

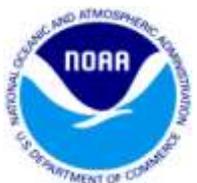
Design to Improve the Productivity and Execution of Gravity Surveys

NOAA - Gravity for the Redefinition of the American Vertical Datum

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1.0 Context

The National Geodetic Survey (NGS) is a government supported program that provides positioning information to the nation. NGS has several different projects currently underway to aid in the measuring of regional elevation, longitude, latitude, as well as collect shoreline data. This information is vital to NGS' goal in being able to provide improved flood risk data, support ecosystem management, support transportation projects, and advance scientific research.

One project that is currently underway is the Gravity for the Redefinition of the American Vertical Datum (GRAV-D). The GRAV-D initiative is an NGS supported project that the National Oceanic and Atmospheric Administration are spearheading. The newfound data that will be the result of GRAV-D is essential to the nation's economy and safety. New, more accurate gravity data will allow for improved flood plain mapping and evacuation planning which will save lives during intense storms and also see less property loss during these events.

1.1 Gravity Surveys

An essential idea that needs to be examined first is what a gravity survey is. A gravity survey is a collection of measurements of the acceleration of gravity around earth. These accelerations are then used to create a model the earth's geoid. The geoid model is then used to determine the elevations of various locations around the earth.

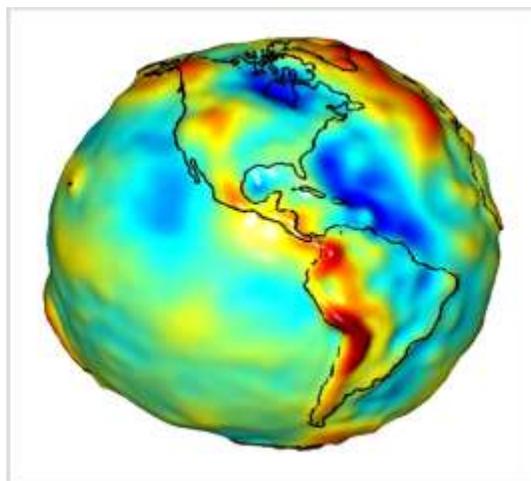


Figure 1 - Geoid Model

Figure 1 (above) represents a model of the earth's geoid focused on the western hemisphere as captured by satellite. The geoid model that is created by satellite creates what is essentially a low definition snapshot of the earth's elevations. Higher elevations are represented in the darker orange and red colors (e.g. Rocky Mountains and the Andes), while lower elevations (e.g. coastlines) are represented in lighter blues and greens.

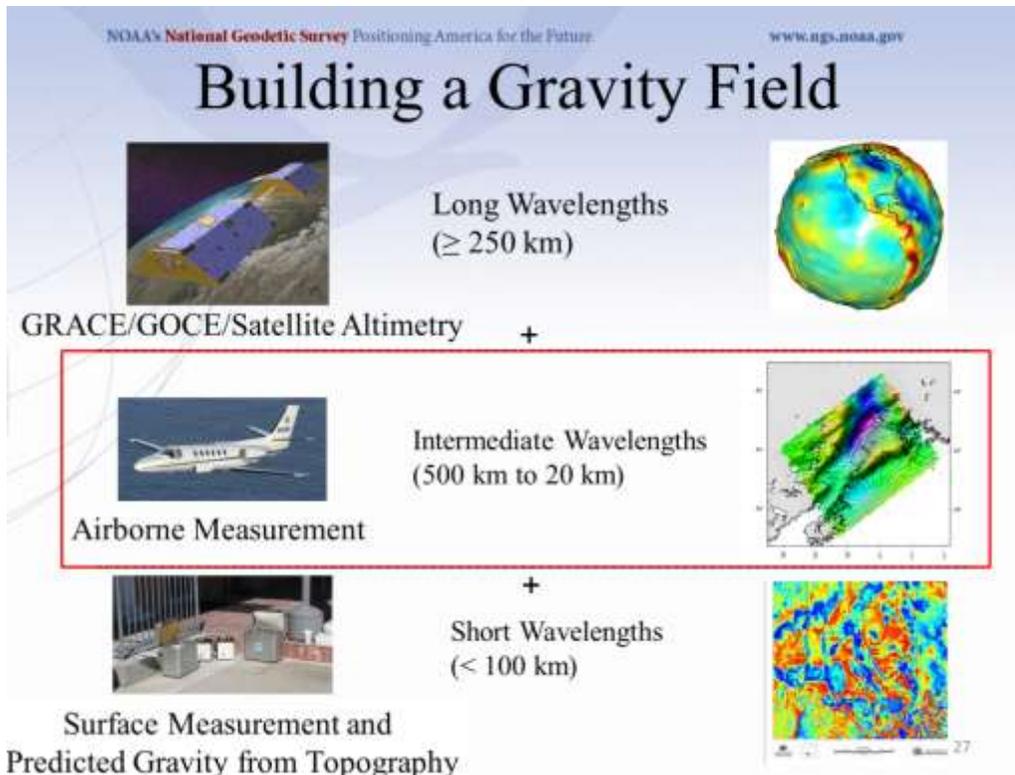


Figure 2 - Wavelength Types

Figure 2 shows the different measurement types that NOAA uses to model gravity. When GRAV-D began surveying in 2008, gravity data was primarily measured using satellites and surface techniques. The surface techniques resulted in very high resolution measurements that were collected over several years using different equipment and different techniques. The result is that data quality varies widely and the spacing of data around the country is non-uniform and there are even mismatches between adjacent surveys which cause large errors in gravity data. Plenty of satellite data exists and it is very accurate, but lacks any substantial detail. The latest satellite, name GOCE is capable of resolution of 200 to 250 km. Unfortunately, these long wavelength measurements cannot correct the surface survey because those surveys are smaller

than 200 x 200 km in size which is the average size of a GOCE satellite data point. Airborne measurements are now being used to bridge the gap between the existing satellite and surface measurements.

Also important, is what is actually being measured through the GRAV-D program. In the case of GRAV-D, the underlying goal is to model and monitor the Earth's geoid; the geoid is the surface of the gravity field, closely related to the global mean sea level. Also important is the relevance of ellipsoidal and orthometric heights. Ellipsoidal heights are easily found using Global Positioning Systems (GPS), but are not linked to water flow and elevations. Orthometric heights on the other hand are related to water flow and are very useful in flood plain mapping, but at the same time, are not as easy to determine. To find orthometric heights, it is necessary to create a model of the geoid using measurements of acceleration of gravity near the earth's surface.

1.2 Importance of NOAA's GRAV-D Initiative

As mentioned in the context, the GRAV-D project is important in many ways. The new gravity datum will help accurately measure the height and flow of water in regions with few elevation changes to help make more efficient use of water resources. This will be important for areas in the Midwest where farming is abundant and the topography is generally flat.

Of critical importance is the contributions that GRAV-D will make to low lying coastal areas and regions that are prone to tropical storms. The Federal Emergency Management Agency currently uses survey data to administer flood control certificates. FEMA actually requires that all new development in storm prone areas provide survey data in an effort to minimize any potential damage. FEMA also uses flood plain maps to determine whether or not flood insurance is necessary for homes and commercial buildings. The National Flood Insurance Program is a FEMA run program that currently has over \$650 billion in insured assets. Also, the data presented by NOAA will help plan evacuation routes for these low lying coastal areas in preparation of storms.

An updated vertical datum will also allow for improved accuracy in atomic clocks that are used in common electronic systems such as cell phones and global positioning systems. Measurements will also become more continuous as opposed to intermittent points that are based on physical monuments alone. State and local municipalities may also be able to take advantage of GRAV-D by using the new elevation measurements during road construction and also water and sewage networks.

1.3 History of Gravity Surveys

The first gravity surveys took place in the mid 1600's when Europeans began taking measurements using pendulums to determine variations in gravity. These pendulum measurements would come to represent just the beginning of gravity surveys. As technology would advance so to would the capabilities of how scientists could measure gravity.

The most recent gravity survey completed by NGS and NOAA is known as the North American Vertical Datum of 1988 (NAVD 88'). Officially completed in 1991, NAVD 88' was created to replace the existing Sea Level Datum of 1929 which was renamed the National Geodetic Vertical Datum of 1929 (NGVD 29) in 1973. NAVD 88's creation was prompted by an additional 625,000 km of new leveling being added to NGVD 29, destruction of old data markers by crustal movement and erosion, and data points showing errors as high as nine meters [1].

