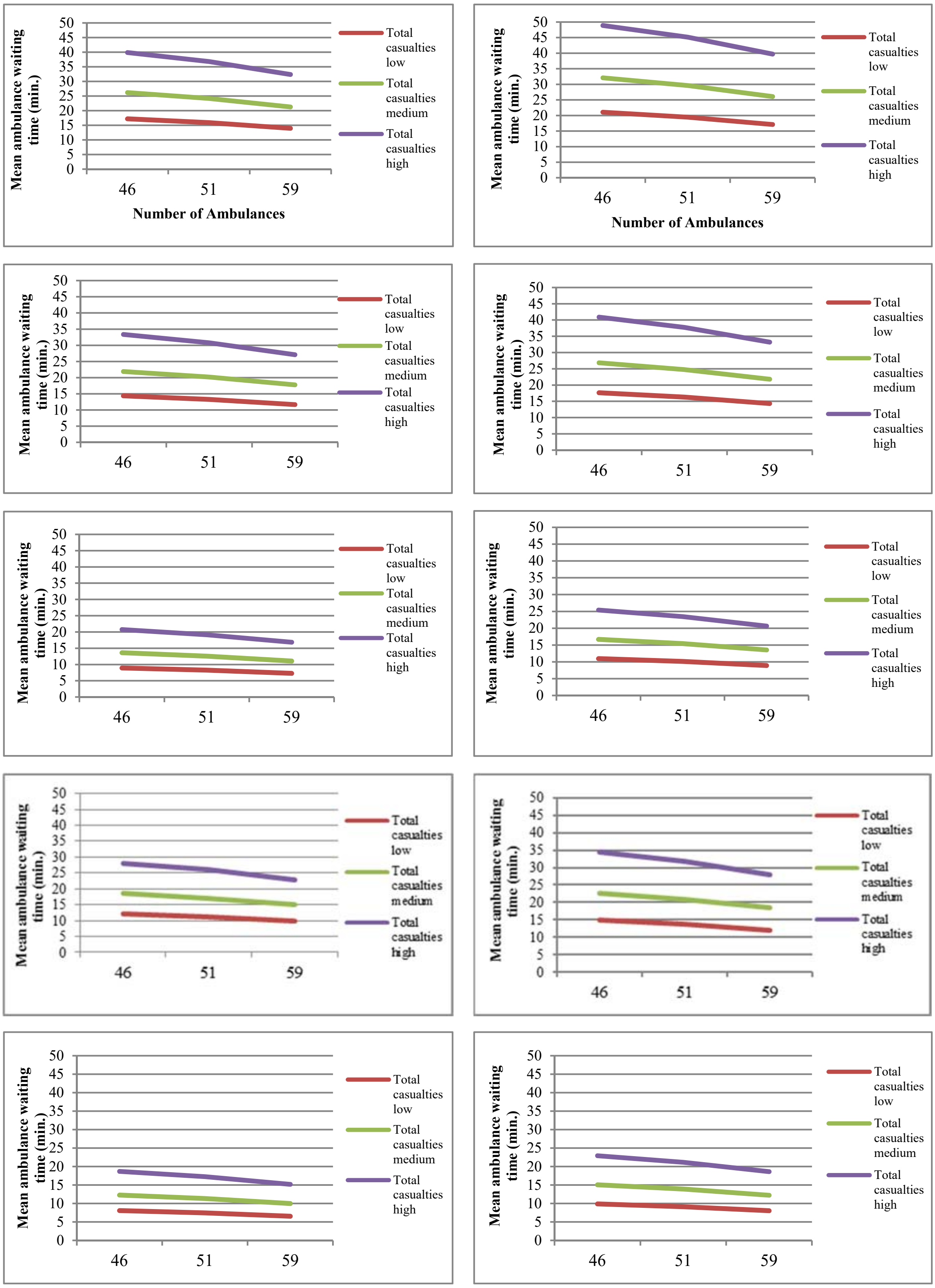

Figure 3. Ambulance waiting times for 5 regions for varying total casualty fractions (0.5%, 1% and 1.5%) at low level of priority 1 casualties (column 1) and high level of priority 1 casualties (column 2)

4.2 Mean Waiting Time for Treatment in Trauma Rooms

In this section, trauma room waiting times are analyzed. It is important to know which factors affect waiting times at trauma rooms, so that before a disaster strikes, resources can be more effectively distributed in order to decrease waiting times, and reduce resulting loss of lives. Table 4 shows factors and the levels used in the experiments implemented in order to determine how various factors are effective on the waiting times for treatment of priority 1 casualties.

