Cost-Benefit Model for the Construction of Tornado Shelters

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Abstract: Tornadoes have been identified as one of the leading causes of death and injuries among natural disasters in the United States. Shelters play an important role in tornado mitigation efforts, since tornado-related mortality and injury rates are higher when tornado shelters are not available. This paper describes a methodology to address the viability of construction of tornado shelters in areas which have significant tornado hazards. A cost-benefit model that estimates the relative advantages of three tornado shelter construction strategies was developed and tested. The model accounts for factors such as probability of tornado occurrence, historical death and injury rates, economic incentives, and local construction and maintenance costs. The implications of factors such as useful life period, discount rate, and occupancy on the viability of the shelter were also studied. Relevance of this model to decision makers, as well as future needs for the model, is discussed.

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Introduction

Tornadoes are one of the most destructive forces of nature experienced in the United States. A wide range of impacts occur when tornadoes strike: not only quantifiable losses of human life, property, and agricultural products but also the destruction of economic and social infrastructure as well as environmental damages. Table 1 lists the fatalities and injuries from natural disasters in the United States for the period 1975–1994, based on results found by Mileti (1999) using monthly data published in *Storm Data* from the National Climate Data Center. Tornadoes were found to be the second leading cause of death and the number one cause of injuries among all hazards during this period. Tornadoes are also the third leading cause of property damage ($5.8–$58 billion) amongst all disasters (Mileti 1999). Analysis of more recent data from 1993 to 2002 (National Weather Service 2003) shows similar trends for tornado-related losses.

About 1,000 tornadoes hit the United States every year (Storm Prediction Center 2003), and they are most frequent during the spring and summer seasons in the Midwest, Southeast, and Southwest regions of the United States. Tornadoes are commonly categorized according to the Fujita Scale, created by Dr. Tetsuya (Theodore) Fujita of the University of Chicago (Fujita 1971). The scale ranges from F0 to F5 and categorizes tornado severity by damage observed, which is correlated to tornado wind speeds. Tornadoes of F4 or F5 scale are capable of tremendous destruction, such as lifting houses off of foundations and causing damage to reinforced concrete structures. Fig. 1 shows the number of tornado occurrences recorded per thousand square miles; this indicates that a substantial portion of the country has a nontrivial hazard associated with tornadoes. Thus analysis of the direct loss and hazard potential data reveals the importance of finding strategies for reducing tornado hazard impacts in the United States.

Disaster reduction measures have evolved to lessen the effects of natural disaster events and reduce disaster assistance costs. Many researchers classify these disaster reduction measures into four overlapping categories: (1) predisaster planning and preparation, (2) emergency response and rescue, (3) short-and long-term recovery, and (4) mitigation (Alexander 1993). Mitigation is defined as a sustained action taken to reduce or eliminate the long-term risk to people and property from hazards and their effects. Experience at the federal, state, and local levels during natural disasters, and a growing body of associated research (FEMA 1997; Hooke 2000), has demonstrated that losses from disaster events in terms of life, property, and community resources can be substantially reduced when mitigation techniques and technologies are applied.

The implementation of mitigation is achieved by a variety of tools, projects, and programs. Tools such as warning systems, land use plans, and building codes are presently being used to reduce risk and minimize damage. Technologies such as geographic information systems (Huang et al. 2001) and remote sensing (Kerle and Oppenheimer 2002) have found new applications in the area of disaster mitigation over the past few decades. Another technology, namely decision support systems, can help in hazard management by analyzing data on building inventories, infrastructure, demographics, and risk. The system can then be used to ask "what-if" questions about future losses to inform today's decision making (Mileti 1999). This information helps decision makers in developing effective mitigation measures tuned to the needs of the locality being served. However, decision support systems have not been widely developed for emergency planning with respect to tornadoes. It would desirable to develop such tools for use by officials responsible for planning emergency

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Table 1. Hazards Ranked According to Number of Deaths and Injuries (1975–1994)

Number	Hazard	Number of deaths	Number	Hazard	Number of Injuries
1	Floods	1,600	1	Tornadoes	23,507
2	Tornadoes	1,090	2	Wind	6,670
3	Ice, sleet, and snow	863	3	Hurricanes	4,525
4	Wind	649			

management in communities. This paper addresses one such tool for the construction of community tornado shelters.

