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Assessing carbon emissions reduction by incorporating automated monitoring system during transit: a case study

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Abstract: The green concept in operations is becoming an inevitable part of global maritime logistics activities and has an important influence on the improvement of efficiency and environmental performance. This paper aims to assess the continuous monitoring and tracking of container shipments at the ports in order to reduce carbon emissions thus improving environmental performance. In this research, near real-time RFID data tracing and tracking container cargo are shared by the automated monitoring system. The collected data gathered via digitalization is further analyzed to ensure a greener maritime logistics system. The significant findings of the study for the literature show that the actual fuel consumption is reduced when automated monitoring systems are used at the ports (Ports and CFS (Container freight station)). The reduced fuel consumption during the transit between the ports and CFS has resulted in a reduction in carbon emissions of environmental performance. The results show a 6 % reduction in emissions from port to CFS and 23% from CFS to ports. Thus, effective practices in Green Logistics are considered to be beneficial for carbon emissions. These findings contribute to the understanding and development of effective strategies for logistic operations using technologies to create a green performance. The study was performed in a certain set of environmental dimensions and the results may vary depending on the organization, which can be studied further in future research.

1 Introduction

Maritime Logistics is the foundation of national development and economic growth. India's freight transportation is likely to be approximately USD 150 Billion [1]. The transportation sector, including both road and maritime, is expected to rise thus, Global Maritime Logistics would have an impact on the world economy. 80% of the amount of world merchandise trade is borne by ships and a high proportion of developed countries' trade is also carried by ships [2]. In India, transport and logistics expense is 14% of its GDP, as opposed to 8% to 10% of the GDP for developed countries [3,4]. International airfare in India has further risen in the past ten years. The major issues for the high cost of transport in India are maritime logistics inefficiency and delays. Ports contribute effectively to the nations and global economy [5]. As ocean ports across economies transact cargo and constitute 80 % by volume, similar are the effects due to carbon emissions emitting 940 million tons of carbon dioxide per annum [6] and this quantum is expected to increase with the growing volume of trade [7].

Therefore, these inefficiencies occur as a result of the lack of proper basic infrastructure, lack of tracking and monitoring systems, lack of protection, and excessive fragmentation of the logistics industry. Contemporary technologies allow logistics processes to change the traditional way of functioning [8]. Maritime logistics will play a major role in the future economic growth of developing countries. It is important that their work needs to be productive and properly organized to support the increase in trade and GDP. Rao et al. say that the implementation of environmental principles can be an advantage in maritime logistics.

Managing the efficiency and productivity of the port is a vital factor in today's economy. Monitoring maritime logistics can forecast shipping routes and delivery times more accurately. The logistics monitoring system has advanced considerably since the comprehensive developments in computer technology and information systems.

Emerging technologies such as big data analytics, the Internet of Things, and cloud computing boost consistency and responsiveness [9]. When these technologies are evaluated in terms of climate, they help to minimize carbon emissions. GPS-enabled navigation and Internet of Things (IoT)-based devices can effectively assist the logistics industry to track efficiency since they can be used to optimize routes. Indian logistics companies need to use new technologies in their green logistics strategies.

In recent years, technology has offered a great opportunity for the logistics industry at ports, particularly in India, to address the environmental considerations at sea. Due to the absence of information systems in India for tracking marine containers, here is a case study of container transportation in ports through IT-based devices. The results of the study will be used to inspire other maritime logistics companies to use new technology to ensure green logistic operations at the ports.

After that, the rest of the paper is structured as follows. Section 2 briefly presented the literature review on green maritime logistics, the application of information technology, and performance management. Section 3 discusses the methodology of the research study. Furthermore, section 4 gives the case study of the research and the mathematical analysis. The conclusion deals with the findings, study management, and future.

2 Literature review

As a whole, the global maritime market is demanding. Since 1997, the International Maritime Organization (IMO) has been active in controlling shipping pollution. However, there have been some improvements on that front. In 2008, the Marine Environment Protection Committee (MEPC) of the IMO adopted amendments to the Regulations of Annex VI of the International Regulations for Preventing Collisions at Sea (MARPOL) that deal with SOx and NOx pollution.

On the GHG front, shipping is still not the responsibility of the United Nations Framework Convention on Climate Change (UNFCCC). Shipping is the top energy-consuming transportation and the top major polluter in the world [10]. According to a report from the Intergovernmental Maritime Organization, ships' sulfur dioxide emissions will cause more than 570,000 additional global premature deaths [11]. Recently, being “green” has become very common for maritime shipping due to the lack of harm to the environment. The research combined several sources of knowledge to estimate the exhaust emissions of ships [12].

