Analysis and Design of Systems Utilizing Blockchain Technology to Accelerate the Humanitarian Actions in the Event of Natural Disasters

by

Suresh G. Rajan

M.B.A., Lake Forest Graduate School of Business, 2010
B.E. Computer Science and Information Systems University of Madras, 1994

Submitted to the System Design and Management Program in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2018

Signature of Author: Signature redacted

Department of System Design and Management
May 11th, 2018

Certified by: Signature redacted

Simon Johnson
Ronald A. Kurtz (1954) Professor of Entrepreneurship
MIT Sloan School of Management
Thesis Supervisor

Accepted by: Signature redacted

Joan S. Rubin
Executive Director, System Design & Management Program

This page intentionally left blank.

Analysis and Design of Systems Utilizing Blockchain Technology to Accelerate the Humanitarian Actions in the Event of Natural Disasters

by

Suresh G. Rajan

Submitted to the Department of System Design and Management on May 11, 2018 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering and Management

ABSTRACT

This paper focuses on designing novel ways to alleviate human and economic impacts caused by weather and climate disasters such as droughts and cyclones. Natural disasters are becoming apparent and continue to grow in number, intensity, and impact. Authorities, organizations and community groups who focus on rebuilding and relief efforts are constantly facing challenges in redevelopment effort, environmental hazards, health care and funding support to help communities become recover and be more resilient. When dealing with aftermath due to natural disaster the communities do have heightened sense awareness and come together to provide the necessities of rebuilding infrastructure.

There are short-term actions, such as an evacuation based on the weather forecasting. Can a system that properly communicates with all affected stakeholders to be prepared for the natural disaster. The implemented system takes the appropriate actions thereby by reducing the human and economic impacts. This precious window of opportunity time between the forecast and actual natural disasters is regularly overlooked which affects the recovery and resilience process.

This thesis explains how to design a holistic system that can lessen the risk of natural disaster with a system for forecasting, automatic trigger responses and disburse required funding when certain threshold conditions are met prior to natural disasters. The proposed framework takes into consideration of blockchain technologies that are at the relatively early stage of development. The objectives are to develop novel early funding mechanism and explained using conceptual architecture with private blockchain and smart contracts that can be designed to automatically execute early funding mechanism when the natural hazard thresholds are reached.

Thesis Supervisor: Simon Johnson
Title: Ronald A. Kurtz (1954) Professor of Entrepreneurship, MIT Sloan School of Management

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Professor Simon Johnson for his role as my advisor. His lectures and guest speaker series had helped me to assimilate concepts and understand business model to broadened my knowledge and viewpoints of using blockchain technology.

I am also grateful to Executive Director Joan S Rubin, and the entire SDM staff for making my SDM experience so valuable, rewarding and memorable.

I'd like to my thank my collaborator Bridgit Mendler who had inspired me to think beyond the conventional perspectives. I am grateful Dr. Pablo Suarez, Associate Director for Research and Innovation, Red Cross Red Crescent Climate Centre, who supported me throughout my thesis journey. He connected me with many mentors to help investigate the challenge and conduct my analysis and research.

I would like to thank my MIT friends, who have been like family to me during my 16 months journey. I am grateful for their guidance, and encouragement and I feel lucky to have chance working with them.

I would like to thank my friend and mentor Ali Khan who was the one who encouraged me to pursue MIT SDM degree and I have truly found paradise.

My special thanks to my dear wife Kanchana and my daughter Adhya, simply accepting that fact that I am always buried in my books and meetings. I could not have done this without their constant support and encouragement to pursue my Master's degree at MIT.

This page intentionally left blank.

Table of Contents

List of Figures

List of Acronyms

OCHA	The United Nations Office for the Coordination of Humanitarian Affairs
GRPS	Global Risks Perception Survey
U.S.	The United States of America
DHS	U.S. Department of Homeland security
FEMA	Federal Emergency Management Agency
NCEI	U.S., National Centers for Environmental Information
ERP	Emergency Response Preparedness
IASC	Inter-Agency Standing Committee
DRR	Disaster Risk Reduction
EWS	Early Warning Systems
SDG	Sustainable Development Goals
IFRC	International Federation of Red Cross and Red Crescent Societies
FbF	**Forecast-based Financing**
EAP	Early Action Protocols
PKI	Public Key Encryption
DApps	Decentralized Applications
DAO	Decentralized Autonomous Organizations
PoW	Proof-of-Work
PoS	Proof-of-Stake
UTXO	Unspent Transaction Output
DML	Decentralized Machine Learning

1. Introduction

"The ability to self-organize is the strongest form of resilience. A system that can evolve can survive almost any change, by changing itself (Meadows) ." – Donella Meadows, Thinking in Systems (2008)

"Humanitarian action provides life-saving services and facilitates the return to normalcy for people and communities affected by natural and man-made disasters ("Good Practice Review")." Traditional, response-driven humanitarian funding mechanisms such as grants are not keeping pace with recurring crises driven by natural disasters. An estimated 128.6 million people were affected by disasters both natural and man-made confirmed by The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) (Global Humanitarian Assistance).

The humanitarian system includes United Nations entities, the International Red Cross/Red Crescent Movement, non-governmental organizations, government institutions and donor agencies. They are all united in adherence to the principles of humanity, neutrality, impartiality, and independence ("OCHA Humanitarian Assistance for People in Need"). These are meant to ensure that assistance is provided on the basis of the need by humanitarian actions.

The frequency and impacts caused by natural disasters that are impacting communities require immediate attention and interventions. In my thesis, I will explore solutions to mediate natural disasters and I would start my research with the following questions – What are the barriers to lessen impacts caused by natural disasters? What are inefficiencies in the system for enablers to save lives and reduce sufferings.

1.1 Outline

In this thesis, the first chapter covers background and motivation. This paper is organized as follows.

> Chapter 1: Introduction chapter covers the challenges in humanitarian funding with increasing frequency and impact caused by natural disasters as well as the outline of this thesis.

Chapter 2: Overview chapter covers my motivation of this thesis and analysis on cost implication of natural disasters around the world.

Chapter 3: Overview on Humanitarian organization and its challenges with humanitarian actors and logistics. Current state analysis of humanitarian disaster response and need for early warning system. Detailed analysis of Forecast-based financing, novel method to get funding for early response; covering stakeholders' roles and responsibility on how to trigger early funding based on the threshold levels of natural disasters.

Chapter 4: Overview of blockchain technology covering the design principles and explore blockchain technology and challenges involved.

Chapter 5: Overview of smart contract design principle. Introduced new and evolving decentralized application platform and limitations of smart contract and decentralized application platform.

Chapter 6: Design criteria using blockchain in Forecast-based financing including breakdown of workflow, timeline and working of funding mechanism and proposed using permissioned blockchain and smart contracts for Forecast-based financing.

Chapter 7: Conceptual Architecture for proposed Forecast-based financing using Private Blockchain and next steps and recommendation

Chapter 8: Conclusion and Future Research

The information in this thesis is from three types of sources: literature review, interviews with professors, subject matter experts and my own analysis.

2. Overview

Natural Disasters can be broadly classified into meteorological, hydrological, climatological, geophysical, biological, extraterrestrial(EM-DAT). Tropical storm, flood, drought, wildfire, earthquake and volcanic activity are few subtypes of the natural disaster classification are causing direct and indirect economic impact, and societal impact all around the world. There is profound demand to save humanity and provide necessary essentials when this natural disaster triggers food and water crisis. This chapter will focus on motivation for my thesis, risk and challenges of weather and climate disaster, and challenges faced by non-governmental organizations, government institutions and donor agencies to respond and recover from natural disasters.

2.1 Motivation

I spend last decade building software applications for the large organization. As a software architect, I prefer investigating the socio-technical systems through the path of reconciling system conceptualizations, and stakeholder values. In this paper, I will approach to decompose the physical or functional into distinct components that interact in direct ways. Over the decade, I have been exposed to the dramatic technological transformation that disrupting how the information is processed and disseminated. Knowledge gained from this information is disrupting on the traditional job and organizations. The complexity of decision-making and its consequence are important in designing the system and defining the system boundary. My approach is to understand the requirements, identify stakeholders' needs, develop conceptual architecture, and make design recommendations to address the identifies gaps in the existing systems.

I started this thesis from an idea originated in the class Entrepreneurship without Borders. This class format and structure gave the opportunity to learn and explore the future of blockchain and its implications in the way how business, government, organizations, and individuals work together. I was captivated by the technology and concept on how blockchain can provide simpler and secure way to establish a trust for movement of money, assets and secured information to anyone in peer-to-peer without any intermediators. In addition, guest lecture by Dr. Pablo Suarez, Associate Director for Research and Innovation at the Red Cross Red Crescent Climate Centre, who conducted a participatory activity to bring awareness and understanding that intervention system is required to face the challenges and impacts caused by weather and climate disasters. As the blockchain technology is applied in various ways within various sectors including banking and financial services, I was motivated to look whether blockchain can be sought in humanitarian actions to enhance and improve efficiency in financing aspects as well as tackle the challenges to alleviate losses due to natural disasters effectively.

2.2 Weather and Climate Disaster

In order to understand the cost implication due to weather and climate disaster, I started my analysis with exploration of natural disaster in last 5 years. I have summarized my findings focused on increasing cost and impacts.

Global Risks Perception Survey (GRPS) 2017–2018 conducted by World Economic Forum, Extreme weather events ranked number one and two in likelihood and impact of top 10 global risks (World Economic Forum). The survey participants, from various continents and network of business, government, civil society and thought leaders, do predict that these global risks likely to cause significant impacts in next 10 years. Extreme weather and climate disaster is the most pressing environmental challenge among the others such as major natural disasters, man-made disasters, and biodiversity loss, etc. and continues to remain on top five global risks in the last five years.

The GPRS can be qualitative and could be influenced by perception and viewpoints. I explored in what was The United States of America (U.S.) spent on weather and climate disasters for 2017. In 2017, Atlantic hurricanes—Harvey, Irma, and Maria—was the most intense to make landfall in rapid succession and the cumulative cost of $306.2 billion was the most expensive hurricane season ever (Smith, "2017 U.S. Billion-Dollar Weather and Climate Disasters: A Historic Year in Context | NOAA Climate.Gov"). The same year, U.S. was impacted by 219 weather and climate disaster that includes storms, inland floods, drought and wildfire and cost exceed $1.5 trillion (Smith, "Billion Dollar Disasters 2017").

These extreme weather events continue a trend towards increasingly cost, and a number of events have caused the most deaths in the 2017 and displaced 31million people (Smith and Katz).

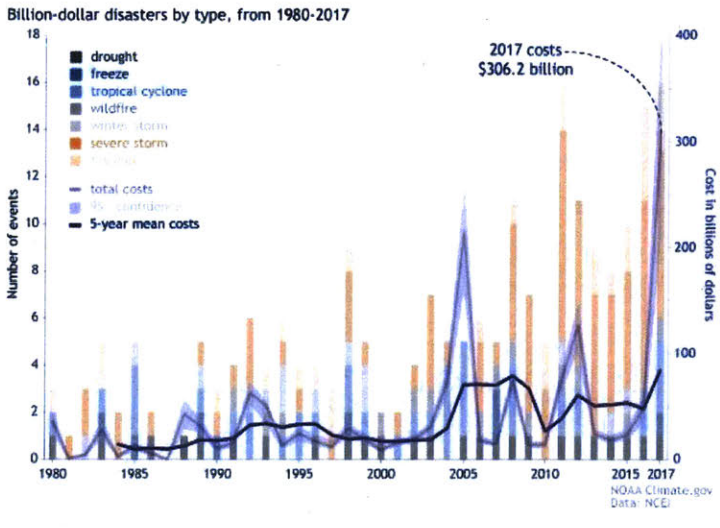

Figure 1: NOAA Climate.gov, based on NCEI data

NOAA Climate time series graph based on NCEI data illustrate the different type of weather and climate disasters in the U.S. over the period from 1980 to 2017, and the number of events and cost shows is steadily increasing over the time period(Smith and Matthews).

