Cranfield University

IoT and Blockchain integrated platform for maritime shipping industry

Traceability and carbon visibility in the emerging Physical Internet era

MCG

Contents

Foreword

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MCG is a London/Montreal-based company focusing on Blockchain-enabled supply chain traceability and carbon visibility solution in the emerging Physical Internet (PI) era.

In 2022, MCG UK STOKEN initiative has been funded by Innovate UK as fast start innovation in net zero transition across the global shipping industry, and MCG UK completed the Net-Zero II accelerator at Cambridge Institute for Sustainability Leadership (CISL) successfully.

In 2023, MCG UK has been financially supported by Innovate UK KTN for the AKT2I by collaborating with Cranfield University and MCG executives won the investment from the Green Future Investments Fund on the Ready for Net-Zero starting from Feb 6th, 2023, and has been selected to launch MCG sustainable product with CISL Canopy on March 30th, 2023.

The Physical Internet will not deal with bulk freight, pallets, or non-containerised goods, it will only deal with π-container packages of goods. MCG envision the introduction of a simple physical object like the **#GS1SMARTBOX** or MCG LIUC system could create a logistics revolution akin to the introduction of the container in maritime transport, helping to integrate supply chains, reduce plastic waste, increase fill rates and pave the way for automation.

MCG Innovate UK-funded STOKEN initiative in the emerging Physical Internet era will track, monitor, and optimise operations throughout global maritime logistics to achieve a net-zero carbon emission-level standard. To achieve such a standard, the platform will include advanced carbon visibility analytics, artificial intelligence, and machine learning tools to automatically compute the carbon intensity index throughout the shipping industry to increase the visibility and control over global operations to develop interventions as strategies to cut down GHG (Greenhouse Gas) emissions. By connecting this tool through Application Programming Interface (API) gateways into the MCG centralised logistics platform, businesses will have access to real-time data, control, and visibility over their operations to make better and more informed business decisions. By standardising and digitising all operations under one platform, we can obtain optimised fleet energy management solutions to reduce the overall carbon emissions. This project will take the asset tokenisation based on MCG Smart PI-containers which are made of green materials, and establish the global open innovation network based on private-public partnership for sustainable development goals (SDGs), companies can easily use carbon credits to offset GHGs and would be able to reduce costs by demonstrating lower emissions, MCG can leverage technologies to show how tokens can be utilised in the trustworthy Blockchain-based supply chain. MCG Blockchain-based platform VUILA captures the journey of the products from manufacturers to the individuals. First, a digital ID for every product and as it moves along the supply chain, our easy-to-use App will capture real-time location, temperature and carbon footprint, the trusted data layer set up by MCG will keep the data recorded on the Blockchain ledger and shared between different stakeholders as a single source of truth; MCG PI-enabled Smart and Modular Container System LIUC will reshape the logistics distribution in an efficient and sustainable manner, the prototype has been demonstrated from our European partners, transshipment cost reduces 50%, loading efficiency increases 20%[1]. MCG certified tracking devices and APIs will make the hardware-software interconnected, and interoperable on moving digital assets in a way that secures the cryptographic authenticity.

This AKTP project will help MCG largely in terms of our growth strategy, by enhancing our technological capabilities through building strong partnerships and trustworthy collaborations. To help UK government meet targets for net zero by leveraging standardisation, digitalisation and tokenisation, MCG UK will create 10-25 high-skilled jobs in the next three years to strengthen the country's reputation a global leader in fighting against climate change, especially in the global maritime shipping industry.

1 https://www.2zeroemission.eu/research-project/modulushca/

Introduction

The term maritime refers to almost everything connected to the sea or waterways throughout the world, especially in relation to navigation, shipping, and maritime engineering. As such, the maritime industry can be an umbrella term that includes various sectors such as shipping, human transportation, leisure, and military purposes. The specific focus of this report is on the maritime container shipping sector, which oversees the seaborn transportation of containerised cargoes.

Maritime logistics is a vital part of today's economies. The UK Department of Transport estimated in 2015 that shipping and ports generate up to 14 billion pounds in revenue and provided more than 250,000 jobs (Department of Transport, 2015). As this sector flourishes over the years, the contributions to the wider economy of the UK continue to increase. Figure 1 shows the recent estimation of GDP and employment contributions from the sector, reported by Maritime UK in 2022

Furthermore, maritime logistics has a strong impact on the environment and sustainability development. The UK domestic maritime vessels represented around 5% of the UK's domestic transport Green House Gases (GHG) emissions in 2020 – more than domestic rail and bus emissions combined (Department of Transport, 2022). On a global scale, maritime shipping produces 940 million tonnes of CO2 annually, which is 2.5% of the global GHG.

To achieve operational improvements and stronger monitoring of CO2, the team at the Centre for Logistics, Procurement, and Supply chain management – at Cranfield University, together with our knowledge transfer partner – MCG UK Ltd, developed a feasibility report of an integrated platform, combining the Internet of Things (IoT) and Blockchain technology for the maritime container shipping sector. This unique and novel solution seeks to provide a holistic platform for container traceability, digitalise the maritime shipping operation, and record CO2 emissions in a reliable and trustworthy manner. Subsequently, the integrated platform can help businesses to improve processes, enhance traceability, and reduce carbon emissions.

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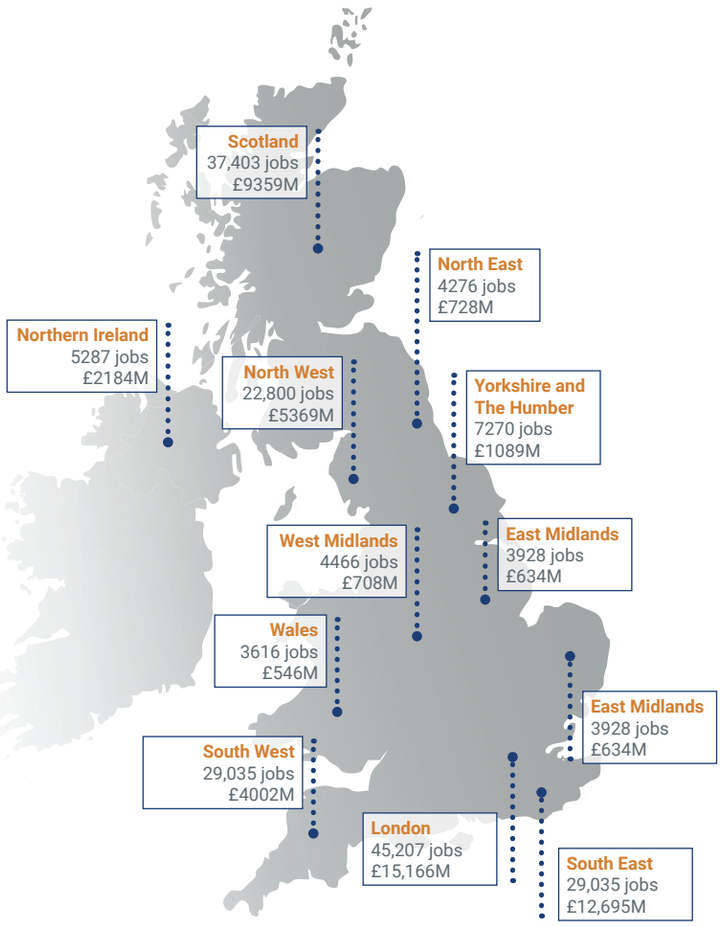


