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MODELING THE INCLUSION OF TRAPPED VICTIMS IN LOGISTICS PLANNING FOR EARTHQUAKE RESPONSE: A CASE STUDY IN THE CITY OF BOGOTÁ

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ABSTRACT

Discrete Event Simulation (DES) has been commonly used in modeling the medical attention of injured people. In earthquakes, a portion of the injured victims are trapped and need to be rescued before receiving medical attention. Hence, the rate of rescue operations and the percentage of victims that are rescued have an impact on the logistics planning of medical attention. In this paper we attempt to improve an existing DES model for medical attention to earthquake victims by proposing an improved way of modeling the inter-arrival rate of trapped people. We compare our results with the DES model applied to an earthquake in the city of Bogotá, Colombia and evaluate the difference of additional logistics requirements. The results show that when the percentage of dead people is below 80% there is a significant increase in the expected number of injured victims in the model, when the trapped people are properly included.

1 INTRODUCTION

Earthquakes are considered to be the most catastrophic natural disasters because of their high death toll in comparison with other events such as cyclones, hurricanes, floods etc., (BBC News Health 2011). In the last 5 years, earthquakes have caused over US $250 billion of financial damages and more than 12 million victims (Guha-Sapir et al. 2010). Due to their massive impact and destruction, there has been much of attention and research on topics addressing post-disaster logistics, response and relief operations after the occurrence of these events (Altay and Green III 2006). Governments and international organizations including the International Federation of Red Cross and Red Crescent Societies (IFRC), United Nations Office for Disaster Risk Reduction (UNISDR) and Federal Emergency Management Agency (FEMA) among others, are investing great amounts of resources in the preparedness and response phases in order to be able to cope with the disaster and reduce to a minimum the number of casualties and injuries. Simultaneously, the academic community has provided significant contributions on the topic with research on the distribution of medical resources, the location of temporary medical facilities and resource warehouses, the coordination of search and rescue activities and estimation models for casualties and injuries (with the last one being the core of all, as it provides the demand, which is essential input to the other models). Among these latest works of research, the contribution of Spence et al. (2011) was notable. In their book they show a compilation of research articles on the topic of natural disaster casualties, with studies developed by the world's leading practitioners in mass-casualty risk management. They include information on casualty loss modeling, lessons learned from previous natural disaster events, earthquake structural damage and casualties databases and approaches in improving casualty modeling.

In the Winter Simulation Conference of 2011, (Noreña et al. 2011) presented a discrete-event simulation (DES) model for the transfer and attention of injured people in temporary and permanent hospitals after an earthquake. The model attempted to determine the extra capacity of hospitals and ambulances required to minimize the expected number of casualties due to lack of medical attention in an earthquake scenario of 6.2 in the Richter scale in five districts of the city of Bogotá, Colombia, during the first 96 hours of occurance. Using information provided by the Bogotá's Emergency Plan (BEP) (DPAE 2007) and Bogotá's Seismic Micro Zoning (Alcaldía de Bogotá 2010), the model could be used by the city officials as a decision-making tool to determine the appropriate capacity of temporary medical facilities and ambulances per district to minimize the expected number of casualties in the city, caused by the lack of the necessary post-disaster resources.

The structure of their model is shown in Figure 1. In their DES trapped and injured people are created following certain known distributions and a percentage of the trapped people are considered to be found dead (this percentage does not enter the model and is not considered in the number of casualties due to lack of resources). The trapped people are different from the injured people in the fact that they need external help in order to be rescued first. Both, immediately injured and trapped victims are classified considering their level of injury and, depending on the availability of communications with hospitals and their capacities, are sent in an ambulance to a permanent hospital (in the case of the severely injured) or with any vehicle to a temporary health center (in the case of mildly injured or if there is no capacity in permanent hospitals). After the arrival, the patients are attended depending on the staff capacity. The service time is given according to the level of injury of the patient. An inventory model is also developed for the hospital medical and pharmaceutical resources. Finally, people are considered dead (due to the lack of medical resources) if the total time of the transportation and medical attention is larger than the survival time of the patient which is considered a random variable with known distribution.

