*Proceedings of the 1997 Winter Simulation Conference*
*ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson*

# APPLICATION OF SIMULATION MODELING TO EMERGENCY POPULATION EVACUATION

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## ABSTRACT

A simulation model was developed to predict with a certain degree of probability the optimal escape routs from the coastal areas of the Rio Grand Valley. Along with that, the model provides information on where traffic bottlenecks could be expected and could assist the authorities in designating official evacuation routes away from the storm. The model provides information about the latest safe evacuation cut off point, percent evacuated, and road capacity availability, in case, the evacuation becomes more risky and the general population must be advised to seek immediate shelter. The simulation model is also able to predict what if situations such as, required warning times to facilitate traffic requirements by areas affected, warning lead times based on storm size and the direction of evacuation and traffic handling capacities of roadways as physical conditions deteriorate.

## 1 INTRODUCTION

Today the residents of the United States and other countries are exposed to yearly assaults by tropical storms and hurricanes, which cause annual damages in the billions of dollars. A sophisticated array of hi-tech monitoring equipment and systems are used to provide early warning alarms. The National Hurricane Center, located in Miami Florida is the nerve center of this safety net. However, in many cases, the storms change path before landing ground and in most cases evacuation may become necessary almost hours before the storm hits.

The simulation model developed could be applied to various emergency evacuation conditions but the case presented is focused mainly on hurricanes originating in the Atlantic Ocean which travel through the Caribbean into the Gulf of Mexico and strike the state of Texas in the Rio Grand Valley. Hurricanes are classified by their intensity and are divided into five categories.

There are three attributes measured or predicted using this rating system. The system itself is named after its developers Herb Saffir an Engineer and Robert Simpson. The Saffer/Simpson method divides the hurricanes into categories based upon the central pressure of the storm, the wind speed and the expected corresponding storm surge as shown in Table 1. This scale classifies hurricanes based upon intensity and damage potential. The scale also provides ranges in which the five classifications fall into. The simulation model is developed for each hurricane category and the solutions generated by the model are compared.

The population surge into the coastal areas in United States has been tremendous in the recent decades. Because of this population increase the importance of a well planned and organized evacuation is much greater than before. Figure 1 shows the population along different coastal regions in United States.

The population along the Atlantic and Gulf Coast counties has increased to approximately 40 million in recent years and very few of these residents have experienced the force of a full blown hurricane.

Due to diverse population pockets along the coast and infrastructure needs that have not kept pace with the rapid local growth, emergency evacuation complications and delays could lead to catastrophic results. This is especially true in the largest cities such as Houston, New Orleans, Miami and Tampa.

Poor evacuation planning can be marginally dangerous to life and economic concerns or can lead to disaster. Since almost one half of the hurricane season overlaps the main tourist season in the area, it is critical to be able to manage risk and limit loss of life and resources. The personal well being of the population will take precedence over economic concerns yet with careful planning the tourist industry may be spared up to 2% of operating revenue.

Table 1: Saffir / Simpson Hurricane Intensity Categories

| Category | Central Pressure | | Wind Speed | | Storm Surge |
|---|---|---|---|---|---|
| | Millibars | Inches (HG) | Miles Per Hr. | Knots | (Feet) |
| 1 | >= 980 | >= 28.94 | 74 – 95 | 64 - 83 | 4 - 5 |
| 2 | 965 - 979 | 28.50 - 28.91 | 96 – 110 | 84 - 96 | 6 - 8 |
| 3 | 945 - 964 | 27.91 - 28.47 | 111 – 130 | 97 - 113 | 9 - 12 |
| 4 | 920 - 944 | 27.17 - 27.88 | 131 - 155 | 114 - 135 | 13 - 18 |
| 5 | < 920 | < 27.17 | > 155 | >135 | >18 |

