Dynamic Smart Numbering of Modular Cargo Containers

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Abstract: In this paper, the authors identify the existence of container imbalance that occurs in different types of ports, depending on the type of inbound and outbound cargo they serve. The authors further analyze international trade realities and maritime companies’ requirements and identified inefficiencies. A comprehensive review of the relevant container regulations and identification standards is performed. Based on their findings, a paradigm change is proposed in the form of a modular container solution that uses disruptive digital technologies to ensure dynamic container identification (numbering) that can be exploited to overcome such inefficiencies. The technical requirements for coupling and decoupling operations are identified, along with detailed analysis of the requirements for embedded electronic components. Considering the strict container data exchange rules, the required changes in global container tracking systems are identified and explained. Coupling, decoupling, and serial number assignment procedures are proposed along with analysis of the measured lead times. Modularization and dynamic smart numbering are identified as viable disruptive technologies to address the global container imbalance. The authors contribute to the existing research on maritime transport sustainability by proposing a modular container solution, exploiting disruptive digital technologies, and clearly defining the prerequisites for the global introduction of the solution as a part of the digital transformation portfolio of involved stakeholders managing global container movements.

Keywords: container imbalance; modular containers; digitalization; electronic ink; shipping

1. Introduction

The operative expenses of existing standardized cargo movement equipment and containers on a global level are so large that the shipping industry’s inclinations are quite traditional and reluctant to accept disruptive innovations, even when their effect is undoubtedly beneficial for all stakeholders included in the logistics chain [1]. One probable reason for this perception is the fact that risk and uncertainty of new technologies in logistics are seen as negative, while research has proven that it can have a negative, negligible, or positive impact on the performance of transportation systems under different conditions [2]. Disruption occurrences in liner shipping operations affect schedule reliability and may increase the total cost of delivering cargoes at ports. If a vessel experiences a disruption occurrence either at the ports of call or at sea, the liner shipping company is required to decide on the schedule of recovery action to execute in order to recover from the resulting delays [3]. Previous studies on liner container shipping operations usually assume identical container ships deployed on the same shipping route. However, in real operations, this assumption does not always hold when considering the distinct capacities, ages, fuel efficiencies, cost structures, etc. of these ships [4]. One assumption of these considerations that could also be challenged is the fungibility of the underlying transport units: containers.

Presently, there are 5461 container ships with a combined capacity of about 24.6 million TEUs [5] operating on the world’s seas, linking continents and providing the transfer of
goods to communities around the globe. The liner shipping industry’s goal remains to prevent mismanagement and displacement of the containers carried on those ships. These carriers continue to explore and implement preventive and realistic measures to make that happen and welcome cooperation from governments and other stakeholders to accomplish this goal [6]. According to the latest available consolidated data for 2020, the international liner shipping industry transported approximately 815.6 million TEUs [7], with the latest cargo transported valuations being more than USD 4 trillion [8]. Proper packing and securing of containers and reporting accurate weights and sizes are very important to all involved parties in the safety maintenance of a container ship from the ship’s crew to shore-based workers, and they could have a positive impact on the port equipment as well as the environment. However, even with proper packing of the cargo into the container, correct container weight declaration, and proper stowage and securing aboard the ship, factors such as severe weather, rough seas, ship groundings, structural failures, and collisions can result in containers being lost at sea or misplaced on the terminals. In 2020 alone, it is estimated that 3000 containers were lost overboard, with a further 1000 being lost until October 2021 [9]. Nevertheless, the liner shipping industry remains committed to continuing to partner with governments and other stakeholders to enhance container safety in order to further reduce the number of such occurrences.

Different types of ports show different characteristics of container movement. There are ports that have balanced importing and exporting, where container imbalance is not high. However, in the case of net export ports and gateway and transshipment ports, container imbalance is more pronounced, especially in the ports that manage incoming containers containing goods where a large quantity can be loaded without weight being a significant limitation (where 40’ containers are usually used), as opposed to outgoing containers containing raw materials (where 20’ containers are typically used). This causes concentration of imported 20’ containers in certain ports simultaneous with lack of 40’ containers needed for export. Previous research has shown that the main features of the vessel scheduling problem are (1) the liner shipping route description, (2) service of vessels at ports, (3) fuel consumption, (4) port service frequency, (5) container inventory, (6) sailing speed selection, and (7) revenue estimation. This means that the container, as a main transport unit, is an important variable in the logistics planning process [10]. Compared with other modes of transportation, the sea freight industry is facing unprecedented and chaotic conditions, such as port congestion, labor strikes, severe weather conditions, shipping container shortages, and customs delays [11]. For port operators, the most important criterion for competitiveness is port location, followed by the service level, port tariffs, and port facilities. In contrast, the most important criterion for carriers is (port) operational efficiency [12].

The authors identified this issue, and they will propose a model to tackle this challenge: the creation of a modular container solution that can utilize mechanical coupling and decoupling procedures to be performed on-site and changing the physical properties of the container that are traditionally unchangeable. However, only a description of the required mechanical manipulations is not adequate, because every container carries a unique data identifier that is stored and exchanged between various information systems of all stakeholders involved on the route. There is a lack of research and scientific papers dealing with the impact of such a change on the information systems. To overcome this research gap and provide a better understanding of the changes required for adoption of the proposed modular container system, the authors analyzed the applicable regulations and conventions, including standardized messages for exchange of information about containers, and identified changes to be implemented. Furthermore, analysis of the available digital technologies suitable for the purpose are made, and appropriate technologies to be implemented with containers are identified and described in detail. Moreover, the goal of this research endeavor was to identify technologies and changes in the information systems required for adoption, keeping in mind the peculiarity of the container logistics chain.

To achieve this goal, the following research questions were addressed in this study:
• Which digital technologies can be exploited (and in what way) in order to overcome container imbalance and close the existing gap with minimum intervention in information systems and maintaining the required compliance with the identified standards and regulations?
• What are the relevant standards and regulations overseeing container traffic?
• What are the coupling and decoupling procedures to be adopted in order to enable modularization with smart container numbering, and what is their time-measured cost?

Finally, as an integral part of the research, the lead times and required tools have been observed and noted, along with the required prerequisites for successful execution of modular container operations.

2. Theoretical Background of Container Imbalance

Before expanding the topic of empty container flow, it is important to make certain clarifications about the countries, their ports, and how the production capacities and geographical situations differentiate them. Thus, there are several types of ports which can be divided into several categories:

“Net” Import Port. These are usually located in countries that are predominantly consumers of foreign products. There could be different reasons for this dependence on third countries, but the fact is that their demand for certain products is higher than the capacity of production. The port of Los Angeles, California (USA) could be an example of this kind of port. Importing is almost totally based on full containers, and exporting is more than 60% empty containers [13]. The fact that relatively few empty containers are imported leads to the realization that the container imbalance is not highly affecting this port, as their immediate market has more demand than a capacity to produce and sell to third countries.

