Tornado Hazard Risk Analysis:
A Report for Rutherford County Emergency Management Agency

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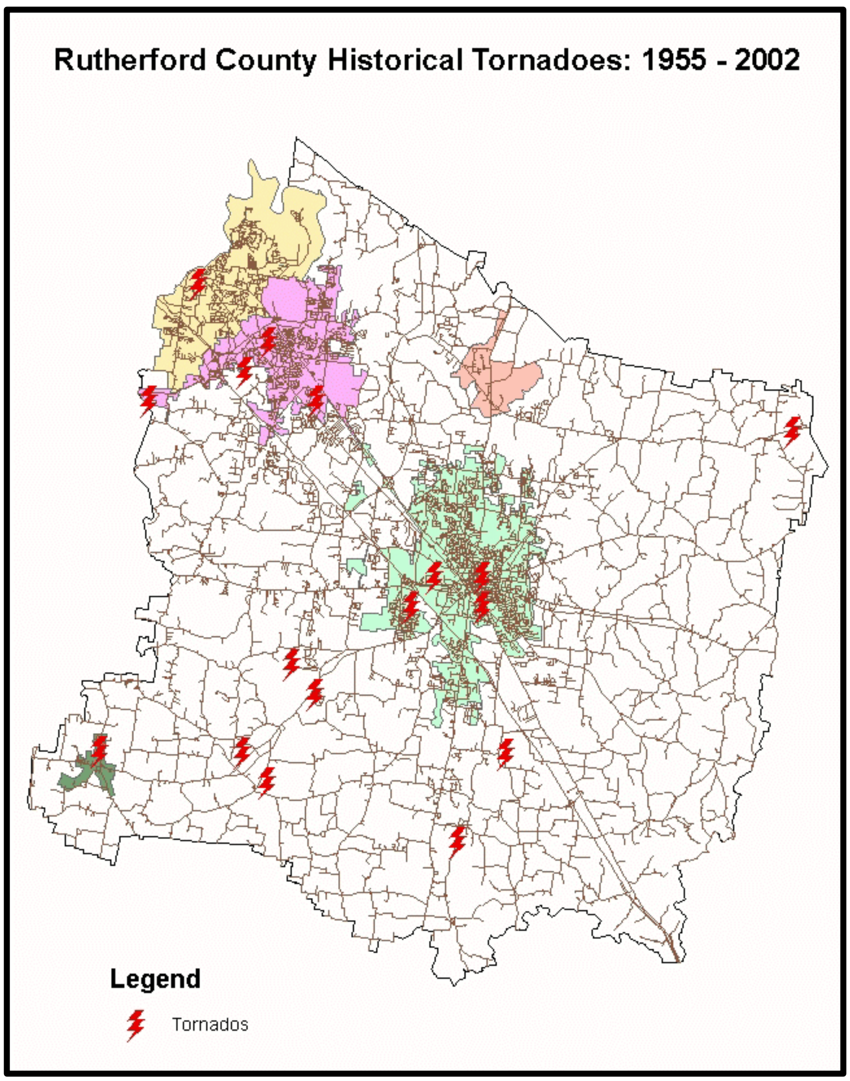

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Introduction

Many types of disasters must be prepared for by emergency management agencies at national, regional, and local levels. These agencies need to identify hazards that can affect the region they support. Hazard identification and risk assessment includes determining what hazard will occur, how often it will occur, and the extent of the effects. These risk assessment issues will be addressed in this paper for the natural disaster of tornadoes and the location of Rutherford County, Tennessee. The paper is divided into three sections: 1) a historical perspective, in which we examine the hazard of tornadoes from a national, state and county viewpoint; 2) a model of tornado paths, in which the historical information is utilized to develop mathematical models and to simulate tornado occurrences; and 3) a cost analysis, that estimates the resulting damage and loss if the simulated tornadoes were to occur.