In the modern world, ship speed is a major factor in traffic flow and environmental pollution. The development of a ship traffic emission model is a high spatial-temporal resolution for evaluating ship emissions. A research study produced results on the carbon emission of a leading shipping line while evaluating their network and its implications on marine policy [13]. The study identified the results of regions and ports of the east-west corridor. Various research studies have researched the EU emissions trading system (ETS) [14-17]. The European Commission proposed and defined the scope of ETS (Emissions trading system) for the emissions from the maritime sector [18].

The models considered the various vessels, operating modes, discharge equipment, time, and location. An analysis of the efficacy of the green flag incentive program and the effects of activities on vehicle fuel consumption and emissions in a port city is presented in [9]. The study suggested that implementing reducing speed and fuel transfer, decreased CO2, and SO2 emissions effectively. Moreover, to provide environmental protection, such regulation would affect the strategic decision of shipping lines. The econometric study showed the possible expense of pollution control and calculated its monetary benefits. The largest net profit of this new insurance is 1 billion euros a year, and the equivalent gross expense is 230 million euros a year.

The author suggests that the adoption of a reduction of speed and fuel transfer as a green strategy could result in pollutant emissions decreased and possible monetary incentives for the shipowner. This is done to study the relationship between rates, costs, and efforts of green in maritime shipping. According to the research, there are substantial reductions in the sum of CO2 emissions from steaming slowly relative to high-speed container transportation [19].

A proposition of a quantitative model to measure the voyage cost and landed logistics cost for carriers. The results of the analysis provide all sides with guidance for negotiation [20]. Several researchers have argued that the influences of competition, trade patterns, distribution of economic activity, product styles, and consumer strength are central elements of the shipping market. Another research explored the influence of the dynamic shipping industry on the distribution of trade and the level of economic activity [21]. To devise pollution reduction strategies, the baseline and projected output of pollutants, such as baseline and future emissions, are estimated in emission inventories.

Emission accounting is a policy instrument to rate goals for pollution reduction. Emission estimation models have been used to assess the possible environmental impacts and expense of mitigating risks. A port case study suggests that the supply of berths is crucial in their staterooms case study. There are experiments in which the findings were obtained by the reduction of the shipping speed to improve air quality and lower the emission of toxins [20].

Global AIS data combined with data about vessel characteristics was used to establish comparable vessel environmental indices (EIs) for major Chinese ports [20]. They listed many applications of IoT to enhance port operations, including RFID containers, electronic seals, port equipment condition tracking, engineering equipment asset management, and wireless automatic meter reading. Various research studies have emphasized reducing the impact of emissions by introducing logistics platforms for tracking and monitoring [22-24].

The research emphasized the role of IoT in ports to minimize out-of-date data collection, improve productivity in data collection, and ensure the immediate transmission of such data [25]. These authors identified an overall architecture of such a new generation of ports based on a series of Management Systems (MSs): intelligent planning system, intelligent warehouse system, intelligent vehicle (container) system, smart ship system, electronic monitoring network, and regional data center. The research identified that logistics was a priority sector that required growth. It was shown that there is a correlation between environmental and economical degradation and good green logistics performance in the Asian region.

The green maritime logistics sector will encourage economic development because it will help save money and the energy of the countries. Transportation activity has a significant impact on efficiency enhancements in green logistics. To reduce the effect of globalization problems, the performance management of green logistics activities is very vital [26]. The change in the logistics sector would further lead to a lower carbon footprint. It is challenging to provide green and cost-effective services of logistics when adequate monitoring is not performed.

The lack of implementation of new technology is reducing the effectiveness of logistics services. A study by Z. Bendiabdellah et al. [27] proved the effectiveness of the technology Vehicle to Grid (V2G) which can inject the power contained in the batteries of the electric vehicles (Evs) into the smart grid and thereby control the CO_2 emissions.

Green logistics management ensures that all logistics facilities and operations are handled under sustainability, with environmental issues considered. A major obstacle to logistics resource management systems is the issue of collecting real-time information on logistics infrastructure. Data obtained are either manual or computerized data.

