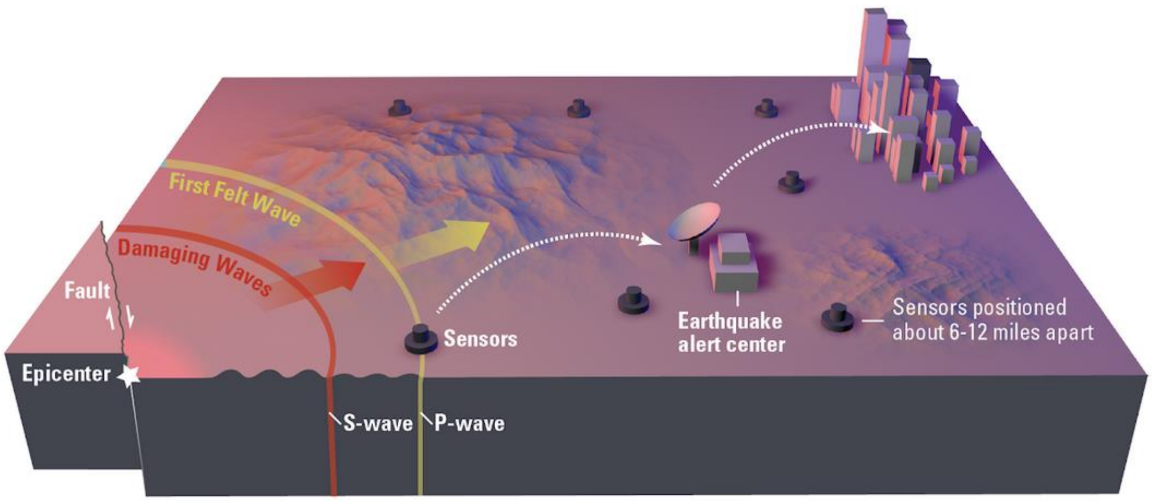

Seismic Prediction System

SYSTEM PROPOSAL AND DESIGN

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1. Executive Summary

Throughout the 2019 fall semester, our team worked to develop a system designed to detect earthquakes early on so timely safety and precautionary measures could be taken. The following content illustrates the design process our team followed, outlining the system presented. Our vision is to develop an all-encompassing seismic prediction system to make the most use out of current available technologies.

Customer's statement of need:

> *There is a need to be able to predict a damaging future earthquake occurring in areas of dense populations. The ability to predict damaging seismic activity can allow for preventive actions to be taken by emergency personal, minimizing the likelihood of an adverse event taking place because of an earthquake. It is possible to measure shifts between the Earth's tectonic plates and the subsequent seismic activity that is resulted from it, and use this data to develop a prediction of a likely location of an future earthquake. In 2016, the reported costs of natural disasters related to seismic activity in the Americas exceeded $50 billion dollars US.The system is expected to be used by government organizations as an effort to improve public safety in areas with large amounts of seismic activity, with the ultimate goal of protecting highly valuable assets and preserving human lives.*

Design Summary

The Earthquake Prediction and Notification System (EPNS) is a centralized hub to be used by geologists, seismologists, and government officials in order to detect and measure seismic activity. This data will be used to predict future earthquakes within a large enough time frame to notify affected populations, such that proactive measures can be taken.

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Abbreviation	Definition
SD	Seismic Detection
GPS	Global Positioning System
KPP	Key Performance Parameter
MTBF	Mean-Time Between Failure
CDC	Central Data Center
EPCE	Earthquake Prediction Computation Engine
CAD	Computer Aided Design
NS	Notification System

Table 1 - Nomenclature

2. Project Schedule

Phase	Start Date	Estimated Duration (Days)	Actual Duration (Days)
Conceptual Design	8/22/2019	60	28
Preliminary Design	9/19/2019	60	47
Detail Design	11/5/2019	90	42
Production	12/17/2019	360	720
Deployment	12/17/2020	60	45
Maintenance	12/17/2020	720	1080

Figure 1 - Project Phases

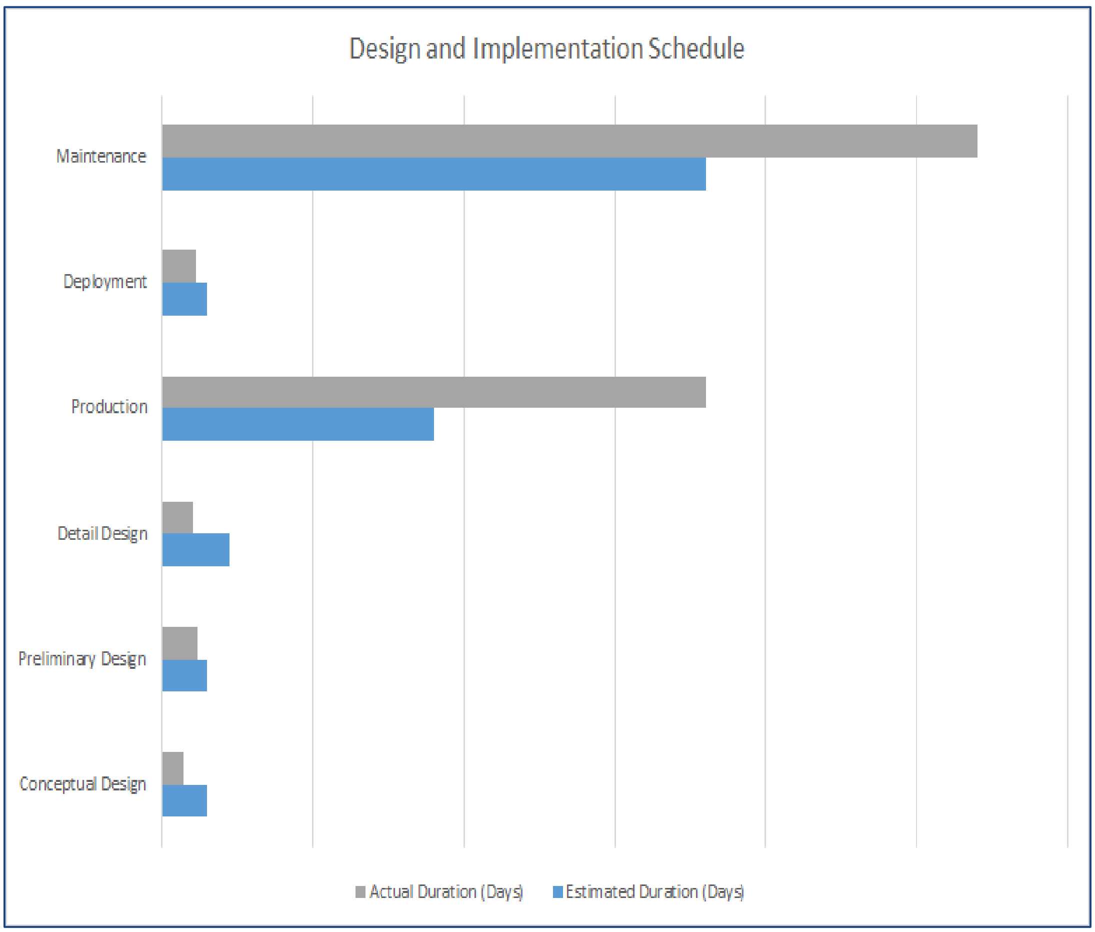


Figure 2 – General Timeline in Days

Feasibility Schedule

a. 6 months for research/design/development
    i. Trade Studies
    ii. Key Performance Parameter (KPP) Comparisons
    iii. Work Breakdown Structure
    iv. Mission Concept of Operations
b. 2 months for prototype
    i. Computer-aided Design
    ii. Engineering Drawings
    iii. System Schematics
    iv. Integration Plan
c. 4 months for production
    i. Order Parts
    ii. Manufacturing
    iii. Assembly
    iv. Integration Troubleshooting
    v. Software Development
d. 4 months for test
    i. Test Readiness Review
    ii. Test Suitability Requests
    iii. System-Test Assurance
    iv. Test Validation
    v. Test Verification
e. 3 months for deployment
    i. Environmental Conditions Assessment
    ii. Troubleshooting
    iii. Gather Real-Time Data
f. We predict a useful system lifecycle of 5 years
    i. Assumes multiple refinement periods
    ii. Accounts for unscheduled hardware and software maintenance periods
    iii. Improved credibility from realized earthquakes while deployed

Description

With the Conceptual, Preliminary, and Detail Designs now complete, the proposed seismic prediction system has a clear foundation to move towards further development and deployment. Immediate tasks preceding Production but within its scope include Computer Aided Design (CAD) rendering, producing engineering drawings from the CAD, CAD analysis, additional feasibility and trades research, prototyping, and design revisioning from the prototype. Considering the resources needed for Production, an aggressive one year scheduling plan was put into place to coordinate its relevant activities.