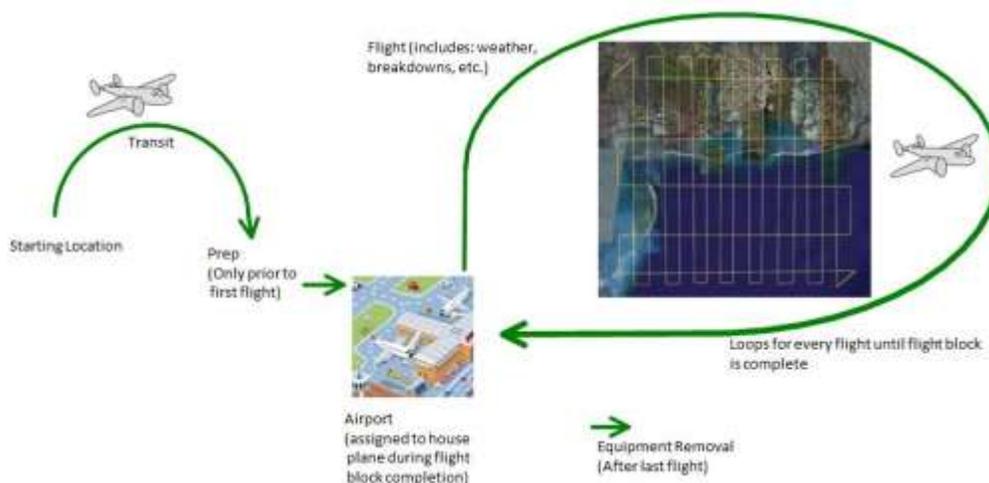
Designed to replace NAVD 88', the GRAV-D project seeks to provide an improved gravity datum for the United States and its territories (e.g. Puerto Rico, Guam). NAVD 88' has reached the end of its useable lifespan and is now in line to be replaced by the new vertical datum (GRAV-D). Even though NAVD 88' was officially completed just over two decade ago, the vast majority of data was collected in the 1970's and 1980's. Over time, these data points have been skewed and damaged by crustal movement and erosion, similar to data markings from NGVD 29'. Some data points have errors as high as 2 meters (6.56 ft.) and many of the data points were completed by outside sources (other than NOAA) using a varying methods to a differing degree of success. More importantly, many regions are lacking complete data coverage

(e.g. Alaska and Guam). These regions are missing data as a result of difficult terrain and inclement weather conditions.

The new GRAV-D project aims to alleviate all of the faults from the NAVD 88' program. Measuring gravity by air allows for more thorough coverage of areas that are lacking sufficient data.

1.4 GRAV-D Logistics Process

The process of a gravity survey can be broken down into several specific steps. The first step of a gravity survey is for NOAA to decide where gravity measurements should be made. The decision on where a survey should take place is based on the area's lack of gravity measurements, the area's lack of accurate gravity measurements, or for other miscellaneous reasons. Once a location is selected, a plane needs to be chosen to perform the gravity measurements in the area. The selected aircraft is then flown to a home base airport from where the gravity survey will operate from. This airport will be used throughout the gravity measurements for this area, so the airport needs to be close to where the gravity measurements will be taken and have an appropriately sized hangar to house the plane. The process of moving the plane to the airport is called transit and will take on average three days. Once the airplane has reached the airport, the plane goes through a preparation period where the measuring equipment is installed into the aircraft, calibrated, and the plane performs test runs.



The area usually covered when performing gravity measurements is a flight block that is 400 km by 500 km, but this size can vary depending on coastlines, borders, or other flight block borders nearby. When a flight block is being completed, multiple separate flights are performed in a parallel fashion with each line being 10 km apart. Once the plane reaches the end of the flight block then flights are taken that are perpendicular to the other flight lines. These cross lines need to be separated by 80 km, a small example of what a flight block looks like is in the figure above. The cross lines are performed to verify the measurements that were recorded originally in the flight block. Each flight block will take over 40 individual flights to complete. With days not flown due to weather and for plane repairs, along with many other reasons not to fly on a specific day, a whole flight block can take over 100 days to complete.

Once the whole flight block is complete, the plane has to get the equipment it used for measurements removed. The process of removing the equipment can take up to three days. Once the equipment is removed the area is complete and the plane will either be returned to its contractor or will be moved to a new area to complete another survey.

1.5 Target Identification and Project Gap

The table below represents the annual targets that NOAA has set forth for the GRAV-D project. NOAA plans to have gathered 28% of its target survey data by the end of fiscal year 2013 (October 2013). NOAA has been averaging a 5.6% completion rate per year but will need to increase output to roughly 8% per year to reach their completion target of fiscal year 2022. If the current pace were to continue, the project may not be completed until sometime in 2026 (as indicated by Figure 4).

FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
28%	36%	44%	52%	60%	68%	76%	84%	92%	100%

Figure 3 – Annual Target Identification

1.5.1 Gap Graph

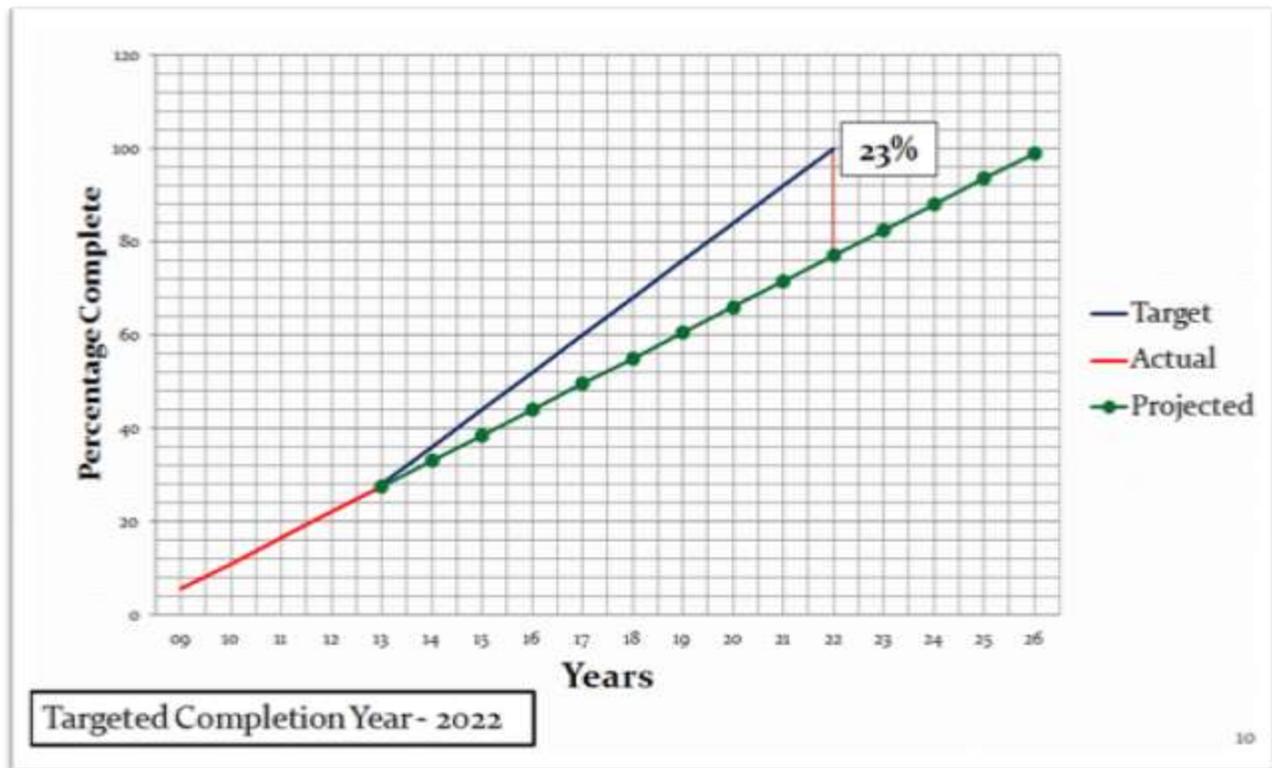


Figure 4 - Gap Graph

Figure 4 is a graphical representation of the projects actual completion percentage, the projected completion percentage, and the target completion percentage. The red line represents the actual completion percentages that NOAA has accomplished so far with the GRAV-D project. The green (dotted) projection line maintains a 5.6 percent completion rate for the project. At that rate, the project would finish in year 2026, rather than the set date of 2022. The blue line represents the target set forth by NOAA. The gap

1.6 Equipment

Several pieces of equipment are needed to complete a gravity survey. Aside from the aircraft itself, there are three main piece of technology used that make of the equipment suite. The equipment suite is comprised of a gravimeter, an inertial measurement unit, and Global Positioning System (GPS) base stations. The gravimeter is a device that is used to measure the vertical acceleration of gravity on the earth’s surface. The gravimeters utilize a system known as TAGS (Turnkey Airborne Gravity System). Inertial measurement units (IMU) are what

essentially locate the aircraft while it is airborne. The IMU utilizes three accelerometers and three gyroscopes and is mounted to a camera or a lidar system to measure the aircraft's position and acceleration. While IMU systems are reliable, they do accumulate error as the aircraft travels. To help aid in accurate position fixing, GPS base stations are placed at known locations and provide updates to the IMU to help maintain accurate information.

1.7 Project Constraints

The Gravity for the Redefinition of the American Vertical Datum project has been underway now for four full years. The team at NOAA has created an extensive list of requirements and constraints that must be considered when completing any sort of design and project plan.