There has to be robust knowledge sharing for Green maritime Logistics management. The given research has found a lack of awareness and the unregulated ability of trackless vehicle systems. Lots of transportation shipments are tracked and handled, globally. They built a foundation for monitoring and tracing activities and have more influence on logistics.

There are difficulties concerning tracking the efficiency of various green practices during the transportation of goods from port to CFS and from CFS to port. The role of green logistics monitoring and management in the future demand equal attention. This field requires research but is lacking in several aspects.

3 Methodology

This research aims to assess the influence of process automation (namely the introduction of RFID) on the reduction of carbon emissions and to propose the approach for automatization of data gathering and monitoring of container cargo. The operational process of cargo tracing and tracking was discussed with the practitioners and experts in the field, considering also the environmental compound of the process. The objective of the discussion was to understand the nature of container tracking operations by port operators for a check on transit time and dwell time of containers, that is directly or indirectly impacts carbon emissions as well. The challenges were considered together with the data comparison of the Logistic data bank project reports of the port industry in India.

As one of the solutions RFID implementations were considered the major technology for monitoring the process of container movement. Considering the lack of information on the data sharing in port the qualitative approach was chosen to provide a better understanding of the problem [28], as it could reveal new perspectives from the environmental point of view. The research comprises two parts: the first part is an interview with practitioners and experts of the port industry; the second is the case study of the data available from the Logistic Data Bank. The interview process comprised semi-structured in-depth interviews based on the snowball approach for discussion. This approach is one of the techniques which enabled researchers and responders to evaluate the response to specific questions and subsequently converse with other respondents while enabling a wider discussion on the topic.

In total there were eleven experts that took part in the interview. The choice of the participants was based on their deep knowledge of the practical side of the problem of congestion of containers and the influence of this congestion on the environmental aspect. The experts represented sectors such as ports, freight forwarders, and IT implementation partners for tracking, along with secondary data from data bank reports. The respondents comprised of hierarchy from directors, managers, and executives across management and operations. The specific set of questions focused on the importance of tracking, and monitoring transit time, dwell time, its management, and scientific impact on carbon reduction while keeping the climate protection goals of the port and country (if any). Subsequently, apart from controlling carbon emissions, other benefits that respondents utilize and foresee for an automated container tracking system. All the questions while interviewing focused on the automation of container tracking while digitizing documentation, notifications, payments, process transparency and customer experience. While respondents were encouraged to share their views, the technique assisted researchers in collating data across the board of container transportation management. The second part of the research consisted of the analysis of secondary sources and Logistic Data Bank project reports. The main idea was to identify the influence of the usage of automatization on the congestion at gate ports and, thus, on the environmental compound. Data analysis was based on the open, axial and selective coding technique [29], which was used to overcome the challenges of the analysis of unstructured data and to maintain qualitative consistency and structure.

4 Results

This section represents the detailed overview of the qualitative study along with the condensing of interview responses, represented in a summarized form (Table 1). The section also illustrates the calculation of carbon emissions through automated tracking data and producing results. Briefly, the study of a single tracking platform for container visibility logistics data bank along with analysis is briefed.

4.1 Qualitative study and data analysis

Data sharing through the tracking and tracing process supports the seamless data exchange between various container stakeholders, thus enabling terminal authorities, container freight stations, transporters, ship liners, and customers to share the data and identify the near real-time location of the container. This assists in responding quickly to any critical situation and leads to minimal waiting at gates and in transit for container movement.

This qualitative study data analysis was performed while evaluating the unstructured interviews performed utilizing the open, axial and selective coding techniques. This method is primarily selected to maintain the qualitative nature of evaluating tracking and its impact on carbon emissions. This method also assisted in overcoming the challenges of structuring and analyzing large unstructured interview data. Responses that were open-ended were analyzed by mapping and refining excerpts into categories for similar conceptual alignment. This process is supported in deriving relations while analyzing the data results and reducing them into similar categories. These were labeled as first, second and third-order aggregates.

Table 1 illustrates the resulting data structure on first, second and third-order affordances and transformational aggregate along with environmental factors that result as the part of the port adopting tracking process for visibility and reducing congestion time and tracking.

