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Dear member of the review board,

My name is Brooke Lamorueux, and I am writing to the review board to convey my research proposal on the use of gravity-type spatial interaction models for improved disaster management and response throughout Haiti. My research and plan shouldn't exceed a considerable and generous $100,000 and will decrease mortality rates along with increase the allocation of resources and money.

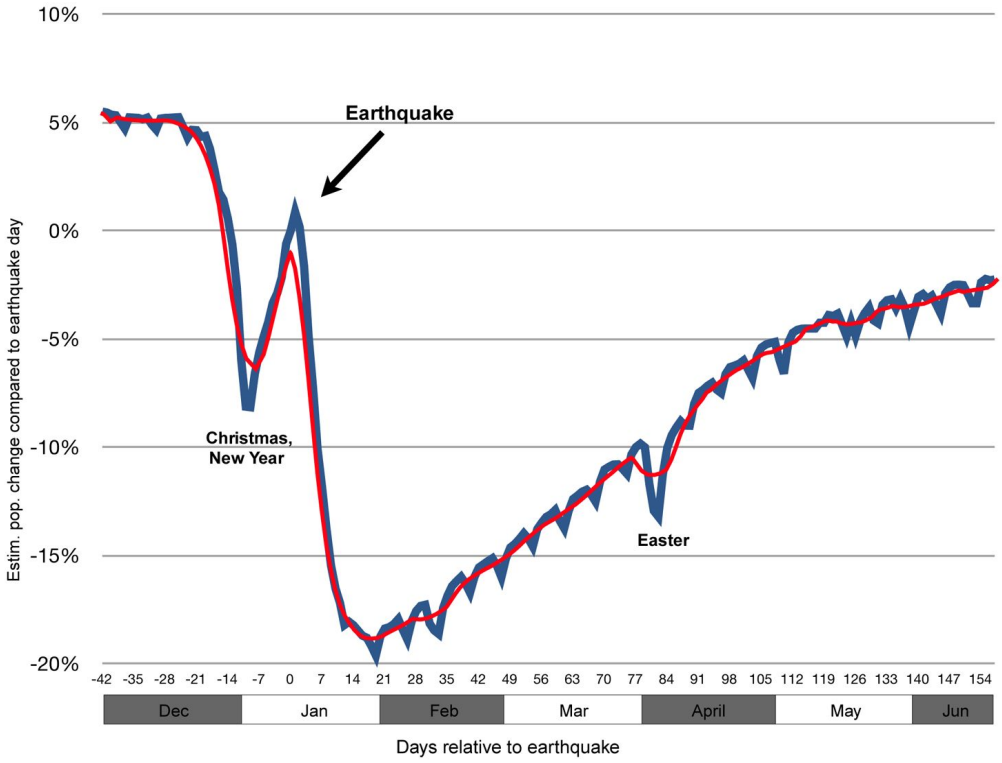
After the 2010, 7.0 magnitude earthquake that shook Haiti, especially it's capital Port-au-Prince, over 31,600 people lost their lives and many are still missing to this day. Especially in low-income countries it is critical to have in place machine learning mechanisms to have a better disaster management response. Data science methods I have evaluated and researched include, but are not limited to, the gravity-type spatial interaction model, and the remote sensing automatic object-oriented damage assessment method. Both techniques mentioned in my research plan work hand and hand to save the lives of Hatians and their freedoms if a disaster of this magnitude were to strike again.

With the help of you and the rest of the world, the constant fight to drag Haiti out of its economic rut and into the new decade starts with disaster control. Being that a natural disaster is unpredictable, there is no way to tell when one will come and devastate Haiti once more, but there is something we can do as a world to control and respond in a more efficient fashion. I look forward to your response and feedback towards my 1-year explanatory study. Thank you.