Role of Tornado Shelters in Mitigation

Significant engineering progress has been made in developing shelters that are capable of protecting residents against death and injury from tornadoes (Coulbourne et al. 2002). Tornado shelters may be implemented as either in-home shelters or community shelters and may be constructed above or below ground. An in-home shelter is a room within a home (e.g., a bathroom, closet, or cellar) that is intended to protect a few people. Community shelters usually protect a large number of people—up to several hundred in some cases. The Federal Emergency Management Agency has taken a leading role in promoting the building of both types of shelters (FEMA 1998, 2000)

FEMA has promulgated the need for community shelters for people who do not have access to personal shelters, and has urged building owners, school and hospital administrators, neighborhood associations, and other individuals and organizations with responsibilities for public safety to consider building community shelters (FEMA 2000). Community shelters are usually built within or near large public, institutional, or commercial buildings and in neighborhoods where residents' homes lack shelters. Community shelters can be single-use or multiuse structures. The advantages of multiuse shelters (e.g., cafeterias, gymnasiums, libraries, etc.) are returns on investment, efficient usage of space, and lower shelter costs.

There are a number or factors affecting the hazard level from tornadoes. Most importantly, the absence of a protective shelter increases the risk associated with tornadoes. Lillibridge (1997) reports that tornado-related morbidity and mortality rates are higher when no effective storm warnings are issued and when no suitable storm shelters are available. Balluz et al. (2000) point out that most people have limited time to respond to tornado warnings, making the presence of a quickly accessible shelter an important concern for emergency management officials. Building shelters in mobile home parks has become a strategy of interest in states such as Florida (International Hurricane Center 2001) and other states, as results from recent tornado investigations (Schmidlin and King 1995, 1997) showed that two important risk factors for death were location in a mobile home and location in a room above ground with windows. Hence the presence of an adequate tornado shelter can be critical in reducing deaths and injuries for residents of mobile homes as well as more "permanent" homes.

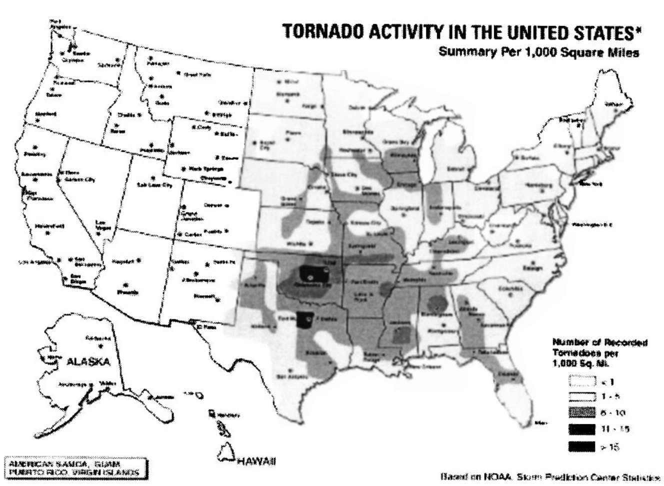

Fig. 1. Number of tornadoes recorded per 1,000 square miles

The research performed by FEMA and others has led to an increased awareness and demand by state emergency management agencies and the general population to provide shelters in areas subject to hurricane and tornado threats (Coulbourne et al. 2002). However, issues associated with the costs of building or retrofitting shelters, along with other funding issues, have generally limited the desire of states and communities to initiate widespread shelter-building programs (International Hurricane Center 2001).

In view of the risks associated with tornadoes, there exists a need for a tool that helps in effective decision making in building tornado shelters.

Prediction of Expected Benefits of Tornado Shelters

The decision to build a community shelter will be based largely on the magnitude of the wind hazard in a given area as well as economic considerations. The magnitude of the wind hazard refers to the probability of occurrence of the tornado and its associated death and injury rates. The benefits (number of lives saved, number of injuries prevented, and other incentives derived from the construction) of the shelter ideally must outweigh the costs of construction of the shelter for it to be viable.

As part of the process of predicting the benefits of building tornado shelters, data regarding the occurrences of tornadoes and the associated deaths and injuries were obtained from Tornado Project Online (www.tornadoproject.com), an organization that compiles tornado information for researchers and weather enthusiasts. Tornado data are available for all counties in all U.S. states for the period l950–l995. The information provided for each tornado includes the month, day, year, time of day in military time, death(s), injury(ies), F-scale (Fujita scale), and county number. From this data, one can estimate the probability of occurrence of tornadoes in a particular location and the associated death and injury rates.

