GPIG – Final Report

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Group D

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Submission by 8th June 2017

This report contains X words, as counted by the *Texpad* IDE.

Contents

1 Introduction

The shipping industry is arguably the only transport sector whose operations remain relatively untouched by developments in technology. Shipping companies have been slow to adopt the latest innovations, instead preferring to stick with tried and tested norms. Ships simply continue to grow in size, putting incredible pressure on coastal infrastructure. In this report we present OceanX: an innovative prototype system which leverages collaborative autonomy in order to improve the efficiency of cargo movement. We believe that our OceanX system seizes several important market opportunities by capitalising on the lack of innovation the industry has shown to date.

We begin with a description of our system's key features, and the architecture of our code base. We outline which elements we decided to implement to showcase the system in our simulation engine, and we assess the work that must be undertaken to bring the system to an initially deployable state. We then conduct a market assessment, reaching a determination as to how technically and financially viable it would be to develop and deploy the OceanX system. We conclude with a summary of our group's performance, outlining areas in which we collaborated strongly, and considering aspects we would approach differently if we were to undertake a similar project in future.

2 State of the Implementation

2.1 Implementation Structure and Capabilities

In order to demonstrate the capabilities of the OceanX system, we developed simulation software that modelled shipping operations both with and without our offshore smart ports and autonomous fleet. We ensured that system components were modelled in a realistic fashion by leveraging real world data, and considering a range of externalities. This allowed us to conduct an accurate quantitative evaluation of the advantages of our model compared to the freight shipping industry as it exists today.

Our solution architecture is composed of three logically distinct tiers: back-end, front-end, and data. The back-end, a Java web application server, contains all business logic related to the simulation and is responsible for correctly and accurately modelling the movement of ships and their interactions with ports. In order to ensure that the simulation is ecologically valid, it uses shipping lane data from a custom dataset hosted on the Mapbox web service. Using this data, the back-end software is able to create a graph whose edges represent the paths that ships are able to take. Information relating to the simulation, such as the location of containers and the velocities of ships, is then served via websockets to the React/Deck.gl front-end for rendering. Our front-end system then uses this information to appropriately display the positions and statuses of all ships and ports in the system.

The simulation itself is executed on a 'tick-by-tick' basis, where a tick can be described as the software's atomic time unit. Each entity in the system is assigned one of several possible agent types, which determines how the agent behaves and moves. Our possible agent types include autonomous ships, freight ships, coastal ports, and offshore ports. On each tick of the system, every agent is provided the 'world' as it appeared in the previous tick. From this, agents are expected to determine an appropriate action. This decentralised control system models collaborative autonomy. It provides more redundancy and resiliency than would be possible with a single monolithic controller, where a single point of failure could disrupt the entire system. The speed of the simulation is controlled by a speed scaling factor that can be set by the user. This factor is used to modify the speed of operations such as ship movement or cargo loading or unloading. Some key classes from the system that provide fundamental functionality in regard to the simulation:

JSONable An interface that requires the implementation of the `toJSON` method. Used to serialise the world and its constituent agents for transfer to the front-end Javascript.

Agent Provides the abstract method tick that all agents within the system are required to implement in order to define their behaviour. Each agent possesses an ID, an agent type and a set of coordinates defining its location. Every agent implements JSONable.

Simulation Ticks the world and all agents that it contains in time with the number of ticks per second specified. Responsible for sending the state of the world to the front-end.

In order to make sure our model was accurate, we had to implement many of the processes that ships would have to follow in a real-world system. For example, we included a mechanism by which ports could request collection of cargo from nearby idle ships. This collaborative process is essential in ensuring that containers are able to flow efficiently through the system. For this purpose, we developed a heuristic algorithm capable of establishing the most suitable ship for collecting cargo awaiting transport. Specifically, idle ships servicing the port at which this cargo is based are required to submit a 'bid' detailing their suitability to collect the cargo. Each bid is a trade-off between the capacity of the ship and the number of containers that require collection. A ship that could collect all cargo but has a large amount of empty space is penalised, with the system instead favouring ships that can be utilized more efficiently. If all nearby ships are occupied, the port will instead request idle ships from other ports that are connected to it by shipping routes. Allowing each ship to create its own bid allows for a much more flexible system than one controlled centrally, which fundamentally increases the reliability of the overall system.