Sincerely,
Brooke Lamoureux

Problem Statement:

Haiti has suffered from many natural disasters in its history. From earthquakes to diseases and hurricanes, Haiti has been put through the wringer. Over 31,600 Haitians lost their lives or have yet to be found after the monstrous 2010 earthquake. Why is it that low-income countries such as Haiti feel the wrath of natural disasters so harshly? Researchers have reason to believe that calculating death tolls after a disaster has already happened can calculate the number of rescue supplies needed, but does nothing to prevent the amount of damage a natural disaster can do on a low-income country. Studies have found that there are new data science methods that could contribute greatly to the idea of prevention rather than forgiveness. Methods such as analyzing the movement of cell phone SIM cards, social media outlets such as Ushahidi, and remote sensing technology are all machine learning techniques that have proved to detect some sort of algorithm that can aid countries when responding, and trying to defend against natural disasters. While natural disasters are uncontrollable, research has proven that there are modern machine learning techniques that can be analyzed to decrease the death toll, and improve the safety of citizens living in low-income countries.



[Figure 1]

As seen in Figure 1 above, the estimated net changes in the population of PaP compared to the population of PaP on the earthquake day takes a very long period of time. The rebuilding of cities and reuniting families in the capital of Haiti, Port au Prince, took more than 5 months. This is just one problem we are looking to fix with modern research and data science techniques. “Since the turn of the century, earthquakes have directly or indirectly (including tsunami) claimed the lives of more than 640,000 people, four times more than in the preceding two decades, and proportionately more than the global increase in population would anticipate,” (Bilham, 2010). Earthquakes are just a few of the natural disasters that have impacted Haiti and it’s economy.

Along with the insane amount of migration and rebuilding problems, major injuries and mortality rates are to be considered when dealing with a natural disaster. “Regardless of the cause of these disasters, however, more often than not the resulting casualties affect large populations; and the majority of injuries are orthopedic. The earthquake that hit Haiti on January 12, 2010, caused between 217,000 and 300,000 deaths, nearly 300,000 injuries, and left about one million homeless—revealing just how unprepared some countries are to deal with mass casualties and disaster-related injuries. It also demonstrated the medical community’s inadequate disaster preparedness and a surprising lack of knowledge about some of the most common injuries and effective surgical procedures to deal with them, e.g. crush injuries and crush syndrome, field amputation, and the delayed presentation of closed and open fractures,” (Wolfson, 2012). Because Haiti is a low-income country and the doctors that are experienced, are slim to none, a natural disaster not handled properly and timely could be devastating to the population. Not to mention, these injuries could leave much of the population impaired and disabled.

“Beyond the screen of fantastic images, the reality is that Haiti remains infamous for being the poorest country in the Western Hemisphere and for its struggles toward democracy in the 21st century. While the accuracy of statistical measures maybe questioned, the following figures are generally accepted as valid. Life expectancy in Haiti is estimated at 50.36 years for men and 52.92 years for women (Central Intelligence Agency 2004). Six percent of the entire population of Haiti is considered to be HIV positive; however, the infection rate may be as high as 13 percent in the Northwest Department (Dubuche 2002), which has been plagued with drought, food shortages, and heavy damage in the aftermath of Hurricanes Georges and Mitch in the fall of 1998. The 2000 Human Development Report (United Nations Development Program 2000) affirms that 63 percent of the population lack access to safe water, 55

percent do not have access to health services, and 75 percent lack access to basic sanitation. Twenty-eight percent of children under age five are below normal weight. The infant mortality rate is 95 per 1,000 live births. Overall, at least 80 percent of the population lives in abject poverty (Central Intelligence Agency 2004). At the time of this writing, the unemployment rate is believed to be nearly 70 percent. In terms of its economy, Haiti ranks a low 170th out of 206 countries, with a GNP of only US$460 per year (World Bank 2001)," (James, *THE POLITICAL ECONOMY OF 'TRAUMA' IN HAITI IN THE DEMOCRATIC ERA OF INSECURITY,* pg 135) These are only a few of the problems Haiti has faced within the last few decades of its existence. Much of the reason I have chosen to focus my research and problem-solving in low-income countries such as Haiti. Haiti is in need of the world's help and for some reason keeps getting hit with every different natural disaster you can think of from earthquakes to hurricanes, even deadly diseases. It is our job to focus our attention and bring the world together on a common goal.

