

# Numerical Approximations and Costings

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# Fermi Approximations

## Why approximations are needed

Regardless of your role within the UKSDC, we can guarantee that at some point in the competition you will have to come up with an estimate for an obscure value for which even the almighty google can give no useful answer. Examples could include values such as 'the average power consumption per capita on a luxury space settlement in earth orbit' or 'the temperature variations at a given depth below the surface of Mercury'. For values such as these it will be up to you to come up with a sensible estimate using more readily available information, with one of the best techniques for this being the Fermi Approximation.

## Video suggestions

The basic premise of a Fermi Approximation will be explained in a worked UKSDC example below, but readers may find the principle easier to understand from the plethora of online resources on this topic. This author would personally recommend the following video <https://www.youtube.com/watch?v=INIPbfBGptw>, although feel free to find your own source of information.

## A worked UKSDC example

For the worked example, we will look to calculate the first of the examples given above: 'The average power consumption per capita on a luxury space settlement in earth orbit', focussing specifically on their direct power consumption, as well as the consumption of essential life support systems to support them. It must be specified that this approximation is not universally applicable to all settlements within the UKSDC universe, as factors such as settlement location and standard of living play key factors in determining the power consumption. This approximation also does not include power consumption of industry or research that could take place on a settlement, and therefore should not be directly copied as a method of approximating settlement power consumption during the competition, although it may act as inspiration.

Firstly, we will look to approximate the power consumption of a luxury home on earth, as this should give a good representation of the power consumption for things such as lighting and electronic devices within the

home. Using information from <https://www.energyatlas.ucla.edu/>, which documents power consumption across California, and focusing on usage in Los Angeles, <https://www.latimes.com/science/la-me-1001-ucla-energy-data-20151001-story.html>, we can see that the power consumption of the average household was 7000kWh (25,200,000,000J) per annum. We can also see that buildings larger than 10,000 square feet made up 4.4% of these households, but used 47% of the electricity. For our purpose, these are the 'luxury' households, suggesting each one consumes 269,000,000,000 Joules per year, or 8500 Watts. Given the average household consists of 2.6 people (<https://www.census.gov/quickfacts/fact/table/US/HCN010217>), this means an average power consumption per capita of 3300W for luxury living.

In order to approximate the power consumption of Environmental Control and Life Support Systems (ECLSS) for a settlement in earth orbit, we shall base our values off of the international space station. The ISS can use anywhere between 84,000W and 120,000W ([https://www.nasa.gov/mission\\_pages/station/structure/elements/solar\\_arrays-about.html](https://www.nasa.gov/mission_pages/station/structure/elements/solar_arrays-about.html)) to support its inhabitants, which is typically 7 people (<https://www.space.com/16748-international-space-station.html#:~:text=There%20is%20typically%20an%20international,in%20space%20at%20one%20time>). Making an educated assumption that around 25% of this power is used for non-essential purposes, such as research missions on the station, we can assume a per capita power consumption for ECLSS of around 10,000W.

Combining these values, we obtain a per capita power consumption of around 13,000W, which can be multiplied by the number of people in the settlement to give an estimation for the total power consumption to support the residents with this lifestyle.

## Costs

### Costs Introduction

By my last UKSDC event, the 2018 Nationals, I was calculating every single cost for every single item in the settlement for my company. Everything from bleach, computers and the pipe runs for the pneumatic delivery tube system (a feature critical to evoking a steampunk theme in your moonbase) was accounted for. I was able to do this due to a gigantic spreadsheet and way too much time on my hands before the competition to prepare.

While that spreadsheet exists out there on the internet, I don't recommend anyone try to use it as it is difficult to get it working without inside knowledge. I also, in hindsight, don't recommend anyone to create a spreadsheet of that scale. It isn't required. Automating the last 20% will double the work and, especially during the nationals, you will barely save yourself any time on the day by having it fully automated. However, for me, it was primarily a learning experience for *Microsoft Excel*, which I didn't know how to use before, and to explore the intricacies of costing for the UKSDC.