Our simulation engine allowed us to compare the OceanX system with traditional shipping operations. In order to achieve this, we built a separate shipping lane dataset that did not contain the offshore ports, again fetched from the Mapbox web service by the Java back-end. We developed and integrated a comprehensive statistics suite, which collects and displays information pertaining to the performance of both the OceanX and legacy systems. It is based on these statistics that we reached informed conclusions as to the benefits our system can attain. The statistics we collected include:

- the total number of containers moved;
- the throughput, or number of containers moved per time tick;
- the average waiting time at ports.

2.2 Future Work

By designing, implementing, and evaluating these control mechanisms now, we have reduced the future work required to develop the system to an initially deployable state. We have ensured that the low-level detail and functionality of the system is sound, and we have verified that it improves on the existing shipping industry methodology through quantitative testing.

We would need to invest a significant amount of time, effort and capital to develop both the hardware and software required to develop the system into an initially deployable state. Firstly, we would need to design and construct the autonomous shuttle ships, including the communication and navigation software that enables ship-to-ship and ship-to-port communication. Using this software, we could design mechanisms for collision and danger avoidance systems. Software for the control of the cargo collection and storage systems is fundamental to the automatic functionality of the offshore ports, but we do not currently consider this as part of the simulation. This software would determine how containers are automatically unloaded, stored, and routed to their onward destination when they are ready to leave the port.

Further to this, we need to develop software to control the docking procedure for shuttle ships with coastal and offshore ports. This software would take advantage of the communication capabilities of the ship to interface with these ports, allowing the efficient transfer of cargo. Finally, we must consider procedures for the handling of shuttle ship breakdowns, failure, or power loss. This functionality would mitigate the risk of losing hardware by ensuring that these ships are recoverable and serviceable following unforeseen hardware or software failure.

3 Market Assessment

Thus far, we have considered the technical capabilities and structure of our system. In this section, we show that it would be viable to bring our system to market. We explore trends and challenges in the shipping industry, and make predictions about its future growth. We then propose a market penetration strategy for OceanX, indicating how it might obtain trust and funding from other organisations. We conclude with a quantitative analysis of our proposed system, suggesting approximate operating costs and indicating how much up-front capital would be required to roll out our system in the countries we are targeting.

3.1 Industry Analysis

The shipping industry consists of a number of freight companies, each providing transportation services to global exporters and importers. A typical interaction between a shipping company and goods producers is as follows. Goods importers will place an order with an exporting company, and exporters will then pay for storage and transfer of goods onto a ship, as well as any insurance required for the goods. The exporter will choose a shipping company based on the quoted freight rate, which indicates how much will be charged for the transportation of the goods. However, other considerations such as the quality of the insurance and transit time are important factors.

The process of globalisation has caused rapid growth in international and intercontinental trade. With 90% of all such trade conducted by sea [1], the shipping industry has played, and will continue to play, a vital role in satisfying global demand. Figure 1 shows the historical demand for cargo, along with the projected figures into 2030 and beyond. In almost all cases, an increase in the volume of cargo is expected. In particular, containerised shipping is expected to almost double in quantity in the next 15 years.

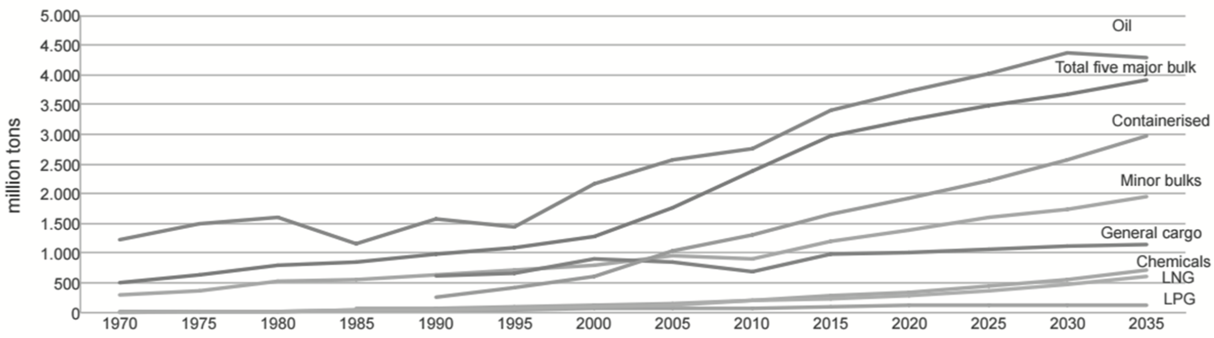

Figure 1: The trends in amount of cargo distributed globally, measured in millions of tons [2].