This brings me to my main research question being: How can geospatial data science methods be implemented to ensure faster disaster response times and lower mortality rates in low-income countries such as Haiti? Basically, how can the modern big data machine learning techniques be implemented and how effective are they at improving disaster management and response, especially in a low-income country.

Geoffrey West defines scale as "... how a system responds when its size changes. What happens to a city or a company if it's size it doubled? Or to a building, an airplane, an economy, or an animal if its size is halved? If the population of a city is doubled, does the resulting city have approximately twice as many roads, twice as much crime, and produce twice as many patents? Do the profits of a company double if its sales double, and does an animal require half as much food if its weight is halved?" (West, *Scale,* pg 15). One theory West follows is the idea that as a city grows or shrinks, it follows a linear path, meaning that of Haiti were to double in size, the economy might get twice as bad. Being that this idea could be true, how can we fix it in terms of disaster relief and management? West refers to networking as a possible answer to our prayers. Networking. "... the great commonality is the universality of social network structures across the globe," (West, *Scale,* pg 281). The more networking a country can do the better off it will be and the more manageable a disaster could be if it strikes. Mentioned later in my literature review is a method known as a gravity-type spatial interaction model. This model provides data that once imputed, can connect people around the globe to how many supplies are needed and where to get them to. This means that low-income

countries such as Haiti can get the assistance they need to respond much more efficiently and save the lives of many after a disaster.

In conclusion, the research I am about to present deals with and tries to solve problems that are common in low-income countries such as poor economy, limited amount of medical and humanitarian supplies, and the rebuilding of buildings- all issues associated with post-natural disaster situations. To restate, the goal of this research is to evaluate geospatial data science methods, and how they can be implemented to ensure faster disaster response times and lower mortality rates in low-income countries such as Haiti. There is an endless list of problems surrounding low-income countries but one shouldn't be the unpreparedness of natural disaster response tools. With the use of different geospatial data science techniques, the people of Haiti and any other poor country for that matter should feel some sort of relief that if a natural disaster happens, because at some point they are bound to, there are methods in place to keep them safe. Throughout this research process, I have learned many things and have a good idea about what Haiti, among many other low-income countries that should follow suit, should do if they want to improve their quality of life and defense against natural disasters. I have read and analyzed many areas that need to be improved upon including but not limited to infrastructure buildings and traditional post-disaster survey methods. I have also analyzed various methods that can be put in place to improve some of these shortfalls for future disaster management including cell phone SIM card movements, social media 3-T frameworks, and automatic object-oriented techniques, just to name a few. Natural disasters such as earthquakes cannot be controlled, but the steps taken after them can be, and it is the world's job to aid and assist low-income countries such as Haiti when figuring the right methods to put in place for future disasters.

Literature Review:

The purpose of this research is to advance the use of different post-disaster management techniques in low-income countries such as Haiti. By estimating, specifying, and analyzing cell phone SIM card movements, and remote sensing technology, researchers and rescuers alike will be able to decrease the mortality rate of Haitians following natural disasters. Though traditional methods worked well for a long period of time, they lacked the ability to prioritize data that flowed in from outside sources, which is crucial being that Haiti is the least developed country in the Western Hemisphere. I will achieve the goals of increasing response time post-disaster and

becoming more prepared pre-disaster using methods such as the use of automatic mapping to measure infrastructure damage to provide rapid assessments of building damage, estimate the magnitude of population movements after the Haiti 2010 earthquake, and connect responders on the ground to all information available around the world so they can respond accordingly to how, when, and where supply resources need to be distributed.

This work will build on previous traditional methods of response that were time and labor-intensive and only circulated information among a small number of researchers. This method has proved to be effective for a number of years but as the risk of more dangerous natural disasters continues to grow, building upon these techniques with the use of methods mentioned previously will save more lives in low-income countries such as Haiti.