“Net” Export Port. These ports are usually located in countries with a strong industrial capacity that covers all their internal demand and still allows them to sell abroad or to countries with a large capacity of raw material production. In these countries, the internal demand is either already covered via other routes or practically does not exist due to economic, social, or cultural reasons.

Gateway Port. These ports are usually located in countries that need products from abroad but which in turn have large internal production that allows them to sell products to third countries. These ports are usually connected well with demand and distribution centers and in a favorable geographical location that facilitates ship access. Such a case would be that of the ports of Valencia, Spain. In these ports, the unloading operations (imports) create a large volume of empty containers, and their impact can be seen on export cargo operations. This clearly identifies the ports where the use of modular containers would have an immediate effect in reducing the volume of trafficked empty containers.

Transshipment Port. These are usually ports with an excellent geographical situation that implies a minimum deviation from the main maritime routes, which makes them attractive for shipping companies since their main function is to unload containers and load them later on other ships that will take them to their final destination. These ports can coexist in the same country with gateway ports, since they are not governed by the internal market but their wider strategic situation. A clear case of a transshipment port is that of Algeciras, Spain which, given its excellent geographical location in the Strait of Gibraltar, makes it a key port for the distribution of containers from Asia to the rest of Europe and Africa.

Once the types of ports are defined in terms of balance of importing, exporting, and the resulting empty containers, further analysis of the flow of empty containers in them can be derived. The main question is why gateway ports load and discharge empty containers. The flow of containers in ports is marked by needs such as production capacity, production characteristics, market trends, and variation in the price of products, so countries vary in their capacity and need to import or export products. Gateway ports are usually the ports most affected by an imbalance of containers, and therefore their need to load and unload...
empty containers is the most pronounced. This fact is motivated by the difference between the types of products that its domestic market demands and those that cannot be produced internally or are more economical to import from third countries, as well as the types of products that can be manufactured domestically and sold abroad.

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Figure 1. China product export and import structure in 2019 (authors).

Figure 2 shows the details of the dynamics affecting the global container imbalance. China’s main exports, according to World Bank 2019 data, are capital goods at around 45%, machinery and electronics at 43%, and consumer goods at 36% (Figure 2a). Regarding their imports, the main commodities are electronics at 32% and raw materials at 27% [15] (Figure 2b). Therefore, there is a high percentage of the products manufactured and exported that has certain characteristics, as electronic and consumer goods tend to have a low density (kg/m$^3$). Therefore, they can be loaded in large quantities without weight being a limitation. This means that the type of container that is usually adapted to these characteristics is the 40′ container.

Analysis of the imports shows that a large percentage are raw materials and minerals, usually having a high density (kg/m$^3$). This means that the type of container best suited to these characteristics is the 20′ container. Therefore, China needs 40′ containers to load its exports but receives a large part of its imports in 20′ containers, which it cannot load with cargo. It is forced to import empty 40′ containers to cover its exports (Figure 2c), and since it does not have cargo for the 20′ containers in which its imports arrive, it has to “export” them empty (Figure 2d). That is the reason why the gateway ports need to load and discharge empty containers. The larger the difference in the products that a country imports and exports, the more pronounced the issue of container imbalance is.
In situations of the overall imbalance of trade and imbalance in the container type, in addition to seasonal imbalances in trade between particular markets, the supply chain is facing a surplus of empty shipping containers accumulating on one side or a shortage or excessive demand for empty shipping containers on the other [16]. The global full container trade reached 180 million TEUs in 2020, with the port turnover (including the handling of full, empty, and containers in transit) being 796 million TEUs in the same year [17]. This means that one in three containers are moved empty, and this adds up to a total of nearly 60 million empty container moves per year at an annual cost of USD 20 billion to the industry, or up to 8% of a shipping line’s operating costs. In addition, 56% of a container’s total life span is spent empty or “waiting” for the availability of cargo for transport or being repositioned to the point of demand [18]. The costs of empty container repositioning include the inland transport charges, terminal dues (storage and handling charges), and carriage by sea to the market or port where empty containers required for export are in short supply.

Therefore, a key aspect ports are facing at the present moment is the flow imbalance impacting the over-congestion and capacities of yards, berths, and roads. The COVID-19 pandemic created further disruptions in consumption and, therefore, in the distribution flow of goods. These disruptions have revealed how fragile and sensitive supply chains are. Ports and shipping lines must identify procedures and ensure human resources and equipment to avoid such inefficiencies and bottlenecks without compromising their security standards. The basic premise of this paper is that these processes can be adapted for use with modular containers and disruptive digital technologies, effectively achieving dynamic numbering and being easy to implement, contributing to the increase in ports’ capacities, efficiency, and efficacy. Moreover, they can help to restore container and good stocks back to a more favorable situation. This confirms the hypothesis of the preparatory research work, as it has been noticed that the scientific research in this area is very often oriented toward analysis of and improvements to already existing technologies. The maritime logistics industry is somewhat traditional and hesitant to introduce new solutions and technologies to tackle its main issues, so movements and changes in this area are often minor, and this is also reflected in the research topic. In order to achieve such an ambitious goal, the main container regulation and identification standards need to be identified, described, and taken into consideration, and a proposal for a novel dynamic container identification system supporting the scenario of joining and separating two 20’ modular container units.
to and from a single modular 40' container unit needs to be aligned with the existing data exchange system on container-pertinent data.

3. Review of Container Regulations and Identification Standards

In order to identify the technical possibilities of container modularization and digital technologies applicable to these operations, it is necessary to perform analysis of the applicable conventions, regulations, and standards that need to be respected when developing such innovative solutions.

3.1. ISO 6346:1995 Standard

ISO 6346:1995 (short: ISO 6346) is the International Organization for Standardization’s standard for container identification and marking [19]. Its purpose is to provide standard marks that give specific information about containers and which have an internationally accepted meaning. Simply by looking at the marks and symbols on the containers, it is easy to retrieve all the information needed in the shortest time possible, which prevents damage, danger, delays, and mistakes. The identification system consists of the owner code, equipment category identifier, serial number, and check digit [20], providing the most important and elementary information about the container. The owner’s code consists of three capital letters. The serial number consists of six Arabic numerals and a check digit, which validate the owner code and equipment category identifier, while the serial number is presented as one numeral [21]. Additionally, the size and type codes show additional details about the container, namely its length and height.

Some containers, however, do not follow the common scenario, so ISO 6346 also provides the codes for 45' and 48' containers [20]. The height of the container could be presented by the number 2, meaning an 8.5'-high container, or the number 5 for high cube containers. There are also standardized marks for some container types: a general purpose container (G1), refrigerated container (R1), platform container (P1), open top container (U1), and tank container (T1) [20].

Not all containers are adaptable for carrying all kinds of goods, but it is possible to determine which cargo the container is carrying simply by observing the container type mark. Operational marks are used to provide information about the container and can be divided into mandatory and optional marks. The purpose of the operational marks is to advise about some technical information and to draw attention to possible ensuing danger. The operational marks are the maximum gross, tare mass, air or surface container symbol, warning sign of overhead electrical danger, and height mark for containers above 8.5', which are mandatory marks, as well as the maximum net mass, which is an optional operational mark [20].

