<u>Team 1186</u>

How many airships would be required to replace the Cook Strait Ferries?

Abstract

We calculated the number of airships required to replace the Cook Strait Ferries as a fleet of **eight airships**. This was done by calculating two key figures. We determined that each airship could feasibly carry out roughly **nine** single way trips, in a day. Then we used a computer-made mathematical model with JavaScript to find that the optimal number of trips needed to transport all current ferry passengers each day is 65 trips. This allowed us to calculate our final answer to the question posed.

Background

The Cambridge Online English Dictionary defines an 'Airship' as 'a large aircraft without wings, used especially in the past, consisting of a large bag filled with gas that is lighter than air and driven by engines' (*AIRSHIP | English Meaning - Cambridge Dictionary*, n.d.). Other terms used for this type of craft include a blimp or a dirigible. Airships are a method of transport primarily relegated to history, but what if they made a comeback? This report investigates how many airships would be required to completely replace the services offered by the Cook Strait passenger ferries in New Zealand.

Cook Strait and the Ferries

Cook Strait is the body of water separating the North and South Island. Currently, the Cook Strait Ferries must make a 96 kilometre crossing to transport passengers between the terminals in Wellington and Picton (*What You'll See on Your Journey*, n.d.). This distance does involve traversing the waterways of Marlborough Sound, which adds some distance. The straight line distance between the ferry terminals at Picton and Wellington is 65.5 km. It is assumed the airships will be able to travel between these terminals in a straight line, because they travel by air and are not limited by geographical barriers. Two companies currently operate passenger ferries across Cook Strait; the three InterIslander ferries (the Kaitaki, Aratere, and Kaiarahi) and two Bluebridge ferries (the MV Strait Feronia, and the MV Connemara) (BlueBridge, n.d.) (InterIslander, n.d.). These 5 passenger ferries will be replaced by our airships.

(above: the straight-line distance from one ferry terminal to the other)

In total, the Cook Strait ferries transport around 1.2 million passengers per year (KiwiRail, 2021). The Interislander services around 850,000 of these people, alongside 250,000 cars. If we assume this ratio of passengers to cars remains true for BlueBridge as well, then in total:

$$\frac{250{,}000\ cars\ on\ InterIslander}{850{,}000\ people\ on\ InterIslander} \times 1,200,000\ people\ total\ = 352,941\ cars\ total$$

Rounding to 3 significant figures (because there is some uncertainty in the values provided), that gives us around 353,000 cars transported in total each year, alongside 1.2 million passengers.

Currently, each ferry trip takes around 3 and a half hours, or 210 minutes (InterIslander, n.d.); across the 96 kilometre trip, this gives an average speed of:

$$\frac{96\ kilometres}{3.5\ hours}\ =\ 27.4\ kilometres/hour$$

Our Selected Airship

In order to answer this question, we needed to examine the specific features of the airships that would be used. In particular, we needed to know the carrying capacity - allowing us to work out how many people and cars could be transported at a time - and the flying speed - allowing us to work out how long each trip would take. Due to airships in the modern world being primarily used for advertising and publicity, finding features relevant to transporting large numbers of people and cars was difficult. However, a number of companies are beginning to invest in airship travel in the coming decade, as a more carbon-friendly alternative to aeroplane travel. One of these is the wrench company ‘Flying Whales’, who are aiming to introduce their airship - the LCA60T - into the market for travel in 2025 (Flying Whales, n.d.). This was the airship model we selected to comprise our fleet to replace the Cook Strait Ferries.

The LCA60T has the following specifications:

- Maximum speed - 100 km/h (54 knots)
- Flight ceiling - 3 000 m (10 000 ft) AMSL for 60 tonnes of payload
- Power - Up to 4000 kW (5360 hp)
- Volume of helium - 180 000 m3 (6 300 000 cu ft)
- Payload - 60 tonnes = 60,000 kg(132 000 lbs)

We selected this airship due to both its carrying capacity and speed being in a useful range for transporting large numbers of passengers. It was also selected due to the planned market release date - 2025 - being relatively close, which would indicate the technology in this model of airship is more feasible and realistic than if it were planned for later in the decade.