- **Revenue is in pounds.**
- **Number of jobs created in each region.**

Figure 1. Contributions of the UK maritime shipping sector to the economy (Maritime UK, 2022).

MCG's solution and vision

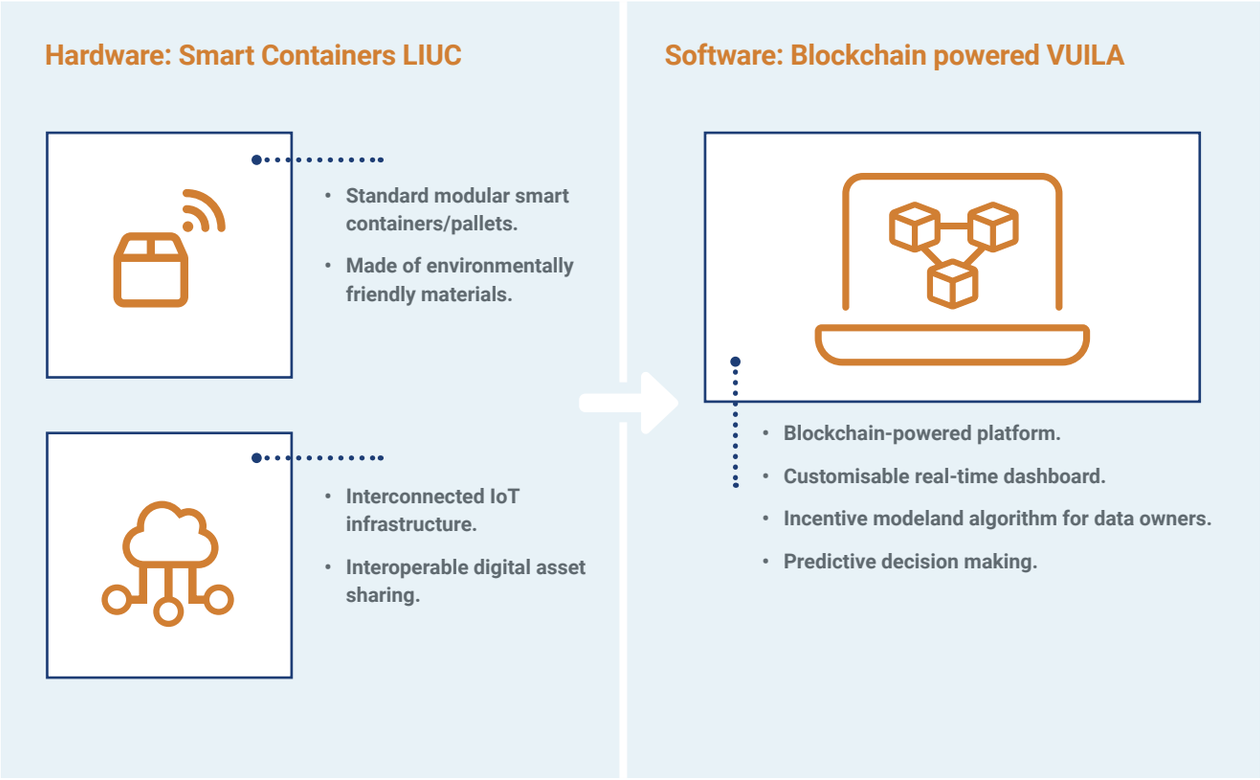


Figure 2. Summary of MCG UK IoT and Blockchain solution.

Figure 2 provides a brief overview of the integrated platform being developed by MCG UK. In essence, MCG UK is developing a novel technological solution consisting of two main components, namely IoT (in the form of smart containers) and Blockchain. Smart containers, equipped with sensors and data transmission technology, act as the physical layer for collecting and sending information. Vital information about the cargo such as the surrounding conditions (i.e. temperature and humidity) and locations are captured by this layer. Blockchain acts as the underlying technology for the digital layer, which stores, secures, and shares data instantly with stakeholders. Together, the two technologies comprise a comprehensive solution that can gather, monitor, and communicate data with high accuracy and reliability. The integration of other technologies is in consideration, particularly Machine Learning and Artificial Intelligence, to further advance the decision-making capability while using current solution.

In the wake of Industry 4.0, the maritime shipping industry has explored various digitalisation tools, such as Blockchain, IoT, and data analytics, to minimise expenditure, optimise operations, and increase the level of competitive advantages (Gavalas et al., 2022). Moreover, calls for reducing emissions from the shipping sector continue to be raised by different jurisdictions. The European Commission highlighted that maritime transport (including goods) is a substantial source of emitting Co2, and the first step to reducing emissions from this sector is to establish accurate and faithful reports of Co2 emissions (EC, 2022). As the Business Partner in this KTP project, MCG UK has a conceptual understanding of how Blockchain and smart containers can address the challenge of digitalising processes and monitoring Co2 in the maritime shipping sector. The company is now seeking to fully develop an integrated platform of these technologies, thus requiring the support of a knowledge base (KB). The Cranfield University team, as a KB, collaborates with MCG UK to provide expertise in maritime/logistics operations, Blockchain and other disruptive technologies implementation, and the development of an architecture for this integrated platform. With the help of the KB, MCG UK can better understand the needs of the maritime shipping industry, and therefore, can build and customise their advanced solution to specifically improve maritime shipping processes, enhance traceability, and improve the transparency of Co2 monitoring.

Objectives

Given the context of the project, three objectives are set:

1. To understand the current operation and challenges of the maritime shipping industry, with a specific focus on container shipping and Co2 reporting.