ISO 6346 specifies the location and appearance of the marks and symbols described above. The owner code, equipment category identifier, serial number, and check digit on the containers would preferably be in one single horizontal line. Another horizontal line containing the size and type code should be located under the first horizontal line. Operational marks should be presented near and below the described horizontal lines, and they should be presented with the symbols whose color, dimensions, and appearance are specified by the ISO 6346 standard [20].

3.2. TIR Convention

The TIR Convention establishes the framework for international transport by road and uncomplicated customs procedures for carriers, vehicles, and containers which comply with the stated rules and conditions. It was adopted on 14 November 1975, and it entered into force on 20 March 1978. The transportation of goods under the TIR Convention is executed without intermediate reloading across one or more frontiers between a customs office of departure and a customs office of destination. Procedures such as the payment of taxes and control of the documents, vehicles, and goods are delayed to the customs office of the destination. There is no need to perform those procedures at all the borders,
since the TIR plate serves as a guarantee of good practice. All the procedures are delayed for the customs office of the destination. Another important fact is that no specific or national documents are required when freight is carried under the TIR Convention, since all procedures are performed by the customs authority. Additionally, the container carrying the TIR plate and its freight should not be the subject to examination. However, there are some exceptions, such as when the examination could be performed in the customs office of the end route. This type of examination of the containers transported under the TIR plate shall be performed only when some irregularities are suspected [21].

There are some technical conditions required for the road vehicles and containers. There is a basic requirement that no freight can be removed from or introduced into the container without breaking the customs seal (it should be simply fixed onto the container), there should be no concealed space where goods could be hidden, and all spaces capable of accepting the freight should be available for customs inspections [21]. These requirements are formed to address the possible irregularities which could arise from the advantages of the carriage of goods under the customs seal.

The evidence of the container using TIR is a TIR Convention document printed in French and English [21] and the blue TIR plate affixed to the container. This creates numerous advantages for customs administrations and for the transport industry. First, the normal requirements of national transit procedures are reduced. Secondly, there is no need to operate national guarantees nor to fulfill national documents. Another advantage is the minimum risk of presenting inaccurate information [22], and therefore it is easier to control the information and its accuracy. Finally, the TIR Convention gives permission to customs authorities to examine the container or the vehicle if some irregularities are suspected, increasing safety and efficiency while decreasing time consumption and costs.

3.3. FAL Convention

The FAL Convention was issued by the International Maritime Organization in 1965 with the aim to prevent unnecessary delays in the maritime traffic. The convention consists of various suggestions with the purpose of facilitating maritime procedures. To prevent delays, the convention suggests cooperation between governments and uniformity in formalities and procedures [23]. These suggestions can be applied to container traffic as well. An amended version of the FAL Convention states that the use of freight containers in maritime traffic should be facilitated. To achieve that goal, acceptance of the simple declaration to the effect that temporarily imported containers will be re-exported within the time limit set by the state is necessary [24]. The reasonable time limit of a temporary import should be helpful in decreasing the delays in the traffic of containers.

In addition, the clearance of imported cargo or the loading of cargo under simplified control procedures and with minimal documentation should be applied to freight containers too [20]. The large number of documents makes the procedures complex and time-consuming. This is why the FAL Convention states that the usage of unnecessary documents and procedures should be avoided where possible.

The FAL Convention also states that the temporary admission of component parts of freight containers should be performed without the payment of customs duties or other taxes and charges when these parts are needed for the repair of freight containers already admitted [24]. At first, it may appear that the reduction of payment does not have much of an effect on the time consumption reduction, but it does. The taxes and charges are not only payments; they also invoke underlying procedures and require time and valid documents. Reduction of the taxes and charge payments applicable to the component parts speeds up the traffic of containers by shortening the time they spend waiting for them, during which they are not capable of handling cargo.

The FAL Convention not only prevents delays but also facilitates many different procedures in maritime business and makes them less time- and money-consuming. Following the FAL Convention suggestions in the transport of containers applies the same advantages to container traffic.
3.4. International Maritime Organization Conventions

The International Maritime Organization (IMO), as the global institutional body for maritime affairs and governance, has the legal capacity and responsibility to create, harmonize, and enforce regulations in all relevant areas of the maritime sector, including the transport of cargo and transportation means. For this purpose, among the very large number of various maritime legislation and provisions, the focus will be only on conventions and regulations with reference to the container shipping segment. A freight container is an article of transport equipment that is of a permanent character and accordingly strong enough to be suitable for repeated use. It is specially designed to facilitate the transport of goods by one or other modes of transport without intermediate reloading. The container can be secured or readily handled, having fittings for these purposes, and approved in accordance with the International Convention for Safe Containers (CSC) (1972) [25]. This convention was made in cooperation between the IMO and ISO in the form of a study on the safety of containers in marine transport, which led to drafting the International Convention for Safe Containers (CSC) by the IMO and the Economic Commission for Europe for regulating the design, strength, and maintenance of containers. Its main goal is coverage of the safety of containerization in maritime traffic.

The term “freight container” includes neither vehicles nor packaging. However, a freight container that is carried on a chassis is included. The external and internal dimensions of most freight containers are standardized by the International Organization for Standardization (ISO).

The maximum gross mass and the permitted payload of a freight container depend on standardized design parameters. It is required by the CSC that each freight container carries a CSC safety approval plate, where the maximum permitted gross mass is specified. Freight containers, including swap bodies and regional containers designed for stacking and approved under the CSC, are basically suitable for all modes of transport. However, freight containers having an allowable stacking mass of less than 192,000 kg marked on the approval plate require special stowage on board a ship, where the superimposed stacking mass will not exceed the permitted limits as marked on the plate. General purpose freight containers are available as closed freight containers, ventilated containers, and open top containers [25].

From the perspective of safety in container and general cargo handling and manipulations, serious and costly damage may occur to the cargo or the equipment. The types of cargo carried in freight containers have been diversified, and innovations like the use of flexitanks allow heavy, bulky items which were traditionally loaded directly into a ship’s hold (e.g., stone, steel, wastes, and project cargo) to be carried in cargo transport units. Therefore, IMO/ILO/UNECE adopted the Code of Practice for the Packing of Cargo Transport Units (CTU Code), aiming to give advice on the safe packing and securing of cargo transport units (CTUs) to those responsible agencies whose task it is to train people to pack such units. The theoretical details for packing and securing containers are outlined, as well as practical measures described to ensure the safe packing of containerized cargo. It is assumed that a shipper is responsible for ensuring that the information concerning the consignment, description of packages, and in the case of freight containers the verified gross mass is transmitted to the consignee.

The use of freight containers, swap bodies, vehicles, or other cargo transport units substantially reduces the physical hazards to which the cargo is exposed. Improper packing of cargo in such units or a lack of proper lashing are the common causes of personnel injury in handling or transport. Freight containers, swap bodies, and road trailers are required by applicable regulations to bear a safety approval plate [26].