An initial analysis of the tornado death and injury rates reveals two significant facts. First, there are higher rates of death and injury associated with high-speed tornadoes (F3–F5) than for low-speed tornadoes (F0–F2). Second, the total number of high-speed tornadoes is lower than it is for low-speed tornadoes. Table 2 shows data representative of these trends for certain counties in Indiana. Since the speed of the tornado has a significant effect on the death and injury rate as well as on the probability of occurrence, the data on the tornadoes was aggregated into two categories, low-speed (F0–F2) and high-speed (F3–F5). This requires one to determine three factors for each type of tornado as part of the benefit estimation process: the expected number of occur-

Table 2. Occurrences of Low-Speed and High-Speed Tornadoes for Selected Counties in Indiana, 1950–1995

	Low-speed tornadoes			High-speed tornadoes			
County	F0–F2	Deaths	Injuries	F3–F5	Deaths	Injuries	Area
Adams	15	0	5	1	1	37	339
Benton	12	0	0	2	0	0	406
Blackford	0	0	0	2	0	22	165
Boone	19	0	15	3	20	80	423
Carroll	7	0	1	3	0	2	372
Clinton	8	0	5	4	1	40	405
Delaware	11	0	0	4	0	1	393
Fountain	5	0	0	1	0	0	396
Grant	10	0	12	3	9	307	414
Hamilton	17	0	1	2	6	35	398
Henry	9	0	1	4	0	7	393
Howard	7	0	4	3	18	563	293
Jay	7	0	2	1	0	0	384
Madison	14	0	3	2	0	1	452
Montgomery	13	3	20	3	3	29	505
Randolph	10	0	2	5	1	19	453
Tippecanoe	22	0	0	6	3	86	500
Tipton	11	1	6	1	1	6	260
Vermillion	9	0	8	0	0	0	257
Warren	6	0	0	2	0	0	365
Wayne	12	0	1	1	0	3	404
Wells	11	0	2	1	1	38	370
	235	4	88	54	64	1,276	8,347

rences per year of a given category of tornado and the associated rates of deaths and injuries. Procedures for determining these factors are illustrated in the following sections for the states of Indiana and Kansas, which were selected as typical tornado-prone regions of the country.

Occurrences of Tornadoes

The number of low-speed tornadoes occurring in a particular county per year is expected to depend mainly on the area of the county. This assumption is consistent with results shown in Simiu and Scanlan (1996), which has been used by other researchers to estimate tornado strike probabilities (Markee et al. 1974). Thus counties with larger areas should have a higher number of low-speed tornadoes per year compared to smaller counties. This assumption is checked in Fig. 2, which shows scatter plots of the number of low-speed tornadoes versus county area for all coun-

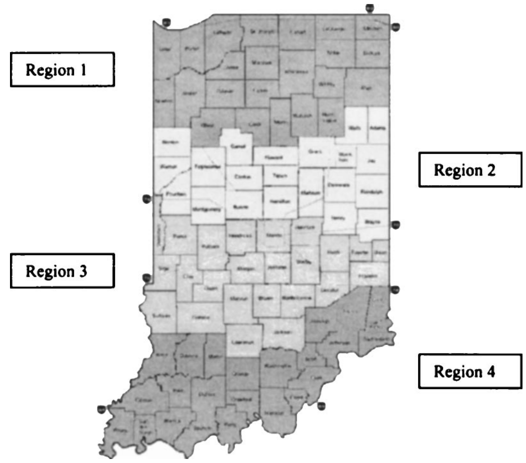

Fig. 3. Regional aggregations of counties in Indiana

ties in the states of Indiana and Kansas for the period 1950–1995. Also shown is the best-fit linear regression line for these data. The regression coefficient for this data was found to be $R=0.526$ for Indiana and $R=0.483$ for Kansas, indicating reasonable support for this hypothesis. (Note that if we assume a single mechanism for tornado arrivals in the two states and combine the data, the regression coefficient becomes $R=0.686$.) Therefore the county area was used as the main variable for predicting the number of low-speed tornadoes occurring in a county per year.