Constraint	Description
General	NGS only owns two equipment suites, so only two field teams may run at one time.
General	Three days at the beginning and end of the survey should be scheduled for installation/de-installation of the equipment.
General	Every survey that requires NOAA personnel must have at least one lead operator.
General	When working on Navy aircraft both operators need to be qualified under Navy rules.
General	Priority Areas: Alaska (sans Aleutians), coastal areas, CONUS, island, Aleutians.
Budget	\$2.4 million budget per year for all survey operations (including aircraft, fuel, pilots, and NOAA personnel travel costs)
Budget	Annual travel costs for NOAA personnel (not including contractors) cannot be greater than \$100,000.
Budget	Hanger costs average \$225 per month.
Budget	Office costs at airport average \$200 per month
Budget	Assume increase in costs of 1% per year
Performance Metrics	All flight areas may be counted (even outside of the base polygon) as long as the final total area overlaps with the planned area by 90%. This generally means that straight lines are drawn to average the curve of the planned area, which means that the areas flown outside the official target polygon and those areas that are missed are about equal.
Performance Metrics	Percents are the minimum that MUST be finished by September 30 of that year. More can be done in any one year if extra money/resources are available.
Schedule	Assume 50% of the days on survey will be spent flying (this includes all downtime, including weather, maintenance, and personnel down days)
Schedule	Each pilot may fly up to 8 hours per day (in most cases this means one flight per day)
Schedule	Because of the holidays, surveying ends the week before Thanksgiving and recommences the beginning of January
Airports	Must use an airport with contract fuel (list provided) when working on a government aircraft
Airports	Each new airport requires a reconnaissance survey, so reusing airports is preferable
Airports	Preference for small airports with 24 hour control tower services, as large airports have a lot of air traffic that can cause problems
Airports	Must have FAA Part 139 certification (for fire emergency service).

Airports	Can also use Naval Air Stations and Army bases with airstrips (contract fuel available).
Weather	Generally northern areas in the summer, southern areas in the winter
Weather	Avoid Eastern seaboard (especially SE) during Hurricane season
Weather	Avoid Tornado Alley in Spring and Fall
Weather	Go to Oregon/Washington area June-August; Go to Western Alaska June - September
Flight Planning	Blocks should be the optimal size for aircraft and airport combination, but at the end of the project must cover at least 15,557,541 sq km with at least 90% overlap with the planned area.
Flight Planning	A standard block is 400 km by 500 km, which is approximately a 100 flight hour survey
Flight Planning	Blocks can vary from the standard size, but not be smaller than 200km or larger than 700 km
Flight Planning	Data lines should be spaced 10 km apart
Flight Planning	Cross lines should be spaced 80 km apart and at a 45 to 90 degree angle to the data lines, 90 degrees is preferred
Flight Planning	Blocks must overlap by 30 - 40 km on the sides
Flight Planning	Flying over Mexico requires special permissions, so minimize the number of fiscal years that data is collected over Mexico

Figure 5 - General Project Constraints

The table above shows the complete list of requirements and constraints as provided by NOAA. There are too many constraints to discuss one at a time, so only the most important will be mentioned in detail.

The general constraint that specifies that only two complete equipment suites are available for use is very important in the teams design philosophy. The constraint means that at any one time, NOAA may only be operating surveys in two locations. This limits the amount of raw data that may be collected and analyzed during the survey year and does not make efficient use of the aircraft NOAA has at their disposal.

The budget is another important constraint that impacts the project greatly. NOAA currently operates on a \$2.4 million per year budget for all survey operations. This budget is intended to cover aircraft use, pilots, fuel, maintenance, travel expenses, equipment, and upgrades. While this is a sizeable budget, NOAA personnel openly admit that they are limited in how much they can accomplish by their budget constraints. A larger budget would allow for more measuring equipment, more personnel, and improved aircraft. If the GRAV-D project can attain more money for their budget, they then could complete more surveys per year and thus reach their annual goals.

Weather plays a large role in the success or failure of the survey. The general rules for avoiding weather systems are quite simple. Stay away from the southeast during the summer to avoid tropical weather systems and avoid tornado alley from spring through the start of fall.

Avoid the northern part of the country during the winter months and limit time in Alaska to June through September.

Aircraft Specifications							
ID	Organization	Aircraft	Availability	Flight Restrictions	Equipment	Range	Pilots
1	Bureau of Land Management (BLM - 1 pilot)	Pilatus PC-12	Sept 15 – Mar 31	Only 40 nm offshore	S-137 or S-161	1050 nm	1
2	Bureau of Land Management (BLM - 2 pilots)	Pilatus PC-12	Sept 15 – Mar 31	Only 40 nm offshore	S-137 or S-161	1050 nm	2
3	Naval Research Laboratory (NRL)	King Air RC-12 (a.k.a. King Air 200)	Any	Not within 200 km of Cuba	S-161	900 nm	2
4	NOAA	Turbo Commander 1000 695A	Aug 15 – Sep 15	Must have hanger at airport	S-137 or S-161	800 nm	2
5	Fugro (1: aircraft, pilots)	King Air E90A	Any	Cannot fly N/S lines	S-137 or S-161	900 nm	2
6	Fugro (2: aircraft, pilots, QC)	King Air E90A	Any	Cannot fly N/S lines	S-137 or S-161	900 nm	2

Figure 6 - Project Aircraft

Aircraft Costs				
ID	Short Name	Wet Rate (includes fuel)	Pilot Rate	# NOAA operators
1	BLM-1	\$800/flight hr	\$850/day/person	1
2	BLM-2	\$800/flight hr	\$850/day/person	2
3	NRL	\$2300/flight hr	NA	2
4	NOAA	\$1100/flight hr	NA	2
5	Fugro-1	\$3500/flight hr	NA	1
6	Fugro-2	\$3500/flight hr	NA	0

Figure 7 - Aircraft Costs

The two tables above display the fleet of aircraft used by the GRAV-D project and the different constraints that pertain to each aircraft. The most notable constraints from these two tables are aircraft availability and aircraft restrictions. Only three aircraft are available for full time use, the Naval Research King Air RC-12, and the two Fugro King Air E90A's. The NOAA Turbo Commander is unavailable due to scheduling and the Bureau of Land Management Pilatus PC-12's are used for firefighting missions during the summer months and are unavailable from the end of March through mid-September. Each aircraft used by GRAV-D have restrictions. The two BLM aircraft are single engine and are required to stay within 40 nautical miles of the coastline in case of an engine failure. The Naval Research King Air RC-12 cannot fly within 200 kilometers of the Cuban coastline because of prohibited airspace. NOAA's Turbo Commander must be stored in hangars to limit its exposure to inclement weather as it

experiences electrical issues when exposed to weather. The Fugro (contractor aircraft) King Air E90A's both have autopilot issues which cause the aircraft to drift away from north/south lines.

The range of each of these aircraft also poses a dilemma for NOAA and their goals of surveying the islands of Hawaii and Guam. The distance from Los Angeles, California to Honolulu, Hawaii is roughly 2,500 miles, which is about 2,200 Nautical Miles (Guam is 3,400 Nautical Miles). Unfortunately, none of NOAA's current fleet has the range to even come close to reaching Hawaii, let alone Guam. NOAA is currently reviewing all possible solutions for obtaining aircraft in these areas.

1.8 Historical Data and Analysis

1.8.1 Summary by Survey

Survey (Days)	AK08	AL08	AK09	LA09	PV09	TX09	AK10-1	AK10-2	AK10-3	AK11	CA11	NY11	IN11	IN12	TX12	MN12	ME12	NH12	MI12	Total
Survey	15	16	19	8	15	19	28	24	6	23	25	15	20	8	10	26	19	16	17	329
Prep	2	0	2	0	0	1	2	0	0	5	3	0	2	4	2	3	17	1	3	47
Transit	0	0	2	1	3	2	5	0	0	4	3	1	0	0	1	6	8	1	4	41
Weather	2	2	2	1	0	0	5	4	0	8	3	9	7	0	1	17	6	8	9	84
Aircraft maint.	0	3	4	15	0	0	13	7	0	3	13	2	12	0	34	0	0	0	0	106
Aircraft repair	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Instrument issue	0	0	0	0	0	1	3	0	0	3	2	0	1	0	1	10	17	0	3	41
Personnel day	3	1	2	1	3	0	4	3	0	7	4	0	1	1	13	6	5	2	2	58
Use by Owner	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	2	0	7
Political	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Holiday	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	3
Unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	22	22	31	26	21	23	61	39	6	53	53	27	48	13	62	68	73	31	39	718

Figure 8 - Survey Data (AK08 – MI12)

The table above shows completed survey data provided by NOAA from the Alaska 2008 through the Michigan 2012 survey. Each column represents a survey and the year in which it took place (multiple surveys were completed in Alaska in 2010). The rows on the right hand side represent different factors that impacted the survey (# of days).