Our Approach and Methodology

We programmed via JavaScript to produce a model, which will be explained in further detail in the next section. There were also a number of variables we needed to find in order to properly run this model:

How Many People and Cars Each Airship Carries

The average weight of a New Zealander is 77 kg. This figure comes from a 2011 University of Otago and Ministry of Health nutrition survey (Stuff New Zealand, 2015) that shows that the average male adult in New Zealand weighs 85.1 kg and the average New Zealand adult woman weighs 72.6 kg. As the male to female ratio in New Zealand is almost 1:1 (*New Zealand Population 2024*, 2024), this means that a simple average calculation of $\frac{72.6+85.1}{2} = 78.85$ kg was performed. This average is rounded down slightly to account for the children, who are lighter than the average adult weight, who will also be aboard the airships. Therefore, the final weight of each passenger is determined to be 77 kg.

The weight of the average car is 1848 kg. This is because in 2022, the average car in the US weighed 4,094 pounds (*How Much Does the Average Car Weigh? 2024*, 2024), or 1857 kg. This is rounded to 1848 kg, so it is a multiple of 77, which makes code execution easier as 24 people have the equivalent weight of one car.

As established previously, each of our LCA60T airships has a carrying capacity of 60,000 kilograms (Flying Whales, n.d.). The airships will be filled in a way that loads equal weights of cars and passengers (ie. 24 passengers board per car) until either no more passengers or cars can be filled up. Then, the remaining weight allowance will be filled up by whichever (passengers or cars) is left over. This allows for the most efficient and equitable outcome.

Probability of Breakdowns and Weather

Airships cannot operate if they are broken, or if the weather is extreme - particularly if there are strong winds (43+ kmh). The percentage of days in each month with strong wind is given in Table 1 (Windy.App, n.d.):

Table 1:

January - 16%	February - 14%	March - 10%	April - 14%
May - 16%	June - 16%	July - 18%	August - 15%
September - 20%	October - 18%	November -18%	December - 12%

Regarding breakdown of the airships, Science Direct states that "the failure probability reaches its maximum of 0.025"." for airships generally (ZHANG et al., 2020). This is thus used in our future calculations, as a part of our report.

How Many Trips per Day

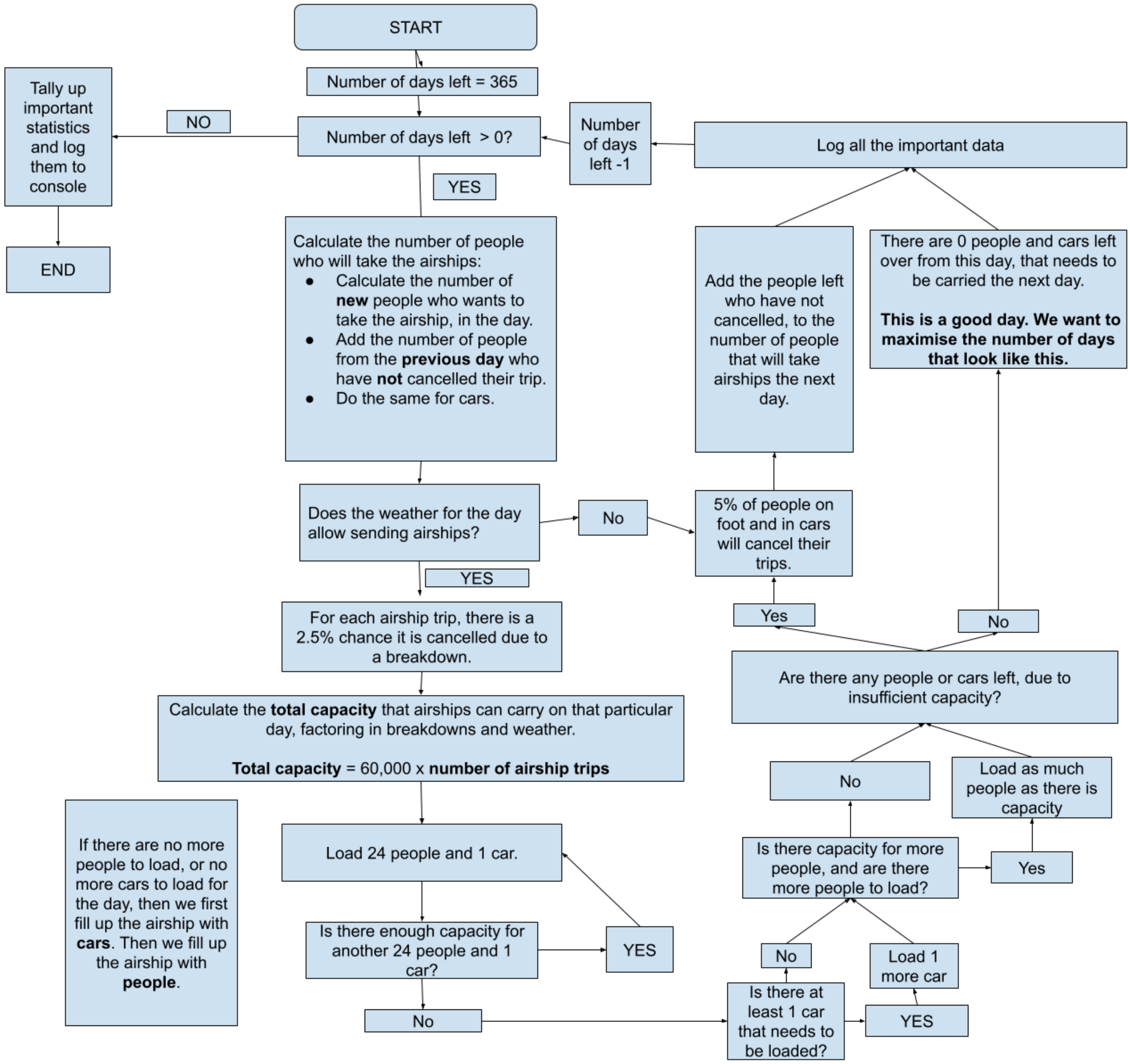
Using Google Maps, we found that the direct straight-line distance from the Interislander Ferry Access (Wellington) to Picton Port (Picton) is 65.5 km. Also, the maximum speed of our LCA60T airships is 100km/h (Flying Whales, n.d.). This means that the airships should take $\frac{65.5}{100} = 0.655$ hours, or around 39.3 minutes, to make a one way trip (ie. from Wellington to Picton or vice versa). Assuming an approximate of 1 hour for docking, boarding and refuelling time, the total time between an airship departing for one trip and departing for the next trip is 1 hour and 39 minutes.

