STATISTICAL ANALYSIS OF INJURY DATA AND THE CONCEPTUAL DESIGN OF A ROLLOVER PROTECTIVE STRUCTURE FOR AN ALL-TERRAIN VEHICLE

Bhavana Parvathareddy
University of Kentucky

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ABSTRACT OF THESIS

STATISTICAL ANALYSIS OF INJURY DATA AND THE CONCEPTUAL DESIGN OF A ROLLOVER PROTECTIVE STRUCTURE FOR AN ALL-TERRAIN VEHICLE

The rising statistics of fatal and non-fatal injuries involving an all-terrain vehicle has called for an analysis of the accumulated data from the past years. The analysis has led to the conclusion that in the past years, the fatal and non-fatal injuries have been rising rapidly in spite of the consent decrees which were brought into effect from 1988-1998 by the consumer product safety commission.

A necessity to provide increased safety while riding an all-terrain vehicle is recognized. Rollover protective structures which were used with successful results in curbing the injuries on agricultural tractors have been identified as having a potential to serve the purpose. A conceptual design of an automatically deployable rollover protective structure has been dealt with, in the thesis.

KEYWORDS: Statistical analysis, All-terrain vehicle, Rollover protective structure, CPSC, rider safety.

Bhavana Parvathareddy

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By

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(Director of Thesis)

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07/18/2005
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THESIS

Bhavana Parvathareddy

The Graduate School

University of Kentucky

2005
A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Mechanical Engineering in the
College of Engineering
at the University of Kentucky

By

Bhavana Parvathareddy

Lexington, Kentucky

Director: Dr. O. J. Hahn, Professor of Mechanical Engineering

Lexington, Kentucky

2005
Dedication

To my family, especially my mom and dad for being such wonderful parents.
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CHAPTER 1

INTRODUCTION

This chapter presents a briefing on the history of all-terrain vehicles and the developments in the past that led to an agreement in the form of consent decrees. The rules of the consent decrees and the age recommendations proposed, while riding an ATV, are also listed. The chapter concludes with the motivation and scope of effort presented in the thesis.
1.1 INTRODUCTION AND BACKGROUND

In 1972, the Honda motor company introduced all-terrain vehicles to the United States. In the later seventies, companies like Kawasaki, Suzuki and Yamaha also introduced their models of all-terrain vehicles, following suit by Polaris in the eighties. When the all-terrain vehicles were introduced, they were an estimated 12,000 of them in use in the United States [1]. The popularity of the all-terrain vehicles rose rapidly and by the year 1992 they were an estimated 2.5 million of them in use [1] and by 2001 this figure went up to 5.6 million [6]. All-terrain vehicles or ATVs, as they are more popularly known, were introduced to the market as three-wheeled vehicles meant to be driven on unpaved terrains, by a single rider. They have since evolved as four-wheeled motor vehicles. Some pictures of four-wheeled ATVs that are available in the market have been included.

Fig.1.1. Model of an all-terrain vehicle by Honda
1.2 DESCRIPTION OF AN ALL-TERRAIN VEHICLE

The ATV can be described closely as a three or four-wheeled motor vehicle designed with low-pressure tires, a steering handle and a wide straddled seat. It runs with motorcycle type engines with the power ranging from 50cc to 500cc. The vehicle can weigh anywhere between 100 pounds to 600 pounds. ATVs are used for non-recreational purposes like in farming, ranching and other agricultural purposes. They are also used very popularly for recreational purposes such as racing.

Fig.1.2. A bulkier model of an all-terrain vehicle
1.3 ATVs AND THEIR CONCERNS

Until the beginning of the 1980-1990 decade, all-terrain vehicles were considered as fun vehicles with lots of people riding it for recreational purposes. Concern regarding the safety of the all-terrain vehicles rose, when statistics of injuries and deaths involving an ATV started rising during the eighties. Experts say that a rider requires adequate physical strength, size, and stamina and of course visual perception along with motor skills to handle an ATV skillfully. It is estimated that the chances of an inexperienced driver getting injured, is 13 times the average risk of injury while driving an ATV [3]. As most of them lack visual perception and physical strength, all-terrain vehicles are not easy to be maneuvered by children under the age of 16 in particular. It was noticed that, as of March 1987, 45 percent of the ATV related deaths were of children under age 16, and 20 percent were of children under age 12. 50 percent of ATV-related injuries were to children less than 16 years of age. These figures were noted before the consent decrees came in to effect.

The Consumer Product Safety Commission’s statistics showed a dramatic increase in the deaths and injuries involving an ATV during 1982-1985, and they were continuing to rise in the following year. It is estimated that emergency situations rose from 8,600 to 86,400 between 1982 and 1986 [3]. The instability of an ATV can be attributed to its height from the ground. Also, the three-wheeled ATV is laterally more unstable than the four-wheeled ATV. The following article was published in the Lexington Herald-Leader, on the 26th of February, 2005. It shows that there is a rising concern among a few regarding the safety of the rider, especially children, when riding on ATVs.
State needs tougher ATV rules

It’s hard to understand why parents allow children to ride all-terrain vehicles too big and powerful for them to handle. And without helmets, even.

Thirteen children, age 4 to 16, died in ATV crashes last year in Kentucky — a record number since the state began keeping count two decades ago, according to a Kentucky Youth Advocates study.

The numbers of ATV-related deaths and injuries nationwide are up, in part because the vehicles are more powerful, according to the Consumer Product Safety Commission.

In 2003, 621 Americans were killed and 125,500 suffered injuries serious enough to send them to emergency rooms in 2003, up 10 percent over 2002.

Kentucky Youth Advocates offers some common-sense suggestions for government, such as requiring child drivers to wear helmets, passing and enforcing “no passenger” laws and keeping track of the incidents of ATV-related injuries.

We still like the Kentucky legislation proposed a few years ago that would punish parents with community service and fines if their children do not wear helmets or follow other ATV safety rules.

Perhaps that would give parents second thoughts about giving a child the controls of a motorized vehicle.

Fig.1.3. Article published in a newspaper raising the safety of a driver while riding an ATV
1.4 SUMMARY OF EVENTS

Consumer Product Safety Commission or the CPSC, started to investigate the injuries and deaths caused by ATVs in 1984 when the death toll was rising rapidly. The events that took place soon after have been summarized as follows, by the then directorate for Economic Analysis, U. S. Consumer Product Safety Commission, Gregory B. Rodgers in [1]:

1984: CPSC started an investigation after noticing a sudden increase in the death and injury toll involving an ATV.

1985: A formal regulatory proceeding was carried out to evaluate the hazards of all-terrain vehicles.

1986: Consumer Product and Safety Commission requested the United States Department of Justice to bring in an enforcement action against all-terrain vehicle distributors.

1987: The government of the United States and the all-terrain vehicle industry filed preliminary consent decrees in the United States District Court. A suit was filed in the U.S District Court against major distributors of all-terrain vehicles, requesting relief under section 12 of the Consumer Product Safety Act, 15 United States Code (U.S.C) Section 2061, as amended (1981).

1988: Final consent decrees were approved by the Court on April 28 (U.S District Court 1988a, 1988b). As a result of these consent decrees, awareness among the public was on a rise.
1.5 CONSENT DECREES

According to the Consent Decrees [1]

- An agreement was reached to stop the sale of all three-wheeled all-terrain vehicles. Three-wheeled ATVs were reported to have less lateral stability when compared to the four-wheeled ATVs and hence this agreement

- A nationwide riders’ training program was to be implemented

- Voluntary standards were to be developed to make all-terrain vehicles safer

- Stringent age recommendations while selling all-terrain vehicles were to be followed

- A multi-million dollar public awareness campaign was to be developed

- Extensive safety warnings to both past and prospective purchasers were to be provided

- Strictly implement the rule that, children under 16 years of age should not operate all-terrain vehicles with engines more than 90cc displacement

Accordingly, the following recommendations were communicated [1]:

1. A warning label was included with every ATV sold.

2. A hang-tag was affixed to the all-terrain vehicles.

3. Information was to be provided in the owner’s manual.

4. A safety poster was displayed at all the dealership offices.

5. Promotional advertisements were communicated.

6. A safety video was made available at every dealership.
In short, all precautions were taken to increase awareness among new all-terrain vehicle customers. The distributors of all-terrain vehicles were reported to be initially not enthusiastic about the consent decrees and hence, were not very co-operative about incorporating the new rules while selling the all-terrain vehicles. After undercover inspection by the CPSC staff, the distributors showed an increase in compliance with the age restrictions [1]. Apart from the above recommendations, that were propagated to increase the safe riding of an all-terrain vehicle, free training was also offered for buyers of ATVs. Sale of three-wheeled ATVs was also stopped. A voluntary standard was also developed which included requirements for the foot environment, mechanical suspension systems and control switches. It also includes other speed limitations on ATVs and also stability requirements [1].
1.6 **SCOPE OF THESIS**

The background of the situation provided in the previous sections, throws light on the increasing number of injuries/deaths that are occurring involving an all-terrain vehicle. A necessity was realized to put the information together to bring forth the data involved. A statistical analysis of the same is deemed required to study the distribution that the injuries and deaths have followed in the past and to show that there has been an increasing trend in the same. This has led to the conclusion that there is a requirement for better safety equipment.

The following chapters present the numerical data of ATV related deaths/injuries that was collected from a large number of publications. Statistical analysis of the data has been done with the help of Minitab, Release 14 for Windows. Plots of injuries/deaths for the available years have been drawn, to capture the trend of injuries and deaths before and after the consent decrees. The chapters also present the various options available to increase the safety of the person riding an all-terrain vehicle.