Table 4. Experimental design factors for mean treatment waiting time in trauma rooms

Variables		Levels
Number of beds in trauma rooms	Hospital 1	7-12-20
	Hospital 2	2-4-8
	Hospital 3	3-6-12
Number of triage personnel in hospital		1-3-5
Priority 1 casualty fraction in the population		0.15-0.25
Unstable casualty fraction		0.15-0.20-0.25-0.35
Total casualty fraction		0.005-0.010-0.015

Results of analysis of variance (ANOVA) for each hospital are similar. For this reason, only results of ANOVA for hospital 1 are presented here. Assumptions of ANOVA are also tested. Normality assumption of error terms is tested in two ways, using the histogram of residuals, and also Kolmogorov-Smirnov test (Kolmogorov-Smirnov Z= 1.259, p= 0.084). The plot of residuals against fitted values shows that the linearity assumption is satisfied. According to the results of analysis of variance, it is seen that main effects of all factors are statistically significant at the 0.05 level. In addition to this, the interactions between the number of triage personnel and the number of beds, total casualty fraction and priority 1 casualty fraction are also statistically significant at the 0.05 level. The F-value computed for the number of triage personnel (F=12119.41; p=0.000) is higher compared to the other factors, showing that this factor is highly influential on mean waiting time. This is due to the increased number of patients treated in the trauma room per unit time increases as the number of triage personnel increases. Other factors that have important effect are total casualty fraction (F=1057.07; p=0.000), priority 1 casualty fraction (F=719.40; p=0.000) and the interaction between the number of triage personnel and total casualty fraction (F=377.18; p=0.000). These two factors also contribute to higher number of casualties, and hence increase total number of victims for trauma room.

When variance homogeneity cannot be satisfied, as in this case (Levene's test result of equality of error variances: F=8.660, p=0.000), Games-Howell test can be used to determine if there is statistically significant difference between the levels of any one given factor. Games-Howell multi-comparison test is applied to all factors for trauma room waiting time. We present the results on the mean waiting time for treatment in the trauma room which belong to the factors having statistically significant differences between their levels are interpreted as follows:

i) *The number of triage personnel*: According to the test results, as the number of triage personnel increases, it is observed that mean waiting times for treatment also increase (Figure 4) and this increase is statistically significant (for all levels, p=0.000). From the simulation results, long queues are observed (in front of triage process) although the duration of triage operation is short. The longer the waiting time for treatment, the higher the number of fatalities in the queue; therefore, the response of system for the available capacity is evaluated at different triage staff levels. Based on the results, it is recommended that, for each treatment entry point, there should be one member of triage staff or a two member triage team. In this situation, different levels of triage staff would require alternative treatment areas with capacity to conduct emergency service operations, to be constructed in or around hospital. In other words, changes in the levels of triage and trauma room capacity should be closely linked and changed (increased or decreased) together. The relationship between increase in trauma room waiting time with increased triage staff level can be explained by the notion of the shifting bottleneck. Increase in triage staff level allows more victims into the trauma room for treatment per unit time, effectively making the trauma room the new bottleneck. In Figures 4-5, the averages calculated over all the results of the simulation for values of the factor in horizontal axis, are shown by black straight line. In real life, it is quite probable that theoretical distributions will not be (partially) linear. The red dashed lines in Figures 4-5, illustrate the authors' theoretical distribution predictions (convex/concave) based on the obtained results. In this manner, Figure 4 shows the effect of triage personnel on treatment waiting time in trauma rooms.

ii) *Total casualty fraction:* According to the result of the multiple comparison test, as the casualty fraction increases, it is observed that waiting time decreases (Figure 5). This decrease is statistically significant for only the 1st and 3rd levels of the factor (p=0.000). It seems counterintuitive that mean waiting time increases with increased total casualty fraction. Remember that total casualty fraction was also the factor that most affected ambulance waiting time in section 4.1. With increased number of casualties, victims spend more of their remaining life time waiting for ambulances. As the number of casualties increases, it is seen that the number of losses in the treatment queue at the third level of the factor (0.015) is three times greater compared to the first level (0.005). This shows that many are lost before receiving treatment, therefore reducing mean waiting time for those who survive long enough to get treatment.