I. A Historical Perspective

A tornado is a violent rotating column of air extending from a cumulonimbus thunderstorm cloud to the ground. Depending on the intensity, tornadoes can cause tremendous human and economic loss. According to Brooks and Doswell, even though most tornadoes occur in rural areas, tornadoes are estimated to cause about one billion dollars of damage per year in the United States. [2]

Tornado intensity is measure by the Fujita scale (also known as the Fujita-Pearson Scale). The Fujita scale, named for T. T. Fujita, is divided into seven categories, labeled F0 through F6. The divisions are determined by the estimated maximum winds that occurred within the funnel [18] as is shown in Table 1. [16]

Table 1. Fujita Scale Wind Speeds

F-Scale Number	Intensity Phrase	Wind Speed
F0	Gale tornado	40-72 mph
F1	Moderate tornado	73-112 mph
F2	Significant tornado	113-157 mph
F3	Severe tornado	158-206 mph
F4	Devastating tornado	207-260 mph
F5	Incredible tornado	261-318 mph
F6	Inconceivable tornado	319-379 mph

Though the Fujita Scale is considered the industry standard, it is important to note that this classification system is subjective and varies with the experience of the surveyor. A tornado receives its official F-Scale rating after it has already passed through an area. Personnel from the National Weather Service (NWS) office that issued the tornado warning survey the site to determine the F-Scale rating the tornado receives. Occasionally the NWS calls experts in from other locations. When a violent tornado has occurred, aerial surveys are also used to help determine the exact damage track. Insurance companies sometimes call in *wind engineers* to do their own evaluations. The tornado then receives its official rating from the National Weather Service. [16, p 3,4] An F4 tornado path will typically include structures damaged at levels F0 through F4 since a tornado is rated by the *maximum* F-scale value indicated from the structures damaged in its path. In this paper, we examine tornado occurrence and destruction from a national and then a state perspective. This provides a means of comparison of the relative risk associated with these events when we study them in more detail for Rutherford County, Tennessee.

Nationwide Tornadoes

Tornadoes can occur all over the world, but they occur most frequently in the United States. According to the National Oceanic and Atmospheric Administration (NOAA), about 1,000 tornadoes are reported throughout the United States in a typical year. [21] Tornadoes occur predominately east of the Rocky Mountains, but can occur all over the nation. [11] Texas is, on average, the most often hit state with an expected 132 tornadoes per year, while some US states have not been struck by a tornado at all. [19, p. 1] Examining US tornadoes from 1955 to 2002 shows the distribution of tornadoes per year has a skewed distribution with a mean of 874 tornadoes and standard deviation of 237 tornadoes each year. Since 1990, the average has been substantially higher with 1175 tornadoes per year and a standard deviation of 141 tornadoes per year. [10] The large variability in tornado occurrence implies we could have substantially more or fewer tornadoes in any given year. For example, in 2002 there were 854 tornadoes for the entire year, while in 2003 there were nearly 500 tornadoes in May alone. Table 2 shows the United States tornado occurrences broken down by months averaged for 2000, 2001, and 2002 along with the preliminary counts for 2003. A tornado is classified as "killer" if at least one human death occurs. Comparing these three-year averages with 2003 counts shows the variability associated with number of tornadoes and tornado-related deaths. [10, p. 1]

Table 2. Monthly Counts of Tornadoes, Deaths and Killer Tornadoes

Month	Number of Tornadoes		Number of Tornado Deaths		Number of "Killer" Tornadoes	
	3-Year Average	2003*	3-Year Average	2003*	3-Year Average	2003*
January	8	0	0	0	0	0
February	29	11	9	2	2	1
March	60	49	2	8	1	4
April	129	118	4	0	4	0
May	229	499	2	41	2	10
June	160		2		1	
July	112		0		0	
August	69		0		0	
September	64		1		1	
October	78		2		2	
November	84		17		7	
December	23		5		2	
Total	1045	677	44	51	22	15
Mean	87.1	135.4	3.7	10.2	1.8	3.0
Standard Deviation	62.7	208.4	4.9	17.5	2.0	4.2

* 2003 data is preliminary and may represent tornado segments.

