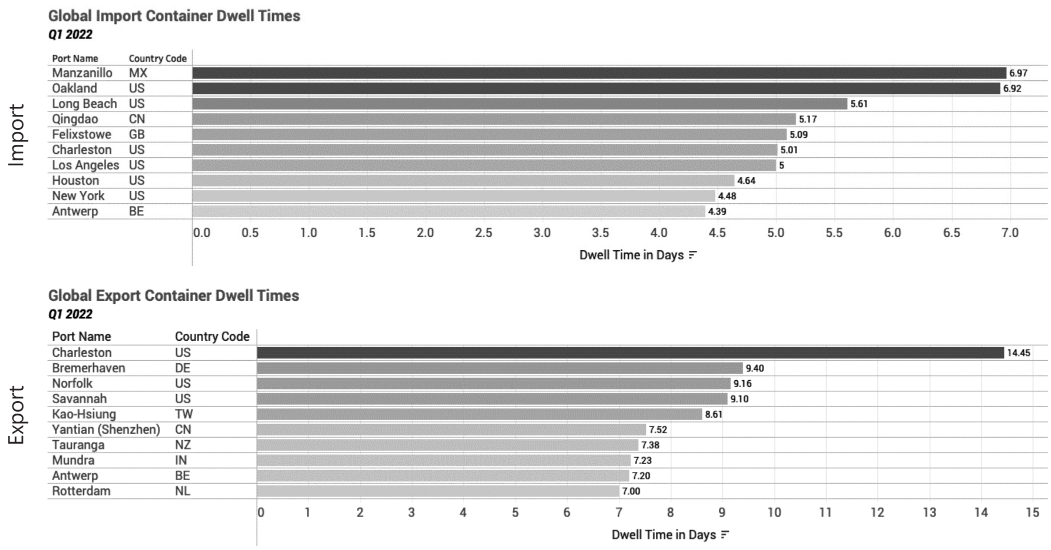


Figure 2. Dwell Time comparison at global ports (Cooke, 2022)

port terminal (Marlow & Casaca, 2003; Woo et al., 2011; Brooks & Schellinck, 2013).

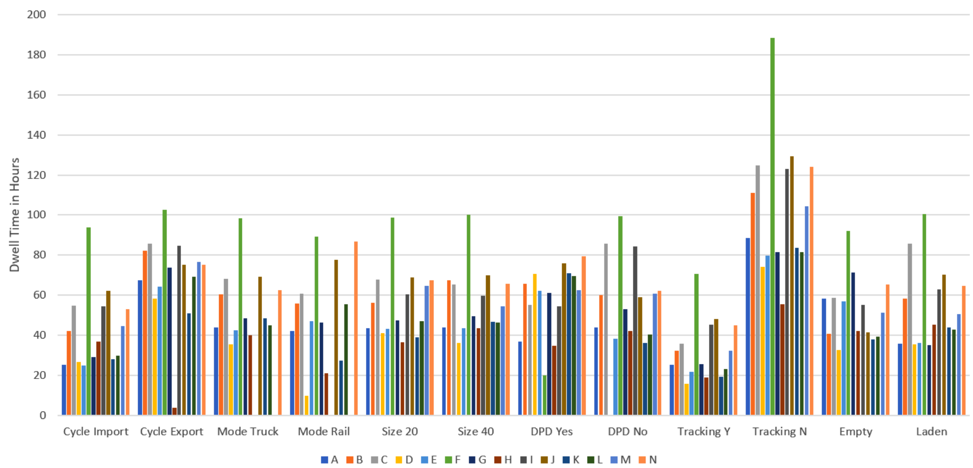
Figure 3 illustrates the relationship between the average ship size berthed at the port and the duration in years. According to these findings, the size of the vessels is growing while the space available for port operations remains constant. Consequently, it is essential for a container port terminal to implement optimization strategies to assure the effective management of standard operating procedures, as well as to reduce the time spent by container at a port terminal.