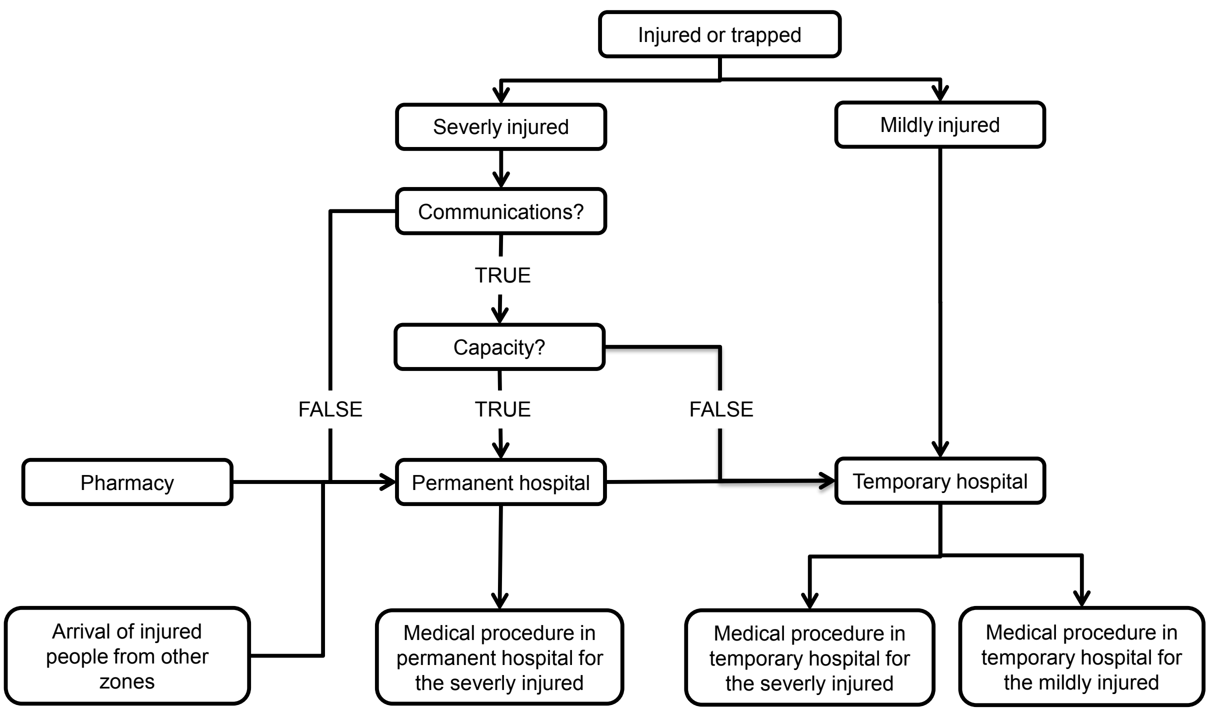

Figure 1: DES Model Structure (Noreña et al. 2011).

Their results showed that an increase in the number of ambulances was only meaningful if an improvement in the capacity of hospital beds for each district was also achieved. Among the final considerations they suggested as next steps the extension of the model to all of Bogotá's 19 districts and the inclusion of more details regarding information on the injured people, such as the levels of injury and medical care needed by the patients, among others. With the use of Arena a simulation software an expansion of this model was done by Rıos Hurtado and Akhavan-tabatabaei (2011), but the assumptions for the creation of trapped people needed a deeper look. In the DES developed by Rıos Hurtado and Akhavan-tabatabaei (2011), the creation of trapped people was assumed to have a constant rate of 8 $hours^{-1}$, which was not in accordance with what the real experiences and studies in the literature show. This difference between the model and real scenarios could underestimate the number of people entering the model, and by doing so also underestimate the number of casualties due to the lack of medical resources.