From these tornado occurrences, there is frequently damage and loss. In a typical year, we could expect the destruction of tornadoes to result in approximately 74 fatalities [19, p. 2] and over 1,500 injuries. [21, p. 1] From 1983 to 1990, the average reported economic damage from tornado destruction is approximately $590 million per year. [21] Part of the reason tornadoes pose such a threat is because individual events surpass expectations. For example, in 1998 a record 1,424 tornadoes hit the nation, in May 2003 there were almost 500 tornadoes, and on the single day of March 18, 1925, eight tornadoes hit Missouri, Illinois, Indiana, Kentucky, Alabama and Tennessee resulting in 689 deaths. During that single day in 1925, there were over nine times the expected number of tornado related fatalities for the entire year. If a similar system of tornadoes were to occur in 2003, the expected result would be damages in the billions of dollars. Appendix A lists average number of tornadoes and average number of deaths for each state from 1961 to 1990.

Tennessee Tornadoes

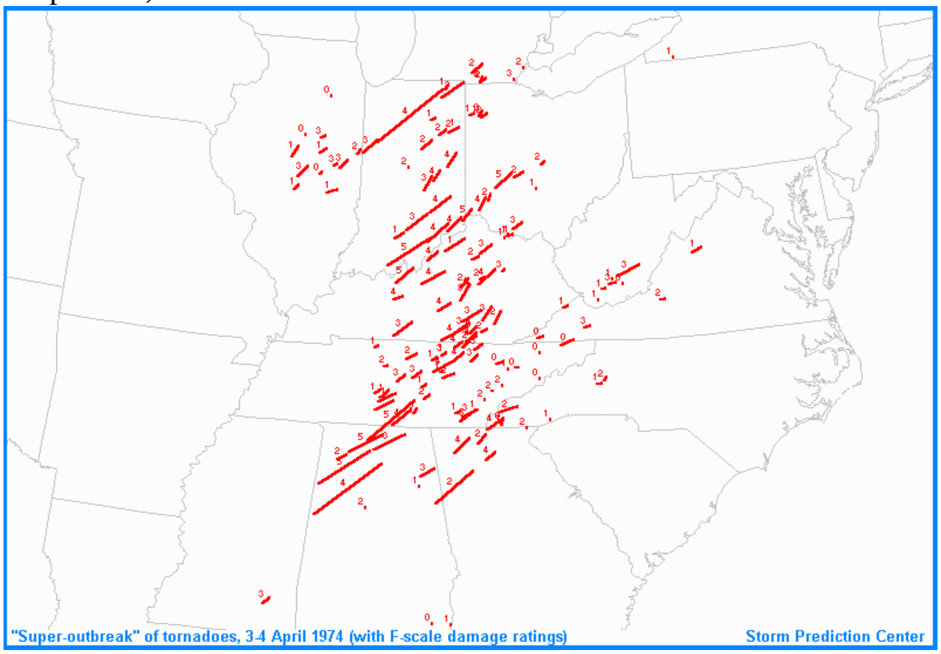
The state of Tennessee does not typically have the number of tornado occurrences experienced by states such as Texas and Oklahoma. Examining historical data from 1950 until 1995, Tennessee experiences on average 12 tornadoes per year and during four of these years they experienced at least 25 tornadoes per year. The number of tornadoes alone does not give a complete picture of the risk associated with Tennessee tornadoes. Tennessee has suffered a high percentage of tornadoes associated with death, injury and loss. In particular, Tennessee has had more "killer" tornadoes[1] as a percentage of total tornadoes than any other state in the nation. Tennessee is also ranked number one in the nation in injury-causing tornadoes as a percentage of total tornadoes. [6]

In one year, the state of Tennessee experiences on average four tornado-related fatalities, 58 injuries, and damage costs, adjusted for inflation, of over five million dollars. However, between 1950 and 1995 there were four years with over 100 tornado-related injuries and eight years where the losses exceeded ten million dollars. Some examples of extreme tornado occurrences in Tennessee include: the year 1952 when there were 75 tornado-related fatalities and 659 injuries, the year 1974 when there were 774 injuries and damage costing over $30 million (2002 dollars), and the two days April 3 and 4 in 1974 when there were 47 tornado-related deaths. Those two days in April were the country's worst tornado outbreak, during which time Tennessee had more tornadoes than any other state. Figure 1, on the next page, shows the tornado paths with their corresponding F-scale rating during those two days. [1]

Even as recent as May 4, 2003, an extreme tornado occurrence affected Tennessee. This single tornado which struck downtown Jackson, Tennessee resulted in 11 deaths, 175 buildings destroyed in the downtown area, and a preliminary cleanup cost estimate is $30 million. [12]

[1] A "killer" tornado is one that caused at least one human death.