2. To determine various facets of adopting MCG's integrated platform, including the alignment with businesses' needs, drivers and barriers, and development opportunities.

3. To develop an architecture of a Blockchain and IoT integrated platform for the specific maritime shipping industry.

To accomplish these objectives, the research team collected empirical data from in-depth semi-structured interviews. A panel of experts was contacted to provide insights regarding the maritime shipping sector and the potential of an IoT and Blockchain integrated solution (to assure their confidentiality, they were referred to as Expert 1, 2, 3 etc throughout this report). Participants of this panel have extensive experience working in maritime logistics, especially in bulk transport such as containers and oil tankers. Insights from the experts were extremely helpful for understanding the operation of maritime shipping, the current hurdles in the industry, and how the transformative solution can address some of the challenges. Further, secondary data from credible sources such as industry reports and white papers were also utilised.

The rest of this report is disseminated as follows. First, a comprehensive analysis of the maritime shipping industry is presented, including typical processes, key actors, information sharing, container traceability, and Co2 monitoring. Second, an in-depth discussion of several key topics related to the feasibility of such a solution, particularly the alignment with the needs of the industry, drivers and barriers to adoption, and future development suggestions. Third, the architecture of an integrated IoT and Blockchain solution for maritime shipping is conceptualised. The final section concludes the report with remarks about the future outlook of IoT and Blockchain technology for maritime shipping and its role in facilitating a Physical Internet future.

The International Maritime Organisation - a United Nations specialised agency – sets the ambition to reduce 40% of CO2 emissions per transport work by 2030 compared to 2008 across international shipping. Among the work plan issued by the agency to achieve the said aim, the Annex 19 – Resolution MEPC.323(74) specifically invites Member States to support "the industry's collective efforts to improve quality and availability of data and develop necessary global data standards that would allow reliable and efficient data exchange between ship and shore" (MEPC 74/18/Add.1 Annex 19, p2), signifying the importance of improving information sharing for operation excellence and emissions reduction in the maritime shipping.

1 A closer look at the maritime shipping industry

It is important to first establish a fundamental understanding of different facets of the maritime shipping operation. Particularly, this section seeks to uncover the general processes of container and bulk shipping, entities involved in the end-to-end operation, and current challenges in information sharing, traceability, and emission monitoring. By understanding these key elements, a following assessment of how the integrated IoT and Blockchain platform can fit into the scene is more compelling.

As container transport is well understood in practice, the practitioner literature is extremely useful for providing insights into the physical flow of containers in maritime shipping. The movement of a container from the starting point (customer) to the final destination (consignee) can be summarised in six key phases, according to Trade Finance Global (2023):

1. **From customer to forwarder:** the process starts with the customer placing an order with the forwarder, then transporting their goods to the forwarder.
2. **From forwarder to port:** the forwarder liaises with the loading port and the chosen carrier, before moving the goods to the port.
3. **From port to carrier:** at the loading port, containers of goods are loaded onto the vessels.
4. **From carrier to destination port:** this is a simple phase, as the vessels carry the containers to the destination port. Containers are unloaded into the discharging port.
5. **From port to last mile shipper:** from the receiving port, the containers are picked up by the next link of the transport process. Different models of freight transport can be used here, such as trucks or trains.
6. **From last-mile shipper to final consignee:** last-mile shipper delivers the containers to the final consignee, completing the process.

Insights from the interviews validated the basic understanding of the maritime shipping process, as discussed previously. Further, the experts provided valuable elaborations for a more comprehensive knowledge of the industry. For instance, an entity can assume multiple roles in the maritime shipping process. Large carriers and shipping lines can act as a forwarder by bidding for a customer's contract, arranging the collection of containers, and organizing loading/ unloading with port dockers. Alternatively, ports nowadays can offer a wide range of logistics services to the end customers, including transporting to port, storing goods on site, containerization, etc. Freight broker is another typical entity in the maritime container and bulk shipping process. The main role of the broker is to connect customer with the shipping services and arrange for the cargo shipment. While seemingly assuming the same role, the interviews indicated that forwarders are more involved in the whole shipping process, and directly oversee various steps of moving goods from one location to another.

Based on the insights from the literature and the interviews, Figure 3 depicts the general process of the container, and bulk, shipping in the maritime industry. It should be noted that the aim here is to generalize and establish a broad understanding of the activities and actors involved in maritime shipping. It is not the report's intention to capture every single possible scenario of the operation.

Table 3. Findings from interviews regarding information sharing and maritime shipping challenges.

	Insights from qualitative data
Current challenges	**Lack of visibility** The visibility of container shipping needs improvement. Various aspects of maritime operations are currently not visible to all stakeholders. Many times, stakeholders have no choice but to rely solely on after-the-fact reports from operators. Fuel consumption and CO2 emission are especially highlighted by interviewees. This information is typically manually collected and calculated by vessels' operators.
	Lack of extensive traceability The industry is still in need of an extensive solution for container tracking. The interviewees emphasised that knowing just where a container is at a given time is not sufficient for today's maritime shipping. Individual cargo within a container needs to be traced for the whole journey, and further various data of conditions and quality inside the containers should be traced as well.
	Information asymmetry Information asymmetry refers to the imbalanced access to vital data of maritime shipping operations. This is typically caused by information in silos and a lack of a common platform for information sharing between stakeholders.
	Process inefficiency Interviewees stressed that the overwhelming amount of manual work and physical documents are greatly impeding the efficiency of maritime shipping operations. Several negative implications of manual processes include increasing operational costs, exposure to manipulation of information, and errors and accidents prone.