The specific contribution of this paper is to provide a distribution that could better simulate the arrival of trapped people, taking into account the information found in the literature that considered factors including the building material, the rescue capacity of the city, and the survival rate of people under trapped conditions. The new information was incorporated into the model developed by Rıos Hurtado and Akhavan-tabatabaei (2011) and a comparison was carried out in order to determine if there was a significant change in the results versus when the trapped people are inaccurately included in the model.

The rest of this paper is organized as follows. In the following section we review the relevant literature on survival rate and death percentage of trapped people. In Section 3 we explain the methodology used to tackle the problem. Section 4 contains the results for the different districts in Bogotá and finally we present the conclusions and future research in Section 5.

2 LITERATURE REVIEW

In this section we provide a review of several articles that discuss trapped people, percentage of rescued people, factors affecting the search and rescue process and the survival rate of these victims. It should be noted that most of the consulted literature present information on factors that need to be considered when calculating number of deceased or trapped people, and so present analytical methodologies and results that can be used to establish this information. However two of them also provide simulated results (using the proposed methodologies) and a comparison between them and real data for some specific cases (Shino et al. (1992) and Ohta et al. (2004)).

Among the articles found in Spence et al. (2011), Zuccaro and Cacace (2011) presented good information regarding the factors that should be considered while estimating the number of deaths in an earthquake, which include the casualty percentage by building type and damage, population distribution, occupancy rate by hour of the day and touristic index. Ikuta and Miyano (2011) focused on the type of injuries caused by collapsed buildings and used databases of the Great Hanshin earthquake of 1995 and Kobe earthquake in the same year, to determine the percentage of people with a specific type of injury among all the affected population. Based on the information provided by the consulted articles and the structure of the DES model previously explained for the simulation of the arrival rate of trapped people, two main factors were considered to be the most important: the survival rate of trapped people (which finally determines for how long a person can stay alive while being trapped) and the percentage of dead among the trapped people (a characteristic that will depend mainly on the disaster's magnitude and the structural vulnerability). These factors were also chosen because they were better documented than the others. Until today, there is a difficulty in the research and study on the topic, as there is not enough information or data to compare the results with. This is basically a consequence of the complexity and in some cases the impossibility of acquiring data in the aftermath of a disaster, because of the lack of time and resources. There are a few post-disaster complete reports, and as each disaster is unique in its characteristics, the assumption of using the acquired information of one event may not be appropriate to model some other event. However, considering the lack of better procedures and practices, the use of these few reports may contribute to improving the modeling of trapped and injured people in general.

Shino et al. (1992) modeled the search and rescue activity, and simulated the live and dead recoveries from the Juarez Hospital after the Mexico City Earthquake in 1985. This is one of few well documented cases which made it possible to compare the theoretical or simulated results to the real ones. Once the simulated results and real data were compared, a good fitting between them was graphically observed. As an important result on the behavior of the system, it was found that both, live and dead recoveries, decreased rapidly after some time. On a second article, by Ohta et al. (2004) a model for the evaluation of life span characteristics of entrapped occupants after an earthquake was developed. In their research they considered the classification of trapped people by death modes, and the assignment of survival time lengths and percentage of the total trapped for each mode as shown in Table 1, based on the case study of the Kobe earthquake. Considering that there is a lack of trapped or rescued information and that the scenario in the city of Kobe at the time had similar characteristics to the one that is being simulated for Bogotá (Earthquake magnitudes of 7.0 and 6.2 respectively, same earthquake mechanism by subduction plate, similar structural types), the percentage distribution of trapped by death modes given in this article was used for our case study. Among the important results obtained by Ohta et al. (2004) they observed that the survival rate decreased with time and depended also on the death mode. In their results a figure presenting the survival rate by death mode can be found in which people classified in Mode 5 have a survival rate that begins to decrease after approximately the 30th hour and reaches 0 after the 100th hour(the person is considered dead) while for Mode 1 it decreases from the first moment to the 5th or 6th minute.

