GPIG – Initial Report

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Group D

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1 Introduction

Unsustainable growth in the cargo shipping industry, paired with a lack of innovation, puts incredible pressure on the environment and threatens to destabilise the economy. In this report, we illustrate how we intend to leverage collaborative autonomy to develop a more sustainable approach. We describe a possible solution involving the use of 'offshore smart ports' along with small, autonomous shuttle ships which serve to provide a link with traditional coastal ports.

We begin with a discussion of the challenges facing the industry, and we make some informed assumptions about the capabilities of the technology at our disposal in the year 2030. We then describe our proposed solution, outlining key benefits, and explaining how we will justify our approach through simulation. We also provide a brief summary of our team structure, the key processes we will follow, and our customer communication strategy. We conclude with a register of significant project risks.

2 Problem Analysis

With more than 90% of all international trade conducted by sea, the shipping industry plays a crucial role in the modern interconnected world [1]. Over the past 50 years, the size of the world shipping fleet has increased from 36,000 to over 100,000 [1]. In order to maximise efficiency of transportation [2], the capacities of these ships have increased substantially. In 1956, for instance, a typical container ship had a capacity of 101 Twenty-foot Equivalent Units (TEUs) [3]. By comparison, ships operating in 2015 have capacities of up to 20,000 TEUs [2].

The rapid expansion in both fleet size and freight capacity raises many questions about the sustainability of the shipping industry. In 2016, freight rates (the wholesale price of shipping) fell to the lowest levels since the 2008 global recession. This caused Hanjin, a major operator in the shipping industry, to enter administration [4]. We argue that, if existing companies wish to meet future demand and survive further economic turmoil [5], the industry must adapt.

Since the growth of seaborne trade shows little sign of slowing, we can expect to see further increases in both the number of ships and their capacities. This necessitates the development of coastal infrastructure to accommodate larger vessels, putting extra pressure on already taxed resources [3]. At the same time, there will be increasing pressure from political bodies, such as the EU, to reduce the impact the industry is having on the environment [6]. This is forcing the industry to explore 'greener' approaches, perhaps at the cost of more economical alternatives.

Collaboration and autonomy in shipping systems have the potential to mitigate these problems, and many techniques are in development today. For instance, Rolls-Royce plan to bring autonomous container ships into service by 2020 [7]. These ships will combine data from satellites, weather reports, and an array of LIDAR and infrared sensors to enable completely unmanned navigation. It is therefore reasonable to assume that by 2030, these techniques will be commonplace and can be incorporate into our solution.

Autonomous ships generate a wealth of data, which can be leveraged by other ships and ports to make more informed decisions [5]. The automotive industry is already exploring ways in which the data generated by autonomous vehicles can be applied to solve pressing problems. One proposed system collects broadcasted information from other vehicles, such as speed and position, to create a model of the environment and provide the driver with an early warning system for potential hazards [8]. With development of these systems already in progress, we believe that the shipping industry must consider investment into collaborative and autonomous technologies.

3 System Description

To mitigate some of the issues discussed in Section 2, we propose a new system taking inspiration from the decentralised nature of land-based courier networks. Parcels in transit over land typically pass through several large distribution centres, taking an indirect path to their destination. While this means each individual parcel travels further, it greatly improves the efficiency of the system as a whole. Our system will leverage collaborative autonomy in the form of a fleet of autonomous shuttle ships, which connect a series of 'offshore smart ports' to existing coastal infrastructure.