ATVs by themselves may not be unsafe machines, but the lack of skill and negligence by the riders make them dangerous to ride, thus calling for engineers to build quality and safety into the product. The aim of this thesis is to suggest a safety device for the all-terrain vehicle to improve the safety of the rider and decrease the chances of a head/neck injury, incase of a rollover or overturn of the ATV. The effort has been to design a rollover protective structure for an all-terrain vehicle keeping in mind the compatibility to mount it on the vehicle. It is believed that the suggestion will bring down the injuries and deaths incase of an accident while riding an all-terrain vehicle. Since the safety device presented is similar to a device used on agricultural tractors, benchmarking has also been done with agricultural tractors.
CHAPTER 2

STATISTICAL ANALYSIS - I

Following the consent decrees, a number of studies were carried out to examine the effect of the consent decrees on the injury and death toll involving an all-terrain vehicle. The Consumer Product Safety Commission began collecting ATV related injury and death data in mid-1980s. The commission brought out quarterly reports, after the consent decrees expired. The first formal report from the commission came out in April 1998 [4], exactly 10 years after the consent decree was signed. The report had statistics of the deaths and injuries that had occurred from January 1, 1985 through December 31, 1996. The commission has been releasing reports on a regular basis since then.

The following chapter discusses the statistics of the injuries/deaths that have occurred due to an ATV. A brief description of how data had been collected by the commission and also approximated at certain instances has been cited. The numerical data has been plotted using Microsoft excel and a statistical analysis of the data has been done using Minitab, Release 14 for Windows.
2.1 DATA COLLECTION AND PRESERVATION BY CPSC

According to reports, the Consumer Product Safety Commission collects statistics of deaths and injuries that have occurred due to an all-terrain vehicle, from a variety of sources like news clips, medical reports, death certificates, consumer complaints [3, 4, 5] and NEISS respectively. As it was not guaranteed that the commission should have received a 100% reporting, a statistical capture-recapture procedure was implemented to estimate the number of deaths that have occurred over the past years.

Data for the statistical capture-recapture analysis was collected from two separate files:

1) The Injury, Potential Injury Incident (IPII) file

2) The Death Certificate (DCRT) file

The IPII file maintains data collected from news clips, paid and voluntary MECAP (Medical Examiner and Coroner) reports, consumer complaints, etc.. The DCRT file contains death certificates collected from various states and jurisdictions across the country. A total estimation of deaths is made after eliminating the overlap between the data contained in the two files. An explanation of the capture-recapture method that is followed for the approximation is given in the sections to follow. According to the data brought out in the first report in 1998 [4], the following statistics were highlighted. Estimates for injuries are derived from data collected through CPSC’s National Electronic Injury Surveillance System or NEISS.
2.2 STATISTICS OF DEATHS/INJURIES INVOLVING AN ATV

Out of the total estimated 3200 deaths, the following ratios were noted among different groups.

![Ratio of male to female deaths](chart1)

Fig.2.1. Comparison of gender fatalities collected from 1985-1996 [3]

![Related deaths on ATVs](chart2)

Fig.2.2. Ratio of fatalities of related people from 1985-1996 [3]
Fig. 2.3. Percentage of ATV deaths calculated for years 1985-1996 [3]

Fig. 2.4. Types of hazards from 1985-1996 [3]
Fig. 2.5. Type of collisions that have occurred from 1985-1996 [3]
2.3 APPROXIMATION METHOD FOR DEATHS/INJURIES INVOLVING AN ATV

All reports following the year 1999, estimated the deaths occurring due to riding an ATV in an improved capture-recapture method [4, 5]. Unlike in the past, the Consumer Product Safety Commission started collecting data of all deaths that occurred on public as well as non-public terrain, as coded under the tenth revision of the International Classification of Diseases (ICD-10). This resulted in a complete collection of fatality data involving an all-terrain vehicle by the commission.

As stated in [4, 5], the Consumer Product Safety Commission tries to make every effort to collect as much statistical data as possible about the injuries and deaths occurring, due to riding an ATV. The data collected may not however account for all the deaths that are occurring annually on an ATV. To make a better estimate, the commission approximates the data involving the deaths by using a statistical capture-recapture method. The statistical capture-recapture method was also used on data collected right from 1985, but until 1999 it was used only on fatalities that came under non-public road fatalities. Until 1999, the DCRT file collected death certificates from various states, of fatalities that came only under non-public road fatalities. The IPII file contained data for both public as well as non-public road fatalities. Hence, for public road fatalities, the data was collected only from the IPII file. Once the public-road fatalities estimate was collected from the IPII file, the statistical capture-recapture method was applied to collect the non-public road fatalities by comparing the overlap between the DCRT file and the IPII file. The two estimates were then clubbed to get a total estimate of the deaths occurring annually on ATVs. This resulted in an underestimate of the deaths that were actually occurring, as some of deaths and injuries occurring on public roads went unaccounted for.

From 1999 onwards, death certificates for both public and non-public road fatalities were being collected from various states under the DCRT file. The IPII file continued to list the fatalities occurring under both non-public road and public road categories as was done before 1999. However, estimates after 1999 were made using an improved statistical capture-recapture method. This method compared the overlap of fatalities collected in both the files as opposed to only the non-public road fatalities before 1999, hence providing a better estimate after 1999.
2.4 NUMERICAL DATA OF INJURIES/DEATHS

The latest report that was released by the Consumer Product Safety Commission in January 2005 [29] holds the following data of the deaths and injuries that have occurred since 1982 to December 31, 2003. Some of the data was also revised according to the latest adjustment factors that resulted from the 2001 ATV injury and exposure studies. The report indicates that there are 5,791 deaths that have been reported since 1982 because of using an all-terrain vehicle. This includes 4,641 deaths that have been reported since 1985 to 2001. Estimation shows that there were a total of 5,559 deaths in the same period of 1985 to 2001.
2.4.1 REPORTED AND ESTIMATED NUMBER OF DEATHS: 1982-2003

The following table provides numerical data of reported and estimated deaths that have occurred due to a 3, 4 and unknown number of wheeled all-terrain vehicles [5] since 1982.

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<thead>
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<th>Year</th>
<th>Reported Number of Deaths</th>
<th>Estimated Number of Deaths</th>
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<td>2003</td>
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Table 2.1 Numerical data of deaths since 1982 in the United States
Fig. 2.6. Reported deaths from 1982-2003 [29]

Fig. 2.7. Estimated deaths from 1985-2002 [29]
Since the estimation of the number of deaths is available only from the year 1985, a comparison between the numerical data is possible only from 1985 through 2002. However, the graph for comparison includes data of reported deaths from 1982 through 2003, just to include the whole set of data available.

![Comparison of the data](image)

Fig.2.8. A comparison of reported and estimated number of deaths [29]

It can be seen, from the graph, that there is not much difference in the reported number of deaths and estimated number of deaths right through year 1985 through 1998. There is however, a peak increase in the estimated number of deaths from the year 1999. Two reasons can be attributed to this peak rise. One, it should be noted that 1999 is the year when the consent decrees came to an end and two, there has been a change in the methodology of collecting and estimating data. Both reasons could have had their impact on the statistics.
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Table 2.2 Estimated number of deaths since 1985 on four-wheeled ATVs
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<th>Year</th>
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<tr>
<td>1986</td>
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<td>1989</td>
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<td>1993</td>
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<tr>
<td>1995</td>
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</tr>
<tr>
<td>1996</td>
<td>59</td>
</tr>
<tr>
<td>1997</td>
<td>48</td>
</tr>
<tr>
<td>1998</td>
<td>42</td>
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<tr>
<td>1999</td>
<td>48</td>
</tr>
<tr>
<td>2000</td>
<td>51</td>
</tr>
<tr>
<td>2001</td>
<td>48</td>
</tr>
<tr>
<td>2002</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 2.3 Estimated number of deaths since 1985 on three and unknown number wheeled ATVs
Fig. 2.9. Estimated number of deaths involving a 4-wheeled ATV from 1985-2002 [29]

Fig. 2.10. Estimated deaths involving unknown and 3-wheeled ATVs from 1985-2002 [29]
### 2.4.2 RISK OF DEATH ASSOCIATED WITH ATVs

<table>
<thead>
<tr>
<th>Year</th>
<th>Risk of death per 10,000 four-wheeled ATVs in use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>1.5</td>
</tr>
<tr>
<td>1986</td>
<td>1.3</td>
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<tr>
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</tr>
<tr>
<td>1990</td>
<td>0.9</td>
</tr>
<tr>
<td>1991</td>
<td>0.8</td>
</tr>
<tr>
<td>1992</td>
<td>0.8</td>
</tr>
<tr>
<td>1993</td>
<td>0.7</td>
</tr>
<tr>
<td>1994</td>
<td>0.8</td>
</tr>
<tr>
<td>1995</td>
<td>1.0</td>
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<tr>
<td>1996</td>
<td>0.9</td>
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<tr>
<td>1998</td>
<td>0.8</td>
</tr>
<tr>
<td>1999</td>
<td>1.4</td>
</tr>
<tr>
<td>2000</td>
<td>1.2</td>
</tr>
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<td>2001</td>
<td>1.1</td>
</tr>
<tr>
<td>2002</td>
<td>1.1</td>
</tr>
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</table>

Table 2.4 Risk of death associated with four-wheeled ATVs from 1985-2002
Risk of death per 10,000 four-wheeled ATVs in use

Fig. 2.11. Risk of death on a 4-wheeled ATV from 1985-2002 [29]
### 2.4.3 ESTIMATED INJURIES ON ATVS