Figure 8 contains twelve different factors that impact or occur during a survey. For this project, five of these factors will be the primary focus, weather, aircraft maintenance, aircraft repair, instrument issues, and personnel days. Weather serves as an uncontrollable factor to the survey, but one that can be monitored by the survey planners. NOAA planners can utilize historical weather data to make intelligent decisions on when to plan surveys in certain regions (e.g. Alaska has severe winters that would impact survey productivity, and the southeast United States should be avoided during the late summer months due to the increased risk of hurricanes). Aircraft maintenance refers to scheduled maintenance that is carried out by the aircraft contractor. Some maintenance items can be handled on location (e.g. A-Checks), but in other instances, the aircraft must be flown back to the contractor's facility to undergo more time consuming maintenance (e.g. B-Checks and C-Checks). Unfortunately, the time consuming checks cannot be completed before embarking on the survey. Instead, the maintenance is performed whenever the aircraft requires it, not sooner, and not later. Aircraft repair is in reference to any repair that is unscheduled, or anything that is unexpected. In these situations, the aircraft will have to be repaired on location in order to become airworthy again (e.g. Aircraft being used in Alaska experienced a hydraulic failure in the front landing gear and required on

site repair). Instrument issues refer to the gravity measuring equipment that is on board the aircraft. This equipment generally suffer electrical or software issues. Personnel days are the days that pilots and NOAA personnel take to rest and relax. These days are typically coordinated with aircraft maintenance and weather delays.

Factors	Type of Distribution	Mean (days)	Standard Deviation (days)	Square Error
Aircraft Maintenance	Beta	5.57	8.18	0.036
Aircraft Repair	Beta	3.85	6.77	0.025
Equipment Repair	Beta	2.14	3.80	0.035
Weather Delay	Beta	4.98	4.00	0.021
Personnel Day	Gamma	3.06	1.84	0.005

Figure 9 - Process Distributions

The above figure is a set of distribution data for each of the historical survey factors that will be implemented into the simulation. Each factor was analyzed through Arena using its input analyzer tool. Once data was processed, trend lines were fitted to each set of data (e.g. aircraft maintenance received a beta distribution). Other information such as the mean (days), the standard deviation (days), and the square error were calculated from the distribution data. These data point would later be implemented into the simulation and varied to see which factor would have the greatest impact on the survey and which would allow for fewer days required to complete a survey.

2.0 Stakeholder Analysis

2.1 Planning Stakeholders

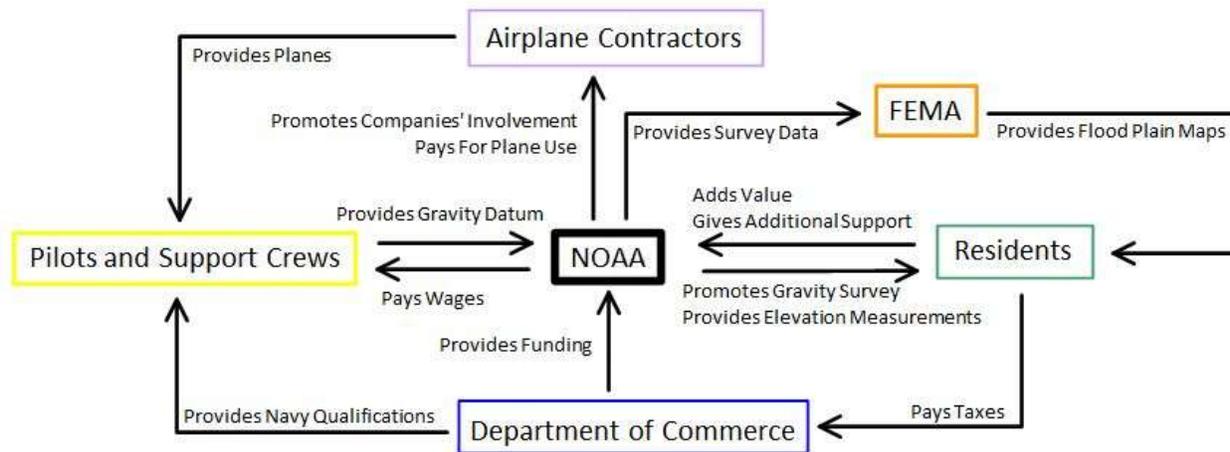


Figure 90 - Planning Stakeholder Diagram

2.1.1 National Oceanic and Atmospheric Administration (NOAA)

There are several important stakeholders involved in the GRAV-D project with NOAA acting as the primary stakeholder in the project. NOAA is responsible for the planning and management of the project. This planning includes giving states priority, moving aircraft and crew around for surveys, creating flight plans, selecting airports and hotels. NOAA does face issues with funding however. They are limited to \$2.4 million per year which limits the number of aircraft that can be used, and more importantly, how many pieces of measuring equipment they can utilize.

2.1.2 Airplane Contractors

Airplane contractors, such as Fugro and BLM, support NOAA's gravitational survey objectives by providing aircraft and pilots. There are several constraints involving aircraft that greatly affect the survey. Firstly, Fugro aircraft cannot fly north/south lines because of aging autopilot systems. The BLM aircraft have the longest range of any other aircraft used, but are limited to how far they travel offshore (limited to 40 nm) because they are single engine aircraft and need to be within close range of shore in case of an engine-failure. NOAA aims to use contractors evenly to mitigate any tension that may arise from using one contractor more than another.

2.1.3 Pilots and Support Crews

Pilots and support crews have the singular goal of collecting physical data for the survey. The tensions these individuals endure are a lack of funding and time to complete surveys. The pilots must also be lodged in hotels and eat. It has been suggested that the pilots stay in quality hotels in larger cities. Pilots may be grounded for multiple weeks based on an aircraft issue and they will need to have an at least adequate selection for food and entertainment.

2.1.4 Department of Commerce (DOC)

The Federal Government (Department of Commerce) provides funding for this project as NOAA is a scientific agency within the department. NOAA must meet yearly goals to continue to receive funding which NOAA heavily relies upon. GRAV-D project managers receive a lack of information regarding funding from the DOC which causes tension and also uncertainty about the project.

2.1.5 Federal Emergency Management Agency (FEMA)

The Federal Emergency Management Agency (FEMA) utilizes survey data from NOAA to administer flood control certificates to homeowners and commercial building owners. FEMA uses survey data and floodplain maps to determine whether or not a home or commercial building will require flood insurance under the National Flood Insurance Program; a program that currently has over \$650 billion in insured assets.

2.1.6. Important Relationship Loops

NOAA pays for the airplane use from the airplane contractors, who then supply the planes to the pilots and support crews. Once NOAA receives the gravity measurements from the pilots and support crews then NOAA can give the data to FEMA. FEMA then can create the flood plain maps for the U.S. and U.S. territory residents.

The Department of Commerce provides the funding for NOAA's GRAV-D project, the amount of money in the budget for GRAV-D limits the amount that can be accomplished in a given year for NOAA. NOAA then can promote the gravity survey and provide the elevation measurements to the residents. The residents in turn pay taxes to the government or the Department of Commerce.

2.2 Execution Stakeholders

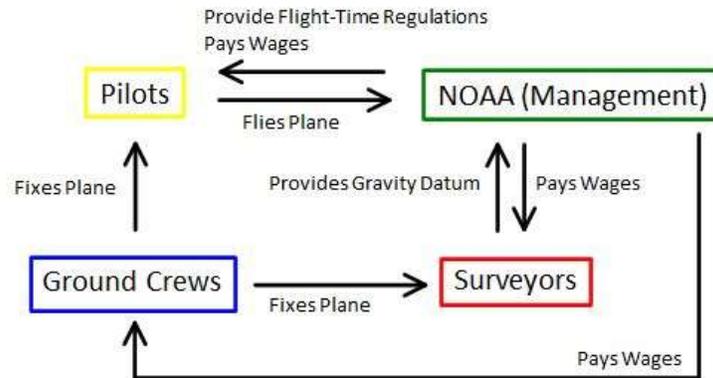


Figure 101 - Execution Stakeholder Diagram

2.2.1 Pilots

The pilots are the individuals responsible for the success of the survey and the overall project. Pilots must conform to FAA mandates on flight hours and make the final decisions about whether or not the plane will fly on certain days. Most pilots used for GRAV-D are contracted and not employed by NOAA.

2.2.2 Ground Crews

Ground crews represent the mechanics that are present on survey days. These mechanics are responsible for maintaining and repairing broken aircraft so that they may return to surveying as quickly as safely possible.

2.2.3 Surveyors

NOAA sends out survey teams on each scheduled survey. These members of the team are responsible for installing survey equipment into the aircraft, calibrating and testing the equipment, flying in the aircraft during surveys, undertaking diagnosis and repairs to broken equipment, and also uninstalling survey equipment from the aircraft upon survey completion. Some survey members are required to be trained by NAVY personnel in order to fly in the NAVY aircraft.

2.2.4 NOAA (Management)

NOAA is responsible for the planning and management of the project. This planning includes giving states priority, moving aircraft and crew around for surveys, creating flight plans, selecting airports and hotels. NOAA does face issues with funding however. They are limited to

\$2.4 million per year which limits the number of aircraft that can be used, and more importantly, how many pieces of measuring equipment they can utilize.

