The Feasibility of Google's Project Loon

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Using a systems engineering approach, an analysis was performed to determine the viability of Google's 'Project Loon'; a system of high altitude balloons creating a moveable and adaptable internet network. The scope of the project was determined based on its mission statement: "to provide internet access to rural and poor areas" (Google, n.d.). Australia and India were selected to be case study locations when discussing the feasibility of Project Loon. The material makeup of each balloon was assessed and an energy audit found each balloon had 70225MJ of embodied energy and an estimated initial cost of $17870. Over a five year period the total cost per balloon was determined to be $40318. To run at no cost to Google each customer would have to pay between $833.19 and $1.86 for the two considered scenarios assuming a 5% take-up rate by users. Due to the relationship between internet access and wealth it is recommended that Google implement Project Loon at no cost to users as the company would indirectly profit from more users due to advertisement revenue. At 5% take-up rate Australia is not a viable location for this project as only 13.5% of the ongoing cost would be covered. India however, would result in Project Loon generating $96.1 million in advertisement revenue, covering its total cost by 6046.1%. Furthermore Project Loon would provide valuable infrastructure to the company ensuring a larger customer base for future projects.

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Cover image: Google, n.d., *Project Loon*

Introduction

A major limitation of existing internet networks is their general reliance on cables and fixed infrastructure to provide high speed and consistent connection. Only 44% of people used the internet in 2013 (ITU, 2014) mostly due to remote and poor communities being unable to install the required infrastructure (IMF, 2015). Google has envisioned a solution to this known as Project Loon; an interconnected network of high altitude balloons providing wireless internet access to remote communities. The project is called Loon because even Google sees it as a near impossible task. This paper will analyse the project using a systems engineering approach in an attempt to determine whether the project is feasible.

Scope

Unfortunately not a huge wealth of information is available with regards to Project Loon. A great way to develop this information would be to interview someone associated with the Project. If the opportunity had presented itself some key questions would be:

1) *What is the most important goal of Project Loon?*
   An answer to this question would help define the scope of this paper as it would distinguish what areas or aspects of the project should be focused upon.

2) *Is Project Loon intended to be a not for profit venture?*
   Google will in inherently earn advertising revenue from people using the internet but it is not clear whether Google intends to charge for access to the network.

3) *What is your biggest concern with regards to Project Loon?*
   Without inside information it is hard to determine exactly makes the project feasible. If one of googles key concerns is known then it signifies a need for emphasized analysis into that specific area.

Without any of this information the scope of this project must be constructed from what information is available. Google's mission statement for Project Loon is as follows:

"Many of us think of the internet as a global community. But two-thirds of the world's population does not yet have internet access. Project Loon is a network of balloons traveling on the edge of space, designed to connect people in rural and remote areas, help fill coverage gaps, and bring people back online after disasters." (Google, n.d.)

This statement formed the basis for the scope of this project as it focussed on giving access to people who do not currently have it, rather than providing an alternative for people who can already connect. Two different sets of scopes were examined in this paper; Project Loon's application in Australia compared to its application in India. These two countries were selected because they are on two extremes: Australia has a population density of 3.11pop/km^2 (ABS, 2012) with an internet connectivity of 83.0% (ITU, 2014); India has a population density of 388.78pop/km^2 with an internet connectivity of 15.1% (ITU, 2014). If Project Loon is shown to be unfeasible in one of these scenarios then it may provide better insight into what should be improved within Project Loon.

Using the Paretto Principle, an analysis of Project Loon's feasibility in Australia was performed. This principle assumes that 20% of Australia's population would make use of Project Loon and that this population is spread out over 80% of Australia's land area. This assumption is supported by the fact that in 2013 the percentage of households in Australia with internet access ranged from a minimum of 78% in Tasmania to a maximum of 89% in the ACT (ABS, 2014). This leaves between 11-22% without access which falls roughly within the Paretto Principle range. Figures 1 and 2 show a population density map of Australia and an internet access quality map respectively. It is clear that there is a direct relationship between population density and internet access. This indicates that the 20% without access will be in lower density or rural areas, which is defined in Project Loon's mission statement as the primary intended user base.

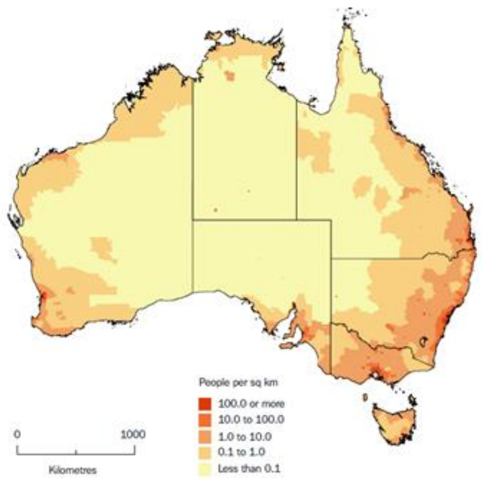

Figure 1 – Population density of Australia (ABS, 2012)