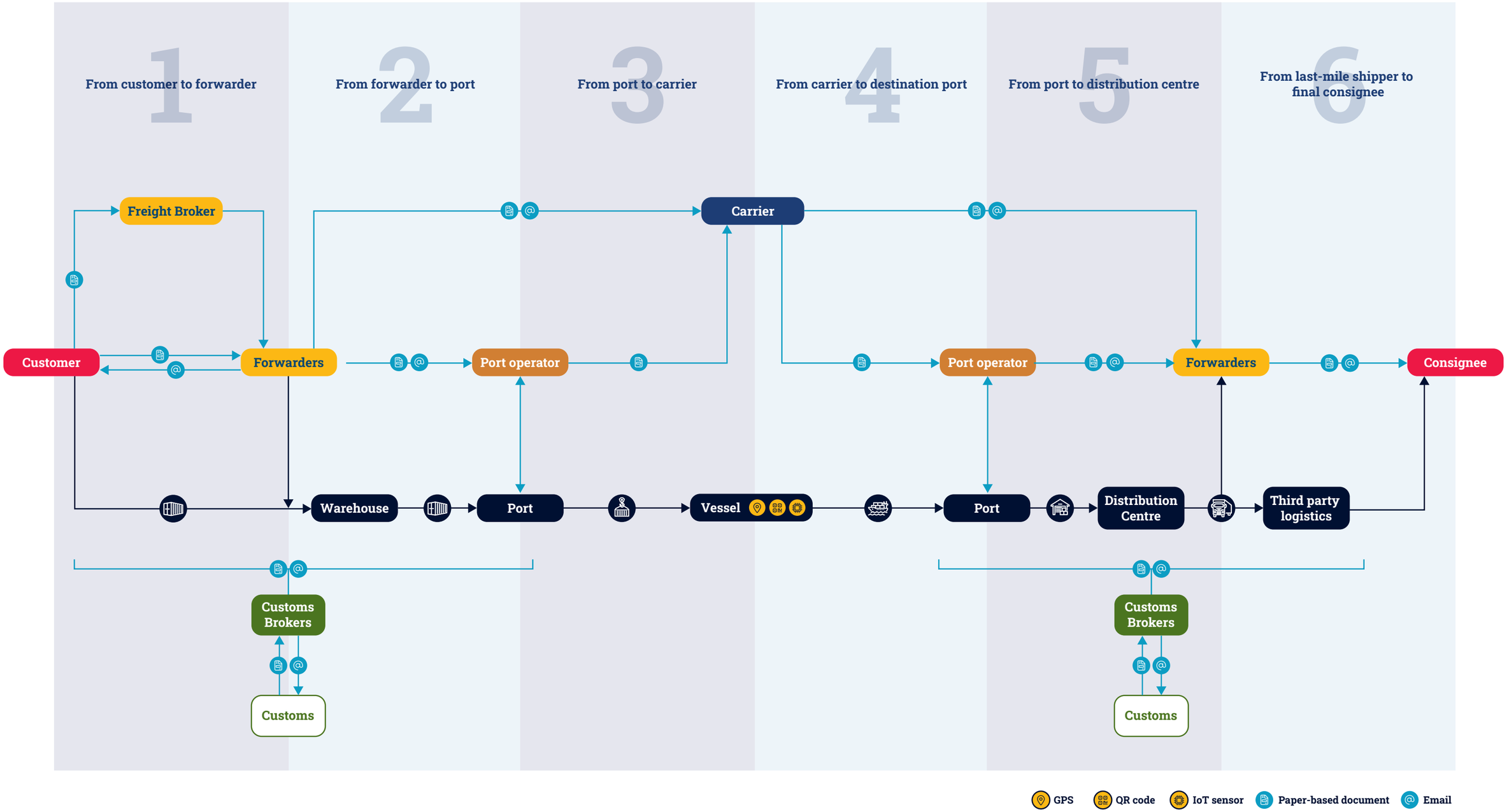
Challenges with data sharing, traceability, and emission monitoring in the maritime industry

The primary interest of this report is to investigate the feasibility of an integrated IoT and Blockchain platform. It is anticipated that this solution can transform how companies track containers, monitor cargo, share and secure vital data, and report emissions. Thus, insights from the experts about the current practices and challenges of data sharing and emission monitoring in maritime container shipping were obtained. Moreover, the interviewees were asked about the pressing challenges in the maritime industry, of which four key issues with information sharing, traceability, and sustainability were identify. Table 3 summarised the key findings from the interviews. These challenges indicate a need for an advanced solution in the maritime shipping industry, which can address the problem of manual processes, information asymmetric, and low visibility.

> **Visibility in transport and logistics is still a big problem. There are good models for detailed tracking of just not a container but the individual cargo inside. However, in the industry the adoption of such model is still low – Expert 3.**

> **Normally data would be stored and process in our system, then we communicate later to other parties if needed. Industry-wise, my opinion is that too much information is left for the directly responsible company to report and share, and there is a lack of a unified and unbiased common data platform. There is not a single information centre where you can see the whole journey of the container. And the industry is very slow in changing this – Expert 1.**

Figure 3. An overview of the maritime shipping operation

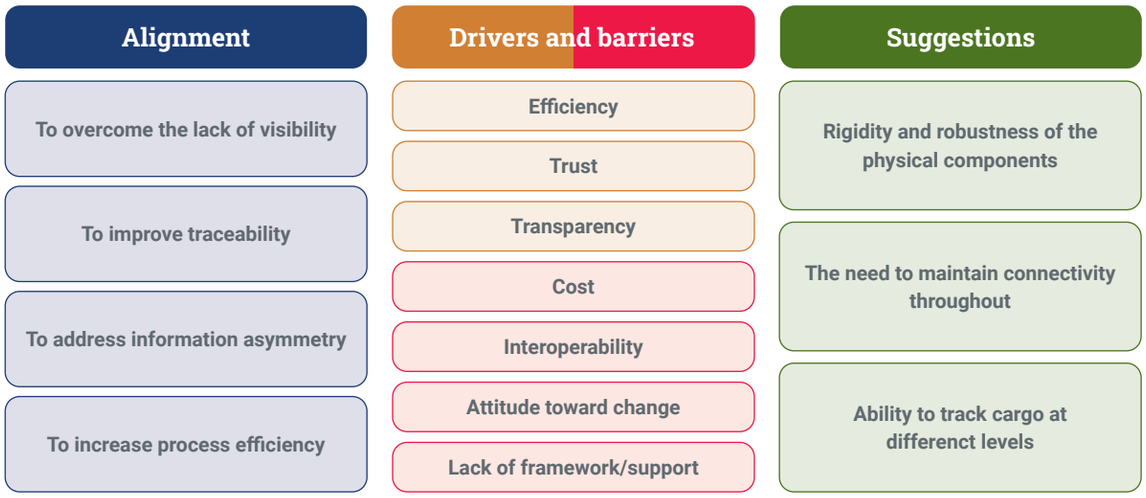


2 Multi-facets of adopting an integrated IoT and Blockchain platform

This section discusses in-depth key aspects associated with the adoption of a novel solution in development by MCG UK. Although still in the early development stage, MCG UK solution shows the potential of transforming and improving certain aspects of the maritime shipping operation. This integrated platform can digitalise different processes in maritime shipping to achieve operational excellence, and enhance the traceability of both containers' movement and CO2 generated from shipping activities. Therefore, it is important to understand the specific facets of how a IoT and Blockchain solution aligns with the business needs, the potential of using such a system, and barriers to the adoption of the solution. Insights from expert interviews were utilised to construe these facets. Additionally, useful suggestions from the panel were gathered to inform MCG UK about their product development in the near future.