The presence of a diverse range of intricate operational processes at ocean ports contributes to the occurrence of delays in container lead times. The increase in the vessel size has led to the limitations in container operations due to the availability of space at the ports. Consequently, it is crucial to identify the factors contributing to variations in dwell time and to optimize delays in order to enhance performance efficiencies. The subsequent stages of the research centred on assessing the influence of diverse components such as (i)Cycle-Import/Export, (ii)Size-20 feet or 40 feet, (iii)Mode-Truck/Rail, (iv)Status-Empty/Laden, (v) Delivery DPD /DPE (Direct Port Delivery or Direct Port Export), (vi)Tracking Technology Availability-Yes/No, on the container dwell time. The data analysis process involves the application of the statistical technique known as ordinary least squares, which was implemented using Python programming language for handling large datasets, as well as SPSS software for independent sample T test. During this phase, the data pertaining to multiple ports in India was subjected to regression analysis. Subsequently, the top three ports were chosen for qualitative reasoning, based on the criterion of having the least root mean square error.

In the concluding phase of the research, discussions were undertaken with the key stakeholders representing the top three ports (Port A, Port G and Port L) with lowest root mean square error. The objective of conducting these discussions was to get valuable insights into the various reasons that contribute to the variation in container dwell time. This research study is of great importance to both the academic and practice, since its objective is to provide a clear understanding of the factors that contribute to the variability in container dwell time. This enhanced the potential for collaboration between port operators and academia in conducting research on methodologies pertaining to container operational planning and establishing standards for container performance. This research study made a unique contribution to the existing literature by examining the effects of various elements impacting container dwell time. The research paper is outlined as literature and theoretical review in section 2, followed by methodology in section 3. Subsequently results are detailed in section 4 and discussion in section 5, followed by conclusions in section 6.

2. Theoretical framework

The logistics sector plays a crucial role in facilitating economic growth and exerting substantial effect on several economic sectors, such as ports, infrastructure for transportation, storage facilities, and systems for information and communication. The establishment of this sector towards becoming a significant component in the development of industry, trade and economy is widely acknowledged. The research on container dwell time and port optimization are lacking dataset and availability of comprehensive analysis of real time operations (De Armas Jacomino et al., 2021). As the global trade is growing, the port operations managers have to strategize towards data-oriented operations to achieve efficiencies (Chu & Huang, 2005). The size of vessels transporting containers is progressively growing (Figure 4), while the availability of land and space for operations remains constrained or same in size/area. Therefore, it is crucial to implement measures that enhance the efficiency of container handling and streamline operational processes.



Note: x-Axis – trimester in years, y-Axis – average size of ship per port.

Figure 3. Average vessel size per port at a given trimester over a time period (Hoffmann & Hoffmann, 2021)

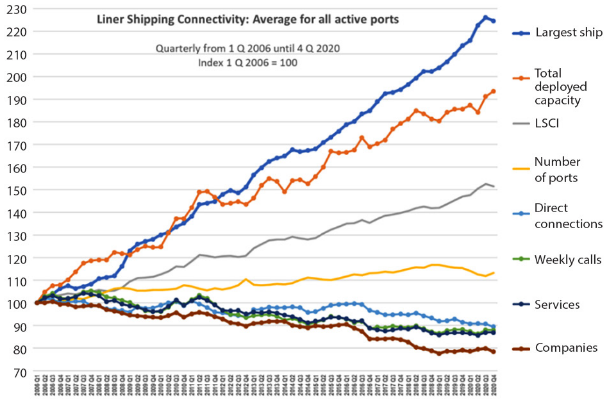


Figure 4. The size of vessel over the period of time (Rodrigue, 2022)

As the investment over increasing land area would be high, one of the optimized and efficient option with terminal operators is to efficiently manage operations through data and reduce reshuffling and dwell time. The literature has focused on suggesting multiple handling strategies and framework to reduce reshuffling. In one of the research the framework based on the pricing scheme for time spent by container in a terminal was suggested to reduce container dwell time (Merckx, 2005). However, many importers and exporters tend to store their container in yards to save their inventory cost. Thus, the introduction of container freight station happened in the industry. However, this does not contribute in the overall reduction of the dwell time of the container (Rodrigue & Notteboom, 2009).

There are multiple studies which have researched on the direct correlation between the reshuffling and time spent by container in a port (Huang et al., 2008). Thus, it not only impacts the port performance parameters and port optimization however leads to more cost in handling as well. The major reasons behind such exuberant handling time and cost are known to be terminal location, adoption of IT system, freight forwarders and the connection available for next immediate ICD (Inland container depot) (Moini et al., 2012). In another research study, a method of genetic algorithm was adopted to identify the factors impacting dwell time and container terminal productivity. In this research, the nature of nature of data for operations at the land side was suggested to be of prime importance. The development of methodological framework for predicting dwell time have been researched as well. The factors identified to be impacting dwell time were the consignee of the container and commodity (Kourounioti et al., 2015).