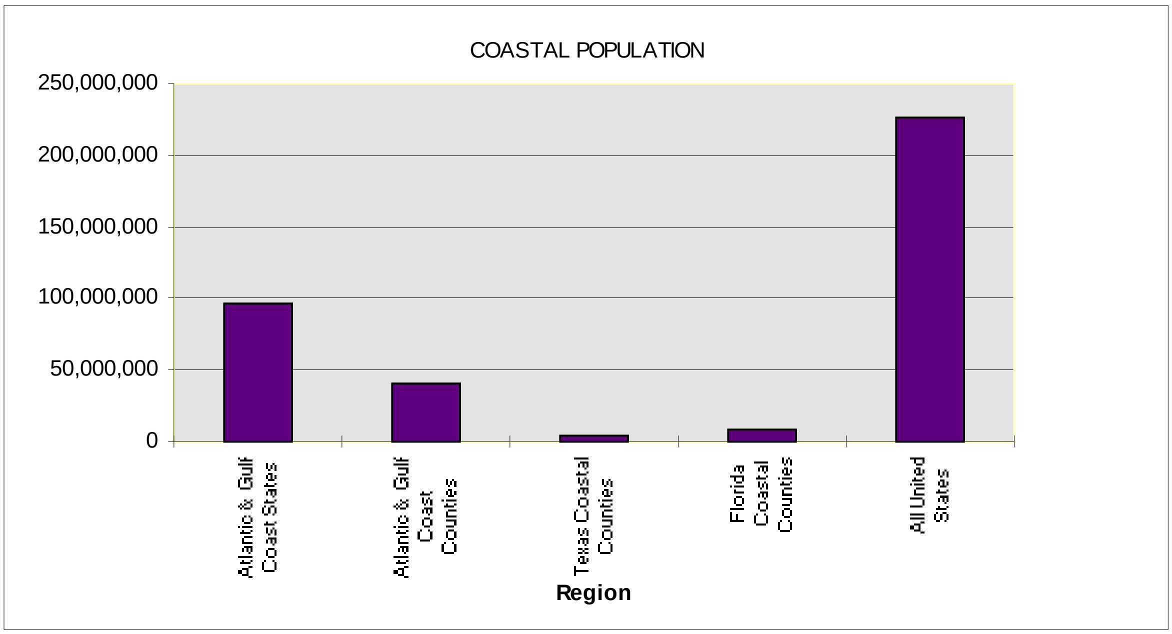


Figure 1: 1980 Coastal Population

## 2 MODEL BUILDING

Before a storm strikes land the area will start to experience what is called a storm surge. This affect can be seen 2 to 3 hours before the storm makes land fall. Storm surges have reached 25 ft in height during class 5 hurricanes. This is just the level of the water before the affects of waves and tides are factored in. If the waves and tide are added to the height of the storm surge the affect could be doubled. For this reason it is very important to heed evacuation notices and evacuate low-lying areas well in advance of the storm. The model developed is focused on evacuation planning for the following South Texas Counties: Cameron, Willacy and Hidalgo. These counties are the most highly populated counties in the Rio Grand Valley. Other counties bordering these three counties are less populated and will not influence the model significantly. By concentrating on these specific counties the model is limited in size and complexity.

Variables such as population increases and road improvements will be constantly changing. This dictates the model to be a living growing example of how to efficiently channel coastal residents away from danger. The modification to the input variables and conditions should be made by some one familiar with the software and the conditions in the area under emergency evacuation notice. Model input variables may include: population, local road capacities, number of registered cars, estimated tourist population, and warning accuracy and integrity based on latest weather forecast. Figure 2 depicts the network model for the evacuation area developed using WITNESS.

