A System Dynamics Approach on Post-Disaster Management:

A Case Study of Bam Earthquake, December 2003

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Abstract

In December 2003, a 6.7 earthquake struck the city of Bam in southeastern Iran. The city lost over 45,000 inhabitants and the historic citadel of Arg-e´ Bam was destroyed. High number of casualties in this disaster has encountered it among most recent hazardous natural events in the world. Although the old structure of the city was the main reason for the massive destruction of the city, but the outcome of so many dead people has other important reasons as well. The most important one is that no scientific study has been on dynamical behavior of disaster management in Iran. In this paper a dynamic system is proposed in order to simulate the activities in the zone after the earthquake has shaken the city. Based on that, key parameters are chosen in order to establish some post-disaster policies which are applied on the model and their effects are studied.

Keywords: System Dynamics Modeling, Disaster Management, Bam Earthquake

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Introduction

Being placed on the Alpine-Himalayan earthquake belt, Iran is vulnerable to tremors disasters. After the deadly earthquake of Boeen Zahra in 1961, the first building codes and safety measurements were authorized in Iran. However such codes have not yet been able to protect Iranian people against natural disasters. Bam's earthquake in December 2003 was a clear and a bitter sample to show not only the weakness and uselessness of such codes but also unpreparedness of government and related organization for early response in case of such disastrous events.

More than 100,000 inhabitants lived in bam before December 26,2003 earthquake shook the city. About 80% of buildings totally collapsed which caused more than 45,000 deaths and about 30,000 injuries [1]. People, who rushed to the city just after the tremors, played an important role in the rescue operation under the leadership of central and provincial officials in the first week. Provincial authorities set up the "Crises Headquarter" in order to coordinate the operation. The Red Crescent was responsible for the rescue and relief operation, while the Housing Foundation-an organization affiliated to the Housing Ministry- was accountable for rescue efforts within the zone. The world's response to the help call for Bam was extensive as well. The international community came to rescue, provide relief and to reconstruct Bam. Medical and Rescue Teams were sent from 44 countries and UN which were equipped with the most modern instruments and specially trained for disaster events. Both national and international humanitarian aids and charities were abundant. Despite all these facts, what was the outcome of Bam earthquake was much worse than similar events in other countries. Stronger earthquakes happen in Japan with far less casualties and destructions.

The question which has bothered many about Bam is "What was the main reason which caused so many casualties?". The answer to this question is related to both before and after the earth quake.

For the pre-disaster phase there are many weaknesses. Most buildings in Iran do not have minimum requirements according to international and even national standard codes. Many cities are placed on or near faults exposing them to earthquake disasters. Not many seismology studies are done. In the Iranian disaster management system, the action of risk identification and mitigation is not clarified so the seismic risk identification is not done. The risk transfer for the most of the building and national facility is not applied. The preparedness activity like evacuation planning, shelter establishing is not fully implemented in the city level [2].

Post-disaster phase risk management has many flaws in Iran. Earthquake identification and damage estimation was done with delay. Because lack of information, national headquarter of unexpected incidents was created delay in national immediate response. The emergency response in the search and rescue team was not organized and had been done with many problems and shortages [2].

Pre and post disaster studies are different from each other. The former one is usually based on long term strategies of a government for reconstruction, public awareness, preparedness of local authorities, seismic studies and etc. These strategies usually take more than five years and some take more than ten years to show their influence on reduction of disaster risks. So for a country like Iran in which natural disasters such as earthquake are common need a great effort, lot of money, time and professionals to work on such strategies. Moreover, there must be shorter programs and strategies for meantime to avoid high casualties and prepare all aspects of the society and government for adoption of long term programs.

In the specific case of Bam earthquake, although old structure of the city was the main reason for the destruction of 90% of buildings, but what seemed the most critical parameter was the disaster management and organization of teams, food, medics and etc. in the zone. In this paper, a system dynamics model is constructed which monitors the city from before the earthquake, captures the earthquake effect and simulates concepts such as teams and food arrival, debris removal rates, corps finding and their burying, disease spread and infection. The goal is to determine and study the key parameters in the post-disaster phase, their influence on the number of casualties and appropriate strategies which could be set to optimize time, efforts and costs. It is our belief that the mere existence of disaster management centers without dynamical modeling and studying them is useless.

Problem Definition

Disaster management is the discipline of dealing with and avoiding risks. It is the continuous process by which all individuals, groups, and communities manage hazards in an effort to avoid or ameliorate the impact of disasters resulting from hazards. Effective disaster management relies on through integration of emergency plans at all levels of government and non-government involvement. Disaster management has four stages of: Mitigation, Preparedness, Response, and Recovery. Mitigation is mainly about knowing and avoiding unnecessary risks which also includes an assessment of possible risks. Preparedness, unlike mitigation activities, focuses on preparing equipment and procedures for use when a disaster occurs, which means pre-planning. Response phase of a disaster may commence with search and rescue but in all cases the focus will quickly turn to fulfilling the basic humanitarian needs of the affected population. Recovery phase starts after the immediate threat to human life has subsided and includes reconstruction of every aspect of a society from buildings to social and economical environment.

Bam disaster in December 2003, clarified how much disaster management has been thought about and used in Iran. It was very clear that Iran has almost done nothing for Mitigation level. Preparedness was in a medium level in most parts. Food and medical care was provided in a very short time, rescue and medical teams were sent on time. But there were many weaknesses in the Response phase. The assistance was provided by various national and international agencies and organizations. But there was a huge lack of effective coordination of disaster assistance. Teams arrived from 44 countries as well as those sent from different national governmental and nongovernmental organizations did not seem to follow a common procedure. It caused delay in debris removal and corps burying which respectively increased number of dead people and disease spread risk. Food and teams were sent to the zone recklessly and without need assessment. No policy was set for broad casting coverage of the disaster, resulting in an unbelievable pile of humanitarian aids gathered from domestic cities and foreign countries which was far beyond the capacity of transportation means to deliver them to the zone.

It is the goal of this paper to introduce the most crucial parameters in the Response phase of disaster management for Bam earthquake, study their effects from a system dynamics approach and propose policies in order to mitigate them. According to what said before and statistical reports published about this disaster [3], five critical questions is setup that their answers lead to most crucial decisions which must be taken in similar cases of an earthquake disaster.

1. How can Broadcast Coverage of the disaster effect on the Humanitarian aids including flow of food, equipment and rescue and medical teams to the zone?
2. Which is the best distribution of food and team's delivery percentage from the total deliveries to the city, in order to minimize the disaster?
3. How much can the presence of special teams just for registering and burying bodies and equipments like body bag help to reduce disease spread, infection and consequently casualties?
4. What is the best percentage distribution for departure of medical and rescue teams to the tremors zone? Which type should have more teams, rescue teams for search and debris removal, or medical teams for taking care of injured or sick people?
5. How much can Team management and matching them reduce disaster level by increasing the total search and debris removal ability of the zone in order to find more people in less time while death probability is still low?

In order to answer these questions, it is essential to study the influence of various parameters in a time scale. Surely doing so needs a dynamical model and simulation to capture the effect of related parameters, which is done in this work.

Theory method:

After a disaster most of the parts in a zone are either damaged or destroyed. This general destruction in every aspect of a city life results in many disruptions in different categories which finally end in many deaths and a great catastrophe. It is obvious that the longer it takes to come back to the natural status the heavier damage and loss in human life will be. So a great effort is essential to use the maximum abilities in minimum time to reduce losses and casualties. To make this effort in the best way every area which is affected by the earthquake should be considered precisely and their effects on each other during the time so on. In order for an earthquake disaster dynamic model to be effective, knowledge of the parts which are influenced by the earthquake mostly is of significant importance (Fig. 1). The obtained results from the model can be viewed as an artifact that can be a useful tool to look into different parameters in and out of the focused environment and lead to the best decision in the disaster time.

To model the earthquake in a city the most important categories which are affected by the earthquake can be divided into eight blocks: 1.Population, 2. Buildings and Destruction, 3.People's Conception and Broadcast Coverage, 4.Food Supply, 5.Teams Arrival 6.Rescue Teams 7.Medical Teams and Disease Spread, 8.Debris Removal.

Among these blocks population is the most important one which shows the behavior of the human life (the most vital case of attention). This block is influenced by other blocks either directly or indirectly. The other blocks which are going to be described in details, show a part of a city that has a natural behavior before the earthquake happen. By simulation and discussion about the key parameters some useful strategies can be made which lead to the most efficiency and less injury and death.

Research method:

In the past, considerable interest has been generated in the study of planning method for earthquake disaster prevention [5]. Some works which are done in this field are: Kaji, 1988; FEMA 1990; Smith, 1993; Spudich et al,1998 ; Mayes 1999; Sentiana 2000; Takanashi 2000; Kobuna 2000; Chen et al 2004; Wang et al 2004, Hufeng Ho 2005. By studying these researches we came to this point that, unfortunately no work has been done in the formulation of earthquake disaster prevention method with a system dynamics approach except the only effort of Yufeng Ho 2005 which as he says, ”It is the purpose of this study to discuss the need for a systematic approach to achieve a better result of this study.”

But as it is mentioned above the purpose of this study by considering the Bam earthquake case is to model a city which is hurt by a severe earthquake using a system dynamics approach, and monitor the behavior of critical variables to reach the best policies which can be made by the responsible organizations to better management of victims and the catastrophe.

System Analysis: In this study system analysis is taken in use. As the earthquake disaster affect many aspects and has a complex system which involves many multivariable, non-linear and time dependent chains, system analysis approach is a convenient tool to be utilized in this case. System analysis takes into consideration all variable and factors of a real or planned system, searches and evaluate all feasible means of achieving the pre-set goal, thus helping the policy makers to choose the strategies to be adopted. Hence, system analysis employs both quantitative and qualitative analytical tools to search and confirm the target through assessing all feasible alternatives. (Ossenbruggen 1984)

System Dynamics: System dynamics can assist in strategy assessment and provides insights into possible changes in the system during policy implementation (Sterman, 2000).

A system dynamics model is used to simulate the city before and after the earthquake. By using the system dynamics techniques all the necessary variables to assume a whole city can be considered easily with their changes during the time. As well as modeling the occurring of earthquake at an arbitrary time and its effects on the other variables of the city simulation by using appropriate mathematical tools. Using the system dynamics approach also brings us the ability to model the suggested policies by changing the key parameters and monitor them easily for comparing them on choosing the best strategy to get the purposed goal.

In general using system dynamics in planning has a number of advantages:

1. The emphasis is placed on the mathematical ideas of planning. Data processing facilities could be used to help in reducing the work load on the planner; (Yufeng Ho 2005) [4]

2. The use of models to understand and predict the behavior of different conditions provides a clear picture of activities which take place leading to so many deaths and casualties.

3. By using (1) and (2) the planner is able to change the behavior through policy making and view the result of that policies in the virtual world during different time intervals.