Nodal agencies and stakeholders of container supply chain have been focusing on the importance of advance intimation and notification for any container movement towards transportation of discharge as the important factor for controlling high dwell times. In one of the research, a simulation model was developed to illustrate on the usage of information on the terminal efficiency (Zhao & Goodchild, 2010). The research study suggested that the advance information on truck arrival can support the terminal operator in planning the stacking of container to minimize reshuffle and the dwell time. For the truck congestion time as well, the methods to reduce waiting time at terminal for efficiency planning is suggested in the literature (Nooramin et al., 2011). The truck routing problem for containers transported via rail were researched to optimize cargo routing (Elbert & Wu, 2023).

The operations managers have been citing various reasons when it comes to higher dwell time of containers. They have also been addressing the issues of quay cranes capacity and complexity. A quay crane can handle thirty-two moves per hour for loading and unloading of container, where as a rubber tyre gantry crane can manage twenty moves per hour. Such transfer of container can lead to truck congestion at vessel area and thus researchers suggest various paradigms to increase crane efficiency. Various strategies such as lift mover with twin facility are suggested and performed to reduce container handling time. However, this is a complex process and there are certain operating procedures which are unavoidable. The advance planning is important to ensure vessel load plan, bay stowage plan, stack weight, and sequencing for ensuring timely and efficient container handling. In another research study, the process cycle efficiency was performed and waste management for container time was performed (Deniz et al., 2021). The importance of technology and IT systems to develop operations efficiency is imperative along with implementation of blockchain and IOT (Saini et al., 2021; Yang & Tan, 2022).

There are multiple research studies which have researched on the dwell time from the various port operations perspective, such as vessel dwell time (Yoon et al., 2023), quay crane operations (Budiyanto et al., 2023), congestion at terminals due to various reasons such as vessel delay, equipment damage, inability to monitor truck arrival information (Ayutia et al., 2023), however there have been rarely any study which focused on comparing multiport operations with specific focus on dwell time. Table 1 illustrates the few research which have been performed on dwell time, port optimization, and port performance parameters. This research study focused on identifying the reasons for varying dwell time across the multiple ports and developing qualitative framework. This was performed

Table 1. Summary of closely related research studies (source: author)

Variables	Literature reference	Research parameters
Dwell Time	De Armas Jacomino et al. (2021), Merckx (2005), Rodrigue and Notteboom (2009), Huang et al. (2008), Moini et al. (2012), Kourounioti et al. (2015), Zhao and Goodchild (2010), Nooramin et al. (2011), Aminatou et al. (2018), Irannezhad et al. (2019), Zuidwijk and Veenstra (2015).	Crane and terminal operations, Port Optimization, Container size, commodity, factors determining dwell time, Tracking, Port performance parameters

Table 2. Summary of research analysis process and steps (source: own research)

Research Objective	Method	Model	Tools
To understand the impact of various variables of port operations such as, (*i*)Cycle, (*ii*)Size, (*iii*)Mode, (*iv*) Status, (*v*)Delivery, (*vi*) Tracking Technology on container dwell time.	Quantitative	Ordinary Least Squares	Python for Data Science and SPSS
To understand the various reasons of the variation in container dwell time and qualitative reasoning.	Qualitative	Qualitative framework	Qualitative technique

with the objective of understanding the reasoning on one port performing better than the other. The results and contribution of this research will support researchers in understanding the characteristics of container which directly impacts dwell time in a multi-port scenario.

3. Methodology

This research study adopted the mixed method approach for understanding the port operations and performing data analysis. The research was initiated by extensively reviewing the literature on the topic of dwell time and container logistics. The subsequent steps included identifying the impact of container size, mode, type, status, delivery and tracking technology on the container dwell time. The research study was conducted based on the combination of the quantitative and qualitative analysis of the data collected from port terminal operating system. Qualitative research involved collecting and analysing non-numerical data analysis from port terminal operating system.