Figure 4 provides a summary of the four critical aspects associated with the adoption of an integrated IoT and Blockchain solution in the maritime shipping industry.

Figure 4. Overview of various facets related to the adoption of an IoT and Blockchain solution.



Alignment of the technology with the needs of business

The first section discusses the alignment between a Blockchain and IoT platform being developed by MCG UK with the need of the industry. Experts expressed that this integrated solution is highly transformative, and further highlighted that it can help overcome operational challenges in seaborne container and bulk shipping. Particularly, findings from interviews identified several mechanisms by which the solution can directly address the current problems in the industry. In the discussion around challenges, interviewees identified four major challenges with visibility, container tracking, information sharing, and process efficiency (See Table 3). A detailed description of MCG IoT and Blockchain integrated solution was provided and explained to the participants during the interviews. Upon gaining an adequate understanding of how the solution works and what advantages it can bring, the interviewees identified several ways the novel solution can help address the previously determined challenges in the maritime industry. In essence, an IoT and Blockchain solution can align with companies' needs to overcome the key challenges by automating and digitalizing maritime operation processes, and providing a unified and trustworthy platform for real-time information sharing. The particular insights regarding this topic are provided in Table 4.

Illustrative quotes from experts regarding the challenges faced by the industry:

> **Ideally with this solution, there is no room for loopholes and manipulation of physical documents. Blockchain platform can provide a single source of truth for everyone, such as customers, shipping lines, etc. This can particularly be useful when companies calculate Co2 and other greenhouse gasses emissions. It will be reliable and trustworthy – Expert 1.**

> **Customers always want to know the current state of my goods. So technologies like these (referring to MCG solution – authors' note) are very necessary. The cold chain would be a good example, or any other temperature-sensitive goods, of beneficiaries from smart container technology – Expert 5.**

> **There are cases where documents must be flown to the destination ahead of the containers to fulfill the paperwork. This is a waste of resources. Having an effective means to digitalise and share documents between stakeholders would cut these cases and improve efficiency considerably – Expert 3.**

Table 4. Alignment of the solution with the need of the industry.

Challenges	How the solution can help overcome the issue
Lack of visibility	With Blockchain capabilities of sharing data in real-time and granting data immutability, the visibility of the whole operation is increased. What should be understood is that the integrated IoT and Blockchain solution's role is not to establish visibility of maritime shipping activities, since there is a certain level of traceability already in the industry. The role of the integrated solution is to add another layer of validation and communication on top of the current means of traceability
Lack of extensive traceability	Smart containers can frequently monitor the quality, condition, and surroundings of the cargo. This can leverage the current traceability process, which is often just about the location of the ship or container.
	Smart containers can also add nuance to the tracking information. For instance, sensor technology can notify cargo owners not only where the container is at the moment, but also what stage of the operation it is at (e.g., being loaded at the port, or in vessels).
	Blockchain can further add another layer of trustworthiness and reliability on top of the current tracking process.
Information asymmetry	The information on maritime shipping operations is typically in silos. This means that many stakeholders either do not have or are delayed in getting access to data. The solution can extensively communicate information to all stakeholders, thanks to Blockchain's decentralisation feature.
	Blockchain can act as a single and unified source of data between various parties, making sure that everyone is on the same page at the same time.
Process inefficiency	Due to legal requirements and the norms of the industry, many vital documents are prepared and signed manually. These documents then are scanned and distributed electronically from a central processing system, which is typically hosted in-house at a node of the shipping process (i.e. carrier, port, or forwarder). This can be time-consuming, and error-prone. To this end, IoT and Blockchain can digitalise important documents and automate the communication of critical information to relevant parties, saving time and labour.
	Smart containers can automatically inform the crew when, where, and potentially how the containers have entered the ship. This can save a tremendous amount of time and resources from the carrier. Moreover, as the docking fee is charged based on how much time a vessel stays in a port, speeding up processes can help companies cut down on costs.
	As a ship often travels through various countries and jurisdictions in one journey, important documents of the shipment must be ready and safe at all times. Thus, having a secured and immutable platform for record sharing and keeping, such as Blockchain could be very beneficial for the industry. Further, as stored data on Blockchain cannot be erased, companies can be assured that they always have the necessary documents for audits and other activities in the future.

Drivers and barriers to adopting an IoT and Blockchain solution

An integrated solution of Blockchain and IoT can align well with the current needs of the maritime shipping industry. Further, the experts anticipate several drivers for using such a system, particularly to improve the efficiency and effectiveness of the maritime operation, strengthen trust, and provide transparency to all stakeholders. However, the experts also noted that this particular industry is still in the exploration phase of novel technologies such as Blockchain and smart containers, therefore several barriers to the adoption of the solutions were suggested. Specifically, cost, interoperability, and the current lack of legal framework and support can hinder the adoption of this novel IoT and Blockchain platform. Table 5 summarizes the drivers and barriers to the adoption of the integrated solution, with key perspectives of industry experts.

Illustrative quotes from experts regarding the drivers and barriers to adoption:

> **For oil tankers, the quality check is mostly only after the fact. If the smart container can help us monitor the quality of the product when oil and other kinds of fuel are being pumped into the tanks, it can really help us with our effectiveness – Expert 2.**

> **Sustainability development is a must in today's maritime shipping industry. And businesses not only understand that but also are under pressure from various regulations to be more green – Expert 5.**

> **Container shipping is a complex process, with many steps, information systems, standards, and legal requirements. So interoperability is definitely an issue that needs to be addressed. For instance, there are seven or eight platforms for electronic bill of lading that I know of, and none of them is interoperable with others. Also I say 95% of the industry are SMEs, and if the solution is not easy to use and well compatible with them, you would lose a large portion of the market – Expert 3.**

> **The application of Blockchain technology has the potential to drastically change the shipping industry environment and practice, which will certainly be resisted by stakeholders – Expert 4.**

Suggestion for development

Interestingly, experts provided valuable suggestions for the future development of the solution. Particularly, MCG UK must be mindful of the rigidity of the hardware. Ocean shipping is subjected to harsh weather conditions, and containers are constantly under pressure and physical impacts from operational activities. Thus the smart containers must be robust and durable. The design and placement of the smart sensor component in the container must also be taken into consideration.