Assuming minor to no delays with steps already listed, part c. in the Feasibility Schedule defines a high-paced development for Production. With proper planning beforehand, 4 months is enough time to realize a functional working model of the system. Within those 4 months, small delays are to be expected for parts ordering and shipment but the commonality of any parts needed for the hardware eases the delay windows. The most tightly constrained timeline in the 4 month Production window is the software development. Producing a working model would not be an issue but to have all the bugs and data feeds incorporate would most likely drive Production towards outsourcing chunks of code.

The four month window for testing, seen in part d. of the Feasibility Schedule, has some flexibility. Some of the testing depends on the earthquakes during the time period the system is ready for testing. By utilizing laboratory acoustic vibrational testing we could artificially determine the system’s readiness but naturally occurring seismic predictions would contribute much more towards validating the system.

After deploying the system, the main factor would be analyzing how the sources of data feed into the system, the lag time between the predictions and the data input, and the big dates whenever a notification would theoretically be sent.

A useful system lifecycle of 5 years was determined. The software will continue to be refined throughout its maintenance lifecycle allowing for a potentially longer system lifecycle. The limiting factors on the system’s life would be the eventually outdated hardware that could be counteracted by periodic downtimes when relevant.

The fast-paced schedule’s goal is to get the system up and running as quick as possible to beat the competition in an already extremely competitive field. Then, modifications and additions can be made to enhance its capability along the way.

3. Conceptual/Preliminary Design Review

3.1 Conceptual Visual

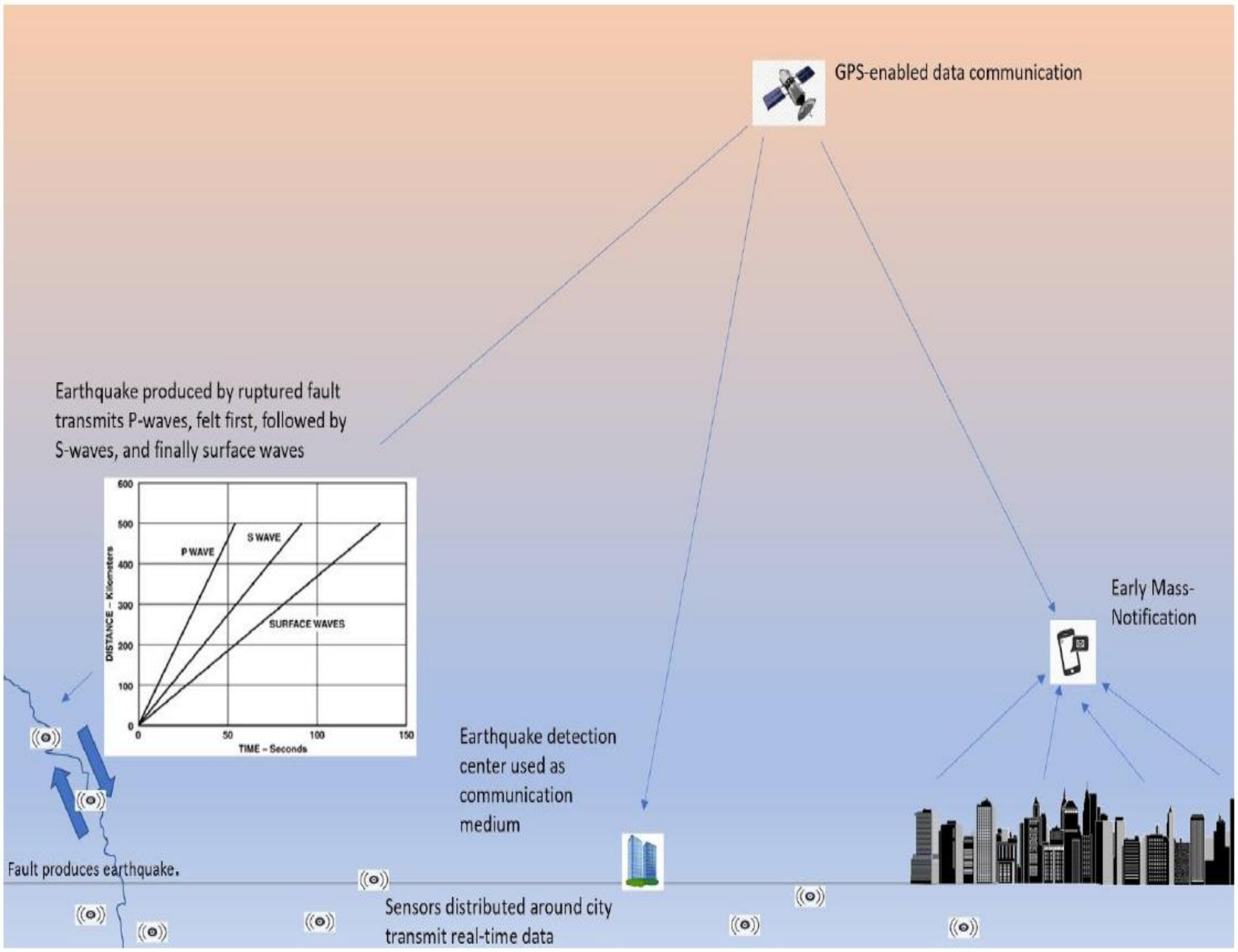


Figure 3 – Operational Overview of System

Description

The Operational Overview of the System shown above in Figure 3, highlights all key advantages our system encompasses. By utilizing seismometers, Global Positioning System (GPS) technology, and accelerometers to feed into a central data center, the system aims to provide a much needed service: a well-rounded machine learning prediction algorithm taking advantage of cutting edge technologies covering different refined aspects in the field of earthquake predictions. From the jumpstart of initial P-wave and S-wave detections to early mass notifications to the affected area, our system strives to provide as many channels as reasonably possible for early analysis and detection. The mass notifications involve the most effective ways of reaching audiences fastest, by phone alerts and text messages.

3.2 Stakeholder Requirements

Index	Requirement	Allocation
0F0001	The system shall provide accurate information	Top-level
0F0002	The system shall handle requests by large populations of people	Top-level
0F0003	The system shall utilize data provided by inputs for analysis and prediction.	Top-level
0F0004	The system shall maintain a price point for affordable to private or public organizations.	Top-level
0F0005	The system shall operate for extended periods of time without requiring maintenance.	Top-level

Table 2 – Stakeholder Requirements

Description

The above-listed Stakeholder Requirements from Table 3 dictate the high-level, driving requirements our system was designed around. Each of the five requirements from the table was considered at every design phase because they are the highest priority requirements of the system. The requirements derived in Table 4 all fit within the framework established by the Stakeholder Requirements.