Table 1 Resulting data structure on interviews (Source: Author)

First Order	Second Order	Third Order Aggregates	Environmental Factors
Tracking and Tracing Electronic Notifications	Automation	Data Standardization	Yes
E-documentation. E-Payment	Process Management	Improved Efficiency	Yes
Congestion Management. On-time arrival of the container	Operations	Digital Innovation	Yes
Process transparency. Marketplace for truck management.	Innovation	Value added service	No
Customer notification. Availability of empty containers.	Customer Experience		No

Additional benefits of data standardization and efficient tracking benefits are as follows:

a) Information exchange between multiple container stakeholders for operational efficiency and productivity.

b) Congestion and delivery times of container, thus leading to a reduction in operational times and carbon emissions. Continuous tracking of container can lead to planning FIFO and LIFO strategies based on urgency of the cargo consumption at last mile user. With coordinated efforts performance parameters of ports, container freight station and transporter can be managed with effective control and better operations.

c) Managing and reducing the dwell time of the container. Coordinated operations between difference stakeholders with continuous information flow leads to better planning and thus reducing the dwell time of container during storage and in transit operations.

4.2 Logistics data bank project summary and mathematical analysis

This section illustrates on the logistics data project brief, while explaining the importance of single window tracking system for benefits on operations and carbon emission control. Subsequently, the focus is given on mathematically relating the reduction in transit time to carbon emissions calculation.

4.2.1 Logistics data bank project

Logistics Data Bank (LDB) is an information communication technology tracking solution that is dealing with supply chain stakeholders and provides tracking information [30]. The goal is to reduce transportation lead time and logistics costs by creating a system for tracking containers through the sharing of information in real-time.

The idea of Logistics Data Bank is to integrate and standardize the existing IT systems and provide a “single window”, thus managing the process effectively by helping in the visualization of container tracking from an end-to-end perspective. The process’s movement can be streamlined in transit and the result of visualized information can be analyzed in order to find the bottleneck of each entity in the supply chain. Visualization of the supply chain would lead to the enhancement of the process.

4.3 Carbon emission mathematical analysis

The mathematical calculation for the effects of carbon emission due to the reduced congestion in time by the automated monitoring system is performed in Table 2.

Table 2 Calculation criteria (Source: Authors)

Calculation formula	$$Carbon\ Emisson = a * b * c \quad (1)$$ where a is the Average Fuel consumption per hour b is the Average Transit time (per hour) and c is Carbon emitted per litre fuel consumption (for diesel)

Vehicle	Gross Vehicle weight (tonnes)	Axle cong	Speed	Fuel consumption upper limit (l/100km)	Average fuel consumption (l/100km)	Average fuel consumption (l/100km)	formulation	
N3 Tractor Trailers	40.2-49.0	6x2	40 km/hour	37.4	40	16 lr	Fuel used per hour = (Speed (40 kmh)*Fuel consumed (40lts))/(distance covered (10km))	
	40.2-49.0	6x4		43				
	CFS							
	Import Cycle				Export Cycle			
	Average distance covered by truck Port to CFS	20-Apr	21-Apr		Average distance covered by truck CFS to Port	20-Apr	21-Apr	
	19	2.4	2.3		19	4.8	3.7	
	Fuel consumed	39.12	36.8		Fuel consumed	76.8	59.2	
Carbon Emission in Import Cycle					Carbon Emission in Export Cycle			
Formula	For Dieseal (Kg CO2/ltr)	20-Apr	21-Apr		Formula	For Dieseal (Kg CO2/ltr)	20-Apr	21-Apr
Carbon emission = Fuel Consumed * Fuel Emission Factor	2.9	113.4	106.7		Carbon emission = Fuel Consumed * Fuel Emission Factor	2.9	222.7	171.7

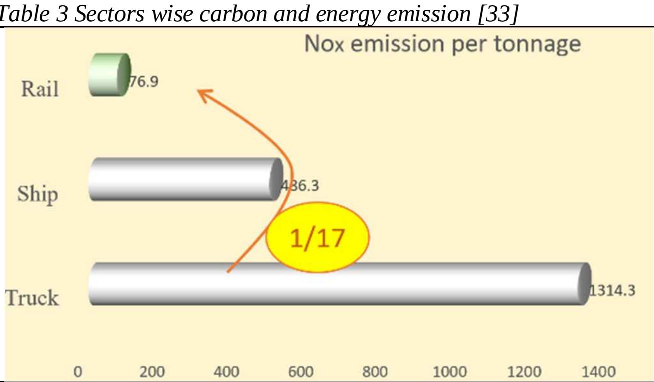
Assumption at that time	Assumption of truck/vehicle movement at a constant speed of 40 Kmph in the Indian scenario.
Reference of numerical value	International Council on Clean Transportation (2017) [31] Cefic and ECTA, Carbon emission for diesel fuel, (2011) [32]