Data from fourteen ocean ports of India, equivalent to 2.8 million container entries was collected for determining the impacting factors on shipping container dwell time. Research variables such as Container size (20,40), Mode (Truck/Rail), Status (Yes – Empty, No – Laden), Cycle – Import/Export, Delivery (Yes/No – Direct Port Delivery/Direct Port Export), tracking availability were regressed against the container dwell time. The regression statistical method, Ordinary Least squares was adopted to understand the impact of track and trace on the container dwell time. For calculating the impact of presence or absence of technology on the dwell time, the well-known technique to identify the dependent variables as weighted sum of the covariates along with coefficients was obtained using regression methods (Maldonado et al., 2019). This method had been widely used in the research studies, for the statistical analysis. Various other techniques of artificial neural network, machine learning methods were adopted to predict the dwell time of a container (Kourounioti et al., 2015; Moini et al., 2012). Since this research primarily focussed on identifying the qualitative reasons, we adopted OLS (ordinary least squared) as quantitative inputs for qualitative study. The OLS test was performed to analyse 2.8 Mn container entries utilizing python language for big data sets and independent sample T test and SPSS. Subsequently, a discussion was scheduled with the port operations managers to understand the qualitative reasoning.

Table 2, represents a brief overview of the research and data analysis steps undertaken in this research study to investigate the factors that influence shipping container dwell duration. The research was primarily conducted in two steps, where in firstly the large data sets of 2.8 Mn entries were regressed utilizing ordinary least squares method to identify the top three ports and the elements where ports are performing efficiently. Subsequently, the port operators of the top three ports were interviewed to identify the reasoning for the variation in the container dwell time. Due to the confidentiality of the port data, we have dummy coded ports as port A, B, C and so on for all the ports till port N. All the ports have been researched and analysed for the correlation analysis, ordinary least squares for impact on tracking on dwell time, T-test for other independent variables and qualitative study with the port operations manager.

4. Results

Data from the fourteen ocean ports was collected for determining the factors impacting shipping container dwell time. Variables such as (*i*) Container Cycle – Import or Export, (*ii*) Container size – 20 feet or 40 feet, (*iii*)Mode – Truck or Rail, (*iv*)Status – Empty or Laden, (*v*)Delivery – DPD/DPE (Direct Port Delivery or Direct Port Export) ,(*vi*) Tracking Technology availability – Yes/No were regressed utilizing ordinary least squares. The date set in Figure 5,

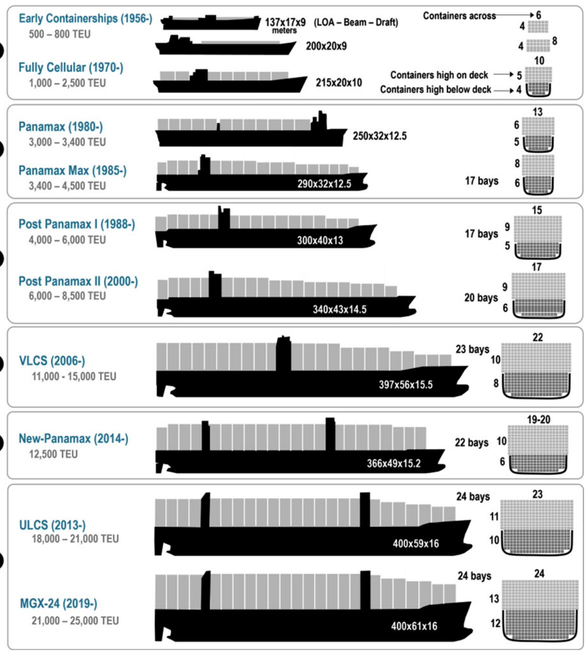


Figure 5. Dwell time across the researched variable (source: author)

visually represents the varying dwell time across the aforementioned six variables. The significance of considering this variability among the ocean ports with standardized operations and the different variables is acknowledged for further research in this study.

The summary of data analysis for all the fourteen ports along with RMSE (Root mean square errors) is illustrated in the Table 3. The objective of this analysis is to understand the correlation and R^2 for the relation between dwell time and port performance parameters. The OLS test was performed to understand the impact of tracking on dwell time along with other variables. The independent sample T test was performed for the different parameters to evaluate the difference in means. Afterwards, root mean square error was calculated and top three ports (Port A, Port G and Port L) were selected for qualitative reasoning. The data in Table 3, is stack ranked for the RMSE (Root mean square error) in ascending orders, showcasing least RMSE.