The cost is accounted from the estimates which include physical damage to residential, commercial and government/municipal buildings, material assets within a building, vehicles, public and private infrastructure, and agricultural assets (Smith and Katz). However, I found that the cost assessment does not take losses into consideration of natural assets, healthcare related losses, or values associated with loss of life. I understand this information contains sensitive personal information (SPI) and so cost wasn't accounted but it is the missing data is important data to support the consequence particularly under conditions of increasing vulnerability and uncertainty related to weather and climate disasters.

In U.S. Department of Homeland security (DHS) provides disaster assistance to the property damages that are not covered by insurance. DHS in support of the Federal Emergency Management Agency (FEMA) provides disaster response, and recovery which are assisting states and communities after weather and climate disaster. FEMA directs their resources on four phases of emergency management focus on the prevention, mitigation, response, and recovery (Branosky). Currently the majority of assistances are focused on after weather and climate disasters for response and recovery phases. The first two phases prevention and mitigation require attention and there is need to shift focus to reduce the cost as well as life impacts in the natural disasters prone areas. The prevention and mitigation can help to understand and prepare with the information known about the infrastructures that are built in an area vulnerable to disasters — along coastlines or in areas vulnerable to wildfire. Policy advocates stress to prioritize focus on prevention and mitigation when dealing with terrorism. There is need to shift focus on changing the policies to include prevention and mitigation to better prepare for future weather and climate disasters.

According to 2017 Annual Report Economic cost of Atlantic hurricanes—Harvey, Irma, and Maria were $220 billion and the insured cost was $80 billion (Benfield). In U.S., National Centers for Environmental Information (NCEI) monitors and assess the cost of impacts of disasters (Smith, "Billion Dollar Disasters 2017"). To calculate the cost assessments, NCEI used various data sources to perform analysis and found that the increase in cost for uninsured and underinsured losses. Yet another research paper (Smith and Matthews) confirms that cost of damages is increasing in the regions that are vulnerable to hurricanes and insurance companies are not able to cover the gaps in insurance claims from the infrastructure damages. So, the government agencies are stepping in to cover the gaps in the insurance coverage. These findings show that the frequency of natural disasters is increasing and the unaccounted cost that covered by the government agencies will have damaging economic effect in the long run.

Developing countries and smaller economies even suffer more greatly from the natural disasters' impacts and communities are susceptible to suffer from the lack of insurance and government aid support. This claim seems to be true from the study conducted on the challenges faced by the people displaced by Typhoon Haiyan in the Philippines (Baudot). Four million people were homeless and disaster recovery program forced communities to relocate away from the coast whose livelihood depends on the fishing industry. In addition, the country faced with challenges such as extended loss of electricity, water, and inability to access necessary infrastructures such as roads and bridges.

Another study paper (Guha-Sapir et al.) showed that the developing countries that were affected by natural disaster total number of people affected by disasters were

569.4 million. The same year, the U.S., along with China, India, Indonesia and the Philippines are among the most frequently hit by natural disasters. There is a significant number of people affected by the natural disasters are from countries that are heavily populated. In India, 330 million people, the highest number of people, affected by the drought. Three natural disasters killed more than 500 people in the countries Ecuador, Haiti and Korea (Guha-Sapir et al.). The direct and indirect economic impact of natural disasters caused by the damages to the infrastructure such as housing and agriculture and the livelihood such as loss of revenues, unemployment and displacement requires attention from international humanitarian assistance. In my analysis, I found that natural disasters caused by the weather and climate are increasing causing huge economic losses as well as life losses. In the next chapter, I will focus on Humanitarian organization, challenges and opportunities.

3. Humanitarian Organization

Humanitarian organization is required go through the complex process to respond to any natural disasters. Majority of activities for natural disaster response operations will require the humanitarian organization to customize the level of preparedness and planning depending on nature and speed at which a natural disaster occurred. The Humanitarian logistical challenges are always complex and daunting; humanitarian actors on the ground need to make difficult decisions, often under time and resource constraints. So, it is important for the actors to be knowledgeable about the principles that are the foundation of humanitarian work and can be an invaluable tool in responding to the natural disasters. OCHA brings together humanitarian organization using cluster method for coordination within various levels of information management for assessing situations and needs, monitoring progress, and mobilizing funds ("OCHA Humanitarian Assistance for

Figure 2: Humanitarian Programme Cycle

People in Need"). The OCHA's objective is to ensure that the humanitarian actors are prepared, plan, execute, empower, monitor and exit according as shown in figure 2("HPC Graphic 2014 (721×466)").

Emergency Response Preparedness (ERP) is a proactive approach to the emergency has three elements – Risk Analysis, Monitoring, Minimum Preparedness Actions, and Advanced Preparedness Actions and Contingency Planning ("The Humanitarian Programme Cycle"). ERP jointly developed for risk analysis, contingency planning, and integration of emergency planning and humanitarian actors are required to spend extensive effort in understanding government players primarily responsible for providing humanitarian assistance. ERP process is slower for the tasks performed to complete risk analysis and other elements required for natural disasters. The humanitarian organization not only spend extensive time but also require to invest in a team with individual expertise in areas specialized in food, water, and medical needs.

3.1 Analysis of Humanitarian Disaster Response

IASC humanitarian programme cycle step by step logical building blocks to ensure the response is delivered in need to people affected by disaster ("The Humanitarian Programme Cycle"). Each element within the cycle face challenges with assessment, planning operations, coordination with other organizations and reporting.

When the natural disaster, such as hurricane, earthquake, or humanitarian emergency, the humanitarian organization work together to quickly and accurately assess the needs and determine the required supplies using the local expertise. However, the assessment tends to vary a lot that is based on rough projections or using the historical data from previous weather and climate disaster. Humanitarian actors also challenged working the affected area when the physical infrastructure such as road, bridges and airports are not functional and transportation is extremely limited. Inter-Agency Standing Committee (IASC) that needs assessment and analysis must consult with local governments which may be severely impacted and may not be willing to provide an actual and accurate assessment to disseminate information that is required for preparing a response plan.

According to Financial Tracking Service website that tracks humanitarian aid flow for each country reported $11.4 billion unmet requirements with 48% not funded for 2017("Global Humanitarian Overview 2018"). Low levels of funding are affecting assistance in many areas including the where communities are displaced. The report "Global Humanitarian Overview 2018" findings show that in Aug 2017 only half of the children treated for malnutrition. The report illustrates with few communities thrived when sufficiently funded and when the humanitarian assistance was able effectively to deliver results. Natural disaster causalities such as human suffering when covered in the news and media get immediate attention from the other countries in stepping up and mobilizing the funds.

One of the challenges in a delay in funding or under funding will affect the mobilization of supplies to the disaster area. First all participating humanitarian organizations need to complete assessments then using the assessment report to request raise funds that be appropriated to the disaster relief needs. While the credibility and accuracy of the needs do have influence in donor decision making process but the securing funding after assessment will slow the disaster relief("Characterising a Slow-Onset or Protracted Humanitarian Situation Clarifying the Scope of the L3 Declaration").

Natural disasters such as hurricanes, typhoons and other weather events are increasing in a number of developing countries and smaller economies can affect the economy and social unrest (Baudot). Humanitarian actions that are currently in operations needs to shift from post disaster response to make decisions about how to avoid recurrent extreme loss from natural disasters and to support early action humanitarian response. There is the need for improved understanding of natural disaster risk in all its dimensions of exposure, vulnerability and hazard and the strengthen the disaster risk governance.

Sendai Framework for Disaster Risk Reduction (DRR) focuses on the existing challenges in natural disasters to develop components of early warning to prepare before the natural disasters (UNISDR). DRR Resilience is defined as: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions"("Terminology - UNISDR"). Some countries are committed to strengthening Early Warning Systems (EWS) based on the DRR framework in order to reduce the risks of natural disasters. The IFRC is addressing these natural disasters to better prepare with good forecasting model, develop better communication for actions and investment in disaster preparedness at all levels – community, local and national to address disaster risk reduction as well as the necessity to achieve the Sustainable Development Goals (SDG) (*Resilience : Saving Lives Today* ,).

3.2 Early Warning Early Action

The International Federation of Red Cross and Red Crescent Societies (IFRC) has built numerous initiatives and invested in early action to prepare the communities for the before the onset of natural disasters(IFRC). Early action activities are implemented in a variety of sectors to rapidly and effectively increase the people, money and materials, depending on the projected scenarios, the livelihoods zone, and the context of disaster.

It is a paradigm shift for IFRC to invest in EWS in preparedness and early response rather than a traditional approach to focus on post-disaster response and long-term preventative measures. IFRC Climate Center has a wide range of solutions such as computer models and satellite images and leverages expertise from national meteorological offices and other government agencies, local field reports to provide early warning for the communities. The objectives for early warning and early action are to leverage the scientific information to appropriately make decisions and develop solutions that will address the four priorities from DRR framework – Understanding the disaster risk, strengthening the governance, investing in disaster risk reduction for enhancing preparedness.

Humanitarian needs for natural disasters require good prediction models to be developed by the scientists and organization. The humanitarian organization needs to be nimble in responding to highly complex information associated with the context of natural disaster response. The early warning and early action system need to have decision making and transparency mechanism in place to enable the support required necessary for wider application in facing the impacts of frequent natural disasters.

IFRC needs a better protocol, flexible technology solution, novel knowledge sharing and management and effective use of communication to address the following questions.

- Whether the level of preparedness and planning could accurately predict the path and occurrence of natural disasters in order to address activities before the natural disasters?
- Are there better methods and technologies can solve complex humanitarian financing to bring aid prior to the natural disasters?

Early Action and Early need to leverage scientific knowledge and technology to facilitate ongoing learning and measurable improvements to address preparedness for humanitarian action before the natural disaster hits the exposed population. The implementation still requires coordination and will require depending on several aspects, ranging from availability of risk information and potential stakeholders' participation in addressing the humanitarian needs. In the next session, I will look at Forecast-based Financing (FbF) interventions method developed by IFRC to the achieve the targets agreed in the Sendai Framework on DRR and answer the questions whether FbF can potentially transform the current humanitarian system.

3.3 Forecast-Based Financing

"Forecast-based Financing (FbF) is an approch that uses climate and weather forecasts to trigger timely humanitarian action, before a hazard hits the exposed population (Coughlan De Perez et al.)." FbF system act on early warning threshold, which are different for each classification natural disasters and the accuracy of prediction is important for preventive actions (*'Forecast - Based Financing '*). FbF system would require to analyze the risks based on the forecast, communicate information to affected areas effectively, trigger response for appropriate actions, disburses required funding when threshold forecasts are reached, and execute standard operating procedures to mandate to act when these threshold forecasts are issued (*'Forecast - Based Financing '*).

