

# **Guardrail Technology Commercialization**

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By

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## **Abstract**

The purpose of this project was to perform a market analysis of the guardrail industry in order to determine if commercialization of a High Density Polyethylene (HDPE) guardrail is feasible. To determine this we conducted survey interviews with numerous state transportation departments, leaders in the guardrail industry, and conducted comparative pricing analysis of the HDPE rail against current steel guardrail products. We also reviewed federal safety standards for guardrails and costs associated with meeting those standards, as well as looking into the cost saving aspects that may be associated with the commercialization and subsequent implementation of the HDPE guardrail system.

## Executive Summary

Over the course of this project we aimed to gather an extensive idea of how the guardrail industry and market operated. With this information we hoped to determine if the market had the potential to take on a new technology and product, and if that product could be Dr. Ray's HDPE guardrail system. What needed to be concluded was the value the end customers, in this case state departments of transportation, placed on their guardrail options. We also wanted to find out what aspects and needs the current guardrail options were not meeting and how the HDPE guardrail could possibly address these shortcomings. Overall we hoped to arrive at a conclusion of whether or not Trinity Industries should license this technology from Dr. Ray and WPI.

In order to determine customer needs and wants, we conducted survey interviews with various state departments of transportation, as well as the Federal Highway Administration (FHWA). We reached out to the 50 state departments of transportation and the FHWA gaining a total of 19 responses. These survey interviews allowed for us to gain an understanding of the guardrail installation process, what the customers look for in their guardrail options, what these options do not address, and what the current options could improve upon. We also determined that the states kept records of where accidents occurred and if the accidents involved guardrail. This was important as we knew going into this analysis that the HDPE guardrail was not aiming to take a large portion of the market, but only areas where accidents often occurred. Most importantly we discovered what the ultimate determining factor was when states looked at new guardrail options, and that factor was price.

In an effort to gain a reasonable estimation of current steel guardrail prices, we were able to gain pricing information from ten companies which sold steel rails. These prices were given for guardrails in 25 foot and 12 ½ foot sections; from these we were able to determine an average selling price per foot for the steel rail options. With this number we looked to the annual financial reports of Trinity Industries in an attempt to gain a cost of materials, manufacturing, labor, selling and profit per

foot. We needed to do this as the only number we had for the HDPE rail was pure material cost. Some assumptions that we needed to make in order to perform this analysis was that Trinity's Highway Safety branch followed the overall profitability of the section it was a part of within the company, Construction Products Group. We also had to assume that Trinity included the aforementioned costs within the various listings in their annual report. With these calculations we were able to determine the profit per foot on steel guardrail which Trinity enjoys.

As we assumed that the HDPE rail would incur similar costs for manufacturing, labor, and selling, we had to calculate the material cost per foot for steel guardrails. Looking at the Steel Index, we were able to gain a price per ton for galvanized steel. Using simple calculations and information gathered from Isaac Ridler Butt's, *The Tinman's Manual And Builder's And Mechanic's Handbook*, we were able to gain a material price per foot for steel guardrail. Assumptions for these calculations were that the Steel Index was indicative of the entire steel market, and that the numbers used in the calculations from *The Tinman's Manual And Builder's And Mechanic's Handbook*, were applicable to the steel used in the creation of steel guardrails. Overall the calculations of these practices yielded the following numbers:

Average Selling Price per Foot for Steel Guardrail: \$12.46  
Trinity Profit per Foot: \$1.00  
Material Cost per Foot for Steel Guardrail: \$1.79

This left us with \$9.67 for process costs that could be assumed in conjunction with the HDPE guardrail.

With the only price for the HDPE rail being calculated in a previous 2007 MQP report which dealt with the creation of the rail itself, we tried to gather current pricing information. Knowing that the HDPE material is closely tied to the price of petroleum, we conducted a ratio of the 2007 price of HDPE per foot and price of petroleum, to the current price of petroleum and subsequent price per foot of HDPE. This calculation was done under the assumption that the price of HDPE material is a direct result of petroleum price. These calculations gave us the following number:



HDPE Guardrail Material Cost: \$52.85 per Foot  
HDPE Material and Process Cost: \$62.52 per Foot

These numbers do not account for markup which, we assumed would not be similar to the markup associated with the steel rail options. We assumed that a cost-plus pricing scheme would fit with the HDPE rail, and that the percentage markup associated with the HDPE rail would be higher than the steel rail percentage due to increased material costs, issues associated with bringing new products to the market and a significantly lower market share potential. Using a cost-plus strategy with a range from ten percent to 50 percent markup, we calculated a selling price range for the HDPE rail per foot to be \$68.77 to \$93.78, significantly higher than the selling price per foot for the steel rails.

What these numbers told us was that the material cost saving benefits associated with the HDPE “self-restoring” guardrail, would not be seen until the end of its lifecycle (six times hit). Because of this huge cost per foot increase and the lack of sufficient testing to highlight subsidiary benefits for the HDPE rail, we cannot at this time recommend this technology as a viable option for Trinity. However, the HDPE guardrail is not a lost cause. What our research has told us is that there is a place in the market for this technology. This project has also discovered that the necessary processes and practices are in place for the HDPE guardrail and its potential benefits to be fully seen in terms of cost savings.

Because there is a place within the market, and the technology fits a customer need, we do not suggest that the HDPE guardrail project be shut down. We believe that further development should be taken in terms of how the HDPE rail is created. Can this be done using less material? We also recommend that Dr. Ray look at other companies outside of Trinity, as some of them have expressed interest in the technology. Perhaps these companies are willing to undertake further development of the guardrail. If further testing is done on the HDPE rail, the potential benefits that can be associated with implementing it, can be quantified.

Overall the HDPE guardrail could have a place in the guardrail industry and market. However, at this time it is simply too expensive, and the overall cost outweighs the benefits that can be associated with it. If some of the measures suggested above are taken, the process for the HDPE rail to enter the market may be accelerated.

## Acknowledgements

This group would like to take the time to thank those outside entities which were instrumental in the completion of this project. These include: project advisor and head of the WPI Management Department, Dr. McRae C. Banks; professor of Civil and Environmental Engineering at WPI and inventor of the HDPE guardrail, Dr. Malcolm Ray; Mr. Don Johnson of Trinity Industries; and the various State Departments of Transportation that participated in our survey interviews and provided us with great insight, statistics, and procedural data. We would also like to thank, WPI librarian, Christine Drew who helped to get this project

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# 1 Introduction

## 1.1 Background

### *1.1.1 HDPE History*

High density polyethylene (HDPE) was first discovered and manufactured in 1951 and was preceded by low density polyethylene (LDPE), which was discovered in 1898 by a German chemist named Hons Von Pechmann (Design of an HDPE Crash Cushion, Gagne, Gagnon, Ray, Tsantoulis).

### *1.1.2 HDPE Properties and Characteristics*

HDPE and LDPE are both polymers, which are plastics that are characterized by basic repeating chemical units comprised of carbon, hydrogen, oxygen, and in some cases silicon (Design of an HDPE Crash Cushion, Gagne, Gagnon, Ray, Tsantoulis). These chemical units are linked together with strong covalent bonds through a process call polymerization (Design of an HDPE Crash Cushion, Gagne, Gagnon, Ray, Tsantoulis; Densign of and HDPE Guardrail, Archambault, Bridge, Fragachan, Kelly). When polymerized, the chemical units form long randomly ordered chains which are then connected through weaker secondary bonds called Van der Waal bonds (Design of and HDPE Guardrail, Archambault, Bridge, Fragachan, Kelly). HDPE is classified as “visco-elastic” and is comprised of two distinct structures, the first being an amorphous structure, which exhibits fluid-like properties when loads are applied, and a crystalline structure, which exhibits elastic properties when loads are applied (Design of an HDPE Crash Cushion, Gagne, Gagnon, Ray, Tsantoulis).

HDPE is considered a thermoplastic as opposed to a thermoset. The key difference is that thermoplastics can be formed into any shape when heated and thermosets cannot (Design of an HDPE Crash Cushion, Gagne, Gagnon, Ray, Tsantoulis). HDPE is allowed to be easily molded when heated

because the secondary Van der Waal bonds loosen and allow the long chemical chains to slide easily across one another (Design of and HDPE Guardrail, Archambault, Bridge, Fragachan, Kelly).

HDPE has a memory that allows the polymer to deform to up to twice its initial length and recover to 100 percent of its original shape and physical abilities (Gagne et al, 2006). The higher amount of crystalline structure and less branching of HDPE give this polymer a higher molecular weight and density as compared to LDPE (Archambault et al, 2007). This makes it a much stronger material than LDPE. Table 1-1 displays the physical properties of HDPE (Archambault et al, 2007).

**Table 1-1: HDPE Properties**

<b><u>Physical Properties</u></b>	
Density	0.955 kg/mm <sup>3</sup>
Melt Index	0.11 g/10min
Hardness	65 “Shore” D
Environmental stress crack resistance hours	2300 hours
<b><u>Mechanical Properties</u></b>	
Tensile strength @ Yield	22.1 MPa
Tensile strength, ultimate	34.5 MPa
Compressive Strength	11.0 MPa
Elongation @ yield	8% min
Elongation @ breaking	750 %min
Modulus of Elasticity	896 MPa
Flexural modulus	931 MPa
<b><u>Thermal Properties</u></b>	
Vicat softening point	C 125 C
Brittleness temp	C < 82.2 C

The following HDPE characteristics are a byproduct of the above mentioned properties:

- High stiffness,
- High abrasion resistance,
- High resistance to chemical corrosion,
- High ultraviolet radiation resistance,
- High moisture resistance,
- High ductility,
- High toughness,

- High tensile strength and
- High impact resistance over a wide temperature range.
- (Gagne et al, 2006).

The characteristics of HDPE make it a good choice for manufacturing many products including: various types of containers, plastic lumber, chairs, tables, storage sheds, plastic bags, chemical containers, chemical piping, geothermal heat transfer piping systems, natural gas distribution pipe system, water pipes, electric insulators, corrosion protection for steel pipe lines, beverage bottles, and ballistic plates (High Density Polyethylene, Wikipedia). It is just recently being looked at seriously in the highway products industries due to its before mentioned characteristics of having high toughness, high tensile strength, and high impact resistance over a wide temperature range.

### *1.1.3 Development of the HDPE Guardrail*

The HDPE guardrail system was co-developed by Dr. Malcolm Ray, professor of Civil and Environmental Engineering at Worcester Polytechnic Institute (WPI), located in Worcester, Massachusetts. While on sabbatical in Milan, Italy, Dr. Ray designed a new HDPE guardrail concept that, if correctly developed, would result in a guardrail that could restore itself after impact. This guardrail design was formed using two United States Patents that had been issued to Dr. Ray and his colleagues. Patent 6,637,971 B1, "Reusable High Molecular Weight/ High Density Polyethylene Guardrail" issued in 2003, and Patent 20,040,011,615, "Variable Force Energy Dissipater and Decelerator" made using HDPE issued in 2004, were called upon in this new guardrail design.

The idea of this guardrail came about to address some deficiencies of the current steel guardrail options. If adopted, in theory, the HDPE guardrail could withstand multiple impacts without repair or replacement, giving it a substantial lifecycle advantage over current steel guardrail options.



This paper will look at various aspects associated with the HDPE technology itself, as well as the market that it could possibly enter. Investigating different forms of literature to gain this understanding, and applying this knowledge to research and exploration of the market, this paper will analyze the market potential for this technology. This analysis will look at costs and potential savings associated with the HDPE technology and its implementation.

Section two of this paper contains the literature review, in which we discuss the history of guardrails, their development, as well as safety aspects associated with them. We also discuss in this section decision factors that pertain to installing and replacing guardrails. We move on to talk about commercialization and innovation processes that the HDPE system would have to go through.

Section three discusses the various methods we undertook in our effort to gain a solid understanding and analysis of the guardrail market as well as the HDPE technology. This methodology section also spells out various practices that we undertook when presented with roadblocks in our attempts to gain valuable information to aide in our analysis.

Section four spells out the results and interpretations that we ascertained as a group, pertaining to customer needs, industry and federal standards, potential cost saving aspects associated with the HDPE guardrail, as well as comparative pricing between the HDPE guardrail and steel guardrail options.

The final chapter, section five, includes our overall conclusions in regards to industry infrastructure, HDPE guardrail and its positive and negative value aspects to customers, as well as its potential implications for possible licensees. These conclusions are followed by subsequent recommendations for moving forward with the HDPE technology.

## 2 Literature Review

### 2.1 A Brief History of Highway Safety

Basic concepts of highway safety design elements were established in the late 1940s and 1950s. Some of these included “horizontal alignment, vertical alignment, hydraulic design, and sight distance” (AASHTO Roadside Design Guide, 2006). By the 1960s the topic of basic roadside safety was coming to the forefront, and by 1970 the standards and procedures set by roadside safety were regularly used in highway projects. This has had an impact. It has been estimated that the United States alone, “suffers approximately 40,000 traffic fatalities each year” (AASHTO Roadside Design Guide, 2006), a number that has remained relatively constant since the 1960s. That being said great strides have been made in the area of roadside safety. While the number of deaths has seemingly not dropped or rose significantly, “at the same time the number of vehicle kilometers [miles] traveled each year has increased...two and one-half times since the mid-1960s” (AASHTO Roadside Design Guide, 2006). In that sense, the rate of fatalities has `dropped close to half since the focus on roadside safety design has been made.

Highways that were fully constructed before that time are now candidates for safety reconstruction and upgrades, including the implementation of guardrails. As the safety standards have been upgraded, these older areas have compromised in terms of these new safety standards. With an obvious need in the marketplace it is clear that guardrail options must meet these standards of safety, in order to promote safety for those who travel on these roads.

On the most basic level the purpose and function of a guardrail is to “provide protection from dangerous areas such as oncoming traffic, pavement edges, drop-offs, overpasses, sharp turns, solid objects close to the roadside like buildings or bridge columns, and other potentially hazardous objects” (Archambault, et al, 2007). Secondly guardrails absorb and redirect energy from collisions in an effort to move the vehicles and passengers involved away from dangerous elements located around the area.

In the current guardrail market, guardrails constructed of steel and wood are the most commonly offered products. “Steel is very strong yet it is still malleable. This combination of properties ensures a level of safety but it is also gentler on the passengers than a rigid barrier such as concrete” (Archambault, et al, 2007).

With over 600 million vehicles worldwide the focus on guardrails and roadside safety is always of growing importance. Guardrails are the most commonly known and implemented aspect of highway safety. While guardrails primarily serve to protect the passengers in the vehicles that are involved in the accidents, they do so in many ways. Through absorbing collision energy and redirecting the vehicle away from potentially harmful aspects, guardrails provide the passengers with added safety that otherwise would not be there to lower the severity of an accident. In addition guardrails serve to keep vehicles in an upright position during and following an accident, in an effort to prevent rollover and the subsequent ejection that often occurs during such a type of accident.

## **2.2 Evolution of Highway Safety Standards**

Kenneth A. Stonex, identified some key problem areas to roadside safety in, *Roadside Design for Safety*, that was presented to the Highway Research Board at the 1960 annual proceedings. In his paper he identified hazards such as “rigid supports for light poles and sign supports, trees, utility poles, blunt guardrail ends, unsafe ditch sections, and steep side slopes” (Ross, 1994). To remedy these problems, solutions such as clearing the roadside of unneeded obstacles, flattening and rounding slopes and ditch sections, burying the end of guardrail, and breakaway supports were suggested and implemented (Ross , 1994). In 1962 *Proposed Full Scale-Testing Procedures for Guardrails* became the first formalized set of guidelines for testing guardrails.

The Highway safety Act of 1966 was the next step in safety evolution. This act placed the federal government in charge of guiding and financing all state safety efforts and strengthening local and state

safety programs. In 1967, the Special AASHTO Traffic Safety Committee prepared a report titled *Highway Design and Operational Practices Related to Highway Safety*. This was the first of two reports addressing highway safety problems. This addressed some methods that would lessen the severity of roadside hazards. Also in 1967, new guardrail designs were initiated. Highway Research Board 174 wrote several papers dealing with the testing and development of new highway barriers (Ross, 1994). One of these new barriers was the w-beam guardrail. They also dealt with the development of what warranted a guardrail. The reports also established basic height and post spacing for the w-beam guardrail, which are still used in today's w-beams. Also included were warrants for guardrails that shield embankments. New barrier designs for strong post and weak post guardrails, bridge rail systems, and improvements in cable rail guardrails and median barriers, were also included in the reports (Ross, 1994).

The Highway Safety Act of 1970 established the National Highway Traffic Safety Administration (NHTSA). In 1970, roadside safety examples include: "the development of truck mounted attenuators, bridge rails for heavy vehicles, and crash cushions. In 1971 the *Location, Selection, and Maintenance of Highway Traffic Barriers*, NCHRP Report 118" (Ross, 1994), was created. This report was an update to the NCHRP Report 54, which was implemented previous to this event. It provided a composition of existing information on service requirements, performance criteria, and warrants for all barrier systems, including longitudinal barriers.

The 1972 paper, *Evaluation of New Guardrail Terminal*, Highway Research Board Record 386 provided information on the development of the first breakaway cable terminal (BCT). These BCT's were used as end treatments for w-beam guardrails and became the most widely used end treatment for w-beam guardrails in the United States (Ross, 1994). Many other end treatments that have been created since have used the BCT breakaway cable feature.

The Highway Safety Act of 1973 was the result of U.S. Congressional hearings. The hearings concluded that large improvements could be made if the Federal Highway Administration took a more active role in highway safety. In 1974, the *Highway Design and Operational Practices Related to Highway Safety* was introduced. This was the second edition of the report to the AASHTO Select Committee on Highway Safety. The new edition discussed new priorities and knowledge for highway safety. It was based on the results of research and field experience (Ross, 1994). Also in 1974 came the *Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances*, NCHRP 153. This report provided recommendations for testing and evaluation of longitudinal barriers, breakaway features, and crash cushions (Ross, 1994).

In 1977, an AASHTO publication was created called the *Guide for Selecting, Locating, and Designing Traffic Barriers*. This publication addressed the subject of traffic barriers. The purpose of the document was to summarize the knowledge of traffic barriers and to present specific guidelines that would establish conditions that warrant barriers (Ross, 1994). The guidelines included selection procedures, how the barrier should be installed, safety and maintenance characteristics, strength, and types of barriers available (Ross, 1994). Other aspects of this presentation touched on cost effective analysis and design methods for barriers.

The 1980's regulatory acts began with *The Rural Mailbox: A Little Known Hazard*, Transportation Research Record 769 (Ross, 1994). This paper dealt with the problem of hazardous mailbox installations, and the results of this paper included redesigning mailbox placement. In 1981, the *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, NCHRP 230 made its appearance. This report updated the NCHRP Report 153 and TRB Circular 191, as well as the evaluation criteria associated with each (Ross, 1994). The report also created new procedures and updated procedures with the available technology and practices of the time. In 1982, *Safety Treatment of*

*Drainage Structures*, Transportation Research Record 868 included results from a study in which safety treatments to transverse and parallel drainage systems were developed (Ross, 1994). The results of the study have been used throughout the U. S. In 1988 came the *Roadside Design Guide*, AASHTO Task Force for Roadside Safety. This guide updated the AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers of 1977. This new version addressed new issues such as “roadside topography and drainage structures, sign and luminaire supports, roadside safety and economics, and safety barriers for work zones” , and lead to developments such as the Breakaway Cable Terminal(Ross, 1994).

In 1990 with the *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report 350 emerged (Ross, 1994). This was yet another update to the NCHRP Reports, specifically the NCHRP Report 230. There were some key changes that were made to the report including guidelines for evaluating a wider range of features, testing on a wider range of levels from which different service level systems may be developed, optional methods for side impact tests, the adoption of the one ton pickup truck to represent the upper end of the passenger vehicle spectrum, and the adoption of SI units for measurements (Ross, 1994). This was also the first test that was officially adopted by the FHWA as a crash performance standard. In 1991 the report known as *Single Slope Concrete Median Barrier*, Transportation Research Record 1302 was transcribed. “This report described the development of a new type of median barrier that incorporated a single slope setup. The shape of the barrier showed increased impact performance, especially for smaller vehicles” (Ross, 1994). Another advantage to the design showed that, if designed correctly, it would not require resetting each time the adjoining surface was overlaid (Ross, 1994). In 1995, the *Geometric Design, Roadside Safety Features, Roadside Hardware Monitoring, and Scenic Tours*, Transportation Research Record 1500 contained ten reports related to roadside safety and roadside hardware. It also contained 13 other reports dealing with safety design of roadways (Ross, 1994).

## 2.3 Effects of Guardrails on Road Safety

Over the years there have been numerous guardrails invented. “There are four general types of guardrail, ranging from weakest *and* inexpensive to strongest *and* expensive; cable and wood posts, steel and wood/metal posts, steel box-beam, and concrete barriers” (Wikipedia: Guardrail, 2009). All of these guardrails serve the same basic purposes. All guardrails work to prevent vehicles from swerving off road into dangerous areas. They also work to prevent vehicles from crashing into solid dangerous objects such as poles, pillars, and rock faces. In the case of an impact, guardrails work to keep vehicles upright and deflect them along the rail itself. Guardrails accomplish this by transferring the force of an impact to several posts along the rail outward from the impact point, thereby not collapsing and deflecting the vehicle on impact.

By functioning as previously stated, guardrails have made roads safer worldwide. However, “in the hierarchy of five roadside safety treatments, shielding with guardrails ranks fourth” (Wikipedia: Guardrail, 2009). While they work great for cars, in many cases they actually increase the severity of accidents involving other types of vehicles. Large semi-trucks, pickups, or even sport utility vehicles are at risk of toppling over guard rails due to the low rail height and motorcycles are at risk of sliding right under them and crashing into the posts. While guardrails do assist in roadside safety, they are still a hazard to some drivers. Transportation engineers continuously try to design their roads with better site selection. They try to stay away from hazards such as cliffs and ravines, and if this is not possible, they have the ravines filled in so as to eliminate the need for guardrails. Still, there are instances where guardrail placement is unavoidable, and there must be better developments of guardrails to put these safety issues to rest.