2.2.5 Important Relationship Loops

The ground crews are in charge of fixing the planes for the surveyors and pilots. Only once a plane is fixed the pilots and surveyors can complete their job. The ground crews are an important piece to make sure that the survey can be completed quickly. The pilots then fly the plane for NOAA and the surveyors collect the gravity datum for NOAA. NOAA then pays the wages for the ground crews, surveyors, and pilots.

3.0 Problem and Need Statements

3.1 Problem Statement

- NOAA has to reach 8% geographic area coverage annually.
 - A plan to reduce variability within the gravitational survey is needed to maximize coverage within budget.
 - Before Fiscal Year 2022

3.2 Need Statement

- NOAA needs to complete the 8% annual quota but receives limited funding from the Department of Commerce.
 - Making the gravity survey reduce variability will remove the tension with the Department of Commerce on NOAA's need for more budget by decreasing time.
- NOAA needs the physical gravity datum but the pilots and support crews have a limited amount of time that they can work.
 - NOAA needs to implement a more effective use of the pilot's hours to maximize time in the air for gravity surveys.
- NOAA tries to prioritize areas by scientific need and by surveying areas that promote their operation.
 - NOAA needs to increase residents' support to in turn gain more support from the Department of Commerce.

4.0 Design Alternatives

The focus of the project is to provide recommendations and design a planning support tool, which will assist in planning and executing gravitational surveys in order to cover all United States territories by year 2022. Due to limited budget and high variability in different aspects of the project, there has been excessive downtime in the past. After analyzing NOAA's historical data, each major process was fit to a distribution. The team has determined that the goal is to reduce uncertainty in controllable variables. There are couple alternatives that may improve the existing logistics process.

The first alternative is to focus on performance to improve the execution of gravitational surveys and reduce variance in several variables that cause extra delays and unnecessary downtime. Improving performance may significantly reduce the amount of delays in a survey. The key is to determine which of the factors has the biggest impact in reducing duration variability of a survey. One example is having more aircraft maintenance to reduce future breakdowns. Certain conditions cannot be controlled, such as downtime due to bad weather.

The second alternative is to acquire additional resources such as aircraft, equipment suites, or personnel. Currently, NOAA only operates with six aircraft, 4 teams, and two equipment packages (equipment packages include a gravimeter, IMU, and GPS base stations). By having only a few resources, NOAA is severely limited by the number of surveys they can complete during a fiscal year. Focusing on availability may provide the needed resources to meet the target goal of 8% annual coverage. Additional assets will cost more money, but will speed up the process by allowing multiple surveys to be done at the same time and may be more beneficial in the long run.

The third alternative is to use a combination of the first two alternatives if the budget allows. By improving the variables with the greatest impact on performance and increasing the availability of the most limiting resources, the gravity surveys may be completed in the fastest possible time. It would take a lot from the budget to implement this alternative and may not be feasible.

5.0 Method of Analysis

To build an effective model, the team must analyze how the gravity surveys are executed. Then create a simulation which will provide close estimates of the duration for an average survey. The black box model of the procedure is shown below.

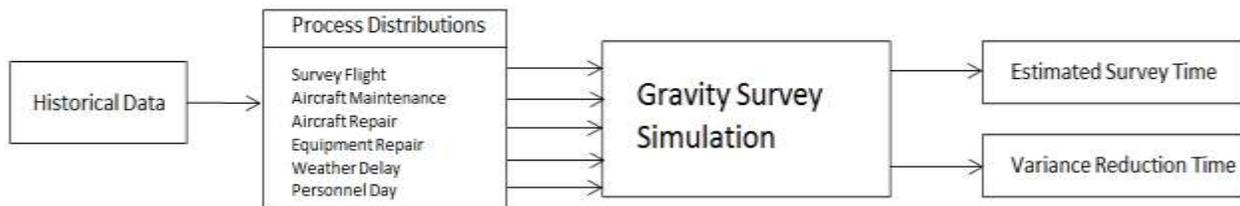


Figure 12 - Black Box Model

After performing analysis on the data of the previous surveys, the major processes were fit to distributions based on the amount of days that the process took. The Grav-D survey logistics process was modeled using the Monte Carlo method as shown below.

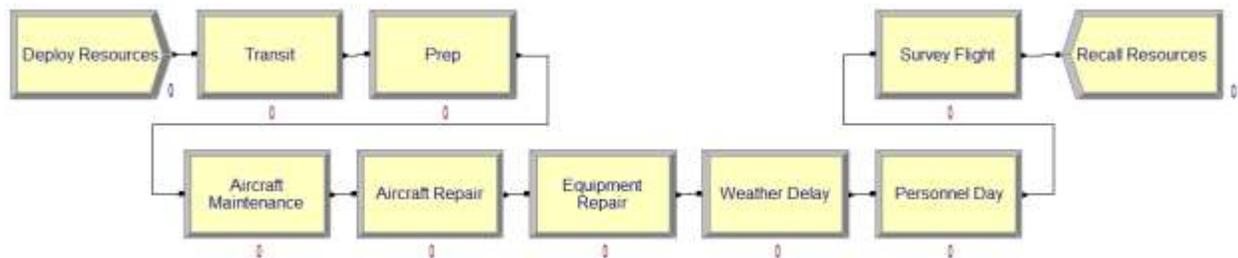


Figure 13 - Simulation (Arena)

There are 10 independent processes in series to reflect the logistics procedure. The simulation begins at the "Deploy Resources" block where an entity is generated. This is the entity that represents the necessary resources to complete a gravity survey. Each process block adds days based on the calculated distributions that the entity spends in the system. There are several decision blocks where the simulated survey may face delays. The output of the simulation is shown below.

Gravity Survey Project						
Replications: 10,000		Time Units: Days				
Entity						
Time						
VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Aircraft	44.0120	< 0.27	17.3427	110.45	17.3427	110.45
MVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Aircraft	0.00	< 0.00	0.00	0.00	0.00	0.00
Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Aircraft	0.00	< 0.00	0.00	0.00	0.00	0.00
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Aircraft	0.00	< 0.00	0.00	0.00	0.00	0.00
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Aircraft	0.00	< 0.00	0.00	0.00	0.00	0.00
Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Aircraft	44.0120	< 0.27	17.3427	110.45	17.3427	110.45

Figure 14 - Simulation Output

To verify that the model is correct, the simulation data was compared to the historical data. The average amount of days that a survey takes using this simulation is 44.01 days. This number is fairly close to the actual survey average calculated from the past data which is 41.63 days. The worst case scenario of the simulation was 110.45 days which is fairly reasonable. From historical data, the worst survey took 76 days and when taking the worst values from each process then it took 130 days. For further verification, the team analyzed the correlation between different processes further supports the model as shown below.

	Weather Delay	Aircraft Maintenance	Aircraft Repair	Equipment Repair	Personnel Day
Weather Delay	1	-0.21	-0.066	0.49	0.17
Aircraft Maintenance		1	-0.0055	-0.16	0.62
Aircraft Repair			1	-0.029	-0.24
Equipment Repair				1	0.33
Personnel Day					1

Figure 15 - Correlation Data

The relationship is symmetric so only half the table is shown. The value determines the magnitude of the correlation and the sign determines the relationship whether it's positive or

negative. There is little correlation between some of the comparable variables, like aircraft maintenance and aircraft repair. Some of the parameters are considered coincidental because they would not make sense in a real world application.

5.1 Design Of Experiment

A Monte Carlo simulation was performed with 10,000 replications per run, with each replication representing a single survey. The simulation provided the results after each variance reduction step. The given data included minimum, maximum, and mean values of days to complete a single survey. From this data the 10%, 50%, and 90% confidence intervals were calculated and recorded in a table. Each confidence interval represents the likelihood chance for the amount of time to complete a survey block.

5.2 Results

The 90% confidence interval showed the greatest change. The difference from the original data was calculated and graphed as shown below.

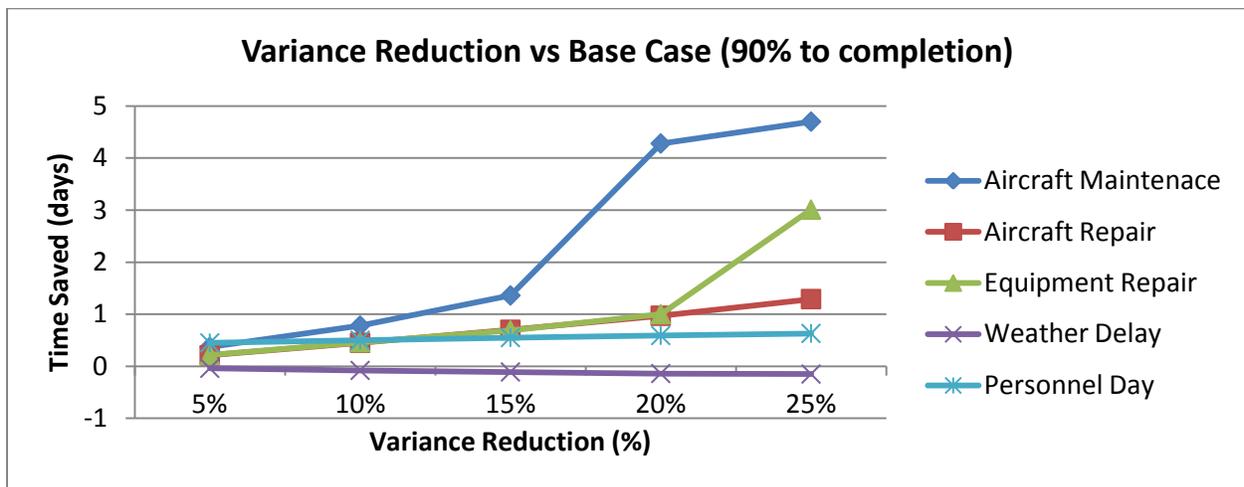


Figure 16 - 90% To Completion Variance Reduction Graph

Based on the results from this chart, the variables with the biggest impact on the length of the survey as well as their magnitude were identified. The rank of each process variability and the possible mitigation strategies are shown in below.