System Dynamics Model

General Structure and Feedback Loop Diagram

According to the theories and researches described above the system dynamics techniques were used and to cover the different aspect of the case eight blocks were generated. To control the complexity of the relation between different part of the diagram the general shape of inputs and information feedback of them to each other was first made to give us an overall view of the model (Fig. 1).

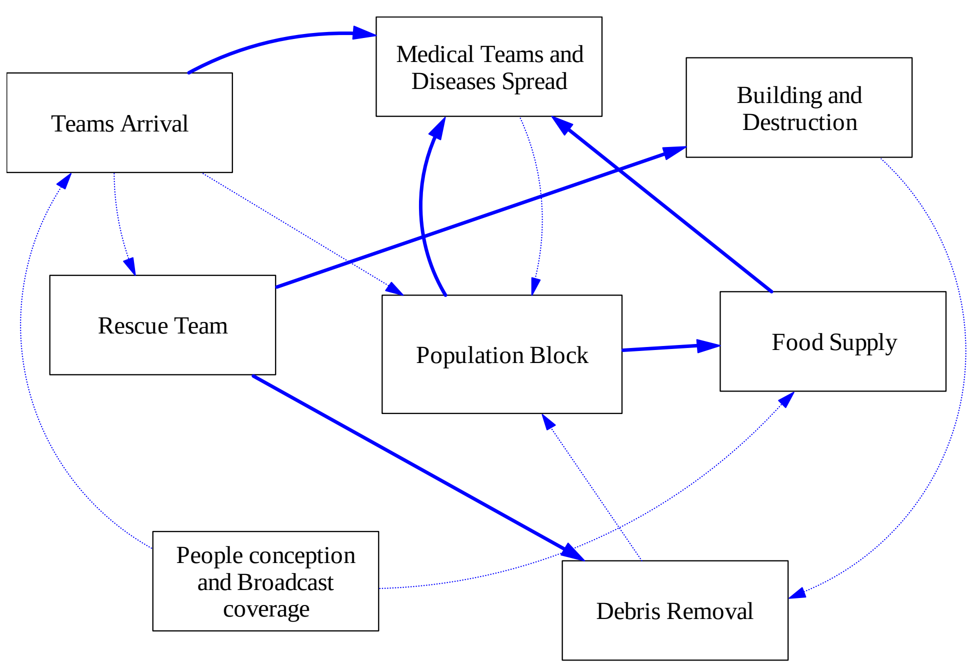

Figure 1- Input and Information Feedback Loop

As can be seen in the Figure 1, although each block works independently they have different effects on each other including information input or information feedback which are shown in the figure and are obvious in the model.

Model Description:

To view the many of parameters of the model and their complex relationships, we assume that the behavior in such systems is in continuous state to facilitate model formulation and its simulation. So the behavior of the system is not the result of probability; rather is the result of causal loops of variables. In dynamic model, the eight blocks of the structure of the city are each formulated and modeled using Vensim PLE (version 5.7) programming language shown in Appendix I. As can be seen in the model the whole model is made up of 134 variables and their related equations (Appendix II). Mention that the initial values for the level variables are obtained from statistics data and the other constant and auxiliary variables are evaluated by the data in hand from various references which are generally listed further.

The general idea of the model is to form a city life in its natural status. This city consists of different parts (the parts which are going to be highly affected by the earthquake). The system runs till an arbitrary time (3 years in our model) to the earthquake happen. Thorough this way we can see the natural behavior of various parts in the model before the disaster and afterwards. Some natural behaviors are such the ones in roads and buildings constructions, the flow of food and other facilities of living, migration in to or out of the city and so on. With occurrence of the earthquake which is modeled mathematically in the destruction rate of buildings as an impulse function on Destruction Rate due to Earthquake, we came into some changes caused by the tremors in separate aspects of city life which are going to be discussed in more details.

1. <u>Population Block:</u>

Population block which is the most critical part in the model monitors the changes in the total population of the city before and after the earthquake. This level variable is influenced by different rates. “Population increase rate” indicates the summation of “Birth rate” and “Death rate” in natural status of a society and came to zero for a while after the earthquake. The “Migration rate” is a way of natural increase in the population of the city which has a specific value before the earthquake and after that naturally people will move to safer places to meet their psychological need for security and protection and so this rate changes to zero or even a negative value. Other rates which start by the earthquakes are: Teams Arrival Rate which is the rate of coming or living of rescue and medical teams to the zone; Injury Death Rate, Disease Death Rate and Death Date due to Debris are post disaster active rates, each one showing a rate due to reasons which are common after the earthquake, the death caused by injuries, contagious diseases or being trapped under debris. Each rate is originated by its related block (Fig. 2).

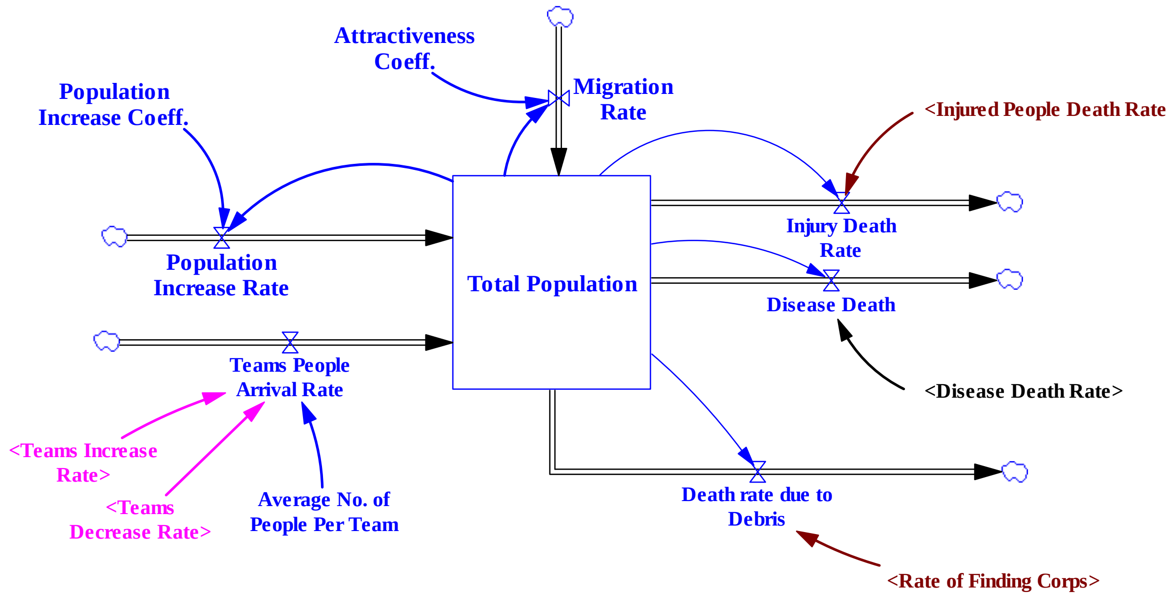

Figure 2- Total Population Block

2. <u>Buildings and Destruction:</u>

This block consists of two categories of buildings, the new ones and the old ones. To be more precise the buildings in the Bam city could be classified as very weak, weak, moderate, good and very good structures [1]. But for simplification and because there won't be much different in the results we assumed the buildings just in two groups. The block shows the natural construction and destruction of each group by noticing the point that the old buildings (the historical texture of the city) have no construction rate.

The occurrence of the disaster is established in this block by having a pulse function in the destruction rate due to earthquake for both old and new buildings. And after that the debris removal is started by the feedbacks from the "Debris Removal Block". As the kind of the buildings in the city during the debris removal is not that much obvious the debris removal rate for both groups are considered equal (Fig. 3).

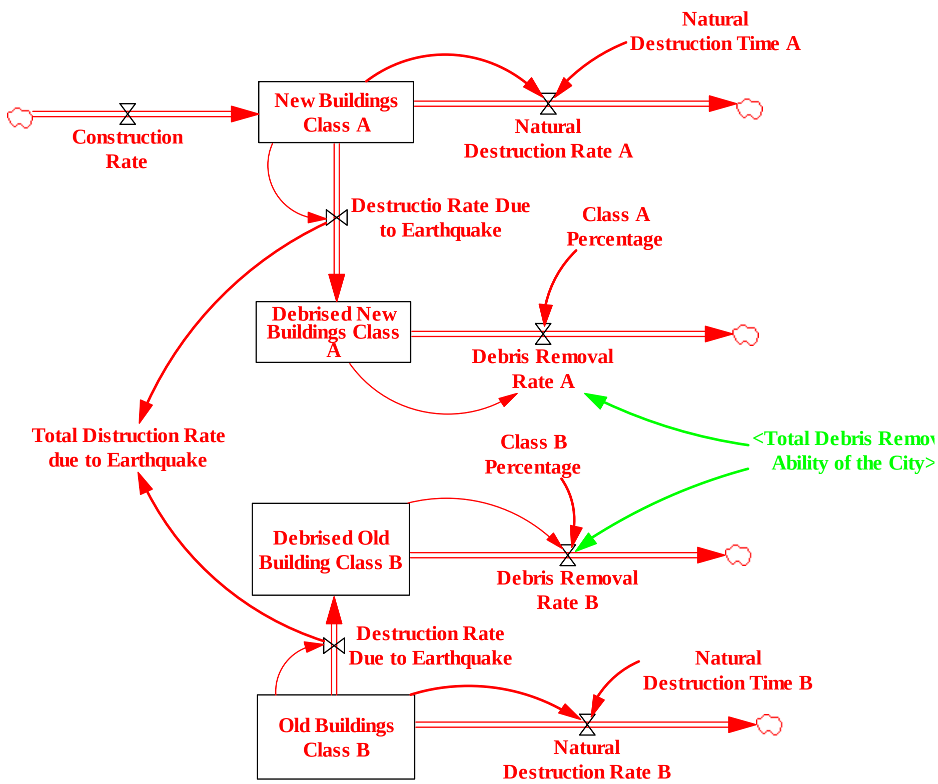

Figure 3- Buildings and Destruction Block

3. <u>People's Conception and Broadcast Coverage:</u>

This block which is mixed with the roads construction is used to apply the effect of broadcast coverage and the people's conception of the disaster on the amount of flows of teams, food and other equipments and humanitarian helps to the zone.