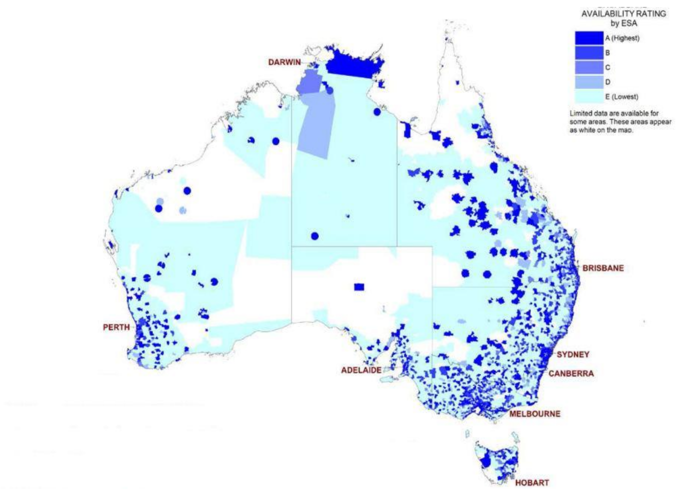

Figure 2 – Internet coverage in Australia (Department of Communications, 2013)

Applying the Paretto Principle gives that Project Loon must be able to support 4.75 million people (ABS, 2012) over a total area of 6.13 million square kilometres (Geoscience Australia, 2004). This translates to one user in each 1.29 square kilometres.

In 2013 15.1% of India's population used the internet (International Telecommunication Union). It was assumed for this report that the remaining 84.9% of India's population (total of 1.21 billion) would be spread out over all of India's land area of 2.97 million square kilometres (Ministry of Home Affairs India, 2011). This gives that Project Loon must be able to support 1.03 billion users over a total area of 2.97 million square kilometres.

Table 1 – Scenario Data

Scenario	Population	Area (km^2)	%Internet Access	Potential Users	Supported Area (km^2)	Users/km^2
#1 (Australia)	23,714,300	7,659,861	80%	4,742,860	6,127,889	0.77
#2 (India)	1,210,569,573	2,973,190	15.1%	1,027,773,567	2,973,190	345.7

The large difference between the two scenarios could highlight differing limitations of the project. For example, a low number of users over a larger area may put a strain on the cost of the system as more materials would be expended with less possible income. On the other hand the second scenario may put a strain on the technological limitations of the systems as a higher number of users per balloon would consume more transmission bandwidth.

People

One of the biggest hurdles with regards to gaining access to the internet is wealth. This general trend was confirmed by compiling data from the International Telecommunications Union (2014) and the International Monetary Fund (2015) (Figure 3). It shows that there is a correlation between GDP per capita and internet availability in countries.

The internet is a powerful tool which can be used to improve quality of life in many regards. It acts as a communication network which from an economic perspective would allow businesses to reach new customers and from a social perspective allows people to contact each other when they otherwise may not be able to. The internet also acts as a conduit for entertainment, leisure and the arts which improves quality of life.

This report will optimistically ignore the fact that someone who cannot afford an internet connection is likely to not have a device capable of connecting to the internet. This falls outside of the scope of this paper as it is concerned with the creation of the network, not people's direct access to it.