> **Ocean shipping can be harsh. Weather can be unfavourable, containers are always under tensions, and the process of loading and unloading can be physically impactful. Therefore, the smart containers must be very rigid to withstand physical forces – P2.**

Further, due to certain areas of the world lacking connectivity, the approach to transmitting data must be carefully examined when designing the solution. First, the company must carefully examine different methods of transmitting data from the smart container to the Blockchain/ database layer. The goal is to make sure that communication with the cargo is stable and consistent throughout the journey. Second, on the software side, what data is collected, and how data is compiled/ processed before transmitting can be vital to solving the connectivity obstacle.

> **In some parts of the ocean, we got very slow and virtually non-existent connections to the internet. Transmitting vessel data in these locations would be a huge challenge – P1.**

Finally, for an effective and end-to-end tracking solution of cargo and containers in maritime shipping, the solution must be able to track items at different levels and through various points of aggregating and disaggregating. P3 emphasised that:

> **Each step along the way, in principle, you need to be able to connect the objects that you pack in the larger container with the container itself. So if I were to put 30 boxes into a single pallet, then there should be 30 individual identifications. The pallet itself is also uniquely identified, and then I have 30 links recorded between the ballot ID and individual box IDs linking them together as long the ballot exists. This approach allows you to create a chain of events for cargo transportation, enabling you to always follow one item along the way despite how many points of consolidation and deconsolidation.**

Table 5. Drivers and barriers for adoption of an IoT and Blockchain solution.

	Sub themes
Drivers	**Efficiency and effectiveness** MCG UK integrated solution can help digitalize and automate certain processes in maritime shipping operations. By reducing the amount of manual work and physical checks, the solution can speed up the overall progress of shipping, thus improving the efficiency of the operation. Further, the effectiveness of maritime shipping operations can be boosted with a combination of Blockchain and smart container technologies
	Trust The sustainability of the maritime shipping industry has gathered great interest from various parties, including customers, service providers, and policymakers. Businesses are well aware of this aspect. The IoT and Blockchain platform can enable businesses to establish greater trust by sharing their CO2 emission at the vessel level and sustainable practices with partners and customers through a trustworthy and immutable manner.
	Transparency Sodhi and Tang (2019) specified that visibility is about gathering information about operations upstream and downstream of a supply chain, while transparency is the extent to which companies are willing to disclose information to all stakeholders, including the public. In this vein, the Blockchain and IoT platform can provide a useful tool for maritime shipping businesses to go beyond just traceability to achieve total transparency
Barriers	**Cost** This is a fundamental determinant of new technology's adoption. When considering a new system or solution, the first and foremost question of businesses is typically about the return on investment. In other words, businesses would like to see a favourable gain from the technology in comparison to the initial investment, before making the decision of adopting that technology. This is particularly relevant in the maritime shipping context.
	Interoperability From experts' opinions, it can be seen that a major challenge for an IoT and Blockchain integrated solution is how it can connect and work with different legacy solutions, and provide common grounds for different standards and rules followed by vessels. Further, the lack of unified support from various jurisdictions could greatly hinder the digitalisation of key documents in maritime operations, such as the bill of lading.
	Attitude toward transparency and change Experts highlighted one considerable constraint to the adoption of an IoT and Blockchain solution, which is the attitude toward using complex technology and full transparency of operations.
	Lack of legal framework/support The current lack of legal framework and support for digitalised/ electronic documents is an interesting point raised in the interviews. This barrier can be cumbersome since all experts stressed that maritime shipping needs to comply with various regulations in different places due to the globalised nature of seaborne container and bulk shipping operations.

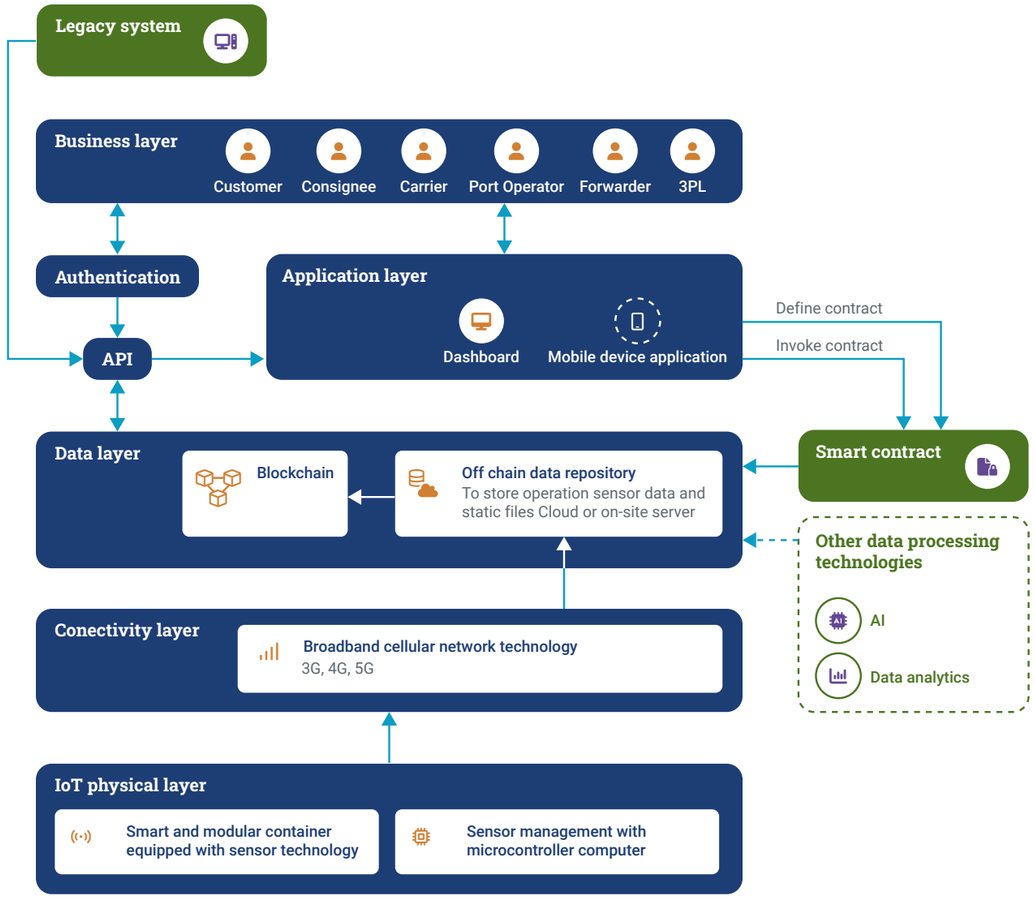
3 A conceptual architecture of a IoT and Blockchain solution for maritime shipping

After gaining an adequate understanding of and mapping the current maritime shipping operation, key stakeholders, and challenges, a conceptual architecture of the integrated IoT and Blockchain solution for MCG UK is developed. Insights from interviews were useful in determining the primary entities of the network, and how the novel platform can be featured in the maritime operational process. Extant literature and information provided by MCG technology development team were also combined. To achieve this, the Cranfield team first built a tentative conceptualisation of the integrated solution from the qualitative data and various industry white papers and academic papers (e.g., Mphasis (2022), Ahmed et al., (2019), and Pavithran et al., (2020)).