If the airship trips will follow the same time schedule as the current InterIslander ferry, albeit with significantly faster times (Interislander, n.d.), then trips will run from 5:00am to 6:30pm each day, a 13 and a half hour time window. In this case we are leaving out the 2:00am and 2:30 am departure trips, as it would be unsafe to pilot an airship across the strait overnight. As our trips are around 1 hour 39 minutes, this allows for 9 trips on average to be undertaken per day.

The Model

The Code

We are using Node.js v20.11.0. Our model simulated the demand from different categories of passengers each day, adding or subtracting a random percentage (up to 20%) to account for variability in number of passengers.



(*Above: A flow chart giving a basic outline of our model)*

Some code snippets from our code model are displayed below:

```
//load a person and a car
while (remainingAirshipCapacity > batchWeight && countTravellerNumbers(true) > 0 && countTravellerNumbers(false) > 0) {
    for (let i = 0; i < peopleForEachCar; i++) {
        if (countTravellerNumbers(true) > 0) {
            loadPerson();
        }
    }
    if (countTravellerNumbers(false) > 0) {
        loadCar();
    }
}

//Now we don't have a lot of airship capacity, because we have already filled them with batches of people and cars
//Do we have capacity to load a car? If so, we keep loading cars
while (countTravellerNumbers(false) > 0 && remainingAirshipCapacity > PARAMETERS.CAR_WEIGHT) {
    loadCar();
}

//Now we have either NO cars to load or not enough space to load a car. Now we load the people
while (countTravellerNumbers(true) > 0 && remainingAirshipCapacity > PARAMETERS.PERSON_WEIGHT) {
    loadPerson();
}
```