There are two main goals of the CSC Convention: at a high level is the safety of human life in transport, as it has been recognized as the most precious thing which should be protected from the safety risks in maritime transport of containers, and facilitation of the international transport of containers by providing uniform international safety regulations which are applicable to all modes of transport [25]. Creating safety regulations applicable
internationally and in the whole traffic system should increase awareness of the importance of safety. The uniform safety regulations should also decrease the possibility of the usage of an inappropriate container. Aside from the safety benefits, uniform regulations improve the time consumption and efficiency. The CSC requires freight containers to be thoroughly examined 5 years after manufacturing and subsequently at least every 30 months, and two methods are used by the container industry to record that the freight container is fit for use [27]. The proof of compliance with the CSC requirements is the CSC plate fixed to the left door of the container, which serves as evidence that the container has been inspected and that it is safe to use.

The Customs Convention on Containers in 1972 recognizes containers as instruments of international traffic and establishes a framework for containers to be used in international transportation [28]. The convention covers various topics related to the international use of containers. It emphasizes the importance of the use of container symbols and marks and some technical conditions applicable to containers which may be accepted for international transport under the customs seal. The marks and symbols giving information about the containers should be placed in a visible location on the container. The information given by the marks shall be the identity of the owner or principal operator, the identity of the container, the tare mass of the container, the ISO number, and other relevant information [28]. The goal achieved by presenting the symbols and marks on the container is to identify the container just by looking at it and to warn about possible danger.

The Customs Convention on Containers contains numerous suggestions, with the aim of facilitating the customs procedures applicable to containers and increasing the safety of international traffic. According to the temporary admission and transport under the customs seal, there are some key benefits to this convention. First, containers are allowed temporary admission and re-exportation whether loaded or not. That was not the case before the acceptance of the convention. Secondly, the containers could be re-exported through a customs office different from the customs office of the temporary admission. This makes the process of re-exportation much easier and faster. Additionally, the convention has encouraged international cooperation, since it is open to worldwide membership. Another advantage created by the convention is the technical development of containers. Strict technical condition requirements have influenced the design of containers. An additional benefit which greatly improves the security of the transport system is the prevention of entry for terrorists, criminals, stowaways, and illegal cargo such as narcotics or weapons [28].

4. Technical Requirements for the Modular Container Solution

To identify the exact technical requirements for the new modular solution, the existing preconditions need to be identified, along with the characteristics of the new digital solution in terms of its hardware and required capabilities. The processes involved in the exchange of data on containers need to be established in order to identify and propose a set of changes required by the new modular solution.

4.1. Embedded Screen Serial Number Operations

In this chapter, attention is focused on the key aspects that facilitate the adoption of modular containers using dynamic numbering by the industry. An effort will be made to keep any changes to the existing system to a minimum as the industry is reluctant to adopt changes, since even minor changes are propagated globally and cause the need to adjust various information systems, increasing the adoption cost.

Container data displays should be resilient and have long-lasting autonomous power sources. Every container should have a unique and non-repeated number that is clearly visible according to international standards that identify it. Therefore, units must have a unique and unrepeatable number when they are working as units of 20’, and this number must have the same properties when they are connected and form a unit of 40’. Furthermore, a huge technical effort is required, as use of the product is carried out in
operational and weather conditions that could be considered extreme, so it is necessary to identify a highly resistant technology while the component and implementation costs are kept low.

LEDs require a continuous supply of electricity by means of batteries. The fact is that having to include high-capacity batteries in the container requires more maintenance and reviews of the units, in addition to compromising certain loads if the batteries get too hot and cause an incident. Therefore, LED technology does not completely meet the requirements needed for a product such as shipping containers, so it should be discarded. Electronic ink technology is the second available alternative, since such displays do not require a continuous supply of electricity for operation.

**Joining plates placement inside each modular container and the use of a reversible design.** The design of the joining system must be simple enough to such that the joining pieces of a modular container can be inserted inside each of them, and they can be attached to any other unit regardless of if they are on the left or right side, roof, or floor. The objective is also to avoid the need for joining pieces to be stocked worldwide, waiting to be used when needed. This premise is a must, as otherwise stocks should be stored, controlled, reported, and most importantly moved out from a location when a surplus appears for a demand area. If this would happen, the container imbalance problem would be replaced by a union pieces imbalance problem. Therefore, joining pieces must travel inside each modular container, being integral parts.

**No mobile pieces.** The use of mobile pieces should be avoided to avoid the threat of vandalism and decrease maintenance and damages. The design needs to be simple.

**Same standard adherence, with no changes in the existing handling and transport industry.** The union of two modular containers does not affect the external dimensions or container shape in comparison with the present international ISO and CSC standards. Terminal operators, depots, haulers, and rail operators cannot notice the difference between handling a standard unit vs. handling a modular container as 20′ or coupled as 40′. As large investments in machinery need to be made worldwide, an attempt to introduce something different than the existing solutions would be immediately rejected by the stakeholders.

**Less stock and easier maintenance.** The use of modular containers will reduce the needed stock to carry the same amount of cargo. Presently, containers waste part of their lifespans sailing empty between ports due to a surplus of empty units.

**Electronic and e-ink display maintenance and repair follows standard procedures.** The maintenance and repair of a modular container can be performed in exactly the same way as it is performed presently for standard containers. The only addition is the substitution of electronic parts and devices. At the moment, depot operators are not trained or qualified to perform this kind of maintenance. All digital and electronic devices need to be of a plug-and-play design. This includes systems on chip controllers, e-ink displays, and the printed circuits that control the displays. With this design, after a short training period, any able operator can test circuits and replace damaged devices.

**Resilience and antifragility embedded in the design.** An issue often encountered by customs is the situation in which the containers arriving at the ports can be manipulated by anyone with access to the ship or the terminals to alter the number of a container with an object of dubious legality. Current container numbers are vinyl stickers that identify them, so they can easily be manipulated. The use of electronic displays on containers could bring additional value in security terms to both customs and customers, as the numbering of the containers cannot be manually modified because the displays are fully integrated into the container design. This provides an additional degree of security in international traffic and opens a window of opportunity for the future incorporation of sensors, allowing the authorities to detect anomalous situations such as doors unexpectedly opening during the route. Some key points to be considered are the power source, temperature operating range, impact resistance, waterproofing, cost, and simple install and repair (“plug and play”):

- **Power source:** Containers must always have their identification visible in all the points established by the regulations. This represents a significant challenge for the use of
displays, since most of them need a constant power source. Lacking an electric power supply would be not only be critical but unacceptable for security reasons (compliance, robbery, smuggling, and track and trace).

- **Temperature operating range**: Shipping containers spend long periods stacked in places with extreme weather conditions, so the proposed technology needs to be able to withstand extreme temperatures.

- **Impact resistance**: During the carried-out operations, both in terminals and warehouses but also during the trip on board, the containers suffer different shocks and stresses. Displays to be used on containers must be sufficiently resistant to impacts and operations so that they do not stop working at any time and allow for continuous identification of the containers.