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated number of injuries on ATVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>10,100</td>
</tr>
<tr>
<td>1983</td>
<td>32,100</td>
</tr>
<tr>
<td>1984</td>
<td>77,900</td>
</tr>
<tr>
<td>1985</td>
<td>105,700</td>
</tr>
<tr>
<td>1986</td>
<td>106,000</td>
</tr>
<tr>
<td>1987</td>
<td>93,600</td>
</tr>
<tr>
<td>1988</td>
<td>74,600</td>
</tr>
<tr>
<td>1989</td>
<td>70,300</td>
</tr>
<tr>
<td>1990</td>
<td>59,500</td>
</tr>
<tr>
<td>1991</td>
<td>58,100</td>
</tr>
<tr>
<td>1992</td>
<td>58,200</td>
</tr>
<tr>
<td>1993</td>
<td>49,800</td>
</tr>
<tr>
<td>1994</td>
<td>50,800</td>
</tr>
<tr>
<td>1995</td>
<td>52,200</td>
</tr>
<tr>
<td>1996</td>
<td>53,600</td>
</tr>
<tr>
<td>1997</td>
<td>52,800</td>
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<tr>
<td>1998</td>
<td>67,800</td>
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<tr>
<td>1999</td>
<td>82,000</td>
</tr>
<tr>
<td>2000</td>
<td>92,200</td>
</tr>
<tr>
<td>2001</td>
<td>110,100</td>
</tr>
<tr>
<td>2002</td>
<td>113,900</td>
</tr>
<tr>
<td>2003</td>
<td>125,500</td>
</tr>
</tbody>
</table>

Table 2.5 Total number of estimated injuries on ATVs
<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated injuries on ATVs for ages less than 16 Years</th>
<th>Percentage of total estimated injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>42,700</td>
<td>40.40%</td>
</tr>
<tr>
<td>1986</td>
<td>47,600</td>
<td>44.90%</td>
</tr>
<tr>
<td>1987</td>
<td>38,600</td>
<td>41.20%</td>
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<tr>
<td>1988</td>
<td>28,500</td>
<td>38.20%</td>
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<tr>
<td>1989</td>
<td>25,700</td>
<td>36.56%</td>
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<tr>
<td>1990</td>
<td>22,400</td>
<td>37.65%</td>
</tr>
<tr>
<td>1991</td>
<td>22,500</td>
<td>38.73%</td>
</tr>
<tr>
<td>1992</td>
<td>22,000</td>
<td>37.80%</td>
</tr>
<tr>
<td>1993</td>
<td>17,900</td>
<td>35.94%</td>
</tr>
<tr>
<td>1994</td>
<td>21,400</td>
<td>42.13%</td>
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<td>1995</td>
<td>19,300</td>
<td>36.97%</td>
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<td>1996</td>
<td>20,200</td>
<td>37.69%</td>
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<td>1997</td>
<td>20,600</td>
<td>39.02%</td>
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<tr>
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<td>25,100</td>
<td>37.02%</td>
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<tr>
<td>1999</td>
<td>27,700</td>
<td>33.78%</td>
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<tr>
<td>2000</td>
<td>32,000</td>
<td>34.71%</td>
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<tr>
<td>2001</td>
<td>34,300</td>
<td>31.15%</td>
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<tr>
<td>2002</td>
<td>37,100</td>
<td>32.57%</td>
</tr>
<tr>
<td>2003</td>
<td>38,600</td>
<td>30.75%</td>
</tr>
</tbody>
</table>

Table 2.6 Estimated injuries and their percentages involving children below 16 years of age
<table>
<thead>
<tr>
<th>Year</th>
<th>Estimate of injuries on a four-wheeled ATV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>14,700</td>
</tr>
<tr>
<td>1986</td>
<td>23,400</td>
</tr>
<tr>
<td>1987</td>
<td>33,900</td>
</tr>
<tr>
<td>1988</td>
<td>39,400</td>
</tr>
<tr>
<td>1989</td>
<td>35,700</td>
</tr>
<tr>
<td>1990</td>
<td>30,800</td>
</tr>
<tr>
<td>1991</td>
<td>34,400</td>
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<tr>
<td>1992</td>
<td>33,000</td>
</tr>
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<td>1993</td>
<td>32,000</td>
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<tr>
<td>1994</td>
<td>33,300</td>
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<td>1995</td>
<td>36,200</td>
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<tr>
<td>1996</td>
<td>40,700</td>
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<td>1997</td>
<td>39,700</td>
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<td>1999</td>
<td>68,900</td>
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<td>2000</td>
<td>82,300</td>
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<tr>
<td>2001</td>
<td>98,200</td>
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<tr>
<td>2002</td>
<td>104,800</td>
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<tr>
<td>2003</td>
<td>116,600</td>
</tr>
</tbody>
</table>

Table 2.7 Estimated injuries involving four-wheeled ATVs
<table>
<thead>
<tr>
<th>Year</th>
<th>Estimate of injuries on a three-wheeled and unknown number of wheeled ATVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>91,000</td>
</tr>
<tr>
<td>1986</td>
<td>82,600</td>
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<tr>
<td>1987</td>
<td>59,700</td>
</tr>
<tr>
<td>1988</td>
<td>35,200</td>
</tr>
<tr>
<td>1989</td>
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<td>1990</td>
<td>28,700</td>
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<td>23,700</td>
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<td>1992</td>
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<td>1993</td>
<td>17,800</td>
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<td>1994</td>
<td>17,500</td>
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<td>1995</td>
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<td>1996</td>
<td>12,900</td>
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<td>1997</td>
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<td>10,700</td>
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<tr>
<td>2002</td>
<td>9,100</td>
</tr>
<tr>
<td>2003</td>
<td>8,900</td>
</tr>
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</table>

Table 2.8 Estimated injuries involving three and unknown number wheeled ATVs
Fig. 2.12. Estimated number of injuries on an ATV from 1982-2003 [29]

Fig. 2.13. Estimate of injuries to children under 16 years of age from 1985-2003 [29]
Fig. 2.14. Estimated injuries on four-wheeled ATVs from 1985-2003 [29]

Fig. 2.15. Estimated injuries on unknown and 3-wheeled ATVs from 1985-2003 [29]
### 2.4.4 RISK OF INJURY ON A FOUR - WHEELED ATV

<table>
<thead>
<tr>
<th>Year</th>
<th>Risk of injury per 10,000 four-wheeled ATVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>391.1</td>
</tr>
<tr>
<td>1986</td>
<td>319.2</td>
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<tr>
<td>1987</td>
<td>305.9</td>
</tr>
<tr>
<td>1988</td>
<td>276.1</td>
</tr>
<tr>
<td>1989</td>
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<tr>
<td>1990</td>
<td>175.1</td>
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<tr>
<td>1991</td>
<td>188.1</td>
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<td>1992</td>
<td>175.1</td>
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<td>164.9</td>
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<tr>
<td>1995</td>
<td>165.7</td>
</tr>
<tr>
<td>1996</td>
<td>168.1</td>
</tr>
<tr>
<td>1997</td>
<td>146.1</td>
</tr>
<tr>
<td>1998</td>
<td>184.7</td>
</tr>
<tr>
<td>1999</td>
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<td>2000</td>
<td>197.2</td>
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<td>2001</td>
<td>200.9</td>
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<tr>
<td>2002</td>
<td>190</td>
</tr>
<tr>
<td>2003</td>
<td>188.4</td>
</tr>
</tbody>
</table>

Table 2.9 Risk of injury on a four-wheeled ATV since 1985
Fig. 2.16. Estimated risk of injury on a 4-wheeled ATV from 1985-2003 [29]
2.5  **EFFECT ON ECONOMY DUE TO ATV ACCIDENTS**

The ATV deaths and injuries cause physical and mental trauma to the person involved in the accident and to his/her family. Unfortunately, these accidents have also been affecting the entire nation economically. The burden is being inflicted on all Americans by hindering economic productivity, in the form of medical bills and disability payments which come from the taxes paid to the government. According to American Academy of Orthopedic Surgeons, in the year 2000 alone, ATV related injuries costed the United States over $6.5 billion in medical, legal and work loss expenses [19]. According to Dr. Jim Helmkamp, “Average annual comprehensive economic loss resulting from fatal ATV-related injuries has been between $10 million and $34.2 million in West Virginia alone between 1990 and 1999” [20]. On an average, children accounted for 37% of the injuries from the total estimate between 1985 through 2002. The average cost per injury is estimated to be $6,899 [21]. Accordingly, “The cost of ATV related injuries among children seen in emergency rooms from 1992 to 1994 is estimated at $643 million for 93,207 injuries”. There have been a total of 1,596,800 estimated injuries on ATVs from 1982 through 2003. This puts the total expense on ATV injuries at approximately $11 billion so far. The expenses could be a little higher or lower depending on the accuracy of the estimate.

This kind of effect on the nation’s economy is not being noticed elsewhere around the world. There are possibly two reasons for it. Other countries like Quebec, Israel, Australia, New Zealand have legislative rules making it compulsory for riders to wear helmets and other safety gear while riding an ATV. The other reason being that those countries do not have the count of ATVs in use, as high as in the United States. However, increased safety means fewer deaths and injuries in any given time period [36, 37].