The above is the code that loads people and cars into airships. The function `countTravellerNumbers` takes one perimeter, `onFoot`. If set to `true`, it will return the number of people without cars, who need to be loaded onto the airship. If set to `false`, it will return the number of cars instead. First, we load airships in batches of roughly 24 people and 1 car, as `peopleForEachCar` is set to 24. If there are no people or cars who are not loaded onto airships, or if the airship has no more capacity to load in batches, we fill up the remaining capacity with cars. Then we fill up the remaining capacity with people. The functions `loadPerson()` and `loadCar()` loads one person onto the airship, and decreases the airship's remaining capacity.

```
//at the end of the day, some people will cancel their trips...
let tripsCancelledPeople = {};
let numberOfCancelledTripsPeople = 0;
for (let purpose in travellersNoCar) {
    let travellersNo = Math.floor(travellersNoCar[purpose] * PARAMETERS.CANCEL_TRIP_PEOPLE_MULTIPLIER[purpose]);
    tripsCancelledPeople[purpose] = travellersNo;
    numberOfCancelledTripsPeople += travellersNo;
    travellersNoCar[purpose] -= travellersNo;
}
dayData.numberOfCancelledTripsPeople = numberOfCancelledTripsPeople;
```

This is the code that runs at the end of the day, where people (**not cars**) who did not go on the airship cancel their trips. `PARAMETERS.CANCEL_TRIP_PEOPLE_MULTIPLIER[purpose]` is 0.05 regardless of the purpose of a person's trip, so roughly 5% of all stranded travellers will cancel. We subtract the 5% from people who are waiting for the next day, add the 5% to the running count of people who have cancelled their trips, and log the data by adding it to the `dayData` object.

```
let totalCarsCarried = 0;
allDayData.forEach(e => {
    totalCarsCarried += e.tourismCarsLoaded;
    totalCarsCarried += e.workCarsLoaded;
    totalCarsCarried += e.familyCarsLoaded;
})

console.log(`TOTAL CAR CARRIED: ${totalCarsCarried}`);
```

This code totals the number of cars that are loaded onto the airships in 365 days.

Our full code can be found at: https://github.com/computers-are-good/NZengineering2024/tree/main

Parameters

The constants to be fed into the model are:

`NUM_DAYS: 365,` The number of days to run the simulation for.

`BASE_POPULATION: 1779,` The base number of people without cars who will use the ferry each day. This number will be multiplied by a random number between 0.8 and 1.2 to determine the number of new people to board the ferry, in a day.

`POPULATION_WITH_CARS: 1508,` The base number of people who will use the ferry, that are carrying a car. This number will be multiplied by a random number between 0.8 and 1.2 to determine the number of new people with cars, to board the ferry.

`AIRSHIP_CAPACITY_KGS: 60000,` The capacity of each airship, in kilograms. We assume that all the capacity will be dedicated to carrying people and cars.

`PERSON_WEIGHT: 77,` The mass of the average person, in kilograms (Perrotta & Edlington, n.d.).

`CAR_WEIGHT: 1848,` The mass of the average car, in kilograms.

`AIRSHIP_BREAKDOWN_CHANCE: 0.025,` The chance that an airship trip will be cancelled due to a breakdown.

`CANCEL_TRIP_PEOPLE_MULTIPLIER: 0.05,` The number of people who have not boarded an airship on a day who will cancel their trip instead of waiting until the next day to board.

`POPULATION_VARIANCE: 0.2` The number of people and cars taking the trip each day will change up to 20% of the original `POPULATION_WITH_CARS` and `BASE_POPULATION` variables.

```
const PARAMETERS = {
    NUM_DAYS: 365,
    BASE_POPULATION: 1779,
    POPULATION_WITH_CARS: 1508,
    AIRSHIP_CAPACITY_KGS: 60000,
    PERSON_WEIGHT: 77,
    CAR_WEIGHT: 1848,
    AIRSHIP_TRIP_NUMBER: parseInt(process.argv[2]),
    AIRSHIP_BREAKDOWN_CHANCE: 0.025,
    CANCEL_TRIP_PEOPLE_MULTIPLIER: {
        tourism: 0.05,
        work: 0.05,
        family: 0.05,
        tourismCars: 0.05,
        workCars: 0.05,
        familyCars: 0.05
    },
    POPULATION_VARIANCE: 0.2
}
```

`AIRSHIP_TRIP_NUMBER` is parsed from a parameter given in the command line, so it is easier to run the model for different number of trips.