There is, however, a need to account for certain biases in the county-specific tornado data. For example, certain counties with high populations such as Marion County, Ind. and Sedgwick County, Kan. were found to have higher numbers of low-speed tornadoes than would be expected based on their areas. Since these counties are more urban and well populated, it was hypothesized that the larger number of observers led to higher numbers of low-speed tornadoes being reported than other less populated counties. This trend has been noted in previous studies on tornado occurrences (Abbey, Jr. and Fujita 1977). On the other hand, some counties have no records of low-speed tornadoes occurring during the time period in question. This situation, while understandable from a statistical sampling perspective, would lead to an erroneous estimate of zero tornado strike probability if county-specific data alone were used to make the estimate. Thus the data was subjected to an aggregation procedure in order to reduce the effect of these biases. For a given state, counties were grouped into regions which were geographically compact and had a balance between high occurrence and low occurrence numbers for low-speed tornadoes. Fig. 3 shows the regional aggregations used

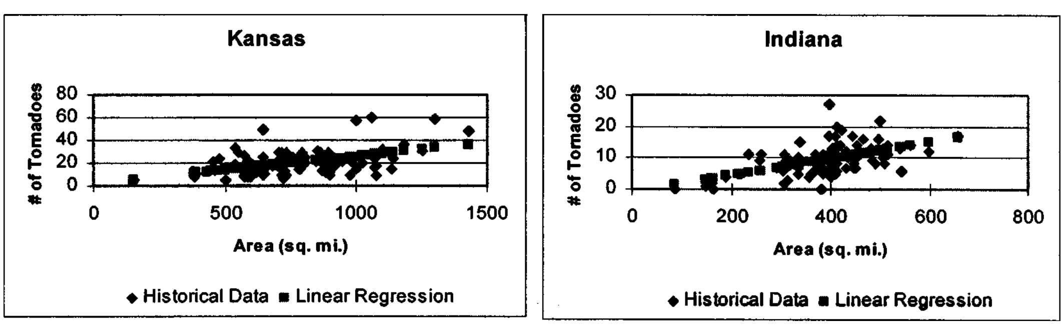

Fig. 2. Number of low-speed tornadoes per county versus county area

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Table 3. Regional Low-Speed and High-Speed Tornado Factors for Indiana

Region	Low-speed tornadoes			High-speed tornadoes			Area	Regional low-speed tornado factor	Regional high-speed tornado factor
	F0–F2	Deaths	Injuries	F3–F5	Deaths	Injuries			
1	251	3	159	57	107	1,176	10,035	0.00056	0.00013
2	235	4	88	54	64	1,276	8,347	0.00063	0.00014
3	229	2	103	44	12	261	8,924	0.00057	0.00011
4	155	5	82	45	24	502	8,560	0.00040	0.00012

for the state of Indiana. A regional low-speed tornado factor was computed as the total number of low speed tornadoes in a region divided by the sum of the areas of all counties in that region. The expected number of low-speed tornadoes per year in a given county is then found by multiplying the regional low-speed tornado factor by the area of the selected county and dividing by the duration of the recording period. This procedure is expected to smooth discrepancies in low-speed tornado strike probabilities while still maintaining a regional character to the data.

The number of high-speed tornadoes occurring in a particular county has the same characteristics as the number of low-speed tornadoes. Counties with larger area typically have higher numbers of tornado strikes when compared to smaller counties. Population and sampling biases for the occurrence of high-speed tornadoes were found to be similar to the data for low-speed tornado occurrences. Therefore the same geographic aggregation process is followed for high-speed tornadoes to reduce these biases, and the regional high-speed tornado factor is calculated in a manner similar to that of the low-speed factor. The expected number of high-speed tornadoes per year is estimated by multiplying the regional high-speed tornado factor by the area of the selected county, then averaging over the duration of the data record. Results for the regional factors in the state of Indiana are shown in Table 3.

Death and Injury Rates for Low-Speed and High-Speed Tornadoes

Deaths per low-speed tornado were expected to be related to the population of a particular county. However, analysis of the tornado data revealed no discernible relation to county population. Certain high population counties (e.g., Hamilton County in Ind.) that were expected to report high death rates had in fact zero deaths. Moreover, the analysis of the data in Indiana showed that 82 of 92 counties had reported zero tornado deaths due to low-speed tornadoes throughout the entire period of record. Similarly, only 7 of the 105 counties in Kansas reported any deaths due to low-speed tornadoes. This low number of incidents precludes any significant statistical analysis. Hence a uniform death rate is assumed across the entire state to estimate the deaths per low-speed tornado. For Indiana, the total number of deaths due to low-speed tornadoes was 14, while the total number of low-speed tornadoes was 870. Thus the number of deaths per low-speed tornado is assumed to be 0.0161. For Kansas, these values are 25 and 2,160, respectively, leading to an assumed death rate per low-speed tornado of 0.0116.