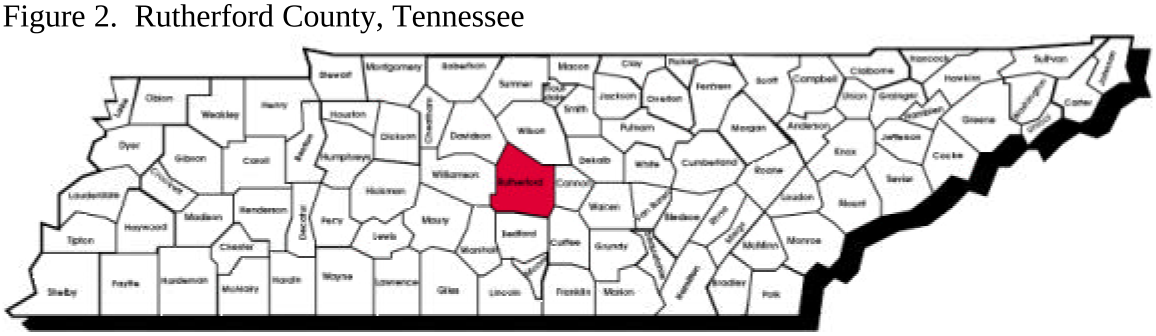
Figure 1. April 3-4, 1974 Tornado Paths



Rutherford County Tornadoes

In this project, our primary interest is tornadic activity in Rutherford County, the county located in the middle of the state of Tennessee as is seen by the shading in Figure 2. [15]

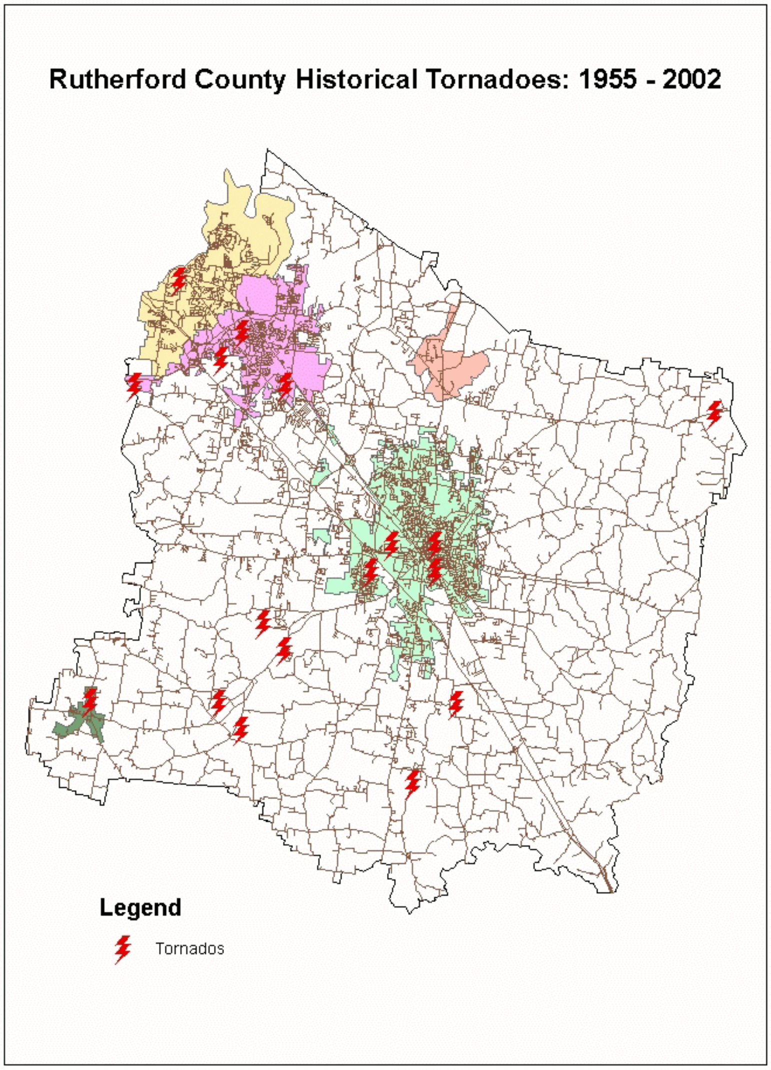
Figure 2. Rutherford County, Tennessee



In Rutherford County, between 1877 and 2002, 34 tornadoes were reported. [14] Beginning in 1955, the latitude and longitude of the starting location of these tornadoes is known. On the next page, Figure 3 shows a map of Rutherford County with the locations of these historical tornadoes from 1955 to 2002 indicated on the map.

