1 **Benefits of Technology Adoption for Enhanced Integration of Port-Hinterland**
2 **Operations**

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4
5 **Agustina Calatayud**

6 Inter-American Development Bank
7 1300 New York Ave NW
8 Washington, DC 20577, United States
9 Email: mcalatayud@iadb.org

10
11 **Mario Monsreal, Corresponding Author**

12 Texas A&M Transportation Institute
13 402 Harvey Mitchell Parkway South
14 College Station, Texas 77845, United States
15 Email: m-monsreal@tti.tamu.edu
16 ORCID: 0000-0001-9856-8259

17
18 **John Mangan**

19 School of Engineering
20 Newcastle University
21 Armstrong Building, Newcastle upon Tyne, NE1 7RU, United Kingdom
22 Email: john.mangan@newcastle.ac.uk

23
24 **Juan Villa**

25 Texas A&M Transportation Institute
26 Shakespeare 15, 1002
27 Mexico City, Mexico 11590
28 Email: j-villa@tti.tamu.edu
29 ORCID: 0000-0002-9394-0119

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ABSTRACT

Because container shipping is the most important means of transportation for international trade, the integration of port-hinterland operations is critical to improve the performance of global supply chains. Information and communication technology (ICT) can assist port stakeholders in addressing bottlenecks and streamlining processes at the port-hinterland interface. However, ICT adoption is often hindered by uncertainties concerning expected gains. This paper shows that the adoption of well-established technologies for supply chain management—namely barcode and global positioning systems technology—can bring significant performance gains for the port-hinterland interface, as evidenced by increased container cycle time, utilization rates, and total throughput. In addition, results show the presence of diminishing returns when implementing multiple readers in the system. System dynamics and a unique database containing real data from the Hutchinson Terminal at the Port of Veracruz, Mexico—selected because it is one of the most important ports in the Americas—are used to show the benefits that both local (nodes) and global (supply chain) levels can obtain from ICT adoption. The results of this research will help to reduce uncertainty and incentivize ICT adoption by port stakeholders, particularly in developing countries where research is lagging. The model proposed herein can be applied to any port to analyze the impact of ICT adoption and provide support for the decision-making of port stakeholders.

Keywords: Maritime transportation; port operations; ICT; system dynamic simulation.

1 INTRODUCTION

2 Seaports are critical nodes in global supply chains. Maritime transportation accounts for
3 90 percent of international trade (*1*), and therefore the efficient operation of container terminals
4 and their seamless integration with both hinterland and seaside operations are key in improving
5 performance in global supply chains. This paper considers hinterland interface operations
6 pertaining to the logistics activities performed upon entry to the port both before and during
7 access to the port terminal.

8 Information and communication technology (ICT) can generate valuable data to monitor
9 supply chain performance and thus assist port stakeholders in addressing bottlenecks and
10 streamlining processes. Consequently, leading global ports such as Hamburg, Rotterdam, and
11 Singapore are implementing digitization strategies, including the use of Internet of Things and
12 artificial intelligence, as a means to generate information and create value for their users (*2*).
13 Indeed, these ports recognize that getting smarter is more important than growing in size and that
14 port–supply chain integration is the new efficiency frontier in maritime logistics (*3*). When data
15 generated by ICTs are shared among port stakeholders, such as terminal operators, customs
16 officers, shippers, and shipping and trucking companies, significant performance improvements
17 can be achieved, including reduced transit times, better asset utilization, and higher port
18 throughputs (*3*).

19 Much effort has been expended to optimize terminal operations through the
20 implementation of ICTs. For example, the use of terminal operating systems is increasingly
21 being adopted worldwide to plan and monitor asset utilization and workforce deployment, as
22 well as to control cargo movement and storage (*1*). In addition, port-seaside integration has
23 increased from the adoption of vessel traffic information systems, thereby enabling, for example,
24 enhanced waterway safety and improved terminal planning activities (*2*). By contrast, the use of
25 ICTs to strengthen the port-hinterland interface is lagging. As a result, both transit times and
26 congestion at port gates have grown, with negative impacts not only on port performance but
27 also on economic competitiveness (*1*). This deficiency is particularly evident in developing
28 countries in which processes are still paper based, and the information shared among port
29 stakeholders is scarce, fragmented, and outdated.