The coming section discusses the increasing hazard rate even during the period when consent decrees were in effect. This only shows that there is a necessity to increase the safety of the rider while riding an ATV.
2.6 WEIBULL DISTRIBUTION PLOTS OF INJURIES/DEATHS: 1988-1998

Although the Weibull distribution is used extensively in the analysis of equipment lifetime data, the fact that it deals with decreasing, constant and increasing failure rates or hazard rates has led to the choice of the distribution to predict if the hazard rate involving ATVs has been increasing/decreasing or has remained constant in the past years. The distributions that follow have nothing to do with the mechanical working of the ATV. They only predict the hazard rate of the injuries and deaths for the given years. The weibull distribution has the advantage that by adjusting the distribution parameters, it can be fit to many life distributions [29]. The value of shape factor or $\beta$ determines the shape of the weibull curve. When $\beta = 1$, the weibull distribution is a simple exponential distribution, when $\beta = 2$, it is an approximation to the log-normal distribution and when $\beta = 3.57$, it is a close approximation to normal distribution [30]. Also, $\beta = 1$ means constant hazard rate, $\beta < 1$ means decreasing hazard rate and $\beta > 1$ means increasing hazard rate. This can be diagrammatically represented as follows:

![Diagrammatical representation of the effect of the value of $\beta$ on weibull curve](image)

Here, $\beta$ is the shape factor or parameter and $\eta$ is the scale factor or parameter.
Fig. 2.18 3-parameter Weibull plot for reported number of deaths

Table 2.10 Goodness of fit results for 3-parameter Weibull plot for reported number of deaths
Fig. 2.19 3-parameter Weibull plot for estimated number of deaths

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Anderson-Darling</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weibull</td>
<td>164.650</td>
<td>0.926</td>
</tr>
<tr>
<td>Lognormal</td>
<td>65.864</td>
<td>0.965</td>
</tr>
<tr>
<td>Exponential</td>
<td>3252.438</td>
<td>*</td>
</tr>
<tr>
<td>Loglogistic</td>
<td>110.210</td>
<td>0.940</td>
</tr>
<tr>
<td>3-Parameter Weibull</td>
<td>66.537</td>
<td>0.955</td>
</tr>
<tr>
<td>3-Parameter Lognormal</td>
<td>65.843</td>
<td>0.965</td>
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<tr>
<td>2-Parameter Exponential</td>
<td>387.296</td>
<td>*</td>
</tr>
<tr>
<td>3-Parameter Loglogistic</td>
<td>110.191</td>
<td>0.940</td>
</tr>
<tr>
<td>Smallest extreme value</td>
<td>165.122</td>
<td>0.926</td>
</tr>
<tr>
<td>Normal</td>
<td>65.843</td>
<td>0.965</td>
</tr>
<tr>
<td>Logistic</td>
<td>110.190</td>
<td>0.940</td>
</tr>
</tbody>
</table>

Table 2.11 Goodness of fit results for 3-parameter Weibull plot for estimated number of deaths
Fig. 2.20 3-parameter Weibull plot for estimated number of deaths on 4-wheeled ATVs

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Anderson-Darling</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weibull</td>
<td>82.960</td>
<td>0.940</td>
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<td>Lognormal</td>
<td>50.105</td>
<td>0.962</td>
</tr>
<tr>
<td>Exponential</td>
<td>2249.935</td>
<td>*</td>
</tr>
<tr>
<td>Loglogistic</td>
<td>79.583</td>
<td>0.939</td>
</tr>
<tr>
<td>3-Parameter Weibull</td>
<td>48.438</td>
<td>0.960</td>
</tr>
<tr>
<td>3-Parameter Lognormal</td>
<td>50.041</td>
<td>0.962</td>
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<tr>
<td>2-Parameter Exponential</td>
<td>372.212</td>
<td>*</td>
</tr>
<tr>
<td>3-Parameter Loglogistic</td>
<td>79.529</td>
<td>0.939</td>
</tr>
<tr>
<td>Smallest extreme value</td>
<td>83.190</td>
<td>0.940</td>
</tr>
<tr>
<td>Normal</td>
<td>50.039</td>
<td>0.962</td>
</tr>
<tr>
<td>Logistic</td>
<td>79.528</td>
<td>0.939</td>
</tr>
</tbody>
</table>

Table 2.12 Goodness of fit results for 3-parameter Weibull plot for estimated number of deaths on 4-wheeled ATVs
Fig. 2.21 3-parameter Weibull plot for estimated number of deaths on unknown and 3-wheeled ATVs

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Anderson-Darling</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weibull</td>
<td>83.728</td>
<td>0.896</td>
</tr>
<tr>
<td>Lognormal</td>
<td>20.199</td>
<td>0.965</td>
</tr>
<tr>
<td>Exponential</td>
<td>990.532</td>
<td>*</td>
</tr>
<tr>
<td>Loglogistic</td>
<td>30.419</td>
<td>0.944</td>
</tr>
<tr>
<td>3-Parameter Weibull</td>
<td>19.779</td>
<td>0.946</td>
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<td>3-Parameter Lognormal</td>
<td>17.516</td>
<td>0.969</td>
</tr>
<tr>
<td>2-Parameter Exponential</td>
<td>55.847</td>
<td>*</td>
</tr>
<tr>
<td>3-Parameter Loglogistic</td>
<td>28.789</td>
<td>0.946</td>
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<tr>
<td>Smallest extreme value</td>
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<td>0.896</td>
</tr>
<tr>
<td>Normal</td>
<td>20.234</td>
<td>0.965</td>
</tr>
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</table>

Table 2.13 Goodness of fit results for 3-Parameter Weibull Plot for Estimated Number of Deaths on 3-Wheeled and Unknown no. of Wheeled ATVs
CHAPTER 3

STATISTICAL ANALYSIS - II AND BENCHMARKING TO AN AGRICULTURAL TRACTOR

This chapter discusses the conclusions from the statistical analysis done in the previous chapter. The change in statistical data incase of better safety in the past, is also discussed. Since an ATV has a lot of similarities to an agricultural tractor, benchmarking to an agricultural tractor is also done. Suggestions to improve the safety of the person while riding an all-terrain vehicle have been made and the concept of rollover protective structures has been introduced in this chapter. The chapter ends with the introduction to the necessity of a rollover protective structure.
3.1 SUMMARY OF STATISTICAL ANALYSIS

The data of reported number of deaths involving an all-terrain vehicle is available from 1982 through 2003. Estimation to the total number of deaths has been made from 1985 through 2002. While the comparison of the reported number of deaths in 1985 and 2002 show an increase of deaths by 88%, the comparison of estimation shows an increase of deaths by 110%. The estimated number of deaths in 1985 was 295. In 2002, the estimation rose to 621 deaths. A slight increase in the number of deaths can be attributed to the change in the method of estimation of deaths after 1999. However, the values in the risk estimate table given year by year in table 2.4 indicates that the change in method is not solely responsible for the peak increase in deaths. This indicates that there are other factors that have affected the increase in number of deaths in all these years.

The estimated number of deaths on a four-wheeled ATV has been rising with the number of years. One reason for this rise could be due to the increasing number of four-wheeled ATVs in use. Keeping in terms with the consent decrees in 1988, the three-wheeled ATVs have not been produced so far after the decrees went in to effect.

As can be concluded from table 2.4, the risk of death had come down after 1988, only to rise after 1999. The risk of death was defined as the number of estimated deaths divided by the number of ATVs in use [5]. Risk estimates were in fact recalculated for the years 1995 to 2000, so as to ensure a smooth transition between the 1994 model and 2001 model, as stated in [5]. Recalculation of the risk of deaths did not change the numbers for years 1987 to 1994. Thus, the change in the method of estimation of deaths did not in anyway affect the calculation of risk of death. The increase in the risk of death after 1999 could mean that the risk of riding an ATV is going up with the years. The cause of increase in the number of deaths and injuries is worth investigating considering the number of people at risk and considering its effect on the economy.

The estimated number of injuries on an ATV is also rising with the number of years. In the year 1982, the estimated number of injuries on ATVs was 10,100. The most recent data in 2003 shows the estimation to be 125,500 for that particular year. The number of deaths occurring on a four-wheeled ATV is also going up. But, the risk of injury on a four-wheeled ATV has come down since 1985.
The rise in number of deaths and injuries could be attributed to a number of factors

- First and foremost there has been a tremendous rise in the production of ATVs, as they are being used by a number of people for various purposes. With the usage of ATVs going up day by day, the risk of getting injured, while riding it, is also going up.

- There has been a change in the method of estimation of number of deaths and injuries that are occurring involving an ATV, after 1999. This could have also resulted in a slight increase in the number of deaths and injuries. Though, this cause may not be entirely responsible for the increase it does have its share of contribution for the increase.

- With the expiry of the consent decrees, the distributors are no longer under the compulsion of passing on the message of the unsafe handling of the ATVs, especially by children. This could also result in a slight increase in the chances of injuries/deaths on ATVs.

The following points have been noticed based on the ATV data in the past few years. The report that was published by the Consumer Product Safety Commission in 2005 had data on death and injuries that had occurred until December 31, 2003.

According to the report,

- Children under 16 years of age accounted for nearly 37% of the total estimated injuries from 1985 through 2003.

- The increase in the number of four-wheel ATVs in use can be clearly seen from statistics which also show an increase in fatalities that involved four-wheeled ATVs from 19% in 1985 to 93% in 2002.

- Estimates indicate that out of the 5.6 million ATVs in use in 2001, four-wheeled ATVs accounted for 86% of the total.