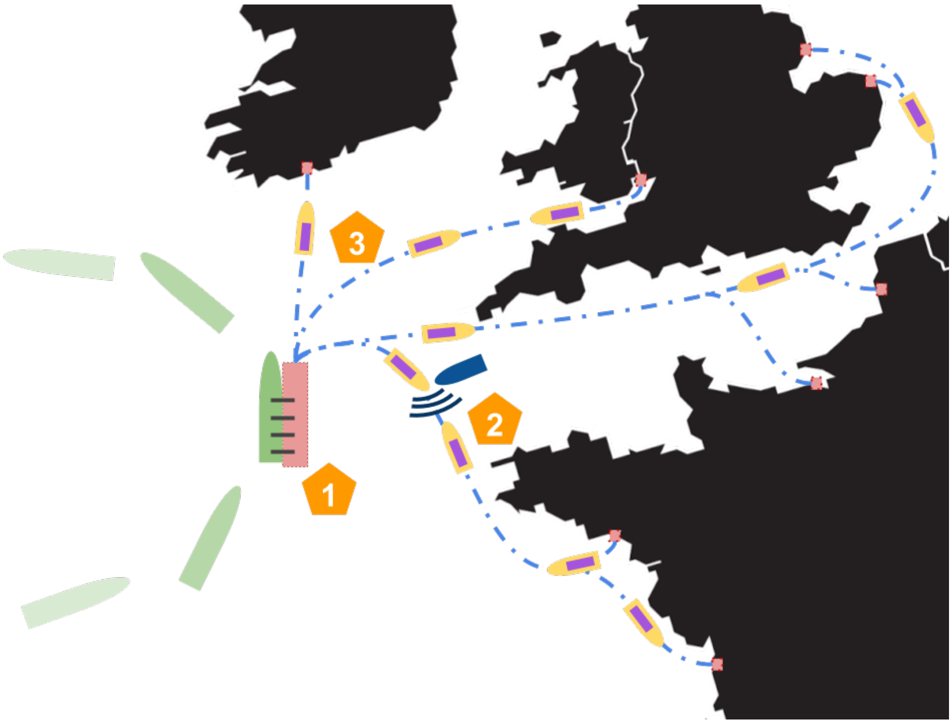

Figure 1: A diagram illustrating the main components of our proposed system. **(1)** An offshore smart port loading and unloading cargo from a docked intercontinental freight ship. **(2)** An autonomous shuttle ship coordinating with other ships to avoid traffic. **(3)** An autonomous shuttle ship navigating to a costal port.

Each offshore smart port will act as a regional hub, accepting cargo from existing intercontinental freight ships. This cargo is subsequently forwarded to several coastal ports. The offshore ports are stationary and fixed to the seabed, in much the same way as oil extraction platforms. Aboard each offshore port is an automated container storage and transit system inspired by automated parking facilities [9]. This system will enable simple storage and retrieval of individual containers through the avoidance of stacking. When each container is ready to leave the offshore port, it is automatically routed to a crane for transfer to a docked vessel. The offshore port will be powered with an onsite nuclear reactor. We assume that it will be both technically feasible and within nuclear regulations to deploy such a reactor to our offshore ports in 2030.

The offshore smart ports will be serviced by a fleet of small autonomous shuttle ships, each capable of transporting a varying number of freight containers between the coastal and offshore ports. The fleet will employ swarm intelligence mechanisms to self-organise. This coordination will help individual ships plan their paths around bad weather and other obstacles, and will also allow the system to respond dynamically to demand at different coastal ports. When goods at a coastal port are ready for dispatch, the shuttle ships will collectively decide an optimal assignment strategy based on their proximity to the collection point. On arrival at the offshore port, the vessel communicates with the storage system to provide information regarding the final destination of the carried goods. Control of the vessel is then delegated to a control system on the offshore port, which is responsible for positioning of the vessel so that the cargo can be offloaded. The shuttle ships will be powered primarily by an on board battery, which is charged at port when necessary. Additionally, on-board solar panels will be used as a means of emergency power generation. We assume that battery technology has developed sufficiently to support the powering of these autonomous vessels for a journey between ports. We also assume that these batteries will be charged using 'green' energy sources.