30 Uncertainty about expected gains is one of the main barriers hindering ICT adoption (*4*).
31 Thus, this paper aims to answer the following research question: To what extent can ICTs
32 improve the performance of port-hinterland operations? This question is explored by modeling
33 the impact of ICT adoption at one of the main container terminals in Latin America and the
34 Caribbean (LAC): Hutchinson Terminal at the Port of Veracruz, Mexico—the 15th largest
35 terminal in LAC—with a throughput of 1,117,304 TEU in 2017 (*5*). System dynamics and a
36 unique database containing real data are used to show the benefits that both local (nodes) and
37 global (supply chain) levels can obtain by adopting machine-readable tags and location
38 technologies. It is expected that the results of this research will help to reduce uncertainty and
39 thus incentivize ICT adoption by port stakeholders in developing countries.

40 This paper is organized as follows: Section 2 reviews available literature on port-
41 hinterland integration, the use of ICTs in maritime supply chains, and the benefits obtained from
42 it. Section 3 details the system dynamics methodology used to explore the benefits from ICT
43 adoption in port-hinterland operations. Section 4 presents and discusses the results obtained for
44 the Port of Veracruz. Finally, Section 5 presents the conclusions, limitations, and further work
45 related to this research.

LITERATURE REVIEW

Ports are central infrastructure nodes for global trade flows and key gateways to international markets. Because of the emergence of global value chains and the fragmentation of global production, ports have become strategic nodes in the wider logistics chain and a key part of global distribution channels (6, 7, 8). Within this critical role, leanness, agility, and seamlessness in supply chain management requires an increase in information sharing between port facilities and other supply chain nodes (7, 9). Available literature in the fields of maritime transportation and supply chain management has delineated the benefits that port stakeholders can obtain from such increased information sharing, including reduced order cycle times, a cut in inventories, and more flexible systems (9, 10). Beneficiaries also include port terminals due to the strong impact on port performance. Indeed, higher availability of information from both hinterland and seaside operations can help port terminals to better accommodate the growing capacity of maritime transportation in a highly fluctuating, competitive, low-margin industry (9, 10). The integration of supply chain information with port operations and systems is consonant with the emerging interest from the public, private, and academic sectors in moving toward integrated transport systems so that the joint management of infrastructure, services, policies, and information results in a more efficient and seamless movement of goods (3, 11).

ICTs are key to generating and sharing information among port stakeholders (9). Various ICTs are being used by port stakeholders around the world, from global positioning systems (GPSs) to detect and track movable objects such as containers, vessels, vehicles, and equipment, to port community systems to facilitate paperless procedures and the electronic coordination of port stakeholders through a common information platform (2). Available literature suggests that ICT adoption enhances visibility (the capability of sharing on-time and accurate data throughout the entire supply chain [12]) and supply chain integration (the coordination of operations among supply chain partners), thus improving global supply chain performance (13). Abundant literature confirms the benefits of ICT adoption to enhance port-seaside operations. For example, research has shown that more accurate information on vessel movements, sea traffic, and vessel arrival times can enhance berth planning and quay crane allocation. Together with this information, more precise data on tidal windows can help to better tackle the ship scheduling problem in restricted waterways (2).

By contrast, the use of ICTs to improve port-hinterland operations has received significantly less attention in the academic literature. Most available studies focus on analyzing the impact of truck appointment systems on the performance of port assets such as container yards and gantry cranes (14), as well as estimating the benefits of radiofrequency identification technology to optimize yard operations at container terminals (15). Among the main barriers to conducting research in this area are (a) low technology adoption by trucking companies and public-sector agencies that makes it difficult to empirically estimate gains from ICTs; and (b) reluctance from port stakeholders to share data on sensitive issues such as time and cost performance (15, 16). In turn, uncertainty about expected gains deters ICT adoption. This paper aims to fill this gap and provide evidence on the benefits of ICT adoption for port-hinterland operations by leveraging a unique database collected from one of the main container terminals in the LAC region. In addition, while most available research has focused on advanced economies, this paper contributes by generating knowledge for developing countries and explores whether ICT benefits can also be obtained in a less-advanced economic context.