- **Waterproofing**: Waterproofing is a key part of maritime containers, since it is necessary to guarantee that the merchandise inside does not suffer water damage. Displays need to be resistant to saline water and protected from its effects during operation.

- **Cost**: All these requirements imply a cost (displays, electronics, and installation). It is of paramount importance that the used technology should be cheap enough to make a final product that is still attractive for shipping lines and end users to adopt it.

- **Plug and play**: Shipping containers are tough and resistant, and their repairs are carried out by professionals used to dealing with the materials and rough environment. Introducing displays in the containers can be simple, but they must be easily repaired worldwide by shipping lines or the container owners’ usual suppliers. Therefore, the system must be simple enough so that any operator can repair one after a short training period and certification.

Additional points may be considered, such as the flexion resistance and compression resistance.

### 4.2. Definition of Standards Relevant to Container Information Exchange

Shipping container industry information flow is based on the container number as the primary identifier. Once a commodity is loaded into a container, they are directly linked until they reach their destination. All the track and trace information of the transported goods from the time they are loaded in the exporter’s factory until they reach the destination is based on this number, which is also the link for all the documents being issued. Examples of such documents are a bill of lading, commercial invoice, customs clearance, the credit contract, cargo lists, the cargo manifest, and the import clearance that must be issued to withdraw the goods from the port of destination. That means that all the parties involved in the process of transporting the maritime containers are using the container number as the primary key to carry out their functions of transport, review, loading, unloading, or any other required operation. Therefore, the fact that international regulations establish that each container must have a unique and unrepeatable number is not taken lightly and needs to be at the core of any design of digital numbering of modular containers. This ensures that there are no two containers arriving at the same port with the same serial number but with different merchandise, sellers, and buyers, which would cause administrative and legal problems and a disruption in the process flow.

The United Nations CEFACT [29], working with the International Standards Organization (ISO), designed EDIFACT in 1986, and the protocol was formally adopted as a global standard in 1987. This fact, together with the advancement of new technologies associated with the transmission of information through the network, is when a viable alternative begins to emerge and have updated information on all operations carried out with the containers. The United Nations standardized the information interchange through those messages by using Electronic Data Interchange for Administration, Commerce and Transport (EN/EDIFACT) and defined the following standard messages that need to be considered when altering the information flow on container data:
1. **COPRAR** is a container discharge or loading ORDER message, which is used to order the container terminal that the containers specified must be discharged from a seagoing vessel or must be loaded into a seagoing vessel [30].

2. **CODECO** is a container gate-in and gate-out REPORT message by which a terminal, depot, etc. confirms that the containers specified have been delivered or picked up by the inland carrier (road, rail, or barge). This message can also be used to report internal terminal container movements (excluding loading and discharging the vessel) and to report a change in status of the container(s) without them having physically been moved [31].

3. **COARRI** is a container discharge or loading report message, by which the container terminal reports that the containers specified have been discharged from a seagoing vessel (discharged as ordered, overlanded, or shortlanded) or loaded onto a seagoing vessel [32].

4. **COPARN** is a container announcement message. The message contains an order to release, make available, accept, or call down containers or to announce the impending arrival of containers [33].

5. **IFTMIN** is a message from the party issuing an instruction regarding forwarding or transport services for a consignment under the agreed conditions to the party arranging the forwarding or transport services [34].

6. **FTMBF** is a firm booking message. It is a message from a party definitely booking forwarding or transport services for a consignment to the party providing those services. The message will contain the conditions under which the sender of the messages requires the services to take place [35].

7. **APERAK** is an application error and acknowledgement message. The function of this message is to inform a message issuer that his or her message has been received by the addressee’s application and has been rejected due to errors encountered during its processing in the application, as well as to acknowledge to a message issuer the receipt of his or her message by the addressee’s application [36].

All those messages, even when standardized, are flexible in terms of which segments or data can be shared. Knowing that the transfer of information is standardized and assimilated by the different members of the logistics chain, a methodology needs to be devised for how to incorporate the connection and disconnection operation of a modular container with the least possible impact for the users.

The regulations are clear and common in most countries of the world, as they are the result of decades of small evolutions and international agreements. An attempt to change or adjust them to a new and specific standard, even when possible, would require years of administrative negotiations between countries and international organizations. This fact effectively eliminates the possibility of any immediate start-up for a disruptive new product with a global impact that would change the way container information is exchanged. The only way to carry out the implementation of modular containers in the current logistics environment is by adapting to the current regulations and standards without having to pose major administrative changes.

Modular containers are a recent innovation and not yet in wide operation, so the proposed approach is technologically feasible but theoretical in its application. Aiming to envisage all possible changes, including those in information exchange, an analysis is required to identify software development changes in order to enable adequate track and trace control. Since the method of identifying modular containers differs from the present vinyl sticks, and both systems are supposed to be in force in the future, it is necessary to evaluate and analyze how modular containers’ serial number changes can be tracked and traced over the time and how original serial numbers are recovered when necessary after decoupling.

Once these adjustments are made in the shipping company’s equipment control module, it would be necessary to face the issue of how to transmit the information. Shipping containers are continuously traveling around the world, and operations are being car-
ried out with them in different countries and by different suppliers. There is a need for the container owner to have exhaustive control over the position of their units and the operations that are carried out with them. For years, this visibility was very poor, and shipping companies depended almost entirely on the information they received from their agents in each of the countries where the ships called and the containers were handled. Current control of containers is executed using a specific software module integrated into global container management software. This module is fed by the information from service providers (carriers, container terminals, and container depots) through information exchange messages in different formats (EDI, .xml, and others).

The minimum modifications in the software arising from the nature of modular container operations are as follows:

- Associating two container serial numbers (one corresponding to 20’ and the other to 40’) to a unique physical 20’ modular container;
- The inclusion of a new container number statuses—hold or active—as one of the two numbers will remain active, and the other will be inactive. In the 40’ configuration, both numbers may be inactive, depending on whether the 40’ serial number takes precedence over the other number.

4.3. Required Changes in Modular Containers’ Information Flow

Certain important conditions must be considered when defining a new information flow:

1. Modular containers can only be coupled or decoupled if they are empty. The characteristics of the units will make it impossible to perform any connection or disconnection operation, as well as a change in number, if they are full.
2. The operation should only be carried out in facilities authorized by the owners of the containers in a safe manner.