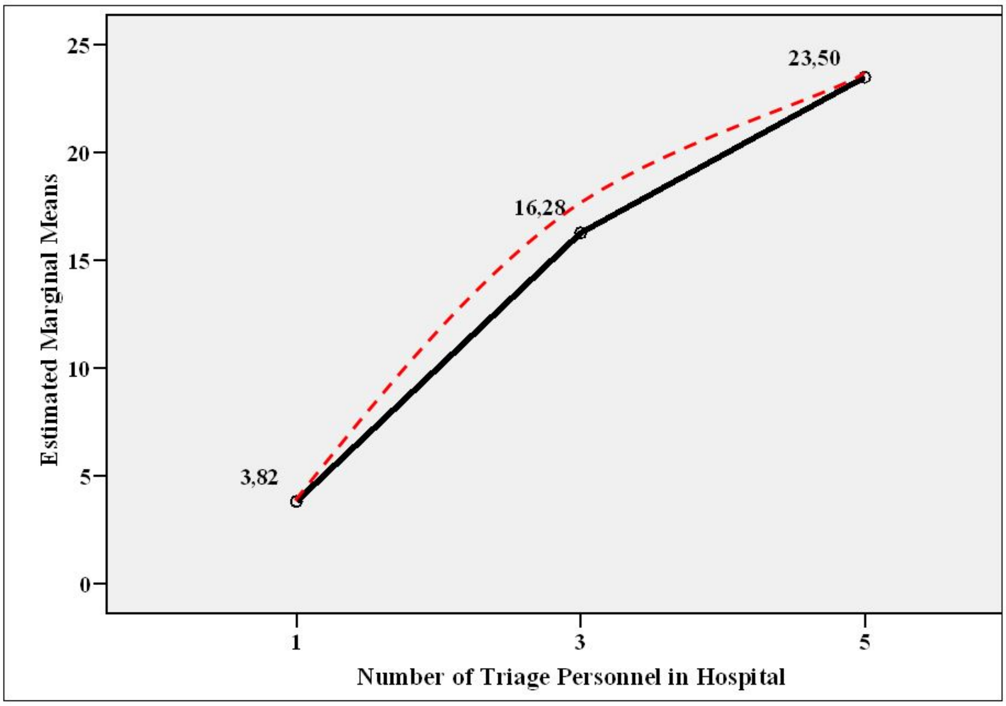

Figure 4. Effect of the number of triage personnel on mean waiting time for treatment (min.) in trauma room