3.3 System Functions

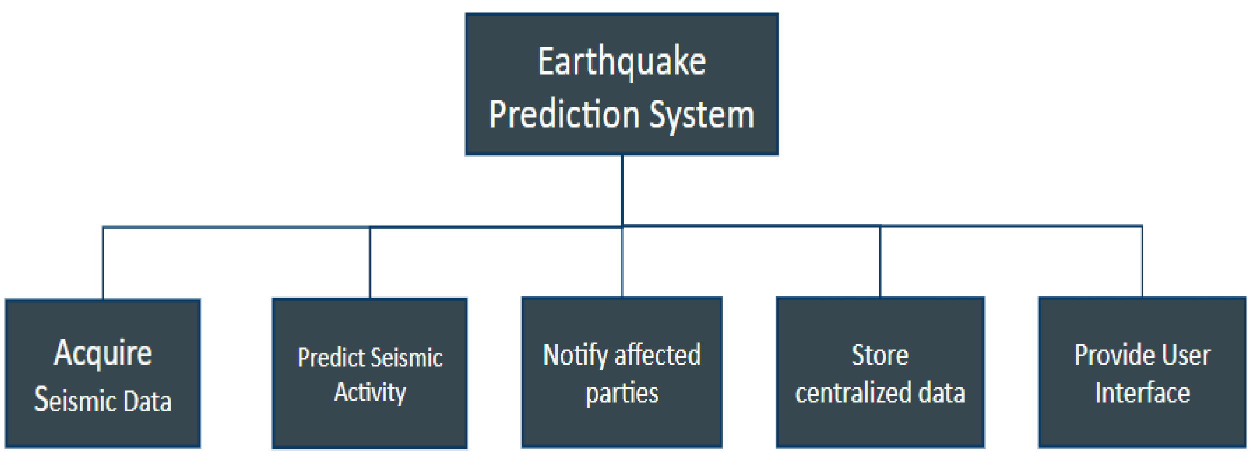


Figure 4 – System Functions to Requirements

Description

Mapping System Functions to the Requirements provides a function-operand relationship for a holistic approach in generating a working architecture for the system. The five requirements seen in Figure 4 translate a conceptual requirement into a working framework more malleable to system application. Acquiring seismic data doesn't specify the types of data to be collected but establishes a necessary starting point for predicting earthquakes. Predicting seismic activity is the main function of the system and obviously needs to be included as a high-profile function generated from the requirements. Notifying affected parties evolves from the need to predict earthquakes earlier; without a notification system in place an early prediction is moot. Storing the centralized data developed alongside the vision to feed all of the sources of acquired seismic data into one centralized location for prediction. Providing a user interface means grounding the developed design in such a way that it is easily operable and trainable. The system gains definable characteristics by profiling some of its most basic functions.

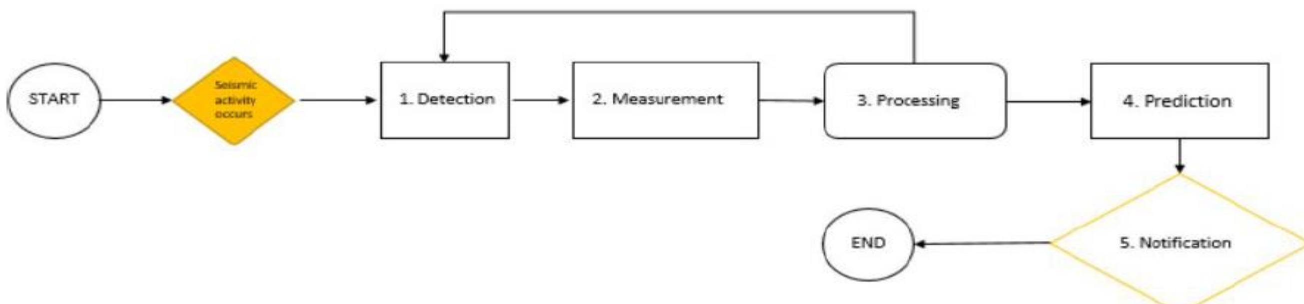


Figure 5 – System Level Functional Flow Diagram

Description

In Figure 5 above, the basic process of the system takes shape. A chronological timeline of the functions show how each function feeds into the next. The loop between processing and detection may undergo many iterations before outputting a prediction and notification. Although a prediction is technically outputted from the loop, the major output highlighted by a diamond shape is the notification. The reason for only focusing on the notification output is that predictions may be made without sending out notifications. Earthquakes not falling within a high enough magnitude are not worth a notification distribution to the affected parties. Designed to constantly monitor seismic activity, the prediction algorithm will constantly be churning out small-scale earthquake predictions, however, our system only aims to send out notification alerts when affected areas/parties have a reason to take precautionary safety measures. The mental walkthrough from the System Level Functional Flow Diagram shows a step-by-step system solution to help define the scope and boundary of the system.

3.4 System Requirements

Index	Requirement	Allocation
1F0001	The system shall detect seismic waves (P-waves and S-waves) greater than 2.0 in magnitude.	SD
1F0002	The system shall interface with GPS technology in order to quantify the movements of tectonic plates	SD
1F0003	The system shall store data provided by data inputs.	CDC
1F0004	The system shall allow stored data to be retrieved and analyzed by computation engines.	CDC
1F0005	The system shall analyze the stored data to predict the next earthquake.	CDC/EPCE
1F0006	The system shall interface with high-speed internet (networks).	CDC
1F0007	The system shall enable the transfer of data between components	CDC
1F0008	The system shall collect data from the following inputs: seismographs, ground motion sensors, global positioning systems.	SD

Table 3 – System Functional Requirements (1/2)

1F0009	The system shall use the prediction algorithm to provide a time and place <within some tolerance or confidence level> of a potential future earthquake.	EPCE
1F0010	The system shall use both real-time and historical data as inputs to the prediction algorithm.	EPCE
1F0011	The system shall collect data for 24 hours a day, 7 days a week, not considering service events.	SD/EPCE
1F0012	The system shall process data 24 hours a day, 7 days a week, not considering service events.	SD/EPCE
1F0013	If the system predicts an earthquake of at least 2.0 in magnitude, the system shall send a notification to specified parties.	EPCE/NS
1F0014	The total system uptime shall <operate> 24 hours a day, 7 days a week per year, excluding unexpected service events.	Support
1F0015	The downtime for service events shall require a maximum of <2> hours, unless in the case of a total component failure.	SD
1F0016	The system shall provide routine functionality in the event of a service for specific component.	EPCE/CDC
1F0017	The system shall have defined procedures for the proper disposal of faulty system components.	Support
1F0018	The system shall use defined replacement procedures for service events in the field.	Support
1F0019	The system shall use HR 2420 compliant components to meet US Environmental Design of Electrical Equipment standard.	Support

Table 4 – System Functional Requirements (2/2)

Description

Tables 3 and 4 above list out all 19 System Functional Requirements, indexed with “1F00XX”. The far-right categories in the table indicate the allocation of the requirement and its division it falls into. The purpose of allocating the different requirements is to group them by function which further organizes the respective functional requirements. As the end product moves into new phases of Scheduling, more requirements may be added as the product evolves or the Stakeholder places new demands on the system.

3.5 System Architecture

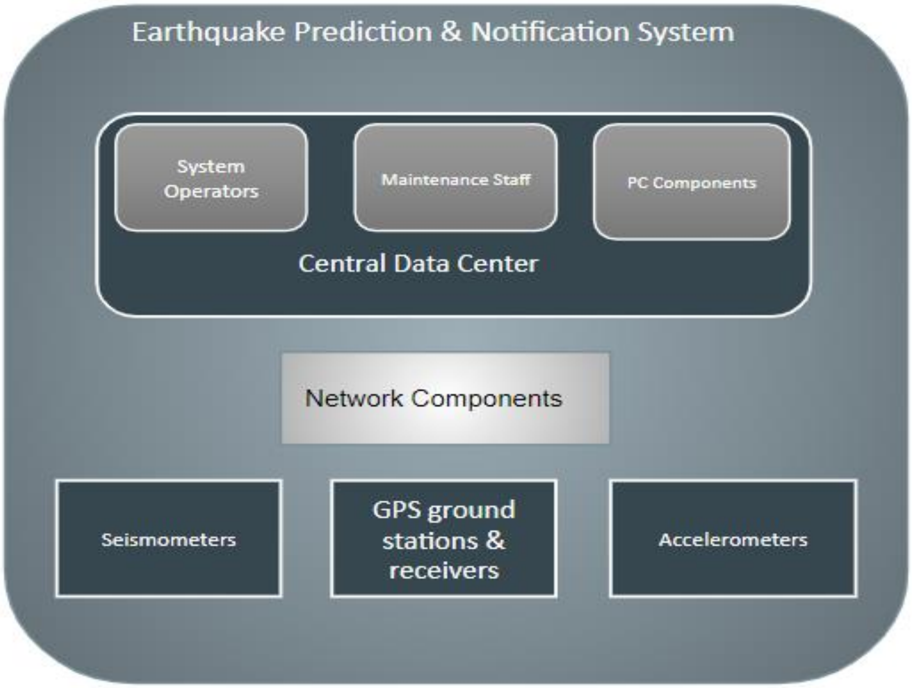


Figure 6 – Physical Architecture

Description

The physical architecture of our system consists of 3 primary sensor components, network components needed to facilitate an extended network of transmissions between the components and the central data center, and the central data center itself. Our team envisions the central data center as being a physical location, which will serve as a workplace for system operators as well necessary maintenance staff. The heart of the system will operate from the central data center, where PC components responsible for the computation and prediction algorithms, notification functionality, data storage, and processing. The user interface of the system consists of PC command hub within the central data center.