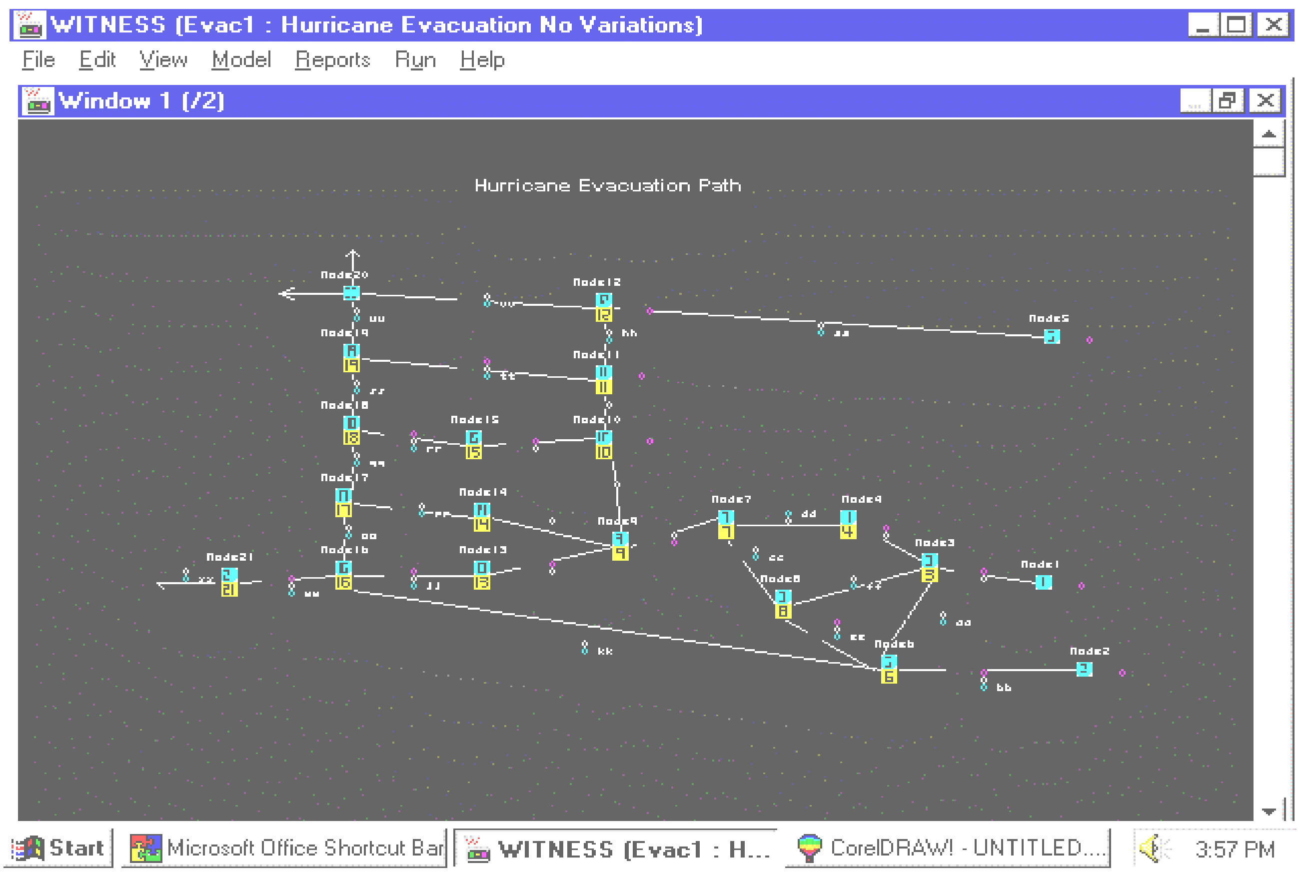


Figure 2: Model Run Mode Display Using WITNESS

The selected software for this model is Witness 7.0. Witness is a graphical interface software based on windows 3.1. To start with the development of the program, the type of output needed is first defined. What parameters will be looked at and what inputs will be used? Due to the unlimited number of possibilities only the theoretical evacuation time (no variation in the model), human tendencies variations (accidents and late evacuation), and unidirectional traffic flow on major four lane highways (all four lanes temporarily going in the same direction) were considered. The human tendency variations are present in the unidirectional model.

## 2.1 Sensitivity Analysis

Table 2 presents the data used to evaluate the model's sensitivity based on the storm category and evacuation percentage recommended at each level. Notice that for a category 5 hurricane, 100% evacuation was recommended at all levels. There are 5 storm categories, 5 unique runs per storm category and 5 levels per storm category. The different levels represent the various areas exposed to the storm surge. Level one represents the shoreline which is exposed to the maximum storm surge and therefore requires 100% evacuation regardless of the hurricane category. A category 5 hurricane generates 18 feet or more storm surge which forces 100% evacuation in all 5 levels. Level 5, which is the furthest from the coast, is only evacuated fully when category 5 hurricane is forecasted. The hurricane evaluation break points and determination of different levels are presented in Table 3.

To limit the number of simulation iterations only runs 1,3 and 5 were analyzed. This limited the number of iterations to 30.