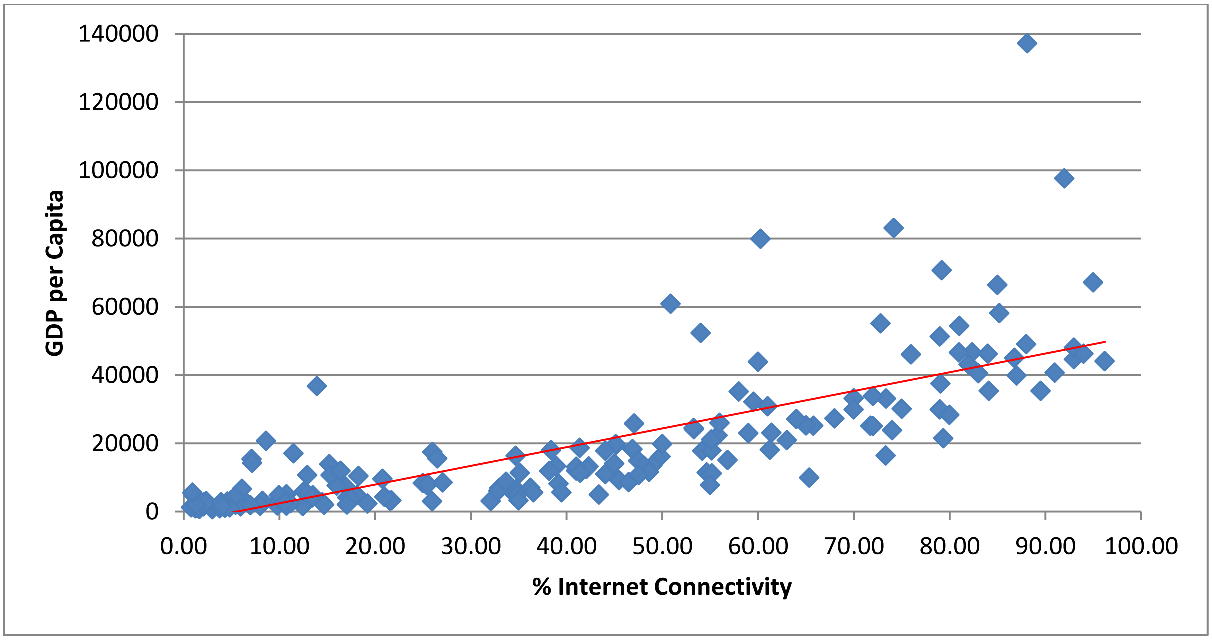

Figure 3 – percentage of people with internet access vs GDP per capita

Balloon Overview

The basis of Project Loon is the actual balloons which will form the network. Each balloon uses LTE (4G) technology to provide internet coverage over an area of 40km in diameter. Each balloon is designed to operate in the stratosphere and use wind currents to dynamically change the network to meet demand. They are designed to operate on a 100 day cycle, at which the end of they will descend and undergo maintenance. Each balloon is comprised of:

- Envelope: polyethylene plastic 15 meters wide and 12 meters tall when fully inflated
- Solar panels: To provide energy to on board equipment
- Radio antenna: To communicate with other balloons in the network
- LTE antenna: To generate coverage network
- Lithium-ion battery: To store energy from solar panels
- Parachute: To safely lower balloon
- Gas cylinder: To control the balloons altitude

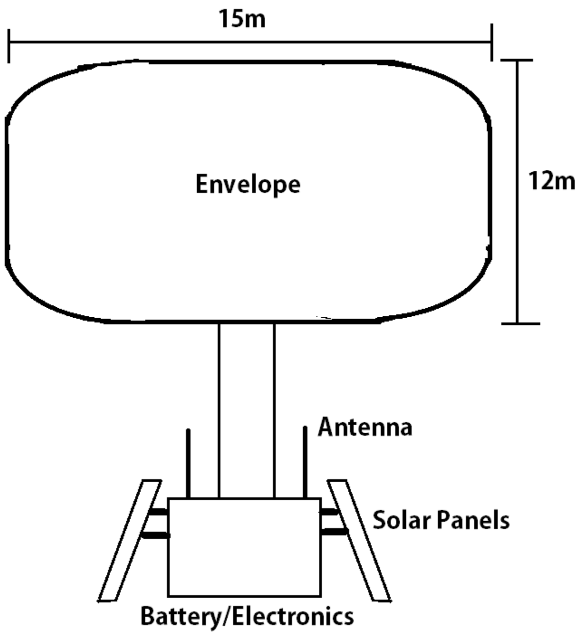

Figure 4 – A Project Loon balloon

Wireless Technology

The biggest disadvantage of wireless communications compared with traditional wired methods, is the limited bandwidth available for transmission. Data is transmitted by sending signals over certain frequencies. Limited frequencies are available and if two signals occupy the same frequency space they may interfere with each other (Goldsmith, 2013). This means that the number of users that can be supported by each balloon has an upper-limit and adding more balloons to a densely populated area may not improve the situation.

A simpler way to imagine it is if the network is a single-phase multi-channel queue (Figure 5). The bandwidth available is the channels, once you run out of bandwidth you cannot fit any more queues into the system.

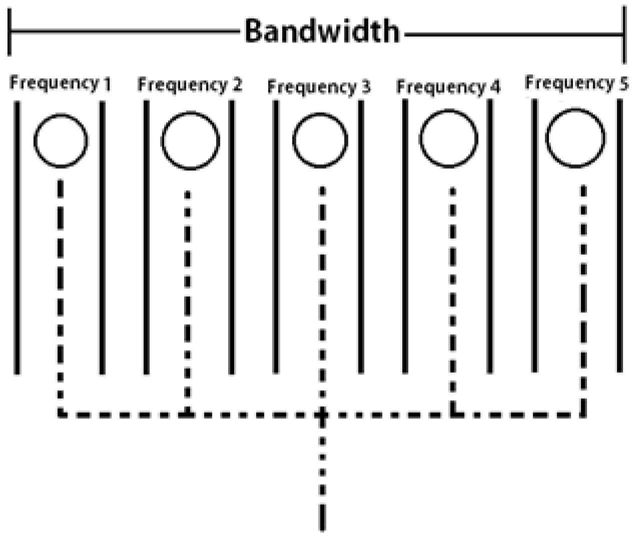

Figure 5 - Simplistic Representation of bandwidth network

Unfortunately Google has not released information in regards to the number of users per balloon. For this report it will be assumed that each balloon will not have a limit on the number of supportable users. However there is a possible solution if this problem were to arise. If the balloons are able to shrink their coverage area when over high density population zones then they will each have fewer users to cover, meaning interference will be less likely (Goldsmith, 2013). The trade-off to this is that in a more densely populated area more balloons will be required to cover the same space.

Material Audit

Based on information provided by google about each individual balloons structure, a material audit can be conducted (Table 2). The envelope was estimated as a rectangular prism measuring 15mx15mx12m (Google) with a thickness of 100μm. Little information is available with regards to the exact types, weight or dimensions of the remainder of the balloon, so each component was estimated.