Despite this clear growth, the industry is arguably more sensitive to world events than most. For instance, Hanjin, a large Korean shipping company, was forced into administration in 2016 due to heavy drops in freight rates [3]. As well as danger from economic recession, the industry is somewhat unique in threats from piracy, often involving crew kidnapping with heavy human and economic costs. In addition, the industry must comply with environmental regulation from political bodies, which seek a 40% reduction in carbon emissions by 2050 [4].

Alphaliner provides data on the split of market share of top shipping companies with respect to the total cargo capacity, measured in Twenty-foot Equivalent Units [5]. The biggest players in the shipping industry are APM-Maersk, Mediterranean Shipping, CMA CGM Group, and COSCO

Shipping. Together, they constitute around 50% of the market. Much of the success of the 'big 4' is attributed to their ability to manage costs through efficient organisation and conservative development of ship capabilities [6], with the opportunity cost of additional business.

A key trend in shipping industry is a drive for more efficient ships with greater capacities in order to combat falling freight rates [7]. These larger ships are not without their own problems, since they require significant changes to port side infrastructure in order to be sustainable [8]. As an alternative to this heavy investment, ultra-deep water ports have been deployed, which have the advantage of accommodating the depth requirements of larger vessels. The UK government has considered the commisioning of an offshore deepwater port for the purpose of decommissioning the North Sea oil operation [9].

Another important trend in the short to medium term is the emergence of "big data". Firstly, the recently deployed Automated Identification System of satellites offer greater monitoring of ship positions and weather conditions. This allows for the informed route planning [10]. Secondly, big data will be used to improve the visibility of market and pricing trends, stabilizing freight rates, and avoiding cases such as Hanjin in 2016.

Finally, further adoption of autonomous systems is expected in the medium to long term. Rolls-Royce is beginning this process with a global research project ultimately aiming to deploy a fully autonomous system by the end of the decade [11]. The main advantage of the autonomous approach is the cost saving in reduction in required crew size. However, fully autonomous systems still require occasional human maintenance. Autonomous systems address the problem of piracy, by removing the opportunity to hold human lives hostage [12].

3.2 Market Penetration Strategy

We envision that the system will be deployed initially at a single location. In other words, we propose one offshore smart port servicing multiple land ports with a fleet of autonomous shuttle ships. To determine the path to realising this goal, we have identified the key players in bringing the OceanX system into the shipping industry.

The company (OceanX) shall work with companies who wish to move goods (exporters) by offering freight and cargo insurance services in competition with existing freight companies. To the exporter and importer, there will be no additional steps required in order to use the OceanX system. On successful bid for exported goods, our fleet of autonomous shuttle ships will transfer the cargo from the coastal port to the offshore port. Next, in order to transfer the goods onward to their destination, we will employ services of the existing shipping providers using a portion of the fee levied on the exporter. The large intercontinental cargo ships will dock at our offshore ports instead of a coastal port. For importing, we shall have a similar relationship with the freight companies. Large freight ships will deliver cargo bound for multiple coastal destinations to the offshore port, then the fleet of autonomous ships will be deployed to forward cargo to the specific coastal destination.

The primary motivation for the competition to use our system, instead of docking at coastal ports, is the ability for larger ships to be serviced. This enables higher utilisation of ship resources, since cargo from many coastal ports can be coalesced at a single offshore port. This allows our competition to continue the trend of building larger ships at higher cost effectiveness, while allowing OceanX to avoid heavy investment in the newest and largest freight ships. The fleet of autonomous ships will initially consist of repurposed freight vessels. Ultimately, we hope to build our own ships with autonomous control in mind, allowing maximal use of space and energy. However, significant initial cost savings can be made through adaptation of existing resources.

We will seek co-investment for the construction of the offshore port. As mentioned, the UK government has already expressed interest in building such a port. Additional funds can be raised by partnering with existing freight companies in exchange for priority/preferred usage rates. Additional sources of revenue come from the use of the offshore port by non-OceanX vessels. For instance, the air solution developed by Team A involves making long flights over water, and our offshore ports may be used to charge these aircraft for a fee. In addition, fuelling and docking services will be charged to freight ships using the system.

Crucially, we shall build trust with the exporter, freight companies, and wider public. To this end, the system will be rolled out incrementally, with a strong focus on reliable and secure operation. Initially, the system may function as a single offshore port and a small repurposed fleet. To gain the trust of exporters we shall offer a generous insurance policy on the transfer of goods, with our liability kept low by the fact that goods are transferred at the offshore port. In addition, we will promote the autonomous aspect of the system in enhancing user privacy, lowering the risk of piracy for the exporter by removing the possibility of human hostage taking. To gain the trust of freight companies we may simply point to the cost efficiency gains from allowing the trend of larger ships to continue.