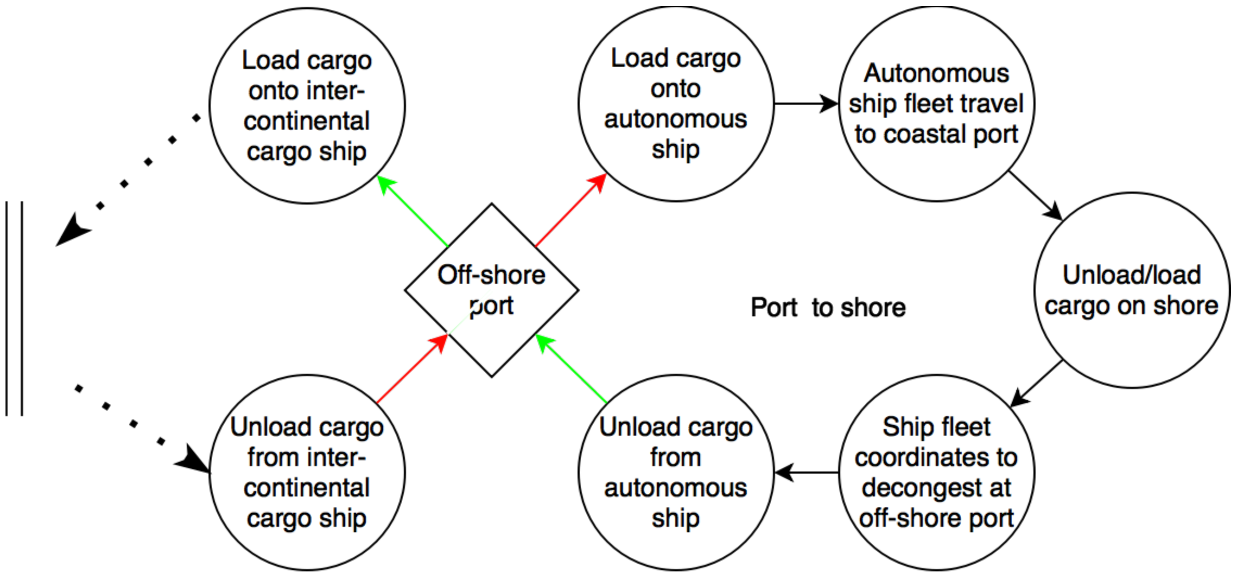

Figure 2: A flow chart tracing the flow of cargo through of our system. The left hand side illustrates how cargo enters and leaves the offshore port through intercontinental freight ships. The right-hand side shows how cargo is received from and forwarded by our autonomous shuttle ships.

Although system components will be fully autonomous, control of the system is transferable to remote human operators in exceptional circumstances, such as malfunction or disaster, in order to mitigate potential adverse consequences of these events. The offshore port and autonomous fleet will initially function at a single location. However we envision that a network of these systems will be deployed at key locations around the world.

4 Advantages and Benefits

To be economically viable, maritime transportation relies heavily on economies of scale [2]. The number of days spent in port is a fixed cost which does not increase as a function of the number of transported units [10]. To absorb these costs, ships have to increase in size. The current rate of growth, however, is not sustainable. Wright [3] argues that “the next step-up in size would impose such significant costs on ports that they would outweigh the advantages of moving cargo in ever-larger vessels”. The size of modern freight ships also significantly limits the number of ports in which they are able to dock [2, 11]. By moving ports offshore, we enable the continued growth of freight ships, thus allowing shipping companies to sustain profits.

For a given shipping journey, the expenses incurred by the shipping company are largely fixed irrespective of the number of containers transported. For this reason, it is more profitable to make the journey with the ship filled to its capacity. Our small autonomous shuttle ships allow for cargo from multiple low-demand ports to be coalesced at a single offshore port, reducing the likelihood that ships will be forced to make journeys only partially loaded. This approach is more economical, and also offers significant environmental benefits since fewer overall journeys need to be made to transport the same volume of cargo.