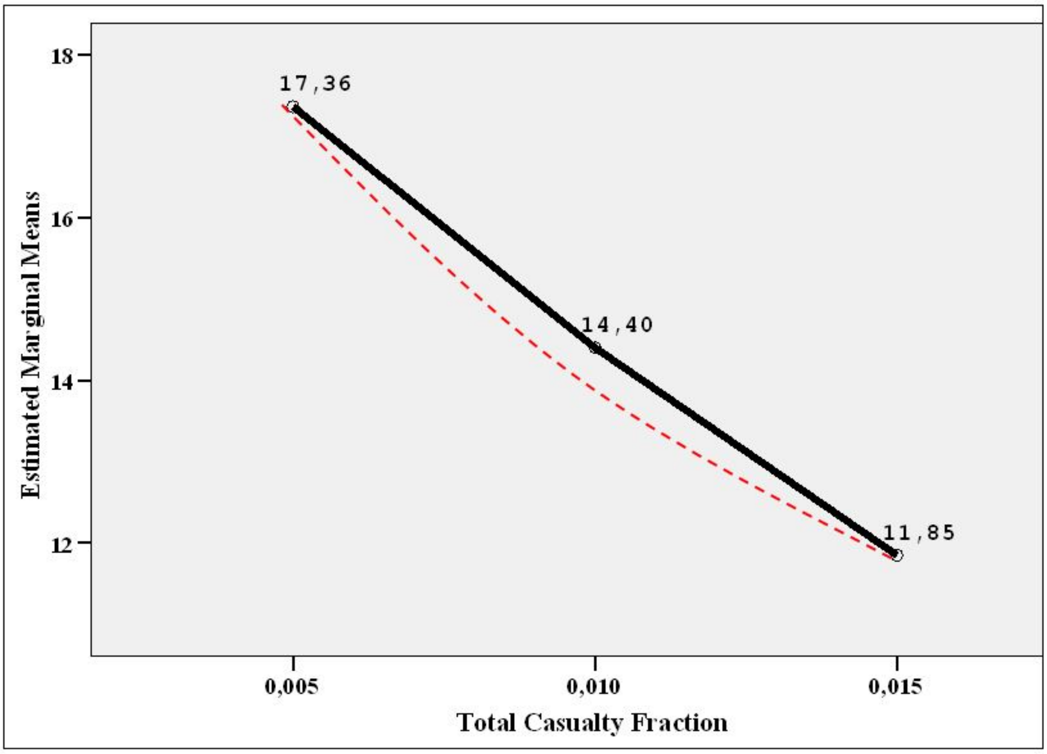

Figure 5. Effect of victim fraction on mean waiting time for treatment (min.) in trauma room

4.3 Mean Waiting Time for Treatment in Observation Rooms

Lastly, we present an analysis determining the effects of various factors on mean waiting times at observation rooms. The second (2nd) class priority victims are forwarded to observation rooms. Table 5 shows the factors and the levels used in the experiments implemented in order to determine effectiveness of various factors on the waiting times for treatment of priority 2 casualties.

Table 5. Experimental design factors for mean treatment waiting time in observation rooms

Variables		Levels
Number of beds in observation rooms	Hospital 1	15-25-35
	Hospital 2	4-8-15
	Hospital 3	4-8-15
Number of triage personnel in hospital		1-3-5
Priority 2 casualty fraction in the population		0.25-0.35
Total casualty fraction		0.005-0.010-0.015

Analysis of variance (ANOVA) is performed based on the results of the experimentation. As in section 4.2, the results of ANOVA are similar for each hospital, and therefore results for only hospital 1 are discussed here. Again, normality assumption of error terms is tested by both analyzing the histogram of residuals, and conducting Kolmogorov-Smirnov test (Kolmogorov-Smirnov Z= 0.922, p= 0.363). The plot of residuals against fitted values shows that the linearity assumption is satisfied. According to the results of ANOVA, main effects of all factors, except number of beds, are statistically significant. However, similar to the previous analysis results, interactions between priority 2 casualty fraction, total casualty fraction and the number of triage personnel are also statistically significant. We also observe that the factor with the greatest impact on the average waiting time in the observation room is the number of triage staff (F=9451.33, p=0.000). The second greatest effect was the interaction of this factor with total casualty fraction (F=1741.54, p=0.000). For the reason explained in section 4.2, increasing levels of mentioned factors will increase the number of victims reaching the observation room in the given time interval, resulting in increased waiting times in the observation room.

When variance homogeneity can be satisfied, as in this case, (Levene's test result of equality of error variances: F=1.278, p=0.125), Tukey HSD test can be used to determine if there is statistically significant difference between the levels of any one given factor. Tukey HSD multi-comparison test is applied to all factors relating to observation room waiting time. According to Tukey HSD multiple comparison test, the effects on the average waiting time for treatment in the observation room which belong to the factors having statistically significant differences between their levels are as follows:

i) *Number of triage personnel*: When the number of triage staff at the entry of emergency room is increased from 1 to 3, an average of 19-minute increase in the waiting time is observed. Similarly, when the number of triage staff is increased from 3 to 5, an increase in the waiting time of approximately 1 minute is observed (Figure 6). According to the test results obtained, it can be said that differences for all levels are statistically significant (p=0.000). The mean waiting time in observation rooms is higher when compared to trauma rooms. This is due to priority 2 casualty fraction being larger than priority 1 fraction, and priority 2 patients' ability to survive for longer without treatment.