## 2.4 Development of Guardrails

As safety has been recognized as a major importance in the United States and the world in general, the standards by which guardrails are held have been amended. Currently the guardrails that are eligible for use in the United States need to pass two tests in accordance with the NCHRP Report 350. These tests will be discussed later in this paper. There are many options for guardrails that currently meet these standards; however, they differ based on location and materials used. Each of these guardrails has its own advantages and disadvantages, though all serve the same purpose.

“One of the most common designs is the W-beam guardrail (See Figure 2-1). This type of guardrail can be designed as a weak or strong post system...A weak post system means that some of the posts are purposely designed to fail upon impact. This allows for the vehicle to be stopped more gently than if it hits a more rigid system” (Archambault, et al, 2007). This system uses changes in the post spacing to help deflect the impact of accidents. This is a durable design that can withstand minor impacts, but, like all of the current guardrails, would need replacement in the event of a major collision. It also has met the standards so it can be implemented basically in any setting, however, it is very large and the metal design lacks aesthetic appeal for some settings.



Figure 2-1: Standard W-Beam Guardrail



Another weak post guardrail design is the three strand cable (See Figure 2-2). “As the name suggests, this system relies mostly on tension forces in three strands of wire-rope cable to redirect vehicles in the case of a collision” (Archambault, et al, 2007). This option also attempts to reduce the impact of a collision through decreasing the spacing between posts; however, it is less effective in this instance than the W-beam. The three strand cable is an attractive option since it can fit on narrow shoulders, it is not as visible as other guardrail options, and it takes up less space on the shoulder allowing for more room during repair and non-automotive traffic. Negative aspects of this option include that it usually requires more clear space from the rail to the next object behind it. This allows for the vehicle to be stopped by the rail in enough time so it does not interact with the obstacles and other potentially dangerous objects located behind the guardrail. In addition to the large clear zone needed, this guardrail does not withstand a great deal of impact before it needs replacement. This is a result of the guardrail losing functionality once the cables become separated from the posts (Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, 2003).



**Figure 2-2: Standard Three Strand Cable Guardrail**

Another commonly implemented weak post system is the Weak-post-box-beam. This design does a much better job of deflecting energy upon impact, and therefore is able to absorb the collision faster and without using as much guardrail as the three strand cable design. This option is more

appealing to the eye than the bulky W-beam, however, costs associated with implementation and repairs are on average higher than the aforementioned options. These high costs stem from sections that need to be custom designed to fit corners and tight areas, as well as aspects of the system that are expensive and difficult to replace (Archambault, et al, 2007).

Strong post W-beam systems are the most commonly installed guardrail in the United States. “One feature of the W-beam design is called “blocking out” the guardrail. Posts and rails are separated by spacers called “block-outs” that create extra space, reducing the chance of tires snagging on the guardrail or the vehicle vaulting over the guardrail...As with all strong post systems, this design relies on the ability of the material to withstand the bending and shearing forces in the post while using the tensile stress and material stiffness of the guardrail to redirect the vehicle” (Archambault, et al, 2007). In this system the posts are designed in such a way that they can withstand impact and remain strong or act as blunt force, when impact occurs. This system has the ability to withstand some accidents and even remain partially useful after a major impact. This allows for additional time as replacement and repair are deemed necessary. The Thrie beam guardrail (See Figure 2-3) is also available in a blocked out version. This is a stronger option than the blocked out W-beam, and has better resistance to collisions. The blocked out Thrie beam has a lower cost associated with repair and replacement since it simply needs them less, due to its innate ability to remain in better shape following impact. The system is quite versatile as the posts can be made of steel or wood, and, like some of the other options, the spacing between the posts can be moved around to address impact absorption.



**Figure 2-3: Standard Thrie Beam Guardrail**

Another option that is used, but not as common is Steel-backed timber guardrails. These systems subscribe to many of the same aspects and functions of typical guardrails. “They use wood but have a back plate for extra strength made of steel. They also use inserts to block-out the posts. This design not only functions to meet the strength needs of the guardrail but is also aesthetically pleasing” (Archambault, et al, 2007). While these guardrails fit the safety mold and also look the part, they are expensive and take up most of the room on the shoulder due to their structural makeup. Due to their limitations and expensive installation and upkeep, these are guardrails that are recommended for small areas and special order areas such as parks, estates and landmarks (Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, 2003).

A final category of guardrails is the fully rigid systems, which simply aim to stop the vehicle rather than absorb the impact. These options include concrete and stone barriers. These, for obvious reasons, are the strongest options in the guardrail market. However, these do not deflect the impact of an accident, and simply aim to make sure the vehicle does not go beyond the barrier. The stone barrier, which has a concrete center to promote its strength, is a very attractive guardrail for areas that are looking for an artistic safety solution. However, they are quite expensive to install and maintain, so much like the steel-backed timber option they are recommended for small areas (See Figure 2-4). The

concrete barriers are very large slabs of concrete that do not appeal to the eye (See Figure 2-5). These are mostly seen in highway areas that are highly concentrated with large vehicles and the subsequent increased risk of a large vehicle accident.



Figure 2-4: Standard Stone Barrier



Figure 2-5: Standard Concrete Barrier

Each of these guardrail options offer different safety techniques and attributes. They all have their positive and negative aspects, as they aim to keep the passengers involved in accidents as safe as

possible. There is one common theme in these options, which is they all require repair and replacement after accidents. As we move towards the new age of highway safety and passenger well-being, we need to look at options that can take guardrails to the next level. One of these options may very well be a guardrail that can absorb more impact than any other option, and repair itself on multiple occasions.

## 2.5 When to Put In Guardrails

For guardrails to be considered options for installation there must first be a need for one. This need can be found in determining the best way to keep motorists safe from a run off the road. To accomplish this, accident obstacles alongside a roadway need to be analyzed. A number of different treatment options exist such as complete removal of the object, placing the object outside the designated clear zone, making it breakaway, allowing it to be traversable, or simply shielding the obstacle. The option for shielding an obstacle should be exercised in the case of the object not being able to be removed, moved, made breakaway, or traversable. A complex problem arises for the design engineer when the obstacle being considered is within the clear zone. “Projected traffic and crash history can provide insight as to whether or not to shield a particular existing obstacle. Other factors include: type of roadway, treatments for similar objects along the roadway, and presence of other side obstacles in the area. Often times the decision to shield a side obstacle comes down to the sound engineering judgment on the part of the designer” (Iowa DOT Design Manual, 1997).

There are three major factors to consider when deciding on a barrier system. These are:

1. Deflection of the barrier system: If a system is impacted then there needs to be a sufficient amount of space between the back of the barrier system and the front surface of the protected obstacle to allow for deflection. For example the typical maximum deflection for a W-beam guardrail with six feet three inch post spacing and a W-Beam guardrail with three feet one and a half post spacing is three feet and two feet respectively.
2. Maintaining an open shoulder: Every effort should be made by the designer to make sure the barrier system does not encroach on the shoulder.

3. Design vehicle: Traffic within the area of the barrier should be considered because for example, in instances where high truck traffic exists barriers with higher performance capability may be required, especially if penetration of the system must be avoided. (Iowa DOT Design Manual, 1997)

In addition to the above, other factors include cost, maintenance, snow removal, and aesthetic appeal.

Although the ideal placement for a barrier system is two feet from the shoulder, if necessary, it may be placed just outside the shoulder line (Iowa DOT Design Manual, 1997). The system should be placed close enough that work required around the end terminal will not be invasive but far enough away that vehicles do not come into contact accidentally, while reducing the chances of impacting at a steep angle.

It has been clearly recognized that guardrails reduce the consequences of accidents in which vehicles run off the road or intersect highway medians. However, district and state agencies receive limited funds to address their guardrail needs whether it is guardrail installation in a new location or where there exist guardrails that are damaged or sub-standard. Due to the limited funding of guardrails there needs to exist a decision aid for allocation of transportation funds to guardrails. A number of methods exist mostly utilizing a cost benefit or cost effectiveness analysis. "Cost effectiveness analyses formally compare the costs of the improvement to the benefits derived from them" (Lambert et al, 2003). The American Association of State Highway and Transportation Officials (AASHTO) has their own cost effectiveness procedure in which "the technique calculates the total present worth of accident costs and highway department costs incurred over the life of the project" (AASHTO Roadside Design Guide, 2006).

In a survey questionnaire addressed to states across the country in order to understand how states allocate their funds for roadside safety improvements, which includes guardrails, Lambert et al (2003) point out that maintenance divisions of the particular state DOT often manage the allocation. They also mention that other involved divisions include roadway design, policy and budget, design and traffic engineers, highway safety engineers, state traffic engineers, and highway operations. In a survey

conducted for the purposes of this MQP, a survey questionnaire was presented to various state DOT's across the country. It was also shown that the first step in the process of allocating guardrails begins with the maintenance division at any state department of transportation. Typically the maintenance division sends out a design engineer to inspect a guardrail. This can either be after a vehicle has struck it, or after a long period of implementation.

Lambert's study also found that states evaluate characteristics such as lack of block-outs, substandard end treatments, insufficient length of need, and crash-worthiness. Accident history, presence of a 3R/4R project, and compliance with Federal Highway Administration mandates are other factors planners evaluate. (Lambert et al, 2003)

In many cases a new guardrail may be needed but might not be purchased immediately. This may not be due to funding, but rather in many states guardrail installations are usually included as part of an overall construction project such as constructing a new road or building a bridge.

When a new highway project is authorized, the guardrail gets replaced. This happens through a bidding process. The state DOT's usually advertise a new construction project and contractors bid to get the job. The DOT's have a few things in mind when selecting their contractor. They typically look for the lowest bid price, contractor prequalification's, contractor past performance, a timely response and completion, conformance to upgrade and crash test standards, compatibility with existing systems, an anticipated performance. Once the DOT finds the cheapest most qualified contractor, they hire them and the contractors go to work setting up the guardrail along with the rest of the construction project. (See Appendix " DOT Interviews")

## **2.6 The HDPE Guardrail System**

Dr. Ray's HDPE guardrail system starts with a steel base plate measuring 600mm by 600mm by 50mm thick that is bolted to a concrete base that is buried in the ground (Archambault, et al, 2007). A

50mm length, 88mm diameter, HDPE cylinder is then bolted to the base plate (Archambault, et al, 2007). It is important to note the measure of the diameter of the cylinder as the inside diameter of the post that attaches to it measures 86mm (Archambault, et al, 2007). This causes a tight connection between the post and cylinder that is further strengthened with a “U” bolt (Archambault, et al, 2007). (See Figure 2-6)

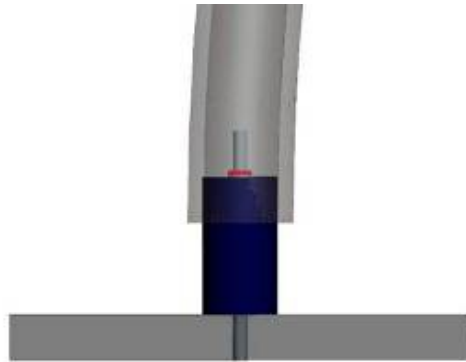


Figure 2-6: Post Base Connection

The post mentioned above is also made of HDPE. It is curved forward with a radial bend of 1071.8mm (Archambault, et al, 2007). Radial bend refers to the radius required for a circle with the amount of bend in question (See Figure 2-7). This unique bend design helps prevent any kind of vehicular tire snagging with the post on impact, but it is not enough to prevent tire snagging, so blockout is still needed (Archambault et. al, 2007).



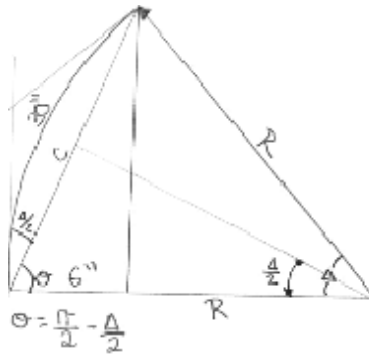


Figure 2-7: Radial Bend Diagram

The blockout of the rail is another unique feature of the system. Where typical guardrail systems provide blockout through the use of square wood and steel blocks, the HDPE system uses an HDPE cylinder with a diameter of 115mm and a length of 250mm as its block (Archambault et. al, 2007). Not only is the shape of the blockout important to the system, but so is the way in which it is attached. The cylinder is attached to the post with a steel bolt. However, the slots that are cut into the post are longer in the front than they are in the back (See Figure 2-8). This allows for the rotation of the rail on impact, which maximizes the surface area between the vehicle and the rail during impact (Archambault et. al, 2007). The rail itself is a 25mm thick by 406mm wide HDPE rail (Archambault et. al, 2007).

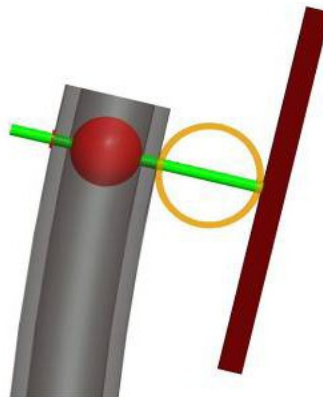


Figure 2-8: Post Rail Blockout Connection

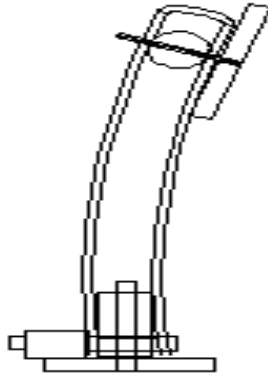


Figure 2-9: Entire Setup

With this guardrail design the rail rotates to maintain maximum surface area between the vehicles and the guardrail surface. The design allows for more energy to be absorbed by the system and works better to deflect the vehicle back onto the road (Archambault et. al, 2007). The system overall was shown to withstand forces up to 3.2 kilonewtons (KN) before the posts popped off the base (Archambault et. al, 2007). This is opposed to the 2.8 KN which a typical 150X14 steel w-beam can withstand (Archambault et. al, 2007). In addition, the HDPE system also provides the typical blackout space of 200mm, provided by the common w-beam guardrail (Archambault et. al, 2007).

This HDPE guardrail system acts as both a strong post and weak post system (Archambault et. al, 2007). A strong post system stays rigid on impact in order to deflect the vehicle back on the road, where as a weak post system yields on impact while absorbing energy and slowing the vehicle to a gradual stop. This system acts as a strong post, remaining rigid and deflecting the vehicle back onto the road when impacted with forces up to 3.2KN as previously mentioned. Throughout this process the posts bend to the vertical position while absorbing energy (Archambault et. al, 2007). The vertical position is typically reached at the 3.2KN mark and any force in excess of this mark causes the posts to pop of the base plate (Archambault et. al, 2007). From this point on the system acts as a weak post absorbing energy while gradually slowing the vehicle to a stop.

Characteristics of the HDPE system include the fact that it has reforming capabilities. Laboratory tests were done on the HDPE system by a previous MQP group from Worcester Polytechnic Institute, which showed that the rail, posts, and cylinder blockouts all reformed back to their original shape and strength after impact (Archambault et. al, 2007). Dr. Ray, the inventor of this technology, stated that after being hit six times the HDPE rail was able to regain 90 percent of its shape (Ray, 2009). The laboratory tests run by the students mentioned above show that even if a post gives during impact, as long as it does not surpass its elastic range, the mouth of the tube will reform to its original shape, a benefit of the entire system (Archambault et. al, 2007). In these lab tests, the proper size of the cylinder in order for the mouth of the tube not to surpass its elastic range was determined to be 50mm (Archambault et. al, 2007). Another characteristic of this system is that the HDPE material is significantly lighter than the current steel guardrail options. Furthermore, the properties of the HDPE material make it more corrosion resistant to the harsh elements when compared to the steel guardrails (Archambault et. al, 2007).

These characteristics of the HDPE guardrail system have implications that can be applied to cost saving aspects to the end customers, state departments of transportation. Repair costs, and installation costs could potentially be reduced with this system installed. The potential of these saving costs will be discussed later in this paper.

## **2.7 Commercialization and Innovation**

Inevitably the day will come when current guardrail systems become somewhat obsolete and a new form of guardrail technology will surface and need to be commercialized. Commercialization is the ability to convert or move technology into a profit-making position. The definition may appear simple, however, the process of commercialization is one that many innovators find hard to grasp. Depending on the nature of an idea there are a variety of ways in which one can commercialize. Some take form

through the creation of a startup company in which funding is required from investors such as friends and family, private angels, or venture capitalists. Others take the route of getting started through a joint venture, in which organizations agree to join forces to bring the idea to market. However, some ideas are commercialized through licensing of technology where the rights of the idea are granted to established companies (also referred to as cooperation strategy) (Carlson, 2006).

All in all, no matter what path to commercialization one takes, ultimately one must prove to the investors that one's idea has high potential for commercial success with limited and manageable risk associated with it.

### *2.7.1 What's The Idea?*

To commercialize great technology it is of paramount importance to be able to articulate the value proposition that represents that great technology in a convincing yet simple manner. Hundreds of great technological ideas and innovations are born every year that never make it to the commercial phase because, although the idea may have been great, it failed due to the inability of the inventor to explain the value of the idea. To turn a great idea into a great opportunity you have to get others to understand why it is great. This section will discuss some of the steps in communicating an idea in terms that investors, buyers, or licensees can identify with.

### *2.7.2 "KISS" Principle*

In the beginning phases of commercialization the inventor often makes the mistake of losing the interest of his or her investors or customers by revealing too much detail about the technical aspects of the product. Many businesspeople do not share the same expertise in the field that the inventor does so, rather than overwhelming the investor with the technical specifications of a product, the inventor should explain the opportunity the product can provide. In doing so the inventor should be aware of

the “KISS” principle, which was originally an acronym for “Keep it Short and Simple”, and became more popularized as the phrase “Keep it Simple, Stupid”.

A way to focus on simplicity is through an “elevator pitch”. WPI Professor of Entrepreneurship, Jerome Schaufeld, also an angel investing consultant, describes the elevator pitch benefits as “A good way to create a visual image that can be easily taken in by investors. In an elevator pitch you create an overview of an idea or product in the same span as if you were to pitch the idea to someone on a short elevator ride” (J. Schaufeld, 2009). Using this technique the inventor is forced to provide only the most essential elements of his or her idea, thus giving just enough important information to pique interest and the desire to hear more about the product.

### *2.7.3 Value Added*

One can advance an invention down the path to commercialization by clearly stating in simple terms the value of the invention. The difficulty here is trying to refrain from inventing products that are cool and interesting rather than focusing on important customer and market needs. Curt Carlson, author of *Innovation: The Five Disciplines of Creating What Customers Want*, believes that selecting an important unmet customer and market need at the right time is the critical starting point for all success. To improve on this advantage, the inventor must make sure the concept is feasible and the necessary infrastructure is in place to make the project commercially viable.

*The only way to systematically create a compelling customer value in the marketplace is to simultaneously interact with both the marketplace and the sources of new ideas...You must continually interact with the marketplace to identify important unmet customer and market needs...You must continually interact with sources of new ideas to understand what is possible, so as to be able to develop new innovation concepts (Carlson, 2006).*

The inventor must determine the core value to a customer in what he or she has created.

A common way to start this process is by showing that the technology potentially can reduce costs or generate revenue for the customer. This is known as the value statement or value proposition, and it has a “snowball effect” aspect to it in that it starts off short and simple and as you progress over time you will refine, revise, and build upon it so that the technology is supported with optimal and compelling value significance. Discovering value cannot solely be based on what customers say they want. John Heskett, co-author of the article “*Product Management*”, states “few users can suggest substantially new ideas and the result can often be products barely distinguishable other than in incremental detail from those of competitors. The aim is to give customers products they never knew they wanted” (Heskett, 2000).

The value of a technology should stem from trying to solve a problem or meet a need that is presently not being solved or met, or is not being solved and met efficiently or effectively. The inventor must identify to the investor that a major issue or challenge actually exists in the business or market that your technology is attempting to address. Along with this, the inventor should have direct factual data that can justify that a problem exists. The technology provides the solution to the problem and unveils the opportunity to make money and penetrate or disrupt the market. In the end, it comes down to being able to produce problem solving products with high customer value while simultaneously not extracting too many resources (e.g., financial, human capital) in the process.

#### *2.7.4 Identify the Customer(s)*

Understanding and defining who the customer is remains a crucial part in the commercialization path. “A customer is not any person or group that expresses an interest in your idea. Customers are defined by three characteristics:

1. They have a problem to solve.

2. They have money or a budget to spend to solve the problem.
3. They are willing – and authorized – to spend that money on a solution” (Kennedy, 2006).

In most instances there exist multiple customer segments.

*The end customer takes center stage in our world. At the same time there are other “customers” who must be satisfied. Value must be produced for the company, the shareholders, the employees, and the public. ...but the starting point is always the customers and the ability to create value for them...The path to success means connecting new ideas with customers who can use them (Carlson, 2006).*

The end customer and investor will have separate sets of values they hope to get from a product, therefore, the metrics for defining value will be approached differently for each. For example, in a value proposition to a prospective customer the metrics would include benefits per cost and how those benefits per cost compare with those of the competition and alternatives. In a value proposition for the investor the metrics would include market size, profit, revenue growth, and return on investment. By understanding who all the customers are the inventor is better suited to satisfy the needs of everyone involved.