By shifting traffic away from the shore, we reduce the need for coastal port expansion. Due to pre-existing surrounding structures such as buildings, the expansion of these ports cannot continue indefinitely. Since our autonomous shuttle ships are significantly smaller, they have more freedom in the destinations they serve. This means that deliveries can be distributed more evenly across smaller coastal ports, removing bottlenecks and reducing congestion. Furthermore, our autonomous shuttle ships can reach deeper inland, travelling down rivers and canals to take cargo shipments closer to their intended destination. This ultimately reduces the need for long-haul land transportation and lowers congestion and pollution on roads.

In addition, the ratio of surface area to mass of our drone ships, when compared to that of intercontinental cargo ships, makes solar-assisted propulsion feasible. The use of batteries enables the autonomous ships to operate at night and during bad weather. The shuttle ships will produce almost no harmful emissions, minimising their impact on the environment. Keeping polluting ships out to sea offers obvious public health benefits. Since these ships are not reliant on diesel fuel, their operation is resilient to fluctuations in oil price.

Autonomous ships are inherently invulnerable to attacks from pirates and other malicious parties, since there is no crew to hold to ransom and no possibility of cargo theft, assuming that the containers themselves are adequately secured. Theft of the vessel itself is more likely, but risky for any potential attackers due to the fact it will be tracked through GPS, and extensive anti-tamper measures will be put in place.

Finally, our fleet’s swarm intelligence mechanisms make it much easier for ships to avoid each other and resolve any congestion efficiently. This is very important given the large number of drone ships we anticipate will be necessary to service our offshore ports. Swarm behaviour also presents opportunities for faulty ships to receive assistance from other nearby ships – allowing them to be safely returned to shore without the intervention of a human maintenance team.

5 System Prototype

Our prototype will demonstrate three key aspects of the system:

- the interaction of autonomous ships with coastal ports;
- collaboration and planning during transport;
- interaction of autonomous ships and offshore port.

Some of the key advantages of the proposed system are increased throughput and decreased congestion at coastal ports. To demonstrate this, we will produce a simulation showing how autonomous ships will dock with existing coastal ports to load and unload goods. We will demonstrate the control systems required to enable the shuttle ships to avoid other ships and obstacles, and to guide them into an unloading facility at the port. In addition, autonomous ships will collaborate to minimise the time they spend in the dock – queueing in a logical order in the event that no unloading facilities are available. Our simulation will also include a comparison to traditional transport systems to further motivate the autonomous approach.

To demonstrate the fleet's ability to coordinate at sea and plan routes, we will introduce adverse weather conditions and the presence of other physical obstacles. An early warning system will be implemented through ship to ship communication: when an obstacle is detected, the ship will use the communication system to inform nearby vessels. The route planning system for each ship will recalculate the optimal path, taking into account the obstacles detected by the fleet. We will compare the collaborative approach with a non communicating fleet, to exhibit the benefits of ship to ship communication.

In addition, we will examine the core functionality of the offshore port through its interaction with large intercontinental freight ships and smaller autonomous ships. In this simulation, cargo will be loaded and unloaded using the offshore port storage and retrieval system. The aim is to show the feasibility of the offshore port system, examining container throughput and efficiency of cargo routing.

Finally, we will perform two more simulations to demonstrate the impact of the system at national distribution and global distribution scales. The national level simulation will demonstrate the system's potential to utilise existing small ports for more efficient transportation of goods on land. The global level simulation will show a network of these systems placed at key locations, we will compare the efficiency of the global system against the traditional shipping network.

6 Team Structure and Roles

We elected at an early stage to adopt a well-defined team structure by assigning a logistical role to each member. Members conduct their logistical role in addition to any writing or engineering tasks assigned to them. The assignment of members to roles was a group exercise. We took into account individual strengths and areas of previous experience.