Once the network of OceanX offshore ports is established, there is scope to expand the capabilities of the company. Firstly, purpose built autonomous shuttle ships would be developed for coastal to offshore delivery. In addition, OceanX may explore the use of its own intercontinental autonomous freight ships to “cut out the middleman”, triggering competition with existing freight companies which are already deeply invested in the OceanX system.

We believe the key threat to our deployment plan is that historically, the shipping industry has been reluctant to embrace new technology – instead opting to stick with tried and tested economics. This is evident just by observing the slow pace at which Maersk and other big companies upgrade their fleets to larger, more cost-effective vessels. As mentioned previously, in order to address this threat, we would seek to initially partner with government programmes focusing on the development of offshore ports. This reluctance to innovate, however, can also be viewed as a key opportunity for OceanX. In particular, since existing companies can dock at our offshore ports without modifying their ships, they can retain their current model without being held back by a lack of shore-side investment.

3.3 Quantitative Market Analysis

As outlined in the industry analysis, revenues in the shipping industry have fluctuated significantly in recent years. The Great Recession caused a substantial reduction in the rate of growth of the volume of cargo shipped, which in turn has hurt the profits of major shipping lines through a “prolonged slump in the shipping market” [13]. Despite this downturn, however, the 4 largest shipping lines still collectively generate $75bn in annual revenue [14]. One contributing factor to this decline is that in order to maximise efficiency, lines have invested in larger ships, with modern vessels having 30% greater capacity (20,000 TEUs) than those from before the Great Recession (15,000 TEUs) [8]. This means that despite efficiency savings through an increase in vessel capacities, the availability of cargo space has often exceeded demand. This has lead to crashes in freight prices.

With the volume of cargo doubling by 2030 [2], it is reasonable to assume the revenue for the industry will increase by a similar amount, in addition to price increases caused by inflation. Furthermore, we assume the response by the shipping industry will be to continue investment in larger ships.

As the number of high-capacity ships increases, substantial investment on port side resources will be needed to meet demand. The OceanX system reduces pressure on existing coastal ports, and enables investment from these ports to be redirected into a single local offshore port. Assuming the costs of our offshore port solution will be approximately equal to that of a typical oil rig, we expect that each offshore port will require a capital investment of around £500m [15]. However, we aim to recycle materials from decommissioned oil rigs as the world becomes less reliant on fossil fuels. With regards to the investment required to develop our fleet of autonomous shuttle ships, either new vessels can be commissioned, or used ships can be retrofitted. As such, it is estimated the average cost of a ship will be in the region of £1-2.5m [16], excluding any specialist autonomous control hardware.

As well as the initial development costs, there will be daily costs to maintain and run the fleet of ships and the offshore port. Based on operating costs for similarly-sized ships today, we estimate initial daily operating costs totalling £30k per ship [17] and £500k for the offshore port [18]. These values are based on existing ships and semisubmersibles, and therefore are pessimistic cost projections. Two major cost reductions will come from the reduced number of personnel, and the use of renewable energy.

We anticipate that the main source of revenue for the OceanX system shall be the fees we collect from exporters, in addition to fees from import contracts for moving goods from our offshore ports back to coastal ports. Freight rates vary based on destination, we would expect to charge between £500 and £3000 per container [19]. We would like to generate additional revenue through dock-side services, such as refueling and charging.

In summary, the initial aim of the OceanX deployment plan is to secure trust and financial investment from the key stakeholders such as government, coastal port operators, and shipping companies. To begin with, we will begin to draw market share from businesses wishing to export products with a competitive insurance and freight rate package. While we expect substantial up-front costs in development and procurement, we believe that the long-term cost savings of our approach will lead to rapid growth and eventual world wide adoption of the OceanX system.

4 Group Evaluation

We believe that the project was a productive exercise; our chosen team structure was very effective, and all team members made a significant and unique contribution. In this section, we evaluate the overall performance of our group and the processes we followed. We also discuss how we would improve our processes if we were to undertake a similar project in the future.