Level 2 - System Architecture

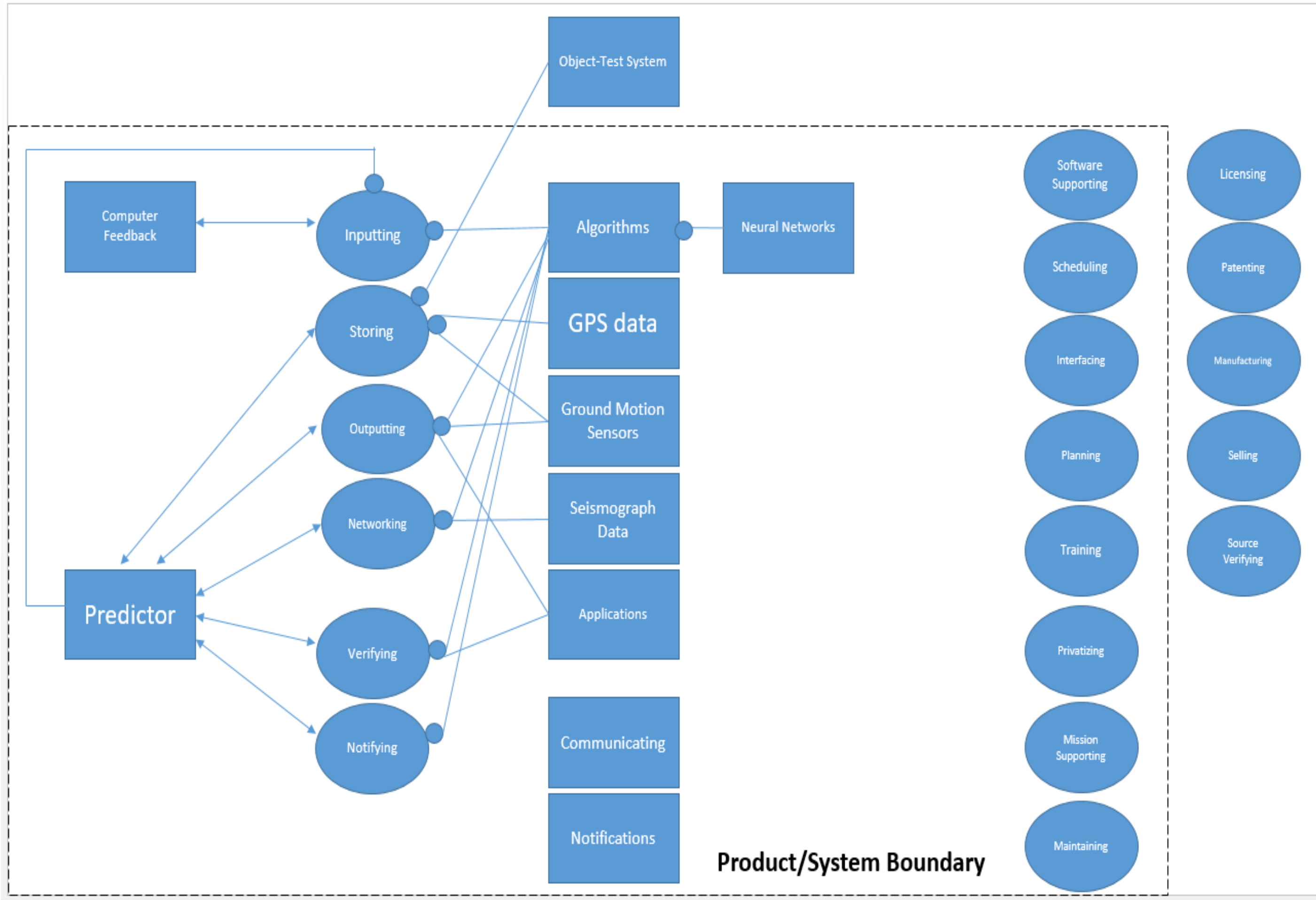


Figure 7 – Level-2 System Architecture

Description

The basic level-2 system architecture can be seen below in Figure 7. Note the secondary functions to the right extend to the system boundary showing explicitly what is part of the system and what falls out of the scope of the system. The level-1 functions consist of the following: inputting, storing, outputting, networking, verifying, and notifying. The level-2 functions consist of the following within the system's boundary: software supporting, scheduling, interfacing, planning, training, privatizing, mission supporting, and maintaining. Outside of the system's boundary, the level-2 functions follow: licensing, patenting, manufacturing, selling, and source verifying. The level-1 operands are simply the predictor and computer feedback. The level-2 operands are the object-test system, algorithms, GPS data, ground motion sensors, seismograph data, applications, communications, notifications, and neural networks. The relationships observed in Figure 7 summarize a high-level plan for the approach taken to timely predict and distribute pertinent earthquake information.

The level-2 architectural framework reflects a high-level functional model for what to expect from the system. For example, the design of the system is not expected to include proprietary data sources, only incorporate other data sources into its own system. The functions draw on a generalized concept of what actions define the system. When applying the operands to their functional relationship, the operands describe the crucial sub-systems of the system gathering the most attention. The operands listed out all trace their roots back into how they fit into the seismic predictor system as a whole. As attention is turned to a more detailed breakdown of the architecture at level-3, more relationships are added.

Level-3 System Architecture

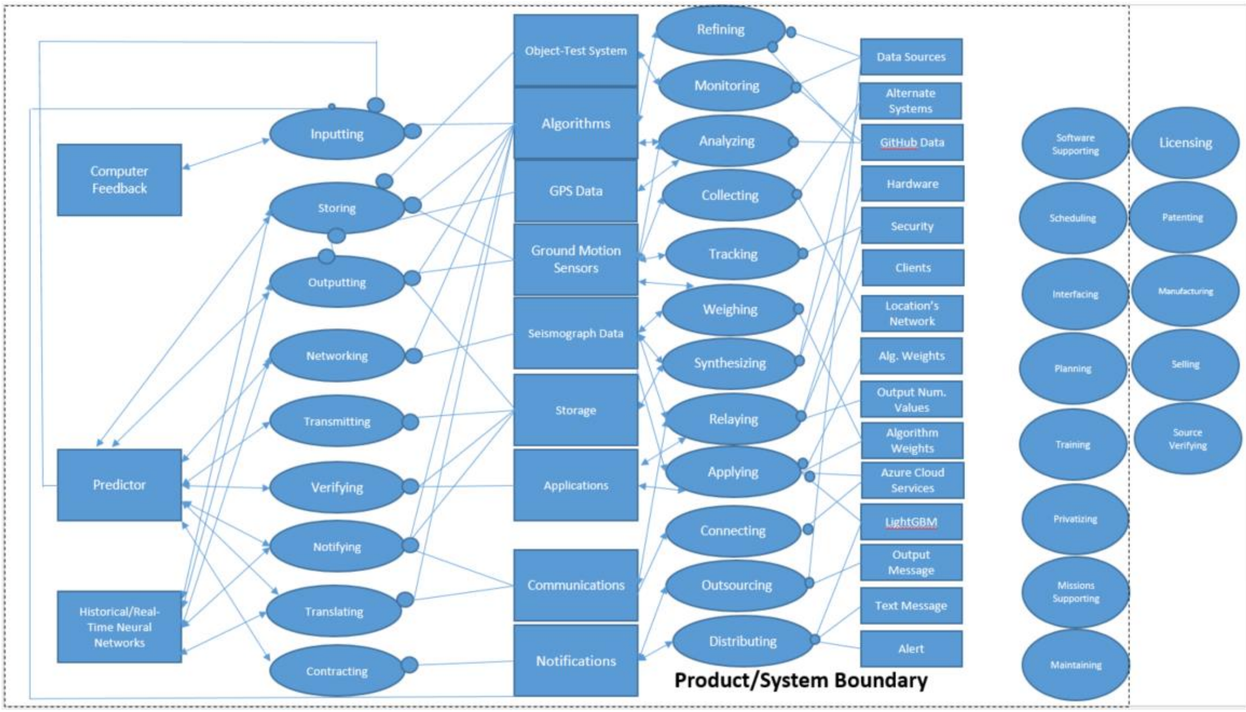


Figure 8 – Level-3 System Architecture

Description

The level-3 system architecture provides sufficient details of the inner-workings of the system to corroborate its eventual realization. The thought given to the 3rd-level of the architecture puts the system into more of a mission planning and concept of operations frame of mind. The functions added at level-3 consist of refining, monitoring, analyzing, collecting, tracking, weighing, synthesizing, relaying, applying, connecting, outsourcing, and distributing. The operands added at level-3 consist of data sources, alternate systems, GitHub data, hardware, security, clients, location's network, algorithm weights, output numerical values, Azure cloud services, LightGBM, output message, text message, and alert. Figure 8 shows the various relationships formed between the operands at level-2 and the functions at level-3 and the functions at level-3 with the operands at level-3. The newly developed functions at level-3 formed as a direct reflection of the level-2 operands to flow into how the level-3 operands would operate. The level-3 operands provide new, more detailed subcomponents of the system to create a more detailed picture of how the system functions. The level-3 architecture represents the final level of sufficient detail to design the system. Sufficient thought has been given to the necessary components needed in the system.