Table 2: Evacuation Model Sample Runs

| **Evacuation Times (Theoretical, Human Tendencies, Unidirectional)** | | | | | |
|---|---|---|---|---|---|
| Population Evacuation Participation Percentage (Storm Category # 1) | | | | | |
| | Run # 1 | Run # 2 | Run # 3 | Run # 4 | Run # 5 |
| Level # 1 | 100% | 80% | 60% | 40% | 20% |
| Level # 2 | 80% | 60% | 40% | 20% | 0% |
| Level # 3 | 60% | 40% | 20% | 0% | 0% |
| Level # 4 | 40% | 20% | 0% | 0% | 0% |
| Level # 5 | 0% | 0% | 0% | 0% | 0% |
| Population Evacuation Participation Percentage (Storm Category # 2) | | | | | |
| | Run # 1 | Run # 2 | Run # 3 | Run # 4 | Run # 5 |
| Level # 1 | 100% | 100% | 100% | 100% | 100% |
| Level # 2 | 100% | 80% | 60% | 40% | 20% |
| Level # 3 | 80% | 60% | 40% | 20% | 0% |
| Level # 4 | 60% | 40% | 20% | 0% | 0% |
| Level # 5 | 40% | 20% | 0% | 0% | 0% |
| Population Evacuation Participation Percentage (Storm Category # 3) | | | | | |
| | Run # 1 | Run # 2 | Run # 3 | Run # 4 | Run # 5 |
| Level # 1 | 100% | 100% | 100% | 100% | 100% |
| Level # 2 | 100% | 100% | 100% | 100% | 100% |
| Level # 3 | 100% | 80% | 60% | 40% | 20% |
| Level # 4 | 80% | 60% | 40% | 20% | 0% |
| Level # 5 | 60% | 40% | 20% | 0% | 0% |
| Population Evacuation Participation Percentage (Storm Category # 4) | | | | | |
| | Run # 1 | Run # 2 | Run # 3 | Run # 4 | Run # 5 |
| Level # 1 | 100% | 100% | 100% | 100% | 100% |
| Level # 2 | 100% | 100% | 100% | 100% | 100% |
| Level # 3 | 100% | 100% | 100% | 100% | 100% |
| Level # 4 | 100% | 80% | 60% | 40% | 20% |
| Level # 5 | 80% | 60% | 40% | 20% | 0% |
| Population Evacuation Participation Percentage (Storm Category # 5) | | | | | |
| | Run # 1 | Run # 2 | Run # 3 | Run # 4 | Run # 5 |
| Level # 1 | 100% | -NA- | -NA- | -NA- | -NA- |
| Level # 2 | 100% | -NA- | -NA- | -NA- | -NA- |
| Level # 3 | 100% | -NA- | -NA- | -NA- | -NA- |
| Level # 4 | 100% | -NA- | -NA- | -NA- | -NA- |
| Level # 5 | 100% | -NA- | -NA- | -NA- | -NA- |