A large component of the embodied energy is the envelope. This is compounded by the fact that the envelope is the component of the system that will be replaced most often; every 100 days. Therefore to reduce the total embodied energy of the system a different material could be used for the envelope. The major difficulty with selecting a replacement is that it must be gas-tight.

Table 2 – Material audit for a single balloon

Component	Specifics	Material/process	Amount
Envelope	12mx15m balloon with 100μm thickness (estimated as rectangular prism)	polyethylene plastic density of $0.95g/cm^3$ (British Plastics, n.d.)	$1170m^2$ 111.5kg
Electronics (antenna and other transmission equipment)	Estimated as 4 desktop computers (Wattz O, n.d)	aluminium plastic steel copper glass nickel tin lead (Victoria University, n.d.)	4.368kg 7.176kg 6.552kg 2.184kg 7.800kg 0.312kg 0.312kg 1.872kg **30.577kg**
Solar Panels	Estimated as 2 20kg panels	silicon aluminium copper plastic	14kg 16kg 2kg 8kg **40kg**
Battery	Based on 12V 200AH Lithium Ion Battery (Smart Battery, n.d.)		33kg
Gas cylinder	Based on Praxair 128bar pressurized cylinder (Praxair, n.d.)	Cylinder Hydrogen ($1.8m^3$ at 13.8MPa)	30kg 18.65kg **48.65kg**
Parachute	Based on Mills G-12E cargo parachute (Mills Manufacturing, n.d.)	Nylon (Victoria University, n.d.)	57kg
TOTAL			320.73kg

Energy Lifecycle

The majority of embodied energy in the balloon is taken up by the solar panels which power it. It is arguable that this may be an acceptable amount because by using the solar panels the long term non-renewable energy consumption of the project is lowered. For example, if it is assumed that each of the two panels generates 250W of power (total of 500W), then it will take 4.45 years for each balloon to generate its own embodied energy in power.

Table 3 – Embodied Energy for single balloon

Component	Material/process	Amount	Embodied Energy	% Total
Envelope	polyethylene plastic Density of 0.95g/cm^3 [2]	111.5kg	11484.5MJ	16.4%
Electronics (antenna and other transmission equipment)	aluminium plastic steel copper glass nickel tin lead manufacturing (Wattz O, n.d)	4.368kg 7.176kg 6.552kg 2.184kg 7.800kg 0.312kg 0.312kg 1.872kg - **30.577kg**	804MJ 716MJ 288MJ 212MJ 172MJ 112MJ 64MJ 52MJ 6000MJ **8420MJ**	12.0%
Solar Panels	silicon (Ashby, 2010) aluminium copper plastic	14kg 16kg 2kg 8kg **40kg**	26868MJ 2208MJ 98MJ 800MJ **29974MJ**	42.7%
Battery	(Ashby, 2010)	33kg	10692MJ	15.2%
Gas cylinder	Cylinder (steel) Hydrogen (1.8m^3 at 13.8MPa)	30kg 18.65kg **48.65kg**	1218.7MJ -	1.7%
Parachute	Nylon	57kg	8436MJ	12.0%
TOTAL		320.73kg	70225.2MJ	

Furthermore over an entire five year life span they would generate 78.84GJ of energy. Converting this amount of energy into an equivalent amount of gasoline burnt shows a massive reduction in emissions (Table 4) (U.S Department of Energy, 2011)(U.S Energy Information Administration, 2015).

Table 4 – Energy and Emissions saved through Solar Power

Scenario	Required Balloons	Total Power Consumed (GJ)	kg of Gasoline	Million Metric Tons of CO_2
#1 (Australia)	4875.01	383,345	8,823,076	25,908
#2 (India)	2365.31	186,552	4,293,684	12,608

Most of the other equipment on the balloon will rarely be replaced and if so, most electronic or metallic components can be recycled. The plastic used to create the envelope is also recyclable. The major risk in regards to the envelope is pollution. Should the envelope be jettisoned for any reason it poses an environmental risk, especially to wildlife which may become tangled in the remains. Therefore a major focus of the design should be to ensure that the envelope is securely fastened whereby even if it is damaged it remains attached to the easily locatable balloon.

Operational Consumption

Figure 6 is a Sankey Diagram for the estimated flows of energy within Project Loon. The major loss of energy is through the inefficiency of the solar panels (Hirst, Elkins-Daukes , 2010). This loss is acceptable because as discussed all energy entering the system is renewable.

The mechanism by which the balloons control altitude is not fully detailed by Google but it is assumed that they operate in the same manner as weather balloons, by altering the pressure in the envelope through the pumping or releasing of hydrogen gas. To do so a small pump would have to be used which would consume more energy during operation.

The final major use of energy is through the actual creation of the network. Whether communicating between themselves or with users on the ground each balloon must transmit many signals over long distances. If a signal is required to travel a further distance without distortion then it requires a greater amount of power (Goldsmith, 2013). This means that an increase in energy that the battery and solar panels can supply would result in improved performance by the antennas. Therefore it is recommended that every few years the balloons be updated with the most efficient solar technology. This will not be integrated into the cost as this paper is concerned with the feasibility of Project Loon with presently available materials.