In this block the broadcast coverage is a function of time and destruction percentage. As the Bam earthquake was very destructive due to the mentioned reasons, destruction percentage was considered a fixed value of 90% and "Time Effect Function" was described as a look up variable. This look up variable which is a graphical one is based on this idea that, after the time of the earthquake for a time interval (60 days here) the disaster broad cast is 100% which is reasonable for a catastrophe like that, and after that by time passing little by little the coverage of the disaster slakes and approaches a fixed limit remaining in people's mind forever. Besides the "People Conception of the Disaster" is function of the broadcast coverage of that, in a simple look that conception is a linear function of the broadcast coverage so the "Broad Average Effect Function" is described as a linear function noticing that there will be a time needed to form the conception. There is also another look up: "Conception Percentage Function" which is the effect of people's belief about the depth of the disaster and so the percentage of maximum flows to the zone which is also a linear function, but starts from a non-zero value which is the indicator of government activities for the help to the zone. As can be seen in the block two ways are considered to transport to the city, the caravans from the roads and the landings from the airport lanes. The values are added to the model by the data of Bam city in 2003 [3] (Fig. 4).

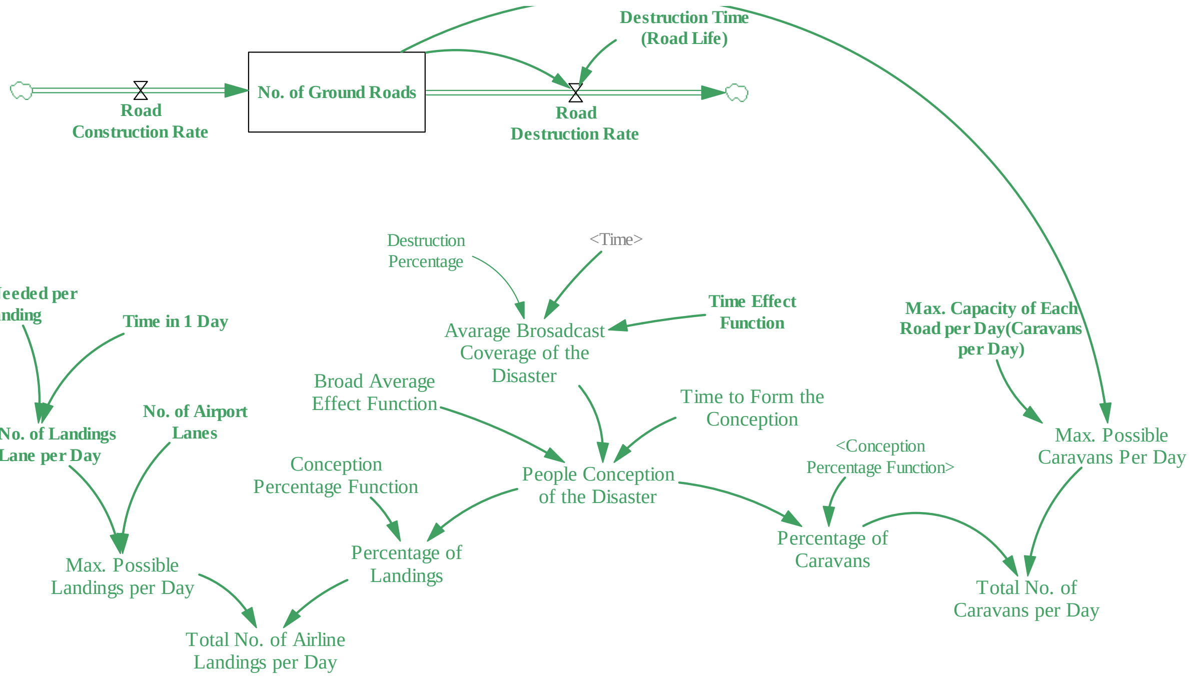

Figure 4- People's Conception and Broadcast Coverage Block

4. Food Supply:

This block indicates the flow of food as the most vital need for the people to stay alive and to survive from injuries and diseases, with this emphasis that the supply food to the zone occurs from land and air way. But the important thing is that "what percentage of each delivery should be occupied by food?" the answer to this question will be discussed in the policy making part. The consumption of the food reservoir of the city is influenced by the standard packages per person for one day (For example two packages in this model) and the total population present in the zone either inhabitants or different teams (Fig. 5).

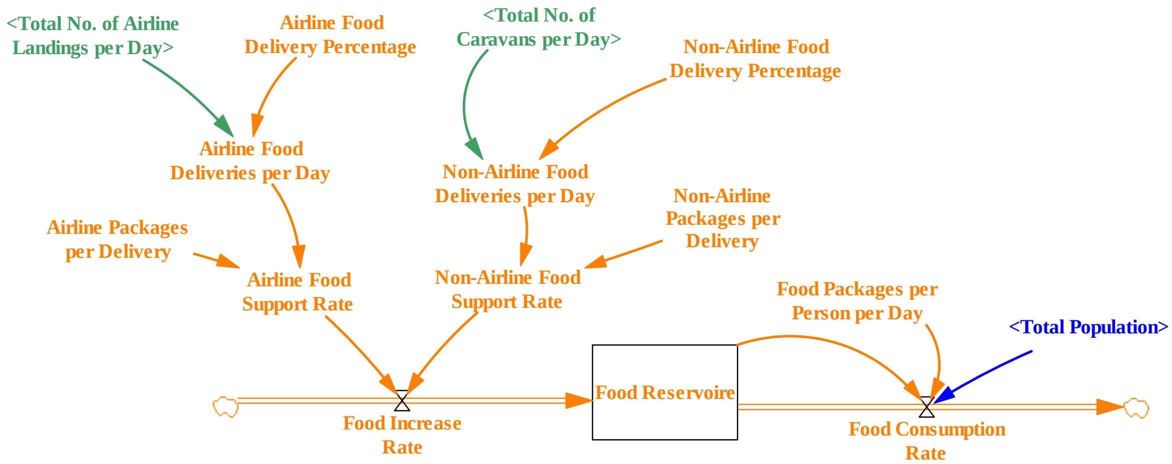

Figure 5- Food Supply Block

5. <u>Teams Arrival:</u>

A percentage of each air or land delivery is allotted to the teams' delivery including humanitarian teams, NGO's and etc. This block shows the information of the arrival and departure of the present teams in the zone. Also an assumption of rescue teams and medical team's percentage is used in this block to indicate the number of each team in the zone in any time. The best percentage distribution between these two teams is being discussed in the policy making part. Important to say is that this block is a demonstrator of the attention of the society to the focused zone so it has an indirect information feedback from the people's conception block by the linkage of "Total Number of Landings per Day" and "Total Number of Caravans per Day". Another noticing point in this block is the time for each team to stay that has considered nearly two months having known that the tragic situation of the infected zone do not let the rescue teams to stay there more than a finite time as well as medical teams due to psychological effects of the catastrophe.

This block consists of one level variable "Teams Present in the Zone" which increases by the "Teams Increase Rate" coming from the people's conception as described above and decreases by the "Teams Decrease Rate" as a delay function of time, both can be seen in the model (Fig. 6).

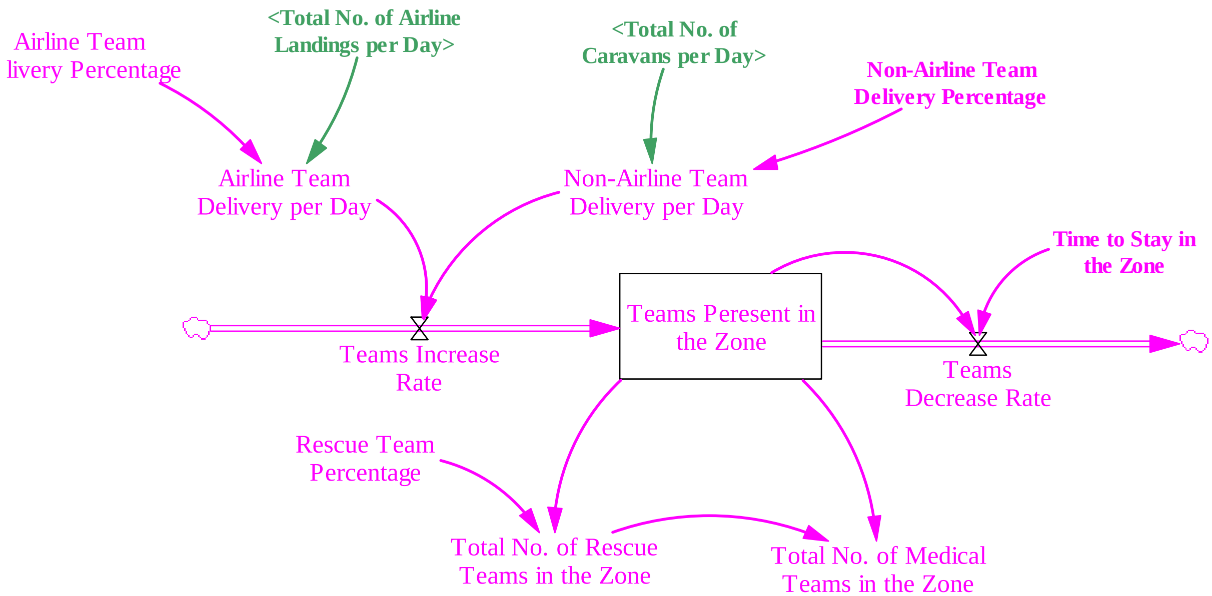

Figure 6- Teams Arrival Block

6. <u>Rescue Teams:</u>

This block is generated to view the effect of all kinds of rescue teams which come to the zone and to have a general look at their ability of debris removal which brings out a total debris removal ability of the teams highly affecting the debris removing rate, the probability of finding more trapped people. As can be seen in the model three general groups are considered to be present as rescue teams, local fire stations which assumed to be active after the earthquake, professional and NGO's teams which are sent to the zone from different national or international organizations, and other humanitarian teams. Each of these groups relatively to their profession has a specific ability of debris removal ability used in the model. This block has no level variable and the relation between group's ability and the total ability of debris removal can be seen in the diagram. Besides it gets information input from the teams arrival block on the total number of rescue teams present in the zone (Fig. 7).