Haiti has suffered from many natural disasters in its history. From earthquakes to diseases and hurricanes, Haiti has been put through the wringer. Over 31,600 Haitians lost their lives or have yet to be found after the monstrous 2010 earthquake. Why is it that low-income countries such as Haiti feel the wrath of natural disasters so harshly? Researchers have reason to believe that calculating death tolls after a disaster has already happened can calculate the number of rescue supplies needed, but does nothing to prevent the amount of damage a natural disaster can do on a low-income country. Studies have found that there are new data science methods that could contribute greatly to the idea of prevention rather than forgiveness. Methods such as analyzing the movement of cell phone SIM cards, social media outlets such as Ushahidi, and remote sensing technology are all machine learning techniques that have proved to detect some sort of algorithm that can aid countries when responding, and trying to defend against natural disasters. While natural disasters are uncontrollable, research has proven that there are modern machine learning techniques that can be analyzed to decrease the death toll, and improve the safety of citizens living in low-income countries.

Being a low-income country has many different meanings and levels. “Wealth is a relative term, however, and the Haitian peasant is so poor that by contrast a few hundred dollars’ incomes a year will seem like riches” (Lundahl, 2011, pg. 108). Haiti is very poor. They have very little money circulating through their economic system which means they need help from the rest of the world when it comes to disaster management and relief. When disaster strikes, Haiti needs help from around the world as fast as possible. One method used by volunteers around the world is the social media outlet known as Ushahidi. Ushahidi can provide reports of trapped people, medical emergencies, and specific needs such as food, water, and shelter. The information

gathered is combined with geographic information and is available to anyone with an internet connection. Responders on the ground can now be connected to all information available and respond accordingly to how, when, and where supply resources need to be distributed.

This research is purely evaluative. It is evaluative because it is seeking to judge the effectiveness of gravity-type spacial interactive models when dealing with disaster relief in Haiti. Variables being evaluated include response time post-earthquake, mortality rates, amount of SIM card data retained, building damage, and the movement of individuals pre- and post-earthquake.

One geospatial data science method that was used after the 2010, 7.0 magnitude earthquake in Haiti was the use of cell phone SIM cards to track the movement of populations after the devastation, also known as a gravity-type spatial interaction model. "We followed daily positions of SIM cards 42 days before the earthquake and 158 days after … We used this ratio to extrapolate from the number of moving SIM cards to the number of moving persons" (Bengtsson, 2011) There are push-pull factors to keep in mind. "This leads to a push-pull hypothesis for human migration: some areas attract or pull migrants in where benefits are perceived to exceed costs, while other areas propel or push migrants out where costs are perceived to exceed benefits. This attractiveness or propulsiveness of a location is a combination of various characteristics as well as the spatial arrangement of locations," (Gordon and Vickerman 1982). In this research, the push factor, being the earthquake, and the pull factor, being the promise of unharmed locations are being considered. The data from the SIM cards are taken and plugged into a modern gravity-type algorithm represented by the flux migration of MIGij, and can be shown in figure 1 below. Where pi and pj refer to the population size at an origin i and a destination j, while dij is the distance between origin i and destination j. Also, the exponents α, β, and γ are unknown and estimated from the data.

$$MIGij = \frac{p_i^{\alpha} p_j^{\beta}}{d_{ij}^{\gamma}}$$

"Population movements following disasters can cause important increases in morbidity and mortality. Without knowledge of the locations of affected people, relief assistance is compromised. No rapid and accurate method exists to track population movements after disasters. We used position data of subscriber identity module (SIM) cards from the largest mobile phone company in Haiti (Digicel) to estimate the magnitude and trends of population movements following the Haiti 2010 earthquake," (Begtsson, 2011). Results from SIM card tracking were compared to results gained from the Haitian National Civil Protection Agency and their post-earthquake survey. The HNCPA survey included 2,500

households averaging 4.9 persons. The survey asked questions such as “Did you leave the metropolitan area after January 12 (earthquake day) even if it was for a short time?” and “to what department (province) did you go to?” This survey conducted by the HNCPA is subject to individual interpretation. For comparison, the SIM card tracking method was much more effective and efficient. It produced results within a day. By tracking the movement of people from their original location to their location after the earthquake, rescuers were able to pinpoint exactly where to get supplies, making disaster management and response much faster. The previous use of survey data proved to be less effective than the modern approach of SIM card tracking.