METHODOLOGY

Simulation models are frequently used in the literature to test, evaluate, and forecast the results of both port terminals and supply chain strategies (17). Indeed, the simulation modeling of hinterland and seaside port operations constitutes a fundamental prerequisite for effective project planning in port development since the influence of numerous, often interactive, parameters has to be addressed at an early stage to maximize port performance (15). Among the available computer simulation methodologies, system dynamics modeling was chosen and used in this study to estimate the impact of ICT adoption on streamlining the port-hinterland interface. This method captures the dynamic of complex systems, which is the case for supply chains and their interaction with port terminals, in which actions taken by one actor can impact the entire supply chain. Causal relationships are incorporated into the model through causal loop diagrams, which help to describe how the multiple interdependent components of a system interact among themselves. In this way, system dynamics modeling demonstrates how complex behaviors may lead to certain results through the complex feedback loops among the components of the system (18). Several studies have shown that this method provides good results in predicting the actual operating system of the container terminals (19).

During the last half of 2018, data for model calibration were collected for the Hutchinson Terminal at the Port of Veracruz, Mexico, the 15th largest container terminal in LAC in 2017, according to throughput. The adoption of ICTs, namely machine-readable tags and GPS technologies, was simulated to explore whether container throughput between the logistics center located in the hinterland and the terminal yard increases with ICT adoption. Both quantitative and qualitative data were collected. This data collection process included 5 interviews with senior port representatives, lasting 2 to 3 hours. The information collected from these interviews related to insights on how the terminal operated and reviewing hard data on shipments. This information allows for model calibration and ensure the structural validity of the model.

Figure 1 shows the container export flow between the logistics service center outside the port terminal (hereafter referred to as CALT, the Spanish acronym) and the container yard at the port terminal (hereafter referred to as ICAVE, the Spanish acronym). Having no ICT adoption (base model), the registration process is currently performed manually, which entails the physical reception and visual inspection of shipment documentation and manually typing information into the terminal system and log. More specifically, when a container truck arrives at CALT, the receptionist manually checks truck plates, truck and container documentation, insurance policy, and more. After registration and revision at CALT, the container truck may wait, or it may immediately move to ICAVE, where it is again manually registered and where it stays in storage before moving to the port docks. In the base model, besides manual registration, no technology is available to locate containers at either CALT or ICAVE, so forklift drivers and other agents need to refer to previously determined yard positions and search visually for a specific container. Figure 1 shows the points of incidence (i.e. the points where the impact of the use of ICT technology is being measured in this study) in dotted (barcode) and squared (GPS) pattern fills.

Figure 1. Diagram of container export flow at Port of Veracruz.

1 The manual nature of these processes causes delays at both nodes, increases the
2 probability of errors, and hinders the ability of a seamless electronical exchange of information
3 among port stakeholders. For instance, interviews with port stakeholders identified the manual
4 container registration process at both CALT and ICAVE as a main bottleneck in the port-
5 hinterland interface. To address this problem, port stakeholders are considering implementing a
6 barcode technology aimed at increasing container throughput while minimizing error rates.
7 Barcodes are a type of machine-readable tag and a well-established technology in supply chain
8 management given that they are easy to implement and provide a cost-effective means to capture
9 information with a low error rate (20). Another key bottleneck identified by port stakeholders
10 was the uncertainty of container location at both CALT and ICAVE, which increases transit and
11 container storage times. Interviews suggested that the implementation of GPS technology is
12 being considered to tackle this issue so that information on container location is made available
13 to port stakeholders, thereby enabling a reduction of both cycle and idling times. Thus, the
14 system dynamic simulations described herein considered the impacts of both barcode and GPS
15 technology as a means to improve the port-hinterland interface at the Port of Veracruz
16 (technology model with technology incidence points in Figure 1). In line with available literature
17 (18, 19, 21), VENSIM software was used to perform the system dynamic simulations.