Over the many competitions that I have now taken part in and all the presentations that I have seen from ones that I haven't, these are my major points of what to do and what not to do:

### **Use the universe**

UKSDC is a set in a large universe in the future, use it. There are over 25 separate settlements set in space, some that will always be there, some you might build yourself in a competition. If you are building a space settlement in 2053, you can get materials from the Moon, Mars, asteroids, and comets. Anything that comes from Earth must have a reason to come from Earth, whenever that is required validation, subcontractor location, or just the scarcity of the required resources outside of Earth.

### **Do use subcontractors**

Ideally, you should aspire to use every subcontractor in the programme booklet if appropriate. You should also buy stuff from other companies. Don't compromise the design or construction of the settlement though, some subcontractors are really quite useless.

On the subject of the programme booklet, if you are responsible for costing, it is the most important document that you have. Read it from cover to cover twice and then underline every product you can buy from subcontractors, other companies, and the ones that your company can supply. You can do this all the night before the competition so it doesn't even take time during the working day.

There is usually something that you can get for free if you read the press release, so it is a good idea to give it a skim and underline as well.

### **Include all costs**

If you buy something from a subcontractor, it costs money. If you buy something from another company, it costs money with some extra money going to *Litigation Limiters*. If you have to provide the service yourself, it costs money. An example I see all too often:

*Company that has been assigned Grumbo Aerospace:*

*Person 1: We have the Grumbo Jumbo, a transport spacecraft, therefore all shipping is free for us.*

*Person 2: That's a great idea, we can undercut the competition...*

Just because you own a spacecraft, it does not mean you can transport everything in the world for free. You may offer a discounted service because you own the spacecraft, but don't discount these costs altogether!

### **Don't include inflation**

You are told everywhere not to include inflation but people still do. Don't include inflation.

### **Shipping costs will be your largest single cost**

For the ISS, shipping costs were around 33% of the total cost. You should ideally aim for something similar to 50% depending on the location.

When I did costs, I always made the mistake of having shipping being 60% or higher of the total cost. I only realised my mistake afterwards which was that:

- High quality military and space grade stuff can cost fantastic amounts. Nuts and bolts are known to be quoted at up to \$12,000 each.
- You can't just buy everything and expect it assemble itself. The cost of piping is not the same as the cost of installing piping. Buying every component of a atmospheric regulator is not the same as having one. You need to account for construction and validation.
- The reason why the ISS was so expensive is the R&D, and you should account for some amount of that. Your R&D won't be nearly as expensive as that, but should cost a measurable percentage of your

total cost. Whether it is a simulations team or a scouting mission, it costs money and should be included.

### **Have sensible shipping costs**

Frustratingly, UKSDC does not always provide you with all costs. This is generally fine and expected (estimating costs is part of the competition), however if UKSDC does not provide you with shipping costs you have a problem. Let's say you have to find out the cost of one kilogramme to lunar orbit in 2040, two estimations of the cost are given below:

- The SpaceX Falcon Heavy is predicted to cost \$1700 per kg by the mid 2020s. Therefore by 2040, it will cost around this much to go to the moon.
- It cost roughly a billion in 1972 to send up 48,600 kg to the moon. That's roughly \$20,500 dollars per kg. The estimated improvements in spaceflight counteract the fact that this mass isn't a true payload, meaning we can present this as the final cost per kg for 2040.

The issue is that there is not really a correct answer, but also that there is no consistent datum of what would be considered a sensible cost. I would say that the first method is a more accurate cost, given the space crazy universe of UKSDC. If you get me as a judge at one of your regionals, I would prefer the first value over the second. However I've attended regionals as a competitor, where I was told the second value wasn't high enough, and was challenged because of it.

I would recommend asking the judges directly for what they would say the shipping cost is, if it isn't included. Even if they don't give the value they will give some insight of what it should be. Personally, I would imagine the true cost would be somewhere in the middle of the two values. The reason this is a large problem is that the wrong shipping budget will dramatically alter your final cost.

### **Construction and Manufacturing Costs**

Perhaps the most criminal off costing offences performed by almost every team at every competition, is to neglect the huge cost of actually manufacturing a product. Having all of the materials required is a completely different thing to having a functioning settlement, and this is often overlooked. Even if you do want to write off all of your manufacturing costs under the 'we built everything with robots' guise, you still need to consider

the vast number of highly specialised machines that will be required for each process along the way and, more importantly, the cost associated with each of these! There is a reason that space missions like the James Webb end up costing so much money; building things for space is very hard, and building machines to build said things is an even harder (and more expensive) task!