These two points will mark how the modular containers’ serial numbers will interchange during the trip. The common movements of a container during its trip are identified and described, as well as the electronic messages associated with these movements:

1. The modular containers are loaded in a factory with joining elements with the configuration of 40’ and a 40’ serial number.
2. The modular container is moved by truck from the factory to the port. In the IFTMIN and IFTMBF messages, the container number declared is the 40’ serial number.
3. The container enters the port terminal. In the COPARN and CODECO messages, the container number declared is the 40’ serial number.
4. The container is included in the loading list by the shipping line. In the shipping line software and in the COPRAR message, the container number declared is the 40’ serial number.
5. The container is loaded in the vessel by the terminal operator. In the COARRI message, the container number declared is the 40’ serial number.
6. The Cargo manifest reflects that the container number is the 40’ serial number.
7. The container is included in the discharge list. In the shipping line software and in the COPRAR message, the container number declared is the 40’ serial number.
8. The container is discharged from the vessel. In the COARRI message, the container number declared is the 40’ serial number.
9. The container is cleared by customs with the 40’ serial number.
10. The container leaves the terminal. In the CODECO message, the container number declared is the 40’ serial number.
11. The container arrives at the final receiver, and the container number remains the 40’ serial number.
12. The container is unloaded in the factory and is now empty. The container number remains the 40’ serial number.
13. The container is delivered empty to the depot. In the CODECO message, the container number declared is the 40′ serial number.

When the shipping line shows an increased need for 20′ containers, the following sequence of movements and related messages is executed:

1. The shipping line or modular container owner instructs the depot to disconnect the 40′ unit to have 2 20′ units available. The depot, with the modular container empty, carries out the disconnection operation and the renumbering. This is the only moment in which the container stops having the original number to have another number and a different configuration.

2. Modular container 1 leaves the depot as a 20′ unit with the preassigned 20′ serial number. In the CODECO message, the container number declared is the 20′ serial number.

3. Modular container 2 leaves the depot as a 20′ unit with the preassigned 20′ serial number. In the CODECO message, the container number declared is the 20′ serial number.

4. Modular container 1 is loaded with merchandise in factory 1 and with the configuration of 20′ and a 20′ serial number before being moved by truck to the port. In the IFTMIN and IFTMBF messages, the container number declared is the 20′ serial number.

5. Modular container 2 is loaded with merchandise in factory 2 and with a configuration of 20′ and a 20′ serial number before being moved by rail to the port. In the IFTMIN and IFTMBF messages, the container number declared is the 20′ serial number.

6. Modular container 1 enters the port terminal. In the COPARN and CODECO messages, the container’s declared identificator is the 20′ serial number.

7. Modular container 2 enters the port terminal. In the COPARN and CODECO messages, the container’s declared number is the 20′ serial number.

According to the proposed model, regardless of whether a standard or modular container is used, the serial number always remains the same when the unit is full. It is only at the point when the container is empty and there is a need for a type of container different than the one available that the coupling and uncoupling operations and the renumbering operations are carried out. Therefore, there is a specific moment when the need to report on container numbering occurs and by a specific type of service provider. This means that only the owner of the container (shipping line, leasing company, or similar) and the providers who perform the operations (depot or terminal) are the ones that need to modify their software. The rest of the logistic chain members (port, customs, authorities, and customers) will not need to perform any modifications in their information exchange systems.

Careful analysis of the CODECO message’s standard format shows that it was initially created for gate-in and gate-out information, but this message allows one to include more information in different segments, so developers have been using this flexibility to allow the exchange of more information. CODECO has an enormous possibility to add segments to reflect the different work or operations conducted with the containers, such as repairing, cleaning, and additional movements. This flexibility in the use of the segments to add information about the operations performed with the containers allows for concluding that there is an easy way to reflect the change in the container numbering and keep the traceability of the units and the container’s serial number change.

5. Results and Proposed Solution

After identification of the technical requirements and changes in the container information flow, it is possible to identify future container serial number operations using a novel digital solution and the changes in container numbering as a consequence of the coupling and decoupling operations.

5.1. Embedded Display Serial Number Operations

To ensure the correct operation of the displays on the containers at any temperature, the previously identified resilience factors need to be considered so the numbering will remain stable and visible on the containers both on their routes and in the place of loading and unloading. The market of outdoor displays is quite extensive, and there are several
display models based on different technologies, with all of them yielding satisfactory performance. Detailed analysis and comparison of the different types of displays and their specifications shows that a major portion of the displays need to have a constant flux of an electric supply to show the serial numbers. In the maritime environment, a power source such as a battery is considered a dangerous good and generates several additional problems, so electronic ink displays remain viable technology suitable for this purpose. These displays require only a short pulse of electricity to change the serial numbers on all displays on the container using small low-capacity alkaline AA-type batteries. The selected technology ensures that the serial number will always remain visible until the new electric pulse is provided, and the usage of the batteries is so low it will allow for prolonged, uninterrupted operations.

Additionally, the operational temperature range (TOR) of the selected technology is between $-40 \degree C$ and $85 \degree C$, which certainly meets and exceeds the operational needs for use in the maritime container sector.

Furthermore, single-number displays are better suited for this purpose instead of integrated seven-digit displays showing the total container number. Small single-number displays could be easily fixed to the corrugated panels of the container without having to modify the structure of the unit. They can differ depending on the container manufacturer, and the serial number can then be placed either horizontally or vertically over a modular container’s structure, reducing the number of spare parts and the repair cost.

As the displays are segmented and magnetic, the crack or malfunction of one of them does not imply the numbering is no longer visible; it simply will not change during the next connection or disconnection, but the valid current number will still be shown. When a damaged digit or display is detected, the one that must be replaced can be easily replaced due to the plug and play design. Replacement of the display would not imply a risk for the serial number integrity, as it only reflects the information provided by the algorithm that controls it. Therefore, when replacing the broken display with the new one, it will show the same number, as it is stored in the memory of the controller. The technology of the seven-segment displays brings the possibility of using a simple and cost-reduced option, but it also has additional benefits because in the case of a failure of one display (for example, due to the impact of the unit during the operations or technical failure of the display), it could be easily replaced with a new one at a lower cost in comparison with replacing a large integral display. The available technology allows for the display to be designed to resist impacts, compression, and bending. The use of magnetic e-ink displays, which receive instructions from a mini-CPU or system on a chip (e.g., Arduino) installed in a factory and being non-alterable after that moment, automatically instructs the containers to recognize if they are in a single (20’) or coupled (40’) mode and show the unique and unrepeatable container serial number for the detected working mode, regardless of whether the containers at a certain moment are decoupled 20’ or coupled 40’ units. The operating mode of a proposed modular container with dynamic numbering is shown in Figure 3.
Each 20’ container is assigned two serial numbers stored in a micro-controller. The first identifies it in a stand-alone state, and the second is for when it is connected to form a 40’ modular container.

Once the 20’ containers are joined to a modular 40’ container, the algorithm automatically changes the serial number to the 40’ configuration using the higher of the two preassigned serial numbers.

The 20’ containers do not have a preassigned pair and can freely be joined with any other 20’ container.

Figure 3. Schematic drawing of modular container serial number operations.