3.6 Seismic Data Requirements Mapping

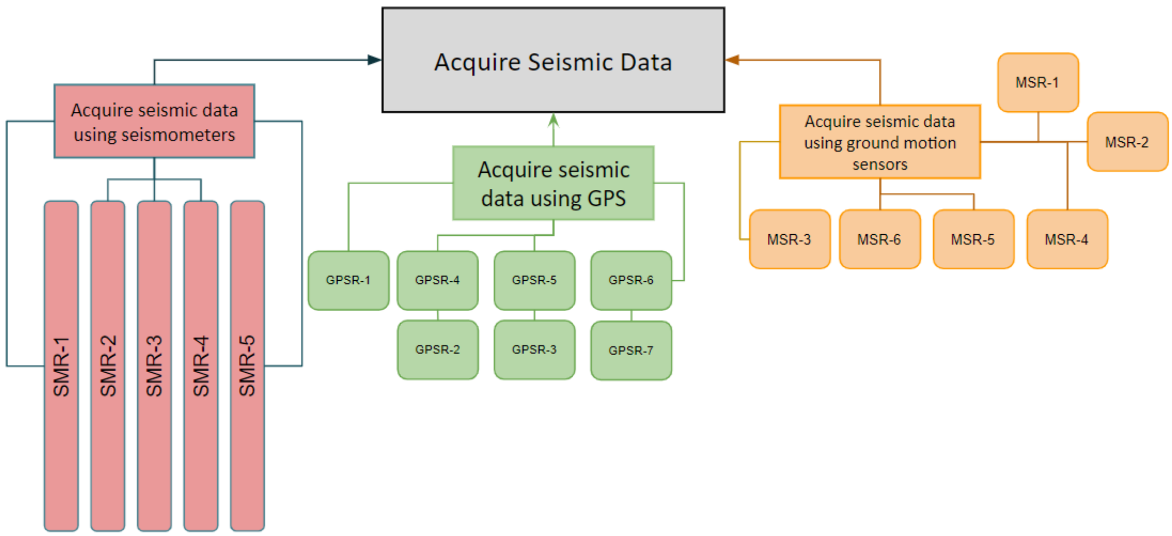


Figure 9 – Seismic Detection Requirements

Index	Requirement	Allocation
SMR-1	The seismometers shall have an operating frequency range between 0.01 - 25 Hz.	SD
SMR-2	The seismometers shall operate daily over 24 hour time period.	SD
SMR-3	Seismometers shall transmit seismic data to central data center daily, over a 24 hour time period	SD
SMR-4	Seismometers shall be able to detect both P-waves and S-waves.	SD
GPSR-1	Global-positioning system receivers shall interface with the system ground stations via broadband network.	SD
GPSR-2	System ground stations shall interface with central data center via broadband network.	SD
GPSR-3	Central data center shall interface with global-positioning system satellites	SD
GPSR-4	Global-positioning system receivers shall send location updates back to central data center 8 times daily.	SD
GPSR-5	System ground stations shall interface with up 20 receivers at a time.	SD
GPSR-6	System operation shall continue in the event of a receiver failure.	SD
GPSR-7	Central data center shall log and store global-positioning data.	SD
MSR-1	Accelerometers shall measure ground acceleration over time at its given location.	SD
MSR-2	Accelerometers shall measure ground velocity over time at its given location.	SD
MSR-3	Accelerometers shall measure ground displacement in the vertical over time at its given location.	SD
MSR-4	Accelerometers shall be equipped to store ground acceleration over time data and transmit back to CDC	SD
MSR-5	Accelerometers shall be equipped to store ground velocity over time data and transmit back to CDC	SD
MSR-6	Accelerometers shall be equipped to store displacement in the vertical over time data and transmit back to CDC.	SD

Table 5 – Seismic Detection Requirements

Description

Figure 9's Seismic Detection Requirements sorts the relevant requirements seen in Table 5 into its proper data format. SMR-1 through SMR-4 correlate to seismic data acquired using seismometers, GPSR-1 through GPSR-9 correlate to seismic data acquired using GPS, and MSR-1 through MSR-6 correlate to seismic data acquired using ground motion sensors. Table 5 is used as a reference for an explanation of the requirements seen in Figure 9.

3.7 Notification Requirements Mapping

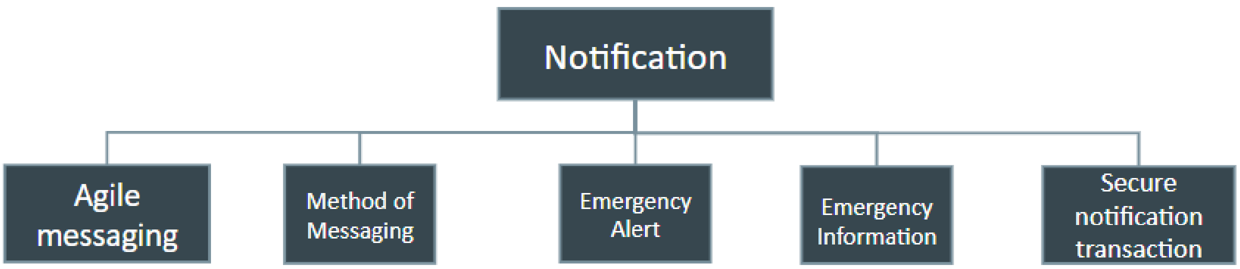


Figure 10 – Notification System Functionality

Index	Requirement	Allocation
NSR-1	System notifications shall be able to be broadcasted over existing emergency broadcast services	NS
NSR-2	Notifications of impending earthquake shall be transmitted from the prediction algorithms to impacted parties in a timely fashion.	NS
NSR-3	The system shall send notifications in a customizable message format.	NS
NSR-4	System shall send reliable emergency alerts.	NS
NSR-5	System shall notify emergency personnel of predicted earthquake	NS
NSR-6	System shall send notifications via the Emergency Alert System of predicted earthquake.	NS
NSR-7	System notifications shall contain relevant disaster information: Earthquake location, magnitude, and impact.	NS
NSR-8	System notifications shall contain safety precautions, or evacuation procedures for affected parties.	NS
NSR-9	System notifications shall be sent across secure transmission networks.	NS
NSR-10	System data shall be secure from outside network traffic.	NS
NSR-11	System prediction and notification function shall require passwords for operation.	NS

Table 6 – Notification System Requirements

Description

Figure 10's Notification System's Functionality shows how the requirements seen in Table 6 fit into the system's framework. The requirements are strategically not mapped to a specific notification method in Figure 10 to preserve the overall concept of the requirements. By describing the system's notification requirements and avoiding the selection of one particular method, multiple avenues for message distribution can be applied as long as they link back to

NSR-1 through NSR-11. The 5 notification functionalities seen in Figure 10 reflect the general qualities needed for an effective notification system.