### **Include a contingency budget**

All engineering projects have a contingency budget built in to account for the factors that are often referred to as Unknown Unknowns. These are the costs that, no matter how hard to try, you will not be able to predict. NASA had a 10% contingency budget for the R&D of the Space Shuttle, which came in on budget, but at the compromise of having far lower capabilities than had been planned.

The spreadsheet my team had was capable of auto-generating a contingency percentage and applying that to the total cost. This was mostly a waste of time (this is disputed by the other author who developed the automatic contingency percentage system). Just use your intuition and 'calculate' a percentage. A settlement on the moon will have a fairly low percentage. A settlement in the asteroid belt will have a much higher one. A settlement without a contingency budget is useless as you haven't given the true final cost.

### **Be reasonable when calculating profits for the Foundation Society**

For the 2017 Nationals, a certain B&M team calculated a profit of "\$20 trillion" a year. For the 2018 Nationals, a certain B&M team calculated a profit of "\$959,600,000,000" a year. Both of these numbers are way out.

What has happened here is that the person assigned to profit calculations decided to trust their calculator rather than their intuition. Ideally all costs should be based on calculations, but mistakes are incredibly easy to make and it takes practice. Don't be afraid to query and change your numbers to make them more reasonable.

We always included a percentage profit for the company we were representing as well. No one ever noticed it, there wasn't much point to including it, but we thought it was a nice little touch.

### **How I calculate a cost**

Doing costs is unfortunately a skill that you don't learn overnight and it relies a great deal on your intuition, built up from experience. You will need to have:

- Good research skills and fundamental knowledge. Knowing what to google and how to google really helps. I am from an Automation and Operations background, and I felt this has always helped me. It isn't always possible, but don't calculate a cost about something you know nothing about, get someone who knows more to do it instead.
- Some calculation knowledge. I am no whizz at maths or anything of the sort, but I do know how to quickly multiply, add and read standard form, and that is really all you need to do.
- Intuition. The final quality control is always when you ask yourself "Is this a reasonable number?" This is the most important step.

An example. For the 2018 National finals, we had to calculate the operating costs of the silicon bucky structure plant as it slowly increased production. I immediately went to look into carbon fibre production and the costs associated with that. I took information from 3 different sources, and generated a number which I multiplied by 10 for good measure.

### **Some general advice**

- Use US dollars. This is a rule that you must obey.
- Don't list costs by department, list them by system or object.
- Make sure your cost table is legible, this was something that I always missed. Strike the balance between legibility and detail. Knowing each cost for the different piping systems is no longer interesting if you can't read anything on the page because of it.
- Don't quote costs in standard form. No one reads money that way.
- \$5,000,000.00
- $\$5 \cdot 10^6$
- I would recommend only quoting costs at the very end of your presentation. If you do them by slide, you will end up with discrepancies between the slides and your final costing table.
- CASSCs are a pain. Just calculate a rough number using the density, don't think about trying to actually geometrically fit everything in.

If you are required to do this (i.e. Internationals); good luck! It is worth simplifying the problem into smaller loads and applying maths and



brain power til you get an answer. Also, isolate what can actually fit into a CASSSC and what can't before doing the calculations

- Make sure your costing table actually adds up. This goes wrong more often than you might think.
- If you have the space, a pie chart is a nice touch, but don't try to fit every cost on to it. Group small costs into a miscellaneous group.

### **Just don't be too wrong**

No one really looks at costing unless it's wrong. Perhaps the best example of this was when a company at the national final confidently told the judges that 96% of their entire cost was to provide spacesuits to their residents. You had to be there to believe it as they tried to justify that one!

The UKSDC is trying to change the way it looks at business and finance with time by expanding the department to have more responsibilities, but for now, what judges typically look for is that:

- The cost is in the same area as their 'back of the envelope' calculation
- You haven't missed costs (i.e. shipping)
- Your cost table looks clever with many subcontractors

That is all. At the end of the day, the most important skill you need is the knowledge of what is a reasonable cost and what isn't. You could make everything else up and no one will notice, except me. I'll notice as I compare your numbers to my spreadsheet. Good luck!