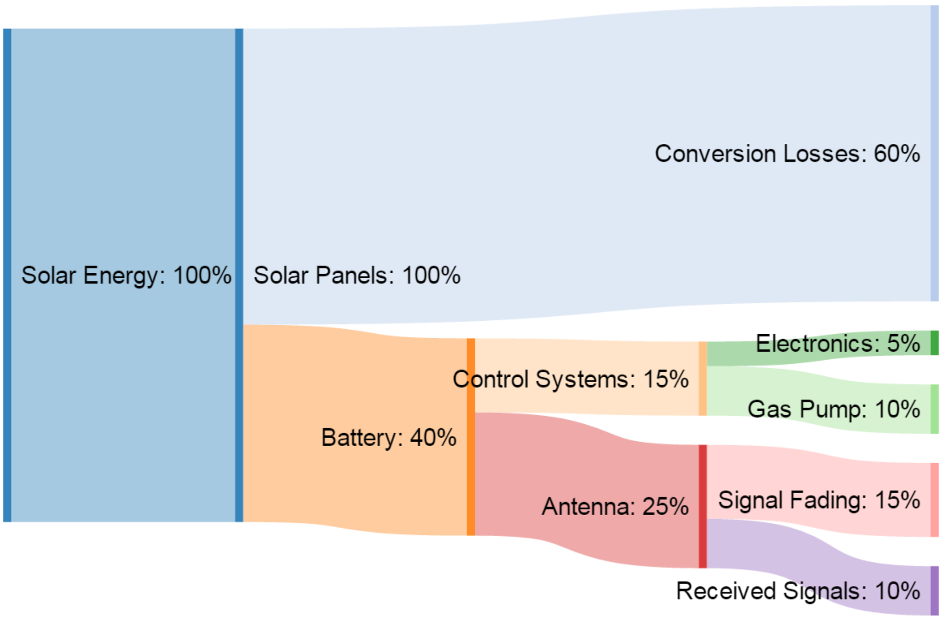

Figure 6 – Sankey Diagram of a Project Loon balloon

Safety

A major safety concern with Project Loon is congestion of air space. Each balloon is designed to operate at an altitude of roughly 20km (Google, n.d.) which is above the ~18km maximum of aircraft (Airservices Australia, n.d.). This means that during normal operation there should be minimum risk of mid-air collisions involving Project Loon balloons and other aircraft as they should not occupy the same airspace. The exception to this rule is whilst the balloons are ascending or descending at the beginning or end of their 100 day operational cycle. The best workaround for this issue is to have certain restricted airspace locations where balloons can safely rise and fall; an example would be an airfield where the balloons can take-off and then land after each cycle. Constructing such zones would require coordination with air traffic authorities.

The second concern is what happens if a balloon is damaged during operating, as a single puncture to the envelope could render a balloon unable to maintain height. If currently suspended over a residential or populated area, the chance of the balloon falling on someone or private property is unacceptable. Google has indicated that this risk will be mitigated by the emergency parachute installed onto the balloon (Google, n.d.). The parachute model was selected so that the rest of the balloon fell within its safe operating range (Mills Manufacturing, n.d.). Care must be taken when altering components of each balloon as weight is an important factor when designing an air vessel. If a more powerful antenna is desired to support a larger service area then it may weigh more; in turn the envelope may need to be larger to support the extra weight, more gas may be used and a larger parachute must be used to support the structure in the event of a failure.

Dynamics and Control

The balloons control their location by riding wind currents in the stratosphere. Above the tropopause traditional weather patterns stop, meaning that conditions at the balloons operation level is more consistent. This means that to reach a desired destination, the balloons merely have to raise or lower their altitude into the desired wind current. This means that Project Loon is an inherently dynamic system as each balloon in the array will be constantly shifting. Another network solution with a similar dynamics nature is satellite networks. Satellites have two major upsides though, firstly the orbits of satellites are 100% predictable; secondly a satellite's orbit can be made geostationary, where its position above the earth does not change. This stability means that organizing a satellite communication network is much easier then what Google intends to do. This can partially be rectified by using feedback systems to effectively control the movement of the balloons (Franklin 2010). A simple block structure of the altitude control system is shown in Figure 7. As discussed a pump or motor is used to release or pump gas into the envelope, thereby changing altitude.

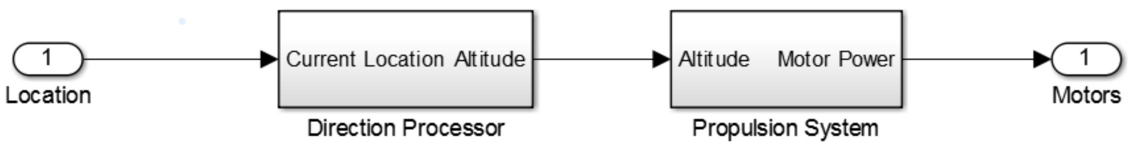

Figure 7 – location to altitude processing

The balloons are also able to communicate between each other meaning that they can organise themselves into a network that best suits the area they are currently covering.