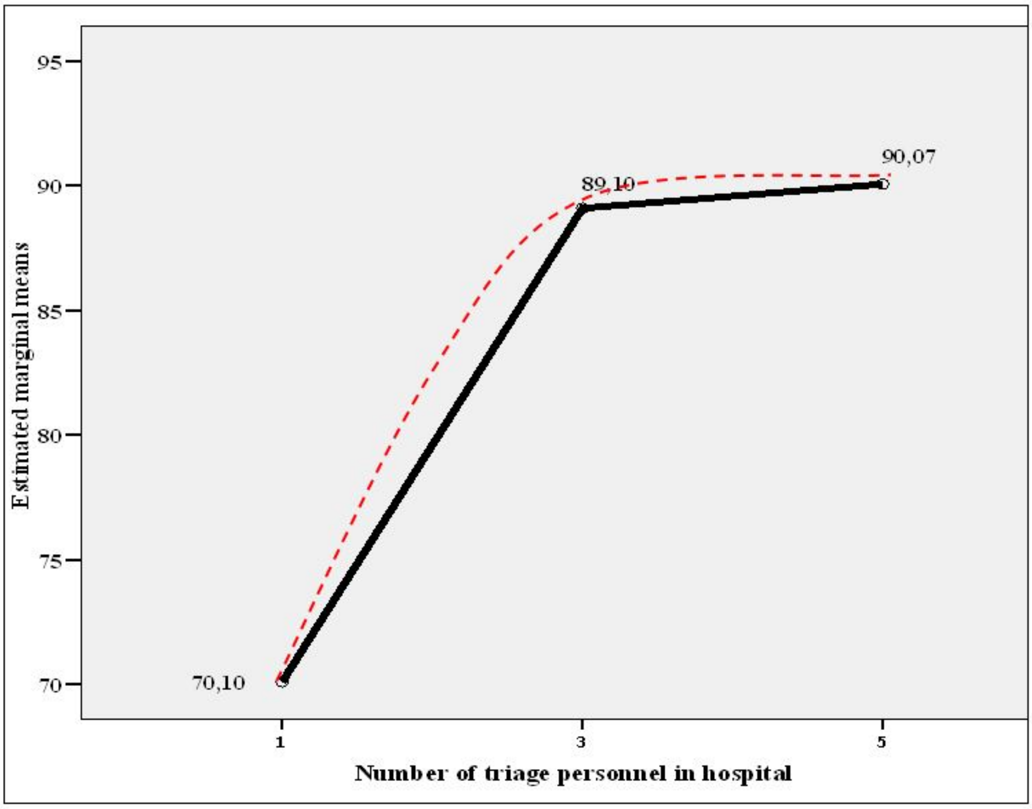

Figure 6. Effect of the number of triage personnel on mean waiting time for treatment in observation room

ii) *Total casualty fraction*: According to the simulation results, when total casualty fraction is increased from level 1 to the level 3 (a three-fold increase); 5.5 times increase in loss of life is observed. This situation explains the reduction in mean waiting time for treatment of increasing total casualty fraction. While this decrease is not statistically significant for levels 1 and 2, it is significant for levels 1-3 and levels 2-3 (p=0.000 for those who are significant). Increasing total casualty fraction from level 2 to level 3 causes an approximately 7-minute decrease in the mean waiting time. Therefore, in terms of waiting time in the observation room, there is a critical value for total casualty fraction between 0.01 and 0.015. The exact identification of this value requires a more detailed simulation study, with more steps between the 0.01 and 0.015 (Figure 7).