18 Five groups of variables were considered in the simulation models: (Container)
19 throughput (or volume variables), number of readings, transit times, loading and unloading
20 times, and storage times.

21 Causal loop diagrams were built to show the relations among variables, with arrows
22 linking input variables and their influence to additional variables. Figure 2 shows the causal loop
23 diagram for simulating barcode adoption at both CALT and ICAVE. To observe the different
24 effects that barcode adoption can have during the registration process, the number of readers, and
25 technology reading and error rates were changed. The arrows show that the implementation of
26 barcodes is expected to impact CALT and ICAVE's processing capacities (the capability for
27 both CALT and ICAVE to perform necessary operations with containers in order to ship them);
28 these output variables are shown in Figure 2. Finally, Figure 2 also shows the stock and flow
29 map, which refers to the physical structure of the port-hinterland interface at the Port of
30 Veracruz. Horizontal arrows represent flows, boxes represent nodes, and all other arrows
31 represent relations or influences.

Figure 2. Causal loop diagram for barcode adoption simulation.

Figure 3 shows the causal loop diagram for simulating barcode and GPS adoption at both CALT and ICAVE to improve container location. The model has the same basic structure as in the case of barcode adoption. The key difference is that it considers transit time to both CALT and ICAVE, which includes the time to locate the container at both nodes. It is expected that the adoption of GPS technology will reduce container location and transit time, therefore increasing both CALT and ICAVE throughputs.

Figure 3. Causal loop diagram for barcode and GPS adoption simulation.

It is important to highlight that in both technology cases: barcode, and barcode and GPS, technology changes are in reading and error rates, and transit time for the case considering GPS. Because of this, other operational factors such as number of yard cranes, are not considered in the model and consequently, in the evaluation.

Data from actual processes at both CALT and ICAVE were collected for the whole year of 2017 and inputted into the base models (i.e. manual registration and manual search for containers). Table 1 shows the input data for container registration at both CALT and ICAVE, with and without technology, for both technology cases (barcode and barcode plus GPS). Since technology has not been implemented at any of these nodes yet, the researchers referred to available literature to estimate the parameters for the models with technology adoption (barcode technology in the first case, and barcode plus GPS technologies in the second case). Hence, these improvement percentages were based on Ramaa (22), Geotab (23), and GFI Systems (24, 25). These studies were selected because they presented data from real operations, and thus already validated in an industry context. As Table 1 shows, reading (registration) times and storage times depicted an 81.1 percent improvement for the barcode technology input data, while transit times show a 26 percent improvement with GPS technology. The first case considered only the improvement percentage with barcode technology (i.e., without the improvement with the GPS technology), while in the second case both improvement percentages were considered, reading (registration) and storage times improvement percentages for barcode, and transit times for GPS technology.

Table 1. Input Data for Container Registration

Concept	Description	Manual		Technology		Unit
		Average	SD	Average	SD	
Volume	Overall Export Volume	407	143	407	143	Ct./day
No. of Readings/ Registrations	Registration in CALT	389	190	389	190	Ct./day
	Call from CALT	388	189	388	189	Ct./day
	Entrance Truck (ICAVE Doors)	441	220	441	220	Ct./day
	Registration Deposit in Patio	444	223	444	223	Ct./day
	Registry Removal from the Patio	444	223	444	223	Ct./day
	Dock Registration	443	222	443	222	Ct./day
	Registration of the Container	444	223	444	223	Ct./day
Reading (Registration) Times	Time of Registration at the CALT	32.5	38.9	6.1	7.4	Minutes
	Time of Registration at ICAVE Doors	3.5	1.2	0.7	0.2	Minutes
	Container Registration Time at ICAVE Yard	3.7	1.9	0.7	0.4	Minutes
Transit Times	CALT to Door	121.5	545.2	89.9	403.5	Minutes
	Yard to Dock	6.5	0.6	4.8	0.5	Minutes
Loading/Unloading Times	Loading or Unloading Times per Container	3.7		3.7		Minutes
Storage Time	CALT	216	138	40.8	26.1	Hours
	ICAVE	216	138	40.8	26.1	Hours