### *2.7.5 Have a Plan*

A business model is a necessary tool to create that gives investors an idea of how the inventor plans to generate a return on the investment. There are a multitude of different types of business plans, however, for the sake of this project, we will focus on the licensing model. A licensing model is most appropriate when the idea or technology created is an improvement on an existing product, when development resources exist to follow through on commercialization, or when the licensee has existing customers and channels to exploit the idea. According to commercialization expert Wendy Kennedy, this type of model should help to answer certain questions, such as:

1. What will the anticipated time to market be? How long will it take to commercialize the idea and what is the date for commercialization by the licensee?
2. What should the scope of the license include? Is the license exclusive or non-exclusive and should there be limits on its field of use?
3. Should there be geographical limits on the license?
4. What costs need to be recouped? What development and other costs must be considered?
5. What is the ideal way to structure financial payment for the license? The financial payment can include: an upfront payment and ongoing royalty stream, a minimum annual royalty that must be paid regardless of the amount of sales, or depending on the amount of additional R&D required the license may provide a royalty holiday for the first few years.
6. What are the terms, conditions, and timeliness for the agreement? (Kennedy, 2006)

A financial forecast can also be used to supplement the business model and give investors a quantifiable means of evaluating the business plan. Some metrics might include: the current market size (in units and dollars), percentage of the market one is hoping to grasp and when, planned revenue to receive from customers (monthly, annually), further development costs if applicable, and projected costs of material. A good way to build a financial forecast is to use spreadsheet software so that the metrics or variables involved in the business model can be changed and adjusted depending on different “what-if” scenarios that are raised.

### *2.7.6 Identify the Competition*

Every product or technology that is created will have competition. Focusing the product to be different, not merely better, will improve its chances for commercial success. The product has to be distinct so that it stands out from the alternatives that already exist. However, you cannot begin to differentiate yourself from the rest unless you understand what it is that the competition is doing. It is a good idea not only to point out the weaknesses in what the competition is doing, but their strengths as well. Then use their strengths and weaknesses to build a competitive edge by identifying the core benefit of the technology and the key differentiator that sets it apart from the rest. The technology will certainly have a number of benefits and differentiators but the key is to narrow it to one that will make



the customer see it as a must have product that is more efficient and effective than what they already own.

To dig into how a product is different than all others in its field of use it might be easier to “wear the shoes” of the competition. Try and come up with things that the competition might say to a customer to get them not to buy your product. It is beneficial to draw on the good and bad because there does not exist one piece of technology that is perfect in all aspects. Every product has its flaws, but the important thing to keep in mind is that the message the customer hopefully will understand is what your product lacks in some areas, it will substantially make up for in other areas. An investor will much more likely be willing to take on a technology knowing that the technology is well received by its customers.

### *2.7.7 Building a Team*

As stated earlier, there will often be multiple customers that must be won over. The investor is considered a customer and they must be shown that you stand out over the competition. This is why building the right team to carry out the plan is of paramount significance and it is this factor that often determines commercialization success. Although investors are investing in a new technology, they are equally investing in the people that are bringing the idea into fruition. Investors often refer to the metaphor that they invest more on the jockey than on the horse. (Kennedy, 2006) In other words, investors want to know that there are credible and committed people with a proven track record to go along with a great technological idea. If you are able to show investors that the people you have on your team have the vision, skills, and commitment to make and take the idea to a commercial success then you place yourself in a position above that of your competition.

### 2.7.8 Intellectual Property

Companies that license a technology look for opportunities to: enhance or add value to existing product lines, boost sales momentum, or add product features that will extend the life of their current products. Most often this involves the creation of new intellectual property.

Taking a deeper look into licensing, as it is the commercialization path most pertinent to the purpose of this project, the innovator essentially chooses to earn returns on the innovation through the market for ideas rather than directly through the product market. The innovator can formally license intellectual property to one or more “idea buyers” or investors.

*Under licensing each investor has the right to exploit the innovation, receives technical assistance according to the terms of the agreement, and pays according to a fixed fee, royalty or more complex payment agreement. While the optimal structure of a license depends on features of the technology and contracting environment, the key element of licensing is that both the innovator and licensees cooperate in commercialization while maintaining organizational independence (Gans and Stern, 2002).*

Gans and Stern, authors of ‘*The Product Market and the Market for “Ideas”: Commercialization Strategies for Technology Entrepreneurs*’, believe that licensing confers several benefits in that it allows buyers and sellers of technology to soften downstream product market competition, avoid duplicative investment, and engage in complementary technology development. Established market power is reinforced and competition is softened.

“Since the total profits associated with competition are lower than the profits associated with monopolization, choosing a cooperative path preserves industry rents precisely because it subverts potential competition” (Gans and Stern, 2002). In addition, licensing allows innovators to avoid sunk investments in complementary assets necessary for commercialization. At the same time, established

firms avoid investments in imitative research programs necessary for “catching-up” to the new market entrant. Finally, the availability of a market for ideas provides incentives to develop innovations reinforcing the value of current technology.

Commercialization through licensing lends itself to a set of shortcomings as well.

*The contracting aspect of licensing can discourage collaboration between an innovator and the more established firms, which potentially increases the relative returns to a competition strategy. In other words, when trading in ideas or technology, the willingness-to-pay of potential buyers depends on their knowledge of the idea, yet knowledge of the idea implies that potential buyers need not pay in order to exploit it. Disclosure increases the buyer’s intrinsic valuation but reduces the inventor’s bargaining power (Gans and Stern, 2002).*

When formal intellectual property is not set in place, if an inventor discloses his or her idea or product to a potential investor, the investor can now claim that idea and take control of that invention because there are no patent right protections to permit the investor from doing so. The disclosure problem can be improved if strong intellectual property protection is established that would allow the property owner to gain profit even if information is disclosed. Most common types of IP protection include patents, copyrights, trademarks, and trade secrets. In this project, patents are of the most importance as they relate to protection of products or processes that are new, useful, and non-obvious works (Kennedy, 2006).

### *2.7.9 Technology Transfer*

Transfer of technologies from universities to already established business firms plays a key role in the commercialization of a new technology. There are a multitude of models that describe the technology transfer process. In a more formal approach, technology transfer is seen as a straight-line progression or steps that begin with the university’s development of the idea and technology, to gaining

a patent on the technology in order to then establish a university-private firm relationship through a formal search process. The process is concluded in licensing of patent rights. Other approaches are more informal and formulated around strong ties and relationships.

A university should also understand and heavily consider the options in which the transfer could occur. It may occur between the university and an already established business, or it could result in the creation of a new business entirely. Technology, for example, could be transferred to a large company that uses the transferred technology as a basis for just one of many product lines, or to a small firm that makes the transferred technology a cornerstone of its product strategy.

One model that can be used to transfer a technology effectively is a model in which the inventors and future users of the technology act independently of one another as no relationship or communication has occurred until the first discussion regarding a technology of interest. The relationship is usually brought about through a formal search process that is often facilitated by a technology transfer officer. "Within this model technology transfer is a process bridging the disparate cultures of the donor and recipient organizations" (Harmon et al, 1997). Steps along the way may involve changes to the technology in terms of its nature and intended use being different from the original ideas of the creator. Further developing this model, two types of innovations exist.

*The first, "unshielded information" involves basic research, which creates innovations that then undergo further development. In the second, "shielded innovation", a university office of technology licensing assesses the innovation's commercial potential and seeks licenses for promising inventions. In both cases the transfer agency plays a major role: first by mediating the patent rights transfer and second by actively searching out technologies to be transferred and by finding potential technology buyers (Harmon et al, 1997).*

Other models rely on some form of pre-established relationship and partnerships that exist between the university (individual inventor) and the private firm prior to the transfer. "These relationships can range from long-term friendships and or cooperation to such less involved forms such

as interaction at research seminars, university-sponsored events, and presentations” (Harmon et al, 1997).

### **3 Methodology**

#### **3.1 Learning about HDPE Technology**

The main purpose of our project was to determine if the HDPE guardrail system, created by Dr. Malcolm Ray, could be commercialized, licensed, and ultimately sold in the guardrail market. There were many processes involved in accomplishing this objective, however, to start this project, we had to learn about the technology itself. We felt that this was of paramount importance as we attempted determine if the technology was marketable.

We accomplished this task in two different methods. The first way in which we attempted to tackle this intention, was to contact Dr. Ray himself and set up a meeting. Through this meeting and several others we were able to ask him several questions about the technology, which gave us a good idea of what this technology actually entailed and how it worked. We then followed up these meetings with research done via the internet. We sought out any and all articles dealing with the HDPE guardrail system, such as “US Patent 5507473 - Guard rail post”, “Patent title: Guard rail mounting block and guard rail system incorporating the same”, and “Evaluation of Recycled Content Guardrail Posts,” to name a few.

In the end, the most detailed and thorough literature written about the HDPE system came in the form of an MQP named “Design of an HDPE Guardrail.” This Major Qualifying Project dealt with the creation and preliminary testing of the HDPE system. This MQP was completed by former WPI students Beau Archambault, Jo Bridge, Rodrigo Fragachan, and Katherine Kelly and was supervised by Dr. Ray.

This MQP described the system in great detail and gave us the most insight into how this guardrail is put together and functions.

The aforementioned MQP tested the guardrail to see how it would stand up to various crash situations. However, this testing was done as preliminary testing, and was not nearly in depth enough to pass testing standards to make the technology road ready. Because of this, we determined that our next step would be to learn of the testing standards and specific tests that new guardrail technologies needed to pass in order to be implemented on highways and roads. Our first action was to use our greatest resource in Dr. Ray. Through meeting with Dr. Ray we were able to get the names of the roadside safety testing standards that are required for new roadside safety equipment and technologies. Armed with this new information, we again turned to research on the internet to expand on what we recently learned.

Using the internet we were able to find copies of the actual tests Dr. Ray had pointed us to. With these tests in hand we were able to read through and analyze the requirements the HDPE system would have to pass. The tests that the HDPE would need to pass were found in the NCHRP Report 350 for implementation in America, and the European equivalent, the EN1317. Future testing standards were found in MASH, which had not been fully implemented, but was on track to replace the Report 350 standards.

We believed that these were necessary and important steps in order to gain an understanding of what our technology would bring to the market, as well as the standards it would need to pass in order to be commercialized.

## 3.2 Innovation and Commercialization

### 3.2.1 Innovation

In order to assess the commercial feasibility of the HDPE technology we needed to understand what it means to innovate and the subsequent process that it entails. To do this we modeled the innovation segments of this project after the methods mentioned in the book *Innovation: The Five Disciplines of Creating What Customers Want*. This highly touted book co-authored by SRI International President and CEO Curt Carlson (the innovators behind the computer mouse, HDTV, robotic surgery, and other world changing ideas) describes how a disciplined approach to innovation – the successful creation and delivery of a new or improved product or service – will provide value for customers and organizations alike (SRI International, 2009).

More specifically, we used the NABC approach discussed in the book as a framework on how to turn a great idea or invention into a product that customers will need. NABC, also referred to as the “value proposition”, revolves around four questions that should surface when in the process of innovation.

Those being:

1. What is the market *need*?
2. What is your *approach* to addressing this need?
3. What are the *benefits per cost* of your approach?
4. And how do those benefits per costs compare with the *competition*? (Carlson, 2006)

### 3.2.2 Commercialization

To learn about what it takes to commercialize a technology, we formed the commercialization portion of this project after the *So What? Who cares? Why You?* methodology provided by Wendy

Kennedy. Kennedy is a seasoned technology industry executive, award-winning professor, and author who has written on the subject of commercializing innovative technology ideas (wendykennedy.com, 2009). Her trademark book *So What? Who cares? Why you?* offers a methodical approach to help facilitate the often painful process of inventors and innovators to articulate the commercial opportunity that a great technological product or idea may behold.

More specifically, we used this book to create the compelling answers needed to convincingly answer some of the following questions:

- So what?
  - What's your idea?
  - What's the Problem?
  - Where Does your Idea Fit?
- Who cares?
  - Who's your Customer?
  - What's Your Path-to-Market?
  - Where's the Money?
- Why you?
  - What's your Competitive Edge?
  - Who's on the Team?
  - What's Your Story?
  - Now What? (Kennedy, 2006)

In essence our project is centered on an extensive research into answering the abovementioned questions. By following the steps discussed in both books we work towards meeting the objective of this project by potentially placing the HDPE guardrail in a better position to be commercialized because it enables us to substantiate the product with a concrete, proven, and systematic way of innovating and commercializing.

### **3.3 Determining Customer Needs**

Our next initiative was to determine what customer need in the market the HDPE guardrail would serve. In an attempt to determine such customer needs, we embarked on the task of interviewing



and surveying the end customers. Some aspects of these surveys and interviews touched on deficiencies of current guardrails as well as the desires customers may have for new guardrails. In addition to contacting the customer base, we conducted an interview with Trinity Industries (TX.) with longtime employee Mr. Don Johnson. We believed this interview with Trinity would be quite helpful since they would be the sole company we would be licensing the technology to. Mr. Johnson was able to tell us exactly what Trinity looks for in a guardrail system and what requirements are needed in order to sell it. This provided valuable insight into the guardrail industry from a selling point of view; however, we still believed that we needed to address the needs of the end customers. In the case of guardrails the end users were determined to be the state Departments of Transportation (DOT) as they are ultimately the ones who purchase the guardrails from the manufacturers. In an effort to determine the needs of the 50 different state DOT's, we created a survey questionnaire (See Appendix A1) and scoured the internet for contacts at each of these agencies.

Initially the questions conducted for the survey were derived from a prior study performed by James H. Lambert et al, 2003, in which their purpose was to understand how states allocate their funds set aside for safety improvements, including guardrails. Their questionnaire consisted of six questions, which we amended for this specific project. We sent these questions to, Department Head of Management and advisor of this MQP, Dr. McRae Banks to ensure that they were good and well-phrased. Upon getting the questions back from Dr. Banks we were told to try and avoid yes/no questions, organize the questions so they flow in a natural order, and make sure that we ask permission to follow up or contact again in the future. After revisions we then were able to send off to the various DOT agencies.

Most of the communication was through the form of email communication, however, a number of the interviews were through telephone communication. We really sought to push the questions out

to the DOT's via email because it decreases the chances of missing critical information when trying to record responses while simultaneously holding a phone conversation. Also we opted to primarily communicate through email because we felt it would give the respondents ample time to generate well thought out and meaningful answers to our questions, as opposed to cold calling, which often leads to quick responses that lack depth and value since the person receiving the call was not expecting nor able to anticipate what would be asked of them. The emails were performed in one of two ways: 1. through general query messages that can be found on most websites and, 2. through direct email contact with actual department figures within the organization.

As with many surveys, response rate is probably the biggest variable that is hard to capture. We found that the response rate was higher when we gained contact through direct emails with actual employees of the organization as opposed to the general queries. In the cases where we received no responses we then resorted to making contact through phone communication which resulted in some good responses, but again, as stated before, it compromises the ability to capture verbatim what the recipient has to say.

Overall the information gathered from these contacts and survey responses aided us in drawing conclusions based off customer needs. The information also led us to look at other aspects of the guardrail market which we believed the HDPE guardrail addressed. We felt that the process of contacting the Departments of Transportation allowed us to determine customer needs as well as the added benefits which the HDPE guardrail system could have as a byproduct of these needs.

## 3.4 Methods of Analysis

### *3.4.1 Competitive Pricing Analysis*

In an effort to gain an understanding of current market trends and expectations, we looked at the pricing differential between steel guardrail systems and the projected prices of the HDPE system. We felt that this was a necessary and essential piece to this overall project mainly because it would provide us a standard for which to compare the HDPE prices with the steel pricing.

In order to gain knowledge about the current pricing for steel guardrails, we exercised our main source of guardrail industry information, Mr. Don Johnson of Trinity Industries (TX). While we were confident that Mr. Johnson would be willing and able to provide us with some form of standard guardrail pricing that Trinity follows, we also understood that there may be some information that Mr. Johnson and Trinity would not be willing to divulge to us. Gaining pricing from Trinity would be very valuable since they are the main company with which the HDPE Guardrail co-inventor, Dr. Malcolm Ray, wishes to work. However, we made the decision that even if we were to gain this pricing information, it would be good practice to look elsewhere at pricing for steel guardrails to gain a better estimate of the market.

Through meetings and conversations with Dr. Ray, we learned of a guardrail manufacturing company here in the northeast, specifically in Glastonbury, CT. Highway Safety Corp, sales manager and WPI graduate, John Roy, was willing to talk with us about pricing. We believed that talking with Mr. Roy would be very helpful, as we were unsure about the information and data we would receive from Trinity, and also because we felt it would be an accurate representation of standards of pricing here in the northeast. Along with pricing information from Highway Safety Corp, we were also able to gain pricing information from brief phone calls and emails with sales representatives at: GSI Highway

Products, Adarand, Lake Erie Construction Company, Jensen Bridge, Hawkins Traffic and Safety, JMHP Incorporated, Fensco Incorporated, RG Steel Corporation, and Connecticut Galvanizing Corporation.

We conducted these interviews through e-mail as well as over the phone. We took these routes of communication due to the distance between ourselves and the personnel. While flying to Texas to meet with Don was out of the question, we also felt that driving two hours to Glastonbury and back would not be an efficient use of time for Mr. Roy or ourselves. Mr. Roy had expressed to us that he was quite busy but was willing to spend twenty minutes or so talking to us about the pricing that his company engaged in, which was echoed by those who responded by email or brief phone calls from the other companies mentioned above.

In order to gain pricing information about the HDPE guardrail we used three methods. The first method was to pull the pricing information from a previous MQP report; the second was through contacting an HDPE distributor, and the third was to use a direct ratio comparison from the time of the previous MQP (Archambault et al, 2007) to the time of this MQP report.

As we tried our best to project the pricing for the HDPE, we looked at the original MQP report from Archambault et al, which discussed the actual design and construction of the HDPE guardrail. In this report there was a section which pricing was discussed as they purchased sections of HDPE to construct the guardrail. With this information in hand, and having it validated through conversations with Dr. Ray, we felt it would again be good practice to look at the current pricing.

Donald Pellegrino, of WPI, pointed us in the direction of a company in Pennsylvania, Lee Supply, which is a distributor of performance pipe and HDPE. We attempted to contact Lee Supply over the phone to gain estimated costs of the HDPE sections involved in the HDPE guardrail sections.

Again our main forms of contact in these instances was the use of email and the telephone. Travel was not an option to contact Lee Supply, and Dr. Ray was out of town when we wanted to validate the numbers produced in the MQP report.

For the direct ratio comparison we had been instructed by Dr. Ray that the price of HDPE was tied closely to the price of petroleum. In order to conduct the direct ratio we had to find the price per barrel of petroleum at the time of the previous MQP report, as well as the current price per barrel. We then had to use the price per foot calculation from the previous report as we calculated the current price per foot.

Another aspect of pricing that we decided needed to be investigated as we strived to complete a thorough comparison of the two options was to separate profit per foot (markup), material cost per foot, and manufacturing, labor, and selling costs per foot in relation to the steel guardrail. In order to calculate all the above costs per foot, sans the material cost per foot, we looked to the annual financial statements provided by Trinity Industries. In order to calculate the material cost per foot we found the average thickness of W-beam guardrails and applied that to the measurements and weights found in, Isaac Ridler Butt's *The Tin man's Manual and Builders and Mechanics Handbook*.

We understood that some characteristics, such as markup, of the HDPE guardrail would not be comparable to the steel guardrail options. Because of this we looked to a comparable industry to gain markup information. To do this we talked with John Kirwan, President of Incite Innovation LLC, in Springfield, MA. Visiting the Incite office and sitting down with Mr. Kirwan, also a WPI graduate, we were able to gain information of revenue stream that new projects needed to project and the markup percentages that needed to be made in order to meet these projections. Former Chairman of the Board at Blackstone Medical Inc., William Lyons III, and Former President Matthew Lyons, also provided insight into medical device industry markup.

We also looked at pricing schemes that new products may follow as they are priced and brought to the market place. These schemes were spelled out in, Robert J. Dolan's Harvard Business Review article "*How Do You Know When The Price Is Right?*".

As a group we felt that completing these conversions and calculations gave us a good estimation of the pricing that takes place in the guardrail industry, the pricing that would take place if the HDPE rail was brought to market, and the selling price of the HDPE system. Using email, telephone interviews, and face to face conversations, we were able to gain the information needed to provide a complete and in depth analysis of pricing comparisons.

### *3.4.2 Benchmarking Analysis*

Due to some restrictions placed on our research of the guardrail industry, we needed to find a way to gain information about testing and sales markup of new projects. To do this we used the method of benchmarking to gain some insight and use these numbers. By definition benchmarking is the practice of finding "a standard by which something can be measured or judged" (Benchmarking, 2009). With this in mind, and the fact that some information we deemed necessary we were unable to gather through our guardrail industry contacts, we reached out to the medical device industry.

In an interview with John Kirwan of Incite Innovation LLC, we were able to gain an idea of the evaluation of new projects in the medical device field. We felt that gaining this information was necessary since the HDPE guardrail would be a new project category for Trinity should they choose to license the technology. Through this contact and interview we were able to get an idea of project evaluation and the characteristics associated with projects that were accepted and that did not meet the criteria to be developed. Some of these characteristics included: expected revenue stream, selling markup percentage, project evaluation framework and evaluation, development costs associated with pass/fail projects, and how new projects are brought about.

Another aspect of the medical device industry we looked at was the tests and testing costs new products needed to go through in order to become commercially viable. Interviewing Matthew Lyons, former President of Blackstone Medical Incorporated, and current President of Blue Slate Inc., we were able to obtain information in regards to testing costs for new products in the industry. We felt that this was necessary because it would give us an idea of the scale costs when applied to the testing fees Trinity would incur if they licensed the HDPE. This information also gave us insight into what makes a project worth bringing to the testing stage and what projects or ideas need to have smaller testing done before the expensive, large scale testing costs are spent.