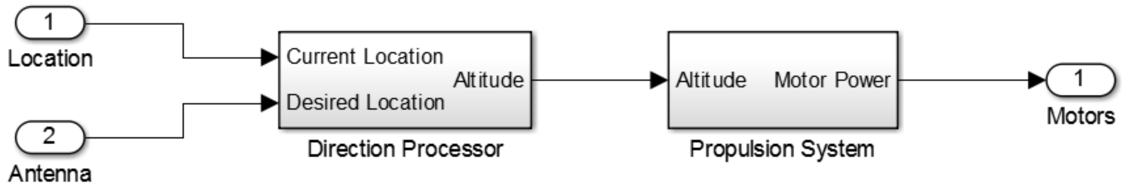

Figure 8 – addition of communication to prioritise locations

As the wind currents may gradually shift, a weather data feedback loop can be implemented which allows balloons to adapt to shifting conditions. Furthermore using their communication systems if one of them enters an unstable or undesirable condition then it can warn other balloons of the situation. This is mainly a further safety precaution as the altitude at which they operate is largely devoid of traditional weather which could damage them.

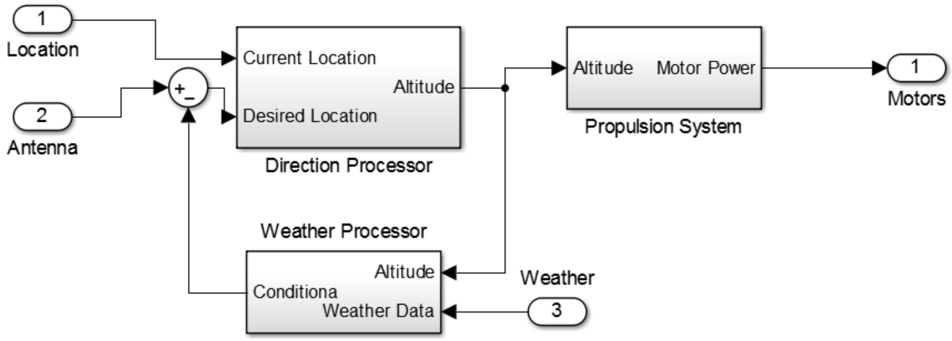

Figure 9 – Feedback loop with weather and wind data

This control system is one of the most key aspects of the project. If not implemented correctly then balloons may not be able to reach areas in need of coverage or may interfere with each other. The worst case scenario would be two balloons colliding due to a controller malfunction. Therefore this paper recommends extensive testing of the control systems, especially in scenarios where several balloons are in the same area, for both safety and efficiency reasons.

Coverage

Each balloon only has a limited coverage area of 40km in diameter (Google). This translates to a circle of 1257km^2 on the ground. This area can be used to determine how many balloons are required in each scenario (Table 5). This can then be extrapolated to determine how many users each balloon would have to support, assuming 100% take up rate.

Table 5 – Coverage of each balloon

Scenario	Potential Users	Supported Area (km^2)	Users/km^2	Required Balloons	Users/Balloon
#1 (Australia)	4,742,860	6,127,889	0.77	4875.01	967.89
#2 (India)	1,027,773,567	2,973,190	345.7	2365.31	434544.90

It should be noted that the above numbers incur a slight error due to circle packing (Figure 10). With no overlap the balloons would only be able to cover 90.7% of the total area

(Stephenson, 2003). To solve this, a greater number of balloons could be deployed so that a slight overlapping occurs. The trade-off to this is that once again interference can occur when several balloons are in each other's operation area.

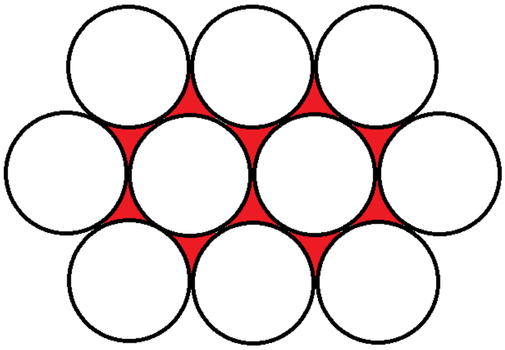

Figure 10 – Circle Packing Error Illustration

Cost

A major consideration for this project is whether to charge the public for access and if so, how much. This paper will assume that Google intends to make no profit directly off of Project Loon and that any costs to the user merely keep the project from running at a deficit. Firstly the material audit is used to estimate the cost per balloon.

Table 6 – Estimated material costs per Balloon

Component	Material/process	Amount	Cost
Envelope	polyethylene plastic Density of 0.95g/cm^3 [2]	111.5kg	$1080
Electronics (antenna and other transmission equipment)	aluminium plastic steel copper glass nickel tin lead	4.368kg 7.176kg 6.552kg 2.184kg 7.800kg 0.312kg 0.312kg 1.872kg **30.577kg**	$12100
Solar Panels	silicon aluminium copper plastic	14kg 16kg 2kg 8kg **40kg**	$1140
Battery		33kg	$2400
Gas cylinder	Cylinder (steel) Hydrogen (1.8m^3 at 13.8MPa)	30kg 18.65kg **48.65kg**	$500 $150
Parachute	Nylon	57kg	$500
TOTAL		320.73kg	$17870

The total cost of implementing the required number of balloons for each of the scenarios is then calculated.