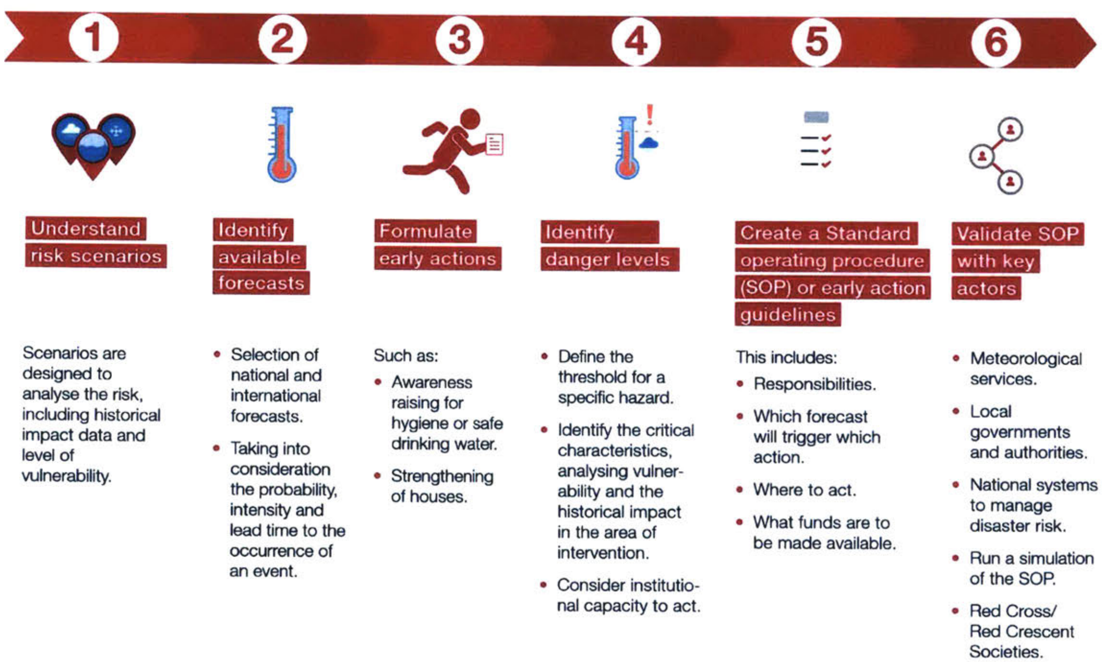

Figure 3 Forecast-Based Financing - An innovative approach

Figure 3 ("DRK Manual | Manual") illustrates the innovative approach on how the humanitarian funding based on forecast information can address the challenges when financing option is only available after the natural disaster strikes. "The FbF has three components triggers, selection of actions and financing mechanism that can be summarized to one method called Early Action Protocols (EAP) ("DRK Manual | Manual")."

3.4 Analysis of Forecast-Based Financing System

EAP is social-technical system includes the community of donors, scientists, humanitarian actors and local authorities who are responsible for completing their delegated functions before the natural disaster and when the trigger is reached the threshold. An integrated system where all the participating stakeholders whose roles and responsibilities are defined to take part in coordinated dialogue process for technical and financial coordination. The alliance requires FbF mechanism to be adaptive working at national and local levels of the community and accuracy to the prediction disasters where the loss-avoiding action is possible.

There is not the much humanitarian organization has a mechanism in place to act before natural disasters. The criteria to design FbF intervention to develop strong analysis model to predict the disasters and to generate information for building capacity and measure impact.

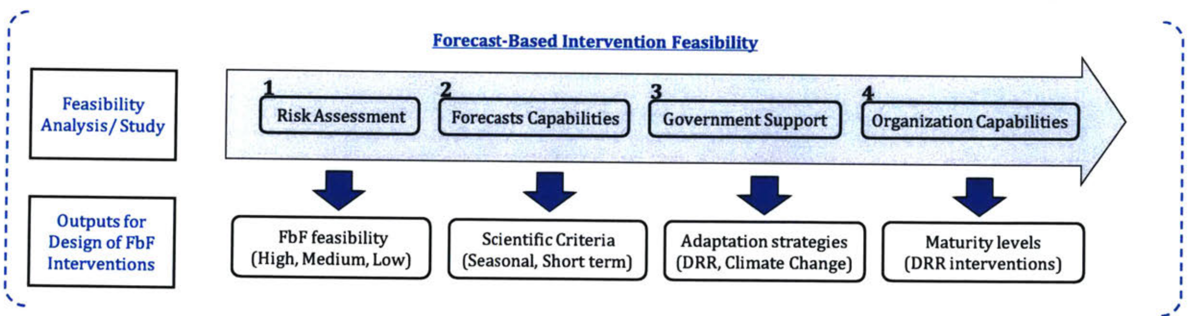

Figure 4: Criteria for identification and design of Forecast-based Financing interventions

Before the FbF intervention can be implemented for country and region, a feasibility study is required to understand risk assessments for the feasibility of FbF, analyze the current system reliability of a forecast, review government adaptation strategies of DRR and other intervention programs in the respective region or country and explore the capabilities for FbF supporting organization.

FbF interventions require strong evidence-based information system and robust coordinated process in place to ensure the stakeholders participate and take actions throughout the process. In order to encourage the stakeholder participation in technical and financial coordination, IFRC and Climate Centre developed methodological guidelines based on the lesson learned from Pilot countries Peru, Togo and Uganda. The pilot program objective is to manage and increase confidence in FbF.

- Impact research on forecast-based actions
- Comprehensive risk assessments to select danger levels and actions
- Cost-benefit analysis of actions
- Forecast verification analysis to allow high-cost actions
- Test of prototype EAPs and actions

In the context of developing the robust EWS, the impact research will aid in defining the danger levels that can be used during the risk assessments and help prioritize early actions. Cost benefits compare the cost of actions before and after the disaster to provide justification for FbF. The availability of risk information and engagement of stakeholders are required for monitoring the actions, dissemination of funds, and responding to take actions.

The FbF system the uses the climate and weather forecast to enable timely response for disbursement of funds and implement preventive actions. Classification of Natural disasters (EM-DAT) has differing rates of onset and impacts that require different types of warnings, lead times for mitigation and preventative actions.

Climatologist and meteorologists deal with large and complex systems involving more variables that can be handled analytically, and predictions are not accurate enough to take action might cast doubt on the prediction. There are a number of factors need to be analyzed and actions are taken for FbF to be successful.

A collaborative research study by the University of Reading (*FORECAST- BASED ACTION*) covers in details the aspects of setting the probability threshold in EAP, deciding which magnitude to set the appropriate level of disaster to trigger in EAP, necessary preparation steps for FbF actions. Designing the preparedness actions will come together on a response plan ince necessary steps are formulated. In the final step is developing cost for the actions for preparedness or preventative actions.

Cost of preparedness or preventative actions is much lesser than the cost of responding to the natural disaster and rebuilding infrastructure cost. This is a new type of financing where the funds will be available for disbursement only when a forecast trigger has been reached, at which point the appropriate amount of money will be released to carry out the risk-reducing action based on that forecast.

The necessary steps for FbF action will be worthwhile when acted upon and disaster materialized. However, when the forecast predictions are not accurate and then preparedness actions will go in vain. These actions will onset bad publicity on the decision makers including the humanitarian actors. So, it is important to get participating stakeholders to agree on the proposed actions that were calculated based on the probability and magnitude during the EAP.

The table adapted from Suarez and Tall (2010) depicting the possible scenarios for forecast-based actions and benefit of funding for early action based on the trigger will outweigh the cost of acting in vain (Coughlan De Perez et al.).

	Does the extreme event materialize?	
	Disaster	No Disaster
Action	**"Worthy Action"** *(Decide to act, then event materializes and losses are avoided)*	**"Act in Vain"** *(Decide to act, then event doesn't happen – perceived as wasteful)*
Inaction	**"Fail to Act"** *(Decide not to act, then event occurs leading to avoidable losses)*	**"Worthy Inaction"** *(Decide not to act, then event doesn't happen)*

Figure 5: Illustration of possible outcomes of forecast-based action

In my analysis, I found that the three components of FbF for preparedness or preventative actions requires following the necessary steps. The first component is to identify the different classification of natural disaster and forecast probability and magnitude for a trigger for action. The second component is to ensure that actions taken by the decision-makers and stakeholders would be appropriate based on the trigger. Finally, the third component is to have a mechanism for disbursement of the required funds in order to carry out the appropriate actions when the forecast is triggered.

I also learned that FbF in operational context on what challenges are encountered in linking actions with forecasts and coordination with stakeholders. The first challenge involves in the complexity of the model that calculates the probability of various natural disasters. For different classification of natural disasters, there are many different with features, functions and variables that need to be translated into a probability of impact. The second challenge is with the selection of an action for developing risk assessment and cost-benefit analysis to formulate necessary actions. To collate the data required to perform the necessary validation for a given probability and magnitude of forecast and defining the roles and responsibilities of the stakeholders. There are also institutions and political barriers to using forecast information when the given consequences of acting in vain. Lastly, developing the flexible funding sources for forecast-based early action and mechanism by which funding is released based on the agreement tied to the trigger and the action performed by humanitarian actors.

In the next session, I will explore the FbF Stakeholder to understand their roles and responsibilities for interventions.

3.5 Forecast-Based Financing Stakeholders

To better understand and diagnose the mechanics of FbF system and its operations, it is important to understand interactions of identified stakeholders within the network and the roles of government and other organizations. Primarily, it is imperative to perform stakeholder assessment, which includes identifying the needs of stakeholders, stakeholders' functions, areas of intervention within the network, and the reasons for stakeholders' interactions within FbF. The critical relationships and value flow within the network will provide robust frameworks for better designing the future Forecast-based solutions.

FbF three components triggers, selection of actions and financing mechanism requires interactions with stakeholders: Climate Centre, IFRC, Governmental

Organizations, Other NGOs and UN Stakeholders for sharing information, getting approvals or agreements and engaging humanitarian workers. The stakeholders identified are working with objectives to prepare and respond and take the necessary timely implementation of actions, while maintaining transparency and accountability with donors and communities.

The Climate Centre works with IFRC and other humanitarian agencies to reduce the impacts of natural disaster events on vulnerable people who are confronted with challenges living in along coastlines or areas vulnerable to natural disasters. IFRC works with the key stakeholders who have sufficient power to compel influence and willing to put their goods and services for responding towards the objectives of DRR.