The results of observing trends for various port performance parameters and dwell time is illustrated in the Figure 6. In majority of the cases, we can observe that dwell time variation is correlated with cycle, size, mode, and the other parameters. The graphical representation is the visual trend performance to understand the variation in dwell time. The data is visually depicted on a graph, with the x-axis representing a semi-annual time period and the y-axis representing dwell time measured in hours. The provided visual representation illustrates the fluctuations in the dwell time variable as a result of alterations in the corresponding independent variables. In case of Port A, the dwell time in export cycle is more than 2.69 times than in import cycle, 0.96 times in Rail over truck, almost similarly fluctuating in size 40 feet is 1.01 times of 20 feet, 1.19 times for delivery via CFS(container freight stations) over direct deliveries, 3.51 times higher in containers that are not tracked, and 0.61 times lower in laden containers. This variation is important to be researched and is covered in detail in subsequent chapters of this research study. For the Port G, The variation in export cycle is 2.5 times higher than in import cycle, almost similar however 0.96 lesser for rail container, 1.04 times for the 40 feet containers, 0.87 times lesser for the container delivered via CFS (container freight stations), 3.19 higher for container that did not have tracking technology and 0.49 times lesser for the stuffed containers. In case of Port L, The variation in export cycle is 2.3 times higher than in import cycle, 1.23 times higher in Rail mode, almost similar for sizes with 0.98 times lesser for the 40 feet containers, 0.5 times lesser for the container delivered via CFS (container freight stations), 3.5 higher for container that did not have tracking technology and 1.16 times higher for the stuffed containers.

Figure 7 illustrates the heat map of correlation between container performance parameters and dwell time for Port A, G and L. These are the ports with the lowest RMSE (Root mean square error) for which qualitative reasoning was performed for the variation in dwell time. It is to be observed that correlation between presence of tracking technology and dwell time is very high (Port A : 0.86, Port G : 0.85, Port L : 0.87, with $p < 0.001$).

5. Discussion

The data for the qualitative discussion was performed by structured interviews with the key operations resources of the port terminal. The questionnaire was prepared from the quantitative analysis performed in the section 3. Total eleven resources across the three ports with lowest RMSE were inter-viewed for the reasons of varying dwell time for each of the variable such as (*i*)Cycle(Import/Export), (*ii*)Size(20 feet/40 feet), (*iii*)Status(Empty/Laden), (*iv*) Mode(Truck/Rail), (*v*)Delivery(DPD – Direct Port Delivery or DPE – Direct Port Export), (*vi*)Tracking(Yes/No). The snowball approach for discussion interviews and expert responses was adopted which provided key details for

Table 3. Summary of data analysis (source: author)

Port	ρ: Tracking and Dwell Time	R^2	Sig. Tracking	Track	Cycle	Size	Mode	Status	Delivery	RMSE
A	0.86	0.78	<0.001	Y	Import	20	Rail	N	Y	15.6
G	0.85	0.761	<0.001	Y	Import	20	Rail	N	N	15.7
L	0.86	0.77	<0.001	Y	Import	40	Truck	Y	N	15.86
K	0.87	0.77	<0.001	Y	Import	20	Rail	Y	N	16.9
B	0.86	0.74	<0.001	Y	Import	20	Rail	Y	N	19.2
I	0.81	0.67	<0.001	Y	Import	40	NA	Y	Y	21.5
N	0.83	0.7	<0.001	Y	Import	40	Truck	N	N	22.3
M	0.84	0.71	<0.001	Y	Import	40	NA	N	N	23.15
J	0.82	0.68	<0.001	Y	Import	20	Truck	N	Y	23.4
H	0.82	0.667	<0.001	Y	Export	20	Rail	Y	Y	31.3
C	0.75	0.74	<0.001	Y	Import	40	Rail	Y	Y	34.6
F	0.82	0.67	<0.001	Y	Import	20	Rail	Y	Y	34.82
E	0.86	0.77	<0.001	Y	Import	20	Rail	N	N	36.9
D	0.62	0.40	<0.001	Y	Import	40	Rail	Y	N	47.3

the information gathering. The selection of discussion respondents was based on the level and their connection with the operations of the container transportation. Data analysis for the structured interviews was performed using the methodical approach of the selective coding technique (Strauss & Corbin, 1990; Saldaña, 2021).