- ATVs are harmful not only to children below 16 years of age but they are harmful even to adults. This is supported by the data that shows an increase in injuries in the age groups of 25-34, 45-54 and 55 - older age groups between 2002 and 2003.
According to a document brought out by the U.S. Consumer Product Safety Commission, “CPSC Urges Caution for Three- and Four-Wheeled All-terrain vehicles”, CPSC Document #540,

- Out of the death reports that the commission received involving children between 12-15 years of age, most of them had occurred while the kids were riding adult size ATVs

- The risk of injury for children between 12 and 15 years of age is about one and a half times to two times the average risk of injury for an individual on an ATV

- The average risk of injury for inexperienced drivers is thirteen times the usual risk in their first month on an ATV

- Almost half of the drivers of an ATV have less than a year’s experience riding it and about one-fourth of the drivers have less than one-month’s experience riding it, according to a survey conducted by the commission

- 25% of the deaths that have occurred due to head injuries in ATV mishaps could have been avoided by simply wearing helmets

- The risk of a head injury by not wearing a helmet is doubled relative to when wearing a helmet

- The survey showed that about 31% of the drivers rode double and 20% of those injured were passengers

- Alcohol was also reported in about 30% of all fatal ATV accidents

- And finally reports indicate that riding a four-wheeled ATV is much better than riding a three-wheeled ATV in terms of safety
3.2 EFFECT ON STATISTICS IN CASE OF BETTER PRECAUTIONS/SAFETY

If the number of deaths and injuries because of riding an ATV continue to rise, it will be a good suggestion to enhance the safety of the rider while driving an ATV. From the above discussion, it can clearly be concluded that if the riders were more careful while riding an ATV, it could have resulted in far less statistics of deaths and injuries than those that have occurred in the past. An all-terrain vehicle is not suitable to be driven by children under the age of 16, especially ATVs with engine power more than 90cc. However, the rise in the death statistics of riders in all age groups proves that the ATVs are not as safe as they seem to be, to be driven by adults either. Though, riders above the age of 16 may have better riding skills and most importantly, perceiving skills, it still calls for more safety equipment while driving ATVs. Considering the conclusions made from the reports in the previous section, the statistics would have varied a lot by just wearing a helmet.

As reported in the document brought out by the U.S. Consumer Product Safety Commission, “CPSC Urges Caution for Three- and Four-Wheeled All-terrain vehicles”, CPSC Document #540, 25% of the deaths that have occurred due to head injuries in ATV mishaps could have been avoided by simply wearing helmets. The numbers of deaths that have occurred in past years are shown below. A comparison, if 25% of them would have been reduced each year, by just wearing helmets is also shown. The numbers have been rounded to the nearest decimal.
<table>
<thead>
<tr>
<th>Year</th>
<th>Reported Number of Deaths by Year</th>
<th>Reported Number of Deaths-25% of Reported Number of Deaths</th>
</tr>
</thead>
<tbody>
<tr>
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<td>29</td>
<td>22</td>
</tr>
<tr>
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</tr>
<tr>
<td>2002</td>
<td>357</td>
<td>268</td>
</tr>
</tbody>
</table>

Table 3.1 Variation in the number of reported deaths, by wearing a helmet while riding an ATV
<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated Number of Deaths by Year</th>
<th>Estimated Number of Deaths-25% of Estimated Number of Deaths</th>
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<tbody>
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<td>1982</td>
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<td>476</td>
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<tr>
<td>2002</td>
<td>-</td>
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</tr>
</tbody>
</table>

Table 3.2 Variation in the number of estimated deaths, by wearing a helmet while riding an ATV
Fig 3.1 Comparison of statistics of reported deaths by wearing/not wearing a helmet

Fig 3.2 Comparison of statistics of estimated deaths by wearing/not wearing a helmet
The revised figures of data are only if a helmet would have been worn while riding an ATV in the past years. Installing safety devices could have brought down these statistics further. The deaths and injuries on an ATV occur mainly when most of the safety norms are not followed i.e., when it is used for racing, where riders ride it at high speeds; when it is used on paved roads, against the recommendation to ride it only on unpaved land; when going up and down a slope, where the vehicle has high chances of toppling; and when riders ride it double, as against the recommendation to ride it single. The ATV, being a very versatile vehicle, is used a lot by agriculturists and farmers. Being a versatile vehicle, it definitely means convenience to riders. Also, it is used a lot in recreation where riders have fun while riding an ATV. Hence a solution to increase the safety of the rider on an ATV, while he completes his chores or has recreation, is to increase the safety ergonomics of the rider on an ATV. Some of the suggestions to increase the safety of a rider have been listed in the section to follow.

Fig. 3.3 Comparison of the variations in reported and estimated number of deaths due to wearing a helmet
3.3 SUGGESTIONS TO IMPROVE THE SAFETY OF AN ALL-TERRAIN VEHICLE

The United States Consumer Product Safety Commission estimates that an approximate of 90,000 ATV related injuries are treated in hospital emergency rooms annually, out of which nearly 10,000 are hospitalized [6]. Over 120 deaths are recorded on an average every year [6]. Out of these, nearly fifty percent of the deaths involve children under the age of 16. Twenty percent of these accidents are to children under the age of 12. The department of labor and industries claims that a recent study has shown that 16.4 percent of all accidents involving an ATV have occurred on farms [6]. According to the National Safe Kids Campaign, fracture of bones, head and facial injuries are the most common non-fatal injuries that occur in an accident involving an ATV. According to reports, about 22 percent of injuries to children under 14, involving ATVs, were to the head and face [7].

Consumer Product Safety Commission reports that about 37% of total injuries and about 33% of the total deaths that have occurred since 1985 to 2003 have occurred in children less than 16 years of age. Also, skin and orthopedic injuries are most frequent injuries that occur in a mishap involving an ATV [8]. It can thus be concluded that the accidents involving an all-terrain vehicle could result in head injuries, facial injuries, fracture of hands and legs, broken bones and also spinal injuries leading to paralysis. From the accidents that have occurred till date, it can be inferred that most of the injuries/fatalities due to ATVs are because of rollovers and collisions.

The Consent Decrees signed by the United States Consumer Product Safety Commission in 1988 was expected to bring down the injuries and deaths that were on a rise. Unfortunately, it still did not curb the increase in the death and injury toll, including the death and injury toll among children less than 16 years of age. One reason that could have caused a not so satisfactory outcome could be because not all states of the United States of America had implemented the regulations for the age and passenger limitations that are believed to be the main drawbacks of the all-terrain vehicles [8]. The Consent Decrees had been signed for a period of 10 years and has expired since 1998. The CPSC and the industry entered into company specific voluntary agreements that addressed many of the safety issues. These came to be known as ATV action plans. But there are only a few companies which are bound by the action plans. The action plans do not apply to manufacturers that sell or import into the United States.
The use of a smaller engine with reduced maximum speeds may help in reducing the number of deaths and injuries, particularly among children, while riding an ATV. To reduce the number of injuries caused due to burns, a casing around the exposed muffler of an ATV could be a good suggestion. One suggested step to curb the injuries and deaths on an ATV would be to increase the safety while riding an all-terrain vehicle. The National Electronic Surveillance System estimates that the use of a helmet while riding an ATV could bring down the risk of death by 42% and the risk of a nonfatal head injury by 64% [9]. Another study had concluded that a state with no ATV helmet legislation had a fatality rate of 0.17 per 100,000 people when compared to a rate of 0.08 per 100,000 in states with ATV helmet legislation [10]. A comparison of the data, if a helmet would have been worn by all riders in the past years, has already been shown in charts in the previous chapter.

While the usage of a helmet may no doubt, relatively increase the safety of the person riding an all-terrain vehicle, the protection provided by a helmet could still be insufficient when the weight and speeds attained by an ATV are taken into consideration. As stated previously, an average ATV can weigh anywhere between 100 to 600 pounds and the speeds could go as high as 90km/h. More than half of the children in a study conducted, had died due to a spinal injury, thoracic, abdominal injuries and asphyxiation [11]. These fatalities were definitely not avoidable by wearing a helmet. Wearing a helmet would have definitely reduced the risk of injury or death due to injuries to the head. However, it is only reasonable that there should be more safety gear, than just a helmet to safe guard a person while riding an ATV.

A large seat is provided on an ATV to let the passenger move about freely on the seat to maneuver the vehicle while he rides it. By doing so, the rider controls the stability of the vehicle. However, the provision of a large seat also encourages riding an ATV with a passenger which is highly not recommended. Also, an ATV does not have a proper suspension system. The provision of low pressure tires takes in the shocks while riding into bumps. It is desirable to provide a suspension system if possible [31]. It has been proved that a 3-wheeled ATV with full suspension has lower roll and vertical displacements [33]. And lastly, the operator’s weight, movement and location, play an important role in the dynamic system centre of gravity of the vehicle. The CPSC chairman has recently passed a memo, asking “to review all regulations which could make a difference in reducing the number of injuries and deaths”. This memo came
in the wake of the rising number of injuries and deaths associated with ATVs as was stated in the June 10th 2005 edition of the Lexington Herald-Leader newspaper. Looking into the short comings of the ATV, it is only desirable to provide better safety equipment on the vehicle. The discussion of better safety equipment for the all-terrain vehicle continues in the coming sections

3.4 BENCHMARKING TO AN AGRICULTURAL TRACTOR

A tractor can be defined as a two or four wheeled vehicle or a track vehicle of more than 20 engine horse power. The major cause of deaths related to tractors is reported as due to the over-turning of the tractor. A number of studies conducted nationwide had revealed that about 50% of the tractor related deaths are due to the rollover of the tractor [12]. The safety of the tractor has immensely increased over the past years due to using a rollover protective structure or ROPS on it. The following section discusses the advantages of fixing a rollover protective structure and the possible advantages it may provide to an all-terrain vehicle. Also, coming sections discuss the different designs which could be considered while designing the rollover protective structure for an all-terrain vehicle. Similarities between an agricultural tractor and an all-terrain vehicle have been listed.

3.4.1 ROLLOVER PROTECTIVE STRUCTURES/ROPS

The all-terrain vehicle is basically used for recreational and farming purposes. A suggestion to improve the safety of the operator of an all-terrain vehicle is the provision of a roll cage or a roll bar. To validate this suggestion, the all-terrain vehicle can be compared with a tractor whose main utilization all these years has been for farming purposes.