To evaluate the performance of the system, this study used four measures, or output variables:

1. Average throughput rate—The average number of containers passing through a system's reading point in a specific period of time.
2. Average error rate—The percentage of reading errors (e.g. misreads that represent actual versus system reads or identification discrepancies).
3. Average yard cycle time—Dwell time at the yard, in days, based on the throughput rate. In other words, the number of days it will take, at current throughput, to deplete the container volumes at the yards.
4. Total throughput—Total number of containers passing through a system's reading point in a specific period of time.

These four output variables were the basis of the results of the analyses.

System dynamic simulations were conducted to estimate the impact of technology adoption on output variables, namely average throughput rate, average error rate, average yard cycle time, and total throughput at the Port of Veracruz. Simulations were run for 365 iterations, which represented a year of operation. This simulation runtime is considered sufficient to visualize different behavior between cycles, if any, given that it comprises all operation seasons. Simulations took into account the availability of 1, 4, and 10 readers—officers (i.e., manual reading) in the case of the base model and barcode readers in the case of both technology models. Indeed, more than one reader is often used for container registration at logistics centers and port terminals.

RESULTS

Table 2 shows the results of the simulation experiments when considering barcode technology. Technology adoption provides large improvements when compared to the base model. With only one manual reader at CALT, throughput is very low at both CALT and ICARE because the manual reading time at CALT is extremely high (about 32 minutes vs. 3.5 at ICARE), which creates a bottleneck for container flow in port-hinterland operations. By adopting barcode technology, the bottleneck is resolved, and overall performance is improved. When using one barcode reader, the average throughput rate more than doubles, going from 43.8 to 106.7 containers/day. When the number of barcode readers increases from 1 to 4, the average throughput rate is more than three times higher, going from 106.7 to 392.4 containers/day. Interestingly, going from 4 to 10 barcode readers does not provide significant gains in average throughput rates; in other words, there are diminishing returns, showing that 4 readers may be sufficient to read the current number of containers per day. Noticeably, for all cases, the error rate decreases from 4 percent to 0.05 percent.

Table 2. Simulation Results with and without Barcode Adoption

	Base model (manual readers)			Technology model (barcode readers)		
	(1 CALT reader)	(4 CALT readers)	(10 CALT readers)	(1 CALT reader)	(4 CALT readers)	(10 CALT readers)
Average throughput rate (containers/day)	43.8	161.9	368.5	106.7	392.4	405.8
CALT	39.7	158.6	374.6	103.2	391.2	404.7
ICAVE	47.9	165.1	362.6	110.2	393.6	406.9
Average error rate (%)	4.02%	4.02%	4.02%	0.05 %	0.05 %	0.05 %
CALT	4.05%	4.05%	4.05%	0.05 %	0.05 %	0.05 %
ICAVE	3.98%	3.98%	3.98%	0.05 %	0.05 %	0.05 %

Figure 4 shows the changes in average throughput rate with the implementation of barcode technology at both CALT and ICAVE. Adopting just one barcode reader increases the average throughput rate at both CALT (about 260 percent growth; left plot) and ICAVE (about 230 percent growth; right plot).

Figure 4. Average throughput rates at CALT and ICAVE under base and technology models.

When GPS technology is implemented in addition to barcode, the average yard cycle time, average time at yard, and total throughput are improved. Table 3 shows the impact when implementing both barcode technology to streamline registration processes and GPS technology to improve container location at CALT and ICAVE. Total throughputs are increased, while average times at yard are reduced from about 10 days to 2 days for both nodes.