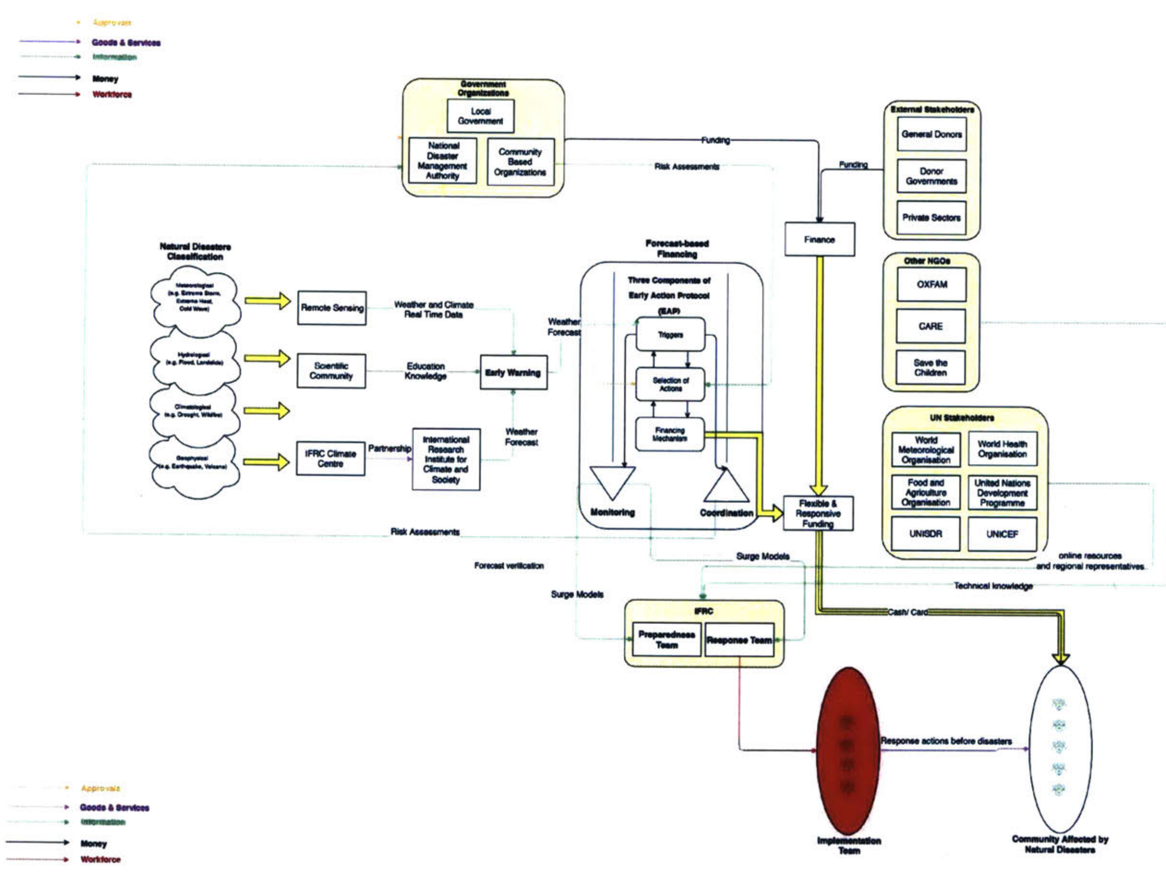

Figure 6: Early Action Protocol and FbF Stakeholders Interactions

Climate Centre is working with governments and disaster management agency whose plays the primary role of contributing to the DRR approach. Local government is influential to leverage military for a rescue effort as well as provide useful equipment required for the relief effort. Local government can employ local community-based organizations who can provide intelligence and background the potential disaster-prone areas. Some community-based organizations already set up operations, and coordinate with local groups, partners in terms of providing assistance and maintaining good communication with the local groups.

The national disaster management agency plays important role respond to natural disasters and they can determine what best ways to coordinate, distribute and monitor all the different organizations participating in humanitarian actions which must meet agreed upon standards.

Other NGOs have considerable experience in providing technical knowledge on approaches to disaster risk reduction, methods to communicate and useful online resources and materials. UN organizations representative can provide information that can be used for activities such as the development of a background document, humanitarian diplomacy, and communications materials.

The key stakeholders, Local Government, Disaster Management Agency, Local Community Partners, Other NGOs and UN Organization are essential for effective action within the FbF systems. The focal point to reach an agreement between the stakeholders based on the interpretation of probability and magnitude of the prediction requires a tremendous amount of resources and time. FbF mechanism is structured to organize the critical stakeholders and establish collaboration for the anticipatory actions and invest in additional aspects such as human capacity, technological and scientific capacity, infrastructure, communications and information management, and equipment. Finally, additional structure is required for governance to timely and adequate disburse for funding before the event of natural disasters.

This decision-making process involves a complex interaction between stakeholders covering government, scientists and humanitarian workers. The combined model analysis is complex; requires multiple statistical variabilities to formulate Disaster

Risk Index (DRI) and data analysis using the climate and weather data to develop the probability and magnitude is not robust. The current process emphasis involving multiple stakeholders to perform additional qualitative analysis to make decisions. There is a need for comprehensive information management systems at a national level that can be used for communication between stakeholders and performing aggregated risk assessments. In addition, information and data collected on vulnerabilities require transparency to avoid institution and political barriers and avoid using uncertain information. Finally, FbF is currently deployed and improved iteratively based on evidence of the effectiveness of early humanitarian actions. There is a need for better solutions that can improve traceability and enforce trust in the mechanics of Forecast-based Financing.

4. Blockchain Technology

Blockchain original inception was part of the digital currency Bitcoin built with capabilities to provide with identity, perform record keeping. Distributed Ledger Technology (DLT) has shared transaction database, with the ability to update the ledger with consensus and record the ledger with timestamped with unique cryptographic signature and in tamper-proof auditable history. The blockchain is one of the type of DLT with one additional feature to sequential updating the database records in a chained cryptographic hash-linked blow. The blockchain is now finding a wide range of applications in finance, property, contracts and identity. Use cases in payment services - the movement of currencies, supply chain tracking - goods and secure data are designed in a way that makes the transaction immutable and visible by other participants in the network. In this chapter, I will cover how the blockchain technology works, discuss seven design principles and underline the implementation challenges.

4.1 Blockchain Process flow

Blockchain where the blocks are added to the chain, which contains transaction records securely using cryptography. Blockchain provides a secure way to establish a trust for movement of money, assets and information could revolutionize the way business, government, organizations, and individuals work together. Blockchain application is decentralized and verification is done via consensus of multiple users in contrast to the majority of transactions that are verified and stored in a centralized organization.

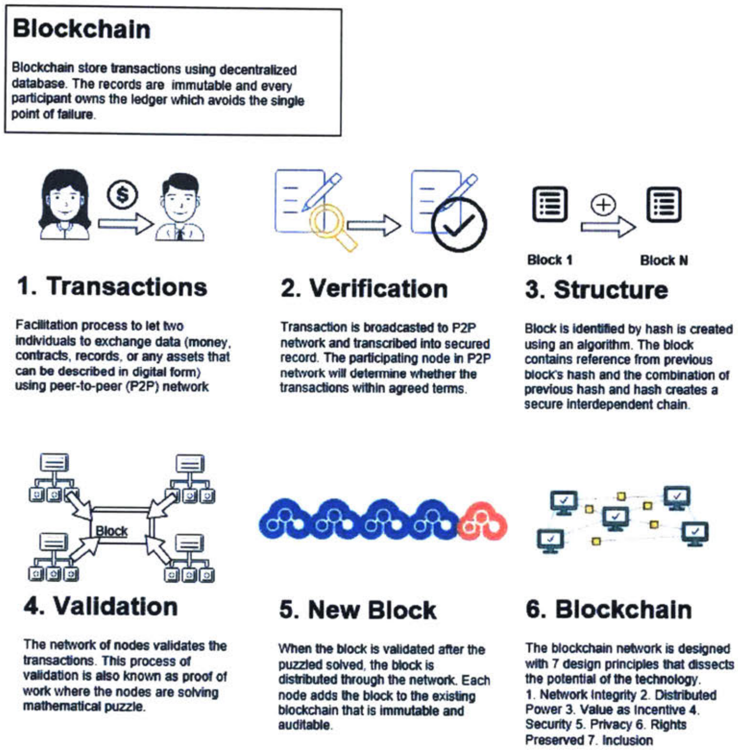

Figure 7: Blockchain Process Flow

Blockchain transactions are recorded and shared with other computers in the network. These transactions are recorded with a timestamp and combined with other transactions into a block. The updated block will hold all the transactions in sequential records with no duplicate entries. The completed block is sent to the network where the block is appended to the chain. At the same time other participants updating their own blocks will be placed in right order to the chain organized by timestamp. The hash function takes the information in each block and creates the hash which is cryptographic security makes the link between the block virtually unbreakable. An important step is to take hash from the previous block to create a new hash and this of hash function process continues throughout the chain. This feature will deter any attempt to alter previously created block since the hash that is encoded in the next block won't match anymore and the mismatch will continue through the subsequent block denoting an alternation in the chain. All the participants within the network holding the copy of entire blockchain will be able to detect the tampering. This is feature ensure to create a trust of the records stored in the blockchain.

Blockchain can also help to remove bottlenecks in the market where multiple parties are involved as intermediaries. Blockchain can bring in efficiencies to the systems can help to avoid errors, delays, added costs and unnecessary risks. The blockchain potential is real and has many applications to real word transactions; however, the technology is still in the nascent state before blockchain can be wildly adopted. The blockchain is newer technology that has just begun and will continue to evolve. There are valuable use cases that are identified for using the distributed ledgers to advance into the new decentralized business model and this will require a transformation of many roles within the ecosystems.

4.1.1 Digital Identification

Digital Identification (ID) ensure secure and appropriate access to sensitive data to the approved users. One of an important use case that blockchain is exploited for digitally issued identification. Digital ID using blockchain can provide secure and protect sensitive information and also provide the ability to verify and connect members within the community to be able to exchange intrinsic values.

Current Digital ID has become ubiquitous and has many uses such as to access to bank accounts, purchase products on the website and access social media using computers and smartphones. Many of these Digital ID is not linked directly to government issued identity such as driver license, a passport which makes authenticity more challenging than physical identity. Some of the existing digital ID management systems such as dual-factor verification provides features reset a forgotten password and authenticating users with second factor identity. Companies with centralized database when it exposed to security breach will lose confidence with the customers and end up losing profits. Current digital ID has challenges with security, privacy and convenience with the limitation of using centralized database and inconsistent methods signup.

Blockchain that is decentralized can solve the existing digital ID. One of the objectives is to make use of government issued ID and improve the delivery of services in the public and private sectors. The hash function will accept the new block using the previous block to form a chain that makes the record impossible to tamper. The existence of the blocks will be transparent to the whole world, and others cannot claim once the identity established in the blockchain network. The privacy can be set to and only visible to authorized transaction recipients.

4.2 Blockchain Design Principles

Design principles are sets of guidelines, and considerations serve as a starting point for the creation of new designs to solve problems. Design principles help teams and organizations in the decision-making process and touch various disciplines, including behavioral science, sociology, physics, and computer engineering. The next generation of blockchain that designed is around well understood principles, advancement of computing power, and stimulated by the cheaper resources feeding the digital economy (Tapscott and Tapscott). Seven design principles from the "Blockchain Revolution" explains the virtues of blockchain technologies. In this chapter, I will summarize seven design principles from the book from what I have assimilated and in the following chapter I will continue to discuss how these principles can be prescriptive to designing for humanitarian actions.

4.2.1 Network Integrity

This is the most important design principle where network integrity is enabled with no single point of trust and no single point of failure. To understand network integrity in the blockchain, one needs to recognize the double spend problem. Digital currency cannot exist in multiple places, needed a digital ledger to hold transactions. In double spending problem happen when the system cannot resolve who is the actual owner of digital currency and risk and trust in the system. It is important that integrity of the system must be determined every step when dealing with transactions that involve digital currencies. One of the reasons this challenge happens due to the nature of digital systems where records, files and data can hold multiple copies and stored in multiple places. However, when dealing transactions involving digital currency, the technical solution must ensure money leave from one system to another system in order to complete transactions. Conventionally, this solution is provided when online payments and the transactions are cleared in the centralized intermediary system. The centralized system acts as a ledger to facilitate these transactions and is a single point of trust and failure. The breakthrough in the blockchain technology when there are no integration points or central authority required to verify these transactions. This is achieved by leveraging the two concepts distributed peer-to-peer network and consensus mechanism. The blockchain is able to achieve network integrity in the system with no single point of failure using this design concept.

4.2.2 Distributed Power

The advantage of centralized power lies in the coordination of efforts by the leader and typically follows a hierarchical structure. Centralized power resides on the actor who has power authority to maintain or cut off from the system. Centralized decision-making limits the ability to respond to highly complex information associated with local tasks. Distributed power can perform complex tasks without any intermediaries in the network where no centralized point. The incentive for distributed power comes from mass collaboration where the power shifts towards members in the system. The design principle in the blockchain offers the ability to be adaptive where members have control over the data and level of participation.

4.2.3 Value as Incentive

When the participants are acting on their own self-interest in the network, they have the freedom and power to choose the level of participation. There should value as an incentive to increase the level of participation. Governance can play a role in identity monitoring for the need to increase the number of unique users. In the distributed power where there are no centralized control or oversight within the network can be exposed to Sybil attacks (Tapscott and Tapscott). The reputation of the distributed peer-to-peer network will lose its integrity when forged with multiple identities. Value as incentive design principle requires an arrangement in the system to create a structure that aligns and maintains reward structure for all different stakeholders who are participating in the network. This structure aids in keeping the integrity of the peer-to-peer network and ensures participants actions to identify themselves without the governance as well as benefit the system thereby increasing the stakeholder's reputation.