To increase the safety of the rider of a tractor, ROPS or rollover protective structures had been introduced in mid 1960’s. ROPS can be defined as a structural attachment, such as a roll cage or roll bar, which is fixed to the vehicle either by a weld or with screws. Its purpose is to protect the operator of the vehicle from possible injuries, in case of a rollover or overturn, and minimize the injuries. Rollover protective structures had first been introduced to the market as optional equipment on a tractor [13]. However, tractors manufactured immediately thereafter did not introduce ROPS as an addition to the tractor. In 1966, tractors were introduced with ROPS on John Deere tractors [14]. The American Society of Agricultural Engineers (ASAE) introduced standards for designing a ROPS in 1967. In 1976, OSHA (Occupational Safety and Health
Administration), made the addition of ROPS on a tractor a compulsion. Every tractor operated on
the field was supposed to be operated with the rider wearing a seat belt and having a ROPS on
the tractor. The effect of this compulsion showed in a few years. A decrease in the injuries/
deaths could clearly be noted.

All new tractors sold in the United States since 1985 have been equipped with ROPS as a
result of voluntary agreements. The standard brought out in 1984 describes the test and
performance requirements for ROPS [14]. Accordingly, all ROPS mounted should have a fixed
permanent label with the manufacturer’s name, address, ROPS model number, make, series
number and stating that the model is designed to fit and that the model was tested according to
the requirements of the standard. The mounting of a ROPS minimizes the risk of injury or death
and does not rely on the operator for avoiding hazards.

According to I-CASH Director, Dr. Kelley Donham, the chances of death are 75% if a
tractor rolls over and does not have a ROPS [15]. If the tractor has a ROPS and a seat belt is
worn, then there is 95% or a greater chance that there will be no injury incase of a tractor
turnover [15]. The effectiveness in preventing injury or death, when using a ROPS and a seat
belt, is 99% incase of a roll-over [16]. The purpose of a ROPS is to absorb the energy in an
impact and create a protective zone for an operator by limiting the degree of a rollover. This also
reduces substantial damage to the tractor. However, the ROPS should be properly designed
according to the standards and should never be designed by the user’s themselves, as they may
not be properly designed or fixed, and may only give a false protective environment to the
operator, which is more dangerous than not having a ROPS.

It is also important that the seat belt always be worn when operating a tractor with a
ROPS. The use of a seat belt confines the operator and holds him in the protective zone incase of
a rollover. Neglecting the wearing of a seat belt while operating a tractor with a ROPS, increases
the risk of being crushed by the ROPS itself incase of a rollover. There are standards that are to
be considered while designing a seat belt for a vehicle with a ROPS. Wearing a seat belt on a
vehicle without a ROPS will surely cause the death of the operator incase of a rollover. The
ROPS and seat belt make a good protective gear in conjunction with each other. It would be fatal
when either one of them is used without the other.
According to the conclusions from a study conducted in Sweden, the rollover fatalities between 1964 and 1986 had decreased from 12 per 100,000 tractors to 0.2 per 100,000 tractors [17]. It is reported that in the same period, the number of tractors equipped with ROPS increased from 6% to 93%. The number of tractors also rose by 275%. Though ROPS would definitely not be the single factor affecting these statistics, it definitely had an impact on the reduction of the injury or death rate.

National Institute of Occupational Safety and Health (NIOSH) has reported that a study had shown that 40% of the people had died in a tractor rollover while another similar study had shown only 2% death from similar incidents involving tractors with ROPS [17]. The reported 2% of deaths was due to not wearing a seat belt in the operation of a tractor with a ROPS. The following regulations had been introduced by the Occupational Safety and Health Administration (OSHA) and were to be met by all tractors manufactured after October 25, 1976:

1. An employer is supposed to provide a rollover protective structure (ROPS) for every tractor that is to be operated.

2. The provision of a ROPS should also include:

   i. A seat belt, which should be designed according to SAE standard J4C.

   ii. Make sure all operators of the tractors are using the seat belt and tighten it enough to hold and confine the operator in case of a rollover.

The usage of a ROPS on a tractor is stressed upon by different organizations for the safety of the operator of a tractor. ROPS, for tractors manufactured before 1976, are being designed and all operators are advised to mount them on to the tractors. The only glitch is that the ROPS cost an additional 400$ to 600$ to mount.

Some of the operating instructions given to operators of a tractor include [12]:

1. The seat belt should be secured tightly while operating a tractor mounted with ROPS.

2. For safe operation of the tractor, slopes should better be avoided.
3. Always ride single.

4. Speed is to be reduced when turning on slopes and while riding on muddy surfaces.

The slope of the field, turning radius, speed of the tractor and center of gravity are some factors which determine the potential for a turnover of a tractor. To increase the safety of the operator further, an audible warning system, forewarning the operator of a possible rollover is being considered [12].

From the above discussion, the similarities between a field tractor and an all-terrain vehicle can be clearly observed. As of today there are no legal requirements to mount a rollover protective structure on an ATV. The turnover potential of an all-terrain vehicle is also determined by factors like slope of the field, speed of the vehicle, turning radius and the instability of the all-terrain vehicle is attributed to its high center of gravity. Rollover protective structures or ROPS could prove to increase the safety of the rider of an ATV. Similar results were noted on the agricultural tractor. Therefore, ROPS can be highly recommended on an ATV.

3.4.2 SUGGESTED DESIGNS OF ROLLCAGE/ROLLBAR FOR AN ATV

Guidelines for the construction of a ROPS for all-terrain vehicles were first prepared in 1995 [18] by Occupational Safety and Health services of New Zealand. The guidelines were voluntary and were proposed to ensure that the ROPS manufactured for an ATV, would be designed according to correct standards. A number of designs have been suggested for a rollover protective structure for an all-terrain vehicle [18]. They include

1. The full cab with enclosure which covers the operator completely. This is ideal though not recommended as it increases the height of the vehicle further.

2. A roll cage with a four post frame. This provides complete coverage to the operator but may restrict the motion of the operator. Also, it has the same disadvantage of increasing the height of the vehicle, making it more unstable.

3. A two post roll bar that can be mounted on either side of the ATV. It could provide a safe volume to the operator in conjunction with two roll bars fixed to the both ends of the vehicle.
4. A single pole roll bar can also be mounted either on the front or the rear of the ATV. It also however provides a safe volume when in conjunction with another single pole roll bar on the vehicle.

The user is recommended to choose the model which suits his ATV best. However, having a single pole roll bar on the front end may turn out to prove inconvenient to the rider as it may block his/her view.

Structural performance requirements have also been suggested by the guidelines [18]. It is recommended that the all-terrain vehicles be mounted with ROPS capable of withstanding the loads it is likely to be subjected to, when a rollover or overturn occurs. The ROPS are therefore recommended to be designed to meet strength criteria adopted from ISO 3471, AS 2294 and SAE J1040 [18].
The following picture has been taken from an article published in a Lexington Herald-leader newspaper on the 17th of June, 2002 and shows an all-terrain vehicle with a fixed ROPS for protection of the workers on site.

Fig.3.4. Picture of an ATV with ROPS attached published in a local newspaper

A high percentage of injuries and deaths are noted among children riding ATVs. The reason being the inadequate skills they possess in maneuvering the vehicle apart from the instability of the vehicle itself. The addition of a ROPS to an all-terrain vehicle could prove to be very safe for such riders.

However, some riders may not prefer having a ROPS mounted on their ATV as they may consider it to be a hindrance while riding it or due to personal preferences. The National Institute for Occupational Safety and Health or NIOSH has developed a ROPS for tractors that is automatically deployable. This AutoROPS has been designed mainly to provide protection to the rider incase of a tractor turnover. The advantage to this automatically deployable ROPS is that, it is not seen mounted on the tractor. The AutoROPS pops out when the sensor senses a situation of a turnover/rollover. The chapter that follows, deals with a proposed conceptual design of an AutoROPS for an ATV based on the same guidelines as that of the NIOSH proposed AutoROPS.
CHAPTER 4

AUTOROPS FOR AN ALL-TERRAIN VEHICLE

This chapter brings forth a major suggestion to increase the safety of the person riding an all-terrain vehicle. In general, it is recommended that the rider should equip himself/herself with appropriate safety gear. As discussed in the previous chapter, this can include a helmet. However, the combination of a seat belt and a rollover protective structure is suggested, to provide better protection to the rider of an all-terrain vehicle. Keeping in mind the safety of the rider in lieu with the personal preferences of a rider for a ROPS being mounted all the time on the ATV, this chapter will deal with the conceptual design of an automatically deployable rollover protective structure or AutoROPS for an ATV. While putting forth the design, the ergonomics will also be kept in mind.

An automatically deployable rollover protective structure has been used on agricultural tractors prior to this. The conceptual design of the suggested AutoROPS for all-terrain vehicles has its origin from the design of the AutoROPS for the agricultural tractor. Hence an explanation of the design of the AutoROPS used on agricultural tractors has been provided, to help give a better understanding of the suggested model for the all-terrain vehicle.

The chapter delves with the working of each of the components of the suggested structure and ends with the complete structure in picture in terms of its working principle as well as its diagrammatic representation.
4.1 INTRODUCTION AND BACKGROUND: DEVELOPMENT OF AUTOROPS

An automatic rollover protective structure was designed by the Division for Safety Research, National Institute for Occupational Safety and Health (NIOSH) to curb the high number of overturn fatalities that were occurring due to the overturning of the agricultural tractor. The AutoROPS was developed to meet the requirements for a roll cage for tractors working in low clearance situations. In the event of an overturn, the roll cage would pop-up in time, to protect the rider of the tractor. The conceptual design of the AutoROPS for an all-terrain vehicle is being proposed based on the design of the AutoROPS designed by NIOSH for an agricultural tractor [22].

The AutoROPS developed by NIOSH consisted of two main subsystems:

1. A retractable rollover protective structure.
2. A sensor that is used to detect an overturn condition of the tractor.

![Retracted and deployed states of the AutoROPS used by NIOSH on an agricultural tractor](image)

Fig.4.1. Retracted and deployed states of the AutoROPS used by NIOSH on an agricultural tractor
The AutoROPS are held in the retracted stage for day to day use. While the tractor is in operation, incase the sensor detects an overturn condition, it actuates pyrotechnic squibs which provide the force needed to deploy the roll bars by disengaging pins, that usually hold the structure in a retracted position. Once the bars are disengaged, two pins snap beneath the upper tube and hold the bar in the deployed position. In this design, the pins provide critical support for the structure.