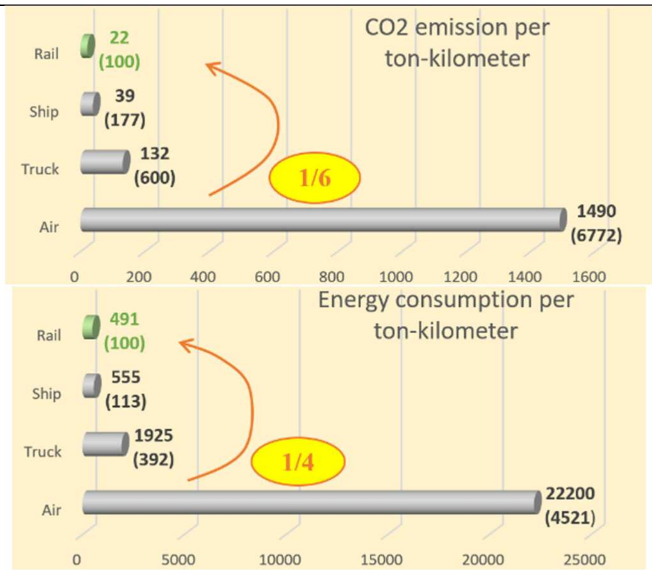
The traveling time or transit time is calculated based on the analysis of the secondary reports of the logistics data bank project which provides the timestamp (location 1, IN time & location 2 Out time) between two location(s). This is calculated by the difference in the time stamp of location 1 & Out timestamp of location 2. This travel time constitutes all container trucks that have transported cargo containers between Mumbai-Delhi industrial corridor. Logistics data bank data and reports are in reference to all the logistics container custodian stakeholders where RFID tags can be read, and the calculation includes Port Terminals, CFS's (Container freight station), toll plazas around JNPT port region & toll plazas on Maharashtra-Gujrat National highways.

The calculation of Carbon emission for diesel fuel is referred to as per the report published by [32]. A detailed summary of the analysis of carbon emission and the energy consumption is illustrated in Table 3.

Table 3 Sectors wise carbon and energy emission [33]

NO_x emissions classified through transportation



Transportation wise CO2 emissions and energy consumption	

The analysis of the effect of the automated monitoring system is performed for two legs of container transportation. First the movement between port to CFS and afterward between in transit to toll plans for the onward delivery for the last mile. Figure 1 illustrates the reduction in transit time from 2.4 hours to 2.3 hours for Port to CFS and 4.8 hours to 3.7 hours for CFS to Port during the time of 2019-2020 to 2020-202. This has resulted in a reduction in carbon emissions from 113.4 kg CO2 per liter to 106.7 kg CO2 for Port to CFS and 222.4 to 171.7 kg CO2 per liter for CFS to port. These reductions attributed to the reduction of 6% and 23% respectively in these two movements of container cargo.