Table 3. Simulation Results with and without Barcode plus GPS Adoption

	Base model (manual process)			Technology model (barcode + GPS)		
	Base model (1 CALT reader)	Base model (4 CALT readers)	Base model (10 CALT readers)	Location system (1 CALT reader)	Location system (4 CALT readers)	Location system (10 CALT readers)
Average yard cycle time (days)	1,107	186.3	22.3	305.2	4.5	3.9
CALT	2,204	362.5	23.8	607.1	5.9	2.1
ICAVE	10	10.0	20.9	3.3	3.1	5.7

Total throughput (containers)	34,499	127,285	275,447	76,668	298,254	302,343
CALT	15,720	62,653	140,593	37,557	147,842	149,043
ICA VE	18,779	64,632	134,854	39,111	150,412	153,300
Average time at yard	9.7	9.7	9.7	1.9	1.9	1.9
CALT	9.6	9.6	9.6	2.0	2.0	2.0
ICA VE	9.7	9.7	9.7	1.8	1.8	1.8

Figures 5a and 5b present the impact on cycle time based on the adoption of different number of barcode readers at CALT and ICAVE, and GPS technology at both by showing the cycle time in days in the x axis. GPS+BC_1+1 indicates both technologies with 1 reader at CALT and 1 reader at ICAVE. GPS+BC_10+1 indicates both technologies with 10 readers at CALT and 1 reader at ICAVE. Correspondingly, NoTech_Reader1+1 and NoTech_Reader10+1 indicates 1 and 1, and 10 and 1 readers at CALT and ICAVE respectively. Although cycle time at CALT improves with 1 barcode reader, cycle times in both cases increase over time (Figure 5a left plot). When using 10 barcode readers at CALT, while leaving ICAVE with 1 barcode reader, cycle times at CALT remain stable in both cases (Figure 5a right plot). ICAVE's cycle times show a lump behavior after 100 days of simulation for both "NoTech" and "GPS+BC" cases; however, this accumulation is corrected by the system in both cases, resulting in an improvement with barcode and GPS technologies (Figure 5b).

Figure 5a. Cycle times at CALT with different number of barcode readers.

Figure 6b. Cycle times at ICAGE with different number of barcode readers.

These results show the improvement of cycle time that would be reflected in the connectivity to the downstream supply chain. In addition, they show that technology increases the number of containers moving through the seaport terminal and reduces the dwell time at yards. For instance, Table 1 shows 407 containers per day as the total export volume from the port (not necessarily throughput at a reading point). Examination of a specific registration (in Table 1) shows that CALT registrations (389) are lower than the ones yielded by the simulation using barcodes (404 in Table 2) and far lower than barcode plus GPS (302,343 containers throughput at CALT with 10 readers, divided by 365 days = 828, Table 3). The simulation starts by inputting information from Table 1, which makes the model receive 407 containers per day, and, depending on the number of readers (manual or with technology), the system can process a certain amount of those containers or all of them. These technology improvements increase the utilization rate and reduce the idling time of resources (i.e., containers). Moreover, although resource availability was not considered within the scope of this study, the fact that the simulation considers certain resources, such as fleet size and storage capacities, and demonstrates that increasing cycle time trends are dampened when technology is implemented denotes that available resources can handle the expected throughput increase in these scenarios.

CONCLUSION

This research provides evidence that ICT adoption can help improve the performance of port-hinterland operations. Specifically, the study used system dynamics simulation with data collected for the Hutchinson Terminal at the Port of Veracruz, Mexico considering the adoption of ICTs, namely machine-readable tags and GPS technologies. Five groups of variables were considered in the simulation models: (Container) throughput (or volume variables), number of readings, transit times, loading and unloading times, and storage times. The simulation was run for 365 days considering three different scenarios: No technology, barcoding only, and barcoding plus GPS. The results of the system dynamics simulations show that adoption of well-established technologies for supply chain management (namely barcode and GPS technology) can create significant performance gains in terms of container cycle time, utilization rates, and total throughput, thus streamlining operations for the supply chains that use the Port of Veracruz. In addition, results show diminishing returns when increasing the number barcode readers to more than 4, hence suggesting that 4 readers may be sufficient to read the current number of containers per day. Although resource availability was not considered within the scope of this