Role	**Member**	**Primary Responsibilities**	**Previous Experience**
Chair	KM	Compile the agenda for each meeting; run each meeting; maintain the risk register; distribution of writing tasks.	Kieran acted as an academic representative and Chair of the departmental Staff Student forum for two years.
Secretary	LW	Organise each meeting; take minutes for meetings; assign actions; distribution of writing tasks; report submissions.	During his placement, Liam organised and ran several client meetings with stakeholders for his project.
Product Owner	AZ	Perform code quality reviews; review and merge pull requests; resolve merge conflicts; code repository management.	Andrei is an active volunteer for large open source projects, conducting code reviews and synchronising contributors.
Scrum Master	LS	Assign ‘story points’ and risk values to each task; collect productivity and code quality metrics; coordinate ‘stand up’ and ‘scrum’ meetings.	During placement, Lloyd has participated in and lead agile meetings. He also managed metrics collection for his placement project.
Lead Architect	MW	Decide the core technologies, languages and libraries to use; create project code structure; identify control/data flows, model structures etc.	On placement, Mark worked with a very broad range of platforms and languages. He has studied system architecture and model driven engineering modules.
Lead Engineer	OL	Oversee development activities; assign programming tasks to members; ensure compatibility of different parts of the solution; coordinate pair programming.	Oliver has lead software projects across multiple international companies and has a strong understanding of software design principles.
Customer Relations	PK	Acting as the single point of contact with the customer; maintaining records of discussions with customer; keeping customer informed of progress.	Having dealt with internal customers on a daily basis during placement, Paulius has experience addressing, investigating and solving customer problems.

7 Key Processes

The team will follow agile practices by conducting regular 'scrum' meetings. The aim of these meetings is to gather system requirements, and break down the development of large, complex features into a series of actionable tasks. These tasks are each assigned a number of 'story points' depending on their complexity, added value, and thus the amount of time they will take to complete.

The use of kanban boards on GitHub to track the status of each task allows for the effective management of feature development, defect tracking and writing tasks. The tasks will be distributed among team members using a pair programming scheme, with the aim of ensuring the correctness and quality of initial code [12]. The persons responsible for each task will maintain and update the status of their tickets on the kanban board.

Progress will be presented to the team in the form of daily 'stand ups'. The purpose of the stand ups is to ensure the team is focused, and consistently progressing towards its goals. Stand ups will take place online using Slack, where each team member will report the following:

- What progress they have made since the previous stand up;
- What tasks and goals they are currently working towards;
- What obstacles they anticipate facing, and what methods they will use to overcome them;
- What progress they aim to have achieved before the next stand up.

We will conduct unit tests in order to assess the functionality of each component. In addition to continual code review within each pair, code will be reviewed before being merged to the main branch. This is handled by the designated product owner, to ensure compatibility between functional components.

8 Metrics

In an agile development setting, measuring progress is often difficult. Hartmann and Dymond [13] identify 11 properties of effective agile measurements. It is important for metrics to be meaningful, and focus on highlighting delivered value as opposed to output quantity. This ensures that the metrics accurately represent the team's progress, and the quality of the product. In view of these properties, we opt to measure the following key performance indicators:

Story Points Completed per Day – represents the velocity of progress. More complex tasks are assigned more story points. Therefore, the number of story points completed per day acts as an accurate measure of how much work is actually being completed – more so than quantitative output metrics such as lines of code [14]. Measuring on a per day basis allows for trends to quickly be established, despite the short project duration.

Estimated vs. Actual Time – represents the deviation from our initial effort estimates, plotted on a graph on a daily basis. Deviation from the estimated time has been shown to be an effective performance measure, and will act as an indicator that team efforts need distributing more effectively [15].

Number and Severity of Faults per Day – represents the maturity and correctness of the system. By logging number of defects alone, we cannot obtain a representative measure of maturity. This is because a fault could be a simple one line code change, or it might require significant modifications to functionality. We therefore opt to log the severity of faults on a scale of Minor, Major and Critical – with the aim of observing a decrease in severity of faults over time.

Team Satisfaction – represents the extent to which team members are satisfied with both their own, and team progress. Measured on a linear scale that ranges from 1 (very dissatisfied) to 5 (very satisfied). Team morale has been shown to provide an important indication as to how successful the final outcome will be [16].