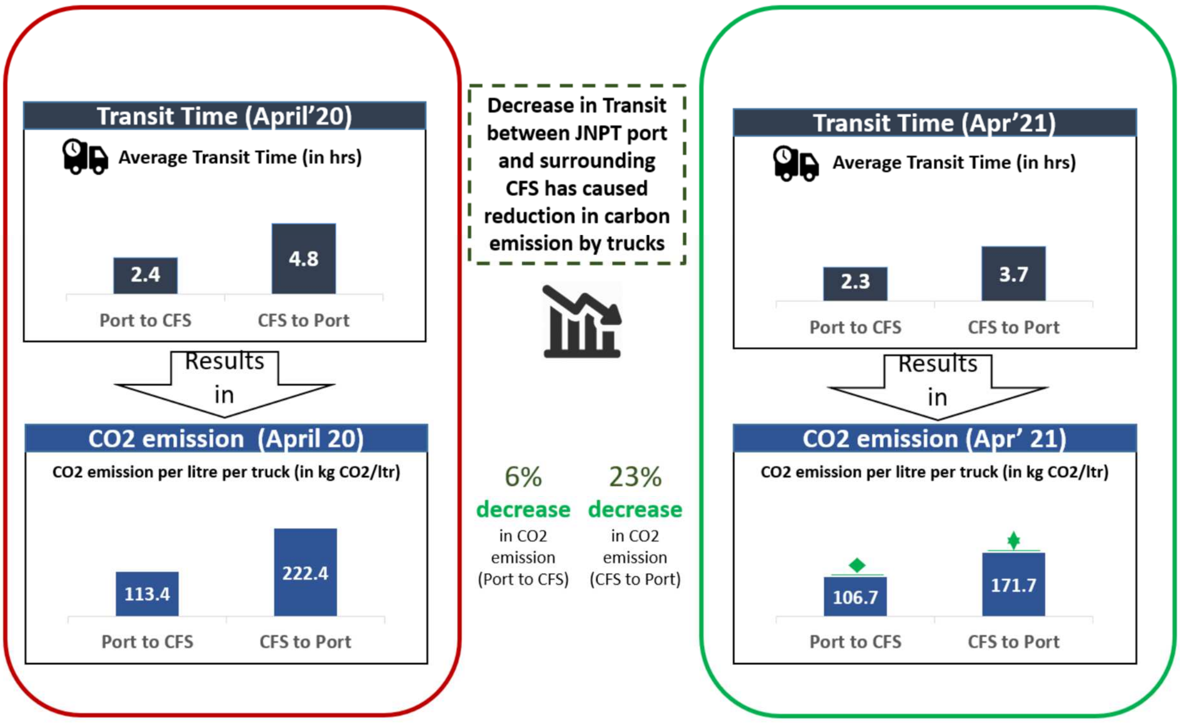


Figure 1 Comparison of reduction in congestion time through automated monitoring (Source: LDB Reports [34] and Authors computation)

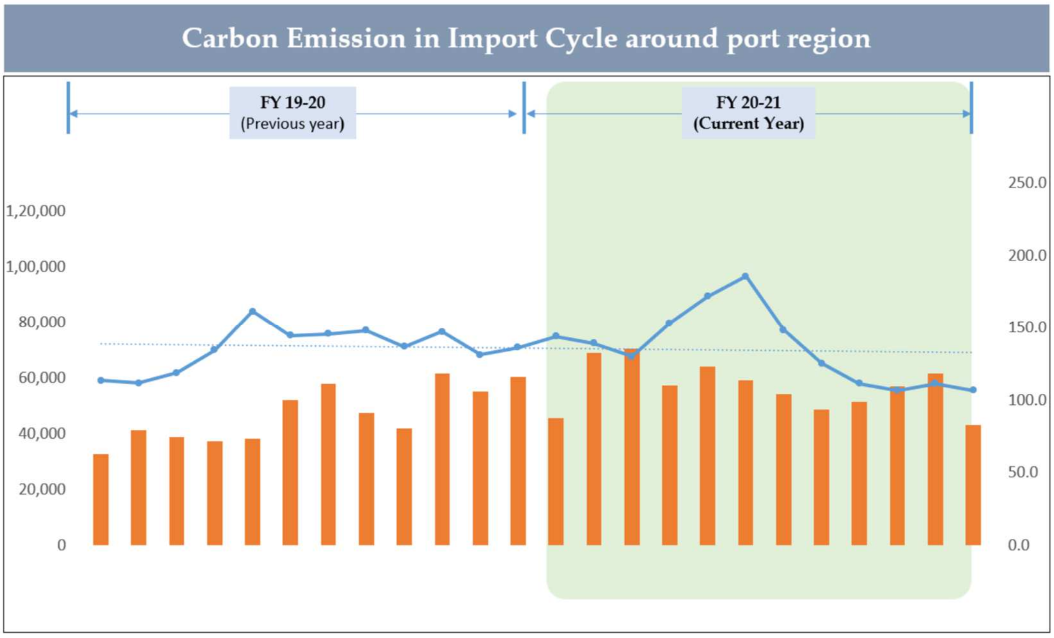


Figure 2 Annual comparison of carbon emission from Port to CFS (Import)
(Source: LDB reports [34]/authors computation)

Figure 2 illustrates the Carbon Emission during the import cycle between Port and CFS for the last financial year (FY 19-20 & FY 20-21) to observe the cyclical movement of container transportation during seasonal activity. The overall volume has increased in the year (FY 20-21) compared to the previous year (FY 19-20), however, the carbon emission has decreased by 6 % in the FY 20-21, due to the automated monitoring system resulting in continuous tracking and reduced congestion during in transit.

Figure 3 depicts the Carbon Emission during the Export cycle between CFS and Port for the financial year (FY 18-19 & FY 19-20). The overall volume has increased throughout the year (FY 19-20) compared to the previous year (FY 18-19), and the carbon emission has decreased by 23 % in the FY 19-20.