Of these 34 tornadoes, more than half (53%) have an intensity rating of F2 or higher and are labeled as "significant tornadoes." Significant tornadoes have wind speeds of greater than 113 miles per hour and typically cause considerable damage. It should be noted that prior to 1955 there were no F1 or F0 tornadoes recorded in Rutherford County.

Figure 3. Rutherford County Tornadoes, 1855 - 2002



Twenty-one percent of Rutherford County tornadoes were reported as F2, 26% as F3, and 6% as F4. These tornadoes and their sources are listed in Appendix B along with existing details about their intensity, location, path length, path width, and damage costs. Damage costs were reported for only 19 of these tornadoes of which 17 were rated F2 or higher. These total damages were slightly over $14 million in 2002 dollars, which is on average over $750,000 per tornado. Table 3 categorizes the average cost of the resulting tornado damage with respect to the F-scale intensity rating for tornadoes rated F2 or higher.

Table 3. Average Cost of Rutherford County Tornado-Related Damage by F-Scale

F-Scale	Average Cost Per Tornado	Number of Tornadoes
F2	$353,738	7
F3	$886,313	9
F4	$5,311,000	1

The peak months for tornado occurrence in Rutherford County are March, April, and May. Seventy-eight percent of these significant tornadoes (F2 or higher) and 65% of all of these tornadoes occurred during these three spring months. In Rutherford County, 50% of all tornado occurrences are clustered between the hours of 3:00 p.m. and 8:00 p.m. Figures 4a and 4b represent these patterns of tornado occurrence.