We interviewed Mr. Kirwan face to face at the Incite offices in Springfield, Massachusetts, and conducted phone and email interviews with Mr. Lyons since he is now located in New Jersey. The information we gained from this benchmarking process, we felt would aid us in our analysis and comparisons for the HDPE guardrail and its viability of being brought to the marketplace. We entered this benchmarking technique in the hopes of gaining information which the guardrail industry was reluctant to provide to us.

## **4 Results and Interpretations**

### **4.1 DOT Interviews**

#### *4.1.2 Request for Bid*

In order to determine if the HDPE guardrail is an eligible option that would be utilized by the end customer (state departments of transportation) we needed to get a handle on who the guardrail would have to appeal to and the process required for procuring guardrails.

Generally guardrails are purchased in two manners: as a part of a completely new overall construction project, or as a repair/maintenance contract. Rod Erikson of Washington DOT specifies

that “The majority of barriers used on our highways are supplied through construction projects. The barrier needed on a project is generally presented as an individual pay item(s) within the plans, specifications, and estimates for each project as the project is developed” (Erikson, Washington DOT Interview, 2009). Dave Piper also informs us that “guardrail is generally purchased as part of construction projects, including furnishing and installing the systems. Other means of purchasing guardrail include repair contracts, which also include furnishing and installing the needed repair parts” (Piper, Illinois DOT Interview, 2009). Although guardrail is not primarily acquired through repair contracts, it is an expense that takes a heavy toll on state departments because, as we learned from Don Johnson of Trinity Highway Products, funding for guardrails is very limited. In an interview with Mr. Johnson he states, “Guardrail purchasing is a function of federal funding. Usually the federal government funds about 80-90 percent of the money needed for a road project and the individual state pays the other 10-20 percent. Even so, sometimes the states still can’t come up with their share, thereby freezing the federal dollars which are waiting to be spent” (Johnson Interview, 2009). With the price of steel continuing to increase, replacements are becoming more expensive (Abbott, Nevada DOT Interview, 2009). Table 4-1 tabulates the description, unit-price and quantity of guardrail repair parts bought by the Iowa department’s Office of Purchasing for use in guardrail repairs made by field maintenance staff in 2008 (Younie, Iowa DOT Interview, 2009). Additional repair items were purchased locally by maintenance and are not reflected in Table 4-1 . With the limited funding and budget of state departments money that could otherwise be spent on other state needs is instead spent on the purchase of guardrail repair items. The HDPE guardrail would allow for a state to alleviate the need for procuring guardrails for repair as frequently as they would if and when a steel guardrail is struck.



Table 4-1: Iowa DOT 2008 Guardrail Sales

Iowa Department of Transportation  
 Inventory Management  
 Guardrail Sales for Calendar Year 2008  
 and Current Prices as of 3/6/2009

Sum of Calendar08		
Description	Price	Total
GUARDRAIL (12'6) PUNCHED 4'2IN RE-76	\$98.73	20
GUARDRAIL (12'6) PUNCHED 4'2IN RE-76 Total		20
GUARDRAIL ANCHOR BOX FOR RE-76	\$38.93	6
GUARDRAIL ANCHOR BOX FOR RE-76 Total		6
GUARDRAIL ANCHOR PLATE W/BOLT 1'4 RE-52&53	\$47.14	8
GUARDRAIL ANCHOR PLATE W/BOLT 1'4 RE-52&53 Total		8
GUARDRAIL BACKUP PLATE RE-70(3)	\$5.41	2
GUARDRAIL BACKUP PLATE RE-70(3) Total		2
GUARDRAIL BEND FIRST 6'3" 20DEG 12'6" RE-70(1)	\$130.87	12
GUARDRAIL BEND FIRST 6'3" 20DEG 12'6" RE-70(1) Total		12
GUARDRAIL BOLT & NUT 5/8X1 1/4 RE-12	\$0.87	2773
GUARDRAIL BOLT & NUT 5/8X1 1/4 RE-12 Total		2773
GUARDRAIL BOLT,WASHER & NUT 5/8X10 HEX HEAD RE-76	\$2.17	48
GUARDRAIL BOLT,WASHER & NUT 5/8X10 HEX HEAD RE-76 Total		48
GUARDRAIL BOLT,WASHER & NUT 5/8X10 IN RE-12	\$2.56	207
GUARDRAIL BOLT,WASHER & NUT 5/8X10 IN RE-12 Total		207
GUARDRAIL BOLT,WASHER & NUT 5/8X12 IN RE-12	\$2.62	59
GUARDRAIL BOLT,WASHER & NUT 5/8X12 IN RE-12 Total		59
GUARDRAIL BOLT,WASHER & NUT 5/8X18 RE-12	\$2.88	703
GUARDRAIL BOLT,WASHER & NUT 5/8X18 RE-12 Total		703
GUARDRAIL BOLT,WASHER & NUT 5/8X20 IN RE-12	\$3.14	82
GUARDRAIL BOLT,WASHER & NUT 5/8X20 IN RE-12 Total		82
GUARDRAIL BOLT,WASHER & NUT 5/8X22 IN RE-12	\$3.98	76
GUARDRAIL BOLT,WASHER & NUT 5/8X22 IN RE-12 Total		76
GUARDRAIL CABLE ASSY. 6' 6 IN RE-52&53	\$57.61	13
GUARDRAIL CABLE ASSY. 6' 6 IN RE-52&53 Total		13
GUARDRAIL CABLE END POST&CLIPS 5.7# 5.5 RE-29A	\$82.78	47
GUARDRAIL CABLE END POST&CLIPS 5.7# 5.5 RE-29A Total		47
GUARDRAIL CABLE INTEMED. POST 5'-0 IN RE-29C	\$50.80	429
GUARDRAIL CABLE INTEMED. POST 5'-0 IN RE-29C Total		429
GUARDRAIL CABLE SHORT BOLT HOOK 5/16 W/NUT RE-29C	\$0.88	1986
GUARDRAIL CABLE SHORT BOLT HOOK 5/16 W/NUT RE-29C Total		1986
GUARDRAIL CABLE SPLICE KIT RE-29A	\$51.36	20
GUARDRAIL CABLE SPLICE KIT RE-29A Total		20
GUARDRAIL CABLE SPRING COMPENSATING RE-29A	\$130.94	10
GUARDRAIL CABLE SPRING COMPENSATING RE-29A Total		10
GUARDRAIL CABLE TURNBUCKLE W/RODS 3/4"(30") RE-29A	\$78.56	19
GUARDRAIL CABLE TURNBUCKLE W/RODS 3/4"(30") RE-29A Total		19
GUARDRAIL CABLE WEDGE RE-29A	\$2.88	43
GUARDRAIL CABLE WEDGE RE-29A Total		43
GUARDRAIL CONVEX 40' RADIUS 25' GALV. PER/ RE-56	\$169.33	12
GUARDRAIL CONVEX 40' RADIUS 25' GALV. PER/ RE-56 Total		12
GUARDRAIL CONVEX SEC. 5' RADIUS 12'6"IN GALV RE-53	\$134.99	28
GUARDRAIL CONVEX SEC. 5' RADIUS 12'6"IN GALV RE-53 Total		28
GUARDRAIL DIAPHRAGM PLATE RE-70(3)	\$31.97	13
GUARDRAIL DIAPHRAGM PLATE RE-70(3) Total		13
GUARDRAIL IMPACT HEAD ASSEMBLY (COMPLETE) RE-76	\$670.66	28
GUARDRAIL IMPACT HEAD ASSEMBLY (COMPLETE) RE-76 Total		28
GUARDRAIL PLATE WASHER 1 3/4 X 3IN RE-12	\$0.94	498
GUARDRAIL PLATE WASHER 1 3/4 X 3IN RE-12 Total		498

Table 4-1: Iowa DOT 2008 Guardrail Sales (Continued)

GUARDRAIL RE76 12'6" SPECIAL SLOTS AND ANCHOR HOLES	\$148.26	58
GUARDRAIL RE76 12'6" SPECIAL SLOTS AND ANCHOR HOLES Total		58
GUARDRAIL SECTION THRIE BEAM 12'6" (5 SLOTS) RE-68	\$139.29	2
GUARDRAIL SECTION THRIE BEAM 12'6" (5 SLOTS) RE-68 Total		2
GUARDRAIL SHELF ANGLE RE-70(2)	\$12.89	3
GUARDRAIL SHELF ANGLE RE-70(2) Total		3
GUARDRAIL SHOULDER BOLT FOR RE-76	\$3.15	86
GUARDRAIL SHOULDER BOLT FOR RE-76 Total		86
GUARDRAIL SOIL TUBES 6X8X6' RE-76	\$137.22	18
GUARDRAIL SOIL TUBES 6X8X6' RE-76 Total		18
GUARDRAIL STRAIGHT SECTION 25' RE-12	\$199.73	200
GUARDRAIL STRAIGHT SECTION 25' RE-12 Total		200
GUARDRAIL STRAIGHT SECTION 12'6" IN GALV RE-12	\$113.41	81
GUARDRAIL STRAIGHT SECTION 12'6" IN GALV RE-12 Total		81
GUARDRAIL STRUT & YOKE ASSEMBLY RE-70(1)	\$58.53	4
GUARDRAIL STRUT & YOKE ASSEMBLY RE-70(1) Total		4
GUARDRAIL STRUT & YOKE ASSEMBLY RE-76	\$53.98	8
GUARDRAIL STRUT & YOKE ASSEMBLY RE-76 Total		8
GUARDRAIL TERM. BENT END TYPE F 12-1/4 X 30 RE-52	\$48.81	9
GUARDRAIL TERM. BENT END TYPE F 12-1/4 X 30 RE-52 Total		9
GUARDRAIL TERMINAL SEC. F/E-F COMBO ON RE52 ANCHOR	\$77.00	1
GUARDRAIL TERMINAL SEC. F/E-F COMBO ON RE52 ANCHOR Total		1
GUARDRAIL TERMINAL SEC. TYPE E 12 3/8 RADIUS RE-2	\$54.53	2
GUARDRAIL TERMINAL SEC. TYPE E 12 3/8 RADIUS RE-2 Total		2
GUARDRAIL TERMINAL SEC. TYPE E&F 1-PIECE RE-70(1)	\$111.35	51
GUARDRAIL TERMINAL SEC. TYPE E&F 1-PIECE RE-70(1) Total		51
GUARDRAIL TERMINAL SECTION TYPE B RE-2A	\$41.44	5
GUARDRAIL TERMINAL SECTION TYPE B RE-2A Total		5
GUARDRAIL TERMINAL SECTION TYPE J RE-2B	\$68.10	3
GUARDRAIL TERMINAL SECTION TYPE J RE-2B Total		3
GUARDRAIL THRIE BEAM (9 SLOTS) 12'6"IN NEWER RE-68	\$151.29	22
GUARDRAIL THRIE BEAM (9 SLOTS) 12'6"IN NEWER RE-68 Total		22
GUARDRAIL TRANS. SECTION W TO THRIE 6'3"IN RE-2B	\$95.61	15
GUARDRAIL TRANS. SECTION W TO THRIE 6'3"IN RE-2B Total		15
GUARDRAIL TYPE F BRIDGE CONNECTION	\$42.55	19
GUARDRAIL TYPE F BRIDGE CONNECTION Total		19
POST GUARDRAIL 6X8X6'	\$28.81	199
POST GUARDRAIL 6X8X6' Total		199
POST GUARDRAIL (ANCHOR POST) 6X8X6' RE-52/53	\$28.98	60
POST GUARDRAIL (ANCHOR POST) 6X8X6' RE-52/53 Total		60
POST GUARDRAIL 5 1/2X 7 1/2X 45IN. RE-70, RE-76	\$26.17	216
POST GUARDRAIL 5 1/2X 7 1/2X 45IN. RE-70, RE-76 Total		216
POST GUARDRAIL BREAKAWAY (CRT) 6X8X6' RE-70/76	\$30.45	198
POST GUARDRAIL BREAKAWAY (CRT) 6X8X6' RE-70/76 Total		198
POST GUARDRAIL SPACER BLOCK 6X8X14IN. RE-76	\$7.07	136
POST GUARDRAIL SPACER BLOCK 6X8X14IN. RE-76 Total		136
POST GUARDRAIL SPACER BLOCK 8X8X14	\$11.10	95
POST GUARDRAIL SPACER BLOCK 8X8X14 Total		95
POST GUARDRAIL SPACER BLOCK 8X8X22.5 RE68	\$24.54	28
POST GUARDRAIL SPACER BLOCK 8X8X22.5 RE68 Total		28
POST GUARDRAIL SQUARE 6X6X6'	\$23.80	21
POST GUARDRAIL SQUARE 6X6X6' Total		21
POST GUARDRAIL SQUARE 10X10X6' RE-12	\$63.77	14
POST GUARDRAIL SQUARE 10X10X6' RE-12 Total		14

Table 4-1: Iowa DOT 2008 Guardrail Sales (Continued)

REFLECTOR 3M LDS 346 6 IN. FLUORESCENT YELLOW	\$10.88	224
REFLECTOR 3M LDS 346 6 IN. FLUORESCENT YELLOW Total		224
REFLECTOR GUARDRAIL AMBER 965Y STIMSONITE	\$3.91	14
REFLECTOR GUARDRAIL AMBER 965Y STIMSONITE Total		14
REFLECTOR HI INTENSITY YELLOW 8 X 24 SHOP MADE	\$6.95	83
REFLECTOR HI INTENSITY YELLOW 8 X 24 SHOP MADE Total		83
REFLECTOR HI INTENSITY YELLOW 12 X 12 SHOP MADE	\$5.37	36
REFLECTOR HI INTENSITY YELLOW 12 X 12 SHOP MADE Total		36
Grand Total		9053

Through the survey interviews we conducted all of the states revealed that a significant portion of their guardrails are obtained through a request for bid process in which contractors are awarded projects through a “competitive bidding process” (Younie, Iowa DOT interview, 2009). Typically each state prepares a bid document which is then released and advertised to contractors. Typically the main criteria sought after when acquiring guardrails are the lowest bid price and that the guardrail adheres to individual state specifications. Most states require guardrails to conform to the NCHRP Report 350 and ASSHTO Roadside Design Guide for specification standards along with any additional specifications that each individual state may require. A new standard for guardrails to follow, MASH, is a manual of specifications and regulations similar to the NCHRP Report 350 that will provide consistency between all 50 state departments. With the introduction of MASH there is a possibility that current steel guardrails may become obsolete because they have not been tested on against these new standards. This could make way for new alternatives like the HDPE guardrail to surface.

Other criteria states look for include:

- Contractor prequalification’s
- Contractor past performance
- A timely response and completion
- Conformance to upgrade and crash test standards
- Compatibility with existing system
- Anticipated performance

### *4.1.3 Guardrail Replacement Decisions and Factors*

Determining when DOT's decide that replacing a guardrail is the correct procedure, was an aspect of DOT protocol which would give us an idea of situations in which the HDPE rail would be installed. Understanding how the customer went about evaluating guardrails that were candidates for replacement, and if they indeed did have a process for doing so, was information we needed to determine if implementing a new guardrail into that process was feasible.

Obviously if the guardrail was destroyed in the accident it would necessitate installation of new guardrail. But if the accident only damaged the guardrail, the evaluation process for which replacement or repair is determined is an essential aspect to the potential market for the HDPE guardrail. The overwhelming response from the survey was that individual inspection would result in a decision to replace or repair. Rod Erickson stated the procedure for the state of Washington was,

*WSDOT has written policy relating to the replacement of some types of older guardrail systems. In addition, WSDOT designers and maintenance personnel evaluate the general condition of existing barrier systems. Considering these factors, systems are replaced as part of contracted construction projects or by WSDOT maintenance personnel. Also, many barrier systems are replaced during roadway improvement projects that necessitate the removal of existing systems for widening, new alignments etc...(Erickson, WA DOT Interview, 2009).*

In Tennessee, Joe Holt described the process as, "We have thresholds in our contracts which tied down some of the other instances for repairing guardrail when not destroyed" (Holt, TN DOT Interview, 2009). Other statutes for evaluation include: In Nevada, "Functionality is the biggest factor. If it has maintained its integrity and continues to meet Federal Safety Standards it is generally NOT replaced" (Abbott, NV DOT Interview, 2009). In Michigan,

*In general if the guardrail run consists of substandard guardrail or guardrail in poor condition, only the damaged and/or substandard*

*portion will be replaced. In most cases, when the Department develops a project, Department staff will review the corridor and upgrade any substandard or poor guardrail runs along that corridor. As a result, MDOT makes efforts to keep its existing guardrail up to current standards (Torres, MI DOT Interview, 2009).*

Vermont standards are much stricter than most. Wayne Gammel told us that “We replace most guardrails that have been damaged by accidents. We then charge the responsible party’s insurance company to cover the cost, provided we have an accident report...Guardrail that is damaged without accompanying accident reports are looked at by Area Supervisors, they then determine whether replacement is necessary (Gammel, VT DOT Interview, 2009). This process was very similar to the one found in Illinois, as Dave Piper told us. Dale Cook of Florida and Lisa Schletzbaum of Massachusetts, provided answers within the same realm of evaluation, which was that “visual field inspections” are what determine the course of action for their respective DOT.

Answers from Ohio and Colorado gave us a more in depth look into this process. In Ohio they follow, “Maintenance guidelines, such as percentage torn or flattened, or the number of posts or blockouts missing” (Focke, OH DOT Interview, 2009). Colorado’s process is as follows:

*We replace them during construction of projects in which they lie if they do not meet current design standards, or are so worn out as to be effective. This is a decision by the design engineer. Our division prepares Safety Assessment reports for each project during the early stages of the design phase. As a standard comment in every report, the engineer should adjust, repair and upgrade existing guardrail to meet current standards (Matthews, CO DOT Interview, 2009).*

With this information, we knew there was a process in which HDPE guardrail could be recommended for installation in place of damaged guardrail. This revelation was an encouraging development as we tried to assess the potential for HDPE rail fitting in the guardrail market.

Factors related to the guardrails themselves were important considerations when determining replacement. These factors for replacement vary from state to state. Some examples show states recognizing replacement factors and upgrade factors including “guardrail height, damaged guardrail, and new guardrail standards” (Matthews, CO DOT Interview, 2009). Others subscribe to “damage, dilapidation, obsolescence, or a change in performance requirements, such as the need to accommodate larger vehicle types” (Abbott, NV DOT Interview, 2009). Understanding these, and knowing that MASH will soon replace the current standards, suggests good timing for the introduction of a new option. This is further reinforced by changing standards and end customers subscribing to ideals such as being “involved with the roadside safety community locally and nationally. We strive to stay current with recent developments in traffic barrier design, installation, and maintenance” (Erikson, WA DOT Interview, 2009). The timing for a new option may be in the cards.

#### *4.1.4 Current Drawbacks*

A critical aspect of commercialization is recognizing the competition and understanding their weaknesses so that in turn you can provide a better product. To see how the HDPE guardrail stacks up against that of the current guardrails we looked to the various state departments to find out some of the greatest drawbacks of the guardrails currently in use. Various state DOT’s noted that time, costs, and effort are a few of the major shortcomings that must be overcome when utilizing current guardrail systems. More specifically maintenance costs continue to be a huge burden on the budget of state DOT’s. KC Matthews of the Colorado DOT suggests that “Metal rails require repair after most incidents” (Matthews, CO DOT Interview, 2009).

#### *4.1.5 Maintenance Costs*

One of the reasons for inquiring about maintenance costs to different state departments of transportation is because Dr. Ray feels that the number of crashes the system can accommodate with

no or little repair is the driving factor for determining if the commercialization of the HDPE guardrail is practical (Ray, 2009). For this reason it was essential to find out if in fact maintenance information is recorded and kept on file by state DOT's. While some states made it clear that they do not track such information or that it was difficult to ascertain, others have tracking systems in which their maintenance departments readily have accessible the component costs that contribute to their repair costs. Warren Abbott reports that "Nevada Department of Transportation has a computer based Maintenance tracking program called the Maintenance Management System (MMS) that is input by the field crews and queried in many different ways to determine costs and amounts of work done" (Abbott, NV DOT Interview, 2009). Like Nevada other states such as Iowa, Michigan, Connecticut, and Vermont have some sort of database, report, or system in which they track items such as person hours, labor costs, equipment costs, and material costs that go into repairs for guardrails in a given year. Some states such as Vermont did not have tracking systems readily accessible, but were able to inform us that they spent a total of \$442,937.65 repairing guardrail from March 08-March 09. This cost broke down into \$88,376.79 in material costs, \$113,446.06 in equipment costs, and \$241,114.80 in labor costs which represented 10,496.75 hours of labor time. (Gammel, VT DOT Interview, 2009) The state of Massachusetts reported that it expends about \$500,000 per year for contracted guardrail work. An astounding figure obtained from the survey interviews is from the Rhode Island DOT in which it was said that approximately \$1.2 million per year is spent on maintenance and repairs in which, similar to other states, roughly 60 percent is recouped from insurance claims. (RI DOT Interview, 2009)

In states where systems were in place we were able to collect data pertaining to guardrail repair costs by maintenance departments. Among the states, Iowa, Michigan, and Nevada, were a few that provided a breakdown and total figure for how much money was spent on repairs of guardrails for specified years. Figure 4-1 displays repair costs done by the state of Iowa's maintenance department from fiscal year 1985 to 2008. It can clearly be seen that within the last two decades or so Iowa's

maintenance costs have followed a steadily increasing trend. Within the past ten years Iowa's costs have averaged slightly over \$500,000 and in 2008 rose to over \$643,000, the latter being the second highest cost level it has seen since 2000. Table 4-2 tabulates the person hours, labor costs, equipment costs, material costs that contribute to the overall maintenance total cost. In 2008 the state recorded \$643,908 in total costs which was a direct result of 14,375 person hours, \$385,147 in labor costs, \$175,501 for equipment costs, and \$83,260 in materials.