The research on container dwell time in the academia lacks data sets and empirical studies (De Armas Jacomino et al., 2021). The few studies which were empirically researched either focused on single port scenario or had limited dimensions. The context in developing countries has been very limited and the one's which exist are either for single port or only the qualitative study. The information and transactional flow has been understood as an important parameters for terminal efficiency utilizing smart containers (Owusu-Oware et al., 2023). This research

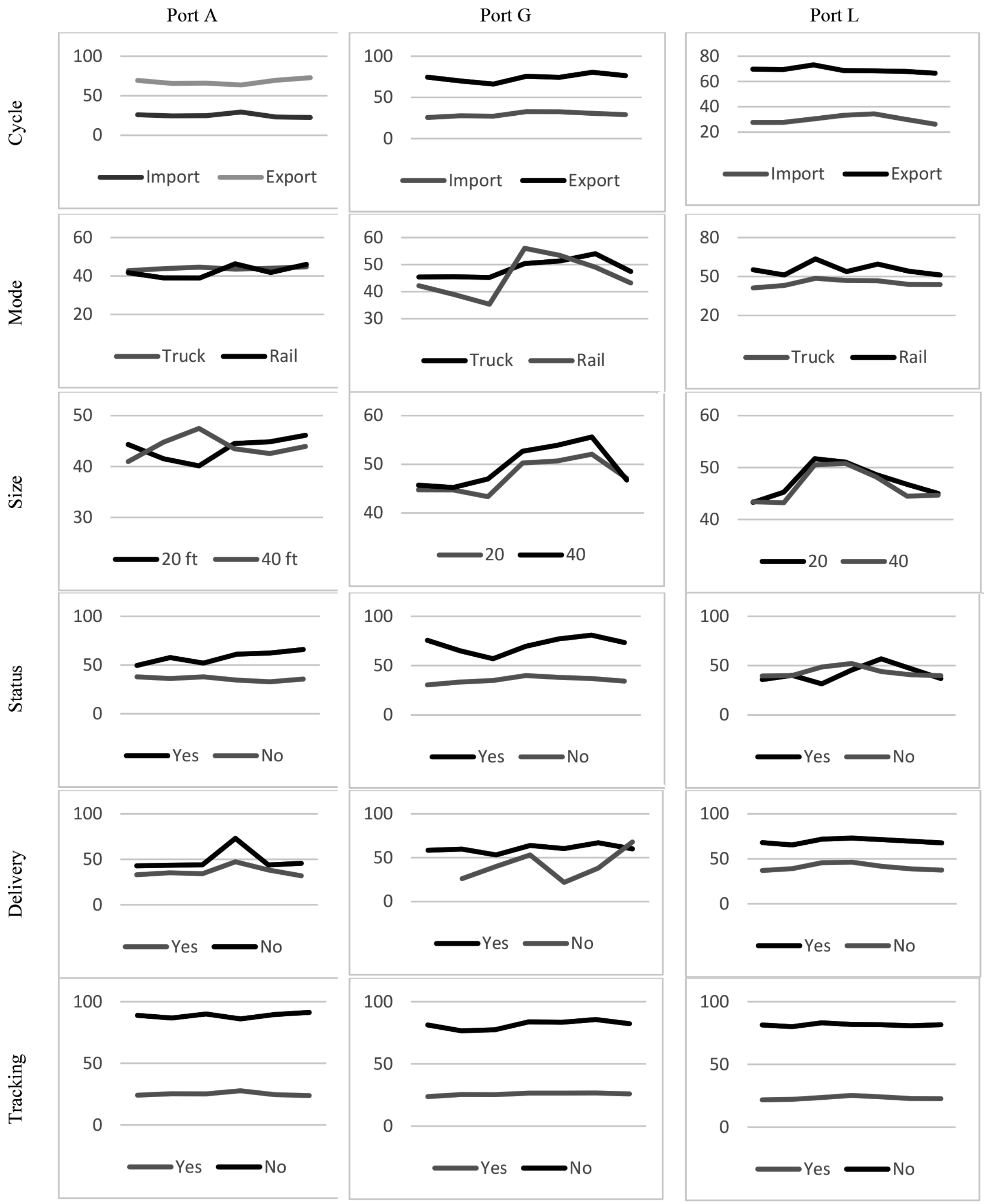


Figure 6. Dwell time and port performance parameters (source: author)