3.8 Data Linkage

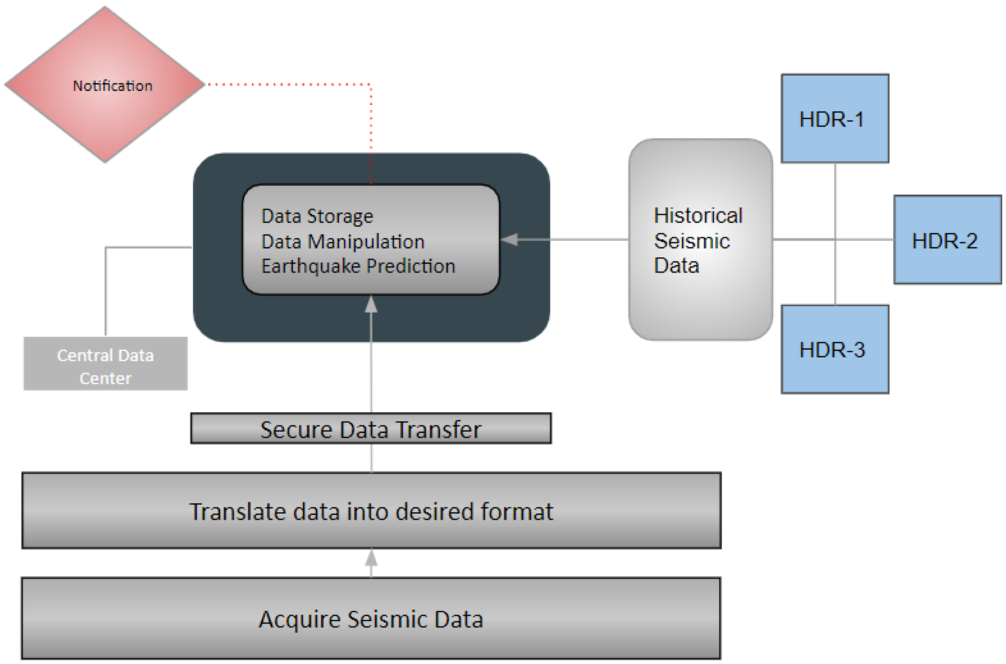


Figure 11 – Data Migration through System

Description

Figure 11 describes the migration of data through the Earthquake Prediction System. After acquiring seismic data via the methods described in Figure 9, the data is translated into the desired format and securely sent back to the central data center. At this point, the earthquake prediction computation engine uses real-time and historical data in order to determine the next seismic event. Once a defined threshold is reached, a notification of dangerous seismic activity will be sent to the necessary parties.

3.9 System Requirements Summary

Index	Requirement	Allocation
EPR-1	The system shall be able to predict the location and time of future earthquakes with 90% confidence level	EPCE
EPR-2	The system shall allow the use of custom data sets as inputs to computation engine	EPCE
EPR-3	The computation engine shall use real-time data for earthquake prediction compuation	EPCE
EPR-4	The computation engine shall use historical data for earthquake prediction compuation	EPCE
EPR-5	The computation engine shall use real-time data from the following inputs: Seismometers, GPS, ground motion sensors.	EPCE

Table 7 – Earthquake Prediction System Requirements

Description

Table 7 references high-level requirements for the system as a whole, seen in EPR-1 through EPR-5. The usefulness of Table 7 is for quick reference as a guide to the 5 key behaviorals of the system.

Summary

The figures and tables presented above define the system without delving into the research conducted for determining more specific metrics of the system. Requirements defined so far are aimed at what the system's value aims to produce with limited technical discussion. The content presented hereafter examines specific values generated to support the architecture of the whole system. Requirements guide the technical measures presented. The functionalities synchronize with the measures to explain their existence.

3.10 Key Performance Parameters

Key Performance Parameter (KPP) Table

KPP	Value	Weight (1-5)
Prediction Magnitude	>2.0	3
Cost	X	5
Mean Time Between Failure	8760 hours	2.5
Notification Time	2 weeks	4
Prediction radius	25 miles	3

Table 8 – Key Performance Parameters

KPPs Defined

a. The system will be able to make a prediction of future seismic activity greater than 2.0 in magnitude within a 2-week time frame, based on the input data provided.
b. The implementation of the system must use existing technologies in order to limit the cost of system infrastructure (no need for new measurement devices or seismic sensor stations).

c. The Mean-Time Between Failure (MTBF) for the system in hours, must be greater than 8,760 hours at the launch of the product.
d. The system's prediction algorithm must be able to provide a location of the focus of seismic activity (epicenter) within 25 miles of the actual location.
e. The system will notify users if it detects seismic activity greater than 2.0 in magnitude (social media alert, text message, new alert, etc…).
f. The system will notify users if it predicts seismic activity greater than 2.0 in magnitude within a 2-week time frame (social media alert, text message, alarm notification, etc…).

3.11 System-Level Analysis of Alternatives

Alternate Data Communication Options

Many different information communication methods and sub-systems could be utilized. The hardware and software needed to receive and transmit vast amounts of data with fast upload/download speeds. Factoring into this consideration was the reliability of the hardware and software selected. The hardware is more directly related to budget constraints depending on the amount of computing power needed. The ease, familiarity, flexibility, and universality of C++ make it the perfect software language compliment to any hardware selection. The programmed hardware will communicate with data collecting sources and distribute algorithm outputs to the proper channels in an easy-to-understand format. The methods and channels by which the information will be collected and distributed is expanded on in the following sections. A detailed analysis of the considerations given for communication can be seen in Tables 9 and 10.

KPP	KPP Rank	KPP Weight	Autonomous Source Monitoring	Direct Sensor(s) Comms.	Direct Fault Line Monitoring	Real-Time Monitoring
Costly	7	0.075	9	5	2	9
Maintainable	9	0.033	8	7	5	8
Reliable	5	0.10	7	8	9	5
Proprietable	3	0.15	9	4	8	9
Future Growth Capable	2	0.20	9	5	6	5
Precisionable	10	0.033	6	6	8	4
Operable	8	0.033	7	6	3	7
Profitable	1	0.20	9	4	4	6

Versatile	6	0.075	8	6	2	6
Universal	4	0.10	9	7	3	9
Total		1.00	8.5	5.4	5.3	6.7

Table 9 – Alternate Information Distribution Methods with KPPs

Criteria	**Autonomous Source Monitoring**	**Direct Sensor(s) Comms.**	**Direct Fault Line Monitoring**	**Real-Time Monitoring**
Data transmittal technology is mature	8	9	9	8
Data transmittal technology directly correlates to earthquake predictions	9	9	9	9

Table 10 – Alternate Information Distribution Methods Feasibility Comparisons

Autonomous Source Monitoring

Autonomous source monitoring allows for both real-time data collection and improved performance over time as it can learn from past data. The concept is extracting public data from many sources of information pertaining to earthquake monitoring and applying that data to a computational algorithm designed to earlier predict the chances of a catastrophic earthquake striking. The accuracy of the system improves over time as artificial learning techniques are applied and the system already has immediate value and a solid foundation to start from based off of the numerous sources of past earthquake data. The cost of the proprietary technologies are low due to its inherent value coming from the software designed to find variable comparisons where they may not be intuitive. As long as data is collected across each fault and shared, the program could apply that data to any fault and would not be limited to certain regions like other technologies. Once the program is up-and-running, its potential future growth is high because of the amount of publicly available data able to be inputted allowing for improved variable causations and chance happenings over time.

Direct Sensor(s) Communications

Direct sensor(s) communications is a method of gathering earthquake data by networking a potential system directly to the sensors surrounding fault line areas of interest. The main benefit of connecting directly to pre-existing or new sensors is the ability to interact with the sources of data directly giving a sense of added credibility to the data. The relative uncostliness of adding a system's own sensors increases the system's worth because a wider net is cast for a proprietary domain. The technology on a surface level is practical but the ease with which the system could be duplicated is high. The number of available sensors around faults and onedimensionality of the measurement method place burdensome limits on growth and development.

Direct Fault Line Monitoring

Direct fault line monitoring aims to maximize the number of ways to gather data by direct observation along fault lines. Instead of just collecting data from sensors, the fault lines can be tracked over time to monitor changes in their behavior. To properly observe the seismic activity along faults where impacts would affect citizens and infrastructure, the costliness would be absurdly high. Some points along faults are more susceptible to earthquakes than others leading to the possibility of only covering some critical areas along the faults for observance but the more areas losing focus, the more unreliable the system. Using the Global Positioning System (GPS), fault lines may be tracked but the data correlating precision and accuracy of tracking strictly behavior to the likelihood of an earthquake occurring is still in research and development.

Real-Time Monitoring

Real-time monitoring originates from the same idea as an autonomous source monitoring system but without the historical data for added convenience. A simplistic autonomous source monitoring system offers benefits such as slightly reduced cost and accurate monitoring but fails to significantly improve over existing technologies. With the primary goal of early detection as possible, real-time monitoring does little systems in place can already do. The innovation required for substantial profitability and future growth is limited by its ability to produce a better system over time, even if big data can be inputted and outputted in a sensible manner effectively.

Alternate Notification Options

Many platforms could be used to communicate the collected data to affected organizations and people; television, application-enabled phone notifications, wide-reaching Internet domains, text message alerts, and social media. The KPPs to compare the methods at the system's component level for notifications are as follows:

a. Cost: A measure of the cost of the component throughout its lifecycle as part of a system developed as a marketable product.
b. Reachability: A measure of the amount of market participants and organizations capable of receiving the earthquake notification with ample time.
c. Timable: A measure of how quickly the earthquake notification reaches members capable of receiving the communicated message.