The collection of these metrics will be aided by the use of kanban boards and a Gantt chart, allowing us to keep track of development time, story points, number of defects and fault severity. Soft metrics such as team satisfaction will be collected via an automated process in Slack.

9 Communication Strategy

Ensuring that the system we design and prototype meets customer needs is a central focus at each team meeting. In our first meeting, we established a communication strategy which we leveraged in order to gather requirements from the customer. We continue to use this strategy to keep the customer updated with any new ideas, or modifications to existing plans. Namely, we defined that the Customer Relations Manager (PK) is responsible for soliciting any queries, updates or requests. The customer relations manager keeps other team members informed of any intended communications using a dedicated channel in our team coordination tool, Slack. This gives team members the opportunity to review pending communications – checking them for clarity and relevance to the project. The customer relations manager is also responsible for arranging and leading any face-to-face meetings with the client.

Our initial contact with the customer took place during the first project briefing. In this briefing, we discussed the issues facing the maritime industry and discussed some potential areas on which our solution should be focused. We noted the customer's priorities, and they shared several pressing issues to which they assign a particular importance. We evaluated potential solutions, and how feasible it would be to develop them in the timescales available. The customer expressed interest in several of our initial ideas, and notably in the concept of autonomous cargo. After further discussion with the client, the team decided to pursue the different, but related concept of offshore ports paired with autonomous shuttle ships.

In a subsequent team meeting, we discussed the our proposed solution further in order to establish its viability. We drafted and sent an email to the customer to gauge their interest and enthusiasm, and to solicit feedback for our initial design. The customer responded positively, giving us confidence in our idea, and allowing us to proceed with a more detailed design concept. In the next assessment phase, we intend to work closely with the customer to refine our prototype and system design.

10 Risk Register

We identified the following ongoing risks, assigning a mitigation strategy to each, as well as a relevant owner based on the roles described in Section 6.

ID	Description	L/hood	Impact	Owner	Status/Mitigation
1	Team members are unable to complete writing tasks in a timely fashion due to illness or preoccupation with other work.	Low	High	KM/LW	**Reduction:** Ensure interfering factors are communicated promptly in order for work to be reassigned.
2	Team members struggle to complete programming tasks on schedule due to lack of experience with chosen technologies.	Med	High	OL	**Reduction:** Collect information from each team member about their confidence with certain technologies.
3	The chosen languages, frameworks, or libraries are too difficult to learn, have compatibility issues, or do not have the expected capabilities.	Med	High	MW	**Reduction:** Choose technologies that are already familiar to team members, with known capabilities and limitations.
4	Progress on programming tasks is delayed due to poor code quality, duplication of effort, or conflicting code commits by team members.	Med	Med	AZ	**Reduction:** Communicate intention and ownership of particular work through GitHub Projects and Slack, as well as during stand-ups.
5	The customer is not available to give comments on proposed changes or additions to the system specification.	Med	Low	PK	**Reduction:** Ensure questions are asked within a reasonable timeframe from when a response would be required.
6	Incomplete metrics due to members not completing the daily online 'stand-up' or forgetting to log their activity/ticket progress.	High	Low	LS	**Reduction:** Team reminders that notify individuals that have yet to complete the stand-up.
7	Loss of report or code due to failure of team members' hardware and lack of regular backups.	Low	High	KM/OL	**Reduction:** Use of git and GitHub as a software versioning and backup system for the code-base.
8	Team members unaware of assigned tasks, or complete wrong tasks, due to not attending meetings, or being late to meetings.	High	Med	LW	**Reduction:** Communication between absent members regarding prompt and required attendance to team meetings.
9	Difficulty completing programming tasks on time due to underestimation of work involved or too broad a scope.	Med	High	MW/OL	**Reduction:** Ensure assigned tasks are well-defined and properly understood before producing estimations.
10	Delays in creating the prototype due to the identification of a major design flaw in the system specification.	Low	High	KM/LW	**Reduction:** Guarantee the software specification is complete and agreed upon before the development process begins.

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