study adopted mixed method of quantitative and qualitative analysis to understand the variation in container dwell time. The quantitative method performed in section 4, illustrated on understanding the parameters which impacts the container dwell time. Subsequently section 4 results were discussed with the port operators to understand the qualitative reasoning. The discussion with the top three ports shortlisted on the basis of lowest root mean square error (Port A, Port G and Port L), was conducted. The qualitative reasoning for one port performing better than other on a specific parameter was collected. Figure 8 illustrates the reasoning for the port performance parameters such as cycle, size, mode, status and delivery. It was understood that all the ports performed better in the import cycle due to the demurrage charges imposed on the importers or

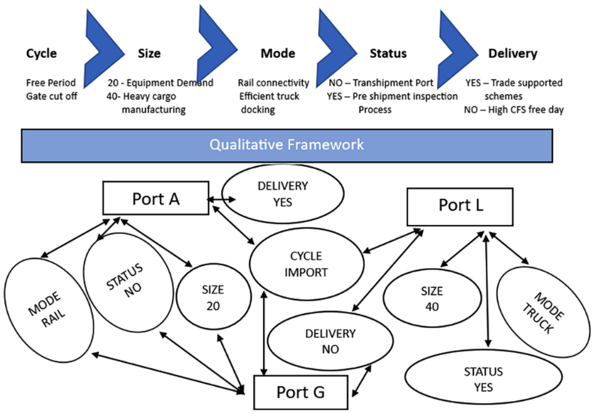


Figure 8. Qualitative framework for dwell time variation (source: author)