Figure 4a. Rutherford County Tornado Occurrence by Month for all F-Scales

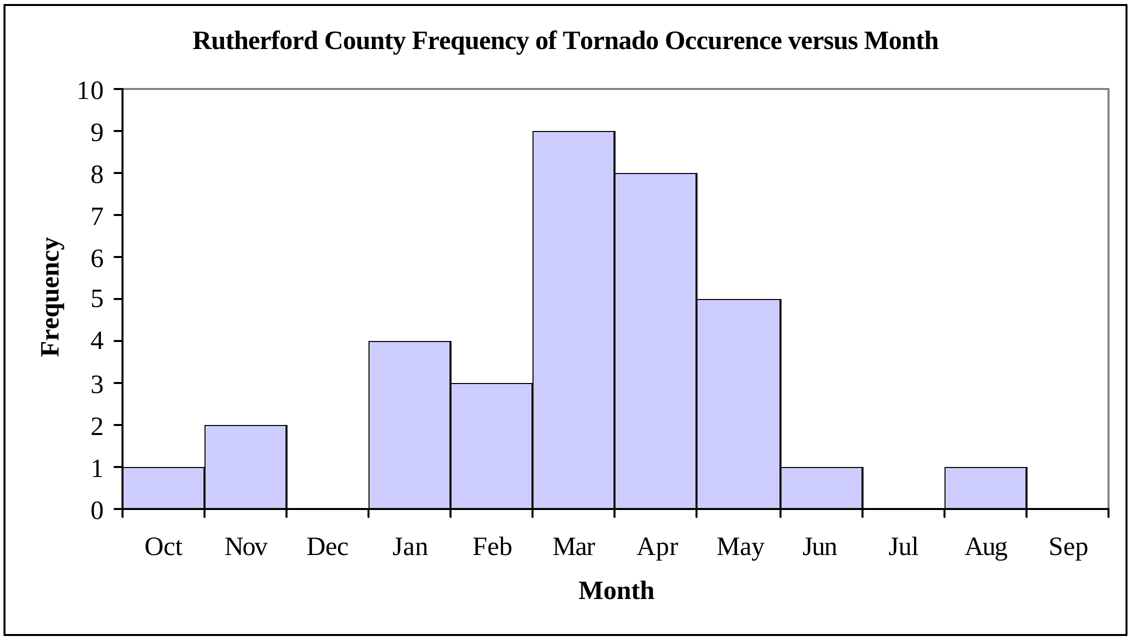
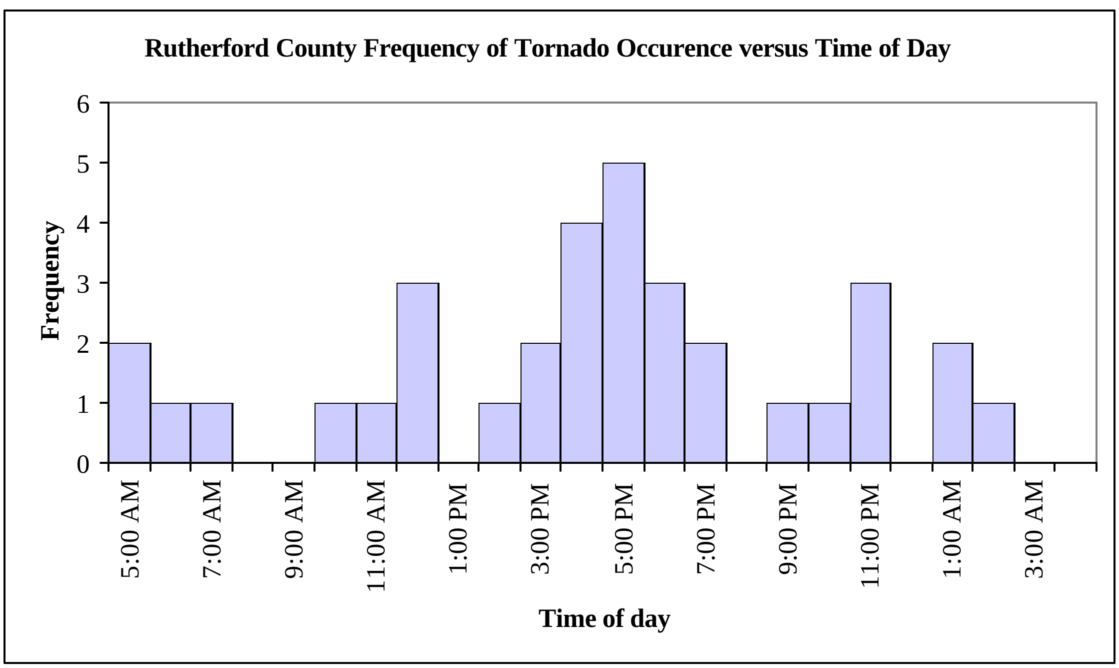


