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  Artificial Intelligence for Environmental Risk

MRes project report 2022

Optimising remote field station supplies

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# Abstract

Background

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# Introduction

The British Antarctic Survey (BAS) conduct research on a range of important scientific topics including climate change, biodiversity and the natural sciences. Field expeditions to Antarctica are necessary to facilitate much of this research.

BAS operations teams are responsible for providing all the resources required to sustain hundreds of people working at Antarctic research stations daily. The Rothera research station is the largest of these stations, regularly housing over a hundred people at once. Demanding work in remote, harsh conditions necessitates that these people are given the best possible diets, and there is no room for compromise or oversight when planning their nutritional intake. However, supplying the food is logistically challenging and has a considerable carbon footprint and financial cost.

Edmund investigated where BAS could improve their carbon footprint, and identified food supply adjustments as having the most potential, because although food amounts to around one percent of greenhouse gas (GHG) emissions associated with BAS’ operations, it is likely easier to change than other things such as shipping schedules, which are more tightly controlled and constrained.

This work uses carbon dioxide equivalent (CO2e) as the unit to express the global warming potential of GHG emissions associated with actions, decisions and objects. Reference it. CO2e values are often estimated based on averages, and not precisely measured, but justify why it was used. More references. The terms ‘carbon footprint’ and ‘global warming potential’ (GWP) are also used to express the potential effect of choices on GHG emissions and their contribution to climate change. references!

Constraint modelling of optimisation problems is a field of Artificial Intelligence (AI) in which combinations of parameters are chosen to search for optimal solutions to a given problem, measuring performance by a defined objective. reference this. Show a diagram later on when we explain this in more detail.

The aim of this project was to create a model which was able to suggest meal plans and food purchasing strategies which minimise the associated carbon footprint, financial cost and waste.

# Background

## Rothera research station

Rothera houses a minimum of 22 people in the winter and up to 170 people in the summer, including a resident chef who prepares the meals for the group. Movements of people, aircraft and the Sir David Attenborough (SDA) ship are scheduled a year in advance and food orders are then made according to these plans. Food is brought in bulk on the SDA. Because the food needs to last a long time in storage, fresh food is considered a treat and is not usually part of the standard menu, although some fresh food is brought by air when there is space available. Food waste is incinerated at Rothera and packaging waste is returned to the UK on the SDA to be recycled or otherwise handled according to UK waste disposal practices.

The clients at BAS advised that for this plan, meals would be offered as varied buffets, with a number of meal options from which people could choose, and optional side dishes for people who desire extra portions. Some members of staff stay at the station for 18 months. Due to their long stay in such a remote, bleak environment, their mental health is a serious concern when planning meals. It is essential for meals to be enjoyable and varied to help prevent boredom.

## Objectives

Although the aim of the project is expressed simply in human language, it is a multi-objective optimisation problem which is computationally complex to solve reference this. The program seeks to minimise GWP, financial cost, food waste and packaging waste, while maximising the variety and enjoyment of meals, and satisfying nutritional requirements, dietary restrictions and delivery schedules.

A satisfactory solution could be used to produce a meal plan for the coming year and its associated food order details along with measurements of objective performance. These suggestions could be used to help the operations team plan the meals and food purchasing strategy.

# Methodology

## Communication and organisation

Fortnightly meetings were held between the developer and the supervisor at BAS. A meeting with people from the BAS operations team was held near the start of the project to agree on the project criteria and required specifications. Minutes from these meetings are in appendices x to x.

A risk assessment and a roadmap, shown in appendices x and x, respectively, were then constructed based on the requirements set out by the BAS operations team to guide the development and ensure that milestones were met. A Trello board was used for project management and task organisation, and code was held in a GitHub repository.

## Data and technology

A spreadsheet containing the previous year’s scheduled arrivals and departures of people and transit vehicles, as well as people’s job roles and genders, was provided by BAS. A copy of the spreadsheet, shown in appendix x, was then created with people’s personal information removed to protect their identities and to ensure the original data remained unchanged.