4.2.4 Security

Blockchain technology uses public key encryption infrastructure (PKI) – public and private key. All participants in the network must use encryption infrastructure to send and receive transactions. The public key is known to all participants within the network and the private key is only known to the recipient. The use of a private key is to decrypt the encrypted message to a readable format. It is impossible to reverse engineer a public key to a private one where the safety measures are embedded with no single point of failure. This secured design principle can make transactions to be authentic and nonrepudiation.

4.2.5 Privacy

There is friction between privacy and identity layers. In the traditional approach organization adds more layers of protection to achieving greater privacy. The assumption was that data anonymization could protect privacy started to crumble when data scientist and security researcher were able to demonstrate re-identification using re-engineering principles to a certain degree of confidence. The system that can provide users to control own privacy gives the ability and freedom to choose what information to be shared. In the blockchain the option to separate identification and verification layers are separate from the transaction layer. The blockchain offers options to choose the level of privacy in order to maintain a degree of personal anonymity and doesn't store in the centralized database. In contrary to traditional approach blockchain data is not vulnerable to identity centric model which are susceptible to data getting breached. Blockchain offers flexible forms can help users to be selective and control their own data privacy.

4.2.6 Rights Preserved

Blockchain ensure to preserve the rights by confirming the rights registered that is cryptographically signed and tamper-proof. A special purpose code can execute complex instructions to enforce the contractual obligation involving multiple parties. The design principle of rights preserved by guaranteeing the transactions is immutable and irrevocable to confirm the rights in any type of trades such as real property and intellectual property that is stored in digital contracts. Blockchain solution can be developed for digital rights management with the ability to trace the right owners and improved in copyright ownership.

4.2.7 Inclusion

The key construct of blockchain distributed ledger, security and network integrity provides a great window of opportunity and lower the barriers for unbanked individuals to participate in formal financial systems. The blockchain can provide powerful remittance service in addition to providing digital identity thereby reducing frauds and mistakes in the transactions. The design principle for inclusion is multiple dimensions to the problems that bring speed and transparency to make solutions.

4.3 Blockchain Classifications

The key categories to classify the blockchain is established based on which who have access to manage consensus within the network. The governance structure determines the authorization and the control policy management functions. This structure provides permission for which users have read and write access. In addition, there are rules to manage the users, system and node permission. The consensus agreement defines the set of rules where transactions are independently updated by the nodes in the distribution systems. Based on the user permission to read, write and consensus agreement the classification are permissionless and permissioned blockchains

1. The permissionless Public blockchain is the for anyone can read and write into blockchain and uses consensus algorithm for any given set of participants. In public blockchain any peer can join and leave the network at any time. There is no central organization which manages the membership.
2. Permissioned Private blockchain where the read, write and consensus are managed by the central organization. These selected members can record transactions and can only be read by the members of the organization. The use of private blockchain can be supported centralized database where only the authorized set of readers and writers and the central entity decides and attributes the right to individual peers to participate in the operations.

3. The permissioned Public blockchain is where anyone can read the blockchain and write and consensus are managed by the central organization. In this type of blockchain every participant can choose just using the network for information retrieval.

The blockchain Bitcoin and Ethereum are instances of permissionless public blockchains, which are open and decentralized with ability to participants to join or leave the network. The use permissioned private blockchain will only make senses for the interaction require multiple mutually mistrusting entities to use data. Alternatively, the regular database can be better suited as it provides better performance in terms of throughput and latency. A permissioned public blockchain system the method of consensus is generally less computationally intensive. In this situation the trust is not extended to all users and the maintainer of the blockchain to designate a limited set of mining nodes.

4.4 Blockchain Applications Beyond Digital Currencies

Digital currencies with the distribution of a global ledger containing all transactions were one of the first application to be using the blockchain technology. There are many potential use cases for blockchain technologies and it is important to understand that the blockchain technologies network integrity, cryptographic, and recordkeeping can potentially release an important element of creativity and invention for anyone who can understand the design principles and develop applicable use cases in financial and supply chain applications. The traditional business model needs to adapt and to focus on the design principles for value exchange and not as a centralized store value.

Blockchains can be used in digitizing assets other than currencies maintain a public record, such as holding the land title, marriage, or birth records. Blockchains also have strong potential for storing and recording supply chain records in each step of the product lifecycle from the origin to the destination. The other applicable industries, such as digital notaries, insurance and clinical trials where blockchain does have the power to disrupt. The potential use case of blockchain can also be extended to address the real-world problem in humanitarian, social, politics, economics and scientific domains. Blockchain technology can connect people and facilitate transaction without any intermediaries and can serve as the public records repository.

The blockchain enabled solutions is causing a proliferation of multiple use cases in various domains. The four blockchain application domains finance, property, contracts, and identity are worth looking how blockchain is transforming the business process. To highlight few examples cases that are applying blockchain to use payments and clearing process in finance, smart property for cryptographic asset registries, smart contracts for IP registration and financial clearing and identity confirmation. These use cases require being defined with a set of conditions where multiple parties agree and there are automatic trigger mechanics need to be placed for payments or completing the transactions. In the next chapter, I will discuss on how Smart Contracts can help to eliminate the cost and delay in these domains.

4.5 Limitation in Blockchain

Blockchain distributed ledger with no central authority has few challenges. The nature of distributed ledger with no central authority requires participants to keep track of transactions and ensure no double spending problem occurs. This is achieved by the miners who are operating fully functional nodes to settle the recent transactions in form of a block of data and process is repeated every ten minutes. In the public blockchain where anyone can see transactions, so using consensus method to reach agreement algorithmically is necessary step. Blockchain records must maintain in the participating node of full copy of transactions with all historical data. The limitation is when running the full nodes would be costly and required compensation for operations and maintenance.

Next challenge is latency is due to the process where the transaction confirmation process repeated every ten minutes and for larger transfer amount the confirmation can take more than ten minutes and may be even an hour to confirm. Transaction throughput is another challenge where blockchain transaction processing rate are slower when compared to traditional payments transactions system which takes only seconds at most for the merchants to confirm the transaction.

Finally, the consensus mechanism, require the full node participant to perform complex algorithm for mining. This process wastes an enormous amount of energy to ensure node performing POW effort with rationale get reward for the work performed and to make the node trustable. These are some of the potential limitation and blockchain is still in the early stages of development and other technical challenges such as usability, versioning, hard forks and interoperability requires additional technology solutions and infrastructures.

5. Smart Contracts

The term 'Smart Contract' was proposed by Nick Szabo, a computer scientist and cryptographer and his definition "a set of promises, specified in digital form, including protocols within which the parties perform on these promises (Szabo)". Smart contract is executable code that describes transaction step by step, connect multiple blockchains, and track multiple assets. Smart contracts using blockchain can be used to model the terms of a real-world contract and automatically enforce its clauses as contractual conditions that need to be met and the disintermediation of intermediaries from the execution of contracts.

Smart contracts can use permissionless blockchain where sufficient quantity of participants or nodes reach the consensus. Smart contract is also executable programmable contract that is capable of automatically enforcing itself upon the occurrence of pre-defined conditions.

A simple smart contract between two parties would consist not using any paper or electronic document but rather using executed code that validates the business rules and then applicable consensus protocol to determine the transaction to be added into the blockchain. Smart contracts can contain the same level of detail as a physical contract and perform tasks such as negotiating prices, tracking of supply chains and monitoring inventory levels. Blockchain technology allow the distribution of information without the need for distribution channels and the terms and conditions within the smart contract provides the trust and remove intermediaries to facilitate transactions, audit and control processes.

Distributed ledgers that enable smart contracts can lead to decentralization of a number of services, leading to gain efficiency and scalability. The financial services that can leverage the smart contract, are currently using the third party or centralized system for validation. The distributed ledger functionality of the blockchain can register, confirm, and transfer the contracts and allow peers on the network to interact directly.

5.1 Smart Contract Design Principles

Smart contracts alone cannot fulfil the executable contracts without the underlying component that does the modeling and automation of business logic and augmented with the components of blockchain such as public key infrastructure, cryptographic signing, hash functions and consensus algorithms. There are number of concepts about contract needs to be understood to define the design principle of smart contracts better. A traditional contract is an agreement and between two or more participants that is performed between people, organizations or both in exchange for currencies, services or agreements. The traditional contract is time bound and executed with the objectives to make sure that each participant in the contract trust each other and fulfill its side of obligation.

Smart contracts feature similar agreement between one or more participant and defined and enforced by the code. The three components from the "Blockchain: Blueprint for a New Economy" the design characteristics of smart contract are autonomy, self-sufficiency, and decentralization(Swan). Smart contract can execute automatically based on the initiating conditions and doesn't require for agent intervention. Autonomy enforces rules more efficiently than legal code. Second, smart contracts have set of capabilities built in the code to execute workflow reliably. The self-sufficient ability to initiate with information and pre-defined event will triggers raising funds by providing services and spending them on needed resources. Third component of smart contracts are decentralized which is one of characteristics of blockchain is the ability to allow self-executing of any type between any parties and does not require single centralized serve.

Smart contracts execute the prespecified code but, it also comes with a series of limitations. "Code is law to law is code" refer to the ideal state for smart contract executing the law but there are implementation challenges and difficulty to transpose the legal rules into formalized language (Filippi, Primavera De; Hassan). The paper provides four phase approaches to support progressive technology readiness for eventually move to law is code. In the first phase which is already in place where the physical papers are converted into readable digitized information. In the second phase is to translate legal provisions into computer code. There are few legal provisions that are existing in the system where the code is embedded into the rules engine and can be executed when right conditions are met. The challenges with this phase is where there are needs in the code to make exceptions for legal norms to be flexible and fact dependent. The third phase is incorporating rules into code which has entered into enforcing copyright laws. The advantage with this type of enforcement of regulation by code will ensure that laws are difficult to break in first place and avoid the situation for third party to enforce the law. The final and fourth phase where radically new approach where "Code is law" (Filippi, Primavera De; Hassan). In the phase where the legal construct is built into the smart contracts that can executed based on the three components autonomy, self-sufficiency, and decentralization (Swan) to be a replacement to legal contracts.

Bitcoin underlying blockchain technology is primarily used as digital currencies. Ethereum, another blockchain technology, is a programmable code based on same principles for peer-to-peer network protocol provides ability to use beyond the digital currencies and often referred to as smart contracts. Using Ethereum Virtual Machine (EVM), people deploy smart contracts to execute agreements between multiple participants. In the next session, I will cover the design aspects of decentralized applications (DApps) and decentralized autonomous organizations (DAO).

5.2 Autonomous Smart Contracts - Decentralized Applications

In the previous sessions, I described the design principles of blockchain and its application beyond digital currencies, and smart contract for performing verification and executing contracts. In this session, I will analyze to understand the decentralized network and its interfacing function to effective in building consensus. Decentralization can help to lower the friction caused by intermediation and in an ideal state of decentralized ecosystem where every transaction is supported in the network by every participant.

The distributed nature of the network requires collaboration of untrusted participants to reach consensus. In blockchain consensus is achieved by mechanisms such as Proof-of-Work(PoW) or Proof-of-Stake(PoS). There are many other mechanisms that are developed and used for consensus and PoW and PoS are two top popular choices. The consensus process ensures the immutability of the database. When a node is created more than fifty percent in the network needs to agree on the transaction to be accepted. The new blocks that is added to on the end of the chain with many nodes at once will use consensus mechanism to decide which block is accepted by the network. Bitcoin uses PoW algorithm, where nodes must prove by solving complex cryptographic puzzle to partake solving the block and reward with incentive. Other blockchain systems use PoS algorithm which requires that node prove to hold enough asset in the system.