4.1 Team Structure and Logistical Roles

In our initial report (§6), we defined a team structure in which members adopted a logistical role in addition to any writing or programming responsibilities. There were several reasons why we decided to implement this structure:

- to ensure that administrative workload was divided evenly;
- to reduce the likelihood of conflicts or duplication of effort, by making it clear from the outset who is ultimately responsible for each area;
- to allow us to hold individuals to account in the unlikely event that work was not being completed in a timely fashion;
- to give everybody the opportunity to gain experience in management, report writing, and programming.

On balance, we believe this approach was highly effective – team members quickly became familiar with their assigned roles. Arguably, the most difficult part was deciding what roles were necessary and allocating them in a way to fit people's existing skillsets. It was also challenging to arbitrate effectively in the event that two or more people wanted to take on the same logistical role. We found that having some degree of flexibility with role titles and responsibilities helped us to arrive at our final role assignments.

Our fixed structure, however, did not come without problems. There were several occasions where team members were unavailable or away, rendering them unable to make important decisions. This left other team members wondering whether they should delay or proceed without the approval of the absent team member. In most cases, a delay could not be justified. It was clear that our contingency plans were insufficient, and in future we would make additional effort to ensure that a suitable backup plan was in place so that decisions could be taken in the absence of critical team members.

4.2 Meetings and Communication

The team held meetings at least once every two days to discuss progress and assign work. Where possible, the Chair planned all meetings in advance, and compiled a formal agenda. The Secretary booked a meeting room to reduce distractions and ensure we had whiteboard facilities available. The Secretary also took minutes, which served as an important register of all the decisions we had taken in meetings. We made sure everybody was aware of upcoming meetings by using a shared calendar, and we enabled automated reminders in our group communication tool, Slack. Generally speaking, attendance at meetings was high. Latecomers sometimes caused delays, but the situation improved after we voiced our concerns.

Particularly towards the end of the project, we found that meetings were called with short notice, and it therefore became difficult to create agendas in advance. We believe, in hindsight, that the team could have benefitted from a more fixed meeting schedule. That being said, many team members appreciated the flexibility to “work from home” in the later stages of the project, since they found that they were more productive when working alone. For this reason, we are unsure to what extent a more rigid meeting schedule would have actually improved our productivity.

4.3 Planning and Scheduling

The Chair and Secretary worked together to carefully plan out each phase of the project. We are very pleased that the team managed to adhere to this schedule closely. We had different phases for initial report writing, planning, implementation, final report writing, and presentation planning. These phases are presented graphically in the Gantt chart in Figure **??**.

[Gantt Chart]

4.4 Daily Stand Ups

We tracked the progress of individual team members and collected metrics through an automated daily stand-up process. While we had some initial reservations that people would forget to complete it, the participation rate was around 95%. This gave us a comprehensive picture of our productivity and team sentiment. On several occasions, team members recorded low sentiment scores. We were able to investigate why people were unhappy, and address these problems as soon as they occurred. Since this process was fully automated, it required no additional effort from team members to coordinate.

The burndown chart in Figure **??** illustrates some of the metrics we were able to collect during the daily stand up. Amongst other things, we recorded the number of story points that each team member completed per day.

[Burndown chart]

We also included in the daily stand up a range of qualitative open-answer questions, such as “What progress do you hope to complete before the next stand up?” and “What obstacles do you anticipate facing?”. These facilitated reflection, but were sometimes seen as burdensome, and we would probably include less of these questions if we were to undertake a similar project in future. We found that, while they improved the ability of the team to focus, they did not tell us anything we didn’t already know.

4.5 Issue Tracking and Code Maturity

We used GitHub Issues to record pending tasks and faults identified with our code. We then placed these issues on a ‘kanban board’, allowing us to keep track of the current status of each ticket. A screenshot of our kanban board is provided in Figure **??**.

[Kanban Board] We used issue tickets to triage issues and assign a number of story points to each, indicating the amount of development effort that the issue ticket would require to complete. We found that this provided useful reference information when completing the daily stand up. However, we sometimes forgot to create or update issue tickets, meaning that the kanban board was not always up to date. In future, we would make more of an effort to create all of our tickets at the start of each agile sprint, along with story point estimations. We would also schedule a short daily review session to make sure that completed issues are always marked as resolved.

4.6 Architecture Selection and Programming

All team members took part in programming activities, allowing us to draw upon a very broad range of experience. Deciding on programming languages and frameworks was not a straightforward task, and we had to reconcile several opposing viewpoints. We were able to reach a consensus through compromise: splitting our code base into 'front-end' and'back-end' components, each using a different language and set of frameworks. Those who were initially less comfortable with one of the languages were able to learn from those who were. Incidentally, this structure worked strongly in our favour, and we believe our solution was far superior to any we could have produced using just a single language.