Thi-Thanh-Hiên Pham and colleagues bring to light the use of optical images (15cm of spatial resolution) combined with height data (LiDAR, 1m of spatial resolution) to measure building damage throughout the capital, Port-au-Prince, after the earthquake. “Satellite and airborne images are increasingly used at different stages of disaster management, especially in the detection of infrastructure damage. Although semi- or full automatic techniques to detect damage have been proposed, they have not been used in emergency situations. Damage maps produced by international organizations are still based on visual interpretation of images, which is time- and labor-consuming,” (Pham, 2014). The data was organized into three categories of destruction: intact buildings, collapsed buildings, and debris. Through the use of this automatic object-oriented technique, the amount of damage done to each building is measured immediately and proved to be very reliable. The accuracy of classification varied from 70- 79 percent. There were various reasons for error including limited spectral information of the optical images, resolution difference between the two data, high density of buildings but most importantly, certain types of building collapses could not be detected by vertically taken images. The automatic damage mapping strategy discussed in this article could absolutely be used in emergency situations. The entire process took approximately 15 hours, which is much faster than any semi- or fully automatic technique that has been proposed in the past. Semi-automatic techniques are based on visual interpretations of images and are very time and labor-intensive. Automatic damage mapping could be combined with manual visual interpretation to increase and accelerate response times of humanitarian rescues and resources.

In the fight to improve response times and reduce mortality rates, there are some gaps still needing to be addressed, especially when considering the use of the automatic remote sensing building assessment technique. Errors/ Gaps include: limited spectral information of the optical images, resolution difference between the two data, high density of buildings, but most importantly certain types of building collapses could not be

detected by vertically taken images. While the automatic remote sensing building assessment technique is much more helpful and 70-79% more accurate than previous methods, more research will need to be done to improve the quality of images vertically taken and bridge this literature gap.

Research Plan:

Being that natural disasters are unpredictable, it's impossible to prevent them. With that being said, coming up with a plan that controls, manages, and allocates already scarce resources is the exact method needed to gain a faster responder response time and decrease the mortality rate. The first few steps that must be put into effect are the first few steps of the gravity-type spatial interaction model and the automatic object-oriented remote sensing model. First, start the tracking of everyone's cell phone SIM cards. This will provide us with the proper information that would be compared with later information post-disaster. The same preparation must be done to examine building damage post-earthquake. This also must be done prior to a natural disaster. Using the remote-sensing automatic object-oriented technique, a remote sensing satellite takes vertical images in order to gather intact building damage information.
Using both methods I went into further detail previously, we are able to gather the correct information we need to compare it with post-disaster information to get the most valuable information possible.

After the initial parts of each method are put into effect, and a natural disaster decides to strike, the next step would be to track exactly where people have migrated to using the gravity-type spatial interaction model. Using the next step of this technique, we will be able to track exactly where people have migrated to. For example, SIM card information from 42 days before the earthquake and 158 days after, can help rescuers allocate where to get resources and where safe havens are. This is a very crucial part of the plan because locating where each individual person is can save more lives than previous methods once used, they can also get materials to them much faster. Once the information has been gathered from SIM cards, the information is imputed into the gravity model and is easily assessable to on a database for the rest of the world to lend a helping hand. When the data is imputed, people with special access around the world can log in and look at the information. Now that this information is accessible, rescuers and researchers alike can help a nation like Haiti, who doesn't have a large abundance of rescue supplies and help. "The government of Haiti is known for corruption. It also

appears that an earthquake the magnitude of 7.0 would not have easily destroyed so many of its infrastructure and people, if, in the past, the surrounding countries, including the United States, would have assisted in providing this country with safer and stronger foundations for buildings and especially shelter for the residents and the many visitors who were the true victims," (Brown, 2010). This adds to the number of supplies a country will receive and the number of people wanting to help and donate.

In regards to the building of cities and buildings, the remote sensing images brought to us via the automatic object-oriented technique can now be evaluated using the pre- and post- earthquake picture information. These pictures could now be used to analyze which areas were hit worse by comparing images taken before and after the earthquake. The information is taken and plugged into an algorithm. This algorithm then figures out quite how hard each building has been hit and classifies each building into three different categories: intact, collapsed, and debris. With this new level of classification, it is now much easier to locate which buildings are worth saving and putting money towards versus which buildings are too badly damaged to put time, money, and effort towards. The final step, which is very optional, would be to apply methods previously used to accentuate the remote sensing technique. Automatic damage mapping can be combined with manual visual interpretation to increase and accelerate response times of humanitarian rescues and resources.