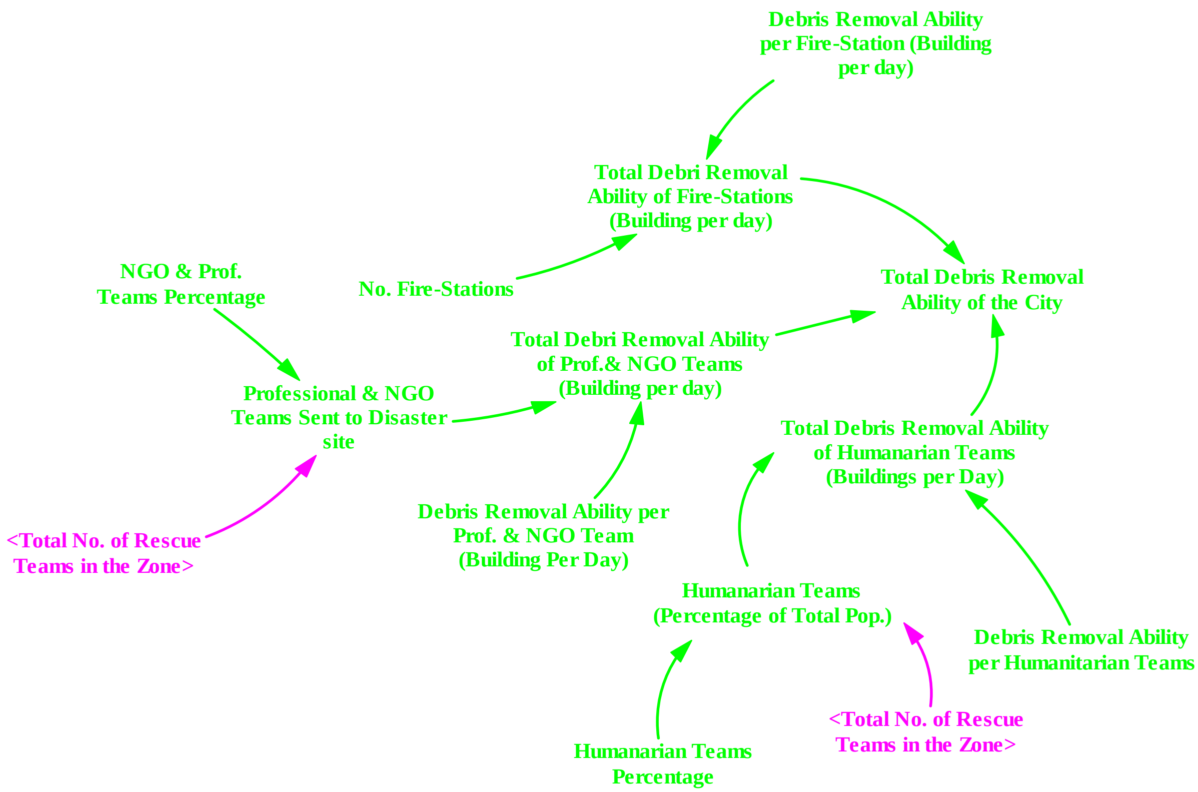

Figure 8- Recue Teams Block

7. Medical Teams and Disease Spread:

One of the most important worries which put the city into a great danger is the epidemic diseases infection through the city due to unburied corps and the septic environment. From this point of view the necessity of managing medical team to have the best effect in this situation and the knowledge of the process of infection in the town is so useful to make policy for facing with this problem. This block is monitoring the mentioned points. From this view all the live people in the city are susceptible to the disease, these susceptible people change to the infected people by two ways, first due to environment pollution directly and second due to contact with infected people; So we have two level variables "Susceptible People to Deadly Diseases" and "People Infected with Deadly Diseases" as well as two rate variables between them as can be seen in the model. Besides the infected people either recover or die due to that disease so these rates are added to the model. Two important points in this block is the two look up variables which will be described. In this block the "Pollution Infection Percentage" is considered a linear function of burying time meaning that as the time of burying the corps increases, the number of unburied corps in the environment increases and the percentage of being infected goes higher so on. The other look up variable is "Food-Medic-Time Function" which shows how number of medical teams per person and food per person affect on the recovery time. This function is a negative goal seeking which means that as the medical team per person or food per person approach zero the recovery time approaches a high value (200 days in this model) and as that effective parameters (food and medical team) increases the recovery time is decreased and finally in the best situation it approaches a finite limit. This block gets the input information of total population from the population block, food consumption rate from food supply block, and the total medical teams in the zone from the teams arrival block (Fig. 8).

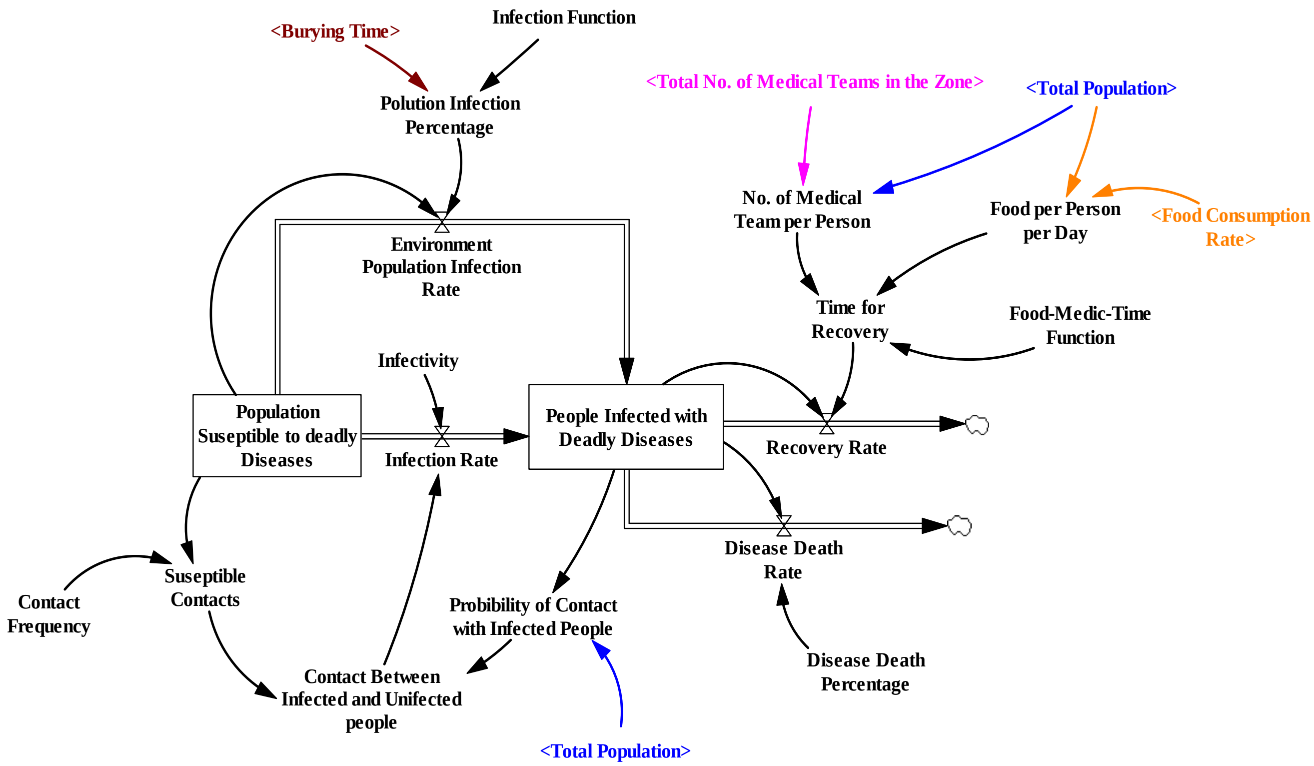

Figure 8- Medical Teams and Disease Spread Block

8. Debris Removal:

This block is made to show the process of debris removal by teams in the city. The level variable of trapped people in this block changes by rate of finding trapped people and get information feedback from buildings destruction rate. These trapped people are found and have two statuses either corps or injured. Here we used a living percentage function which indicates that how probable is a person alive after a definite time of being trapped under debris (Table 1).

Table 1- Living Probability under Debris as a Function of Time

Time being under Debris	Probability of being Alive
30 min.	99.3 %
1 day	81 %
2 days	53.7 %
3 days	36.7 %
4 days	19 %
5 days	7.4 %

The injured people are assume to recover after a while by a recovery rate which is a function of food and medical team as described before and the corps are buried by a delay time called burying time. This variable is also a look up one which is a function of time itself, that has a behavior such that by the time of earthquake the burying time increases because of the pulse shape of the dead people and so less teams are to bury the corps but as time passes the number of dead people decreases and the burying time approaches its natural value. This block has the feedback information from buildings and construction block, debris removal block and team arrival block as well (Fig. 9).

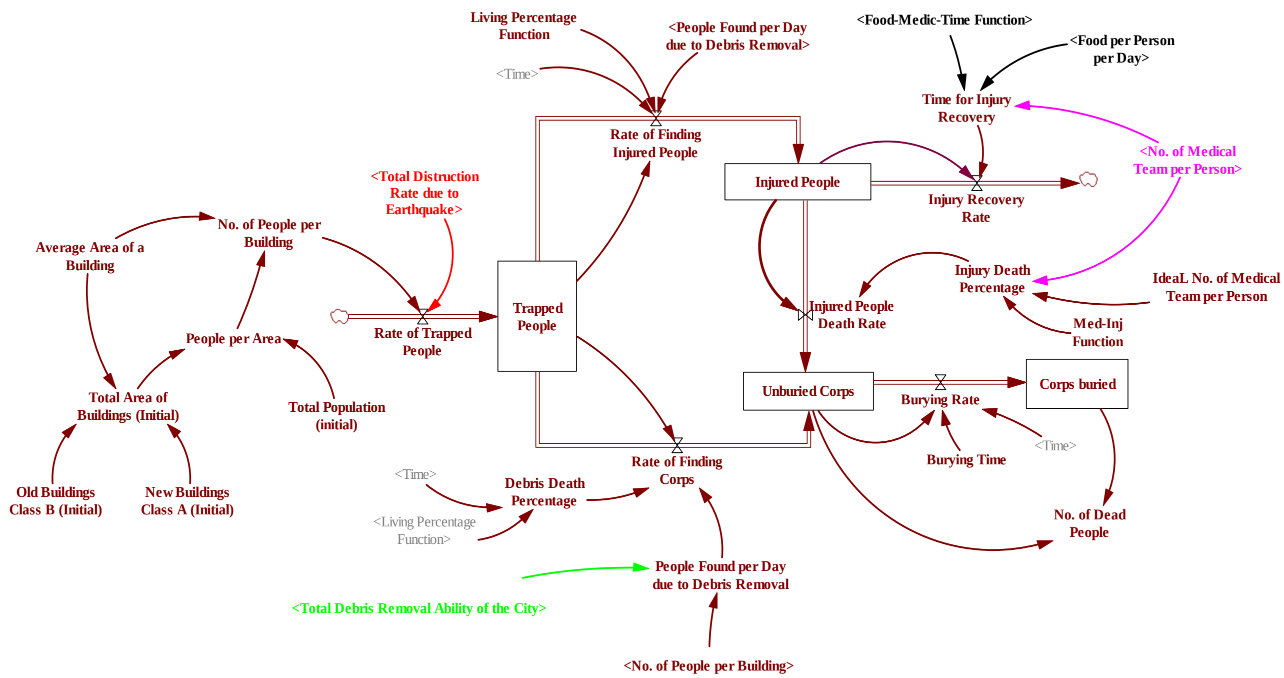

Figure 9- Debris Removal Block

Simulation and Validation

The simulation is based on initial statistics about Bam 3 years before the earthquake [5]. Initial values for stocks and constant variables are listed in Tables 2 and 3.