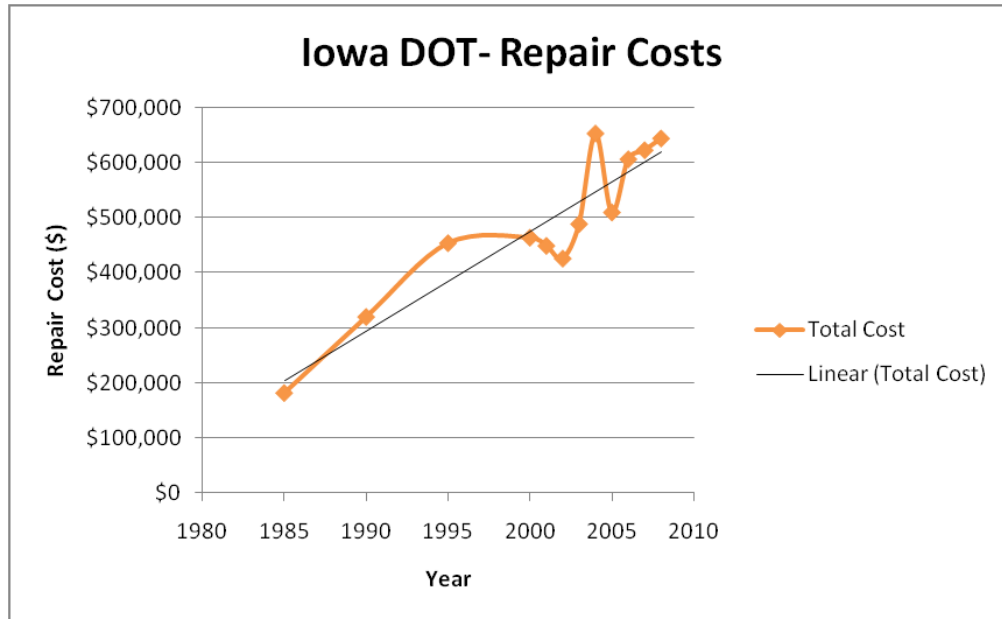


Figure 4-1: Iowa DOT Total Maintenance Costs



Table 4-2: Iowa DOT Maintenance Costs

<b>Iowa DOT - Guardrail Repair Done by Department Maintenance Forces</b>					
<b>FY</b>	<b>Persons Hours</b>	<b>Labor \$s</b>	<b>Equipment \$s</b>	<b>Materials \$s</b>	<b>Total \$s</b>
2008	14375	\$385,147	\$175,501	\$83,260	\$643,908
2007	16398	\$417,329	\$152,416	\$52,871	\$622,616
2006	17548	\$432,695	\$133,187	\$40,150	\$606,032
2005	15001	\$365,543	\$96,617	\$47,260	\$509,420
2004	20976	\$475,999	\$131,023	\$45,838	\$652,860
2003	15887	\$334,389	\$96,336	\$57,585	\$488,310
2002	14309	\$282,457	\$85,323	\$57,779	\$425,559
2001	14767	\$263,858	\$93,142	\$91,760	\$448,760
2000	16247	\$266,714	\$72,857	\$123,985	\$463,556
1995	18188	\$264,251	\$84,208	\$105,139	\$453,598
1990	15253	\$182,259	\$61,747	\$75,504	\$319,510
1985	11964	\$107,370	\$44,740	\$28,965	\$181,075

Nevada has also seen its total maintenance expenses increase. Figure 4-2- represents the increase in maintenance costs from fiscal year 2000 to 2008, where in 2008 total maintenance expenditures was nearly two times the cost in FY 2000. Table 4-3 provides the person hours, labor costs, equipment costs, and material costs that contribute to the overall maintenance total cost. In 2008 the state had reached its highest cost total of \$417,482 which was comprised of 9,019.5 person hours, \$172,418 of labor costs, \$88,614 in equipment costs, and \$156,405 in materials.

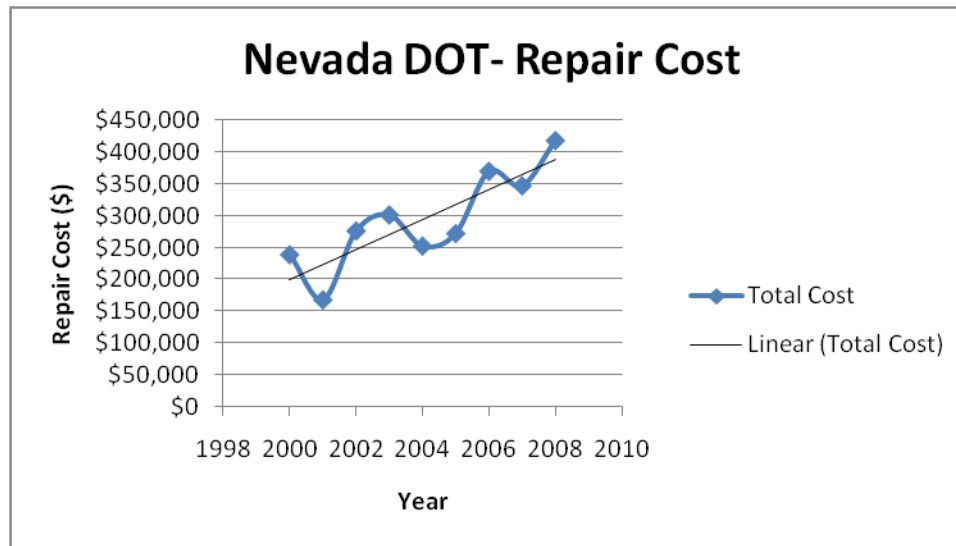


Figure 4-2: Nevada DOT Total maintenance Costs

Table 4-3: Nevada DOT Maintenance Costs

<b>Nevada DOT - Guardrail Repair CPT by Direct Maintenance Forces</b>					
<b>FY</b>	<b>Persons Hours</b>	<b>Labor \$s</b>	<b>Equipment \$s</b>	<b>Materials \$s</b>	<b>Total \$s</b>
2008	9019.5	\$172,418	\$88,614	\$156,405	\$417,482
2007	7828	\$137,668	\$45,821	\$163,223	\$346,712
2006	9539	\$173,824	\$40,279	\$155,312	\$369,414
2005	8029.5	\$134,108	\$32,884	\$104,982	\$271,974
2004	8345	\$135,072	\$40,057	\$77,271	\$252,400
2003	9807.5	\$163,571	\$53,599	\$83,782	\$300,952
2002	8682.5	\$140,144	\$72,166	\$63,679	\$275,989
2001	5295.5	\$79,031	\$48,556	\$40,527	\$168,114
2000	2655.5	\$127,539	\$57,193	\$54,053	\$238,785

The state of Michigan exhibited costs reaching close to a million dollars for guardrail repairs done by its maintenance department. More notably, guardrail repair performed by contract maintenance forces was in excess of a million dollars and in some years well over two million dollars. Figure 4-3 highlights the total maintenance costs for guardrail repairs done by Michigan’s maintenance

department from fiscal year 1999 to 2008 and Figure 4-4 shows the total maintenance costs for repairs done by contracting maintenance departments for the same given time period. Table 4-4 and Table 4-5 display the corresponding component costs for repairs done by Michigan’s maintenance department and repairs done by contract maintenance forces, respectively.

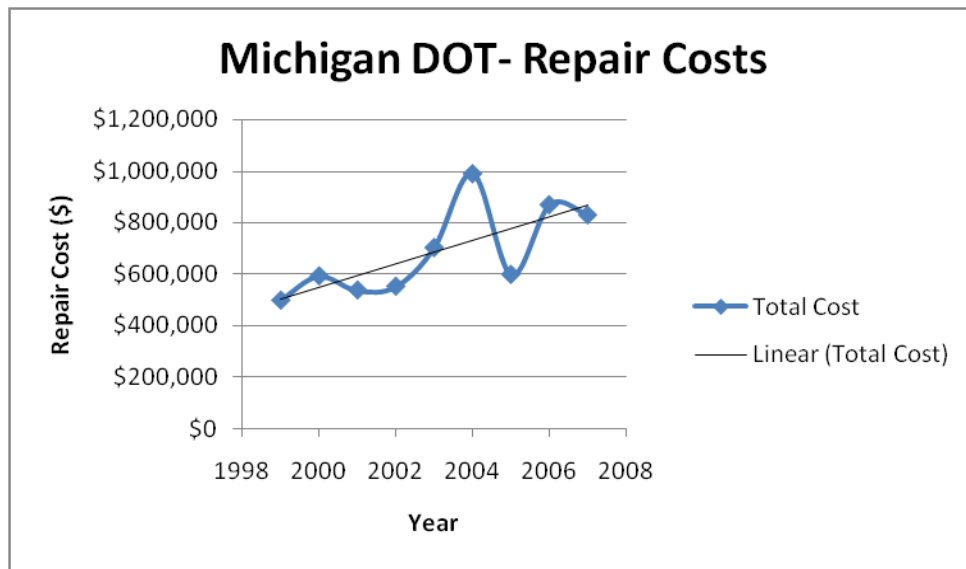


Figure 4-3: Michigan DOT Total Maintenance Costs

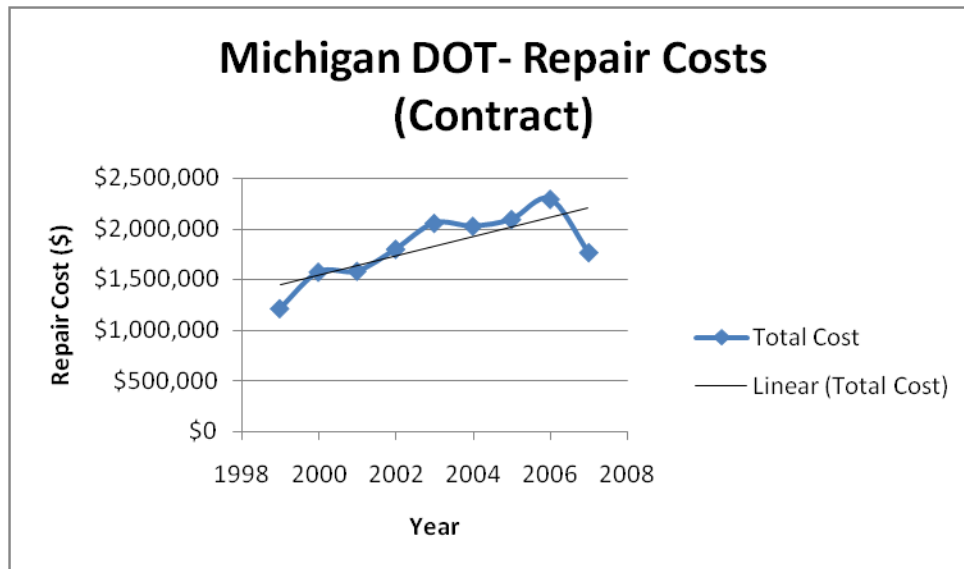


Figure 4-4: Michigan DOT Total Maintenance Costs (Contracted)

Table 4-4: Michigan DOT Maintenance Costs

<b>MICH DOT - Guardrail Repair CPT by Direct Maintenance Forces</b>					
<b>FY</b>	<b>Persons Hours</b>	<b>Labor \$s</b>	<b>Equipment \$s</b>	<b>Materials \$s</b>	<b>Total \$s</b>
2008	18804	\$377,380	NA	\$494,937	NA
2007	17441	\$333,263	\$3,303	\$493,178	\$829,744
2006	15553	\$285,556	\$2,007	\$581,540	\$869,103
2005	14834	\$253,792	\$3,584	\$340,290	\$597,666
2004	14559	\$240,355	\$138,088	\$611,601	\$990,044
2003	15293	\$250,797	\$174,279	\$277,406	\$702,482
2002	15411	\$245,817	\$146,172	\$159,701	\$551,690
2001	14284	\$219,767	\$143,447	\$173,812	\$537,026
2000	14024	\$206,633	\$153,325	\$232,128	\$592,086
1999	12054	\$174,536	\$108,383	\$214,421	\$497,340

Table 4-5: Michigan DOT Maintenance Costs (Contracted)

<b>MICH DOT - Guardrail Repair CPT by Contract Maintenance Forces</b>					
<b>FY</b>	<b>Persons Hours</b>	<b>Labor \$s</b>	<b>Equipment \$s</b>	<b>Materials \$s</b>	<b>Total \$s</b>
2008	NA	NA	NA	NA	NA
2007	35918	\$691,013	\$717,362	\$358,825	\$1,767,200
2006	39442	\$739,582	\$710,354	\$843,899	\$2,293,835
2005	42538	\$729,644	\$659,391	\$705,208	\$2,094,243
2004	41357	\$673,158	\$573,397	\$780,911	\$2,027,466
2003	39177	\$643,802	\$564,336	\$848,336	\$2,056,474
2002	38501	\$604,517	\$503,628	\$691,896	\$1,800,041
2001	23037	\$549,712	\$383,586	\$650,347	\$1,583,645
2000	31125	\$689,545	\$541,190	\$343,743	\$1,574,478
1999	23566	\$475,525	\$397,139	\$341,286	\$1,213,950

The charts representing the data consistently show an increasing trend line resulting from the steady rise in maintenance expenses borne by the necessary repair needed for current steel guardrails. Bearing in mind that the HDPE guardrail has the unique feature of restructuring itself back to its original state with little or no repair, these maintenance costs experienced by the state DOT’s highlighted above, and certainly by many of the others, could have been avoided and/or decreased substantially.

#### 4.1.6 Maintenance Injuries

As mentioned, a potential subsidiary benefit of implementing the HDPE rail is that it would cut down on maintenance required in repairing and replacing the steel guardrails. With this maintenance down, the risk that highway workers are put at when repairing and replacing the deformed or broken rails is also lessened. With the survey, we wanted to find out if data were collected and put in a database of highway workers injured on the job. We felt that finding this information could show the potential savings attributable to the HDPE guardrail implemented in high crash areas.

Again, we were skeptical that detailed records would be kept which could access such information. The practices of the departments of transportation (DOT) showed us that this information is not only valuable to us, but also to them. While not all of the DOT’s were cognizant of records and

databases that kept these kinds of records, several of them believed that the information was readily available.

Following are some examples of this information. In Colorado, KC Matthews told us “This information is tracked as part of a larger injury database by the Risk Management section” (Matthews, CO DOT Interview, 2009). Rod Erickson of the Washington DOT stated, “The WSDOT safety office keeps these types of records. There were no known injuries from errant vehicles, unsecured loads etc. The injuries on record were sprains, strains, etc. that were incurred as part of the daily work activities” (Erickson, WA DOT Interview, 2009). In Nevada, Warren Abbott expressed to us that “The Safety Engineering Division of the NDOT does keep records on injuries or deaths related to working on the roadways, but these are not broken up by task” (Abbott, NV DOT Interview, 2009). Dean Focke of the Ohio DOT took another approach to the issue. While Ohio did not have its own database that would be called upon to retrieve this information, he did know of “national figures for work zone accidents from the ATSSA (American Traffic Safety Services Association), which could be filtered out to look at guardrail accidents” (Focke, OH DOT Interview, 2009).

This information did not directly correlate with implementing HDPE rails, but it showed us that a cost saving aspect of the technology could be tangibly accessed. With this access, the injury savings potentially associated with cutting down on the injuries by cutting down on the time spent repairing and replacing the steel systems can be determined. Our findings revealed that most maintenance work is performed on off-peak hours when not many cars are traveling on the road, resulting in minor injuries such as sprains and strains rather than fatalities (Matthews, CO DOT Interview, 2009). However, the fact still remains that maintenance workers are placed in danger by the mere reality that they are put in situations where a serious accident or fatality could occur while performing guardrail repairs. Later in

this paper we will discuss the economic costs associated with fatalities to show how important it is to alleviate the need to place maintenance workers in the way of danger.

#### *4.1.7 Installation Costs*

Maintenance costs are not the only expense pointed out by state agencies. Some states note that installation costs prove to be a heavy expense. “Posts and panels are heavy and cumbersome and labor intensive to replace” (Abbott, NV DOT Interview, 2009), therefore, as result of the lack of ease to handle current guardrails installation costs can become high. Most notably concrete rail is known to be difficult to operate with and is usually two or three times more expensive than other rail systems. A lighter system (such as an HDPE system) could help to alleviate these high costs that are incurred and would be easier to maintain. The need for it exists as Dean Focke of the Ohio DOT states, “Field staff would like easier systems to maintain. A lot of our staff are not as well equipped as some of the contractors, so they do not have the proper tools to do the job. Lighter systems are a plus” (Focke, OH DOT Interview, 2009). The solution to the need pointed out by Dean Focke comes from the implementation of HDPE guardrail as HDPE material is much lighter than that of steel, therefore transportation and material handling during installation is easier, less expensive, and quicker.

#### *4.1.8 Compatibility Concerns*

On more than one occasion the problem of compatibility and interchangeability are responses that arose by state DOT’s. Although some states mention that overall they are satisfied with their current mix of guardrail options, not having one or a few guardrails to maintain was found to be a nuisance. Monique Burns of Connecticut DOT notes “We have a good number of systems we could use which in and of itself is a good thing. But, the drawback is that each location has to be looked at individually, thus creating on any length of road a variety of systems to maintain. Not one product fits all locations” (Burns, CT DOT Interview, 2009). Currently there exists no system that can act as an all-

purpose system for the fact that there are certain situations in which penetration of a guardrail system must be avoided completely, thus the use of concrete barrier is necessary. Other instances need a rail that is significantly more forgiving on impact in which steel rail is typically used. However, there is no guardrail on the market that can act as a strong and weak post system combined. The HDPE guardrail system's ability to act as a strong and weak post system can be the alternative that eases the concerns of not having a multipurpose system.

Although the survey interviews and this MQP are not specifically addressing the need for end treatments, compatibility of guardrail end treatments was mentioned quite frequently as being an issue. Wayne Gammel states "One of the biggest drawbacks we currently have is that there are several different types of end treatments currently on our highways resulting in compatibility issues. We often have to replace entire end treatments with the newest standards even though it may only be partially damaged. There have been many changes over the last few years and it is not cost effective to have large stockpiles of replacement parts for each type of end treatment" (Gammel, VT DOT Interview, 2009). To add to this, Lisa Schletzbaum informs us that from a maintenance standpoint, end treatments are a constant problem because those that are close to roadways are malleable and frequently in disrepair due to hit and run incidents as well as plow damage. Given that many end treatments require "specialty" equipment that DOTs do not have, guardrail end treatments cannot be routinely repaired (Schletzbaum, MA DOT Interview, 2009).

Routine repairs can be addressed by the HDPE technology and its ability to self-restore. Currently there exists an end treatment, also invented by Dr. Malcolm Ray, which is licensed and manufactured by Trinity Highway Products. This end treatment is known as Hybrid Energy Absorbing Reusable Terminal (HEART) and is designed to absorb energy during impact.

*The HEART is a reusable, restorable, non-gating and re-directive crash cushion...and is compliant with the NCHRP Report 350 Test Level 3. The*



*HEART uses High Molecular Weight/High Density Polyethylene (HMW/HDPE) side panels and a rounded frontal nose piece, which are connected to steel diaphragms mounted on tubular steel tracks. The HEART's HMW/HDPE panels and nose reduce lifecycle costs and minimize maintenance (Trinity Highway Products, 2009).*

This system can serve as a viable option for end treatments that will keep inventory costs down by eliminating the need to have an abundance of on hand materials in case a repair is in needed. Much in the same way that the HEART system functions the HDPE guardrail can provide similar benefits as a guardrail system for state highway agencies.

#### *4.1.9 High Crash Locations*

Although it is our belief that the HDPE guardrail can penetrate the guardrail market if we target high crash locations, we needed to carry out further investigation to substantiate our belief. Through the survey interviews we were able to gain insight on whether or not the state departments of transportation had the ability to track and pinpoint accidents that involved guardrails. We felt that this was a vital question for the possible implementation of the HDPE guardrail, mainly because we realized that this guardrail was not applicable everywhere.

The main goal of this question was to determine if there could be reports that showed areas in the state that had accidents involving guardrails. Understanding that this technology would only be applicable in “high crash areas” resulting in roughly “two to three percent of the market” (Ray, 2009), we needed to determine if these areas could in fact be identified. Establishing that the HDPE guardrail system would be a replacement candidate in certain areas was an essential component in determining if commercializing the technology was viable.

We were pleasantly surprised to find that the majority of the responses from our survey tracked this kind of information. While some states had fully functional systems to access this information, some were in the development stages of drafting such a system. According to Warren Abbott of the Nevada State Department of Transportation, “One of the requirements of our Maintenance Management System (MMS), is for the Supervisor of a field crew to put a location for the work he has completed. So, each time guardrail is worked on it is put in the system by task, location, labor (man power), equipment and material used” (Abbott, NV DOT Interview, 2009). Knowing that the information we needed could be pulled up through reports and databases, we also wondered if it had been put into use.

Talking with Dave Piper of the Illinois Department of Transportation, we learned of a specific system that was ideal for gathering the information we would need. The Illinois GIS database provides excel sheet reports that give “An idea of the proximity of crashes taken from the TS Route and Mile fields (columns X and Y). These give route/milepost locations along the various unique routes” (Piper, Illinois DOT Interview, 2009). These in depth reports give the information of where the crashes occur, if the guardrail involved needs repair or replacement, if death has occurred, as well as other crash information about the individual crashes. Perhaps the most important aspect of this report is that it can generate an image of the state, pinpointing where the accidents occurred. This is seen in Figure 4-5, but the greatest attribute of this image is that areas with a high concentration of accidents involving guardrails can be easily identified , this can be seen in the upper right hand corner of the image, as the large cluster of demarcations indicate a high concentration of accidents involving guardrails.