Table 3: Hurricane Evacuation Break Points

| Name | County | Miles To Coast | Pop.(*) | Elev. Feet | % Exp. | Cum. Exp. | Node # | Evac. Level |
|---|---|---|---|---|---|---|---|---|
| South Padre Island | Cameron | 0 | 26400 | <10 | 3.43% | 3.43% | 1 | ***1*** |
| Boca Chica | Cameron | 0 | 150 | <10 | 0.03% | 3.46% | 2 | ***1*** |
| Port Isabel | Cameron | 3 | 7071 | <10 | 0.92% | 4.38% | 3 | ***1*** |
| Laguna Heights | Cameron | 6 | 1108 | <10 | 0.14% | 4.52% | 4 | ***1*** |
| Laguna Vista | Cameron | 9 | 1846 | <10 | 0.24% | 4.76% | 4 | ***1*** |
| Bay View | Cameron | 12 | 366 | <10 | 0.05% | 4.81% | 4 | ***1*** |
| Port Mansfield | Willacy | 10 | 950 | <10 | 0.12% | 4.93% | 5 | ***1*** |
| Brownsville | Cameron | 19 | 156657 | 23 | 20.34% | 25.28% | 6 | ***2*** |
| Rancho Viejo | Cameron | 26 | 1401 | 25 | 0.18% | 25.46% | 6 | ***2*** |
| Los Indios | Cameron | 37 | 1266 | 49 | 0.16% | 25.62% | 6 | ***2*** |
| Los Fresnos | Cameron | 22 | 3915 | 16 | 0.51% | 26.13% | 8 | ***2*** |
| Indian Lake | Cameron | 23 | 617 | 16 | 0.08% | 26.21% | 8 | ***2*** |
| Olmito | Cameron | 25 | 2216 | 31 | 0.29% | 26.50% | 8 | ***2*** |
| Rio Hondo | Cameron | 25 | 2712 | 28 | 0.35% | 26.85% | 9 | ***3*** |
| San Benito | Cameron | 30 | 31858 | 31 | 4.14% | 30.99% | 9 | ***3*** |
| Harlingen | Cameron | 33 | 77148 | 37 | 10.02% | 41.01% | 9 | ***3*** |
| Combes | Cameron | 35 | 3232 | 41 | 0.42% | 41.43% | 10 | ***4*** |
| Primera | Cameron | 36 | 3213 | 43 | 0.42% | 41.84% | 10 | ***4*** |
| Sebastian | Willacy | 37 | 1900 | 38 | 0.25% | 42.09% | 10 | ***4*** |
| Santa Rosa | Cameron | 42 | 3519 | 50 | 0.46% | 42.55% | 10 | ***4*** |
| Lyford | Willacy | 35 | 2650 | 34 | 0.34% | 42.89% | 11 | ***3*** |
| San Perlita | Willacy | 23 | 810 | 21 | 0.11% | 43.00% | 12 | ***3*** |
| Raymondville | Willacy | 33 | 14057 | 33 | 1.83% | 44.82% | 12 | ***3*** |
| Lasara | Willacy | 42 | 792 | 45 | 0.10% | 44.92% | 12 | ***3*** |
| La Feria | Cameron | 42 | 6902 | 58 | 0.90% | 45.82% | 13 | ***5*** |
| Mercedes | Hidalgo | 49 | 20095 | 65 | 2.61% | 48.43% | 13 | ***5*** |
| Weslaco | Hidalgo | 54 | 34631 | 70 | 4.50% | 52.93% | 13 | ***5*** |
| Donna | Hidalgo | 57 | 20028 | 79 | 2.60% | 55.53% | 13 | ***5*** |
| Alamo | Hidalgo | 61 | 12996 | 94 | 1.69% | 57.22% | 13 | ***5*** |
| La Villa | Hidalgo | 47 | 2197 | 60 | 0.29% | 57.50% | 15 | ***5*** |
| Edcouch | Hidalgo | 49 | 4556 | 65 | 0.59% | 58.09% | 15 | ***5*** |
| Monte Alto | Hidalgo | 50 | 2088 | 52 | 0.27% | 58.36% | 15 | ***5*** |
| Elsa | Hidalgo | 52 | 8298 | 69 | 1.08% | 59.44% | 15 | ***5*** |
| San Juan | Hidalgo | 64 | 17120 | 100 | 2.22% | 61.67% | 16 | ***5*** |
| Pharr | Hidalgo | 64 | 52114 | 100 | 6.77% | 68.43% | 16 | ***5*** |
| McAllen | Hidalgo | 67 | 133005 | 100 | 17.27% | 85.71% | 16 | ***5*** |
| Hidalgo | Hidalgo | 68 | 5211 | 89 | 0.68% | 86.38% | 16 | ***5*** |
| Mission | Hidalgo | 73 | 45358 | 125 | 5.89% | 92.27% | 16 | ***5*** |
| Edinburg | Hidalgo | 62 | 47308 | 95 | 6.14% | 98.42% | 18 | ***5*** |
| Alton | Hidalgo | 72 | 4858 | 175 | 0.63% | 99.05% | 18 | ***5*** |
| Hargill | Hidalgo | 49 | 1630 | 50 | 0.21% | 99.26% | 19 | ***4*** |
| La Joya | Hidalgo | 83 | 4122 | 155 | 0.54% | 99.79% | 21 | ***5*** |
| Los Ebanos | Hidalgo | 87 | 633 | 125 | 0.08% | 99.88% | 21 | ***5*** |
| Sullivan City | Hidalgo | 87 | 950 | 197 | 0.12% | 100.00% | 21 | ***5*** |
| Summation | | | 769955 | | 1 | | | |

## 3 SIMULATION RESULTS

The model is designed to provide theoretical evacuation times, actual evacuation times which considers delays, and a third scenario representing the unidirectional traffic flow away from the storm. Figure 4 shows that the best way to evacuate the selected region is to use unidirectional traffic management in case of a larger evacuation percentage participation rate. As the participation rate decreases the need for road capacity also decreases. This trend is the same for all categories 1 to 5. However, at higher volumes the time savings becomes more pronounced. Also at these levels the delays and late arrivals to the system lose their affect and do not influence the model to a great degree. Also the use of all lanes in one direction does not double the traffic handling capacity, but is quite substantial. The time values could provide authorities with an accurate and up to date profile of the evacuation task at hand as the storm variable changes. The difference being an increase in traffic volume and total evacuation time with a higher participation percentage. Note also the variance between the evacuation times during run # 1. They become larger as the number of people participating in the evacuation increases. This indicates that the extra lanes can play an important role at high volumes but at lower volumes the current infrastructure will handle all needs.