A modular container is initially a standard 20’ unit modified at its front end in a way that its panel has been replaced by a single rigid vertical door built of the same material (Corten steel [37]), which opens inward from the floor toward the roof. Once the panels of two modular containers are open and fixed to the roof, the joining plates can be fixed, enabling that the two units work and operate as a single standard 40’ container. It will retain the same external dimensions, strength, and payload acceptance, and it will be handled in the same way as a regular 40’ container using the present industry machinery. It has to
display a single unrepeatable serial number and will have the same internal dimension as a 40’ standard container, except in the central portion, where the internal height will be reduced by 10 cm due to the space required for the panel to be attached to the roof. The main structural difference is that the modular 40’ container will be a double-door container with two CSC plates screwed to each door. Each door will have one CSC plate for the modular container working as a 20’ unit and the second door for the unit working as a 40’ unit when coupled to another modular container. When operating as a 40’ unit, the serial number displayed on the e-ink displays will be the higher one of the two declared numbers on the 40’ CSC plates.

The main challenge of the new proposed model is how to achieve the transformation (union) of two 20’ modular containers into a 40’ container while maintaining a unique and unrepeatable number instead of two different numbers for the 20’ containers. This is the main requirement for the introduction of modular containers into the container industry without having to modify the international regulations in most countries and allow the immediacy of their use. To achieve this goal, each modular container will have two sets of serial numbers preassigned from the factory—one based on the rules for 20’ unit numbering and the other based on the rules for the 40’ unit—so when it is transported in the 20’ or 40’ mode, they will always have a unique and unrepeatable container number.

5.2. Modular Container Status Message Operations

Taking into consideration the physical properties of the modular containers and the previously identified messages used for data exchange with information systems of various logistics chain stakeholders, two main operations can be identified where a change in serial number is required:

- **The 2 × 20’ containers are connected, and a 40’ container becomes available:**
  - A new movement must be transmitted in the CODECO message: “hold” or “active”;
  - When the operation is finished, the depot should provide the information to the shipping line in 3 CODECO messages:
    - The first one is related to the first 20’ modular container with the information of “hold”. This should automatically put the container numbers in a “hold status” movement in the shipping line software;
    - The second one is related to the second 20’ modular container with the information of “hold”. This should automatically put the container numbers in a “hold status” movement in the shipping line software;
    - The third one is related to the new 40’ modular container with the information of “active”. This should automatically put the container numbers in an “active status” movement in the shipping line software;

- **The 1 × 40’ container is disconnected, and 2 × 20’ containers become available:**
  - A new movement must be transmitted in the CODECO message: “hold” or “active”;
  - When the operation is finished, the depot should provide the information to the shipping line in three CODECO messages:
    - The first one is related to the 40’ modular container with the information of “hold”. This should automatically put the container number in a “hold status” movement in the shipping line software;
    - The second one is related to the first new 20’ modular container with the information of “active”. This should automatically put the container numbers in an “active status” movement in the shipping line software;
    - The third one is related to the second new 20’ modular container with the information of “active”. This should automatically put the container numbers in an “active status” movement in the shipping line software.
Deriving further from the nature of the required changes in information systems, it is possible to conclude that changes would be required in the software packages of shipping lines and depots while all other stakeholders could keep their systems intact, as the envisaged serial number operations do not reflect on them. Changes in the software of the shipping lines depend on its configuration and the interaction between the different modules of the system. Changes in the information systems of depots will be simple, as they do not have the need to register a container number with two associated serial numbers, even though they process two different sets of serial numbers (accept one or two units with one numbering and deliver one or two units with a different numbering). They will only transmit the information of the operations carried out with traceability maintained in the shipowner’s system.

6. Discussion

The use of electronic displays with modular containers to facilitate renumbering, smart numbering, and the rapid incorporation of this new disruptive digital technology to the sector, as there will not be the need to modify the current administrative regulations, opens the door to a huge number of opportunities for the use of digital tools to facilitate the flow of information, security, and customs control for cargo in maritime containers. The logistics chain and the actors involved in it increasingly need visibility into the events that occur during the transport of containers. This ability to have the information while the event occurs allows one to make decisions to solve or avoid problems.

Even though the exchange of information is constantly improving, there is still a marked lack of transparent information, as far as information is concerned, from the moment when the container arrives at the cargo terminal until the moment the container passes customs clearance at the destination port. There are still occurrences where containers are not loaded to the ship or lost among thousands of containers stacked in the terminals, and on many occasions, it can take days to physically locate such a container within the terminal facility. The incorporation of electronic displays with the containers allows not only for renumbering the modular containers so that they have a unique and unrepeatable number but also multiple options to identify and provide the necessary information to each member of the logistics chain at the time required.

When logistics operations are carried out with maritime containers, multiple actors are involved in the attempt to balance the information between producers and buyers, shipping lines, and other involved stakeholders (e.g., governmental administrations and customs). This involves the management of multiple documents (e.g., invoices, loading lists, and shipping documents) that prove completion of the certain action and that the registration and validation processes of these procedures are properly executed. They need to be validated by all parties involved, and the most important part of the flow is completed by worldwide customs offices that need to perform security inspections of the cargo arriving at a port.

With the huge volume of containers moving from one side to other, it is impossible to inspect more than 2–5% of the containers arriving at a port without collapsing the inspection point or generating a queue [38]. Moreover, inspections are linked with a rise in the cost of shipments, which is borne by the final receiver of the goods or the customer. Therefore, there is a key point in how to increase the security of the containers to allow customs to perform easy identification and analysis and simultaneously decrease the need for inspections. Electronic numbering in shipping containers means that it cannot be modified from the outside simply by scratching one of the numbers and replacing it with another, as is currently the case. Electronic numbering ensures that the numbering sequence is perfectly sealed and inaccessible to any unauthorized operator, preventing this type of illegal behavior. Further technological advances in the IoT (e.g., QR displays, blockchain communication, and GPS to control the positioning), complemented by the requirements that customs could utilize (e.g., an unexpected door opening or a place where rgw container
has been stopped for more than 4 h.) would help the customs officers to have an idea about the potential risk of the containers without the need for a physical inspection.

6.1. Methodology Used and Observed Times

It is of paramount importance to identify the time needed for coupling and decoupling the modular containers. Proper identification of this time is the only way to accurately estimate the potential future savings obtained from its use. The involved cost of handling in terminals and depots is fixed, transparent, and can be easily calculated by each container operator according to their individual agreements worldwide. Other savings can be estimated based on the container production cost, average sailing time, and previous experience, including modular containers’ maintenance costs and empty container sailing times, which constitute unproductive time offshore. The coupling and decoupling operation lead time is still an unknown variable, and considering that it involves labor costs, it can have a positive, neutral, or negative economic impact on the owners, operators, or end users. Therefore, this cost is crucial to enhancing or prohibiting the use of modular containers.

Being in front of something new, there is a baseline for comparison: the extrapolation of a simulation to obtain a realistic, accurate, and trustable operation time and cost. Therefore, only real testing performed by the operators could give the initial values to be used as a baseline for further calculations and decision making. The coupling and decoupling prototypes require a certain amount of time until a sufficient operative learning curve has been reached. Only after this learning period can the average operation lead time and cost be calculated. Therefore, a series of tests were performed starting in May 2019 during 2019 and 2020 at the Barcelona Container Depot facilities using the ESES company’s resources and Connectainer [39] prototype as a part of the ePIcenter H2020 project [40]. The proposed solution opens up many possibilities for the implementation of other disruptive technologies like the blockchain, IoT, track and trace, and new sealing systems [41]. Figure 4 shows a traditional container and its markings (left side) and a prototype’s electronic ink-based display marking of the modular container’s serial number (right side).