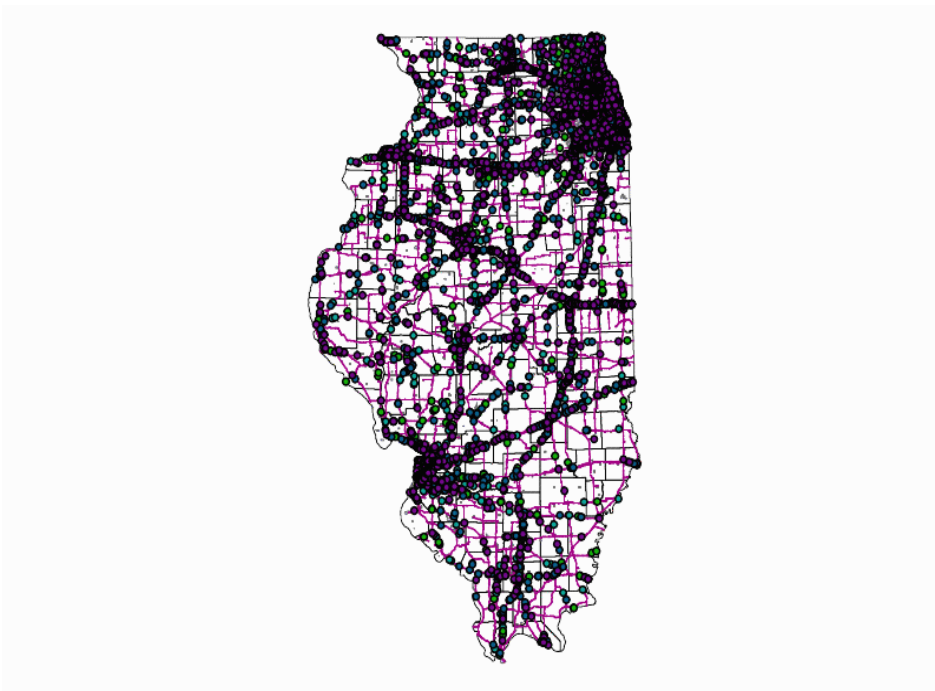


Figure 4-5: Crashes Involving Guardrails from 2005-2009

Knowing that systems like this exist or are in development bodes well for the potential commercialization of the HDPE rail. The overall impact of this information is that determining “high crash areas” (Ray, 2009) is a real possibility, therefore determining the true market for the technology is also possible.

#### *4.1.10 Regulation Standards*

The next aspect we needed to learn from the DOT’s was the standards that the guardrails needed to adhere to in order to warrant consideration for installation. While there has been some preliminary testing done on the HDPE rail, the testing needed to commercialize this technology would be far more advanced.

Learning from our interviews with the state DOT’s and our meetings with Dr. Ray, we knew that guardrails must adhere to certain safety criteria, found in the NCHRP Report 350. Looking at the

particulars of the two mandated tests, we learned that they measured three “dynamic performance evaluation factors: 1) structural adequacy, 2) occupant risk, and 3) post-impact vehicular response” (NCHRP Report 350, 1993). Individually these factors touch on various aspects that need to be passed.

First, “structural adequacy may be satisfied by redirecting the impacting vehicle, by stopping the vehicle in a controlled manner, or by permitting the vehicle to break through the device. The structural adequacy criteria refer to specific requirements associated with the impact itself. The structural adequacy does not include external loads such as snow, ice, or other environmental elements” (NCHRP Report 350, 1993). The second factor of occupant risk is a major component in passing the NCHRP Report 350.

*Occupant risk depends largely on the crashworthiness of the impacting vehicle. To the extent possible, the variability of vehicular crashworthiness has been removed from the safety feature design and external structural design of the test. Detachment elements and fragments from the test article should not penetrate or show the potential for penetrating the occupant compartment or present undue hazard to other traffic, pedestrians, or workers. It is not practical to establish absolute limits on the test article debris scatter or barrier displacement. An example of why limits do not need to be established would be that the debris traveling over another lane could pose a threat whereas the same debris on a single side road poses no threat. They just report trajectories so that the user agencies can make an assessment of the appropriateness of the safety features for individual application (NCHRP Report 350, 1993).*

Still concerning occupant risk testing, the key requirement for evaluation on this criterion is that the vehicle remains up right during and after the crash. In some cases a small amount of rolling will be acceptable. Another assessment factor of occupant risk is done through response testing of what the Report 350 refers to as “a hypothetical unrestrained occupant.” Analyzing the response of this

unbuckled crash test dummy, is done through measuring “the lateral and longitudinal component of the occupant’s velocity at an impact with the interior surface. This is taken by the highest lateral and longitudinal component of the resultant vehicular acceleration averaged over any 10-m/s interval for the collision pulse which was subsequent to the occupant impact” (NCHRP Report 350, 1993). This test is seen as very valuable as information regarding Theoretical Head Impact Velocity, Post Head Deceleration, and the Acceleration Severity, can be gathered and analyzed.

The third factor of post-impact vehicular response is also an important aspect of the testing. An aspect of this section, vehicular trajectory hazard, “is a measure of the potential of the post-impact trajectory of the vehicle to cause a multivehicle accident” (NCHRP Report 350, 1993). What the testing of this aims to determine is where the final position of the vehicle will be following an accident or collision with the rail. “It is preferable that the vehicle trajectory and final stopping position intrude the minimum if at all into adjacent or opposing traffic lanes” (NCHRP Report 350, 1993). A subsequent aspect of this looks at the manner in which the colliding vehicle is absorbed and redirected by the rail. “It is also preferable that vehicles be smoothly redirected, which is typically indicated when the exit angle is less than sixty percent of the impacting angle” (NCHRP Report 350, 1993). In addition to this, a rail may pass this aspect if the vehicle is stopped while the “vehicle-barrier contact is maintained”, assuming the relevant criteria mentioned above is also satisfied.

In addition to the dynamic performance evaluation factors, there are fourteen criteria labeled A through N.

*A) The test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable. B) The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding. C) Acceptable test article performance may be by redirection,*

*controlled penetration, or controlled stopping of the vehicle. D) Detached elements, fragments, or other debris from the test article should not penetrate or show the potential for penetrating the occupant compartment, or present an undue hazard to the other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusion into, the occupant compartment that could cause injuries should not be permitted. E) Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle. F) The vehicle should remain upright during and after the collision although moderate rolling, pitching, and yawning are acceptable. G) It is preferable, although not essential, that the vehicle remain upright during and after the collision. H) The occupant impact longitudinal velocity should be between nine and twelve m/s and the lateral velocity should be between three and five m/s. I) The occupant ride-down acceleration should be between fifteen and twenty G's in both the longitudinal and lateral directions. J) Optional. K) After the collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. L) The occupant impact velocity in the longitudinal direction should not exceed twelve m/s and the occupant ride-down acceleration in the longitudinal direction should not exceed twenty G's. M) The exit angle from the test article preferably should be less than sixty degrees of the impact angle, measured at the time of vehicle loss of contact with the device. N) Vehicle trajectory behind the test article is acceptable (NCHRP Report 350, 1993).*

Every guardrail in use in the United States must meet or surpass each of these fourteen criteria.

Should a European company show interest in the HDPE guardrail, they would have to pass the EN 1317 standards. These are similar to the NCHRP Report 350, and in many cases, if NCHRP testing had already been successfully completed, there is no need for EN1317 (Ray, 2009).

Understanding that the regulations for these tests are specific in nature, we found that individual departments of transportation subscribe to some other standards. Not all DOT's develop their own standards for guardrail warranting, but some, such as Massachusetts, do. According to Lisa Schletzbaum, the Commonwealth of Massachusetts, subscribes to the "Massachusetts Highway Department Project Development and Design Guide, and the AASHTO Roadside Design Guide" (Schletzbaum, MA DOT Interview, 2009). This is not uncommon for states to have their own standards

outside of the nationally recognized standards set in place for guardrails by the NCHRP Report 350. The majority recognize the secondary standards mentioned above, as the American Association of State Highway and Transportation Officials (AASHTO) guidelines in addition to any standards their state develops. The state of Washington “develops policies that are incorporated to the WSDOT Design Manual. Much of this policy is a reflection of AASHTO guidance...In addition, WSDOT is involved with new barrier developments through involvement with other states and committees on a national level that influences our policy development” (Erikson, WA DOT Interview, 2009). The similarities between AASHTO and NCHRP Report 350 are very evident, though not identical.

Overall, NCHRP 350 and AASHTO Roadside Design Guide have different functions. The AASHTO Roadside Design Guide is meant to give engineers acceptable ranges for designs that would still adhere to highway standards. The Report 350 spells out the specific standards designs must meet and offers criteria on how to test designs to see if they meet the standards. AASHTO Roadside Design Guide is not a legally enforced document, the NCHRP Report 350 is applied by law. This was never the case until 1991, when Congress made it mandatory for every state in the U.S. to have uniform highway safety standards (Hansen, 2009). This led to the Federal Highway Administration (FHWA) commissioning Report 350 as the set of standards that must be met by all states (Hansen, 2009).

#### *4.1.10.1 MASH*

In an effort to standardize measures of performance which guardrails in the United States must meet, the Manual for Assessing Highway Safety Features or MASH is in development to replace the NCHRP Report 350. This test calls for two major changes to the Report 350. The changes would include setting a minimum limit to the length of wire rope test rails and changing the impact energy levels on guard rail systems (Hansen, 2009). Looking at the first change to be made, the reasoning behind it is that without a minimum length of rail to test, the system can be tested at a shorter length, which would

make it stronger and thus would hide deficiencies in actual sized rails (Hansen, 2009). MASH looks to set a minimum test length of 600 feet for all wire rope safety systems (Hansen, 2009). Looking at the second major change, MASH looks to change the impact energy levels on rail testing through increased weight of test vehicles, increased impact angles, and increased impacting speed (Artimovich, 2008). The following crash test criteria will change: the small car impact angle will change from 20 degrees to 25 degrees, TL-4 truck speed will change from 80 km/hr to 90 km/hr, small car weight will increase from 1800 pounds to 2200 pounds, pickup truck weight will increase from 4400 pounds to 5000 pounds, TL-4 truck weight will increase from 17,600 pounds to 22,000 pounds, and the test will no longer be run with any vehicles over 6 years old (Hansen, 2009). These changes have the potential to make current guardrails archaic as they have not been previously tested to these standards.

## **4.2 Potential Cost Savings**

### *4.2.1 Maintenance Savings*

Taking into consideration that this HDPE guardrail is planned to grasp two to three percent of the entire guardrail market it is necessary to calculate potential savings as a percentage of the total maintenance costs. Since it is not clear as to the exact percentage of the market that the HDPE guardrail can ultimately seize, it makes sense to project maintenance savings over a range of different market share percentages. Table 4-6, Table 4-7, Table 4-8, and Table 4-9 display the total maintenance savings, for the given years and assumed market percentage (e.g. 1%, 2%, 4%, 6%, and 10%), that the DOT's for the states of Iowa, Nevada, and Michigan presumably would have saved if the HDPE guardrail was installed.



Table 4-6: - Iowa DOT Savings per Market Share Percentage

FY	Market Percentage				
	1%	2%	4%	6%	10%
2008	\$6,439	\$12,878	\$25,756	\$38,634	\$64,391
2007	\$6,226	\$12,452	\$24,905	\$37,357	\$62,262
2006	\$6,060	\$12,121	\$24,241	\$36,362	\$60,603
2005	\$5,094	\$10,188	\$20,377	\$30,565	\$50,942
2004	\$6,529	\$13,057	\$26,114	\$39,172	\$65,286
2003	\$4,883	\$9,766	\$19,532	\$29,299	\$48,831
2002	\$4,256	\$8,511	\$17,022	\$25,534	\$42,556
2001	\$4,488	\$8,975	\$17,950	\$26,926	\$44,876
2000	\$4,636	\$9,271	\$18,542	\$27,813	\$46,356
1995	\$4,536	\$9,072	\$18,144	\$27,216	\$45,360
1990	\$3,195	\$6,390	\$12,780	\$19,171	\$31,951
1985	\$1,811	\$3,622	\$7,243	\$10,865	\$18,108

Table 4-7: Nevada DOT Savings per Market Share Percentage

FY	Market Percentage				
	1%	2%	4%	6%	10%
2008	\$4,175	\$8,350	\$16,699	\$25,049	\$41,748
2007	\$3,467	\$6,934	\$13,868	\$20,803	\$34,671
2006	\$3,694	\$7,388	\$14,777	\$22,165	\$36,941
2005	\$2,720	\$5,439	\$10,879	\$16,318	\$27,197
2004	\$2,524	\$5,048	\$10,096	\$15,144	\$25,240
2003	\$3,010	\$6,019	\$12,038	\$18,057	\$30,095
2002	\$2,760	\$5,520	\$11,040	\$16,559	\$27,599
2001	\$1,681	\$3,362	\$6,725	\$10,087	\$16,811
2000	\$2,388	\$4,776	\$9,551	\$14,327	\$23,878

Table 4-8: Michigan DOT Savings per Market Share Percentage

FY	Market Percentage				
	1%	2%	4%	6%	10%
2008	N/A	N/A	N/A	N/A	N/A
2007	8,297	16,595	33,190	49,785	82,974
2006	8,691	17,382	34,764	52,146	86,910
2005	5,977	11,953	23,907	35,860	59,767
2004	9,900	19,801	39,602	59,403	99,004
2003	7,025	14,050	28,099	42,149	70,248
2002	5,517	11,034	22,068	33,101	55,169
2001	5,370	10,741	21,481	32,222	53,703
2000	5,921	11,842	23,683	35,525	59,209
1999	4,973	9,947	19,894	29,840	49,734

Table 4-9: Michigan DOT Savings per Market Share Percentage (Contracted Maintenance)

FY	Market Percentage (Contracted Maintenance)				
	1%	2%	4%	6%	10%
2008	N/A	N/A	N/A	N/A	N/A
2007	17,672	35,344	70,688	106,032	176,720
2006	22,938	45,877	91,753	137,630	229,384
2005	20,942	41,885	83,770	125,655	209,424
2004	20,275	40,549	81,099	121,648	202,747
2003	20,565	41,129	82,259	123,388	205,647
2002	18,000	36,001	72,002	108,002	180,004
2001	15,836	31,673	63,346	95,019	158,365
2000	15,745	31,490	62,979	94,469	157,448
1999	12,140	24,279	48,558	72,837	121,395

4.2.2. Life Cycle Cost Savings

Preliminary testing shows that the HDPE guardrail has the ability to “sustain about five or six crashes with little or no repair” (Ray, 2009). For this reason we can then divide the total cost savings the HDPE guardrail will eliminate by six hits. We cannot gather information as to whether or not five to six crashes will occur on the same guardrail section within the same year, therefore this could further over-inflate the value of the HDPE guardrail in a year.

Nonetheless, using FY 2008 as an example we find that if the HDPE guardrail will hold one percent, two percent, four percent, six percent, or ten percent of the total guardrail market then as a result we project that Iowa DOT will save (on a six hit life cycle) an average of \$1,073, \$2,146, \$4,293, \$6,439, and \$10,731; respectively per collision. Similarly if the same computation is done for the state of Michigan’s DOT maintenance division for FY 2007 we find that an average savings of \$1,383, \$2,766, \$5,532, \$8,298, and \$13,829 would result per collision. In simpler terms, “if we suppose that it takes on average \$1,000 to repair damage to a typical strong post W-Beam guardrail then implementation of

HDPE guardrail would avoid \$5,000 to \$6,000 of life cycle repair costs. For this reason it is believed that the best place to utilize the HDPE guardrail is in locations where there is a high likelihood of crashes and/or many repeat crashes” (Ray, 2009). Table 4-10, Table 4-11, Table 4-12, Table 4-13, and Table 4-14 illustrate the savings per vehicle collision into a guardrail for the state of Iowa, given the stated market percentages. Tables for other states can be found in the appendix.

**Table 4-10: Iowa DOT Maintenance Savings for 1% of Market**

<b>Maintenance Savings over a six hit life cycle (1%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$1,073	\$2,146	\$3,220	\$4,293	\$5,366	\$6,439
2007	\$1,038	\$2,075	\$3,113	\$4,151	\$5,188	\$6,226
2006	\$1,010	\$2,020	\$3,030	\$4,040	\$5,050	\$6,060
2005	\$849	\$1,698	\$2,547	\$3,396	\$4,245	\$5,094
2004	\$1,088	\$2,176	\$3,264	\$4,352	\$5,441	\$6,529
2003	\$814	\$1,628	\$2,442	\$3,255	\$4,069	\$4,883
2002	\$709	\$1,419	\$2,128	\$2,837	\$3,546	\$4,256
2001	\$748	\$1,496	\$2,244	\$2,992	\$3,740	\$4,488
2000	\$773	\$1,545	\$2,318	\$3,090	\$3,863	\$4,636
1995	\$756	\$1,512	\$2,268	\$3,024	\$3,780	\$4,536
1990	\$533	\$1,065	\$1,598	\$2,130	\$2,663	\$3,195
1985	\$302	\$604	\$905	\$1,207	\$1,509	\$1,811

**Table 4-11: Iowa DOT Maintenance Savings for 2% of Market**

<b>Maintenance Savings over a six hit life cycle (2%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$2,146	\$4,293	\$6,439	\$8,585	\$10,732	\$12,878
2007	\$2,075	\$4,151	\$6,226	\$8,302	\$10,377	\$12,452
2006	\$2,020	\$4,040	\$6,060	\$8,080	\$10,101	\$12,121
2005	\$1,698	\$3,396	\$5,094	\$6,792	\$8,490	\$10,188
2004	\$2,176	\$4,352	\$6,529	\$8,705	\$10,881	\$13,057
2003	\$1,628	\$3,255	\$4,883	\$6,511	\$8,139	\$9,766
2002	\$1,419	\$2,837	\$4,256	\$5,674	\$7,093	\$8,511
2001	\$1,496	\$2,992	\$4,488	\$5,983	\$7,479	\$8,975
2000	\$1,545	\$3,090	\$4,636	\$6,181	\$7,726	\$9,271
1995	\$1,512	\$3,024	\$4,536	\$6,048	\$7,560	\$9,072
1990	\$1,065	\$2,130	\$3,195	\$4,260	\$5,325	\$6,390
1985	\$604	\$1,207	\$1,811	\$2,414	\$3,018	\$3,622

Table 4-12: Iowa DOT Maintenance Savings for 4% of Market

Maintenance Savings over a six hit life cycle (4%)						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$4,293	\$8,585	\$12,878	\$17,171	\$21,464	\$25,756
2007	\$4,151	\$8,302	\$12,452	\$16,603	\$20,754	\$24,905
2006	\$4,040	\$8,080	\$12,121	\$16,161	\$20,201	\$24,241
2005	\$3,396	\$6,792	\$10,188	\$13,585	\$16,981	\$20,377
2004	\$4,352	\$8,705	\$13,057	\$17,410	\$21,762	\$26,114
2003	\$3,255	\$6,511	\$9,766	\$13,022	\$16,277	\$19,532
2002	\$2,837	\$5,674	\$8,511	\$11,348	\$14,185	\$17,022
2001	\$2,992	\$5,983	\$8,975	\$11,967	\$14,959	\$17,950
2000	\$3,090	\$6,181	\$9,271	\$12,361	\$15,452	\$18,542
1995	\$3,024	\$6,048	\$9,072	\$12,096	\$15,120	\$18,144
1990	\$2,130	\$4,260	\$6,390	\$8,520	\$10,650	\$12,780
1985	\$1,207	\$2,414	\$3,622	\$4,829	\$6,036	\$7,243

Table 4-13: Iowa DOT Maintenance Savings for 6% of Market

Maintenance Savings over a six hit life cycle (6%)						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$6,439	\$12,878	\$19,317	\$25,756	\$32,195	\$38,634
2007	\$6,226	\$12,452	\$18,678	\$24,905	\$31,131	\$37,357
2006	\$6,060	\$12,121	\$18,181	\$24,241	\$30,302	\$36,362
2005	\$5,094	\$10,188	\$15,283	\$20,377	\$25,471	\$30,565
2004	\$6,529	\$13,057	\$19,586	\$26,114	\$32,643	\$39,172
2003	\$4,883	\$9,766	\$14,649	\$19,532	\$24,416	\$29,299
2002	\$4,256	\$8,511	\$12,767	\$17,022	\$21,278	\$25,534
2001	\$4,488	\$8,975	\$13,463	\$17,950	\$22,438	\$26,926
2000	\$4,636	\$9,271	\$13,907	\$18,542	\$23,178	\$27,813
1995	\$4,536	\$9,072	\$13,608	\$18,144	\$22,680	\$27,216
1990	\$3,195	\$6,390	\$9,585	\$12,780	\$15,976	\$19,171
1985	\$1,811	\$3,622	\$5,432	\$7,243	\$9,054	\$10,865

Table 4-14: Iowa DOT Maintenance Savings for 10% of Market

Maintenance Savings over a six hit life cycle (10%)						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$10,732	\$21,464	\$32,195	\$42,927	\$53,659	\$64,391
2007	\$10,377	\$20,754	\$31,131	\$41,508	\$51,885	\$62,262
2006	\$10,101	\$20,201	\$30,302	\$40,402	\$50,503	\$60,603
2005	\$8,490	\$16,981	\$25,471	\$33,961	\$42,452	\$50,942
2004	\$10,881	\$21,762	\$32,643	\$43,524	\$54,405	\$65,286
2003	\$8,139	\$16,277	\$24,416	\$32,554	\$40,693	\$48,831
2002	\$7,093	\$14,185	\$21,278	\$28,371	\$35,463	\$42,556
2001	\$7,479	\$14,959	\$22,438	\$29,917	\$37,397	\$44,876
2000	\$7,726	\$15,452	\$23,178	\$30,904	\$38,630	\$46,356
1995	\$7,560	\$15,120	\$22,680	\$30,240	\$37,800	\$45,360
1990	\$5,325	\$10,650	\$15,976	\$21,301	\$26,626	\$31,951
1985	\$3,018	\$6,036	\$9,054	\$12,072	\$15,090	\$18,108

#### 4.2.3 Economic Cost Savings

As previously stated by the Colorado DOT, it is far more likely for a maintenance worker to receive normal work injuries due to ergonomic reasons rather than a fatality occurring. However, the opportunity still exists for a fatality to take place, therefore avoidance of fatalities can significantly decrease the economic costs that motor vehicle crashes impose on society. In the most current statistical analysis performed by the National Highway Traffic Safety Administration it was estimated that the cost of motor vehicle crashes that occurred in 2000 totaled \$230.6 billion. To give an idea of how staggering this figure is, it is enough money to provide every person living in the United States approximately \$820 each. \$230.6 billion corresponds to the present value of lifetime economic costs for 41,821 fatalities, 5.3 million non-fatal injuries, and 28 million damaged vehicles. Component costs of that amount include medical costs, market production, EMS costs (i.e., medical, police, and fire services), court and legal costs, travel congestion costs, workplace costs, insurance administration costs, household production cost, and property damage costs (Blincoe et al, 2002).