There are many decentralized solutions or applications using the blockchain and trustless transaction that are solved by consensus algorithms notably PoW. The Ethereum protocol is Turing-complete computation that is executed on a global Ethereum Virtual Machine(EVM). EVM features includes scalable computation, and network connectivity, blockchain-agnostic and protocol-agnostic platform for application to write and execute smart contracts.

Yet another popular file serving concept that leverage blockchain architecture and decentralized secure file sharing. Inter Planetary File System(IPFS), leverages not only blockchain for peer-to-peer file-sharing technology but also use the tree and versioning functionality of Git (Swan). One of the use case for IPFS is to use peer-to-peer publisher/subscriber model where the provider and subscriber can establish encrypted bi-directional connection and execute contracts or transactions.

Decentralized applications (DApps) self-contained entities based on design principles of blockchain that runs on a network in a distributed fashion with participant information securely protected and operation execution decentralized across network nodes(Swan). There are slightly different variations of decentralized applications. The self-contained entities are automated smart contracts are conducting pre-programmed operations. DApps has two components: autonomous agent is the node which provide computation, storage or any resources and blockchain will handle the incentives and cryptographically stored data in a public, decentralized. DApps must adapt its protocol in response to proposed improvements decided by the majority consensus in order to continue the participation with the network.

5.3 Limitation in Smart Contract and Decentralized Applications

The smart contracts are immutable records and historical data are traceable; however, linked and traceable transaction does not necessary mean faster settlement in case of dispute. Here are some of the challenges:

The smart contract is not smart legal contract in all aspects of traditional legal framework. Smart Contract requires steep learning curve and will take time to overcome different challenges to transform the existing systems and process. There is progression for technology readiness and learning curve to allow operating smart contract autonomously and replacing traditional legal contracts.

Smart contracts in Ethereum networks have forked its open source implementation have been identified one of the limitation to deploy smart contract. One such example, Distributed Autonomous Organization (DAO), a venture capital fund was hacked. The transactions represented by smart contracts was susceptible to high risks of losses. In this situation Ethereum went and changed the code to reverse the transactions. The limitation exhibited by this attack is when immutable record was changed against the blockchain design principles. The complexity involved in enforcement of legal contracts and dispute resolution require for some application to wait until legal and regulatory authorities catch up fourth phase of implementation "code is law" (Filippi, Primavera De; Hassan).

6. Designing Forecast-based Financing using Blockchain

Using blockchain and smart contracts requires careful consideration for what classification of blockchain need to be customized and what design principles are important and necessary to fit the needs of the large global highly regulated organization. The need for Humanitarian organizations are different from the needs of individuals who are using blockchain such as Bitcoin to transfer value between peer to peer network. Humanitarian organizations are structured with accountability and collaboration and hold digital information where the funds are from, where the funds are going and progress on appeal with high degree of auditability. The virtue of IFRC is to efficiently and effectively coordinate humanitarian response as well as sharing of operational information with local government and regulators. IFRC join with community partners to fulfil important obligation of providing communication on what relief workers are doing with the affected community and comply with local laws.

The governance framework collective control over who can transact on the network and applicable selection of action within the limit to rule of laws and jurisdiction. The contract should be follow the data domicile restriction of privacy and confidentiality that must be preserved all the times. The design features of the smart contracts must be modified to suits the needs of local laws. The distributed and encrypted processing platform where the humanitarian actors are able to view the golden source of transaction records. The participants for the transaction has the same ledger information and records are kept by every stakeholders are consistent.

Here are the features that can customized to meet FbF in the smart contracts.

- Auditable – Local Government and UN agencies can review reporting and compliance in real-time, rather than days or weeks after transactions are complete.

- Confidential - Sensitive, contractual information is only ever shared with participating stakeholders who entitled to see it. Stakeholders must be assured and notified of all events requiring their decisions
- Analyzable – IFRC and other stakeholders can run reports against historical records of all previous agreements and analyze all future potential positions based on current agreements.
- Common Workflow - Common business workflows are in place for approvals and independently verified by every stakeholders involved in an agreement to ensure systems are never out of sync.
- Extensible - The platform serves as a common foundation which can be extended with additional functionality.

6.1 Key Requirements for Forecast-Based Financing Intervention

The preparedness actions for the natural disasters needs to be implemented in timely manner to minimize the impact and to ensure that recovery is effective. The criteria to design FbF invention requires to consider the worthy action to act based on the certain thresholds as well as appropriate decisions to be automated in real-time. The objective for designing FbF system is to automatically activate smart contracts for funding mechanisms based on the availability of the risk assessments and forecast information. Lesson learned from the pilot studies suggested two critical goals must be considered as key criteria. One is to ensure that participating stakeholders are engaged to provide consensus based on the predetermined triggers. There are many stakeholders especially regulatory stakeholders require additional steps to complete pre-conditions and these steps can be gathered and analyzed outside of smart contracts. The logical steps such as identify appropriate actions for preparedness at community, governmental and organizational level are required pre-conditions that can be codified in smart contract for coordination mechanism and perform validation automatically.

Transaction model can be traditional distributed private ledger for the kind of coordination and validation process instead of typical blockchain technology that use Unspent Transaction Output (UTXO) which is primarily used for digital currencies. The Smart contracts need to be initiated by satisfaction of certain conditions in event of natural disasters and code can be written in a way to trigger automatically perform transactions when the conditional parameters are met. The consideration of smart contracts in FbF is ability to orchestrate between stakeholders, ability to provide validation based on the decision rules and provide visibility between two or more stakeholders based on the visibility rules. The timing for the trigger mechanism to use when threshold is reached would require interoperability functions known as "oracles" which will feed from the forecast prediction information into the ledger to facilitate the trigger for smart contract funding.

6.2 Workflow and Timeline of Forecast-Based Financing

In this session, I will discuss about assessment necessary to identify the hazard, vulnerability and exposure and information that is necessary for decision makers to define areas of intervention. Understanding the workflow and timeline can help to design conceptual and logical architecture of FbF using smart contracts. The objective is to be able to automate decision making process and execute tasks, when the pre-defined conditions are met, that are often embedded within, and performed on, in the blockchain.

The workflow outlines the decisions and process steps to prepare, deliver and respond financing and help the humanitarian teams to decide and prioritized early actions and preparedness required for response actions. The use of workflow will lead to clear understanding where smart contracts can be used and design to execute tasks when the pre-defined conditions are met.

There are two types of transaction workflow that enables humanitarian teams to carry out early actions which act upon forecast information to enable key stakeholders to prepare and execute the FbF.

- Menu of triggers – to define early action steps for prevention and preparedness response for effective disaster response

- Early Action Protocol (EAP) – step by step process and guidelines that is triggered when the forecast reach predefined danger level takes and to action with the funds.

To understand the activities involved in the transaction workflow, I analyzed the necessary steps involved in menu of triggers and steps to make decisions for EAP. The diagram best illustrates the time period when the preparation phase begins and followed by preliminary phase and get ready phase where the EAP is executed based on the Menu of trigger. The two phases provide the options for decision makers to decide which trigger to select for each of the prioritized early actions and preparedness for response actions. Based on the menu of trigger, the humanitarian actors will get to ready phase which starts from 96 hours to 12 hours before the predicted natural disaster. In this phase, EAP is the step-by-step procedures for actions to be implemented.

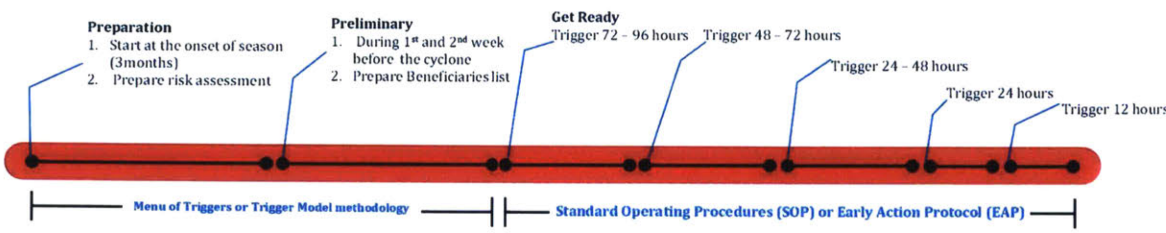

Figure 8: Timeline view of Forecast-Based Financing

In the preparation phase, the steps that are involved to review and analyze the available early warning system, to identify the level of forecast available for the classification on natural disaster and accessibility and coverage in the national and regional levels. The forecast availability and local expertise are necessary to defining the danger level (DL). DL represents the magnitude of the natural disaster that will lead to impact agriculture, infrastructure and people. DL is defined based on the risk and vulnerability assessments that helps to identify and define the thresholds for a specific natural disaster. In the current process, community consultation is part of the process to define DL as well as taking political decisions and consensus among key stakeholders.

DL provide the threshold based on the assessment and it is important to know the probability of crossing the danger level. This will ensure the accuracy of forecast information for the intervention is reliable. Finally, to put together menu of triggers can be done based on the different available lead times, the type of actions that can be taken between the trigger and the event. The accuracy of the forecast and lead time can help the stakeholders to choose feasible actions to prioritize early actions and preparedness.

Menu of trigger has three criteria ("DRK Manual | Manual"):

- Lead time - time between the issuance of forecast and the occurrence of the natural event.
- Accuracy – Probability of crossing the danger levels. The hit rate and False Alarm Ratio.
- Frequency – How many times trigger can happen in a given year.

In the get ready phase the last of the three phases is when the lead time, accuracy and frequency to take action when there is a forecast expectation of exceeding damage levels. The preparation starts as early as three months onset of season, where the humanitarian organization performs the assessments and analysis to design of a menu of triggers. In the next session, I will discuss design features of smart contracts where triggers can be part of operational aspects and automate smart contracts for funding mechanisms.

6.3 Funding Mechanism in Forecast-Based Financing

Since the inception of FbF, several pilot programs have been supported under the umbrella of its Action Plan of the Federal Foreign Office for Humanitarian Adaptation to Climate Change ("DRK Manual | Manual"). The pilot programs have been implemented in more than 15 countries and understand the working mechanism and bring awareness other governments.

Current humanitarian system focused to rise funds primarily after the disaster response. The donations are pledged and goods are delivered to the affected community based on the impact assessment. The assessment determines the necessary aid required and funds are disbursed late to the affected by natural disasters. The challenges in the current system often the appeal coverage is not enough to cover the humanitarian operation cost. The assessment process and historical data is not enough to forecast demand that leads to imbalance between the funds required and aid donation. The donor governments would provide funds at the earlier stages to start the funding process and then augmented with aid from the donors. Humanitarian organizations have been creative to use other strategies such as reaching to local community and using pooling funds for improvements in Humanitarian operations in natural disaster response and recovery.

In FbF mechanism, preparation and preliminary phase provides with prediction data to help determine with the probability and magnitude of natural disasters. The assessment process in the menu of trigger will also provide with how much money should be allocated to early action and preparedness. There is need for solution where the funding for FbF projects to be available to donors and private sectors.

The smart contracts can be used to automatically receive donation for donors based on the criteria on menu of triggers. Smart contracts with options to trigger early funding mechanism require to establish proper governance. The financial data can be managed and integrated with the governance required to feed smart contracts and report financial transactions to enable accurate recording of financial data.

The goal is to develop system to provide platform for donors to provide aid assistance for the anticipatory needs using smart contracts. Smart contracts will be only fulfilled once the menu of trigger is activated based on the criteria. This provides the ability to enable real-time evaluation of understanding the magnitude and also with ability to provide with real-time exposure monitoring. When EAP is triggered there are incremental get ready steps starts from 96 hours. These steps require funding to mobilize and surge in humanitarian actors. There options to automate using smart contracts based on event trigger and build consensus with stakeholders. In addition, the smart contracts can provide reporting transparency about regions that are affected by natural disaster and the donors gets visibility on how their aid money spent effectively.