study, results suggest that the resources considered in the simulation can cope with throughput changes when technology is implemented. Thus, this study contributes to reduce the knowledge gap in performance measures and the impact of technology on the overall port performance in the available literature in both maritime transportation and supply chain management fields. Indeed, while much research has been conducted on the benefits of ICT adoption for port-seaside integration, similar studies for port-hinterland integration are scarce. This research is unique in that it provides results based on real data collected from one of the main port terminals in LAC countries: the Port of Veracruz in Mexico. Currently, the streamlining of port-hinterland operations is hindered by reliance on manual processes for container registration as well as lack of data on container location at both the logistics center and the port terminal. Notably, Veracruz is ranked as the third largest port in Mexico, handling approximately 1,000,000 TEUs yearly. Therefore, the results of this research will provide input for port stakeholders' decision-making and increase their incentives to move toward technologically enhanced operations, which is particularly important for developing countries. Indeed, this paper shows that the benefits from ICT adoption can also be obtained from a context that differs from the more researched experience of advanced economies. In these countries, terminals have achieved a higher degree of technology adoption, supply chain integration, and port productivity. Further research can include applying the simulation model to port-hinterland operations in other developing countries. Another step might include conducting experiments with the proposed technologies to overcome the intrinsic limitations of simulation models. In addition, one of the major handicaps in assessing technology implementation is the lack of adequate data to estimate input parameters. Future work can seek to engage technology providers and users to obtain technical specifications of specific technology and actual performance of such technologies from these two stakeholder groups.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: methodological approach: A. Calatayud, M. Monsreal, J. Mangan, J.C. Villa; literature review: A. Calatayud, M. Monsreal, J. Mangan, J.C. Villa; analysis and interpretation of results: M. Monsreal, A. Calatayud, J. Mangan, J. C. Villa; draft manuscript preparation: M. Monsreal, A. Calatayud, J. Mangan. All authors reviewed the results and approved the final version of the manuscript. The authors do not have any conflicts of interest to declare.