We know from the Background Information Section that 1.2 million people take the ferry each year, split into people on foot and people with cars. 353,000 cars cross the strait every year. Each car carries 1.56 people on average (NZ Transport Agency, n.d.). Assuming that this is the average for people on ferries, then the number of people travelling with cars is:

$353,000\ cars/year \times 1.56\ people/car = 550,680\ people\ per\ year\ travelling\ with\ cars$

Thus,

$1,200,000\ people\ total - 550,680\ people\ with\ cars = 649,320\ people\ per\ year\ travelling\ without\ cars$

To find `BASE_POPULATION:`

$\frac{649,320\ people/year}{365\ days/year} = 1779\ people\ per\ day$ cross the strait every day without a car. We also assumed that `CANCEL_TRIP_PEOPLE_MULTIPLIER` will be 0.05 and `POPULATION_VARIANCE` will be 0.2 based on travel data.

The independent variable is `AIRSHIP_TRIP_NUMBER`, the number of airship trips made in a day. The more trips that are made in a day, the more the total capacity that can be carried on that day, so more cars and people can be carried.

The dependent variables are:

- The number of days where there are more than zero uncarried cars (`daysWithUncarriedCars`),
- The total number of uncarried cars in a year (`totalNumberCarsUncarried`),
- The number of car trips that are cancelled a year, (`carTripsCancelled`),
- And the total number of cars that are carried (`totalCarsCarried`).

We are focusing on cars, because the number of passengers on foot contributes much less to airship load than the number of cars (as cars weigh more than people, and 1 car is equal to 24 people!). Often, there will be enough airship capacity for all foot passengers, but not enough for cars, because each airship can carry fewer cars than people. Therefore, cars are the bottleneck we must account for. We want to find the minimum value of AIRSHIP_TRIP_NUMBER that minimises `daysWithUncarriedCars, carTripsCancelled,` and `totalNumberCarsUncarried` while maximising `totalCarsCarried`.

There will be a point of diminishing returns, because each year, bad weather limits the total number of trips that can be made. There is a certain percentage of days in each month, with strong winds, such that no airship trips can be made. For each day, that percentage is given in Table 1.

Results

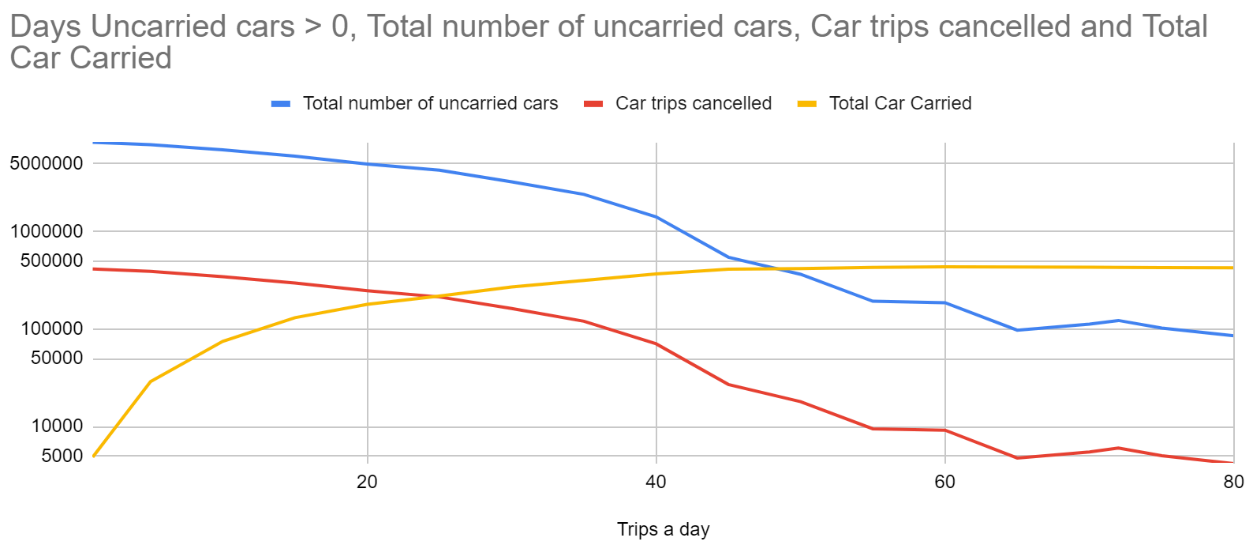
The results are obtained after we run the model several times, changing up `AIRSHIP_TRIP_NUMBER` with each run.