Table 2- Initial values for Stocks

Stocks	Initial Value	Stocks	Initial Value
Total Population	90,000	Trapped People	0
New Buildings Class A	12,000	Injured People	0
Old Buildings Class B	12,000	Unburied Corpses	0
Debrised New Buildings Class A	0	Corps Buried	0
Debrised Old Buildings Class B	0	Food Reservoir	0
No. of Ground Roads	3	Population Susceptible to diseases	10,000

Teams Present in the Zone	0	People Infected with deadly diseases	0

Table 3- Constant Variables

Constant Variable	**Value**	**Constant Variable**	**Value**
Population Increase Coeff.	2.66% (per year)	Attractiveness Coeff.	1.0% (per year)
Average No. of People per Team	10 Persons	Construction Rate	0.65 Buildings per day
Natural Destruction Time Class A	18250 days (50 years)	Class A Percentage	50%
Class B Percentage	50%	Natural Destruction Time Class B	7300 days (20 years)
NGO & Prof. Teams Percentage	0.25	Humanitarian Teams Percentage	0.75
No. of Fire Stations	2 Buildings per day	Debris Removal Ability per NGO & Prof. Team	0.5 Buildings per day
Debris Removal Ability per Humanitarian Team	0.25	Debris Removal Ability per Fire Station	0.5 Buildings per day
Average Area of a Building	300 m^2	Ideal No. of Medical Teams per Person	0.04
Road Construction Rate	0.00091	Road Life	3650 days (10 years)
Time Needed per Landing	20 min.	Time in Day	1200 min. (20 hours)
No. of Airport Lanes	1	Destruction Percentage	90%
Time to Form Conception	0.5 day	Maximum Capacity of Each Road per Day	10 Caravans
Airline Team Delivery Percentage	50%	Non-Airline Team Delivery Percentage	25%
Time to Stay in the Zone	30 days	Rescue Team Percentage	50%
Contact Frequency	10 Persons per day	Infectivity (for a deadly disease)	0.45
Disease Death Percentage	10% per day		

The model is started from three years prior to the earthquake so that the natural population growth and construction and destruction rates play their role so that the population reaches approximate value of 100,000 prior to the disaster as is mentioned in [3]. The earthquake happens in the third year, destructs buildings, and causes trapped people and initiation of other blocks. Figure 10 and 11 show respectively Total Population and number of Teams Present in the Zone up to three years after the disaster strikes.

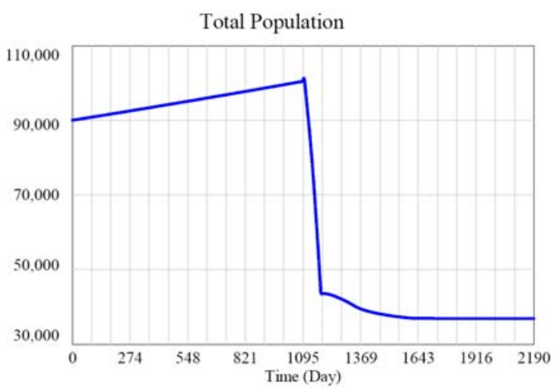

Figure 10 – Total Population Behavior

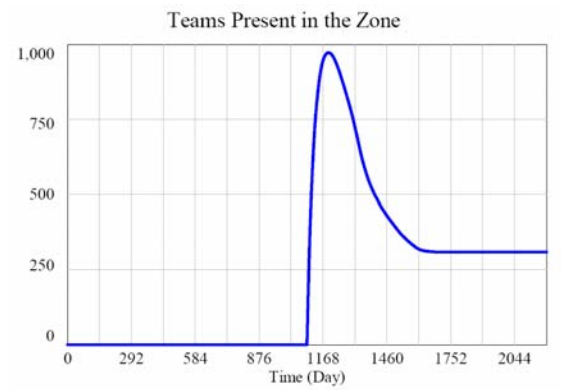

Figure 11 – Teams Present in the Zone

It can be seen that nearly casualties are approximately 50,000 and maximum number of team people present in the zone is 9000 persons. These values are very close to those reported by Kerman Management and Planning Organization [3], which generally validates the system dynamics model's efficiency. Besides, these two variables show a logical behavior. After the tremors, buildings collapse and entrap many people. The destruction is broadcasted which causes people's conception to increase. It leads to increase of teams departure to the zone and consequently debris removal ability of the zone. Therefore, debris is removed and both injured people and corpses are found. As is discussed before, in this model trapped people are considered alive unless there are found dead. It's the reason Total Population is not dropped in a step like function but decreases continuously but with a very grate rate. After a few months, almost all debris is removed; hence not only no more new teams are sent but also teams are sent back.

Results and Policies

In order to find answers to our five key questions, relevant parameters are changed in turn and key variables and stocks are plotted versus time.

1. <u>Broadcast Coverage</u>

For broadcast coverage influence, the maximum value assigned to broadcast coverage is changed from 0.9 to 0.5. Changes in Total Population, Teams Present in the Zone, Food Reservoir and Injured People Death Rate are plotted (Figs. 12-15).

When broadcast coverage is decreased from 90% to 50% more people die. It is because its effect on people’s conception is lower thus less number of teams is sent for rescue and medical operations (Fig. 13). Therefore debris removal is delayed which leads to more casualties. This delay can be seen in the behavior of Total Population (Fig. 12). Since debris removal ability is lower, it takes more time for search and rescue which the slope of change in Total Population stands for it. Note that due to this delay fewer living people are found. In our model it is assumed that all living people found under debris are injured. So the fewer Injured People is, the more casualties will be (Fig. 15). Moreover less food is sent to the zone (Fig. 14) as well which makes infected people with a probable deadly disease like Cholera, more vulnerable to death.

It is out of question that Broadcast Coverage must remain high for a good while. But here some other factors become important. First, the cost of a full Broadcast Coverage is very high and second, due to social and physiological reasons it is not wise to keep an annoying subject broadcasted for a very long time to the society. It will be seen later that the effect of other factors is much more on lowering casualty numbers than Broadcast Coverage. Hence, it might be wise to lower Broadcast Coverage after a while but keep other factors at good level to ensure stability of the zone. Specifying an effective procedure for such an action is very complex and needs a thorough socio-physiological research which is beyond the scope of this paper.

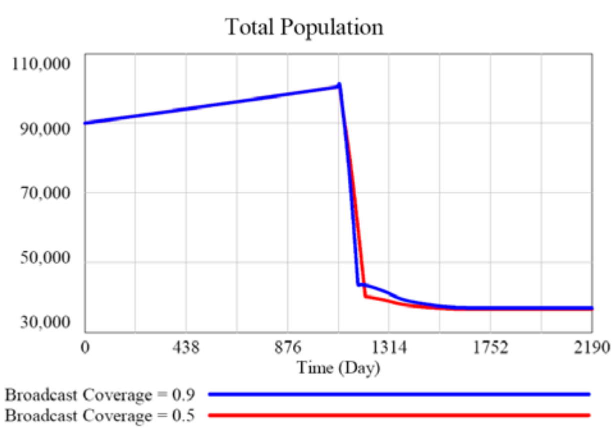

Figure 12– Broadcast Coverage on

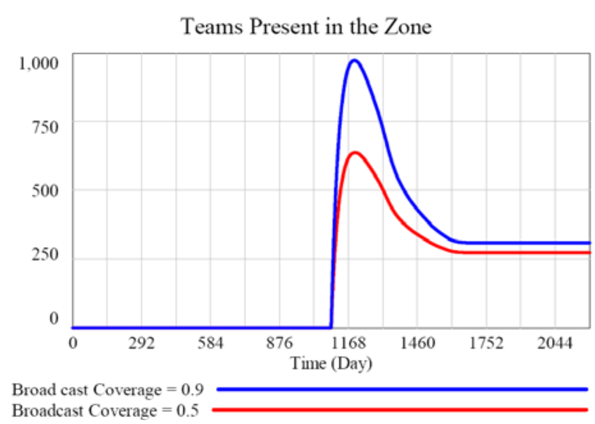

Figure 13 – Broadcast Coverage on Teams Present in the Zone

Total Population Behavior

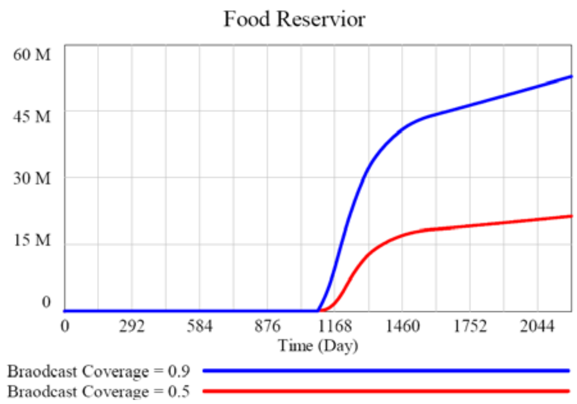

Figure 14– Broadcast Coverage on Food Reservoir

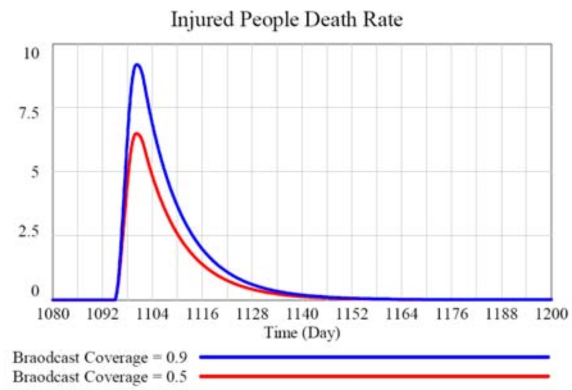

Figure 15– Broadcast Coverage on Injured People Death Rate

2. Teams/Food Delivery Percentage

Another key parameter is the percentage of total deliveries (both airline and non-airline) assigned to Teams/Food Delivery. Initially 50% of total airline delivery was assigned to both Team and Food, while 25% of Non-airline delivery was for Teams and 75% for Food (blue line). Two other different cases are simulated and compared to the initial state. First, 75% of airline delivery and 50% of non-airline delivery are set for Teams (red line); second, 25% of airline and 10% of non-airline deliveries are given for Teams (green line) (Figs. 16-19).

The first thing noticed is that higher percentage for Teams Delivery decreases casualties significantly which is due to higher Total Debris Removal Ability of the city. Meanwhile, Injured People Death Rate has increased (Fig. 16, 17). Although number of Medical Teams has increased but shortage of food increases the percentage of death much severely (Fig. 18, 19). A very important note in disaster management is not to allow food reservoir become empty, but the reservoir should not be very high as well since it would need more facilities to store the food; And if such facilities are not provided foods corrupt and become a source of disease (Fig. 18). The ideal state is that the reservoir reaches a stable condition so the number of food in storage becomes constant.