Table 7 – Total initial cost of each scenario

Scenario	Required Balloons	Users/Balloon	Total Initial Cost	Total Cost over 5 years
#1 (Australia)	4875.01	967.89	$87,116,429	$196,550,250
#2 (India)	2365.31	434544.90	$42,268,090	$95,364,569

Two assumptions are now used to help estimate ongoing costs. If a balloon only operates under normal conditions and as such receives minimal wear and tear, the only components that should have to be replaced every 100 day cycle are the envelope and the gas; a total cost of $1230. The next assumption is that each balloon will be in operation for 5 years.

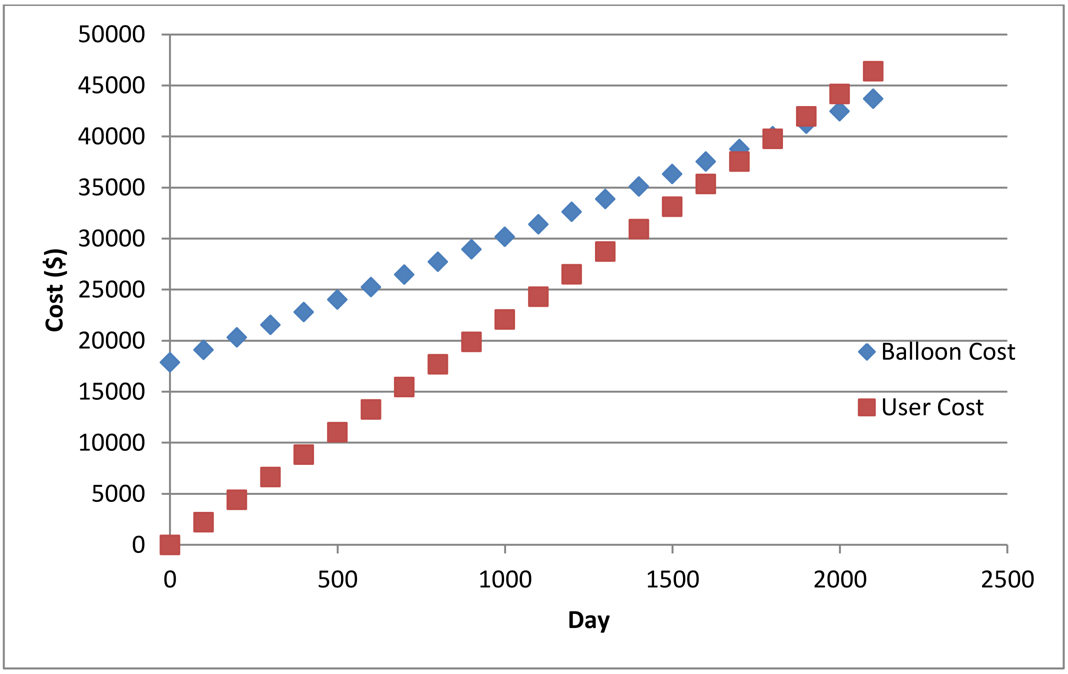

Figure 11 – pay-back period for cost parity

If the project is to be run at no deficit to Google then the entirety of the cost of balloons must be carried over to the customer. A payback period plot (Figure 11) is used to determine the cost to customers to fulfil this zero deficit requirement. Unlike a normal payback period plot which compares two known quantities to each other, this one is designed to find the unknown quantity of cost to customers over five years. This is found by selecting the gradient of the line so that intersection occurs on the five year mark. As each balloon has an ongoing cost of $40318 over the five years, the gradient can be used to determine the cost for each group of customer per day. This is then divided between each scenario in table 8 to find the cost per user per day.

Table 8 – Cost per customer with 100% take-up rate

Scenario	Cost per Balloon over 5 years	Users/Balloon	Cost/User over 5 years	Cost/User per day
#1 (Australia)	$40318	967.89	$41.66	$0.023
#2 (India)	$40318	434544.90	$0.093	$0.000051

This is of course assuming that every single person possible uses the service. Instead we will assume that only 5% of each user base actually makes use of the service, a much more reasonable estimation.

Table 9 – Cost per customer with 5% take-up rate

Scenario	Cost per Balloon over 5 years	Users/Balloon (5%)	Cost/User over 5 years	Cost/User per day
#1 (Australia)	$40318	48.39	$833.19	$0.46
#2 (India)	$40318	21727.25	$1.86	$0.001

The biggest hurdle for Project Loon is that monetizing it will make it less appealing for use. This is compounded by the fact (recalling back to Figure 3) that areas which are in greater need of access are also occupied by poorer people. This implies that Project Loon is inherently unprofitable as charging for access will drive away the core user base.

This leads to the most important recommendation of this report. Google received 187 million unique visitors in the month of February 2014 (ComScore, 2014). For the quarter that included February of that year Google.com reported total revenue of 10.47 billion dollars (Google investor, 2014). Making the simple assumption that this profit was spread evenly over all the users this equates to $18.66 per user per month. This may be too high due to error associated with the fact that not all of the site's income will be directly from user advertisement revenue. To compensate we will take that only 10% of this is due to advertising, or $1.87 for each user.