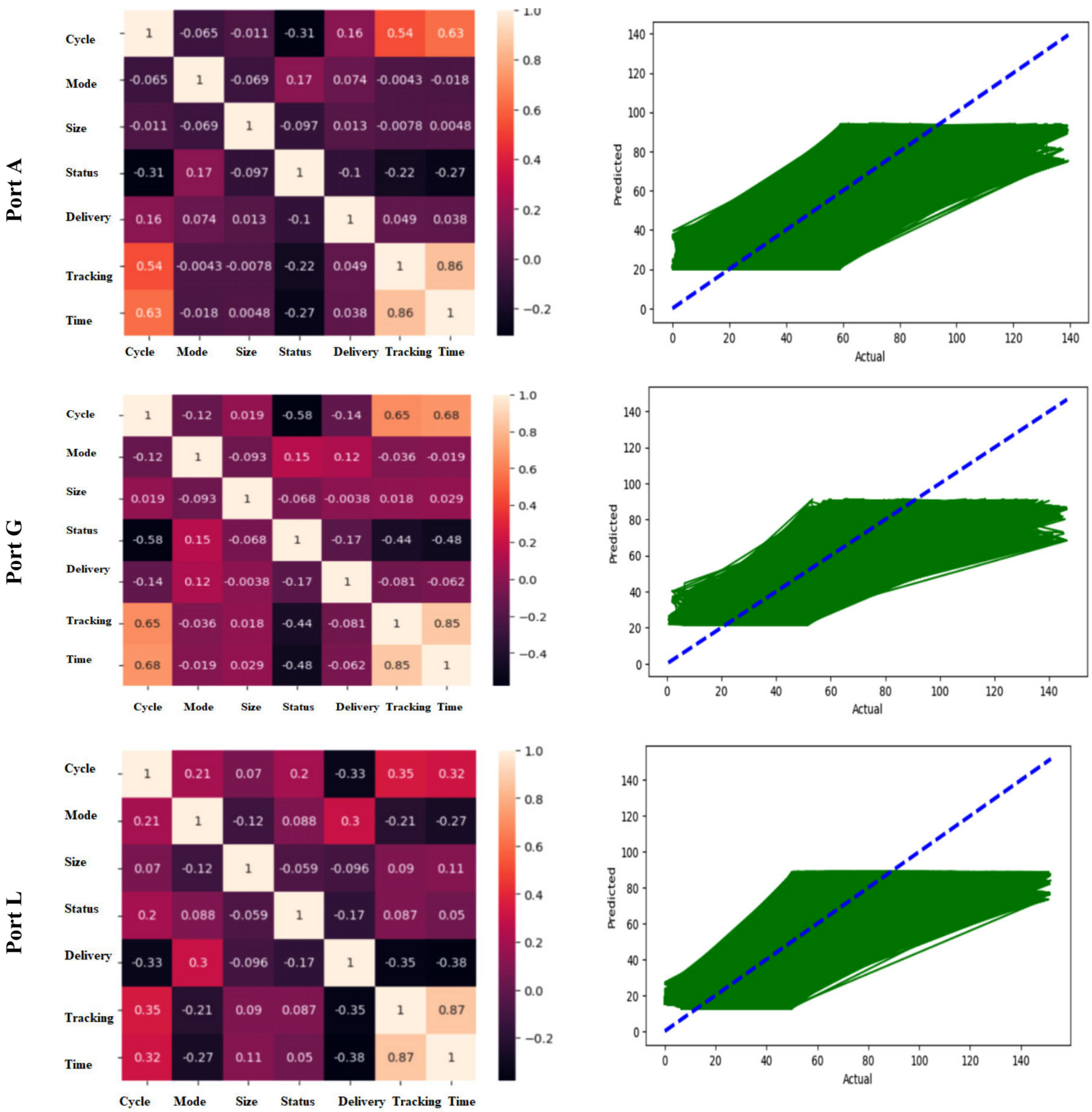


Figure 7. Correlation heat map and actual versus predicted (source: author)

handling CFS by the terminal operators. Thus, during the import journey the dwell time was better for all the ports. Also, during the export journey due to gate cut off timings prior to vessel departure, container is to be gated in four days in advance, thus the higher dwell time at ports.

For the container size parameters, it was understood that due to the nature of operations and equipment demand, Port A and Port G were doing good in twenty feet size and industries or manufacturing units in the vicinity of Port L were producing bulk/heavy cargo to be stuffed in forty feet containers. For the mode category Port A and Port G has good infrastructure for rail connectivity and had sustainability goals as part of their organizational objectives, whereas Port L had faster turnaround times for truck due to efficiency docking strategies. Due to the transshipment nature of Port A and G, the containers which were laden with cargo efficiently planned for movement and further connection to port of destinations. Additionally, the pre-inspection process was quite efficient at these locations to enable faster clearance. In the case of Port L, majority of the empty containers were transacted for relocation and repositioning. Further study will focus on sourcing data around commodity, port of loading and destination along with consignee specific clearance time. Such data points will enable research around customer centric behaviour clearance perspective for dwell times. The operations at container freight station and dwell time during transit must be studied for end to end dwell time evaluation.

6. Conclusions

This research study performed analysis on the variation in dwell time due to the major port performance parameters. The data analysis was performed on the 2.8 million container entries utilizing python machine learning for data sciences and SPSS software for independent T test. Dwell time which is one of the major port performance parameters varies due to certain reasons which are important for the research and practice. The study is conducted at the fourteen major ports of India with an objective to qualitatively analyses the reasoning for variance along with objectifying the standardization tools for further research.

The result illustrated on the data analysis of fourteen ports shows that continuous tracking has an impact on reduced dwell time, where in port managers efficiently pre-plan the containers to be offloaded and onloaded on a vessel with accurate load planning. The major factors of cycle, size, mode, status illustrated that due to the geographical circumstances and port specific strategies there was a considerable variance in dwell time at the ports. The top three ports (A, G and L) were short listed based on lowest RMSE (Root mean square error) 15.6, 15.7, 15.86% for qualitative reasoning. The prime reasons of free period and gate cut off for cycle, equipment demand and heavy cargo manufacturing for size, higher rail frequency, connectivity, sustainability goals and efficient truck docking strategies for mode were identified. Tran shipment ports, along with better pre-inspection clearance steps were few of the major reasons for empty/laden efficient movement. Trade support schemes along with free days due to high competition at CFS were reasons cited by trade for DPD/DPE.

The research contributed to science by providing research on a large multiport data set along with feature of tracking and tracing which is one of the important factors in logistics performance index. The study will also focus on developing a product for practice to have a real time idea of which port is performing on which parameter for the shortlisting of moving container via that port for its onward journey. The practice will be highly benefited by such approach and will foster in bridging the gap between academia and practice. The practice can utilize the results to identify and ship cargo by observing which factor is best performing factor for one port. The study had limitations of researching dwell time with in yard operations, that is from vessel berthing to gate out.

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