The best policy for this parameter is to find the Teams/Food Delivery Percentage at which a stable level for Food Reservoir is obtained. Simulations show that the best percentage is 62% of airline deliveries and 37% of non-airline deliveries to be assigned for Teams Delivery. It is important to note that these values highly depend on the number of roads and airport lanes which exist for transportation goals as well as the total population of the city and the destruction percentage. These values are unique for the state presented in this paper and may not apply for other case studies. But determination of the Team/Food Delivery percentage for each disaster is a requisite for effective disaster management.

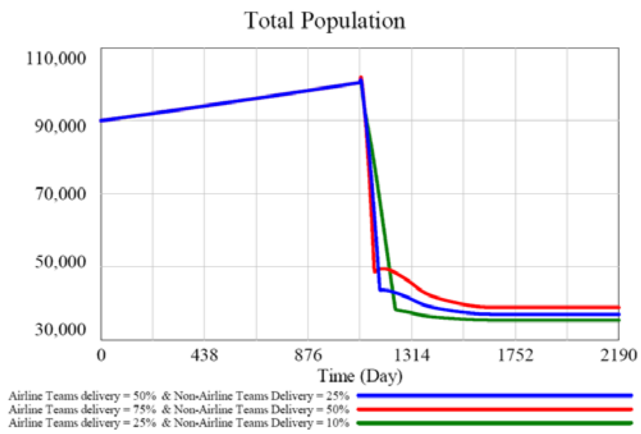

Figure 16– Teams/Food Delivery Percentage Effect on Total Population Behavior

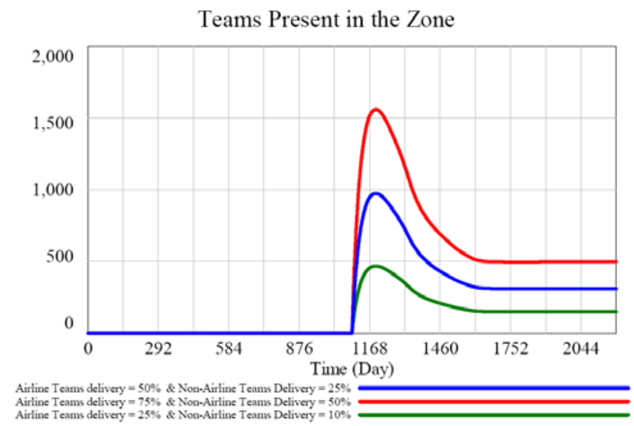

Figure 17 – Teams/Food Delivery Percentage Effect on Teams Present in the Zone

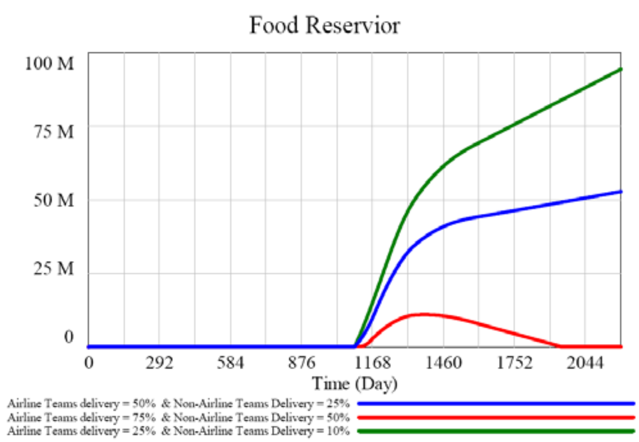

Figure 18– Teams/Food Delivery Percentage Effect on Food Reservoir

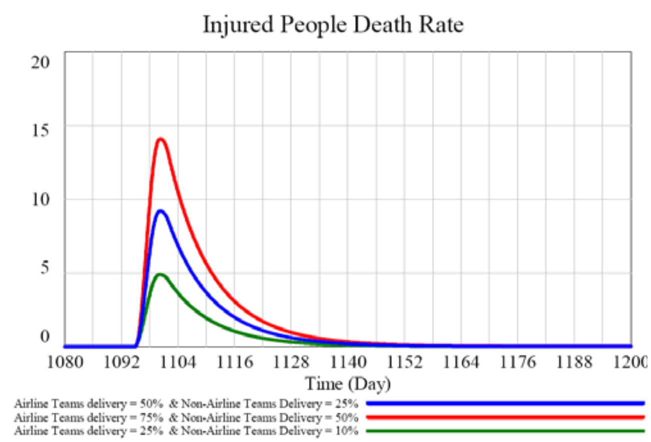

Figure 19 – Teams/Food Delivery Percentage Effect on Injured People Death Rate

3. <u>Special Burying Teams and Equipment</u>

A major problem in post-disaster phase is the mass of corps which should be buried. Being unable to bury the corps causes environmental pollution leading to disease spread throughout the zone, which results in a new problem for authorities to handle as well as the original one. In Bam, the delay of some days in debris removal and corps finding resulted in their corruption and arose of rancid smell in the city. Consequently the probability of Cholera increased to a level that governmental authorities quarantined the zone for NGO and Humanitarian teams and only Professional Teams could be transported there and only after vaccination. In order to prevent such critical situation, not only debris should be removed as soon as possible but also enough human sources should be available for burying them. Besides, since it is vital to recognize and register dead people special equipments like body bags are needed to prevent disease distribution.

In our model, the initial state is compared with the one in which burying time is five times scaled down (i.e. multiplied to a factor of 0.2). The great difference between these two states can be seen in Unburied Corps plot (Figure 20). It causes an approximate decrease of 20% in People Infected with Deadly Diseases. However it has negligible effect on the total casualty numbers (Fig. 21). It is because casualties due to buildings destruction is much bigger than people dying from disease spread. But still a decrease of 20% is a relative significant difference. So it is vital to decrease Burying Time, but it is not as important as the other four key parameters. In case of limited human or money resources the lower importance of this parameter must be taken into consideration seriously.

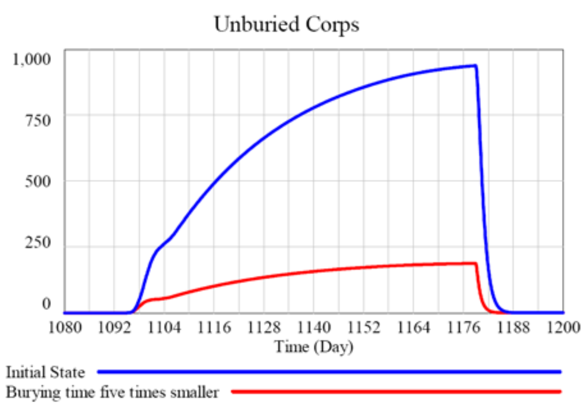

Figure 20 – Burying Time Effect on Unburied Corps

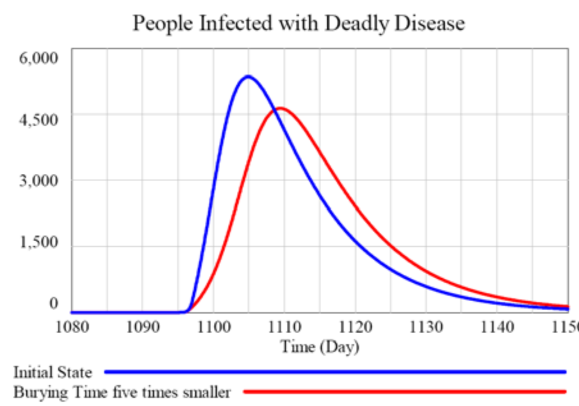

Figure 21 – Burying Time Effect on People Infected with Deadly Disease

4. <u>Medical/Rescue Team Percentage</u>

"Attending injured and sick people" and "search, debris removal and rescuing" are both important in disaster management of an earthquake. In such catastrophes medical and rescue teams are sent in huge numbers to the zone. In the beginning these arrivals are not controlled and are done without paying attention to the need of the zone not to airport or road capacities. It is important to maintain the percentage of both rescue and medical teams in optimum level all the time.

Initially teams are equally divided between rescue and medical teams each having a portion of 50% (blue line). Two different cases are compared with the initial state, in one Rescue Teams make 75% of Teams Present in the Zone, and in the other one 90%. Doing so increases the Total Debris Removal Ability of the city resulting in faster finding of people and corpses (Fig. 22) but higher Injured People Death Rate as well (Fig. 23). As it can be seen from Total Population curves (Fig. 24) although the rate of finding dead people has increased but the total number of dead people has not changed. Two reasons can be proposed for this behavior. First, the death rate due to injuries has canceled out the effect of finding corps and people faster. Second, Figure 23 shows that still it takes more than 5 days to find most of corpses. Living probability of a person under debris after 5 days is very close to zero. So despite of increasing rescue teams portion, still debris removal ability of the city is not enough to ensure a negligible reduction of casualties. So it can be deduced that only increasing Rescue Team Percentage is not enough. It should be done at the same time by increasing Teams Delivery Percentage and Broadcast Coverage.

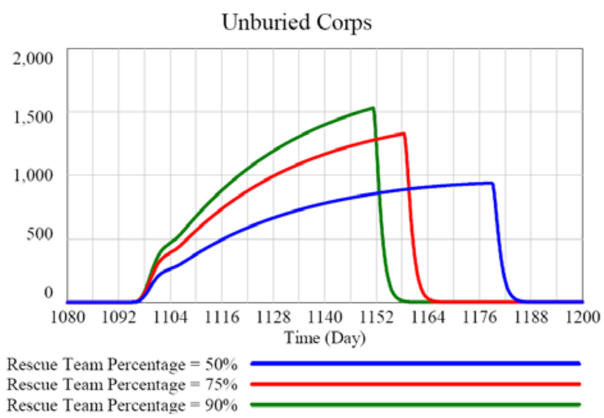

Figure 22 – Rescue Team Percentage Effect on Unburied Corps

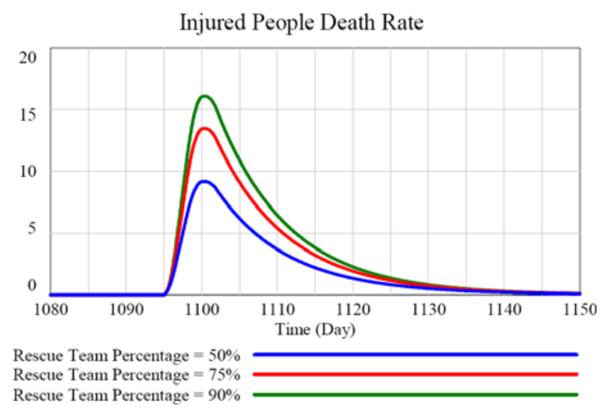

Figure 23 – Rescue Team Percentage Effect on Injured People Death Rate

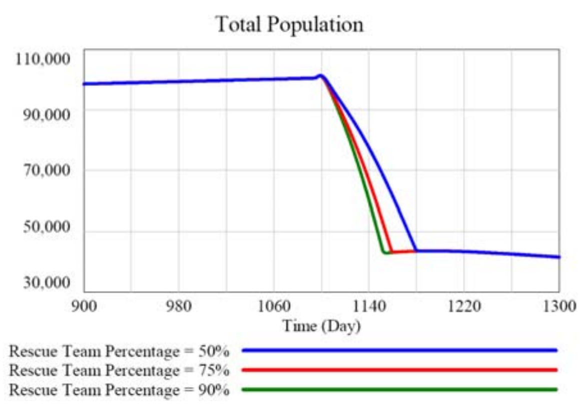

Figure 24 – Rescue Team Percentage Effect on Total Population

5. Team Management (Total Debris Removal Ability)

Having numerous rescue teams for search and debris removal in a zone does not guarantee that they can be efficient. The more teams are present the harder it becomes to manage them, especially when teams are from different countries or organizations, with specific abilities, equipments and tactics. If their operations are not matched by a local management authority, many interactions occur which lead to inefficiency of all those special teams. Even sometimes arguments arise from such mismanagements. But if they do work simultaneously and are coordinated correctly, not only they all work efficiently, but also their joint work results in a higher performance.