6.4 Permissioned Smart Contracts for Forecast-Based Financing

Permissioned blockchain can be used where there are needs to build authorized participants consensus and share data across boundaries of trust, without requiring a central administrator. Most existing public blockchain protocols fail to meet the needs in where performance, confidentiality and strong governance are required. Permissionless blockchain achieve consensus where anonymous participants can execute transactions without trusted third parties. Whereas in permissioned blockchain network, participants in the network are identified and nodes are known and controlled to provide consensus mechanism.

In permissioned blockchain, the transactions that performed for assets exchanges can also provide immutable audit trails. The performance in permissioned blockchain are better when compared with public blockchain where full node required to run all the computation for the applications running on the network. Permissioned blockchain provide better governance and can be used to accomplish very specific needs and optimized to achieve solutions. The trust relationship between the participants in network can be tailored and guarantee with correct information thereby simplifying consensus and reducing duplicative validation.

Smart contracts on permissioned blockchains are tamperproof solution that no one party including the creator can alter the code or interfere with the execution. Smart contract administering digital agreement is self-executing and guarantee to bind all parties to an agreement as written. In contrast, centralized contract execution, there would be intermediator or agent who have rights to alter, terminate and delete the participants during the execution process.

Automation of smart contracts are designed with certain elements of contracting participants to automatically execute based on an event upon satisfaction of pre-defined conditions. Operational clauses within the contracts that are more suitable to automation and self-execution. The clause in the form of "if-this-then-that" conditional logic which can be specified event or time to execute actions.

Smart contracts need to interface with trigger or conditions logic that depends external information. The external information about the state of outside world to trigger certain instructions in smart contracts is known as 'oracle'. The rules based on the external information can be written in programming language and setup to accept by smart contracts using cryptographic signatures.

Using smart contract for FbF will require capability to disbursement of the required funds when the forecast is triggered. This is novel way financing for humanitarian action, in which funds will be available for disbursement only when a forecast trigger has been reached, at which point the appropriate amount of money will be released to carry out the risk-reducing action based on that forecast. Smart contracts automatically execute based on forecast trigger and the prediction must be accurate based on three criteria from menu of trigger. The probability calculated and stakeholders' approvals should be incorporated into the conditional logic for the trigger mechanism. In addition, funding needed for the humanitarian action need to readily available based on forecasted information. This funding is currently provided by donor government and can be augmented with donors and private sectors who can be involved in supporting the components of the EAP.

To develop funding mechanism using smart contract and oracle following conditions and criteria can be used for formulating:

- The probability threshold calculated in preparation and preliminary phase should be different for classification of natural disasters. Smart contract coding includes the probability threshold for various natural disasters.
- Defining the threshold for magnitude requires stakeholders to conduct assessment and will vary based on socioeconomic and demographic factors. Smart contract should expect the risk perception number from oracle to in order to execute the conditional logic.
- Lead time for preparedness actions the necessary steps to be enable in EAP when trigger is activated. Smart contract coding should include binary conditions and expect oracle to provide conditions met or not.

- Costs that are calculated based on the anticipated disaster during the preparation phase and follow the criteria to trigger funding mechanism. Smart contracts could enable to hold funds in escrow and once the required funds are met oracle can provide conditional approval to smart contact prior to EAP.
- Approvals that are linked to local government approval and supporting community prepared during the preliminary phase for surge capacities. Smart contracts need the necessary approval codes included during the preliminary phase to be ready state for execution.

Executing the smart contracts requires to perform complex computational procedures and must be designed with the consideration include the conditions. The parameters that passed from oracle to smart contract must be encrypted to prevent other participants or stakeholders to intervene. Executing oracle must be in trusted server and using permissioned blockchains is best fit to meet these conditions. The execution approach is that smart contracts cannot be formally verified before its execution. The oracle receives the contract call when the trigger conditions are met. The call data is decrypts and oracle proceeds to off-chain execution and returns back the results for executing the funding mechanism. The complexity in executing smart contracts based on the trigger conditions are complex and require human-centric decisions and oracle to act as the gatekeepers.

7. Conceptual Architecture of FbF Prototype

The process to develop conceptual architecture can be done by the analysis of the current system and constraints and followed by communicating the new concepts with design principles of new technologies or frameworks. In this chapter, I will use permissioned blockchain and smart contracts to describe of the proposed conceptual architecture for FbF prototype. This is my attempt to explore blockchain technology and smart contracts concepts and leverage the technology to address gaps in existing business models. In addition, this approach is to provoke interests for iterating better architecture and solutions that can be implemented.

Modular systems where the components are grouped with minimal dependency and all interactions between modules occur over these predefined interfaces. The following sessions are structured with developing modular system where each module perform one or a few distinct functions, connected to each other with a few simple and well-defined interfaces.

7.1 Forecast-Based Financing Blockchain Component

The two functions of FbF Blockchain component are the smart contract with required funding for specific natural disaster and oracle with required updated menu of trigger and required approvals from stakeholders.

The diagram illustrates Aid from donors as input into the FbF blockchain component and allocated funds to the predicted disaster region. The abstraction level in this illustration is clarify that smart contracts and oracle are function of demand and supply side of FbF. This architecture view is to understand the working mechanics of the innovative approach on how the humanitarian funding based on forecast information. The inner working of the smart contract and oracle require additional analysis and understanding of key functional design.

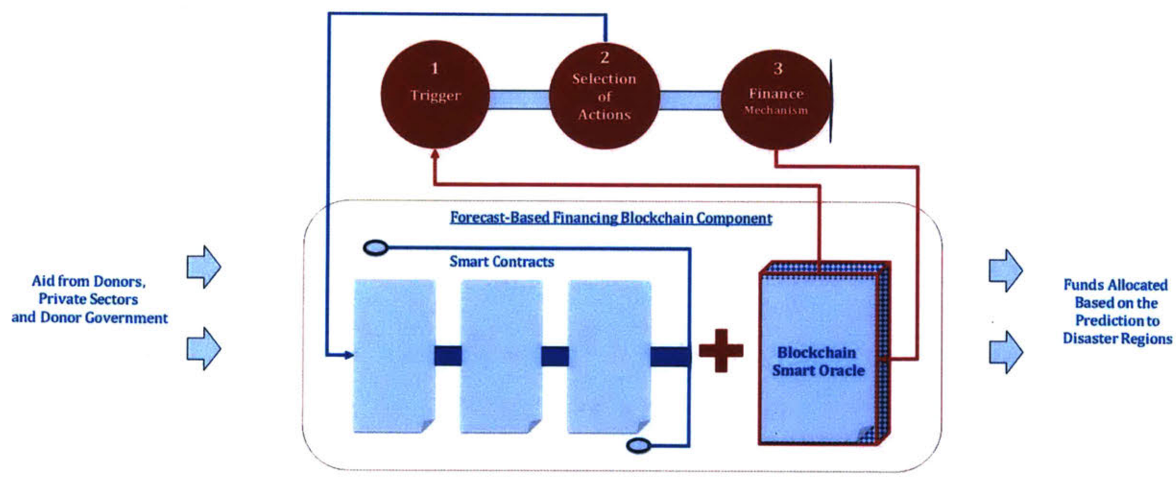

Figure 9: Forecast-Based Financing Blockchain Component

7.2 Forecast-Based Financing Reporting Platform

Current FbF depends on the aid provided by the donor government. The proposed FbF can provide the ability to transition from small pilot program to the traditional way of working. The FbF data stored in smart contract are golden source of transactions with auditable information and can also be analyzed. There is need to move beyond organizing pilot programs and leverage the options to improve FbF mechanism. The objective is to build performance or impact management progress, where the reporting on each project funded by FbF with specific metrics that provides ability to measure progress.

The diagram illustrates tracking and reporting for various stakeholders. There are reporting for aggregated risk assessments and disclosure reporting that can provide visibility to stakeholders and decision makers and understand the evidence based on what measures worked where FbF implemented. Information sharing and learning using the reports can be useful on developing the best practices and steps to incorporate into improvement of FbF. FbF action needs to be built with various levels of stakeholders to act in synergies in order to provide the necessary response. At donor level, information reporting on transparency with regions that are impacted and traceability of funds what is required by FbF can shift the responsibility with donors to take action be trusted partners.

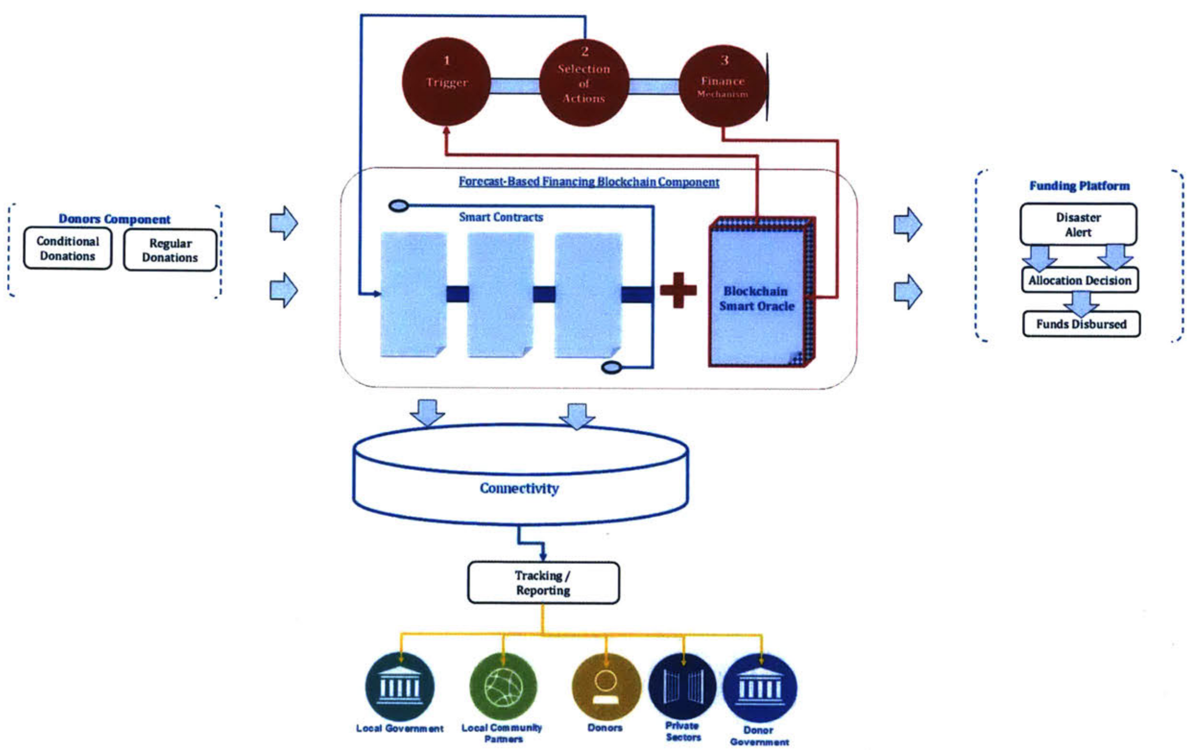

Figure 10: Forecast-Based Financing Blockchain with Reporting Platform

Using smart contract and oracle has potential to transform the humanitarian aid for early action and early response. Similar to financial agreements, funding mechanism can be created and automatically executed for participants to transact seamlessly based on the threshold without adding frictions or intermediaries. The blockchain technology is applied in various ways within the financial services. The humanitarian organizations are just looking ways to use blockchain to enhance transparency and accountability. I believe blockchain technology readiness will move up in the maturity and there would be ways for collaboration or building consensus with stakeholders and maintain, shared records of these agreements. I aspire to define distributed ledger for forecast-based financing use-cases that can be deployed within existing frameworks and which relies on proven technologies. Next steps would require to requirements elicitation from stakeholders, focus on non-functional requirements to develop detailed design before developing solutions.