According to their latest available data, the National Highway Traffic Safety Administration's technical document entitled "The Economic Impact of Motor Vehicle Crashes, 2000" (Blincoe et al, 2002):

- The lifetime economic cost to society for each fatality is over \$977,000. Over 80 percent of this amount is attributable to lost workplace and household productivity.
- Each critically injured survivor costs an average of \$1.1 million. Medical costs and lost productivity accounted for 84 percent of the cost for this most serious level of non-fatal injury.
- Lost workplace productivity costs totaled \$61 billion, which equaled 26 percent of the total costs. Lost household productivity totaled \$20.2 billion, representing 9 percent of the total costs.
- Total property damage costs for all crash types (fatal, injury, and property damage only) totaled \$59 billion and accounted for 26 percent of all costs.
- **Property damage only crashes** (in which vehicles were damaged but nobody was injured) were the most costly type of crash, due to their very high rate of occurrence. Their costs totaled \$59.8 billion and accounted for 26 percent of total motor vehicle crash costs.
- Present and future medical costs due to injuries occurring in 2000 were \$32.6 billion, representing
- 14 percent of the total costs. Medical costs accounted for 26 percent of costs from non-fatal injuries.
- Travel delays cost \$25.6 billion or 11 percent of total crash costs.
- Approximately nine percent of all motor vehicle crash costs are paid from public revenues. Federal revenues accounted for six percent and states and localities paid for approximately three percent. Private insurers pay approximately 50 percent of all costs. Individual crash victims pay approximately 26 percent while third parties such as uninvolved motorists delayed in traffic, charities, and health care providers pay about 14 percent. Overall, those not directly involved in crashes pay for nearly three-quarters of all crash costs, primarily through insurance premiums, taxes and travel delay. In 2000 these costs, borne by society rather than by crash victims, totaled over \$170 billion.

Using similar metrics as those stated above, the Automobile Association of America (AAA) points out in a 2008 report that the Federal Highway administration values the per-person cost of traffic fatalities in dollars to be \$3.2 million and \$68,170 for injuries. AAA estimates the cost of traffic accidents to be \$166.7 billion (AAA, 2009).

Not only are crash victims affected by vehicle collisions, but in many instances friends and relatives, employers, and society bear the brunt of an accident as well, whether directly or indirectly. An accident runs the risk of losing any potential benefit whether it is money, time, or any resource for that matter. For example, travel delay is a cost in terms of forgoing the opportunity to use that same time spent in other more productive activities. While travel delay costs cannot be fully eliminated, the possibility of cutting these delays and reducing the congestion due to guardrail repair by a significant amount is a byproduct of not having to repair and replace the guardrail as frequently. Medical costs are borne by the individual crash victim through insurance payments and uninsured expenses. Costs are also borne by society through workers compensation, increased insurance premiums, and the diversion of medical resources away from other medical needs, such as medical research, disease prevention and control, and basic public health needs. There are also significant costs associated with the lost productivity experienced by an individual and others when the victim dies prematurely or experiences a short or long-term disability. The victim's dependents suffer immediate economic hardship in the loss of the victim's income and other contributions; society also suffers by the necessity to support the victim or their dependents and through foregone contributions to the nation's productivity.

While not all the costs mentioned above will go away with the implementation of HDPE guardrails, notable costs that will improve (due to less exposure for maintenance crews) are medical costs, market production, EMS costs (i.e., medical, police, and fire services), and workers compensation costs.

#### *4.2.4 Value of Life Cost Savings*

Aside from the external costs and factors that raise an issue as a result of a crash, a substantial part is related to the more serious concern of fatal accidents and how we assess and value the quality of life aspect. The value of statistical life (VOSL), or cost of life estimation, is a grey area that has no

definitive solution because agencies differ on the wide array of approaches to calculate this number. Placing a price on a human life is no easy task. Nevertheless, many agencies often attempt to determine a figure in order to ascertain a quantifiable measure of how much they are actually saving in their efforts to avoid fatalities. Although new related coefficients for preventing injuries of varying degrees of severity have yet to surface, the Federal Highway Administration has determined that the best current estimate for the value of a human life is worth \$5.8 million. This \$5.8 million is a revised adjustment of the comprehensive external costs of \$6.1 million per fatality, which can be found in Table 4-15. The difference between the comprehensive value and the revised figure is a reflection of a recent change in the value of a statistical life specified in guidance from the Office of the Secretary of Transportation. The HDPE guardrail reduces the risk and opportunity in which lives can be compromised as it would lessen the need to have maintenance personnel on duty. This is an aspect that would be horrible for the victim's family and also expensive for workers compensation purposes.

Table 4-15: Value of Statistical Life

CPI	Factor	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1.346066	Medical	\$3,204	\$21,032	\$62,585	\$176,747	\$447,509	\$29,741
1.204077	EMS	\$117	\$255	\$443	\$999	\$1,026	\$1,003
1.277512	Market Prod	\$2,234	\$31,960	\$91,283	\$135,977	\$560,451	\$760,577
1.277512	Household Produce	\$731	\$9,354	\$26,924	\$35,782	\$190,743	\$244,696
1.204077	Ins. Adm.	\$892	\$8,319	\$22,749	\$38,934	\$82,114	\$44,695
1.277512	Workplace	\$322	\$2,495	\$5,450	\$6,002	\$10,464	\$11,117
1.204077	Legal	\$181	\$5,998	\$19,034	\$40,559	\$96,153	\$122,982
1.277512	Travel Delay	\$993	\$1,081	\$1,201	\$1,276	\$11,697	\$11,687
1.204077	Property Damage	\$4,628	\$4,761	\$8,187	\$11,840	\$11,374	\$12,369
1.277512	QALYs	\$9,118	\$186,525	\$262,189	\$784,777	\$2,674,628	\$4,889,799
New Comprehensive Costs		\$22,420	\$271,780	\$500,045	\$1,232,893	\$4,086,149	\$6,128,666
Injury Subtotal		\$16,799	\$265,938	\$490,657	\$1,219,777	\$4,063,088	\$6,104,610
QALY Relatives		0.0019	0.0381	0.0536	0.1605	0.5470	1.0000



## 4.3 Financial Analysis

### *4.3.1 Comparative Pricing*

After determining customer needs, guardrail standards, as well as if there were appropriate and functional process in place which would optimize HDPE guardrail implementation, we conducted a comparative price analysis between the HDPE and current steel guardrail options. This process was long and arduous as the guardrail industry was not forthcoming with vital information that would aide us in this comparison. Another difficulty surrounded the HDPE technology itself. Since it had only been developed on a small scale, using those material costs may not provide a good estimation of materials costs in quantity. Also, because the HDPE guardrail had never been produced in a factory or elsewhere, the price of production was not readily available. To make our way around these roadblocks we developed tactics that would allow us to create a broad estimation of numbers and costs.

Although Trinity was not willing to give us costs for their guardrail systems, ten other companies within the industry responded to our request. Averaging the cost per foot of, Highway Safety Corp., GSI Highway Products, Adarand, Lake Erie Construction Company, Jenson Bridge, Hawkins Traffic Safety, JMHP Inc., Fensco Inc R.G. Steel Corp., and Connecticut Galvanizing Corp., we came up with an average selling price per foot of \$12.46 (See Figure 4-6)

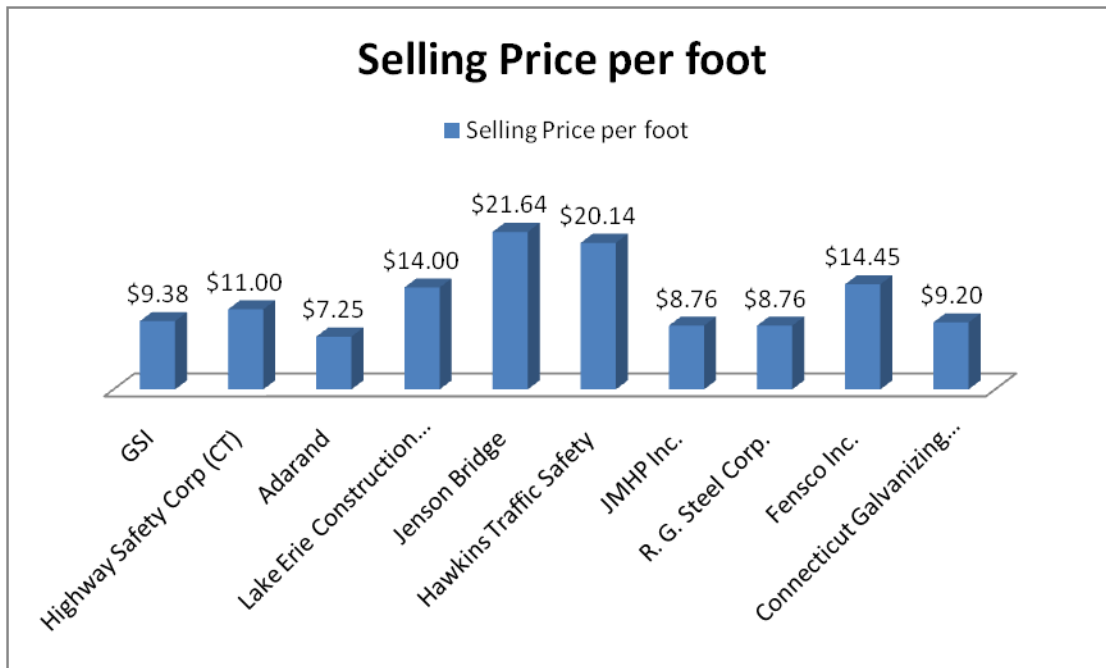


Figure 4-6: Selling Price per Foot for ten Guardrail Companies

Although we attempted to discover the manufacturing costs associated with this number, none of these companies provided that information. Furthermore, none were publicly traded and therefore would not have public SEC documents, specifically a 10-k or annual report. Because this information was lacking, we looked back to Trinity in an attempt to gain some form of cost associated with making steel guardrails. Unfortunately we were unable to determine these numbers as our contact at the company told us “I don't believe you will find any manufacturer who will give you breakdowns of his incremental costs of labor, overhead, SEA, and raw material on any product” (Johnson Interview, 2009). In order to get around this issue, and because Trinity is a publicly traded company, we looked at their most recent 10-k report in an attempt to analyze costs of production and revenue on a per foot basis.

This analysis was conducted as follows:

Trinity Industries Guardrail Breakdown:

Corporate:

Sales	\$ 3,880,000,000.00
Corporate Gross Profit	\$ 792,000,000.00
Gross Profit Percentage	20%

Looking at the entire corporate finances we see that they enjoy at 20% gross profit percentage. But understanding that Trinity is a multifaceted company we narrowed our analysis to look at the sector of the company which dealt with guardrails, the Construction Products Group. The analysis for this was as follows:

Construction Products Group (CPG)

Sales	\$ 741,200,000.00
CPG Gross Profit	\$ 58,200,000.00
Gross Profit Percentage	8%

The value of this brief comparison shows us that the CPG sector of Trinity is not representative of the company as a whole. While the gross profit (GP) of the corporation is 20% of the sales, GP of CPG is only eight percent.

Delving into these numbers we see that the CPG represents, ( $\$741,200/\$3,880,000,000$ ) or 19% of the overall revenues of the company. However, CPG only accounts for seven percent ( $\$58,200,000/\$792,000,000$ ), of the overall profit for Trinity. With this we can assume that there must be other higher margin groups or sectors within the organization. Nevertheless, Trinity's 10-k report breaks down the company numbers by division. Because of this we can still use the numbers given to us from the report.

Within the CPG there are several groups and product categories. The group of interest for this project is Highway Products. Analyzing the financial figures from Highway Products (HP), we learn:

Highway Products (HP)

HP Sales	\$ 284,100,000.00
Total CPG Sales	\$ 741,200,000.00

Being that HP represents a substantial portion of total CPG sales, it is reasonable for us to believe that HP follows the overall profitability of CPG at eight percent.

Using this, and the previous selling price per foot average we calculated (\$12.46/ft), we can establish that within Trinity, the gross profit per foot of guardrail is found by:

$$\$12.46 \times .08 = \$1.00$$

This yields a cost per foot of steel guardrail in Trinity of \$11.46 (\$12.46 - \$1.00).

This calculation is based on several assumptions, and we fully understand that it may not be representative of the actual costs. However, given what we were able to ascertain from Trinity, as well as the information generously supplied to us from the other industry companies, the number is as justifiable as we could make it. One of the questions associated with this is what is Trinity reporting in the Cost of Revenues line item in the 10K? While Trinity accounts for "Selling, engineering, general and administrative" costs, and subtracts this number from their gross profit to generate their net income, they do not identify specific costs associated with those general terms. We must assume that in their Cost of Revenue line, they account for more than simply material and labor. The issue is that other costs would only be known as insider information and confidential, simply information we cannot gather unless offered to us.

Even with these assumptions, the numbers generated by this analysis appear to be reasonable. While originally, a \$1.00 profit per foot seems low, bear in mind that these are sold in 12'6" and 25' sections, and ordered in miles at a time (Johnson Interview, 2009). Perhaps this justifies the large cost for small profit. Overall, we can determine from this that steel guardrails are low technology, high volume, commodity type products that are not very profitable.

Applying these findings to the HDPE guardrail is not a simple task. We know that this guardrail is a high technology, low volume, specialty product, which is only seen as applicable in two to three percent of the guardrail market (Ray, 2009). Because of these differing characteristics, we used our benchmarking comparison to gain better insight into what the costs associated with the HDPE rail may look like.

#### *4.3.2 Benchmarking Analysis*

Through interviews with William Lyons III and Matthew Lyons, formerly of Blackstone Medical Incorporated, as well as John Kirwan of Incite Innovation, we gained insight into the medical device field. While the comparisons between the guardrail industry and medical devices are very loose at best, the HDPE product fits in with some characteristics associated with new products in the medical device industry. Categorically, Blackstone Medical was a "very high in margin and low in volume, medical business that generally carried huge gross profit, in large part because our Research and Development expense was quite large" (W. Lyons Interview, 2009). Looking at the HDPE system in this light, it is a new technology that still needs to be highly tested to be certified, the potential benefits of it must be determined, and it will be sold at low volume, thus the comparison between the HDPE technology and medical devices can be made with some amount of confidence.

Assessing the potential costs for the HDPE system, we must take into account the markup that it will have tied to it. Looking at the steel rail calculation and seeing that \$1.00/ft is the profit made, we can assume that this is a low number due to the high volume. Matthew Lyons told us that at Blackstone

Medical, “a 2x markup was usually the minimum as we had to cover high Research and Development costs” (M. Lyons Interview, 2009). With the similar characteristics, and low volume sales that can potentially associated with the HDPE rail, we can assume that there will be much more than a \$1.00/ft profit margin. At Incite Innovation, President John Kirwan expressed to us that they will not even consider taking on a new product development process unless, “the potential acquisition value is higher than the development costs...To project these costs we look at similar products that have been developed and launched in the market. Incite looks to at least double the investment we’ve made in development” (Kirwan Interview, 2009). With this in mind, and taking into account the acquisition costs of the technology, required testing costs, and manufacturing/production cost, the potential selling price for the HDPE rail will be much higher on a per foot basis than current steel guardrails.

## **4.4 Cost Comparison**

### *4.4.1 Steel Cost per Foot*

We had previously calculated the cost per foot of steel guardrail for Trinity Highway Products to be \$11.46, with costs consisting of materials, manufacturing, labor, and selling. Assuming that the manufacturing, labor, and selling costs would be similar for the HDPE guardrail, we had to determine a material cost per foot for steel guardrail.

Without being able to call on industry numbers, we undertook a lengthy process of determining the price per foot of steel on a standard W-beam guardrail. We found the average thickness of steel on the W-beam to be 3.5mm (B2B Trade, 2009), or 0.1377 inches. Finding this number was the beginning of a long calculation process.

The only price for steel which we had was from The Steel Index Reference Prices, which placed galvanized steel at \$635 per short ton (The Steel Index, April 2009). Looking further, we determined

that one short ton is equivalent to 2,000 pounds (Ton Conversion, 2009). Using simple arithmetic we calculated that cost of steel per pound to be:

$$\frac{\$635}{2000 \text{ pounds}} = \$0.3175 = \$0.32 \text{ per pound}$$

There is no pound to foot conversion, and because of this we looked to Isaac Ridler Butt's, *The Tinman's Manual And Builder's And Mechanic's Handbook*, in an effort to calculate a pound per foot for the steel guardrail. This book placed a ¼ inch thick, one inch in length piece of steel sheet at 0.852 pounds (Butt, 2008). Using this we could then calculate the pound per inch of the aforementioned steel guardrail with 0.1377 inch thickness through the use of a simple ratio and using the cross multiplication process of arithmetic and geometry:

$$\frac{\text{quarter inch thick section}}{\# \text{ of pounds in a 1 inch length quarter thick section}} = \frac{\# \text{ of inches in a standard W-Beam rail}}{\# \text{ of pounds in a 1 inch length of standard W-beam rail } (x)}$$

$$\frac{0.25 \text{ inches}}{0.852 \text{ pounds}} = \frac{.1377 \text{ inches}}{x} \rightarrow .25x = (0.1377) (0.852) \rightarrow 0.25x = 0.117 \rightarrow x = 0.469 \text{ pounds}$$

$$\frac{1 \text{ inch}}{0.469 \text{ pounds}} = \frac{12 \text{ inches (1 foot)}}{\# \text{ of pounds in a foot } (x)} \rightarrow x = (12) (0.469) = 5.6 \text{ pounds in 1 foot}$$

Using this pound per inch calculation for the sheet of steel 0.1377 inches thick, we were able to extrapolate this to the price per pound calculated before. Multiplying the price per pound by the

number of pounds in a foot we calculate the amount per foot of a standard W-Beam steel guardrail to be:

$$\$0.32 \times 5.6 \text{ pounds in a foot} = \$1.79 \text{ per foot}$$

#### *4.4.2 HDPE Cost per Foot*

Attempting to compare the calculated price per foot of steel guardrail options to the HDPE guardrail was no easy task. This difficulty stems from the fact that this guardrail has never been manufactured in bulk, and because of this, any direct cost associated with the technology can only be determined from the materials needed. With no other pricing information other than the Archambault et al. MQP report, we attempted to gain prices from HDPE distributors and extrapolate these to the dimensions of the HDPE rail. This was a wildly unsuccessful process for our group. Not only did we struggle to gain actual responses from the HDPE distributors, but those we did have contact with did not give us viable pricing information.

In an attempt to work around this impediment, we looked to our conversations with Dr. Ray. Understanding that the price of HDPE is largely tied to the price of petroleum (Ray, 2009), we attempted to look at historical prices for petroleum. Knowing that the previous MQP report was conducted and submitted in March 2007, we believed that finding a petroleum price from that time period and the current price would give us somewhat of a read on the accuracy of the MQP pricing.

Gathering petroleum or “crude oil” pricing on a per week basis from the Energy Information Administration, the official energy statistics from the United States government, we calculated the per month average price for petroleum from the previous MQP submission in March 2007, and compared this to the current prices for April 2009 in the United States. These calculations are shown in Table 4-16**Error! Reference source not found.:**



Table 4-16: Petroleum Price Comparison, March 07 vs. April 09

	U.S. Petroleum Prices (\$)					Monthly Average
	Week 1	Week 2	Week 3	Week 4	Week 5	
2007-Mar	55.18	55.53	54.39	54.02	58.08	\$55.44
2009-Apr	47.51	48.85	49.06	46.67		\$48.02

Looking at the monthly averages we see that the average price per barrel has decreased by \$7.42. Taking into consideration the possibility of peaks and valleys in terms of crude oil price, using the current price per barrel is the best estimate of the crude oil market. When calculating this average and using it in order to perform a direct comparison, we operated with the understanding that “There is simply no reason to believe that mere mortals can foretell oil prices or petroleum market shares in the future, absent some sort of time machine” (Taylor and Van Doren, 2008). With this we recognize that there can be severe spikes in the price per barrel of this resource, as well as declines.

In their 2007 MQP report, Archambault et al, placed the HDPE guardrail at \$200.16 per meter (Archambault et al 2007). We know that there is 3.2808399 feet in one meter. Converting this material cost into feet (\$200.16/ 3.2808399), we found that it cost \$61.01 per foot for materials to construct the HDPE rail as of March 2007. Having this number, along with the current average price per barrel, allowed for us to estimate a present day cost to construct the HDPE rail through the use of a direct ratio. These calculations were as follows:

$$\frac{\text{Average Price Per Barrel, March 2007}}{\text{Calculated Cost per Foot to Construct HDPE Rail}} = \frac{\text{Average Price Per Barrel, April 2009}}{\text{Current Cost per Foot to Construct HDPE Rail}}$$

$$\frac{\$55.44}{\$61.01} = \frac{\$48.02}{\$X}$$

Solving for “\$X” through cross multiplication we found that using these numbers the current cost per foot to construct the HDPE Rail on pure materials is:

$$\$61.01 \times \$48.02 = \$55.44(\$X)$$

$$\$2929.70 = \$55.44X$$

$$\$2929.70 \div \$55.44 = \$X$$

$$\$X = 52.85 \text{ per foot}$$

Looking at this cost per foot for HDPE materials, we see that it is actually \$8.16 (\$61.01 - \$52.85) cheaper in material cost per foot, than what had been previously calculated in March 2007 (\$61.01). Nevertheless this cost is still significantly higher than the cost per foot of steel guardrail materials (\$1.79/ft).