Figure 4b. Rutherford County Tornado Occurrence by Time of Day for all F-Scales

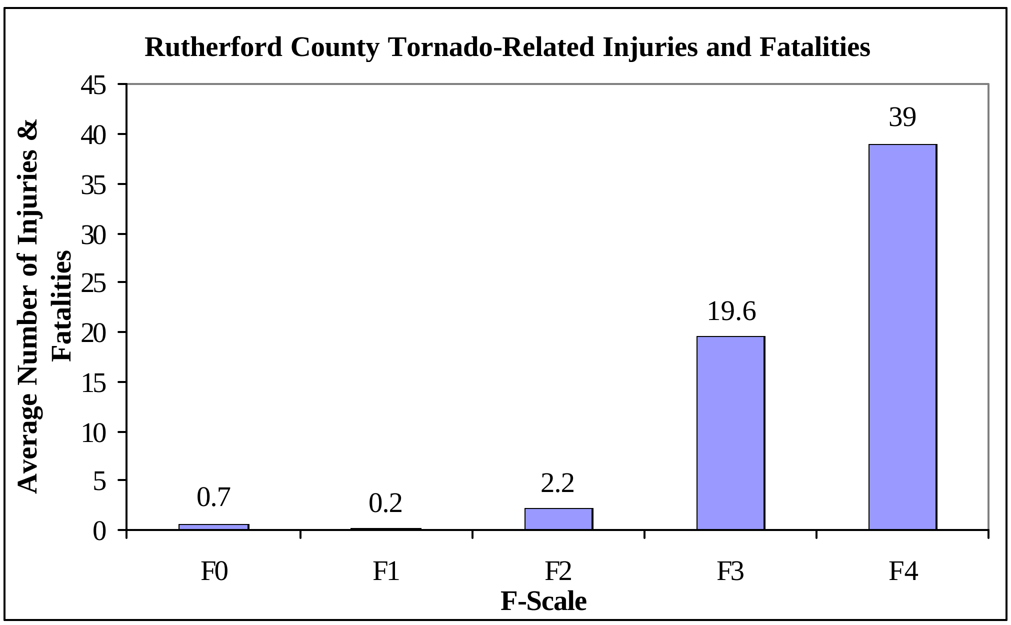


The intensity of a tornado, however, does not appear to be time dependent for either month ($r = -0.146, p=.410, n=34$)[2] or for hour of the day ($r=0.48, p=0.788, n=34$).

In Rutherford County, there does appear to be an association between tornado destruction in terms of both injury and death and the intensity of the tornado ($r =0.674, p=0.000, n=33$). However, the relationship is not as strong as one might expect: only 45% of the variation in the number of injuries and deaths in Rutherford County is explained by the intensity of the tornadoes. We hypothesize that variables such as population density and time of day in combination with other variables would help make better predictions. When we examine a nationwide data set of 52 tornadoes from 1999-2002, we find even less evidence for a relationship between injury and fatality numbers and the intensity of the tornado ($r =0.448, p=0.001, n=52$).

When we look at the average number of injuries and deaths that occur for a given F-scale, we do see the expected increasing trend of higher F-scales resulting in, on average, more injuries and deaths. This relationship is seen in Figure 6 below.

Figure 6. Injuries and Deaths based on F-scale for Rutherford County



Both the average and median tornado path lengths and path widths increase as these tornado intensity increases. However, just as is the case with other tornado-related variables, path length and width also fluctuate a good deal. For example, on April 28, 2002 a Murfreesboro tornado was reported as F3 with path length of 3.2 miles and a path width of 350 yards, while on May 18, 1995 an F0 tornado went from Eagleville to Rockville and had a recorded path length of 8 miles and path width of 75 yards.

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[2] The parameter *r* is Pearson's correlation coefficient, *p* is the p-value, and *n* is the number of tornadoes used in the analysis.

Rutherford County tornado paths are typically long and thin, measuring path lengths in miles and path width in yards. Tornado paths typically travel in a southeast to northwest direction. For the Rutherford County tornadoes, path length was reported for 31 tornadoes and path width was reported for 21 tornadoes. All of the given data was used to in Table 4 to show the minimum, median, and maximum tornado path lengths and path widths for each F-scale. The median path length and width are reported in the tables below because the median is less sensitive than the mean is to extreme observations.

Table 4a. Rutherford County Tornado Path Lengths (miles) by F-scale

F-Scale	Minimum Path Length (miles)[3]	Median Path Length (miles)	Maximum Path Length (miles)
F0	0	0.1	8
F1	0	1	21
F2	2	2	10
F3	3.2	21	50
F4	7	23.5	40

Table 4b Rutherford County Tornado Path Widths (yards) by F-scale

F-Scale	Minimum Path Width (yards)	Median Path Width (yards)	Maximum Path Width (yards)
F0	5	8	75
F1	3	50	440
F2	100	150	440
F3	100	225	350
F4	300	300	300

Appendix C shows an image of the actual tornado path of the Rutherford County "Gum Road" tornado on April 28, 2002. This tornado was an F3 tornado with a NOAA-reported 3.2 mile path length, a 350-yard path width, 37 injuries and $2.3 million dollars in damages. This image shows the actual path was closer to six miles long from the initial point of contact, demonstrating that the measurements of path length and width are subject to human interpretation as is the case with F-scale measurements.

Since it was shown that intensity alone is inadequate to predict tornado destruction, alternative methods for modeling tornado paths are needed. The next section discusses the mathematical modeling processes used in this project.

[3] The miles are rounded to the nearest tenth of a mile.