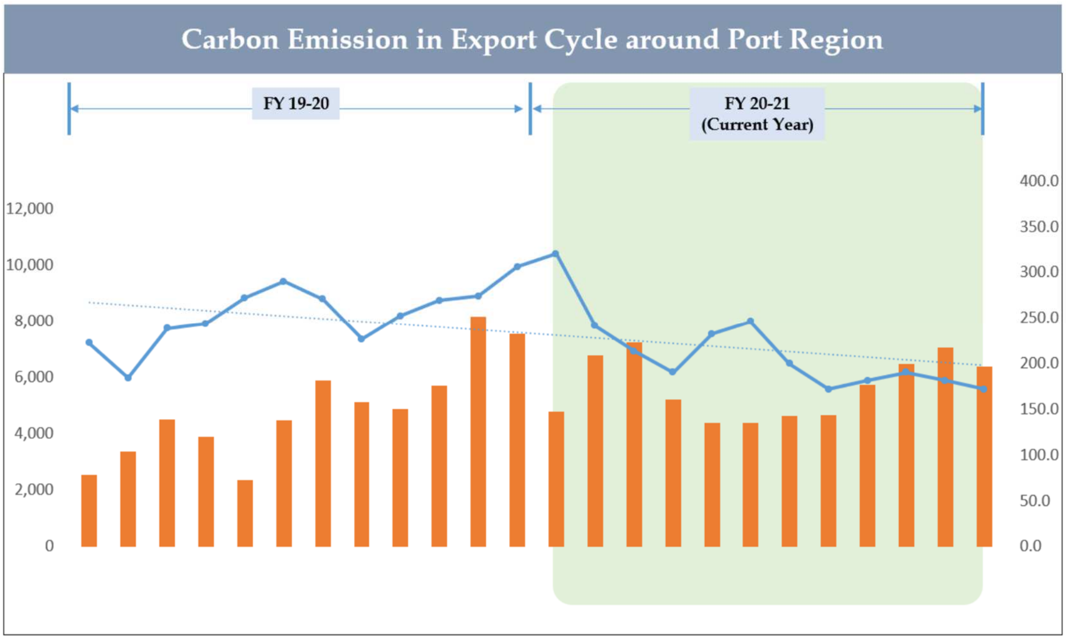


Figure 3 Annual comparison of carbon emission from CFS to Port (Export)
(Source: LDB reports [34]/authors computation)

Results displayed in Figures 2 and 3 illustrate that automated monitoring systems contribute to the reduction of congestion time and transit time of container cargo which is directly proportional to the reduction in carbon emissions during the traveling time of container cargo trucks.

5 Conclusion

Climate change across the globe is at the center stage for discussion at various strategic summits. This is primarily due to the growing demand for reduction in carbon emissions across sectors. This research study presented a mathematical analysis of the impact of the reduction in transit time and congestion time by an automated monitoring system in reducing carbon emissions. A case study of logistics data bank project is evaluated to present the effect of reduction in travel time of containers from Port to CFS (Import) and CFS to Port (Export). This travel time reduction leads to a reduction in congestion at gates and in transit, leading to a considerable decrease in carbon emissions.

It has been identified that implementing automated tracking and monitoring system for container movement between PORT and CFS leads to continuous tracking and, thus, positively influences the operational planning of cargo containers, as tracking and data storage can provide a better understanding of the current situation and contribute to the creation of the activities to desire the better results from the point of view of the creation of greener activities. This has led to a decrease in container cargo travel time from 2.4 hrs to 2.3 hrs for Port to CFS and 4.8 hours to 3.7 hours for CFS to Port. This reduction in container cargo travel time has led to a decrease in carbon emission from 113.4 kg CO2/ltr to 106.7 kg CO2/ltr from PORT to CFS and 222.4 kg CO2/ltr to 172.1 for CFS to PORT. The results are significant to be noted as it has led to a decrease in carbon emission by 6 % in the Import journey and 23 % in the Export journey of container cargo travel time.

An analysis on a year-on-year basis illustrated a considerable decrease in transit time leading to a reduction in carbon emissions. This also contributes significant results on the mathematical analysis of the carbon emission reduction based upon the automated monitoring system management. The results show that an automated monitoring system is vital for the timely planning of cargo to reduce cargo travel time.

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Review process

Single-blind peer review process.