Since simulation of this coordination is very complex, it is assumed that the efficiency of teams due to correct coordination shows itself in the Debris Removal Ability of each team. This variable not only shows teams' readiness and their abilities individually, but also represents their harmony as well. For humanitarian teams, it is assumed that when there is some sort of leadership either among themselves or assigned by local authorities the higher their debris removal ability will be.

Simulations are done for three different levels of debris removal ability. Initially it was set to 0.5 buildings per day for Fire-stations and NGO & Prof. Teams, and 0.25 buildings per day for Humanitarian teams (Medium Debris Removal Ability). Second simulation was done by assuming 0.75 buildings per day for Fire-stations and NGO & Prof. Teams, and 0.5 buildings for Humanitarian Teams (better equipped teams and more efficient coordination, High Debris Removal Ability). In third simulation, debris removal ability of Fire-stations and NGO & Prof. Teams is 0.25 and 0.1 buildings per day for Humanitarian Teams (Low Debris Removal Ability).

Higher Debris Removal Abilities result in higher Total Debris Removal Ability of the City (Fig. 25), faster people finding rate, and therefore more injured people and corps are found in shorter time (Fig. 26). Despite of all of these, still the total number of casualties remains high and unchanged. The reason is like what was discussed for the previous section. Although debris removal ability of teams has increased but still it takes more than five days to remove debris and find bodies. This delay leaves a tiny chance of less than 1% to be alive. So it can be seen that an effective coordination can significantly increase the possibility of lowering casualties while a bad coordination causes a very long delay and problems in teams' works (Fig. 26). But in order to achieve our goal, which is debris removal of the zone in the shortest possible time nearly less than five days, it is necessary not only to set up an skillful coordinating center but also increasing rescue teams number to a great extent.

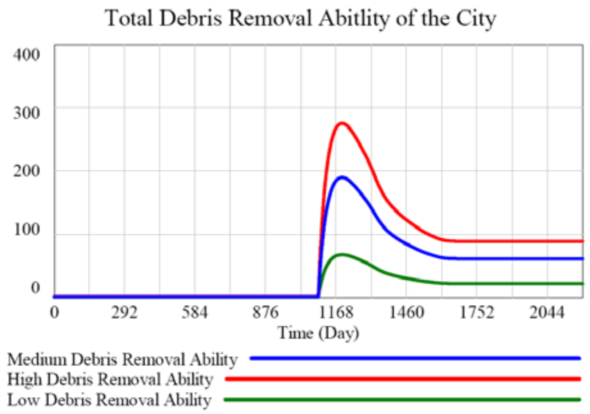

Figure 25 – Debris Removal Ability Effect on Unburied Corps

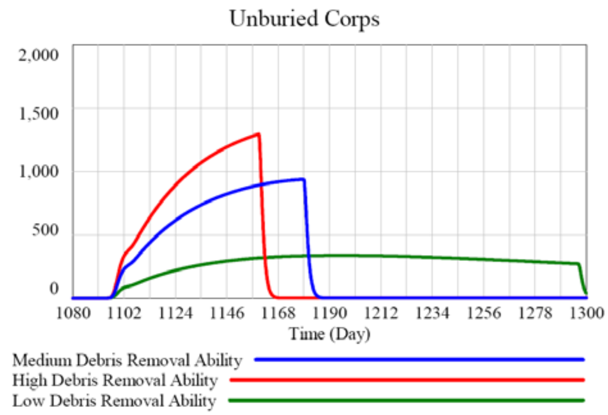

Figure 26 – Debris Removal Ability Effect on Injured People Death Rate

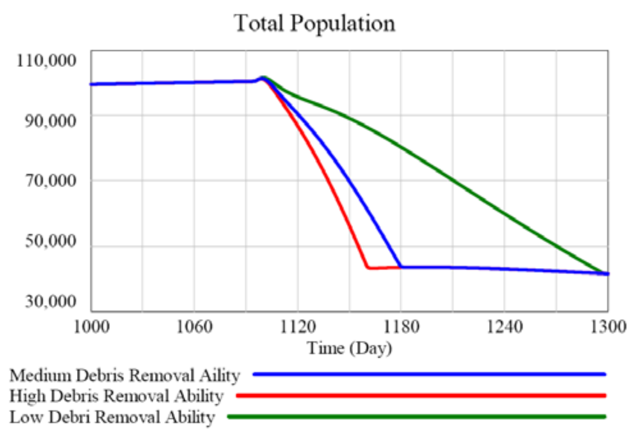

Figure 27 – Debris Removal Ability Effect on Total Population

Conclusion

In previous section, the effect of five different strategies was studied separately. It could be seen that all of them somehow pointed towards wither Total Debris Removal Ability of the city and number of rescue teams present in the zone (which controls the time for total debris removal ability and finding people) or toward People Injured Death Rate or People Infected with Deadly Diseases both of which depend on number of Medical Teams as well as Food Reservoir in the zone.

It was deduced that there are five key parameters which play very important roles in reduction of casualties. These parameters are: Broadcast Coverage, Teams/Food Delivery Percentage, Medical/Rescue Teams Percentage, Burying Time, and Debris Removal Abilities of Teams. For each one of them optimum values or value intervals were obtained through studying their effect. A simulation is done by using all these optimum conditions in order to see their effect when they work simultaneously. Figures 28-31 represent the simulation in best conditions described.

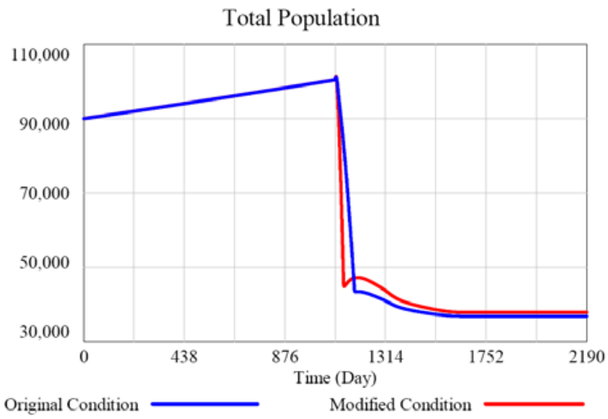

Figure 28– Total Population Behavior in Best Condition

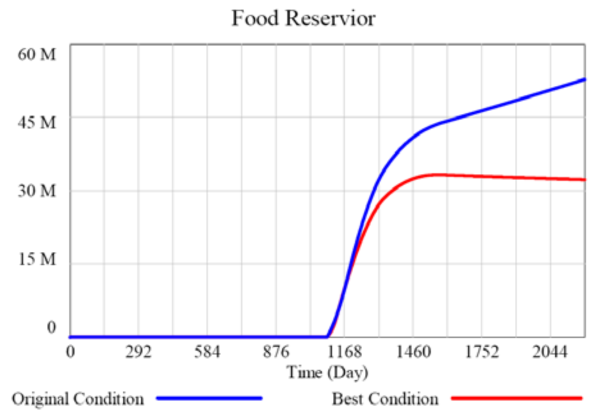

Figure 29 –Food Reservoir in Best Condition

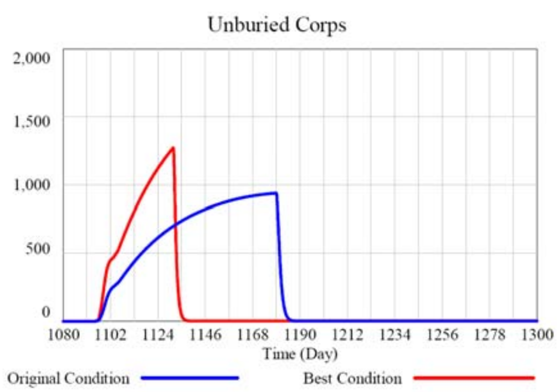

Figure 30 – Unburied Corps in Best Condition

Figure 31 – Total Debris Removal Ability in Best Condition

It can be seen that a system dynamical modeling of disaster management can be of help in great extent to mitigate casualty numbers and an effective coordination of teams and food arrival as well as their operation for search, rescue and medical operations.

Besides, five critical parameters were introduced. Their effects were studied and appropriate strategies were given to keep each parameter in its best and most efficient range. It is of worth to mention that this model and relevant simulations can be generalized to other cases of earthquake disaster as well as other natural disasters with exerting small modifications.

Acknowledgment

The authors are grateful to Prof. Ali N. Mashayekhi (faculty member of MBA Department, Sharif University of Technology) for useful consult and guidance whenever a help was needed.