Factors	Rank in Variability	Max Delay Reduction (days)	Mitigation Strategies
Aircraft Maintenance	1	4.70	Additional maintenance personnel. Preventative maintenance.
Aircraft Repair	3	1.29	Improved maintenance. Available spare parts.
Equipment Repair	2	3.01	Back up equipment.
Weather Delay	5	-0.15	Weather analysis from regional historical data.
Personnel Day	4	0.63	Schedule days off around other delays.

Figure 17 - Variability Rank and Mitigation

It ranks each factor in terms of their variability and the order in which the survey planners should focus their energy and resources.

Aircraft Maintenance shows the greatest reduction in survey days among each factor (4.70 days). It is feasible to see this reduction through several different mitigation strategies. Additional onsite maintenance personnel can help minimize service downtime for the aircraft and preventative maintenance can help prevent future breakdowns. Weather Delays showed no reduction in survey days and instead showed an increase. This factor has lowest priority since weather is uncontrollable. However, survey planners can analyze historic weather patterns from potential survey regions to determine when to schedule surveys.

5.3 Value Hierarchy

Below is the value hierarchy created for this project. The team contacted NOAA to rank the parameters by order of importance. Then the SMARTER method was used to determine the weights and finally adjusted to represent the actual values.

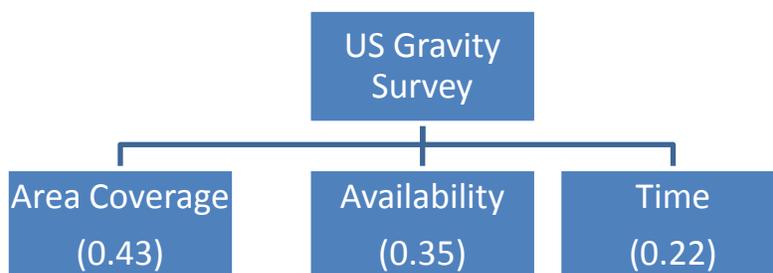


Figure 18 - Value Hierarchy

5.4 Utility vs Cost

Applying the value hierarchy to each alternative, it was possible to determine their individual utilities. Using the budget data provided by NOAA the cost of each alternative was estimated and plotted as shown below.

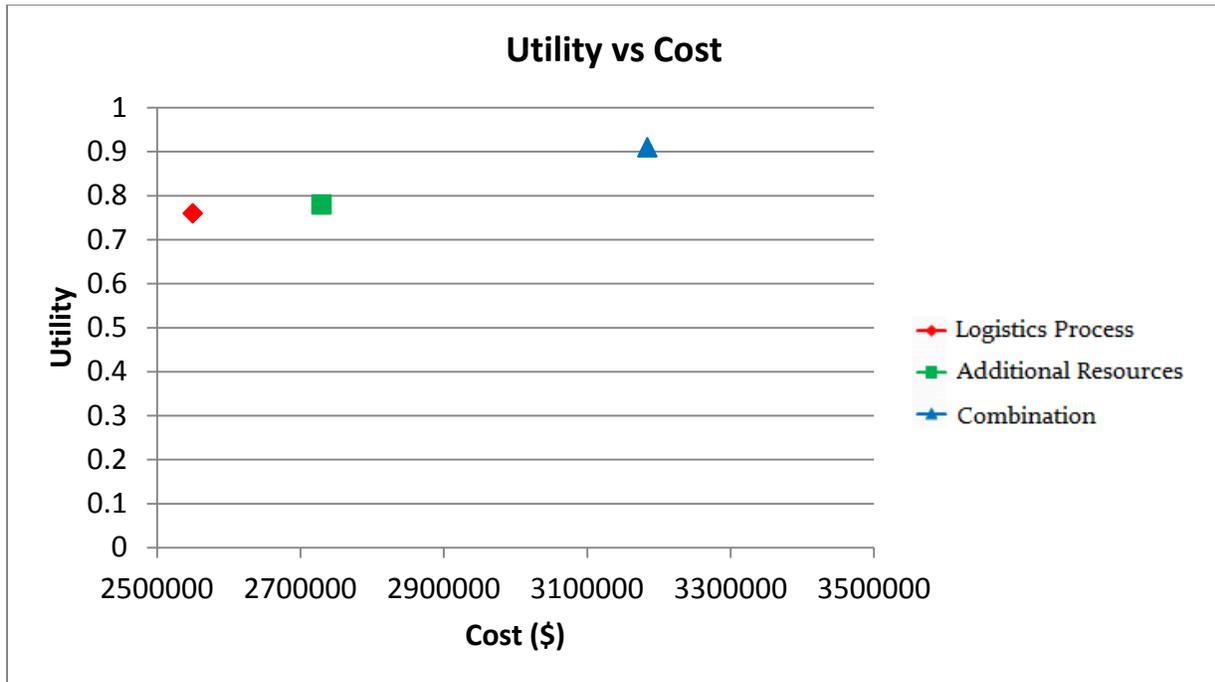


Figure 19 - Utility vs Cost Chart

The utility of logistics and resources alternatives are fairly close while the cost has a difference of a couple hundred thousand dollars. The combination of both the alternatives yields the best utility, but at a great cost.

6.0 Conclusion and Recommendation

6.1 Recommendation

The team recommends to focus on the logistics process of the surveys by allocating budget and resources towards improving parameters based on their rank in variability. This method has the least cost while still providing good way for survey execution based on the output value. Following delay mitigation strategies to maximize the performance and data gathering of the survey.

6.2 Conclusion

Variability reduction will reduce the time to conduct an average survey by 3 - 9 days based on 25% variability reduction. This will result in more surveys being completed in 44 days or less. As a result up to 47.4 days of survey time will be saved annually thus leaving enough time to conduct another survey or result in less spending to stay within budget constraint.

7.0 Project Plan

7.1 Work Breakdown Structure

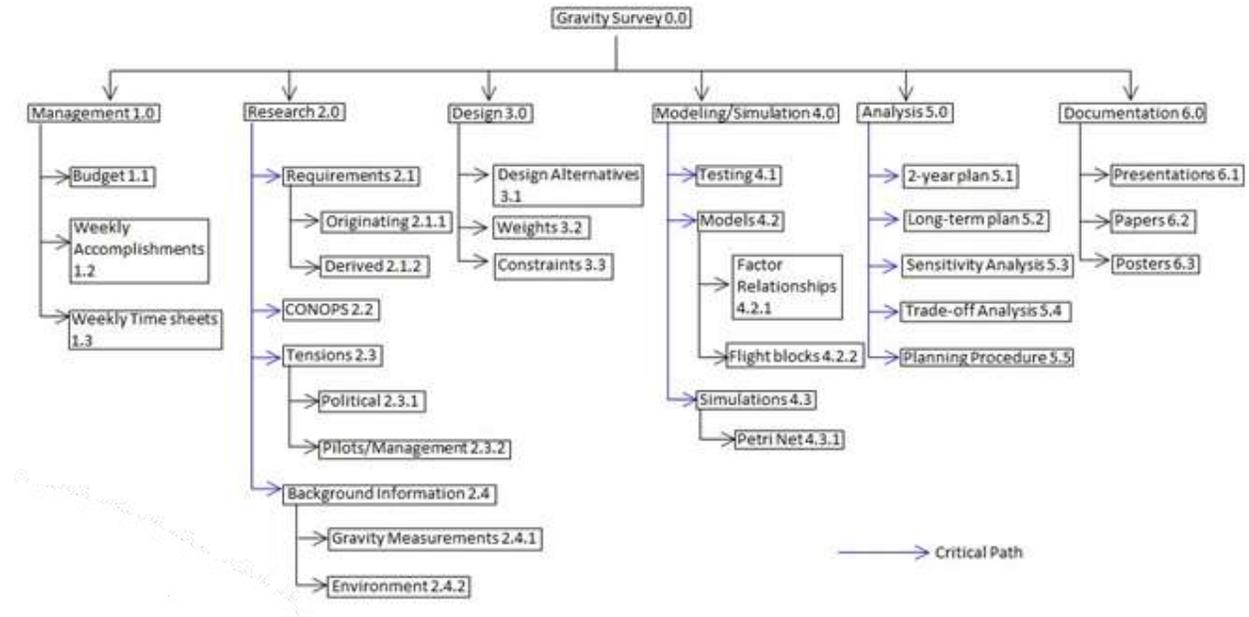


Figure 2011 - Work Breakdown Structure

The Work Breakdown Structure of the gravity survey is divided into six main topics, management, research, design, modeling/simulation, analysis, and documentation. Management is broken down into the weekly accomplishments, weekly timesheets, and budget. Research is broken down into requirements, concept of operations, tensions, and background information. Requirements are further broken down into originating requirements and derived requirements. Tensions are then divided into political tensions and pilots/management tensions. Background information is split up into gravity measurements and environment. The main topic of design is divided into three components, design alternatives, weights, and constraints. The main topic of modeling is broken down into testing, models, and simulation. Models are then divided into factor relationships and flight paths. The main topic of analysis is broken down into the 2-year plan, the long-term plan, sensitivity analysis, trade-off analysis, and planning procedure. The last main topic, documentation, is divided into presentations, papers, and posters.