Subsequently, the Cranfield team held a series of brainstorming sessions, virtual calls, and email exchanges with the development team at MCG to improve and finalise the architecture.

The final framework includes five main layers: IoT physical layer, Connectivity layer, Data layer, Application layer, and Business layer. Three supplementary layers are included, namely Legacy system, Smart contract, and Other data processing data technology. The latter of the three is in a dotted box (See Figure 5) to illustrate that this is a future development plan of MCG and is not an immediate component of the solution. The same applies to the mobile device application component of the Application layer. A detailed description of each layer is provided in Figure 5.

Figure 5. A a architecture of the integrated IoT and Blockchain solution provided by MCG UK.



Architecture components

IoT Physical layer

The main responsibility of this layer is to collect and pre-process information on-site, before transferring information to the data layer.
There are two main components:

- Smart containers are made of recyclable material, modular, and equipped with sensors to capture data.
- Sensor data management acts as the processing node, which receives and pre-processes the data (e.g. filtering, analog to digital conversion, aggregation, compression, etc) from the sensors before transferring it to the next layer. Micro-controller (such as Arduino) is used for managing sensor data.

Connectivity layer

This layer includes the communication modules that help transmit the data collected in the IoT physical layer to the data layer via the internet. Given the specific characteristics of the maritime industry, in which the majority of the containers' journeys are at sea in vessels, the broadband cellular network is currently the choice of MCG. Another solution, which can be taken into consideration, is satellite network.

Data layer

The data layer is the critical component of the solution as it collects and processes all the data. MCG will use an on-chain/off-chain database structure:

- A cloud-based database receives and stores the cumulative data generated by the smart containers.
- An on-chain Blockchain platform stores selective data, which is predetermined between different stakeholders of the maritime shipping process. This component ensures the immutability, security, and real-time communication of key information such as bill of lading, fuel consumption, Co2, etc.

Application layer

This layer contains the application that is built on top of the Blockchain and IoT layer. Applications allow the users of the system to access and interact with the data. For instance, maritime industry stakeholders can see real-time tracking and temperature monitoring on the dashboard.

Moreover, the applications allow users to input vital information that could lead to defining or invoking smart contracts.

Smart contract

In this specific case, the smart contract can be used to predefine the validation requirement for information to be stored on Blockchain. Moreover, smart contracts can be integrated to automate certain activities of the maritime shipping industry, including payment transactions. The information that can define/ provoke the contract comes from the stakeholders through the application layer.

Legacy system

Information outside of smart sensor pickups comes from legacy system. Specifically, since the transition to smart containers typically will happen gradually, container tracking information during the transition period still needs to be taken from existing systems. This layer connects with the data layer through Application Programming Interface (API).

Data processing

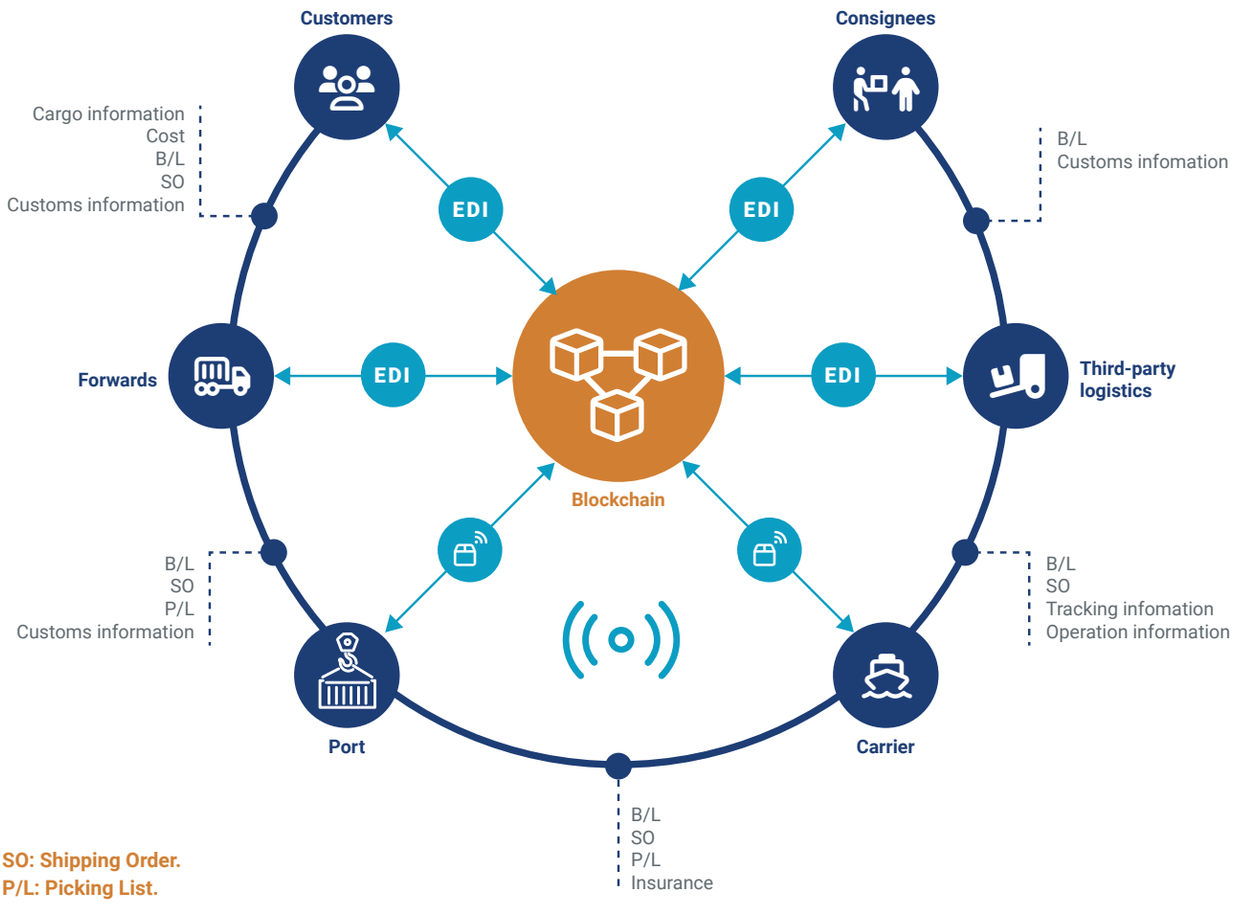
AI and data analytics are the two solutions that MCG is planning to integrate with the primary IoT and Blockchain solution.