Table 1: Classification of Trapped People in Death Modes.

Death Modes	**Life Time Length**	**Percentage (%)**
Mode 1: Suffocation	5-6 minutes	2
Mode 2: Injuries - Head, Chest	3 hours	11
Mode 3: Injuries - Abdomen	12 hours	23
Mode 4: Injuries - Limbs	1 day	30
Mode 5: No injury	2.5 days	34

For the percentage of death of trapped people, information provided by two main sources was used. Coburm et al. (1992) developed a model for the calculation of death tolls in earthquakes. In their model the number of people killed because of the collapse of structures was estimated using the expected number of collapsed buildings and five main factors (M1 to M5) namely, population per building, occupancy at the time of earthquake, occupants trapped by collapse, mortality at collapse and mortality post-collapse. This last factor, which is later referred in the consulted paper as ”Living victims trapped in collapsed buildings that subsequently die”, shown in Table 2, was considered as the percentage of death of trapped people. Similar information was found in the Micro Zoning for the cities of Palmira, Tulua and Buga, Colombia (CEDERI 2005). In this study a methodology for the estimation of the number of affected, injured and trapped is presented, and a classification according to the final state of the person (injured or dead) and the level of injury (if applicable) is provided. For the estimation of trapped people they consider as factors the disaster intensity, the time of occurrence (information on the occupancy rate of structures according to the time) and the type of structure (based on the database on major earthquake events since 1970). Their results show the trapped percentage according to the principal structural types. For Bogotá's most common structural types, masonry and concrete, the percentages of trapped fatalities (without considering other factors such as community's rescue capacity) vary between 15 to 50%. The difference between these percentages and the numbers shown in Table 2 is due to the fact that for the Colombian cities Micro Zoning they assumed that the emergency response is immediate and that there will be enough resources and hospitals in order to cope with the emergency, and so the death percentage of trapped people is lower.

Table 2: Percentage of living victims trapped in collapsed buildings that subsequently die.

Situation	**Masonry**	**Reinforced Concrete**
Community incapacitated by high casualty rate	95%	-
Community capable of organizing rescue activities	60%	90%
Community + emergency squads after 12 hours	50%	80%
Community + emergency squads + Search and Rescue experts after 45 hours	30%	70%

3 METHODOLOGY

A probabilistic analysis was conducted in order to improve the model assumptions regarding the creation of injured people (specifically the trapped people who survive the rescue operations with injuries). As it was shown in the literature review, there is a lack of information on the number of casualties of trapped victims, because of the difficulty to register this information after an earthquake. This makes it very difficult to have real data on the arrival times of trapped people to medical centers after an emergency and in consequence for this study the data was constructed taking into account the estimation of trapped victims by district reported in the BEP, a classification of trapped people by death modes, the estimated survival time for each death mode and the casualty percentage among the trapped people. Considering the classification of trapped people by death modes developed by Ohta et al. (2004), an assignment of survival time lengths and percentage of the total trapped people for each mode was given. The number of people by death mode was then calculated taking into account this percentages and the estimated number of trapped people reported by the BEP for each district. With these results and the survival rate by mode provided by Ohta et al. (2004), a maximum survival time by mode is obtained and different uniformly distributed retrieval times were assigned to all the trapped people (between 0 and the maximum survival time by assigned mode) as shown in Table 3, taking into account that the probability of getting each specific value is the same. The recovery times are then ordered from minimum to maximum and the time between arrivals of trapped people is calculated and modeled. Then various probability distributions are fitted to this data (Table 4), and the one with the best fitting (based on the Chi square and Kolmogorov-Smirnov test and considering a confidence level of 95%) is included in the creation of trapped people entities. For all of the fittings the square error between the data and the distribution was less than 0.5%, ensuring a good fitting.