Table 2:

AIRSHIP_TRIP_NUMBER	daysWithUncarriedCars	totalNumberCarsUncarried	carTripsCancelled	totalCarsCarried
1	365	8327448	415859	4864
5	365	7891660	394071	29015
10	365	6965867	347770	75263
15	365	6002078	299579	131773

20	365	4994574	249196	180573
25	365	4312054	215073	219770
30	365	3279411	163454	272391
35	365	2432194	121087	318171
40	365	1430223	70989	371037
45	313	550631	27127	414553
50	239	367428	18058	421159
55	166	194316	9503	431833
60	144	187594	9189	437782
65	99	97915	4759	437433
70	112	113139	5505	434490
72	108	123260	6033	432704
75	98	103015	5024	430825
80	81	85839	4179	429177

Graph 2:



The results from our model indicate the minimum optimal number of trips per day is **65**.

From 1 to 45 trips/day, increasing the number of trips/day rapidly increases the number of cars that are transported. From 45 to 65 trips/day, increasing the number of trips/day rapidly decreases the days where there are cars not carried due to capacity restraints. Past 65 trips, we get diminishing returns. From the graph we can see that, after 65 trips, the number of car trips that are cancelled, the total number of uncarried cars, and the total number of cars that are carried all begin to plateau.re is little benefit to adding additional trips.

This means that the number of airships needed is given by:

$\frac{65\ trips/day}{9\ trips/day/airship} = 7.22\ airships$, which must be rounded up to **8 airships** to ensure all trips can be made.

As each blimp can make 9 trips a day, we can round the number of trips/day up to 9 x 8 = **72 trips/day**, to ensure full utilisation of every airship each day, without adding many additional costs.

Discussion

We made a few assumptions in this report due either to a lack of clear data or in order to make our model more effective. These include:

- No airships will be delayed until later that day due to breakdowns or bad weather. All breakdowns and bad weather result in a cancellation of services for the whole day. This is reasonable, as large storms and strong winds tend to last for most of the day, and the breakdowns may take a long time to fix, preventing that airship from flying.
- People will stay with their cars if there is not enough room on board the airship. This prevents people from leaving their cars behind when crossing the Strait. This assumption was made as people are unlikely to leave behind their property when travelling, or else they would have travelled on foot from the start. This allowed our model to separately keep track of the number of people and the number of cars that cannot board the ship due to capacity limitations.
- The people using the airships will be representative of the population using the ferries right now. This is reasonable, as the same people will still need to cross the Strait for family or work related reasons, and the number and demographic of the tourists should not be changed by this. This assumption was made so that we could use the available statistics for the Cook Strait ferry passengers for our calculations and modelling.
- The price of fares for the airship trips will remain the same as that for the ferry. This assumption is probably not accurate to the real world, as airships are considerably more expensive than ferries to operate. This would result in a higher fare price and thus a lower quantity of tickets demanded, as per the Law of Demand. However, as we have no data about the price elasticity of demand for Cook Strait crossings, we cannot predict how much the prices will increase. Thus, we have little choice but to assume demand will remain the same with airships as with the ferries.
- The airship terminals will be in the same locations as the ferry terminals, and thus the straight line distance between them will be the same. Without comprehensive knowledge of the geography of the Wellington and Picton areas, or what makes a good airship terminal. The LCA60T seems to be able to land in areas of rough terrain (Flying Whales, n.d.), but this is unconfirmed, so it is difficult to determine where the actual airship terminals may be placed.
- The 60,000 kg airship capacity is used entirely for people or cars. This is also probably not true, as many passengers will have luggage or pets with them, but again, there is very little data regarding the baggage per person that would need carrying. Our model calculates the number of airships needed to carry the *maximum* number of passengers per airship. However, as our 8 airship fleet can make up to 72 trips/day (more than the minimum 65 needed to transport all people and cars) it is likely our model could accommodate the transport of some luggage without increasing the number of airships.

Feasibility (Costs)

Though we have calculated the potential capacity for the airships, this idea may not be fully feasible in real life, due to the high costs of using airships. The LCA60T, our proposed model, does not have a confirmed price, but is likely similar to that of a helicopter (*LCA60T Airship*, 2020), and with a required Helium capacity of 180,000m^3. With an average price of $14 per cubic metre of Helium, the cost to inflate will cost $2,520,000 per Airship (plus occasional reinflations), and with 8 proposed Airships, the total cost for just inflating will be $20,160,000. This, alongside with the cost to purchase the airships, will result in a large financial cost to the government, and thus this may result in Airships being less feasible to be implemented.