The death rate per high-speed tornado was estimated for each state via a probabilistic analysis of the data. All the high-speed tornado strikes in the given state were tabulated as frequencies of events that resulted in zero through n deaths, where n indicates a reasonable estimate of the maximum number of deaths per event. Several different probability distributions were studied for their applicability in fitting the sample frequency data. Since the deaths per high-speed tornado event are discrete outcomes, only discrete distributions were considered. The binomial distribution was chosen for use in our statistical analysis, as the number of deaths per high-speed tornado event resembles the outcomes of a binomial trial where "successes" are interpreted as deaths. In other words, a high-speed tornado event is considered to be a trial where the tornado can strike a population pool and can result in up to n successes (deaths). Hence the probability of death in a high-speed tornado is related to the binomial parameter p giving the best fit to the sample frequency distribution. The parameter p for the fitted distribution is determined via maximum likelihood estimation. The mean value of the fitted distribution is then estimated as np, which is taken as the estimated number of deaths per high-speed tornado.

Note that the estimated death rate for high-speed tornadoes is sensitive to the choice of n both directly and indirectly through its influence on the fitted value of p. The choice of n relates directly to the presence of "outlier" events—high-speed tornado events that resulted in an unusually high number of deaths. To eliminate the influence of these outlier events, the following procedure was followed. When the frequency distribution was analyzed, it was observed that there was a particular number of trials in the distribution beyond which the next five consecutive frequencies were zero. This point was taken as the choice for n, and all the trials beyond this were considered to be the result of outlier events and thus were eliminated.

To illustrate the application of this probabilistic analysis, Table 4 shows the data regarding the deaths due to high-speed tornadoes tabulated as a histogram. The distribution gives the frequencies for number of tornadoes that resulted in zero through 10 deaths. The frequencies corresponding to 11–16 deaths were found to be

Table 4. Sample Frequencies and Binomial Estimations ($n=10$ and $p=0.0557$) for Deaths per High-Speed Tornado in Indiana

Number of deaths	Sample frequency	Sample probabilities	Expected probabilities	Expected frequency
0	153	0.7887	0.5638	109.38
1	20	0.1031	0.3325	64.51
2	8	0.0412	0.0883	17.13
3	4	0.0206	0.0139	2.70
4	1	0.0052	0.0014	0.27
5	2	0.0103	0.0001	0.02
6	3	0.0155	0.0000	0.00
7	0	0.0000	0.0000	0.00
8	1	0.0052	0.0000	0.00
9	0	0.0000	0.0000	0.00
10	2	0.0103	0.0000	0.00
Sum	194	1.00	1.00	

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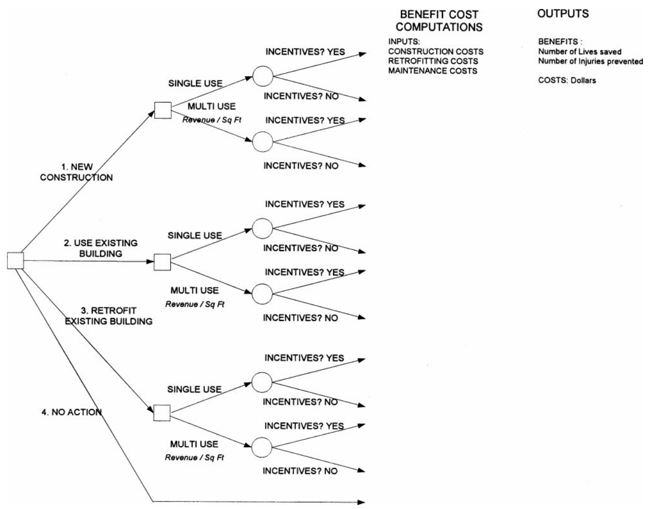

Fig. 4. Decision tree for the cost/benefit model

zero. Hence the number of trials was set at 10 to eliminate the presence of outliers in the data. This data is fit to a binomial distribution with n equal to 10 trials. The parameter p found from the sample probabilities is 0.0557. The fitted binomial distribution using $n=10$ and $p=0.0557$ is also shown in Table 4. The mean value of this distribution is 0.557; hence the assumed value for deaths per high-speed tornado is taken to be 0.557.

Similar to the procedure adopted for determining the deaths for high-speed tornadoes, the data regarding the injuries per high-speed tornado is fitted to a binomial distribution and the mean value of the expected (fitted) distribution is taken as the number of injuries per high-speed tornado. The number of injuries per low-speed tornado is also computed in a similar manner.