No data related to food purchasing or meal arrangements were available for the project. This meant that the developer had no knowledge of where food was purchased, how the logistics were planned, what system was used, whether there was a budget, how food orders were structured, what meals were typically offered, the costs or quantities of food items or how meals were planned. There was also no information available regarding people’s nutritional requirements, allergies or dietary restrictions. Due to the lack of data and knowledge, estimates were made for food purchasing calculations using a supermarket web site (reference) and assumptions were made about the structure and variety of meals. It was assumed that three different choices of breakfast, lunch and tea would be offered each day.

The project aims to satisfy the principles of Findable, Accessible, Interoperable and Reusable (FAIR) data (reference). A copy of the personnel schedule data was included in the program files, but people's names were removed to comply with General Data Protection Regulations (GDPR) reference. All other information sources used for the development of the program were also listed in the program files and are referenced in this report. Instructions on how to reproduce the results were given in the ReadMe file and are shown in appendix x.

MiniZinc was used as the constraint modelling language and Python was used for data pre-processing and post-processing. Both these languages are open-source. No specialist computing infrastructure is required to run the code other than a typical personal computer with an up-to-date operating system. Random dietary requirements were generated for the batches of MiniZinc data. These data files were included in the repository so that the results shown could be exactly reproduced.

## Dietary requirements

Required amounts of macronutrients for guests were estimated according to reference. who state that exact amounts depend on age, gender, state of health, lifestyle, height and other genetic considerations. Same reference states that, typically, men require 25 percent more calories than the amount required by women, with an average daily calorie requirement given as 2000 for women and 2500 for men. The data reference suggests that approximately 80 percent of people at Rothera from 2021 to 2022 were male. All the personnel are adults of working age, so it was assumed that age would not be a significant consideration for calculating nutritional requirements. The cold temperature and physically demanding roles of personnel were important factors to consider. Reference concluded that people with the most physically demanding jobs, such as manual labourers and military personnel, may require double the daily calories they would consume if they had a sedentary lifestyle. Other macronutrients must also be scaled up along with calorie intake, including carbohydrate, fat, fibre and protein.

Reference explains that getting enough micronutrients should not be of concern to people who eat a balanced, varied diet, because micronutrients are found in abundance in vegetables and other ingredients. The exception is real name, known as vitamin D. reference advises that people who spend the majority of their time indoors, or do not regularly expose their skin to sunlight, take a vitamin D supplement alongside a healthy diet.

To calculate nutritional requirements, baseline figures were defined as the average daily macronutrients required by a healthy adult woman with a mildly active lifestyle. Men were identified from the data and their required amount of each macronutrient were increased by 25 percent. Job roles were assessed, using the role descriptions given by reference, and categorised as sedentary, moderately active, with a 50 percent increase in nutritional requirements, or very active, with a 100 percent increase in nutritional requirements. These labels, shown in appendix x, considered the amount of physical work, such as lifting objects and walking, and the amount of time spent outdoors because of the harsh climate and weather. Anyone whose role included field work or diving was classed as very active even if their job role was typically more sedentary. This meant that the majority of personnel were classed as moderately or very active, and an average requirement of 3500 calories per person per day was estimated. Table x shows the nutritional requirements estimated by the program.