Figures 5 and 6 show the evacuation times for category 3 and 5 hurricanes respectively. The traffic volume and total evacuation time increase with a higher participation percentage. Figure 7 shows the increase in the evacuation times as the hurricane intensity increases from category 1 to category 5.

| Estimated Evacuation Times (Hrs.) - Category # 1 | | | |
|---|---|---|---|
| | Run # 1 | Run # 3 | Run # 5 |
| Theoretical Evacuation Time | 23.58 | 11.08 | 2.76 |
| Evacuation Time (Variable Arrivals, Delays) | 24.32 | 11.72 | 2.79 |
| Unidirectional Traffic Flow | 18.09 | 9.59 | 2.56 |

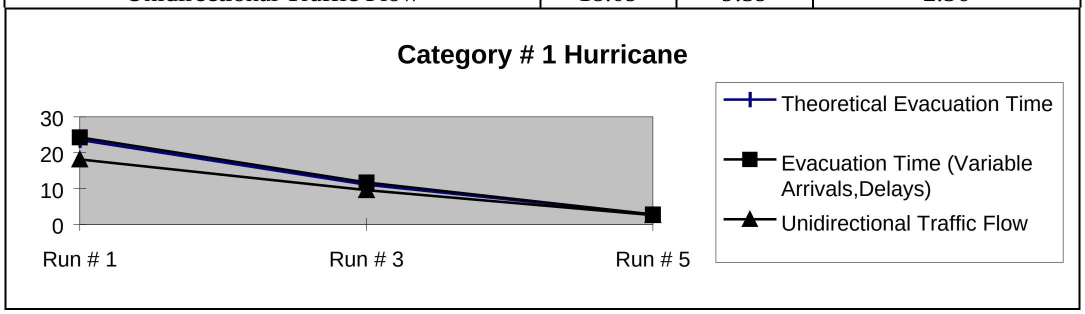


Figure 4: Evacuation Cycle Time (Category # 1)

| Estimated Evacuation Times (Hrs.) - Category # 3 | | | |
|---|---|---|---|
| | Run # 1 | Run # 3 | Run # 5 |
| Theoretical Evacuation Time | 39.27 | 28.53 | 24.3 |
| Evacuation Time (Variable Arrivals, Delays) | 46.19 | 27.81 | 25.57 |
| Unidirectional Traffic Flow | 28.88 | 22.16 | 22.01 |

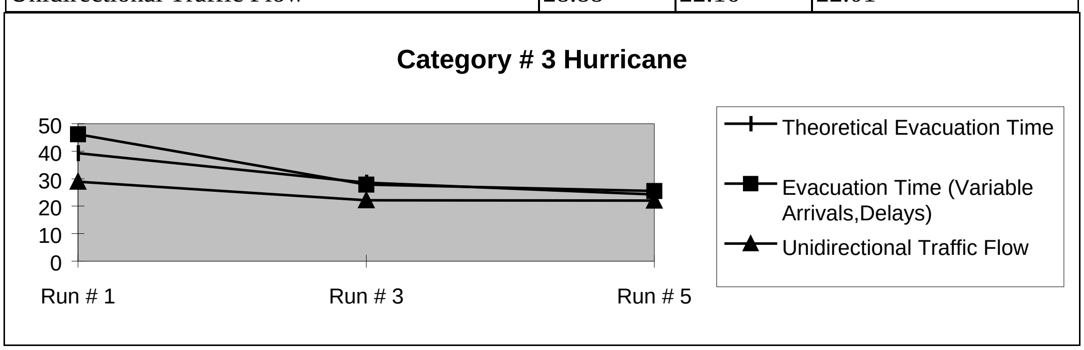


Figure 5: Evacuation Cycle Time (Category # 3)

| Estimated Evacuation Times (Hrs.) - Category #5 | | | |
|---|---|---|---|
| | Run # 1 | Run # 3 | Run # 5 |
| Theoretical Evacuation Time | 39.27 | 39.27 | 39.27 |
| Evacuation Time (Variable Arrivals, Delays) | 46.19 | 46.19 | 46.19 |
| Unidirectional Traffic Flow | 28.88 | 28.88 | 28.88 |