Figure 4. Conventional container markings and modular 40’ container with electronic ink display.

6.2. Operative Precondition Identification

The prototypes’ manufacturer and engineer were asked to perform a fast coupling operation after the prototypes were demonstrated to skilled operators and depot workshop managers for the work to be performed, and they were asked for their best estimations based on their experience to carry out a coupling operation. Their answers were the basis for setting up an initial precondition list and target lead time to perform the operation. The initial precondition list is the following:

- Two 76-mm limit pieces to be placed between the two units before they were attached;
- Two workers were required instead of one to speed up the operation in a safe manner;
- The use of two ladders: one for each operator;
- The use of two electric or pneumatic screwdrivers: one for each operator;
- The use of industry standard personal protection equipment;
- A prepared connection wire to plug in the two Arduinos.

The target lead time estimates used the expert’s estimate method:
- Estimated manufacturer coupling operation lead time: 1 h 30 m;
- Estimated engineering team coupling operation lead time: 1 h 20 m;
- Estimated operators coupling operation lead time: 1 h 45 m;
- Estimated workshop manager coupling operation lead time: 1 h 40 m.

Based on the above, the initial target lead time for the coupling operation was set to 1 h 35 m.

6.3. Observed Operation Lead Times

The next figures show the observed times during the 21 carried out coupling and decoupling operations. The measured learning curve demonstrates a clear trend towards the average time of 35 min per decoupling operation, as shown in Figure 5.

Figure 5. Decoupling learning curve.

Figure 6 shows the operation lead time for the coupling operation. During execution, the operators suffered several problems. The first four attempts did not achieve a complete coupling. The first and second coupling trials were impossible due to the irregular surface area where the coupling operation was taking place, creating small deformations that made it impossible to secure all the bolts. Once the origin of this problem was detected, a more suitable coupling and decoupling area was selected.

Attempts 3 and 4 yielded better results but still had problems caused by the type of union plates used. Once they were replaced by segmented plates, coupling was possible in attempt 5. Coupling trial 6 used long union plates, so this time, the coupling operation was finished, but it was too difficult and slow for the experiment’s purpose. After that, only segmented union plates were used, and from that point on, the lead times started to show an expected learning curve trending toward 1 h 00 m per coupling operation.
1. The union plates need to be unscrewed from the side of each plate to the center and

2. It was detected that the only way to achieve similar operation lead times to those

3. Initially expected was by using a suitable level, flat surface;

4. The use of installation benches instead of ladders is preferred, as the former were

5. Found to be unstable and uncomfortable for the operators when handling roof union

6. Plates, mainly due to their weight.

7. Only two changes were made to the initial list:

8. The union plates need to be unscrewed from the side of each plate to the center and

9. In the following sequence: roof, lateral sides, and floor. This sequence allows both

10. Units to sit on the ground without blocking the screws.

11. In case a screw is tightly blocked, if both units can still be lifted as a 40’ container, they

12. Should be suspended, and that will enable screw removal from the blocked units.

13. In case a screw thread is damaged and unscrewing becomes impossible, its head can

14. Be cut, the units can separated, and the screw stud can be removed.

15. The average observed decoupling time was 0 h 36 m.

7. Conclusions

Innovations in modularization could address the serious problems caused by container
imbalance in global supply chains. Shipping companies already use optimization tools

to manage empty containers, but they have notable shortcomings, and they are limited
to route and utilization optimization without changing the physical properties of the
transported containers. Innovative modularization technology approaching the market
could assist in addressing this issue.

Since the method of identifying modular containers will differ from the existing vinyl
stickers, and since both systems are supposed to coexist for significant amounts of time in
the future, it was necessary to evaluate and analyze how container serial number changes
can be tracked and traced over time and different information systems, as well as how the
original serial numbers can be recovered when necessary after decoupling the modular
containers. The existing data structures and standards largely assume a static one-to-
one relationship between a physical object and its identifier. Containers (ISO 6346) and
ships (IMO number) have unique IDs which are used to track their movement. However, innovative logistics concepts such as modular containers, where units can be joined or split apart to create larger or smaller containers as required, challenge this assumption. Such emerging technologies are likely to offer significant benefits and become more widespread.

The outlined proposal addresses the impact of such technologies, focusing on innovative modularization technologies which are considered closer to market realization. New data architectures should be designed and incorporated with the information systems of all stakeholders to allow these more flexible container entities to be tracked and managed through the supply chain, addressing technical, safety, regulatory, and customs requirements. The information flows needed to properly optimize the use of such assets needs to be redefined, so apart from solving a specific and immediate logistics challenge, the proposed model is also seen as a very important constituent for the realization of such redefinition. Furthermore, as a part of this paper, the authors researched the basic technical issues that need to be addressed by proposing a detailed solution and performed initial pilot testing of the physical properties of the modular containers.

The potential users of this research and parties that will benefit from further research are all stakeholders involved in container shipping. They will also inevitably need to adjust their container management systems to process the identified set of data in order to facilitate the transport of dynamically numbered modular containers. However, industrial stakeholders manufacturing container transport and handling equipment will also benefit from the findings of this research, as they might be able to identify and establish new revenue streams from the proposed innovative modular solution. In addition, the operational research of container route optimization could identify additional possibilities for route optimization, accounting for the risk of modular container operations as single or coupled units and the quantification of risk during such operations. In terms of baseline research, positive findings open up the research possibilities of the feasibility of other modular configurations, such as the trinomial configuration.

The possible impact of the use of modular containers using novel digital technologies over global logistic chains is expected in the form of advantages at different levels: economic, environmental, and logistic chain bottleneck suppression, including the possibility of future synergies with other disruptive technologies. The wide array of the expected impact implies many future venues of research on digital technologies and their connection with modular container solutions. Considering that the proposed prototype has proven its feasibility, some possibilities for future research include quantification of the required adjustment costs in the control software of the involved stakeholders and operational research into possible savings, initially using a sample of relevant ports suffering from container imbalance.

Author Contributions: Conceptualization, S.A., E.T., N.K. and D.Z.; methodology, E.T. and S.A.; validation, E.T. and S.A.; formal analysis, N.K. and D.Z.; investigation, E.T. and S.A.; resources, S.A. and N.K.; writing—original draft preparation, S.A. and E.T.; writing—review and editing, E.T. and S.A.; visualization, N.K. and D.Z.; supervision, E.T. and S.A.; project administration, E.T.; funding acquisition, N.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work received funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement No. 861584 (ePIcenter project). This article reflects only the author’s views, and the Innovation and Networks Executive Agency (INEA) is not responsible for any use that may be made of the information it.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.
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