The critical path of the work that needs to be completed is research, modeling/simulation, and analysis, in that order. Without these steps completed other parts of the project will be put on hold and the total time of the project will be extended. These three steps are the most important and are the core topics that need to be addressed to complete the project on time.

7.2 Project Schedule

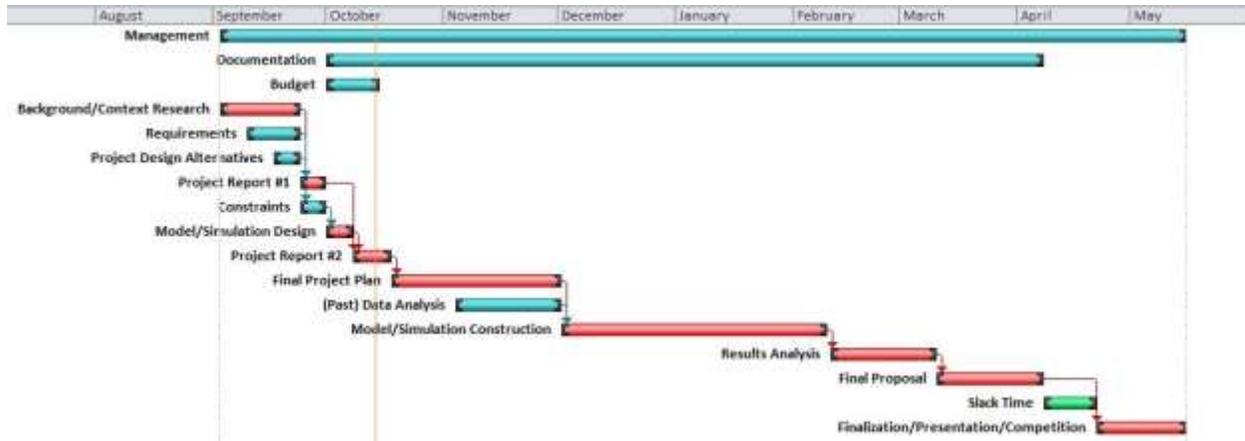


Figure 21 - Project Schedule (Microsoft Project)