Information flow

In this section, the information flow in maritime shipping with the integration of an IoT-Blockchain solution is explained. Figure 6 describes how data is captured and transferred from each node of the operation to the Blockchain layer, and how this layer distributes and communicates with stakeholders.

Various information is generated from maritime logistics activities, such as customer, consignee, shipping lines, details of the cargo, etc. Key information, which needs to be secured and shared among stakeholders, is sent to Blockchain for storing and disseminating. These information typically are related to contracts, payment, tracking, quality monitoring, bill of ladings, etc. EDI aids this process by standardising and digitalising business documents. During the transportation of the containers, IoT devices automatically collect and send data related to the containers' traceability and monitoring to the Blockchain layer. Blockchain stores and shares these essential data to relevant entities. Overall, the IoT-Blockchain solution enables businesses to gain consistent and timely access to information, and automate certain activities with trustworthy information (e.g., when the containers location is updated as arrived at the warehouse, payment can be instantly transferred).

Figure 6. Information flow in an IoT and Blockchain integrated maritime shipping operation.



- **SO: Shipping Order.**
- **P/L: Picking List.**
- **B/L: Bill of Lading.**
- **EDI: Electronic Data Interchange.**

Final remarks

This report studies the feasibility of a novel integrated platform that combines IoT and Blockchain technology, for maritime container and bulk shipping industry. This platform is being developed by MCG UK Ltd. The Centre for Logistics and Procurement – Cranfield Univesity, as the knowledge base, provides expertise and knowledge in logistics and supply chain management to help MCG gaining a comprehensive understanding of the process, challenges, and requirements for traceability and information sharing in maritime logistics . Further, the Cranfield team collaborates with MCG to develop an architecture for the IoT-Blockchain integrated solution, which takes into account the inherent characteristics of maritime shipping. To achieve the aim of the project, the team conducted interviews with experts in the maritime shipping sectors. These experts have extensive experience working in the industry, and represent all relevant stakeholders of the whole container shipping process. Thus, insights from the interviews shed light on important topics such as the current process of maritime shipping, challenges in traceability, information sharing, and emission reporting, the potential application of the novel IoT-Blockchain solution, and various aspects related to the adoption of such a solution. Academic papers and industry reports were also used in conjunction with the empirical data to derive key findings of this project.

Learning from interviews insights and relevant literature, a comprehensive map of the maritime shipping operation was developed, including key stakeholders, physical movement of container and bulk goods, means of communication, and information flow. Further, four main challenges were identified as the lack of visibility, insufficient traceability, information asymmetry, and process efficiency. In addition, findings emphasised on the lack of useful means to monitor and report emissions. This means that while companies may be prioritising sustainability and emissions reduction, they may not have the tools or data they need to accurately track their progress and make informed decisions about how to further reduce their carbon footprint. Finally, a feasible architecture of the IoT and Blockchain solution for the maritime shipping industry was developed, in close collaboration with MCG technical team. This architecture provides comprehensive and well-structured layers of a complete solution, while taking into account the specific contextual characteristics of the industry.

Nevertheless, experts caution that the industry is still in the early stages of exploring these technologies and face significant barriers to adoption such as high costs, interoperability challenges, and a lack of legal framework and support. Furthermore, experts suggested that the solution should have robust and durable hardware for smart containers, carefully designed sensor placement, and stable communication methods for the challenging ocean shipping conditions. Furthermore, an effective tracking solution should be able to track items at various levels and points of aggregation and disaggregation.

Build to last - Towards the emerging Physical Internet era

The IoT Blockchain platform also paves the way for the Physical Internet (PI) future, serving as a critical component of this innovative logistics system. The Physical Internet is a global network that interconnects logistics networks through a standardised collection of protocols, modular containers, and smart interfaces, thus enhancing efficiency and sustainability (Ballot, E., Montreuil, B., & Meller, R. D., 2014). Modeled on the TCP/IP protocol of the internet, the Physical Internet represents a novel logistics network in which goods are packaged in standard-sized modular containers, analogous to data bytes, and seamlessly transported across borders in the most efficient manner possible. Similarly, The PI can transform maritime logistics by introducing a system of interoperable, standardised, and modular cargo containers, making it possible to handle and transport goods more efficiently and sustainably. By utilising advanced technologies, PI can enable real-time tracking and optimise the utilisation of shipping routes, ultimately reducing costs, improving delivery times, and minimising the environmental impact of maritime logistics.

We believe that maritime logistics is undeniably heading towards a PI era. PI offers a robust and sustainable logistics system that places a strong emphasis on modularity, interoperability, and collaboration. Furthermore, we anticipate that the solution being developed by MCG will hold an important place in such future. The reasons are two-fold. First, IoT (especially smart containers in this case) and Blockchain will serve as key building blocks for a PI system. As stated by the pioneering works of Ballot et al. (2014) and Treiblmaier et al. (2020), a network of interconnected and standardised components and data exchange are key components of PI. MCG smart containers are standardised, made of sustainable material, and most importantly, equipped with smart sensors to collect and communicate logistics and supply chain information. The Blockchain chain component of MCG's solution does not only facilitate real-time information exchange, but also provides an extra layer of security, immutability, and trust to the communication protocols. Together, they facilitate reliable, efficient, and seamless handling and transporting of goods across multiple points of the network. Second, by adopting an IoT and Blockchain integrated solution such as MCG's technology, businesses in the maritime industry are taking an important step to prepare and welcome a PI era. While technology is one important aspect, the innovative mindset and the appropriate business models are another critical aspect for transforming the maritime shipping industry. This solution provides a foundational framework for stakeholders to establish trust, collaborate, and innovate together. It also equips businesses with the necessary technologies, and technological know-how, to advance into the PI paradigm when the concept becomes a reality. It would be hasty to claim that businesses can achieve PI by adopting an IoT and Blockchain integrated solution, but it is certainly a step in the right direction.

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