The conceptual design of the AutoROPS for an ATV, proposed as part of this thesis, is based on the design put forth by NIOSH with some major changes in the latching system and also proposed changes in the sensor system. The details of the design are discussed further in the coming sections.
4.2 DESIGN CONSIDERATIONS

For the design of an AutoROPS for an all-terrain vehicle, there are certain criteria that have to be kept in mind. Though the basic design of the proposal will be similar to the design made by NIOSH for the agricultural tractor, the proposed design will differ in the latching methods before and after deployment of the AutoROPS. Before the details can be discussed further, the requirements for the rollover protective structure’s release and latching and sensor system are required to be discussed. The requirements of the automatic rollover protective structure can be put forth as follows:

• A retractable rod, which is normally latched in the lowered position until it is propped up in a rollover or an overturn condition

• A sensor system, that can detect a rollover or an overturn condition of the all-terrain vehicle

• A linear actuator, which will receive a pulse from the battery of the all-terrain vehicle on the initiation of a signal by the sensor to deploy the retracted ROPS

• A latching system, similar to that in a gas spring to lock the ROPS in the deployed position and prevent it from coming down to the retracted state

The details of the above listed requirements are discussed in detail in the coming sections.
4.3 DETAILS OF DESIGN REQUIREMENTS

As discussed previously, the AutoROPS for the all-terrain vehicle will have some design requirements that are to be met which will have to be safe, ergonomic as well as cost optimal. Some of these details are discussed henceforth.

4.3.1 DESIGN OF THE RETRACTABLE ROD

The proposal for the retractable rod, for the ROPS of an all-terrain vehicle, is on the same lines as that of the NIOSH proposed retractable rod, for the ROPS of an agricultural tractor. The retractable rod used, is a telescoping rod which can be extended by means of a spring. The retractable rod system for the all-terrain vehicle can consist of two such rods on either end of the ATV at its rear end or just one rod at its rear centre. Further research is needed to come to a conclusion about the requirement. The NIOSH AutoROPS has the height of the ROPS set just below the height of the head, for the operators of the tractor to see over the crossbar ("based on sitting mid-shoulder height for a fifth percentile female"). Based on that, the distance required to engage the AutoROPS for a tractor was kept at 59.05 cm (23.25 in) [22]. The AutoROPS for an all-terrain vehicle will not need the operators to see over the crossbar. The main design criterion is for it to withstand the load in the event of an overturn or rollover. The design may probably need a change in the height of the structure depending on further research.

The most important requirement for the deployment of this retractable rod will be its release from the retracted position, in less than 0.3 seconds. This is based on the criterion used in convertible cars for the protection of its occupants [26]. For protection of the occupants of a convertible car during an overturn, the rollover protection structure is so designed, as to deploy in less than 0.3 seconds. Hathaway and Kuhar had concluded that it takes about 0.75 seconds, from a point of no-return, for a tractor that starts to overturn, to hit the ground [25]. As of today, it hasn’t been recorded as to how much time it might take for an all-terrain vehicle to hit the ground in case of a roll-over or an overturn. Keeping in view the high speeds that the all-terrain vehicle can attain, it is advisable to keep the deployment time below 0.3 seconds, similar to the requirement in convertible cars. Since this thesis deals only with the conceptual design of the AutoROPS, the practical design of the same is proposed to be extended as future work. The mechanical working of the AutoROPS system is what is being proposed as part of this thesis.
The discussion of the latching and locking system, in the retracted and deployed states respectively, is discussed in the coming sections. A 2-d view of the retractable rod will look as shown in fig. 4.2. The figure does not include the linear actuator which will hold the rod in the retracted position. A diagram discussing the linear actuator system and its positioning is discussed in the sections that will follow.

Fig.4.2. Retracted and deployed states of the proposed AutoROPS for the all-terrain vehicle
4.3.2 SENSOR SYSTEM

Sensors that are proposed to be used to detect the occurrence of a rollover or overturn of an all-terrain vehicle will be responsible to judge the chances of a rollover/overturn. Sensors will be the brain and central nervous system of the safety system that is being proposed to increase the safety of the rider driving an all-terrain vehicle. The NIOSH AutoROPS utilizes a sensor to sense an overturn condition of the agricultural tractor. For this, the sensor is used to monitor the operating angle of the tractor [22]. For the rollover protective structure to be beneficial, it is very important for the deployment of the ROPS to occur on time. Since the sensor triggers the whole process of deployment, it plays a very critical role in providing safety to the rider of the all-terrain vehicle. The all-terrain vehicle is a very unstable vehicle when not driven with proper skill or sufficient training and can cause injuries by both rollover and overturning of the vehicle. Therefore, it is wise to incorporate a sensor which can sense both rollovers as well as overturn conditions.

A rollover sensor can be defined as “a microprocessor-controlled, solid-state sensing device that utilizes complex proprietary algorithms along with vehicle specific calibrations to detect rollovers” [24]. A combination of yaw-rate and acceleration sensors can be used to detect rollover situations. Angular rate sensors are now available in the market, which have been developed to detect automotive rollover [23].

In the NIOSH developed ROPS, the operating angle of the tractor was taken as the input for the activation of the sensor [22]. The sensor used in the AutoROPS for an agricultural tractor had the following components [22]: three accelerometers, a multiplexer, a microcontroller and a triggering circuit. The roll and pitch of the tractor were monitored by the accelerometers, whose signals are transmitted to the microcontroller via the multiplexer. The algorithm that monitors the received signals is stored in the microcontroller, and it determines the operating condition of the tractor. Incase of an overturn condition, the triggering circuit deploys the ROPS.
The following diagram depicts the sensor mechanism that had been used by the NIOSH designed AutoROPS system.

![Sensor mechanism diagram]

Since an all-terrain vehicle has high chances of a rollover too, apart from chances of overturning, the algorithm of the sensor used might have to take the yaw-rate along with acceleration of the all-terrain vehicle into consideration while determining the unstable condition. This means that, the sensor that is used by NIOSH can be used in determining the overturn condition of the all-terrain vehicle, and if the algorithm of that sensor could be modified to detect rollover conditions too, then the new sensor could be used to effectively reduce the injuries and deaths that are caused due to rollover by resulting in the deployment of the ROPS, which would protect the rider of the all-terrain vehicle. Incorporation of the sensor that is presently being used in ROPS of agricultural tractors may not be advisable since it can possibly reduce the number of injuries/deaths that are occurring due to overturns but would leave the operator strapped to the ATV incase of a rollover. Therefore it calls for the development of a new sensor for an AutoROPS of an ATV.
4.3.3 LINEAR ACTUATOR

The proposed function of a linear actuator in an AutoROPS system is to act as a holding pin when the rod is in the retracted state and to release the rod when there is a possibility for a rollover/overturn. Linear actuators, like the name indicates, have a linear movement associated with them. The working of the linear actuator involves the movement of an iron rod in a linear fashion, on subjecting the core to a small voltage. On activation of the sensor, a set of wires connected to the actuator on one end can be programmed to come in contact with the battery of the all-terrain vehicle. This results in the generation of a small pulse, which would then pull back the iron rod that holds the AutoROPS in the retracted position, into the core of the actuator. On pulling back of this iron rod, the spring which is held in the compressed state in the retracted position of the ROPS, pushes the telescoping rod up, thereby allowing the rollover protective structure to pop-up, hence justifying the proposal of using a linear actuator.

Linear actuators that are proposed to be used for the above mentioned function are of two kinds. One, which is operated by creating a magnetic field and second, that is operated by a DC motor. Either ways, the principle of their operation results in linear movement of a rod. A brief description of their working follows.

4.3.3.1 LINEAR ACTUATOR WORKING ON A MAGNETIC FIELD

Linear actuators working on a magnetic field are based on the principle of a solenoid. Solenoids consist of a ferrous iron bar which is held at a distance from a coiled wire. When a certain amount of voltage is applied to this coiled wire, current flows through the coil and it develops a magnetic field. This magnetic field attracts the iron bar into the coiled wire, thus creating a linear movement in the bar. The same phenomenon is used in the magnetic actuator to create a linear movement. The following figure shows the intricate details of the inside of a solenoid.
The force generated by the solenoid is a function of the number of turns $N$ of the coil, the current $I$, the pole area $A$, the air gap $h$, and magnet permeability of air $\mu$. The equation for the force generated is given by the following formula,

$$F = \frac{N^2 I^2 A \mu}{2h^2}$$

As such, magnetic solenoids are used as economical solutions in mechanical stops.