Table 3: Limits for the retrieval time uniformly distributed by mode.

Injury Mode	**Percentage (%)**	**Time (hour)**
Mode 1	2	Uniform(0, 0.1)
Mode 2	11	Uniform(0, 8)
Mode 3	23	Uniform(0, 30)
Mode 4	30	Uniform(0, 50)
Mode 5	34	Uniform(0, 96)

The simulation model is then run for different percentages of dead trapped people to determine if there is a change in the model results (expected number of deaths due to late medical attention).

4 RESULTS

A summary of the results obtained for the distribution of arrival rate of trapped people for each of the districts is presented in Table 4. As it could be seen for most of the districts, the inter-arrival time of trapped people best fit log-normal or gamma distributions, consistent with the behavior expected from the system and the shape of these density functions. Immediately after the disaster slow arrival of trapped people is expected, once the rescue operations and community help begin more trapped people will begin to arrive, and finally after the first or the second day this rate will fall drastically to eventually reach 0 because of the survival rate and difficulty of the search and rescue of trapped people.

The results of the number of casualties were obtained after running the model presented by Rıos Hurtado and Akhavan-tabatabaei (2011), for each of the 7 zones in which they finally divided the city. The model considered eleven different scenarios, the first one taking into account the current number of ambulances and medical resources in the districts, and the other ones obtained by gradually increasing by 10% these resources. This model was run 6 times changing the percentage of death among the trapped people from 50% to 100% (which represented the probable percentages according to the earthquake impact and structural characteristics in the zone), in increments of 10%, where 100% means all of the trapped people are found dead, and using 30 replications. Afterwards, the arrival rate of trapped people was replaced with the

Table 4: Distribution of inter-arrival times of trapped people by district.

Zone	**District**	**Probability distribution**
Zone 1	Antonio Nariño	Gamma (0.0665, 0.66)
	Mártires	Gamma (0.0519, 0.641)
Zone 2	Candelaria	Gamma (0.148, 0.821)
Zone 3	Chapinero	Exponential (0.0299)
	Usaquén	Log-normal (0.101, 0.351)
Zone 4	Ciudad Bolívar	Log-normal (0.0853, 0.292)
	Bosa	Log-normal (0.124, 0.389)
	Kennedy	Log-normal (0.0476, 0.157)
	Fontibón	Exponential (0.0137)
	Puente Aranda	Exponential (0.0128)
Zone 5	Barrios Unidos	Log-normal (0.186, 0.596)
	Teusaquillo	Log-normal (0.0629, 0.134)
Zone 6	Rafael Uribe	Log-normal (0.14, 0.421)
	San Cristobal	Log-normal (0.175, 0.587)
	Santafé	Gamma (0.0437, 0.629)
	Tunjuelito	Log-normal (0.106, 0.348)
	Usme	Log-normal (0.974, 2.51)
Zone 7	Engativa	Gamma (0.0541, 0.625)
	Suba	Log-normal (0.0711, 0.166)

distributions shown in Table 4 and the model was run again. A comparison between the results acquired with each of the death percentages was then developed in order to establish if there was a significant difference in the number of casualties between the two models (the one with a constant rate for the arrival of trapped people and the one considering the distributions). This was accomplished by carrying out a two-sample mean comparison test, with a 95% confidence level. For each district and each scenario, the maximum percentage of death of trapped people for which there was a significant change between the models was established and Table 5 was constructed.

According to this, the ones that show a 90% have a difference between models in all cases tested. The ones with 50%, for scenarios where the death percentage of trapped people is over 50% the previous model could be used, but for lower percentages the new distribution for the arrival rate of trapped people should be included in the model in order to better represent the reality. An example of Antonio Nariño district can be seen in Figure 2.

Table 5: Maximum percentage of death people for which there is a significant difference between models.