Because there was no information provided about people’s health or dietary restrictions, a function was created to generate random restrictions and allergies and append this information to the personnel data to be used with the model. Random numbers conforming to a Gaussian distribution assigned a number of people per group who should not be given meals containing any combination of meat, milk, egg, seeds, nuts, gluten and sugar. The probability of each of these was xx which was deliberately higher than found in the general British population, with xx percent of people being vegan, according to reference, and xx of people having a food intolerance, according to reference, to ensure robustness of the program. This takes into account vegetarian and vegan diets as well as common allergies and intolerances, and people with diabetes who need to control their sugar intake. Other considerations include religious diets, such as a provision for halal meats, but it was decided with the BAS operations team that since there would be a choice of three meals at each meal time, and a variety of meats and vegan foods would be offered, this would not likely become a problem. If later desired, meat categories such as red meat, white meat and fish could be introduced and included in the list of potentially refused ingredients. Alcohol was also not included in this list because alcoholic beverages are an occasional, optional treat and do not form part of the main meal plan. It was important to confirm that people with any combination of allergies or special diets could eat a balanced and varied diet. Figure x shows an example of a daily meal plan and which options would be available to some people with dietary restrictions. Person A is unable to eat gluten. They could choose xx for breakfast, xx for lunch and xx for tea. Person B is vegan. They can choose xx for breakfast, xx for lunch and xx for tea. The addition of optional extra side dishes helped to ensure that all personnel could choose to eat as much food as they wish.

An anticipated problem with the buffet system is that all the servings of a particular meal might be taken by other people at the front of the queue, leaving only options which are unsuitable for those at the back of the queue who may have allergies. This problem is not specific to this project and could potentially occur at any buffet type of meal. One option would be to prepare more servings than necessary to create a surplus, but this could lead to increased food waste. Another option would be to provide each person with a set meal and no choice, but this would be restrictive and unpleasant for the diners. A less extreme option would be to provide personnel with a menu so that they could select their desired meal and the chef would know how many servings to prepare for the group. Doing this daily would introduce the risk of running out of certain ingredients, as exact amounts could not be ordered a year in advance. Some ships, including reference, tackle this problem by providing guests with a future menu before they arrive, giving the operations team time to order the food in advance and reducing food waste.

Bearing in mind the current specification for a buffet, the approach taken in this project to both reduce food waste and reduce the risk of running out of meal options was to prepare larger batches of meals, so rather than preparing three different meals for lunch and another three different meals for tea, three different meals would be prepared daily and offered for both lunch and tea. Since there are three options spread across two meal times, people should not be forced to eat the same dish twice in a row. This also takes into consideration that there is sometimes only one chef responsible for feeding the entire group, which is a demanding job with a high workload and little time off.

The meal plan includes breakfast, main meals, side dishes, desserts and occasional treats. The occasional treats were requested by BAS to improve morale and include a snack and an alcoholic beverage, and should not contribute to nutritional calculations but should still be included in the order details. The examples shown in the results have a set frequency for treats as once per week.

Although a vegan or flexitarian diet is often associated with a reduced carbon footprint reference, the consultation with the BAS operations team revealed that some personnel would be unwilling to adopt a vegan diet and requested a variety of meat options. The program aimed to offer at least three meat types per week, such as fish, beef, pork, lamb or poultry.

## Transport

The majority of food is brought to Rothera from the UK yearly in bulk on the SDA. BAS also use Twin Otter and Dash-7 aircraft for smaller, more frequent deliveries of equipment, passengers and fresh food, from South America and the Falkland Islands reference this . The data reference show that all the scheduled flights to Rothera in the period were performed by the Dash-7, and that there was no scheduled transit by any vehicles in the Antarctic winter, which was the period from xx to xx. Because of this, the program does not allow any fresh foods to be included in the menu during the winter season.

To estimate the GHG emissions and financial costs associated with transport of foods, assumptions were made in the absence of specific data. For the SDA, the total potential capacity for food was assumed to be the total cargo capacity minus the fuel storage capacity, given by reference. The voyage was assumed to take 20 days on average from the UK to Rothera sometimes via the Falklands (reference). The emissions and fuel consumption were taken from average cargo ship consumption from reference but this is probably not very accurate because the SDA is a multi-purpose vessel and not a cargo ship. It was assumed that UK fuel prices would apply to the SDA. The cost and emissions of moving 100 g portions of food were then estimated from the overall cost of the journey, one-way, divided by the number of 100g portions that could be transported.