By taking the 5% uptake assumption from each scenario table 10 shows the estimated increase in profits and compares that to the calculated cost of the required balloons over one month (average per month calculated from previous 5 year data).

Table 10 – Project Revenue of Project Loon in each scenario

Scenario	Potential Users (5% take up rate)	Required Balloons	Cost per Month	Revenue per User per Month	Total Revenue Increase per month	% of cost Covered
#1 (Australia)	237,143	4875.01	$3,275,844	$1.87	$4,445,257	13.5%
#2 (India)	51,388,678	2365.31	$1,589,409	$1.87	$96,096,827	6046.1%

Clearly based on these assumptions Project Loon would not be remotely profitable in Australia due to the fact that there are far less possible users and the coverage area is much too large. Conversely it would be extremely profitable in India and make back its running costs by 6046.1%. Using this 5% take-up rate data and the associated costs of each balloon, the critical user density to make Loon profitable was found to be 5.72 users/km^2 (Figure 12).

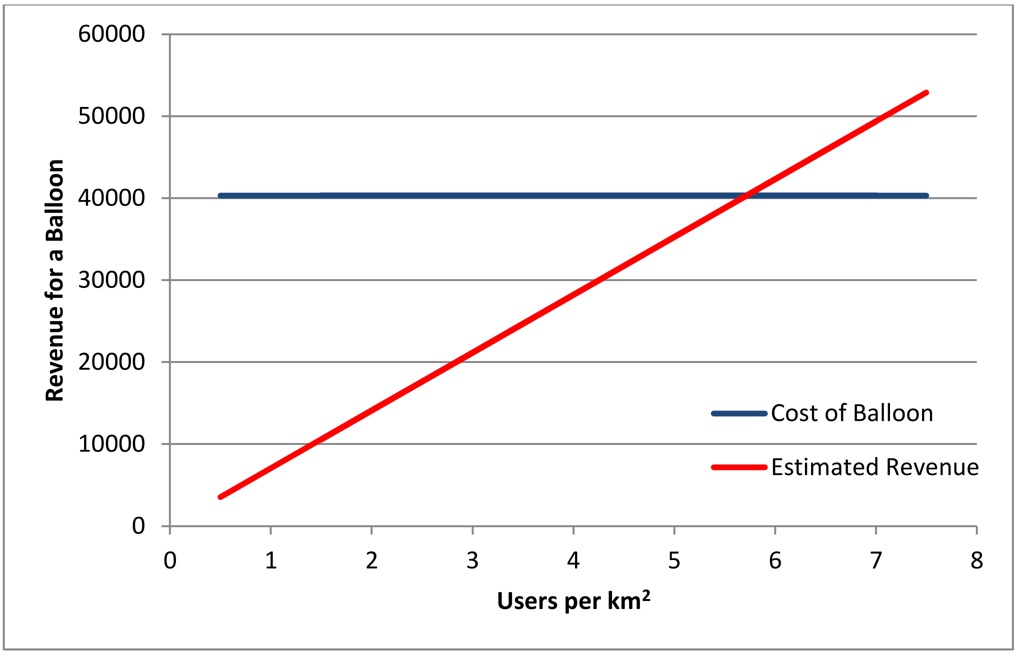

Figure 12 – The critical user density for cost parity

It must be kept in mind that these numbers are estimations and several sources of error or aspects that are outside the scope of this report can be identified. For example, the total calculated costs only estimates the physical cost of each balloon; it does not take into account wages of people constructing or maintaining the network. The distinction between revenue and profit must also be highlighted; the total money gained will be significantly reduced once taxes and other unaccounted for fees are applied.

A way to limit any risks associated with the project is to complete test trials, something that Google has already begun completing (Google, n.d.). By slowly rolling out coverage, if an area is found to be unviable then resources can be shifted from the area. For example with the scenarios discussed, if Australia was determined to not be viable for the project, all Balloons constructed for it could be diverted to more appropriate locations. This not only saves money but embodied energy as fewer resources would be consumed.

Recommendations

The control systems of the balloons must be rigorously designed and tested. Failing to do so would lead to inefficiency in the network due to coverage gaps or interference between balloons. Poorly coordinated balloons also have a much greater risk of collision which would not only be a financial liability but could also prove to be a safety risk.

Safety should also be further emphasized by ensuring that the balloons weight conforms to the installed safety parachute. Google should also coordinate with air traffic authorities to create safe zones for balloon ascent and descent.

The major finding of this report is that Project Loon would be feasible if Google considered implementing Project Loon at no cost to users because this would indirectly generate income due to advertisement revenue. Furthermore Project Loon would act as an investment into future infrastructure for the company as an increased number of internet users results in a larger potential number of customers for future endeavours. However Google should carefully inspect each intended operational area to ensure that implementing the project will at least result in no financial losses. The minimum user density in an area should be 5.72 users/km^2. Financial risk can also be minimized by undergoing a staggered rollout so that already completed balloons and resources can be redirected should an area become unviable.

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