	Extra hospital capacity								
Zone	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**100%**
1	90	60	50	50	50	50	50	50	50
2	70	70	70	70	70	70	70	80	80
3	60	50	50	50	50	50	50	90	90
4	60	70	70	70	70	70	70	70	70
5	90	60	60	60	60	60	60	60	60
6	70	70	70	80	80	80	80	90	90
7	60	60	60	60	60	60	60	60	60

For a better understanding of the results, two different events would be considered as examples. In the case of a catastrophic earthquake, the percentage of death of trapped people is expected to be between

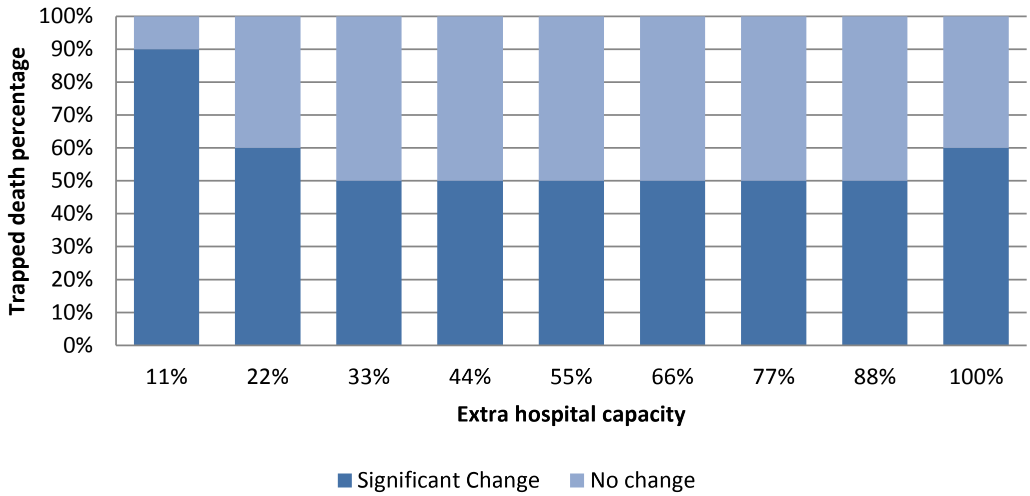

Figure 2: Comparison between models in the case of Zone 1.

80 and 100%. If an 80% is considered, all scenarios with a percentage of 80% or above (the highlighted results) show scenarios where there is a significant change between the two models. This significant change means there is a considerable increase in the number of trapped people that were not contemplated in the model presented by Rıos Hurtado and Akhavan-tabatabaei (2011) in the estimation of the needed resources. This greater number of trapped people will use more resources than the ones that were estimated and this will result in an increase in the number of casualties in the model due to the lack of medical resources. In a second case considering a lower impact earthquake, the percentage of death of trapped people may be lower (60-80%), and so for almost all the scenarios considered in Bogotá's case there is a significant change between the two models. This means that in the previous model there was a underestimation of the trapped people. According to the results it can be seen that for an event where a percentage of death of trapped people of 50% is established, there is always an underestimation in the number of casualties in the model presented by Rıos Hurtado and Akhavan-tabatabaei (2011) (all scenarios have percentages of 50% or more), that may result in the failure to help the city officials to establish the real resources needed to cope with the disaster. In Bogotá's specific case, the only two districts in which the casualties were not underestimated for the proposed scenario were Candelaria and Suba. These results may be replicable to different scenarios. What it is important to show is that for non-catastrophic scenarios, the survivors among trapped people may represent a considerable amount of the injured people and should be taken into account in the models. Also modeling of their inter-arrival time distribution can be very helpful specifically in models considering any kind of the medical attention after an earthquake.