We followed agile practices, allowing us to iterate quickly, mitigate risks, and come up with a 'minimum viable product' as early as possible. We felt that this was the most appropriate strategy given the tight time scale. By design, agile involves less onerous and detailed planning – which we found to be both a blessing and a curse. We firmly believe that it would have been impossible to plan out all of our development efforts right at the beginning, and agile afforded us the capability of planning as we went along. However, there were several scenarios in which well-intentioned team members devoted a lot of effort to completing their tasks only to discover that their code was not fully compatible with what others had developed. This resulted in tedious merge conflicts that could have been avoided with more meticulous planning.

4.7 Writing and Documentation

It appeared that some teams elected at an early stage to segregate their members into engineers and writers. We chose not to adopt the same approach for several reasons:

all members of the team were keen to get involved with programming tasks, and it would not have been reasonable to deprive them of this opportunity; we collectively believed that the best person to write documentation for specific system components is the person who also wrote the code; it would have been very challenging, and possibly wasteful, to write report sections as our solution was undergoing constant changes and adaptation.

Instead, our writing phase followed our implementation phase. We believe that this decision worked in our favour: since our prototype had been completed before writing started, we had little difficulty explaining how it worked. It was the first time many team members had to coordinate and delegate the writing of such a large report to so many people.

We learned a lot from the process of writing the initial report, where we had not left sufficient time to proof-read, edit, and merge disparate report sections. For our final report, we adopted a three-stage review process to prevent a verbatim repeat of the difficulties we faced with our initial report. For both reports, it was sometimes challenging to assign writing tasks to relevant individuals whilst ensuring that the workload was evenly distributed.

4.8 Risk Management

In the initial report (§10), we included a register of the main risks involved with our project. We found that risks did not need to be added or removed as development progressed. Thankfully, many of the risks in the register (R2, R3, R5, R7, R9, R10) did not materialise because we took adequate reduction measures. However, other risks did materialise in some form.

R1: Unavailability of Team Members There were several occasions where team members were ill or had other work to complete, meaning that tasks took them longer to complete than anticipated. We were able to mitigate this risk by building resilience into our schedule, ensuring disruptions did not significantly impact progress. In hindsight, we believe that we underestimated the likelihood of this risk occurring, but also overestimated the impact. We were able to work around disruptions effectively, meaning that an impact value of 'high' was not warranted.

R4: Incompatibilities and Merge Conflcits We were often delayed due to code incompatibilities and merge conflicts. We believe that our assigned values for likelihood and impact were appropriate, because the occurrence of this risk did have a substantial impact. Simply communicating ownership did not turn out to be a sufficient reduction measure. In future, we would also ensure that distinct logical system components have a formal predefined common interface before programming begins.

R6: Collection of Metrics As discussed in Section 4.4, we were able to gather most of our metrics through the daily stand ups, with a very high completion rate. However, not all story points were accounted for due to tickets not always being created. As we mentioned in Section 4.5, we would employ additional measures in future to prevent this from happening. We believe that we overestimated the likelihood of this risk occurring, and in future we would assign a value of 'medium' instead. This is because our automated reminder system was very effective.

R8: Lateness to Meetings Team members were sometimes unaware of what other members in the team were working on because of lateness or poor attendance to meetings. We acted quickly to raise concerns whenever necessary. We believe that our mitigation measures for this risk were appropriate.

5 Conclusion

Overall, we believe that our project was a great success, and we enjoyed the opportunity to develop a product from the inception of our initial idea through to a functional prototype. The team worked well together, and we take away from this project new technical and interpersonal skills. We found that dealing with unpredictable changes to customer requirements was challenging, but we mitigated any adverse consequences through frequent and early communication with the customer.

In contrast to other teams, our simulation operated on a more macroscopic scale — not only because ships need to travel much longer distances, but also because we felt this approach would accurately convey the benefits the system can deliver and emphasise its potential global impact. Our simulation engine used state of the art libraries to generate a rich 3D visualisation, and we elected to logically separate the back-end and front-end to ensure that we were using the best technologies for each component. This logical separation has the added benefit that our visualisation tools are kept completely separate from our control software, making it easier to implement the control mechanisms in hardware at a later stage. Our analysis allowed us to conclude that, with little doubt, the OceanX system would be more efficient, able to handle a 2x increase in cargo volumes over the next 30 years, and move the industry toward greener, safer transportation.

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