Development of Cost-Benefit Model

The cost-benefit decision model developed herein assesses the economic viability of three tornado shelter construction strategies. Strategy 1, termed *new construction*, refers to construction of a new structure to serve as a tornado shelter in a particular location. Strategy 2, *retrofit existing structure*, refers to making changes in an existing structure which is structurally incapable of functioning as a tornado shelter. Two types of retrofitting strategies can be applied, namely structural and nonstructural retrofitting. Some examples of structural retrofitting are reinforcing existing unreinforced masonry walls, bracing gable end roofs, adding permanent storm shutters over exposed glass, etc. Installing plastic film on windows and doors, securely anchoring storage sheds or other outbuildings are instances of nonstructural retrofitting. Strategy 3, *use existing structure*, implies that no modification or construction is required in the existing structure for it to serve as a tornado shelter. The cost-benefit model computes the expected benefits to be derived from the tornado shelter versus the expected costs incurred. The decision maker can thus evaluate the outcomes of each strategy and make decisions in a more structured manner.

The model is based on decision tree analysis. The branches of the decision tree represent the strategies of the tornado shelter. The objectives are to maximize benefits (minimization of the loss of life and injuries during a tornado event and the maximization of incentives) and to minimize costs (minimization of the construction costs, retrofit costs, and maintenance costs). Fig. 4 shows the decision tree for the cost-benefit model. The analysis involves computing the net costs and benefits based on user inputs and the tornado data residing within the model. The outputs are the number of lives saved, the number of injuries prevented, and net costs of the strategies. Thus the decision tree helps in analyzing the outputs in all the branches and choosing the most optimal solution.

The inputs for the model relate to project, building, and shelter related information. Project related information required by the model is the location of the shelter, specifically the state and the target county. Building information is specific to Strategy 2 (retrofit) and Strategy 3 (use existing structure). It refers to the area of the existing building to be used as a tornado shelter. Shelter related information includes the data regarding: (1) benefits of using the shelter, (2) costs of constructing/renovating a shelter or using an existing shelter, and (3) capacity of the shelter.

Three different sources of benefits are considered in this model: multiuse revenues, tax subsidies, and tax incentives. Multiuse revenues can be generated from shelters functioning as multiuse structures, for instance, shelters being used as community recreational centers. The model assumes that the multiuse revenues, which are based on the area of the shelter, are constant every year. There may also be benefits derived from tax subsidies, in the form of grants from the government towards the construction of a tornado shelter in order to encourage more shelters in the community. Tax incentives are assumed to reduce the property taxes. For Strategy 1, it is assumed that this incentive is a flat percent rate applied annually to the initial construction costs of the shelter. For Strategy 2, the tax incentive rate is assumed to be applied annually to the initial retrofitting costs incurred. For Strategy 3, this rate is applied on the maintenance cost, as a proxy for reflecting the reduction in total costs of maintaining the structure. While it would be more desirable to apply the tax incentive rate to property taxes directly, the significant variability of property taxes from location to location precluded a systematic analysis of this mechanism.

Construction retrofitting, and maintenance costs are also considered in the decision model. Construction costs are defined as the costs for initial construction of the structure (excluding cost of land), while retrofitting costs relate to expenses in raising the existing structure's viability to an appropriate level. Maintenance costs include costs needed for maintaining the existing building over the useful life of the shelter. Rather than incorporating a database of these costs, the construction, retrofitting, and maintenance costs are entered as inputs into the model by the user.

The user inputs for the shelter details are the shelter occupancy (based on the number of persons accommodated in the shelter), useful life, and discount rate. In Strategy 1, the area required for the shelter is computed by using a standard unit of five square feet area per person. The maintenance costs for the first year of the shelter for all three strategies are provided by the user. These costs are assumed to have a linear increase of 2% every year throughout the useful life of the shelter, based on the expected deterioration in the building. Discounting is done to bring all the future costs and revenues to present value. The same discount rate is also applied for future revenues such as multiuse revenues and future benefits such as tax incentives. The cumulative maintenance cost which is the sum of the discounted maintenance costs for all the years is calculated over the useful life period of the shelter. Similarly the cumulative multiuse revenues (sum of the discounted multiuse revenues for all the years) and cumulative tax incentives (sum of the discounted tax incentives for all the years) are calculated over the useful life period of the shelter.