KPP / Alternative	KPP Weight	Television	App Notifications	Internet Domains	Text Messages	Social Media
Cost	0.15	6	9	5	7	9
Reachability	0.35	4	8	6	8	7
Timable	0.50	4	9	6	9	6
Total	1.00	4.3	8.7	5.9	8.4	7.5

Table 11 – Alternate Notification Options

Application-enabled phone notifications is the best platform for communicating an impending earthquake. Text messages and social media -- both aspects of smartphones too – had similarly high KPP weighted totals. However, creating a system that could send messages to millions of phones in a short time frame would be costly. Furthermore, it may not reach people away from their phones. Although billions of people worldwide across all socio-economic groups have social media accounts, social media accounts are not always checked in a timely manner. A key requirement of the system is its ability to communicate quickly with its intended audience.

As many channels will be utilized as possible. An application notification gives the most proprietary value to the system but by working in conjunction with other organizations and government agencies, text messages and emergency alerts have also been given serious consideration as the favorites.

Alternate Seismic Detection Options

With all of the seismic detection options available in different locations, the best approach to detecting damaging earthquakes early on is to utilize as many resources as possible to gain a better cumulative understanding and approach. All different kinds of seismographs and sensors are readily available to perform their standard functions. The precision of standard instruments credibly measure tremors but fail to correlate early enough how small tremors may build up to severe tremors. Early improved interpretation of seismographs, sensors, and other measurement forms whether through better placement near faults, better cross-analysis between measurement devices, etc… will result in earlier accurate findings and open up earlier communications with affected parties.

The sub-system options for seismic detectors will be analyzed on each of the following Technologies:

- Sensors - strategically placed to monitor tremors near fault lines and interpret the tremors numerically
- Algorithm Estimators - computational/mathematical attempts to predict when earthquakes will strike next
- Seismographs - measures ground motion in combination with a recording device and timing device
- Correlation of distantly related variables - assess possible leads of variables to improve computational/mathematical analysis not intuitively understood to affect earthquakes

such as climate near faults, weather, etc…

● Combined analytics - a systems-level computational approach to find better relationships between the different detections methods in place

From the listed sub-system alternatives, the following component-level KPPs help to categorize each:

a. Cost: A measure of the life-cycle cost of the component(s) needed to support the seismic predictor system.
b. Accuracy: A measure of how close to the actual magnitude the component gets
c. Operable: A measure of the time and effort needed to run and maintain the component
d. Speed: A measure of the rate the data may be uploaded to the system versus the rate of distribution of the pertinent information after computational analysis
e. Growth: A measure of the potential of the system to improve its marketability and profits

KPP / Alternative	KPP Weight	Weight Sensors	Algorithm Estimator	Seismographs	Related Variables	Combined Analytics
Cost	0.125	2	7	5	9	7
Accuracy	0.20	8	3	8	2	9
Operable	0.125	8	5	8	4	7
Speed	0.30	4	8	4	8	8
Growth	0.25	6	9	5	7	9
Totals		5.6	6.8	5.7	6.2	8.2

Table 12 – Alternate Seismic Detector Options

A combined analytics approach is the preferred seismic detection method. Using a “best of both worlds” approach, the system will input many different readings and sources of information, tying them together in a way best suited for early detection.

Computational Factors

With approximately 100-150 earthquake factors accounting for diverged estimations and calculations, bountiful computational power is a must as the product scales. Since necessary research has already been conducted on directly-linked variables, our system aims to account for secondary linked factors such as sub-soil radon gas emissions, total electron content of ionosphere, vertical electric field, magnetic field of Earth, etc… With the future development of neural networks into our system, the fuzziness of the system should exponentially decrease when accounting for all of these variables. By utilizing effective data sorting and analysis software tools, a large up-front cost can be mitigated by scaling the computing power. One metric to aim for would be 60 seconds/data point analysis with an initial limit of 500 final data points after sorting to the most relevant. The algorithm can afford to narrow it down to 500 data points while still retaining its accuracy by “tiling” the selected areas to zero in on the peaked areas of interest. A three-step analysis approach will be utilized: feed past data sets into neural networks, tile the “hotspots”, and make use of the collecting 3 data sources.

Learning Algorithm Factors

Software Programs under Consideration:

GitHub for past data sets and algorithmic development/deployment
GitLab for cross-functional project collaboration and version control
LightGBM for data sorting
Numerous programs for data handling
Modified M8 and MSc algorithms for scalability to earthquakes less than 8.0
Fortran 77 (favorite), C++, and Python – M8 source code written in Fortran 77
Azure cloud services for data storage and easy access (affordable until large-scaled)

Along with software considerations, the algorithm could utilize “manual” computational methods where the seismic parameters representing the internal geological state of the ground preceding the earthquake are mathematically calculated. Advancing from the concept of manual calculations, the M8 algorithm normally approximates the radius of the Earth meridian to 6 degrees which could be altered for controlled tests. Study bias methods would also be prioritized so learn as much from retroactive predictions as possible. Just as the system aims to utilize every data collection tool at its disposal, it aims to do the same with all of its software making sure to account for as many factors affecting the results as possible.

Machine Learning Factors

Considering machine learning is the fastest growing aspect of earthquake predictions and anything tech related, our system aims to make it the focal point for improvement over the system’s lifecycle. By artificially simulating various scenarios and using past scenario data, the rate of refinement exponentially increases.

Machine learning methods under consideration include:

Random Forest
Neural Networks of various formations
Aggregation
Vector Regression
Enhanced Particle Swarm Optimization
Monte Carlo Simulations
Three Dimensional Pattern Informatics
Radial Basis Functions

The statistical variances between each method make it difficult to determine each method’s effectiveness. When even the relevant statistics still need further study in the field, it’s hard to pick just one method. Ideally, multiple methods could be utilized until a best fit is found.

Additional Alternate Options

The following subsystems require further trade studies and discussion to decide what the best approaches will be for their system integration:

a. Data Storage/Processing: Additional studies will determine the best ways to analyze and process vast amounts of data input into a logical format.
b. Computation Engine: Additional studies will determine computational specifications and needed pseudo-algorithms to make early best predictions from the data.

Although some design decisions still need further research and development, the progress made so far defining the system supports the requirements. The system will undergo further refinement as further studies lead to a solidified design. Documenting the reasoning behind each decision allows for traceability to examine the reasonings behind each decision for future adjustment. After all subsystem decisions are made, a systems-level approach will guide the product and integration between the sub-systems.

4. Detail Design Review

4.1 Risk Management

Risks Associated with Seismic Detection

1. If seismic activity occurs outside our detection range, then it will not be included into the prediction algorithm
2. If the thresholds for seismic detection are not well defined, then it could omit useful seismic data
3. If the thresholds for seismic detection are not well defined, then it could include non-useful seismic data
4. If seismic detection devices are placed in incorrect locations, then costs associated with technical development will increase dramatically
5. If a detection component fails then the system will not be able to detect seismic activity in a given area

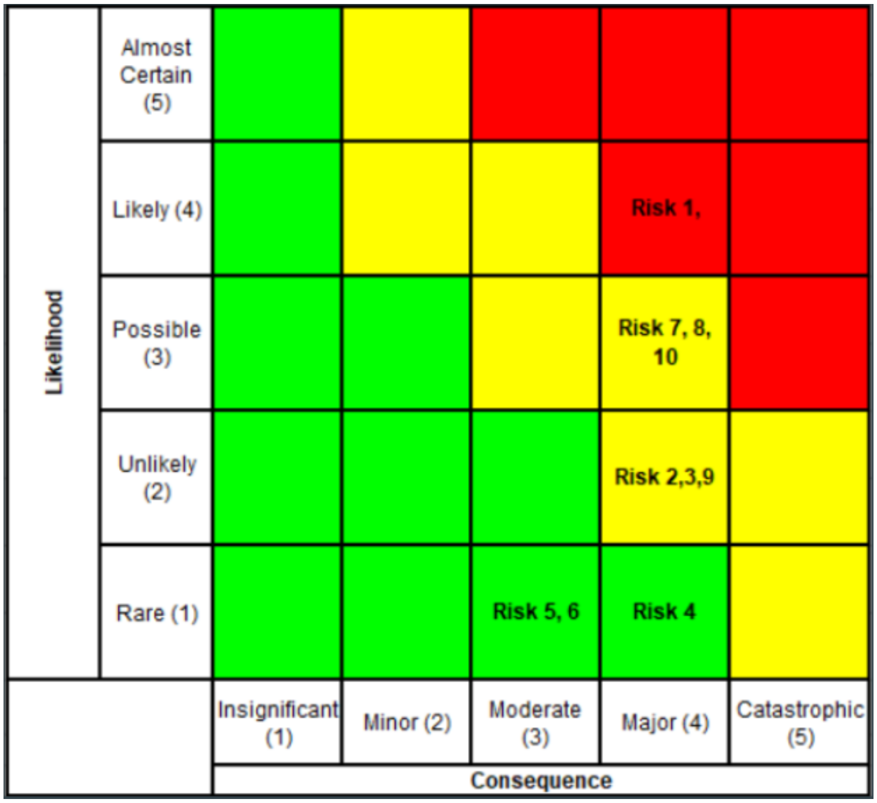
Risks Associated with Earthquake Prediction