In addition, we have assumed that the airships will only carry people and cars, not freight. The statistics regarding how much freight is transported by ferry across the Cook Strait are difficult to find, and airships are inefficient at transporting large loads and heavy goods. Thus it is more likely this freight will remain transported by ship, as it is more efficient and allows for the transport of heavier goods.

Sources

AIRSHIP | English meaning - Cambridge Dictionary. (n.d.). Cambridge Dictionary. Retrieved August 10, 2024, from https://dictionary.cambridge.org/dictionary/english/airship

BlueBridge. (n.d.). *Bluebridge Cook Strait Ferries*. Bluebridge Cook Strait Ferries. Retrieved August 10, 2024, from https://www.bluebridge.co.nz/our-company/

Flying Whales. (n.d.). *Flying Whales — The LCA60T*. Flying Whales. Retrieved August 10, 2024, from https://www.flying-whales.com/en/the-lca60t/

Flying Whales' LCA60T Airship Can Move Cargo Without Landing. (2020, September 6). Business Insider. Retrieved August 10, 2024, from https://www.businessinsider.com/flying-whales-lca60t-airship-can-move-cargo-without-landing-2020-9#as-of-now-the-price-of-the-aircraft-is-confidential-but-according-to-the-flying-whales-team-its-tag-is-closer-to-that-of-a-helicopter-than-a-plane-3

How Much Does the Average Car Weigh? 2024. (2024, February 1). ConsumerAffairs. Retrieved August 10, 2024, from https://www.consumeraffairs.com/automotive/average-car-weight.html

InterIslander. (n.d.). *Ferry timetable*. Interislander. Retrieved August 10, 2024, from https://www.interislander.co.nz/plan/ferry-timetable

Interislander. (n.d.). *Ferry timetable*. Interislander. Retrieved August 10, 2024, from https://www.interislander.co.nz/plan/ferry-timetable#main-content

InterIslander. (n.d.). *A guide to travelling on the Interislander ferries*. Interislander. Retrieved August 10, 2024, from https://www.interislander.co.nz/explore/a-guide-to-travelling-on-the-interislander-ferries

KiwiRail. (2021, June 3). *Interislander Ferries and Terminals*. Ministry of Transport. Retrieved August 10, 2024, from https://www.transport.govt.nz/assets/Uploads/11_Detailed-Business-Case_Interislander-Ferries-and-Terminals.pdf

New Zealand population 2024. (2024, March 17). StatisticsTimes.com. Retrieved August 10, 2024, from https://statisticstimes.com/demographics/country/new-zealand-demographics.php

NZ Transport Agency. (n.d.). *ModeAltShift - Challenge*. NZTA. https://www.nzta.govt.nz/assets/hackathon/shift/ModeAltShift-challenge-statements.pdf

Perrotta, T., & Edlington, A. (n.d.). *How Much Does a Car Weigh?* Savvy. Retrieved August 10, 2024, from https://www.savvy.com.au/car-loans/how-much-does-a-car-weigh/

Stuff New Zealand. (2015, June 15). *The weight we've gained in recent decades*. The weight we've gained in recent decades. Retrieved August 10, 2024, from https://www.stuff.co.nz/life-style/well-good/teach-me/69386822/the-weight-weve-gained-in-recent-decades#:~:text=2011%20University%20of%20Otago%20and%20Ministry%20of%20Health

What you'll see on your journey. (n.d.). Interislander. Retrieved August 10, 2024, from https://www.interislander.co.nz/experience/what-youll-see-on-your-journey

Windy.App. (n.d.). *Cook Strait wind and weather statistics*. Windy.app. https://windy.app/forecast2/spot/5590743/Cook+Strait/statistics

ZHANG, Y., WANG, Y., & WANG, C. (2020, October). *Light weight optimization of stratospheric airship envelope based on reliability analysis*. Light weight optimization of stratospheric airship envelope based on reliability analysis. https://www.sciencedirect.com/science/article/pii/S1000936120301837#kg005