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Table 5. Table Showing the Inputs for the Decision Model

Inputs	Strategy number 1	Strategy number 2	Strategy number 3
Multiuse revenues ($/sq ft/year)	4	2	0
Tax incentive rate (%)	3	0.5	3
Tax subsidy ($)	2,000	2,500	0
Occupancy/area	100 persons	1000 sq ft	750 sq ft
Useful life (years)	50	40	35
Discount rate (%)	3	3	3
Construction/retrofitting costs ($/sq ft)	30	35	—
Maintenance costs ($/sq ft/year)	4	4	5

Demonstration of the Decision Support Tool

To test the viability of the Decision Support Tool, a case study using three possible tornado shelter strategies is demonstrated for Marion County, Ind., an urban county with a high population density. Strategy 1 (new construction) was intended to serve 100 persons for 50 years and was expected to generate multiuse revenues of $4 per square feet area per year and a tax subsidy of $2,000. Strategy 2 (retrofitting) involves an existing building of 1,000 square feet with a useful life of 40 years and multiuse revenues of $2 per square feet per year and a tax subsidy of $2,500. Strategy 3 assumed the use of an existing building of 750 square feet area with no multiuse revenues or tax subsidies. The detailed inputs for all the strategies are shown in Table 5. Fig. 5 shows the lives saved versus the net costs for all the three strategies. Note that the optimal solution should lie as close as possible to the upper left-hand corner of the figure, as this maximizes the lives saved while minimizing the costs. In this example, Strategy 1 was found to be the most optimal solution.

Impact of Model Variables

Sensitivity analysis was performed on three variables—useful life, discount rate, and occupancy—to explore their effects on the level of economic viability of tornado shelters. The influence of population density was investigated by performing the analysis for Marion County, Ind. (an urban county) and Floyd County, a rural county in Indiana. The user inputs used in this analysis are shown in Table 6.

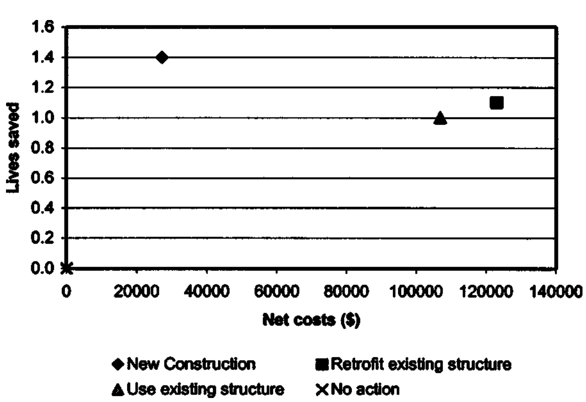

Fig. 5. Results of the decision model

Useful Life

The effect of the variability of useful life of the shelter on the output was examined by considering a new construction of a shelter in Marion County, Ind. The useful life was varied from 10 to 100 years with 10-year increments. It is found that the net cost decreases until a useful life period of 20 years after which it starts to increase. The lives saved increases with increase in useful life since it is directly proportional to the useful life of the shelter. Fig. 6 which shows the variation in net costs accompanied by the increase in lives saved up to a useful life period of 100 years, indicates that the economic viability of a newly constructed shelter in Marion County is maximum at a useful life period of 20 years.

Discount Rate

The discount rate was increased from 0.5 to 6% in increments of 0.5%. There is a decrease in multiuse revenues, maintenance costs and tax incentives due to the impact of the discount rate on the present value of these quantities. Fig. 7 shows that the decrease in net costs for Marion County is greater than that in Floyd County. This tendency is due to the higher construction and maintenance costs in an urban county such as Marion County.

Occupancy

Since occupancy directly relates to the size of the shelter, it is expected that an increase in occupancy translates to an increase in net costs. Thus, when the occupancy was increased from 50 to 300 persons, the net costs showed a constant rate of increase of $2,468 in Marion County and $1,204 in Floyd County, as shown in Fig. 8. This increase in net costs is due to the increase in construction and maintenance costs, arising out of increased size of the shelter.