1. If a detection component fails then the system will have to adjust the computation engine to handle the failure
2. If the algorithm predicts an earthquake in the wrong location, then the system fails
3. If the algorithm predicts an earthquake at the wrong time, then the system fails

Risks Associated with Notification Function

1. A notification of impending earthquake is not received in a timely fashion by emergency personal

2. Notification system is prone to cybersecurity threats due to ability to send out emergency notifications



Likelihood		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
	Almost Certain (5)					
	Likely (4)				Risk 1,	
	Possible (3)				Risk 7, 8, 10	
	Unlikely (2)				Risk 2,3,9	
	Rare (1)			Risk 5, 6	Risk 4	
		Consequence				

Figure 12 – Risk Assessment Matrix

Description

Risks 1-10 seen in Figure 12 are expanded upon above. Note that only Risk 1 falls into the red zone where it is both a major consequence and a high likelihood of occurring. The likelihood of seismic activity occurring outside of the detection range is high because our system's desperate reliance on its data sources that are imperfect at covering faults. The consequence was rated a 4 – major because although there's nothing wrong with not collecting 100% of data on any given fault, the drastic consequences of not collecting enough data and missing an earthquake prediction even once could compromise the integrity of the system.

Risk Mitigation

Seismic Detection				
	Category			
Item	Technical	Schedule	Cost	Risk Mitigation
1	X		X	Place our seismic detection devices in a such a way that it optimizes the system's ability to detect all seismic activity over the range of interest
2	X			Commit resources to define the optimal upper bound magnitude of seismic activity that will aid in future earthquake prediction
3	X			Commit resources to define the optimal lower bound magnitude of seismic activity that will aid in future earthquake prediction
4	X	X	X	Spend ample time outlining and selecting seismic detection device locations through analysis
5	X		X	Purchase seismic detection components with high levels of reliability

Table 13 – Risk Mitigation for Seismic Detection

Earthquake Prediction / Computation Engine				
	Category			
Item	Technical	Schedule	Cost	Risk Mitigation
6	X			Spend time developing software code centered around error handling and certain event cases
7	X		X	Spend time developing the algorithm and computation engine to incorporate certain quality criteria needed for earthquake prediction
8	X		X	Spend time developing the algorithm and computation engine to incorporate certain quality criteria needed for earthquake prediction

Table 14 – Risk Mitigation for Earthquake Prediction/Computational Engine

Seismic Threat Notification				
	Category			
Item	Technical	Schedule	Cost	Risk Mitigation
9	X			Establish communication agreements with surrounding emergency response organizations to ensure notification from the prediction system is received.
10	X	X		Ensure notification and messaging system is compliant to all industry messaging standards. Make sure system is secure from outside cyber-threats.

Table 15 – Risk Mitigation for Seismic Threat Detection

Description

Tables 13, 14, and 15 show the system has a plan in place to mitigate the obvious risks of the system. Sensor adjustments throughout the lifecycle can help mitigate Risk 1 to an acceptable level. Any system will have risks throughout its lifecycle but the mitigation plan accounts for as many “what-if” scenarios as possible.

4.2 Verification Plan

Technical Performance Measure (TPM)	Quantitative Performance Requirement	Current TPM Value	Risk of Not Meeting TPM
Percentage of earthquakes predicted within required time frame	Within 72 hours of predicted time vs. actual time	95% within 72-hour window	1
Percentage difference between earthquake measured on Richter Scale and magnitude measurement of system	2.0 magnitude on Richter Scale	5% difference	4
Time improvement increments with number of GPS satellites utilized	GPS real-time lag time less than 120 seconds	5 seconds per satellite added	4
Number of data sources	5-10 Terabytes of storage allowed by computer(s)	10 sources or more	1
Percentage of data relevant and practical for analysis	5-10 Terabytes of storage software supports for analysis	90%	2
Accuracy improvements in percentage with each data source added for analysis	Less than 60 minutes of analysis for each source of data mined	2% or more	2
Number of people reached by notifications	Number of devices notified (1,000,000+)	1,500,000 people confirmed	3
1 = Very High, 2 = High, 3 = Moderate, 4 = Low, 5 = Very Low			

Table 16 – Technical Performance Measures Evaluation

Description

Table 16 shows technical measures to examine the system's performance and how it should match up to what is expected from it. The TPM starts by outlining it in qualitative terms and then moves to quantitative terms with rankings. The Current TPM Values can be glanced over for a quick overview of what to expect from the end product.

5. Production

5.1 Test Plan

Quantitative Performance Requirement	**Test**
Within 72 hours of predicted time vs. actual time	Feed historical data into system over a period of time that is similar to real time and see if the system flags an earthquake.
2.0 magnitude on Richter Scale	Feed historical data into system and ensure it only flags data that indicates a potential earthquake with a magnitude ≥ 2.0 on Richter scale.
GPS real-time lag time less than 120 seconds	Time and record the lag time.
5-10 Terabytes of storage allowed by computer(s)	Ensure storage is provided.
5-10 Terabytes of storage software supports for analysis	Ensure storage is provided.
Less than 60 minutes of analysis for each source of data mined	Time the amount of time required for analysis.
Number of devices notified (1,000,000+)	Send out a test message to devices.

Table 17 – Tests Derived from Requirements

Description

Table 17 adds onto the requirements to link it to future testing. Requirements play a major role throughout the system development process as indicated here. Each requirement must contain technical measures. Those technical measures must have a way of being tested to show their accuracy.

5.2 System Cost Breakdown

	Conceptual Design Phase	Preliminary Design Phase	Detail Design Phase	Production Phase	Deployment Phase	Maintenance Phase
Engineering Labor	$50,000	$100,000	$200,000	$50,000	$0	$0
Engineering Materials	$0	$25,000	$50,000	$200,000	$0	$0
Production Labor	$0	$0	$0	$5,000,000	$0	$0
Production Materials	$0	$0	$0	$2,000,000	$0	$0
Deployment Labor	$0	$0	$0	$0	$50,000	$0
Deployment Materials	$0	$0	$0	$0	$100,000	$0
Maintenance Labor	$0	$0	$0	$0	$0	$500,000
Maintenance Material	$0	$0	$0	$0	$0	$100,000
Subtotal	$50,000	$125,000	$250,000	$7,250,000	$150,000	$600,000
Company Overhead	$300,000	$600,000	$503,000	$8,276,000	$250,000	$12,414,000
Phase Total	$350,000	$725,000	$753,000	$15,526,000	$400,000	$13,014,000

Design Phases Total			**$1,828,000**	
Acquisition Phases Total				**$17,354,000**
Number of Units to Produce	100			
Cost Per Unit (full cost recovery)				**$173,540**

Table 18 – Systems Cost Breakdown

Labor Rates	$/hr
Engineering	100
Production	50
Maintenance	50
Development	$1,828,000

Table 19 – Systems Wage Scale

Description

The logic behind the overall costs of the system can be seen above in Tables 18 and 19. The numbers and overall cost of the system seem outrageously high but with minor improvements justifying billions of dollars saved in infrastructure costs from a high magnitude earthquake, the system is worth investing in.

6. Maintenance Phase

After the system is deployed and initial resources have been expended, the system officially will enter maintenance mode. Maintenance mode includes bug fixes to the software, routine software upgrades, routine short equipment shutdown periods for hardware/software updates, potential equipment upgrades, and a host of other refinements. The maintenance phase is heavily involved because of the software aspect and consistent improvement over the lifecycle of the product. Assuring technical support regarding the software eases the burden of operability.

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