Red - critical path

Green - slack time

7.2.1 Current Status

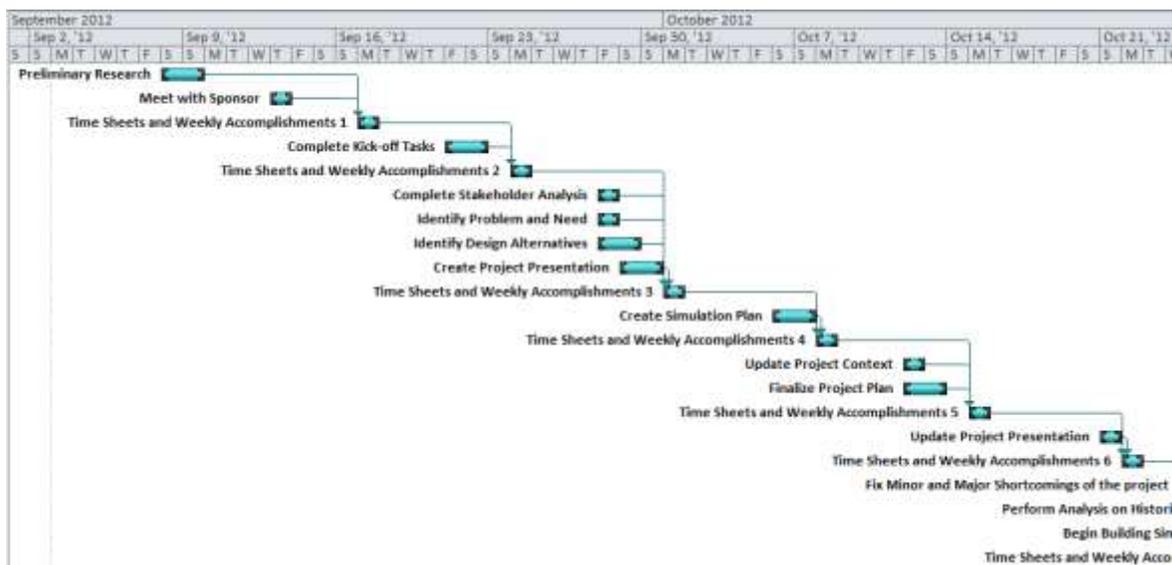


Figure 22 - Weekly Breakdown

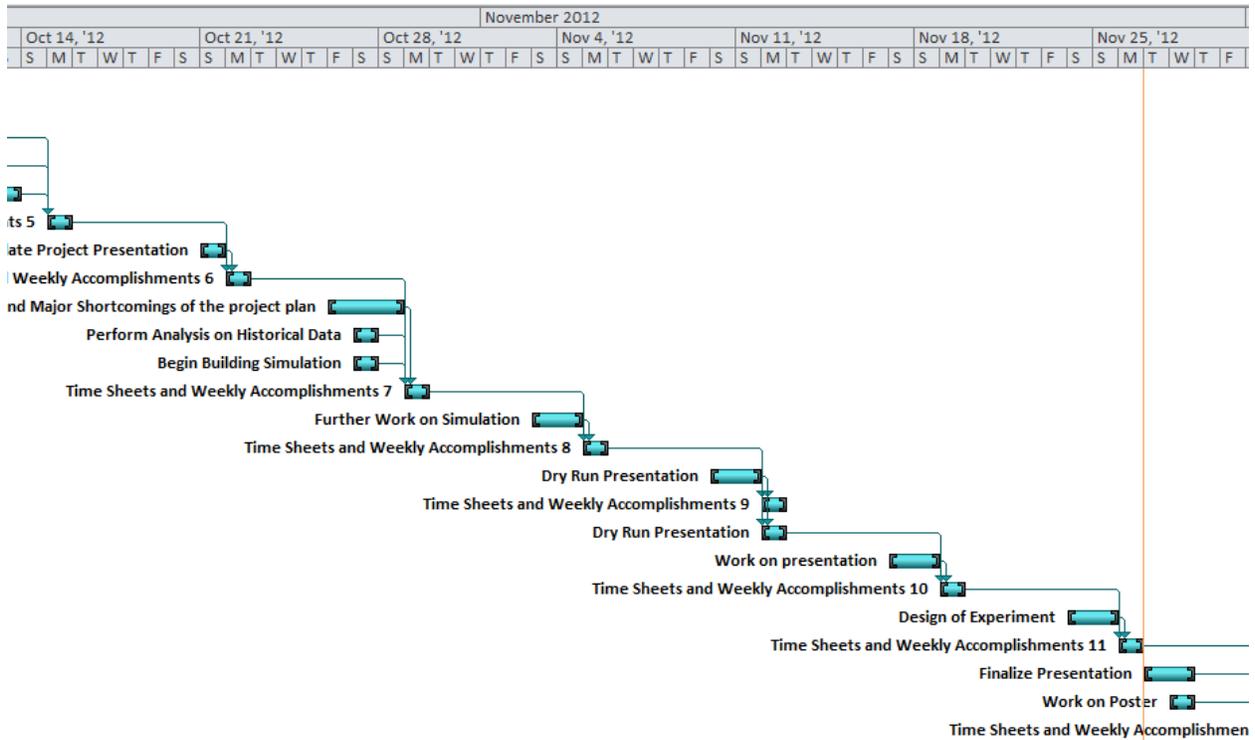


Figure 23 - Weekly Breakdown

7.3 Budget

November 2012																																									
Oct 14, '12	Oct 21, '12					Oct 28, '12					Nov 4, '12					Nov 11, '12					Nov 18, '12					Nov 25, '12															
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Hourly rate																																									
\$65*2.12766=	138.298																																								
Projected EV Hours																																									
Per Week Hour Total	37.5		37.5		37.5		37.5		37.5		37.5		37.5		37.5		37.5		37.5		37.5		37.5		20		10														
Weeks	27-Aug		3-Sep		10-Sep		17-Sep		24-Sep		1-Oct		8-Oct		15-Oct		22-Oct		29-Oct		5-Nov		12-Nov		19-Nov		26-Nov		3-Dec												
Semesters	Fall Semester																																								
Cumulative Total	37.5		75		112.5		150		187.5		225		262.5		300		337.5		375		412.5		450		487.5		507.5		517.5												
Projected Budget=PV																																									
Total Per Week	5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		5186.17		2765.96		1382.98														
Weeks	27-Aug		3-Sep		10-Sep		17-Sep		24-Sep		1-Oct		8-Oct		15-Oct		22-Oct		29-Oct		5-Nov		12-Nov		19-Nov		26-Nov		3-Dec												
Semesters	Fall Semester																																								
Cumulative at Each Week	5186.17		10372.3		15558.5		20744.7		25930.9		31117		36303.2		41489.4		46675.5		51861.7		57047.9		62234.1		67420.2		70186.2		71569.2												
Actual Hours																																									
Per week hour total	6		14		22		27		43		51		46		56		47		41		36		38		19																
Weeks	27-Aug		3-Sep		10-Sep		17-Sep		24-Sep		1-Oct		8-Oct		15-Oct		22-Oct		29-Oct		5-Nov		12-Nov		19-Nov		26-Nov		3-Dec												
Semesters	Fall Semester																																								
Cumulative Total	6		20		42		69		112		163		209		265		312		353		389		427		446																
Actual Budget=AC																																									
Total Per Week	829.787		1936.17		3042.55		3734.04		5946.81		7053.19		6361.7		7744.68		6500		5670.21		4978.72		5255.32		2627.66																
Weeks	27-Aug		3-Sep		10-Sep		17-Sep		24-Sep		1-Oct		8-Oct		15-Oct		22-Oct		29-Oct		5-Nov		12-Nov		19-Nov		26-Nov		3-Dec												
Semesters	Fall Semester																																								
Cumulative at Each Week	829.787		2765.96		5808.51		9542.56		15489.4		22542.6		28904.3		36648.9		43148.9		48819.2		53797.9		59053.2		61680.9																
Value of Work Accomplished=EV																																									
Weeks	27-Aug		3-Sep		10-Sep		17-Sep		24-Sep		1-Oct		8-Oct		15-Oct		22-Oct		29-Oct		5-Nov		12-Nov		19-Nov		26-Nov		3-Dec												
Semesters	Fall Semester																																								
Cumulative at Each Week	724.508		2634.57		5269.15		10538.3		18442		25028.5		34249.5		38201.3		46105.1		51374.2		55326.1		63229.8		69816.2																

Figure 24 - Project Budget

7.4 EV Projection

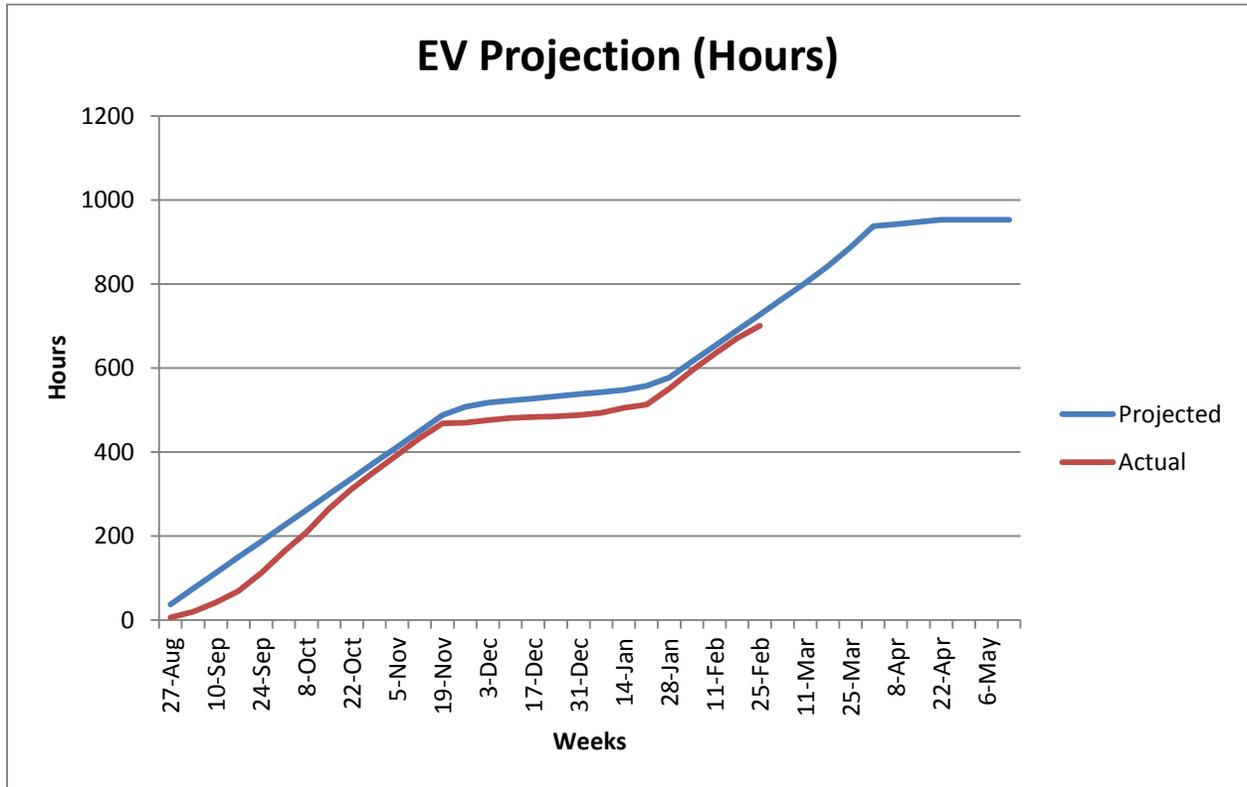


Figure 25 - Project Expected Value

7.5 CPI & SPI

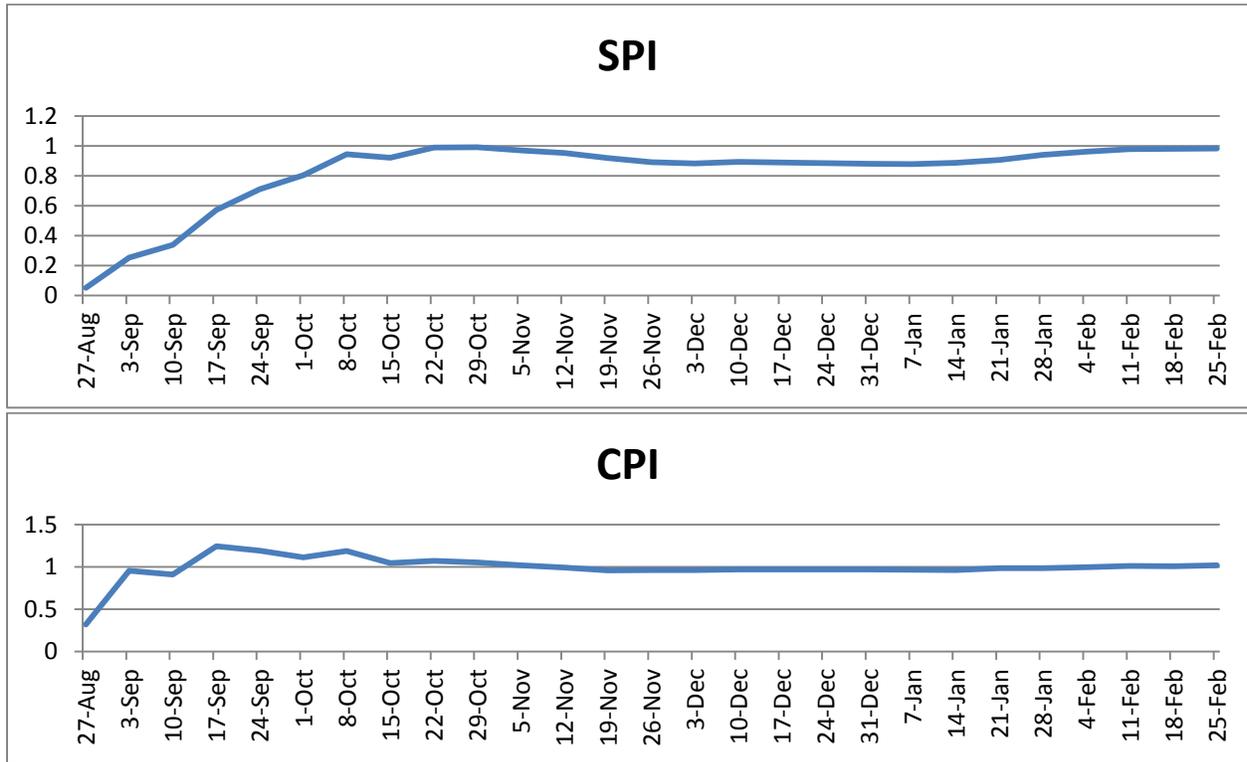


Figure 126 - Project CPI and SPI

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