Table 6. User Inputs for the Sensitivity Analysis

Input	Value	
Multiuse revenues ($/sq ft/year)	5.5	
Tax incentive rate (%)	3	
Tax subsidies ($)	2,000	
Construction costs ($/sq ft)	30 (Marion)	28 (Floyd)
Maintenance costs ($/sq ft/year)	4 (Marion)	3.75 (Floyd)

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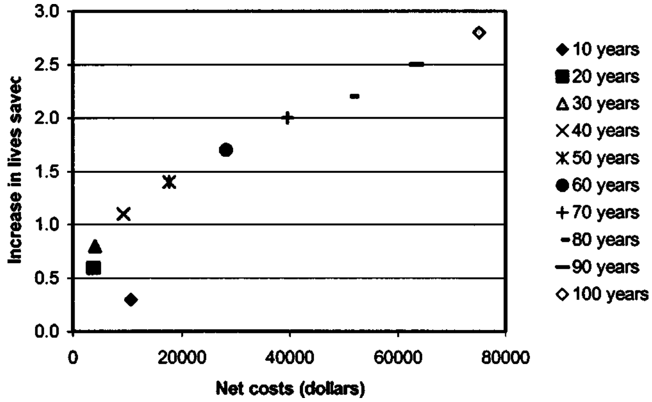

Fig. 6. Sensitivity of the variable useful life for Marion County, Ind.

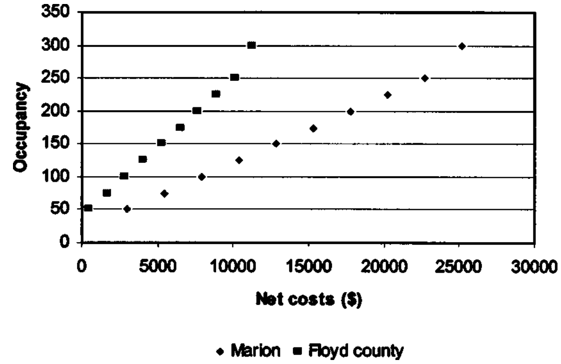

Fig. 8. Occupancy effect on net costs—Strategy 1-for Marion County and Floyd County, Ind.

Discussion

Results of the Present Study

A cost-benefit model that would assist in determining the economic viability of a tornado shelter was developed. This provides one step towards closing the current gap that exists in the area of decision support systems for tornado related hazards. The model was based on decision tree analysis and analyzed the expected benefits and costs associated with tornado shelter construction. The procedure for computations of costs and benefits was developed after considering three classes of variables, namely the probabilities of occurrence, and the rates of deaths and injuries associated with low-speed and high-speed tornadoes. The model considers three strategies for shelter construction—new construction, retrofitting existing structures, and using an existing structure.

Sensitivity analysis was performed on three variables of the model: useful life, discount rate, and occupancy. It was observed that the economic viability of a newly constructed shelter tends to peak and then decline, as the useful life increases. The impact of higher discount rates is more pronounced in urban areas with higher construction and maintenance costs. It was also found that the net costs are directly proportional to the number of occupants in the shelter.

Several development avenues must be explored to make the use of this tool more robust in the case of construction of community shelters. The ability to query other databases of cost information would reduce the user's need to know a wide range of inputs. This would also allow the model to be modified to consider other costs such as costs of land, utilities, and right-of-way in the computation of net costs. Also, the location of a community shelter within a locality is an important factor in the success of the shelter that is not currently considered in the model. Technologies such as geographic information systems (GIS) can be linked to the decision model to assess the need for a tornado shelter in a specific locality, based on population density and access to other shelters. In the future, the decision model could be enhanced to analyze economic viability of shelters under multiple hazards (for example, combining extreme wind disasters such as tornadoes and hurricanes). The benefits from the shelter would increase since it would function as a multiple disaster shelter and help in economizing the shelter costs.

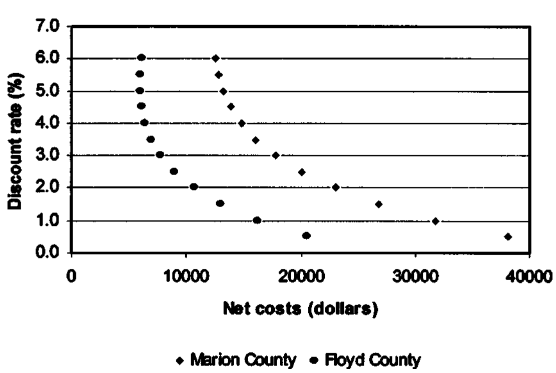

Fig. 7. Sensitivity of the variable discount rate for Marion and Floyd Counties, Ind.

Relevance and Benefits

The decision model will provide local management agencies with a tool to assist in decision-making regarding the construction of tornado shelters. By providing a means to ask "what-if" questions about the impact of local policies (for instance, tax subsidies and incentives) on current and future tornado hazard losses, this tool can assist local governments in developing efficient and practical tornado mitigation plans. This in turn would encourage the development of community tornado shelters in areas where there is a high risk of tornado occurrence.

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