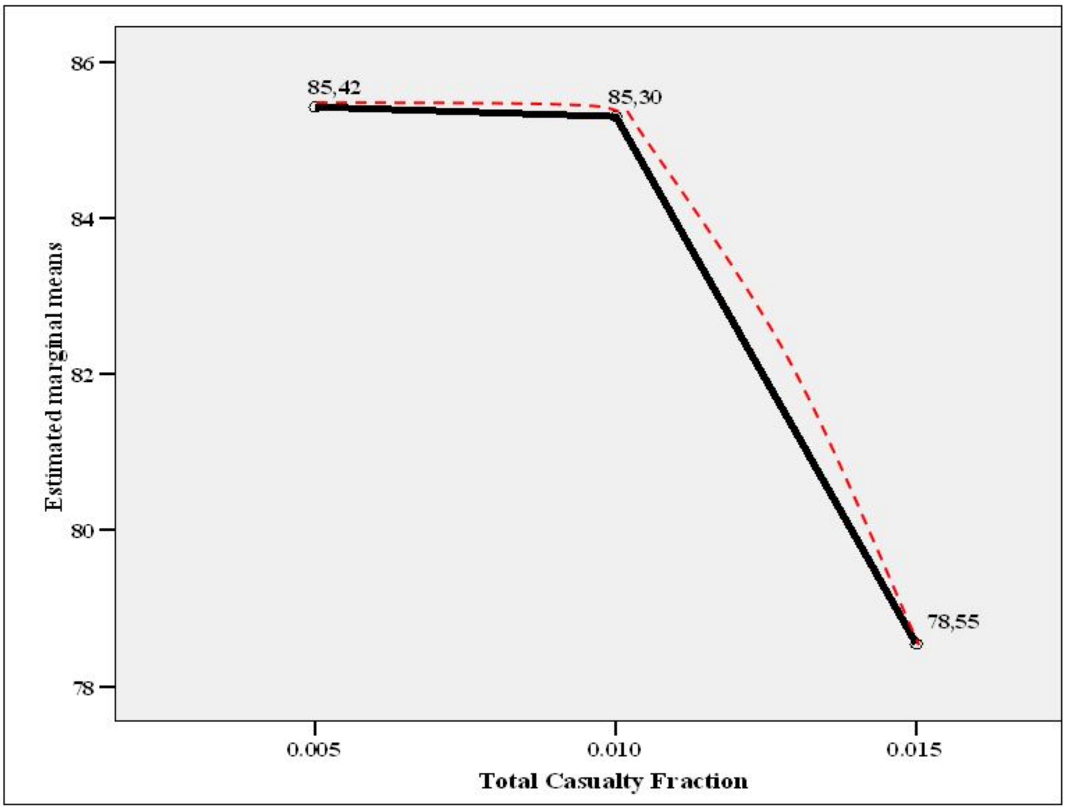

Figure 7. The effect of victim fraction on mean waiting time for treatment (min.) in observation room

5. CONCLUSIONS

The preparedness and planning activities related to emergency aid services in the event of disaster are important in saving lives and returning to normal life conditions quicker after the disaster had occurred. In Turkey, many large cities, including İzmir, are under the significant risk of a major earthquake. Emergency rescue activities in such situations can be modeled analytically; however it is challenging to solve analytical models constructed for the problems with realistic dimensions.

With this aim in mind, a unified simulation model was developed for transporting casualties to medical care centers and their treatment processes in a disaster situation. Victim transportation and treatment processes are clearly linked and it is essential to analyze these two processes simultaneously to achieve optimum results. We propose a simulation model, which includes both victim transportation and treatment, and perform verification& validation steps. The model was developed in accordance with manual and rules, and a case study using real life data from Bornova was presented. The proposed simulation model can easily be adapted to different locations with adaptation of relevant data.

Based on the real data, for Bornova district of İzmir City, this model was applied to the transportation processes to medical treatment locations (treatment points to be built in the site, hospitals) and also treatment processes in the hospitals after a major earthquake.

Based on the results of the extensive experimental design performed, using statistical methods, following were computed: ambulance waiting times, waiting times for treatment in trauma and observation rooms in hospital emergency departments and how various parameters affect these times.

We find that for Bornova case, differences in ambulance waiting times among different regions are substantial. Either a new distribution of ambulances or additional ambulance waiting locations are recommended.

When the number of the triage staff is increased to reduce waiting time for triage operation, the number of medical personnel should be increased accordingly or alternative treatment areas should be constructed parallel to increasing number of triage staff, since it was discovered that waiting times in trauma and observation rooms will also increase. Total casualty fraction also affects waiting times, and at the maximum level of this factor, large number patients lose their lives in the triage and treatment queues are at the large numbers. Significant effects of total casualty fraction were found both on ambulance waiting time and waiting time for treatment. Therefore the analysis of the results shows that before the actual disaster, any activity which will decrease the total casualty fraction will be highly effective in reducing total loss.

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Appendix 1: Data for Figure 3

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	17.209	26.206	39.906
	51	15.886	24.191	36.838
	59	13.977	21.285	32.412

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	21.094	32.122	48.914
	51	19.472	29.652	45.154
	59	17.133	26.089	39.729

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	14.389	21.911	33.365
	51	13.282	20.226	30.800
	59	11.687	17.796	27.100

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	17.637	26.857	40.898
	51	16.281	24.792	37.753
	59	14.325	21.814	33.217

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	8.948	13.626	20.749
	51	8.260	12.578	19.154
	59	7.268	11.067	16.853

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	10.968	16.702	25.434
	51	10.125	15.418	23.478
	59	8.908	13.566	20.657

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	12.139	18.485	28.149
	51	11.206	17.064	25.985
	59	9.860	15.014	22.863

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	14.880	22.658	34.504
	51	13.736	20.916	31.851
	59	12.085	18.403	28.024

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	8.072	12.292	18.719
	51	7.452	11.347	17.279
	59	6.556	9.984	15.203

		Total casualties		
		Low	**Medium**	**High**
# of ambulances	**46**	9.895	15.067	22.944
	51	9.134	13.909	21.180
	59	8.036	12.238	18.636