5 CONCLUSIONS

In this research we show how to improve the DES models for medical attention to injured people in an earthquake by proposing a new distribution for inter-arrival rate of trapped victims and test the new distribution in a case of study in city of Bogotá. Considering the information on Bogotá's possible earthquake impact, building materials and the number of people expected to be trapped, the death percentage of trapped people for an earthquake of 6.2 on the Richter scale could be of 50% or more. As shown in the results, if this percentage is over 80% the inclusion of the new distribution would not present changes in death toll due to lack of medical resources and therefore the previous model could be used as an appropriate tool for policy making. However, it is quite likely that this percentage is below 80%, and so the model developed by Rıos Hurtado and Akhavan-tabatabaei (2011) should consider the proposed distribution in order to improve the accuracy of the expected number of deaths in the city. In some models underestimation or over-estimation of the trapped survivors may not be essential, however in others like the previously presented, the underestimation may conduct to a failure in the estimation of the resources needed to cope with the disaster.

Future work may include a better way to determine the percentages of people by death mode for Bogotá's specific case and the study of the possibility to use the same assumptions or similar ones in other disaster scenarios.

REFERENCES

Alcaldía de Bogotá 2010. "Microzonificación Sísmica de Bogotá". Accessed Dec. 20, 2011. http://seisan.ingeominas.gov.co/RSNC/index.php/amenaza-sismica/microbogota.

Altay, N., and W. G. Green III. 2006. "OR/MS research in disaster operations management". *European Journal of Operational Research* 175 (1): 475–493.

BBC News Health 2011. "Earthquakes have a bigger health toll than other disasters". Accessed Jan. 5, 2012. http://www.bbc.co.uk/news/health-15573361.

CEDERI 2005. "Microzonificación Sísmica para los municipios de Palmira, Tuluá y Buga". Technical report, Centro de Estudios sobre Desastres y Riesgos Naturales (CEDERI) - Universidad de los Andes.

Coburm, A., R. Spence, and A. Pomonis. 1992. "Factors determining human casualty levels in earthquakes: mortality prediction in building collapse". In *Proceedings of the tenth world conference on earthquake engineering*, Volume 10, 5989–5994.

DPAE 2007. "Plan de emergencias de Bogotá". Technical report, Dirección de Prevención y Atención de Emergencias (DPAE).

Guha-Sapir, D., F. Vos, and R. Below. 2010. "Annual Disaster Statistical Review 2010". *Centre for Research on the Epidemiology of Disasters, Universite Catholique de Louvain, Brussels, Belgium*.

Ikuta, E., and M. Miyano. 2011. "Study of Damage to the Human Body Caused by Earthquakes: Development of a Mannequin for Thoracic Compression Experiments and Cyber Mannequin Using the Finite Element Method". In *Human Casualties in Earthquakes*, 275–289. Springer.

Noreña, D., L. Yamín, R. Akhavan-Tabatabaei, and W. Ospina. 2011. "Using discrete event simulation to evaluate the logistics of medical attention during the relief operations in an earthquake in Bogota". In *Proceedings of the Winter Simulation Conference*, 2666–2678. Winter Simulation Conference.

Ohta, Y., H. Murakami, Y. Watoh, and M. Koyama. 2004. "A model for evaluating life span characteristics of entrapped occupants by an earthquake". In *13th World Conference on Earthquake Engineering, Vancover, Canada*.

Rıos Hurtado, J., and R. Akhavan-tabatabaei. 2011. "Capacity and Location Planning of Auxiliary Medical Facilities in Earthquake Relief Operations: A Case Study for City of Bogotá". *Msc Thesis, Universidad de los Andes*.

Shino, K., F. Krimgold, and Y. Ohta. 1992. "Modeling of Search-and-Rescue activity in an earthquake". *Proceedings of the 10th WCEE, Balkema, Rotterdam*:6043–6048.

Spence, R., E. So, and C. Scawthorn. 2011. *Human Casualties in Earthquakes: Progress in Modelling and Mitigation*, Volume 29. Springer.

Zuccaro, G., and F. Cacace. 2011. "Seismic Casualty Evaluation: The Italian Model, an Application to the L'Aquila 2009 Event". In *Human Casualties in Earthquakes*, 171–184. Springer Netherlands.

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