1 REFERENCES

- 2 1. United Nations Conference for Trade and Development. *Review of Maritime Transport 2018*.
3 <https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=2245>. Accessed July 10,
4 2019.
- 5 2. Heilig, L., and S. Voss. Information Systems in Seaports: A Categorization and Overview.
6 *Information Technology and Management*, 2017. 18(3): 179–201.
- 7 3. International Transport Forum. *Information Sharing for Efficient Maritime Logistics*.
8 <https://www.itf-oecd.org/sites/default/files/docs/information-sharing-maritime-logistics.pdf>.
9 Accessed July 10, 2019.
- 10 4. Reyes, P., S. Li, and J. Visich. Determinants of RFID Adoption Stage and Perceived
11 Benefits. *European Journal of Operational Research*, 2016. 254: 801–812.
- 12 5. United Nations Economic Commission for Latin America and the Caribbean. *Port Ranking*
13 *2017*. [https://www.cepal.org/es/infografias/ranking-puertos-top-20-america-latina-caribe-](https://www.cepal.org/es/infografias/ranking-puertos-top-20-america-latina-caribe-2017)
14 [2017](https://www.cepal.org/es/infografias/ranking-puertos-top-20-america-latina-caribe-2017). Accessed July 10, 2019.
- 15 6. Carbone, V., and M. De Martino. The Changing Role of Ports in Supply-Chain Management:
16 An Empirical Analysis. *Maritime Policy & Management*, 2003. 30: 305–320.
- 17 7. Panayides, P., and D. Song. Evaluating the Integration of Seaport Container Terminals in
18 Supply Chains. *International Journal of Physical Distribution and Logistics Management*,
19 2008. 38: 562–584.
- 20 8. Wang, T., and K. Cullinane. The Efficiency of European Container Terminals and
21 Implications for Supply Chain Management. *Maritime Economics & Logistics*, 2006. 8: 82–
22 99.
- 23 9. Woo, S. H., S. Pettit, and A. Beresford. An Assessment of the Integration of Seaports into
24 Supply Chains Using a Structural Equation Model. *Supply Chain Management: An*
25 *International Journal*, 2013. 18: 235–252.
- 26 10. Panayides, P., and D. W. Song. Maritime Logistics as an Emerging Discipline. *Maritime*
27 *Policy & Management*, 2013. 40: 295–308.
- 28 11. Calatayud, A., R. Palacin, J. Mangan, E. Jackson, and A. Ruiz-Rua. Understanding
29 Connectivity to International Markets: A Systematic Review. *Transport Reviews*, 2016.
30 36(6): 713–736.
- 31 12. Somapa, S., M. Cools, and W. Dullaert. Characterizing Supply Chain Visibility—A
32 Literature Review. *The International Journal of Logistics Management*, 2018.
33 doi:10.1108/IJLM-06-2016-0150.
- 34 13. Gonul, C., D. R. Nowicki, B. Sauser, and W. S. Randall. Impact of Cloud-Based Information
35 Sharing on Hospital Supply Chain Performance: A System Dynamics Framework.
36 *International Journal of Production Economics*, 2017. doi:10.1016/j.ijpe.2017.10.008.
- 37 14. Zhang, X., Q. Zeng, and Z. Yang. Optimization of Truck Appointments in Container
38 Terminals. *Maritime Economics & Logistics*, 2019. 21: 125–145.
- 39 15. Dragović, B., E. Tzannatos, and N. K. Park. Simulation Modelling in Ports and Container
40 Terminals: Literature Overview and Analysis by Research Field, Application Area and Tool.
41 *Flexible Services and Manufacturing Journal*, 2017. 29(1): 4–34.
- 42 16. Coronado, A., C. Lalwani, E. Coronado, and C. Coronado. Facilitating Multimodal Logistics
43 and Enabling Information Systems Connectivity through Wireless Vehicular Networks.
44 *International Journal of Production Economics*, 2009. 122: 229–240.
- 45 17. Sun, Z., L. H. Lee, E. P. Chew, and K. C. Tan. MicroPort: A General Simulation Platform for
46 Seaport Container Terminals. *Advanced Engineering Informatics*, 2012. 6(1): 80–89.

18. Wang, Y., C. Chou, and G. Yeo. Application and Improvement of a System Dynamics Model to Forecast the Volume of Containers. *Tamkang University of Science and Technology*, 2013. 16(2): 187–196.
19. Soares, C. J. M., and H. X. R. Neto. A Model for Predictable Capacity of a Container Terminal State: A System Dynamics Approach. *Journal of Traffic and Transportation Engineering*, 2016. 4: 141–154.
20. McCathie, L. *The Advantages and Disadvantages of Barcodes and Radio Frequency Identification in Supply Chain Management*. University of Wollongong Research Online, 2004.
21. Sha, M., and X. Huang. A System Dynamics Model for Port Operation System Based on Time, Quality and Profit. *2010 International Conference on Logistics Systems and Intelligent Management (ICLSIM)*, 2010. doi:10.1109/ICLSIM.2010.5461258.
22. Ramaa, A. *Design and Development of Performance Measurement System for Supply Chain: Chapter 7*. Avinashilingam Deemed University for Women, 2012.
23. Geotab. *Toromont Cat: Saving on Fleet Costs and Time*. <https://www.geotab.com/case-study/toromont-cat/>. Accessed Jan. 2019.
24. GFI Systems. *Benefits of Fleet Management*. <https://www.gfisystems.ca/benefits/>. Accessed Jan. 2019.
25. GFI Systems. *How GPS Tracking Improves Fleet Management*. Blog, Jan. 2018. <https://www.gfisystems.ca/blog/gps-tracking-improves-fleet-management/>. Accessed Jan. 2019.

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