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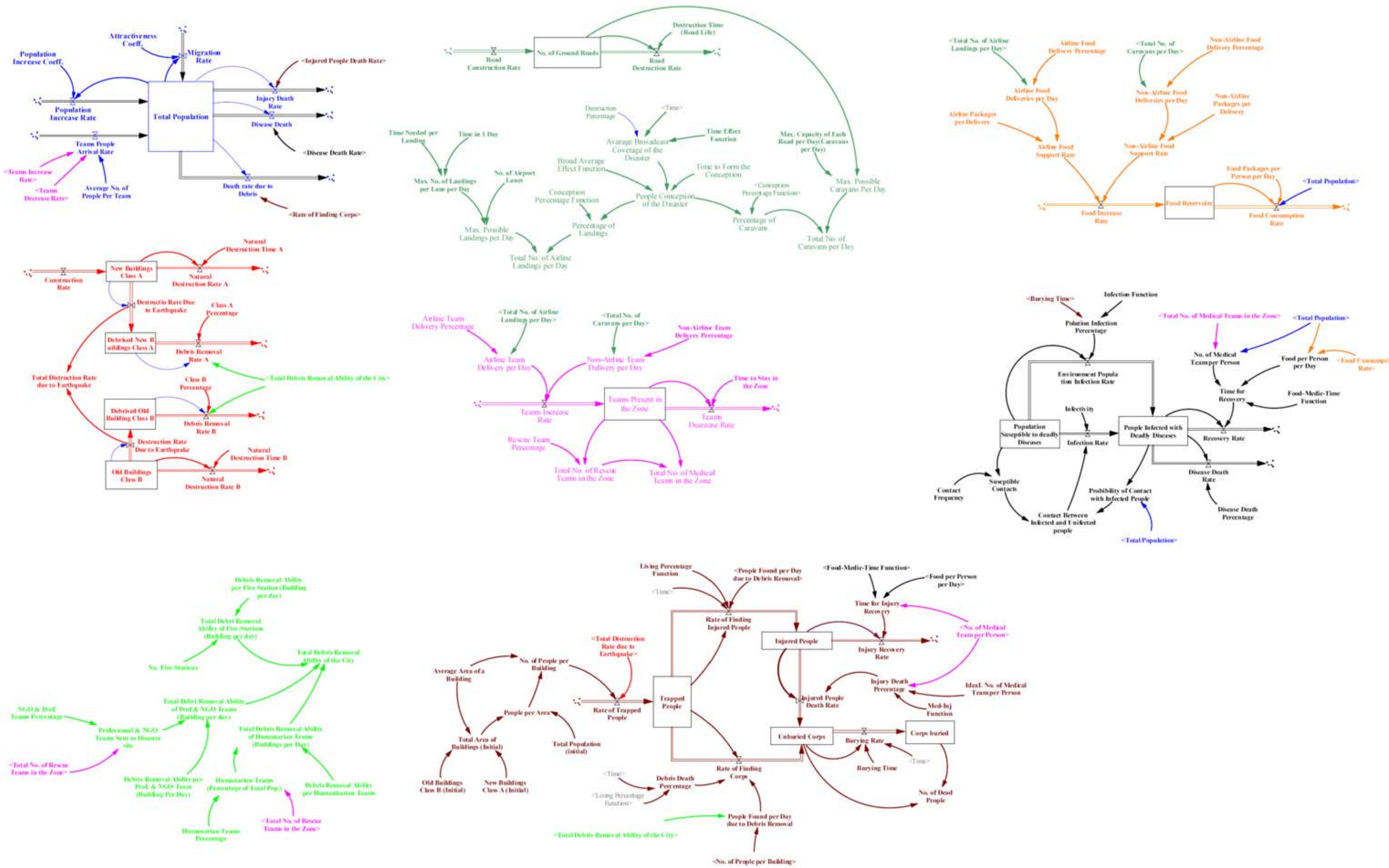
Appendix I (Model Structure)



Appendix II (Governing Equations)

Variables	Equations
Airline Food Deliveries per Day	Total No. of Airline Landings per Day*Airline Food Delivery Percentage
Airline Food Support Rate	Airline Food Deliveries per Day*Airline Packages per Delivery
Airline Team Delivery per Day	"Total No. of Airline Landings per Day"*Airline Team Delivery Percentage
Average Broadcast Coverage of the Disaster	Destruction Percentage*STEP(1,1095)*Time Effect Function(Time)
Burying Rate	Unburied Corps/Burying Time(Time)
Construction Rate	0.65-STEP(0.65, 1095)
Contact Between Infected and Uninfected people	Susceptible Contacts*Probability of Contact with Infected People
Corps buried	Burying Rate
Death rate due to Debris	MIN(Rate of Finding Corps, Total Population)
Debris Death Percentage	1-Living Percentage Function(Time)
Debris Removal Rate A	MIN(Total Debris Removal Ability of the City*Class A Percentage, Debrised New Buildings Class A)
Debris Removal Rate B	MIN(Total Debris Removal Ability of the City*Class B Percentage, Debrised Old Building Class B)
Debrised New Buildings Class A	Integral (Destruction Rate Due to Earthquake-Debris Removal Rate A)
Debrised Old	Integral(Destruction Rate Due to Earthquake-Debris Removal Rate B)

Building Class B	
Destruction Rate Due to Earthquake	0.5*New Buildings Class A*PULSE(1095, 1)
Destruction Rate Due to Earthquake(old buildings)	Old Buildings Class B*PULSE(1095, 1)
Disease Death	MIN(Disease Death Rate, Total Population)
Disease Death Rate	Disease Death Percentage*People Infected with Deadly Diseases
Environment Population Infection Rate	MIN(Population Susceptible to deadly Diseases , Pollution Infection Percentage*Population Susceptible to deadly Diseases)
Food Consumption Rate	MIN(Food Reservoir (Total Population*Food Packages per Person per Day))
Food Increase Rate	Airline Food Support Rate +"Non-Airline Food Support Rate"
Food Reservoir	Integral(Food Increase Rate-Food Consumption Rate)
"Humanitarian Teams (Percentage of Total Pop.)"	"Total No. of Rescue Teams in the Zone"*Humanarian Teams Percentage
Infection Rate	Contact Between Infected and Uninfected people*Infectivity*STEP(1, 1095)
Injured People	Integral(Rate of Finding Injured People-Injured People Death Rate-Injury Recovery Rate)
Injured People Death Rate	Injured People*Injury Death Percentage
Injury Death Percentage	"Med-Inj Function"("No. of Medical Team per Person"/"Ideal No. of Medical Team per Person")
Injury Recovery	Injured People/Time for Injury Recovery

Rate	
"Max. No. of Landings per Lane per Day"	Time in 1 Day/Time Needed per Landing
"Max. Possible Landings per Day"	"Max. No. of Landings per Lane per Day"*"No. of Airport Lanes"
"Max. Possible Caravans Per Day"	"No. of Ground Roads"*"Max. Capacity of Each Road per Day(Caravans per Day)"
Migration Rate	Total Population*"Attractiveness Coeff."
Natural Destruction Rate A	New Buildings Class A/Natural Destruction Time A
Natural Destruction Rate B	Natural Destruction Rate B
New Buildings Class A	Integral (Construction Rate-Destruction Rate Due to Earthquake-Natural Destruction Rate A)
"No. of Dead People"	Unburied Corps +Corps buried
"No. of Ground Roads"	Integral(Road Construction Rate-Road Destruction Rate)
"No. of Medical Team per Person"	"Total No. of Medical Teams in the Zone"/Total Population
"No. of People per Building"	Average Area of a Building*People per Area
"Non-Airline Food Deliveries per Day"	"Total No. of Caravans per Day"*"Non-Airline Food Delivery Percentage"
"Non-Airline Food Support Rate"	"Non-Airline Food Deliveries per Day"*"Non-Airline Packages per Delivery"
"Non-Airline Team	"Non-Airline Team Delivery Percentage"*"Total No. of Caravans per

Delivery per Day"	Day"
Old Buildings Class B	Integral(-Destruction Rate Due to Earthquake-Natural Destruction Rate B)
People Conception of the Disaster	DELAY1I(Broad Average Effect Function(Average Broadcast Coverage of the Disaster), Time to Form the Conception, 0)
People Found per Day due to Debris Removal	Total Debris Removal Ability of the City*"No. of People per Building"
People Infected with Deadly Diseases	Integral (Environment Population Infection Rate+ Infection Rate-Disease Death Rate-Recovery Rate)
People per Area	"Total Population (initial)"/"Total Area of Buildings (Initial)"
Percentage of Caravans	Conception Percentage Function(People Conception of the Disaster)
Percentage of Landings	Conception Percentage Function(People Conception of the Disaster)
Pollution Infection Percentage	Infection Function(Burying Time)
Population Increase Rate	Total Population*"Population Increase Coeff."
Population Susceptible to deadly Diseases	Integral(-Environment Population Infection Rate-Infection Rate)
Probability of Contact with Infected People	People Infected with Deadly Diseases/Total Population
"Professional & NGO Teams Sent to Disaster site"	"Total No. of Rescue Teams in the Zone"*"NGO & Prof. Teams Percentage"
Rate of Finding	MIN(Debris Death Percentage*People Found per Day due to Debris

Corps	Removal, Trapped People)
Rate of Finding Injured People	MIN(Trapped People, Living Percentage Function(Time)*People Found per Day due to Debris Removal)
Rate of Trapped People	"No. of People per Building"*Total Destruction Rate due to Earthquake
Recovery Rate	People Infected with Deadly Diseases/Time for Recovery
Road Destruction Rate	"No. of Ground Roads"/"Destruction Time (Road Life)"
Susceptible Contacts	Population Susceptible to deadly Diseases*Contact Frequency
Teams Decrease Rate	Teams Present in the Zone/Time to Stay in the Zone
Teams Increase Rate	STEP(1 , 1095)*("Non-Airline Team Delivery per Day"+Airline Team Delivery per Day)
Teams People Arrival Rate	(Teams Increase Rate-Teams Decrease Rate)*"Average No. of People Per Team"
Teams Present in the Zone	Integral(Teams Increase Rate-Teams Decrease Rate)
Time for Injury Recovery	"Food-Medic-Time Function"(Food per Person per Day*"No. of Medical Team per Person")
"Total Debris Removal Ability of Fire-Stations (Building per day)"	"No. Fire-Stations"*"Debris Removal Ability per Fire-Station (Building per day)"
"Total Debris Removal Ability of Prof.& NGO Teams (Building per day)"	"Debris Removal Ability per Prof. & NGO Team (Building Per Day)"*"Professional & NGO Teams Sent to Disaster site"
"Total Debris	Debris Removal Ability per Humanitarian Teams*"Humanitarian

Removal Ability of Humanitarian Teams (Buildings per Day)"	Teams (Percentage of Total Pop.)"
Total Debris Removal Ability of the City	"Total Debris Removal Ability of Fire-Stations (Building per day)"+"Total Debris Removal Ability of Prof.& NGO Teams (Building per day)"+"Total Debris Removal Ability of Humanitarian Teams (Buildings per Day)"
Total Destruction Rate due to Earthquake	Destruction Rate Due to Earthquake+ Destruction Rate Due to Earthquake
"Total No. of Airline Landings per Day"	"Max. Possible Landings per Day"*Percentage of Landings
"Total No. of Caravans per Day"	"Max. Possible Caravans Per Day"*Percentage of Caravans
"Total No. of Medical Teams in the Zone"	Teams Present in the Zone-"Total No. of Rescue Teams in the Zone"
"Total No. of Rescue Teams in the Zone"	Teams Present in the Zone*Rescue Team Percentage
Total Population	Integral(Migration Rate+ Population Increase Rate+ Teams People Arrival Rate-Death rate due to Debris-Disease Death-Injury Death Rate)
Trapped People	Integral(Rate of Trapped People-Rate of Finding Corps-Rate of Finding Injured People)
Unburied Corps	Integral(Injured People Death Rate+ Rate of Finding Corps-Burying Rate)