As a foundation looking to better the lives of people living in low-income countries such as Haiti, you should want to support this plan, as it solves many problems associated with natural disaster management especially in low-income countries. Problems such as high mortality rates, slow response times, and limited resources can not possibly be solved completely but with my plan put into effect, people won't have to live knowing that an unprecedented disaster could cost them the rest of their lives. Every human deserves to be as best protected as they can from nature. Amartya Sen defines human development as "The enhancement of freedoms that allow people to lead lives that they have reason to value" (Sen, 1999). The reason for this research is not to simply decrease the number of deaths in Haiti after a natural disaster, it is to consider every single number as human life, and every single life is a life worth living. Sen argues that there is too much emphasis on GDP as a measure of development. In this research, GDP can be compared to the mortality rate post-disaster. While this number is important for analysis, what's more, important is the idea that everyone's lives have meaning and no one deserves to go through life without some kind of security that they will not survive a natural disaster. This research again describes how some modern technologies have

proven to increase human development and quality of life through disaster management and response.

My research plan is partly focused on how to allocate and manage costs after a natural disaster as well as save money. As you may know, one of the most costly things a country could go through would be a natural disaster. The 7.0 magnitude earthquake that struck Haiti in 2010 cost the government millions of dollars. "... almost $2.5 billion of financial aid had been pledged to Haiti to assist its earthquake recovery efforts. Even if half of this aid goes into the reconstruction of the estimated 250,000 damaged dwellings and thousands of commercial and civic structures, the sum will amount to less than $5,000 per structure..." (Bilham, 2010). Using my plan, the information gathered will use the money donated and put it towards the right reasons. In the past, money has gone towards buildings and areas that don't need it as badly as others need it, or resources have been too scarce in areas that need more. With my plan, the money spent will be put to good use and allocated the right way, in turn, saving money and putting that money to the right places. Especially when looking at building reconstruction. With the different categories: intact, collapsed, and debris, no money will be put to rebuild the debris and waste time and money. Instead, we will only focus on the collapsed thanks to the automatic remote sensing technology technique. When dealing with where to allocate scarcely, and donated humanity resources, we will turn to the gravity model algorithm to get the word out and look for areas with the most amount of people and the exact number of people and where they are. In doing this we will save time and reunite families.

Over the course of my plan being implemented for a year, the course of the SIM card tracking, and the remote sensing technology being implemented would be under 100,000. Being that natural disasters are unpredictable, it may seem silly to implement and spend the money on something that hasn't even occurred. However, if my plan is implemented and put into effect, and a natural disaster does strick, less money will be needed after a disaster which proves to be very costly and devastating. Also being that we are dealing with such unpredictable phenomena, it's hard to get a gauge for what exactly how much a one-year exploratory phase might cost, but the rewards and money saved in the long run after a disaster hits will make the entire process worth it. "Because construction projects are likely to offer employment opportunities for many Haitians in the coming decades, earthquake engineers have already articulated the importance of training contractors and laborers in sound construction methods," (Bilham, 2010). In addition, more jobs will be available for Haitians giving the economy a major boost.

What will Hatitas take away from this plan? A better life, and a better outlook on life if devastation were to happen again. "The gravity model as applied to migration uses

population sizes at each location and the distance between them as the push-pull factors. The model can be expanded by adding the previously identified socioeconomic, demographic, and environmental characteristics of the locations that are related to migration, resulting in a series of gravity-type spatial interaction models (GTSIM). These GTSIMs can contribute to understanding migration by providing quantitative estimates of the absolute and relative importance of the location characteristics as opposed to just using population as a crude measure of attractiveness or propulsiveness," (Garcia, 2014). Combined with the remote sensing technique is the future of faster responder times and lower mortality rates following a natural disaster. Thank you for your time put fourth reading my plan and contact me with any questions you might have. Thank you again.

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