**4.3.3.2 LINEAR ACTUATOR WORKING ON A DC MOTOR**

The mechanism being put forth here is of a linear actuator working on a DC motor which is mostly used in a power locking system in a car. However, it can be used where a linear pull-push movement is required and this can be achieved by applying pulses of voltage as low as 12V [28]. Linear actuators working with the help of DC motors are of two kinds again. One is called a master actuator, while the other is called a slave actuator. The difference between the two is that, a master actuator has a set of monitoring contacts which lack in the slave actuator. These monitoring contacts sense the physical position of the actuator. A slave/master actuator is an electromechanical device which can create linear motion when pulsed with an electric current.
The system consists of a reversible DC motor which operates a pinion gear mounted on top of it. The rotation of the DC motor is transferred to another gear which is in contact with the pinion gear on the DC motor. The second gear has another small pinion gear mounted on top of it. Therefore, the rotary movement passes along three gears before the movement is finally transferred to a rack on the armature rod. Therefore, a pulse of current moves the armature rod in one direction while another pulse moves it in the opposite direction. The body of this actuator is provided with molded spigots which allow the actuator to be mounted on to some framework. A rubber boot is also provided to keep the actuator dry. The working of the actuator is controlled by a control unit. The following diagram depicts the working of the control unit.
The control unit is responsible to send signals to the actuator for the operation of the armature rod. The actuator wires can be connected to the moving contacts of the two relays. These moving contacts are usually in contact on the de-energized side or the negative side. Each of these relays are operated by two individual transistors which are in turn operated by two monostable vibrators. When a pulse is triggered for a short time, one of the monostable vibrators triggers a pulse for a short period which energizes the corresponding relay and connects the moving contact to the positive voltage on the battery. The other side still being connected to the negative side allows the flow of a pulse of current through the DC motor. This moves the armature rod connected to the DC motor through a gear system. The triggering of the second shot moves the armature rod in the opposite direction. A slave actuator does not allow the moving of the armature rod with the help of a key but a master actuator has the provision of changeover contacts which allow the movement of the armature rod with the help of a key.

4.3.3.3 PROPOSED TYPE OF LINEAR ACTUATOR

As discussed in the previous sections, there are two options available for the type of linear actuator that can be used as a releasing pin in the AutoROPS system. The linear actuator that runs with the help of a DC motor has a telescopic rubber boot which covers the joint between the rod and the body of the actuator. This is to keep the water from accumulating and corroding the armature rod. Considering the rough terrains that the ATV is usually driven on,
this could be a major disadvantage. A major advantage with this kind of actuator though, is that, once the all-terrain vehicle is brought to a halt, and incase the ROPS had popped up in its course, one just needs a key to move the armature rod of the actuator. The ROPS can be pushed back into the retracted state after cutting off the engine power. Incase of the usage of a magnetic solenoid, one will have to remember to keep the engine running, while the ROPS is pushed back to the retracted state. However, the solenoid does not accumulate water like the DC motor operated actuator. Hence, it is considered idealistic to use a solenoid to function as a holding pin for the ROPS. There are several solenoids in the market which can be used for the above mentioned purpose.
4.3.4 LATCHING SYSTEM

The NIOSH designed AutoROPS, used pins for latching the ROPS in its retracted as well as deployed state. Pyrotechnic squibs were used to create the force needed to disengage the two pins, holding the rod down, by expansion of gases in a chamber. When the rod went up to its deployed state, two pins were used to snap into position beneath the upper tube to hold the rod. These pins essentially supported the whole ROPS. Also, in case of a turnover, the pins had to take in a lot of force acting on the rod. Essentially, the pins played a crucial part in keeping the ROPS in position. Failing of the pins would result in fatal consequences. The tests conducted by NIOSH showed that the pins were strong enough to bear the weight of the tractor. However, an alternate suggestion for the latching system of ROPS is being put forth for the ATVs.

A number of vehicles use gas springs to hold a load up in various vehicles. The same system is suggested in this thesis. The following diagram shows a system which uses a gas spring to hold up the board.
As can be seen from the above picture, the gas spring is a very simple device. Its principle is of a pin holding the outer rod, off-center. When the central rod, acting like a piston, emerges out of the hollow rod around it, the hollow rod automatically falls to one side due to the off centering of the pin supporting it. This new position of the hollow rod obstructs the piston from coming down in to the hollow rod. The only way to get the piston back in to the hollow rod, is to push the hollow rod back in to the central position by hand after raising the piston out of the groove, thereby allowing the movement of the piston back into the retracted position.

Following along the lines of the above mentioned principle, it is perceived that a mechanism of this kind will be a good replacement to the pins that hold the ROPS in the NIOSH proposed ROPS.
Fig.4.8. Latching system of the AutoROPS

The above diagram gives a complete picture of the AutoROPS with the linear actuator in position. As seen from the picture, the latching system is simple and consists of the hollow tube around a rod. The central rod is a telescoping rod which is attached at one end to the ATV and on the other end to the hollow rod along with the spring. There is also another outer hollow tube which holds the rod from toppling over once it deploys. A small rod exists on the side of the structure, to pull back the hollow rod to its initial position so that it would allow the ROPS to be brought back to the retracted state. Also, there is another clamp made of a metal piece that is suggested to be installed, only to strengthen the hold on the ROPS and prevent it from coming back to its initial state, once it is deployed. Since the metal piece is held in position by a spring, it would be easy to bring it back to position and at the same time it would provide support to the ROPS, when in the deployed state. The outer casing also provides support to the hollow rod and prevents it from toppling over. The upper horizontal bar represents the linear actuator which holds the telescoping rod in the retracted position.
This completes the suggestion for an entirely new method of latching and locking of the ROPS. One of the reasons to make this suggestion is that, the design used by NIOSH is indeed error proof. However, it may be expensive to use a ROPS of that kind on an ATV. The design suggested above is almost entirely mechanical, barring the sensor that has to be used. A 3-d design of the same has been provided in the appendix. Each one of its components is being used in other simple, inexpensive applications. Hence, manufacturing costs should be quite optimum.

This chapter dealt with the suggestion of an entirely new concept in the technology of AutoROPS and is only a conceptual design. There is a need for a lot of research before the idea can be turned in to reality. Even then, considering the number of injuries and deaths that occur on an ATV and the dislike of most of the riders for a permanent roll cage on the vehicle, the suggested design is believed to be capable of curbing quite a few mishaps. The building and testing of the AutoROPS is however out of scope of this thesis.
CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

This thesis emphasizes the safety problems of all-terrain vehicles (ATVs). The work was started with the statistical analysis of the injuries and deaths that involved an all-terrain vehicle. A rising trend in the number of deaths and injuries involving the ATV’s was found. The consent decrees implemented from 1988 to 1998 were not successful in curbing the accident rate. The rising trend in the injuries and deaths is supported by the conclusions from the 3-parameter Weibull plots. The value of shape-factor has always been significantly greater than one (ranging from 1.6 to 2.3). Common consumer products have a shape factor of 1.2. This large shape factor leads to the conclusion that a reduction of the needless injuries and deaths to the riders of the all-terrain vehicle is required.

The common engineering design approach for safety (ASME Ref 35) in order of importance emphasizes:

a. Design,

b. Guarding

c. Training and warning.

It can be clearly seen by references and data that the manufacturers of ATVs have done very little for safety in design and guarding. The training and warning of users of ATVs to reduce deaths/injuries is spotty and inconsistent at best. It is strongly recommended that the manufacturers look into the elimination of the hazard by design and the guarding of the hazard at its source to improve the safety of the rider of an ATV. Training of the riders operating an ATV is essential. However, protection of riders holds priority over it.

The need for better safety equipment has given rise to the idea of providing a rollover protective structure on the vehicle. However, the provision of a ROPS which would be a permanent fixture on the vehicle was not seen as a very lucrative option to riders. However,
ATV’s in Israel and Egypt have been seen with permanent ROPS. This thesis explored and dealt with the conceptual design of an automatically deployable ROPS for an ATV. It is also recommended that the ATV be provided with a suspension system. It has been proved that a 3-wheeled ATV with full suspension has lower roll and vertical displacements [33]. The provision of a differential should also be considered. The design of the ATV should be altered to increase its safety and stability with the existing technology.

Manufacturers of all-terrain vehicles strongly recommend against the usage of rollover protective structures on ATVs. According to them, the usage of ROPS on ATVs increases the centre of gravity of the all-terrain vehicle, making it even more unstable. However, Occupational Safety and Health provides instructions on the construction of rollover protective structures for all-terrain vehicles. Some of the designs suggested do not relatively increase the height of centre of gravity of the vehicle. Also, the dynamic system centre of gravity of the all-terrain vehicle is also dependent on the position and weight of the rider as he contributes a substantial part to the mass of the vehicle. Hence, an opportunity is seen in designing a ROPS for better safety of the rider. The mass of the ATV and the rider driving it, together, could weigh around 600lbs-800lbs. Compared to this weight, the addition of a ROPS will not increase the weight of the vehicle substantially. Therefore, the argument by the manufacturer’s that the addition of a ROPS will increase the mass of the vehicle and hence the centre of the gravity is not validated.

Countries like New Zealand, Australia, and Israel have few ATVs operating with ROPS attached to them. The number of injuries/deaths in these countries is not as high in the United States. Though, the countries may not have as high number of ATVs as in the United States, ROPS are still playing an important role in curbing the rise of injuries and deaths. It is strongly recommended that we consider the attachment of this safety gear to the all-terrain vehicle. The automatically deployable rollover protective structure is believed to have the potential to curb the rising number of deaths and injuries involving an ATV.

Apart from the above mentioned recommendations it is strongly urged to recall all the three-wheeled ATVs that are being used in the market. If not, it should be made a compulsion to install a ROPS on a three-wheeled ATV. Installation of a ROPS on a four-wheeled ATV is also strongly recommended.
5.2 FUTURE WORK

The scope of this thesis has allowed us to propose a conceptual design of an automatically deployable rollover protective structure for an all-terrain vehicle. Unavailability of sources has curbed the potential of practically designing the rollover protective structure, mounting it on an ATV and practically testing it for stability and safety.

It is recommended that as part of future work, the designing of the ROPS and the static analysis of the same be done, to follow up with the practical designing of the same. The practical testing of the design is also recommended. Modification of the proposed conceptual design, incase future research shows that the design increases the center of gravity of the vehicle further, is recommended. Consideration for the mounting of the rollover protective structure on an all-terrain vehicle should be given.
APPENDIX

Fig. A. 1. Orthogonal view of proposed AutoROPS for an ATV
Fig. A. 2. Front view of the proposed AutoROPS for an ATV
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