7.3 Autonomous Weather Decentralized Applications

There are technological advances in DApps could be adopted alongside of smart contracts to enhance use of proposed FbF solution. One proposed solution is to develop prototype DApps for gathering weather data using autonomous agent. Weather Node DApps will leverage blockchain technology to run on the distributed network with each node will have weather sensor and agent to collect weather information securely. Weather Node DApps can be standalone and powered with battery without need of central database for data storage. The blockchain technology in Weather Node DApps can handle the identity of the weather node with public key and provide accurate weather data. The reputation of the node can be enhanced in the network based on the accuracy of weather data and blockchain can also handle the incentives for the DApps via micropayments. The objective is to bring weather data from sensor into the blockchain to apply design principle value as incentive and distribute power for robust weather tracking and collection. The illustration is high-level process diagram to explain working of DApps. Weather Agent creates

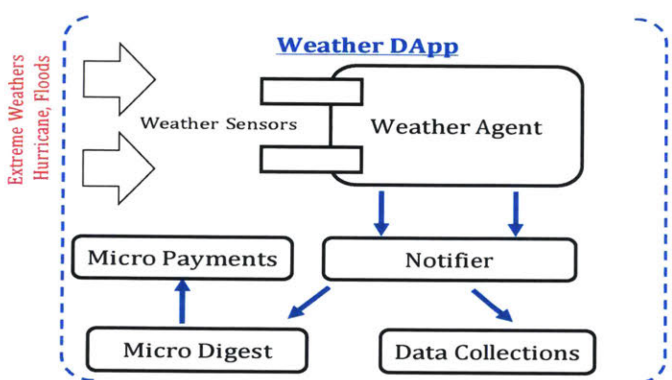

Figure 11: Weather Data Collection DApps

continuous event updates data from the weather sensor from any given location. The weather data will persist in the data stored pass via Data Collections before it is eventually written into blockchain. The blockchain will maintain, integrity, confidentiality and security for data stored. The Micro Digest allows the entity to become weather provider to receive micro payments based on the accurate forecasting of weather in the region.

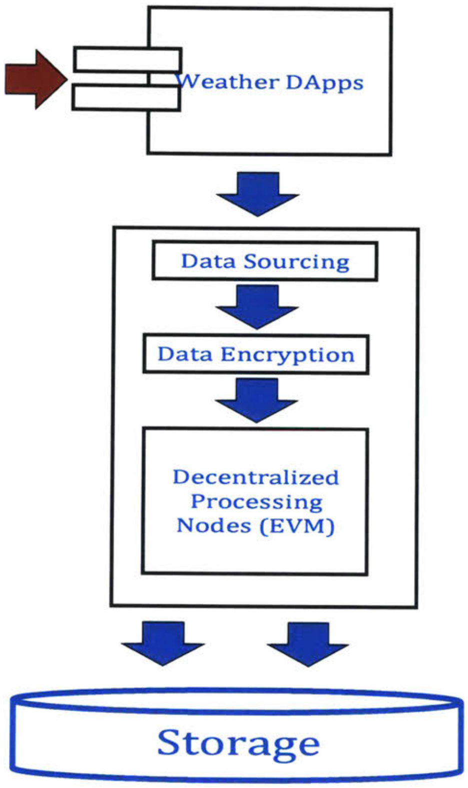

Figure 12: Decentralized Machine Learning Platform

Weather data stored in blockchain can be used for forecasting modeling. In this proposed solution to combine weather data analysts and machine learning models into a single system for Decentralized Machine Learning (DML) platform. DML can be designed to run machine learning algorithm and weather data from Weather DApps. The quality of algorithm is critical for accurate perdition and can be improved by leveraging the distributed platform to performing complex modeling. Blockchain smart contract technology to provide a trustless and middle-man free platform that connects potential contributors in machine learning to unleash the potential to facilitate machine learning development while providing economic incentives and protecting data privacy.

The traditional analytical processing is performed by climate data scientists process data and build predictive models. Humanitarian organization first require to perform data collection, mining and develop deep analysis criteria before the experts can develop the probability and magnitude for natural disaster. There are better ways to perform data processing to allow data providers to freely contribute data in decentralized infrastructure to perform seamlessly and allow climate data scientists to easily develop predictions that are based on these data sources and prepared for them by this decentralized machine learning infrastructure. The illustration is conceptual view of decentralized solution that is easier to scale as well as adding more data sources, computational resources and different types of prediction engines for various classification of natural disasters.

7.4 Next Step & Recommendation

In order to achieve the hypothesized benefits, widespread adoption of private blockchain for funding mechanism in FbF, there are three focus areas need to considered in the next steps.

- Use cases evaluation for early funding mechanism
- Technology feasibility to support Forecast-Based Financing
- Economic viability of smart contract with widespread adoption

The focus areas can be broken into 3-phased approach, starting with a proof-of-concept to demonstrate technical feasibility and to validate functional requirements for use cases for early funding mechanism. In the next phase, customize to design with few critical elements in building prototype. In the last phase, customize to meet the local government and community needs to build pilot countries to prove that the FbF using smart contract is capable of meeting the demanding requirements for broader rollout.

8. Conclusion

The promise of blockchain technology for Humanitarian services has the potential to expand in the area where exchange of information and collaboration are required. The idea of using blockchain technology is prominent in the financial services where the use case to reduce transaction cost and increase traceability in information flows. In humanitarian sectors, there are some potential use cases for blockchain technology that applicable in identification, tracking and cash management. Using smart contracts and blockchain for humanitarian financing is relatively new and takes time to realize its full potential. Humanitarian organization has an optimistic view with use cases and requirements centering around the merits of blockchain technology and reducing reliance on intermediaries as well as frictions associated with the current systems.

Bibliography

Baudot, Caroline. "The Right Move? : Ensuring Durable Relocation after Typhoon Haiyan." *Oxfam International*, 2014, https://policy-practice.oxfam.org.uk/publications/the-right-move-ensuring-durable-relocation-after-typhoon-haiyan-316093.

Benfield, Aon. *2017 Annual Report.* 2018, http://thoughtleadership.aonbenfield.com/Documents/20180124-ab-if-annual-report-weather-climate-2017.pdf.

Branosky, Jason. "Before the Storm: Shifting Federal Disaster Policy toward Mitigation." *Brookings*, 2015, https://www.brookings.edu/blog/fixgov/2015/02/19/before-the-storm-shifting-federal-disaster-policy-toward-mitigation/.

"Characterising a Slow-Onset or Protracted Humanitarian Situation Clarifying the Scope of the L3 Declaration." *InterAgency Standing Committee (IASC).*, 2014, https://www.interaction.org/sites/default/files/final position on the application of l3s to protracted crises may2014 - iasc ad hoc wg.pdf.

Coughlan De Perez, E., et al. "Forecast-Based Financing: An Approach for Catalyzing Humanitarian Action Based on Extreme Weather and Climate Forecasts." *Natural Hazards and Earth System Sciences*, vol. 15, no. 4, 2015, pp. 895–904, doi:10.5194/nhess-15-895-2015.

"DRK Manual | Manual." *German Red Cross*, 2016, http://fbf.drk.de/manual.html.

EM-DAT. "Classification - EM-DAT." *Em-Dat*, 2009, http://www.emdat.be/classification.

Filippi, Primavera De; Hassan, Samer. *Blockchain Technology as Regulatory Technology: From Code Is Law to Law Is Code.* Vol. 21, no. 12, 2016.

FORECAST- BASED ACTION. http://www.climatecentre.org/downloads/files/Stephens et al. Forecast-based Action SHEAR Final Report.pdf. Accessed 28 Apr. 2018.

Global Humanitarian Assistance. “Global Humanitarian Assistance Report.” *GHA Annual Report*, 2015, pp. 1–132, doi:10.1017/CBO9781107415324.004.

“Global Humanitarian Overview 2018.” *United Nations*, 2018, http://interactive.unocha.org/publication/globalhumanitarianoverview/.

“Good Practice Review.” *Humanitarian Practice Network*, 2018, https://goodpracticereview.org/.

Guha-Sapir, Debarati, et al. “Annual Disaster Statistical Review 2016 The Numbers and Trends.” *Centre for Research on the Epidemiology of Disasters (CRED)*, 2016, http://emdat.be/sites/default/files/adsr_2016.pdf.

“HPC Graphic 2014 (721×466).” *2018*, https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/HPC_graphic_2014_transparent_0.png. Accessed 3 Apr. 2018.

IFRC. “Early Warning > Early Action.” *Early Warning and Early Action*, 2009, p. 6, doi:10.5771/9783845252698_123.

Meadows, Donella. *Leverage Points: Places to Intervene in a System - The Donella Meadows Project*. http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/. Accessed 30 Apr. 2018.

“OCHA Humanitarian Assistance for People in Need.” *United Nations Office for the Coordination of Humanitarian Affairs*, 2016, http://www.unocha.org/sites/dms/Documents/this_is_ocha_2016_lowres.pdf.

Resilience : Saving Lives Today ,. 2016.

Smith, Adam. “2017 U.S. Billion-Dollar Weather and Climate Disasters: A Historic Year in Context | NOAA Climate.Gov.” *NOAA*, 2018, https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year.

---. “Billion Dollar Disasters 2017.” *NOAA*, 2018, https://www.climate.gov/sites/default/files/BillionDollarDisasters2017_ani_counts_and_costs_620.gif.

Smith, Adam B., and Richard W. Katz. "US Billion-Dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases." *Natural Hazards*, vol. 67, no. 2, Springer Netherlands, June 2013, pp. 387–410, doi:10.1007/s11069-013-0566-5.

Smith, Adam B., and Jessica L. Matthews. "Quantifying Uncertainty and Variable Sensitivity within the US Billion-Dollar Weather and Climate Disaster Cost Estimates." *Natural Hazards*, vol. 77, no. 3, July 2015, pp. 1829–51, doi:10.1007/s11069-015-1678-x.

Swan, Melanie. "Blockchain: Blueprint for a New Economy - Melanie Swan - Google Books." *2015*, https://books.google.com/books?hl=en&lr=&id=RHJmBgAAQBAJ&oi=fnd&pg=PR3&ots=XQsFBY3Nc2&sig=3YD-tPURJ0aqdwcEe5zbm132kkM#v=onepage&q&f=false. Accessed 29 Apr. 2018.

Szabo, Nick. "Smart Contracts: Building Blocks for Digital Free Markets." *Extropy Journal of Transhuman Thought*, no. c, 1996.

Tapscott, Don, and Alex Tapscott. "Blockchain Revolution." *Blockchain Revolution*, 2016, doi:10.1515/ngs-2017-0002.

"Terminology - UNISDR." *United Nations Office for Disaster Risk Reduction (UNISDR*, 2017, https://www.unisdr.org/we/inform/terminology.

"The Humanitarian Programme Cycle." *InterAgency Standing Committee (IASC).*, 2015, https://interagencystandingcommittee.org/system/files/hpc_reference_module_2015_final_.pdf.

UNISDR. "Sendai Framework for Disaster Risk Reduction 2015 - 2030." *Third World Conference on Disaster Risk Reduction, Sendai, Japan, 14-18 March 2015.*, no. March, 2015, pp. 1–25, doi:A/CONF.224/CRP.1.

World Economic Forum. *The Global Risks Report 2018, 13th Edition*. 2018, doi:978-1-944835-15-6.