For the Dash-7 aircraft, it was assumed that the journey would be directly from the Falklands to Rothera, non-stop. This distance would mean that the aircraft could not travel fully loaded, but the maximum loading capacity was taken from reference. The average number of passengers per flight was calculated from the change in the number of people at Rothera coinciding with scheduled flights in each direction and was found to be 4.26 people including one pilot. The average mass of 4.26 British men in heavy winter attire was subtracted from the carrying capacity, along with the required extra fuel for the return journey and safety surplus. The emissions and fuel consumption were taken from reference and the cost of aviation fuel in the UK was applied.

Realistically, it is obvious that neither the SDA nor the Dash-7 would ever travel with their entire cargo capacity full of food, but this was theoretically assumed for the estimates so that a fair and proportional comparison could be made between the two vehicles. Both journeys were considered one-way for simplicity because the vehicles may have taken detours via other research stations before returning, and would also return with waste, equipment and passengers.

Similar estimates were also made for the Twin Otter aircraft. These assumptions and estimates are shown in more detail in appendix x.

DASH 7 FROM FALKLANDS

distance from Stanley, Falklands to Rothera = 1873 km = 1164 mi

can't fully load the plane or it would not be able to travel this far.

for this journey it can carry 16 passengers or 2,000kg of cargo

number of people travelling on scheduled Dash 7 trips: 7,7,1,9,8,2,2,5,3,3,3,5,2,4,3 avg = 4.26

Average British man in clothes and shoes weighs 84 kg

84kg x 4.26 = 358.4 kg

2000 - 358.4 = 1641.6 kg capacity left for cargo

total number of 100g cargo capacity portions = 16416

equipment is bulky so allocate 1/4 of that to food = 410.4 kg

number of 100g portions of food which can be moved = 4104

maximum useable fuel = 4501.904 kg. Assume this much is required for 1 way journey.

including takeoff

aviation fuel currently costs 61p per kg

cost of fuel = 0.61 £/kg x 4501.904 kg = £2746

cost of fuel per 100g cargo capacity = £2746 / 16416 = 17p

emissions of moving 1 kg cargo = (3.15 x 4501.904 kg) / 1641.6 kg = 8.64 kg CO2e

emissions of moving 100g cargo = 0.846 kg CO2e

considering only 1-way journey (not the return journey)

## Practical considerations and assumptions

Purchasing

Storage

Cooking

Packaging

Assumptions about recycling, degrading, burning, returning waste etc

Meal times and structure

Menu, buffet, pre-planned menu or prescribed

Problems with the buffet style approach

Alternatives to the buffet stye approach

## Constraint modelling

MiniZinc

Choosing which things to model as constraints (fixed) and which to optimize (flexible)

Capture key constraints usually talked about in English in the model, embedded intelligence of operations team. AI

Explain constraints and justify them

Problems and alternatives

Explain why code is repeated (faster loop unrolls, enumerable types).

## Solving technique

How Geocode works.

Why I chose it.

What else could be used.

Floats.

Explain why numbers are scaled up or down later.

Batches of data.

## Objective function

Benchmarks

Trade-off between objectives, constraints and processing time

Weighting and scaling

Would have preferred scaled multiplied objective

Final chosen objective function

# Results & discussion

Show plots, not massive spreadsheets

Compare different diet types

Explain why some which sound better have worse solutions (not enough nutrition)

Compare different objectives and satisfiability

Explain why having too many objectives can reduce performance

Final output menu

Final output shopping list

Compare emissions to ones shown in data

Show that the menu is not reliant on aircraft deliveries

Different optimizer eg chuffed

# Conclusions

# Suggestions for further work

What can BAS do to improve the situation

Which objectives can be best improved

How to improve all objectives

Can all objectives be improved at once

Vitamin D

It may be beneficial for BAS to provide all staff at Rothera with vitamin D supplements in addition to food.

Ruminent meat

Survey people to find out what diets they would be willing to adopt

Take bits of that ^ for conclusion

# References

# Appendices

Links to work (GitHub, Trello)

Shopping list

Menu

Test outputs

## Appendix A –

## Appendix B –