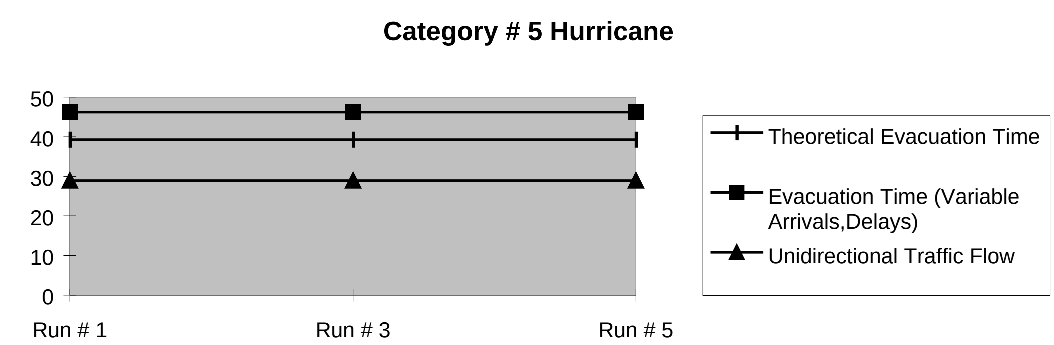


Figure 6: Evacuation Cycle Time (Category # 5)

| Evacuation Cycle Time (Hrs) Run # 5 | | | | |
|---|---|---|---|---|
| | Cat # 1 | Cat # 2 | Cat # 3 | Cat # 5 |
| Theoretical Evacuation Time | 2.76 | 7.96 | 24.3 | 39.27 |
| Evacuation Time (Variable Arrivals,Delays) | 2.79 | 8.62 | 25.57 | 46.19 |
| Unidirectional Traffic Flow | 2.56 | 5.7 | 22.01 | 28.88 |

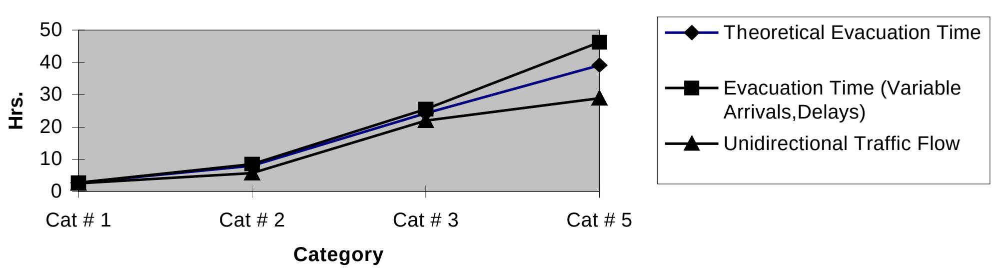


Figure 7: Evacuation Cycle Time (Run # 5)

## 4 CONCLUSION

The emergency evacuation model could help authorities to estimate evacuation time required for selected areas along the path of the storm as the storm variables change. Use of this model cannot guarantee that every one will be able to make it to safety in the event of a major storm, but it will provide safe evacuation windows for the planners and organizers of city or state emergency services.

Figures 4 and 5 show the simulation generated evacuations times required to transport varying percentage of the population from all 5 categories to safety. The estimated times are calculated for unidirectional and two directional traffic considering variable arrivals and delays. The lead-time necessary to evacuate more of the population to safety in case the hurricane has grown in intensity can also be determined using the results from Figure 6.

The decisions such as geographic areas affected and the traffic configurations are resolved. Other major issue that may be considered is budget planning that tie in closely with results generated from such models. These may include expansion of road systems or bridges, building storm shelters, installing emergency services (rescue, police, and fire), and even mass transportation infrastructure required specially for urban areas.

By utilizing the existing roadways to a higher degree and by reacting promptly and expediently to the existing storm conditions at the Rio Grand Valley, safe evacuation is possible for all residents while keeping the cost to a minimum.

This method of evacuation planning can be used in any number of areas. Other coastal areas can use the framework of this model to design or improve their evacuation planning and procedure. Hazardous Materials evacuations and emergency event planning could also be studied and analyzed.

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## AUTHOR BIOGRAPHY

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