If we assume that the HDPE manufacturing, labor, and selling costs are similar to those that are incurred in the steel guardrail process, we must add \$9.67 per foot (steel per foot selling price average (\$12.46) – calculated per foot profit (\$1.00) – calculated material cost per foot (\$1.79) = \$9.67). With this addition, we calculate a cost per foot of HDPE guardrail to be \$62.52 before sales markup. As stated before it is our belief that the markup practice for the HDPE rail will have to be larger than the \$1.00 per foot of steel guardrail. While it is clearly understood that the medical device industry and the guardrail industry are fundamentally different, the benchmarking practice allowed us to determine that this high technology, low volume (2-3 percent of guardrail market), specialty product would not follow the same profit scheme as the commodity product it would replace. It is also feasible to believe that the selling

costs for this new technology would be higher, but that would only be information which Trinity would have to determine as they attempt to make the new product known.

We understand that in order for the HDPE guardrail to succeed the market has to covet it, as well as be willing and able to pay for it. Although the HDPE guardrail appears to have a relatively high price tag, it can enter the market by being a disruptive technology. Typically a disruptive technology improves a product by having a low price or is designed to push up-market toward higher-end customers (Christensen, 2002). The HDPE guardrail will be sold at a premium price but it can still disrupt the market because customers will be attracted to the idea that the enhanced functionality of the HDPE guardrail over the current steel guardrails can recoup the initial losses of paying the premium price.

#### 4.5 Pricing Strategy

Due to the fact that there are no similar products in the guardrail market, competitive parity pricing strategy is not an option for the HDPE rail. The strategy that this MQP will look at in an attempt to determine a selling price per foot for the HDPE guardrail, is Cost-Plus pricing. Out of the three pricing strategies for market entry (competitive parity, cost plus, value pricing), cost plus is the only strategy for which we could create estimates. As stated above, there is not a competitive product of this nature in the market that is a self-restoring guardrail. The value pricing would have to be determined by the company, as they surveyed and determined a price based on the theoretical and actual value the product would have for their customers. This leaves cost plus pricing as the remaining option in an attempt to determine possible selling prices for the HDPE rail. The basic equation for this method of pricing is seen below (Dolan, 1995)

$$\text{Cost to make} + X\% \text{ of Cost to make (markup)} = \text{SellingPrice}$$

Operating under the premise that the HDPE will not follow the same pricing plan as the steel guardrail options, we must look at the percentage markup associated with the steel rail. If we take our

calculated average selling price per foot of \$12.46 and calculated profit per foot at Trinity Industries of \$1.00 we can find the cost plus percentage that the steel guardrails follow.

$$\frac{\text{Profit Per Foot (markup)}}{\text{Calculated Selling Price Per Foot}} = \text{Cost Plus Markup Percentage}$$

$$\frac{\$1.00}{\$12.46} = .0802$$

What this tells us is that the steel guardrails are marked up by eight percent of their material, manufacturing, labor, and selling costs. Using this number we believe that applying the cost plus method to the HDPE rail, we must apply more than eight percent of costs to calculate the expected selling price.

**Error! Reference source not found.** shows various scenarios for applying the cost plus method to the HDPE material, manufacturing, labor, and selling costs:

**Table 4-17: Cost Plus Pricing**

Cost per Foot of HDPE=	\$62.52								
X%	10%	15%	20%	25%	30%	35%	40%	45%	50%
% of Cost	\$6.25	\$9.38	\$12.50	\$15.63	\$18.76	\$21.88	\$25.01	\$28.13	\$31.26
Cost + X%	\$68.77	\$71.90	\$75.02	\$78.15	\$81.28	\$84.40	\$87.53	\$90.65	\$93.78

Assuming that the HDPE rail must be priced at a higher percentage of than the steel rail options, the minimum price Trinity could charge would be \$68.87 per foot. It must be stated again that this number was determined under a large set of assumptions that needed to be made due to the various barriers associated with obtaining necessary information. This number also does not take into account increased selling costs associated with bringing the HDPE rail into the market. Ultimately the percentage markup would have to be determined by Trinity themselves as they set a target profit for this product.

As noted earlier, preliminary tests place the HDPE rail lifecycle at six times longer than the steel guardrail options. That is the HDPE rail will maintain its shape and effectiveness through being hit six times, while the steel rail is compromised after being hit only one time. Analyzing the monetary benefit of implementing the HDPE guardrail in high crash areas, we must look at a crash by crash comparison to see where the breakeven point will be, if the HDPE is priced at our calculated minimum. This analysis is shown in Table 4-18:

**Table 4-18: Steel vs. HDPE Crash by Crash Comparison**

<b># of Impacts</b>	<b>Steel Cost/ft</b>	<b>HDPE Cost/ft</b>	<b>Price Per Foot Difference</b>
0	\$12.46	\$68.87	(\$56.41)
1	\$24.92	\$68.87	(\$43.95)
2	\$37.38	\$68.87	(\$31.49)
3	\$49.48	\$68.87	(\$19.39)
4	\$62.30	\$68.87	(\$6.57)
5	\$74.76	\$68.87	\$5.89
6	\$87.22	\$68.87	\$18.35

What this analysis tells us is that implementing the HDPE guardrail will yield monetary benefits for the end users (state DOT's) only after the specific section of guardrail has been hit and replaced five times. Until that point, any benefits associated with the HDPE guardrail are purely complementary from not having repair and maintenance, and potential injury costs for the end users as mentioned in previous sections of this paper. While confusion may arise from comparing the per foot cost of the HDPE system to per foot cost for the steel guardrail the auxiliary elements of steel guardrail systems are often made from the same material, therefore the same costs will apply.

## 5 Conclusions and Recommendations

This project has attempted to determine if a commercial opportunity exists for Dr. Malcolm Ray's High Density Polyethylene guardrail system. To gather data to conduct this study, we used secondary research in the form of literature and standards analyses, and primary research in the form of interviews with both end users and industry experts and industry companies. As not all the data we needed were available, we developed a set of assumptions and executed a set of calculations to determine the cost of a foot of the HDPE guardrail and its comparative value to steel. This section will summarize our conclusions and provide recommendations for moving forward with this technology.

### 5.1 Industry Infrastructure

In order for the HDPE rail to be considered, it had to be determined if implementing the technology in the previously defined "high crash areas representing two to three percent of the market" (Ray, 2009), was feasible. Through our end user contacts and survey interviews, we were able to ascertain the process by which accidents in specific states were cataloged. Within this process it was determined that so long as the reporting officer of the accident scene, when filling out the specific accident report, marks the box which signifies that a section of guardrail has been hit and compromised, a database exists for this information to be pulled up. This information allowed for us to assume that if states wanted to implement this technology, they would be able to determine where their "high crash areas" were on an individual basis. Some of our contacts accessed this information for their state during the course of this project as mentioned in the findings section of this paper.

This development was of paramount importance, as it allowed us to conclude that if this technology was adopted in the industry or Trinity's line of products, the market for which it would be applicable could be determined.

Recommendation: To refine our analysis, Trinity Industries or other potential licensees will need to exercise their contacts to get more complete data.

## 5.2 Determining HDPE Value to the Customer

A major aspect of an innovative technology is determining the value it brings to the customer. One aspect of value that is commonly focused on is the idea of lowering the price of the product while not sacrificing the quality, or vice versa (Carlson, 2006). When discussing any product, the price of that product is a major component of the value it can or cannot bring. The HDPE material used to make this new guardrail is more expensive than the current steel prices, and for this reason its value is not seen from a reduced price standpoint. However, the unprecedented feature of the HDPE rail is that it can restore itself upon impact, on up to six different occasions.

This feature is where the overwhelming value of this technology lies. Implementing the HDPE rail allows for the possibility of severe reduced installation, maintenance, repair, and replacement costs, which have been calculated in the findings section. It is important to recognize that these savings would only occur in areas which the HDPE rail was implemented, and would only be brought into play if the section of guardrail was in fact hit. These savings are not guaranteed but are implied and expected, due to the installation of the rail in high impact or high crash areas.

Subsequent value aspects of this technology all stem from this improved lifecycle when compared to the steel rail options. Because it can maintain shape and function after multiple impacts, supplementary benefits are allowed to be assumed. However, as calculated in the findings section, material costs saving aspects that can be associated with the HDPE rail are only seen after the specific section of rail is hit for the fifth time. The implications of this are that the state may not see the savings of implementing the HDPE rail, on a pure material basis for an extended period of time. While the states

do track when a section of guardrail has been hit and compromised, none of the information we received showed specific sections of guardrails being struck or replaced five times.

Recommendation: Prospective licensees will need to utilize their cost and pricing structures to determine a more specific comparative value of HDPE to steel.

### **5.3 Drawbacks of HDPE System to the Customer**

Staring this harsh reality in the face, it will be extremely hard for the material HDPE price to overcome the hefty difference it has in comparison to the hot dipped galvanized steel. While the saving costs which can be associated with its implementation can be large in overall number (cost of human life, incarceration costs, costs associated with repair, maintenance, transportation, and replacement), they are largely theoretical. Our end user surveys have indicated to us that highway workers safety and potential costs associated with human life are very minimal, if there are any at all. These findings showed that the vast majority of documented injuries of highway workers occurred during basic highway maintenance and included sprains and other simple injuries. Installing the HDPE rail would not fully alleviate the potential for these injuries.

As mentioned above, no information we have gathered or been supplied with indicates that enough areas and sections of guardrails exist, which will be struck enough times for the saving aspects of the HDPE implementation to be seen quickly. While the potential savings that could be seen from implementing the HDPE system are very attractive from a customer point of view, the reality that these aspects are far from guaranteed make the HDPE system much less appealing.

### **5.4 HDPE Implications for Trinity Industries**

If Trinity were to negotiate with WPI and obtain a licensing agreement for the HDPE guardrail technology, they would have to incur several costs in any attempt to bring it to the market. These costs



would include royalties which would need to be negotiated during the technology transfer process (Manning Interview, 2009). Trinity would also have to incur costs associated with the HDPE guardrail gaining NCHRP 350 approval. As stated earlier in this paper, this requires the rail to pass two tests, which will total a minimum investment of \$100,000 (Johnson Interview, 2009). Due to the overall size of the Trinity as a corporation, this cost would not be something to cause Trinity to back away, however, other aspects of bringing the HDPE guardrail to the market make this a difficult decision.

Trinity must account for increased production and material costs associated with the HDPE material. They must also attempt to project how this product will be received in the market. Understanding that if this product was added to the Trinity portfolio, in theory for each individual section of the HDPE guardrail Trinity sells, it will sell six fewer sections of steel rail. While the net revenue will be increased initially because of the higher price of HDPE, over the longer term there will not only a net reduction in revenue and the distribution of sales will be different. Trinity must account for these changes in their sales and budget models. Also Trinity must decide if heavy investment is warranted for a product that is only projected to capture “two to three percent of the market” (Ray, 2009). Trinity’s return on their initial investment may not be seen for several years based on the adoption of the new technology to the market. To increase the rate of adoption, Trinity would have to sink further funds into the technology and its promotion, highlighting its benefits, and justifying its high cost (Hall and Khan, 2003). Offering a high price, low volume product, with uncertain returns, and a high initial investment, presents a tough case for Trinity to take on this technology.

Don Johnson from Trinity sums up the possibility of taking on the HDPE guardrail as very slim due to its high cost per foot when compared to the steel options. Mr. Johnson states “A premium cost factor of 2 (times steel price options) would be hard to overcome; a premium factor of 5 to 6 pretty well

eliminates the system from any serious consideration by the user, no matter what specialized limited use application may be found for it” (D. Johnson Interview, 2009).

## 5.5 Other Recommendations

At this point in time we cannot recommend that Trinity take on this technology. The associated cost factors, as stated by our contact in the company itself, are simply too much risk to take on. This does not mean that in the future this technology will not be a viable option for commercialization. Several potential factors and happenings could make the HDPE technology much more attractive.

If the price of petroleum were to drop, causing the price of HDPE materials to drop along with it, the overall price of the HDPE rail would also drop. Depending on the significance of this drop, the HDPE technology could become closer to the price of the steel options, making it an extremely viable option. This would also be true if the price of steel were to rise, closing the price gap between the two respective options.

Another recommendation we have is for the inventors and designers of the technology to look into the design. Can this guardrail be made without using as much HDPE material? If so will it still hold the same characteristics and abilities to reform? Could a second material be added into the HDPE to make this design more cost effective, yet just as attractive based on function? We cannot answer these questions, however, investigation by those closely associated with the rail design may lead them to some conclusions about these questions.

We also recommend that the HDPE guardrail undertake further preliminary testing. If tests are conducted that measure the HDPE rail’s ability to lessen crash severity based on force absorption, among other aspects, the attractiveness of the rail can be taken to a new level. However, without those tests all benefits of that nature are purely speculative and cannot be quantified. With solid numbers showing these auxiliary benefits, assuming the tests show them to be true, further in depth analysis of

cost saving features associated with these benefits can be carried out. We note that this benefit, if it exists, will need to be promoted to a coalition involving NHTSA, state DOTs, and auto insurance companies.

It may also be beneficial for both Dr. Ray and WPI to look at other suitors outside of Trinity Industries. While we recognize and respect the relationship between Dr. Ray and Trinity, it does not seem viable for a company with such a large share of the market to undertake projects that will not make a significant monetary impact. However, smaller companies looking for a niche product to offer to the market may have a much larger interest in it. These companies may not currently be in the guardrail industry, however, they may be in the plastics molding industry, or simply companies interested in new and exciting technology. These companies may be able to further develop the technology and find techniques that would enable the HDPE rail to be manufactured in a less expensive manner. During the course of this project several companies, such as Nucor Corporation and Nypro Incorporated, have expressed interest in the HDPE design and specifics, however, at the wishes of Dr. Ray we did not pursue these options.

Overall it is our belief that if several of these recommendations are undertaken there can be a place within the guardrail marketplace for the HDPE guardrail. The end users we spoke to were all very intrigued by the possibility of a self-restoring guardrail. The intrigue is present in the market, and the infrastructure and processes are in place to show the benefits potentially associated with the HDPE rail. Further development, potential changes in design, potential changes in factors associated with pricing, and investigating other company opportunities could all lead to the commercialization of the HDPE rail.

## 6 Bibliography

Abbott, W. (2009, March 16). Nevada DOT Interview. (J. Kirkland, Interviewer)

Administration, E. I. (n.d.). *Petroleum Navigator*. Retrieved April 25, 2009, from <http://tonto.eia.doe.gov/dnav/pet/hist/wtotusaw.htm>

Archambault, B., Bridge, J., Fragachan, R., & Kelly, K. (2007). *Design of an HDPE Guardrail*. Worcester: Worcester Polytechnic Institute.

Association, R. M. (2007, February 28). *Crash Costs and Statistics*. Retrieved February 15, 2009, from Rocky Mountain Insurance Information Association: [http://www.rmiia.org/Auto/Traffic\\_Safety/Cost\\_of\\_crashes.htm](http://www.rmiia.org/Auto/Traffic_Safety/Cost_of_crashes.htm)

*Benchmarking*. (n.d.). Retrieved April 18, 2009, from Dictionary.com: <http://dictionary.reference.com/browse/benchmarking>

Blincoe, L., Seay, A., Zaloshnja, E., Miller, T., Romano, E., Luchter, S., et al. (2002). *The Economic Impact of Motor Vehicle Crashes, 2000*. Washington D.C.: U.S. Department of Transportation.

Burns, M. (2009, March 10). Connecticut DOT Interview. (J. Kirkland, Interviewer)

Butts, I. R. (2008). *The Tinman's Manual And Builder's And Mechanic's Handbook*. Fabri Press.

Byers, T., Kist, H., Sutton, R. I., Mason, T. W., Demmler, L. F., Gompers, P. A., et al. (2000).

Entrepreneurship and New Ventures. *Technology Management Handbook*. Boca Raton, Florida: CRC Press, LLC.

Christensen, C. M. (2003). *The Innovator's Dilemma*. New York: HarperCollins, Inc.

Conard, R. (2009, February 17). Crash Coding. (W. Lyons, Interviewer)

Cook, D. (2009, March 19). Florida DOT Interview. (W. Lyons, Interviewer)

DOT, M. (2005, June). Benefit-Cost Analysis for Transportation Projects. Minnesota, United States.

Erikson, R. (2009, March 23). State of Washington DOT Interview. (W. Lyons, Interviewer)

Focke, D. (2009, March). Ohio DOT Interview. (B. Szpyrka, Interviewer)

Gagne, A., Gagnon, D., Ray, E., & Tsantoulis, R. L. (2006). *Design of an HDPE Crash Cushion*. Worcester: Worcester Polytechnic Institute.

Gates, T. J., & Noyce, D. A. (2005). *The Safety and Cost-Effectiveness of Bridge-Approach Guardrail for County State-Aid (CSAH) Bridges in Minnesota*. St. Paul: Minnesota Department of Transportation.

Hainsworth, G. (2009). Delaware DOT Interview. (B. Szpyrka, Interviewer)

Hale, T. (2009, March). New York DOT Interview. (B. Szpyrka, Interviewer)

Hall, B. H., & Khan, B. (2003). *Adoption of New Technology*. Berkeley: University of California, Berkeley.

Heskett, J., Sanderson, S., Usumeri, M., Cooper, R., Smith, R., Banbury, C., et al. (2000). Product Management. *Technology Management Handbook*. Boca Raton, Florida: CRC Press, LLC.

Holt, J. (2009, March 9). Tennessee DOT Interview. (J. Kirkland, Interviewer)

Hyde, J., & Engel, P. T. (2000). *Lifecycle Assessment Study Guardrail Offset Blocks: Recycled Plastic, Steel, and Pressure-Treated Wood Blocks*. Chelsea: Chelsea Center for Recycling and Economic Development.

Index, T. S. (n.d.). *The Steel Index*. Retrieved April 27, 2009, from <http://www.thesteelindex.com/?lng=en>

Infoplease. (n.d.). *Metric and U.S. Equivalents*. Retrieved April 27, 2009, from Infoplease:  
<http://www.infoplease.com/ipa/A0001661.html>

International, S. (n.d.). *Innovation: The Five Disciplines for Creating What Customers Want-- A New Book by SRI President and CEO Curt Carlson*. Retrieved from <http://www.sri.com/about/innovation-book.html>

IV, W. L. (2009, April 25). Benchmarking. (W. L. III, Interviewer)

Johnson, D. (2009, February 26). Guardrail Industry Interview. (W. Lyons, J. Kirkland, & B. Szpyrka, Interviewers)

Kennedy, W. (2006). *So What? Who Cares? Why You?: The Inventor's Commercialization Toolkit*. Ottawa: Wendykennedy.com Inc.; 1st edition (January 2006).

Kirwan, J. (2009, April 14). Incite Innovation. (W. Lyons, Interviewer)

Lambert, J. H., Baker, J. A., & Peterson, K. D. (2003). Decision Aid for Allocation of Transportation Funds to Guardrails. *Accident Analysis & Prevention, Volume 35, Issue 1*, 47-57.

Lyons, M. (2009, April 8). Comparative testing. (W. Lyons, Interviewer)

Manning, M. (2009, February 17). Technology Transfer. (W. Lyons, Interviewer)

Marshall, D. (2009, March). Kansas DOT Interview. (B. Szpyrka, Interviewer)

Matthews, K., Wieder, D., & Nakao, K. (2009, March 24). Colorado DOT Interview. (W. Lyons, Interviewer)

Office of Design, I. (1997). *Shielding Side Obstacles*. Ames: Iowa Department of Transportation.

Otterness, T., & Donithan, T. (2009, February 20). Arizona DOT Interview. (W. Lyons, Interviewer)

Piper, D. (2009, April 6). Illinois DOT Interview. (W. Lyons, Interviewer)

Products, T. H. (n.d.). *Trinity Highway Products*. Retrieved March 20, 2009, from highwayguardrail.com:  
<http://www.highwayguardrail.com/products/heart.html>

Razgaitis, R. (2003). *Valuation and Pricing of Technology-Based Intellectual Property*. New York: Wiley.

(2009, March). Rhode Island DOT Interview. (B. Szpyrka, Interviewer)

Ross, H. E., Sicking, D. L., Zimmer, R. A., & Michie, J. D. (1993). *National Cooperative Highway Research Program Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Washington: National Academy Press.

Roy, J. (2009, March 19). Guardrail Pricing. (W. Lyons, Interviewer)

Rys, M. J., & Russell, E. R. (1997). *Use of Guardrails On Low-Volume Roads According To Safety And Cost Efficctiveness*. Topeka: Kansas Department of Transportation.

Schletzbaum, L. (2009, March 20). Massachusetts Highway Dept. Interview. (W. Lyons, Interviewer)

Schlicher, J. W. (1996). *Licensing Intellectual Property: Legal, Business, and Market Dynamics*. New York: Wiley.

Torres, C. (2009, March 10). Michigan DOT Interview. (J. Kirkland, Interviewer)

Trade, B. (2009). *W Beam Crash Barriers/Guardrail,Safety Barriers*. Retrieved April 23, 2009, from B2B Trade: [http://www.b2btrade.biz/leads\\_137444/](http://www.b2btrade.biz/leads_137444/)

White, T. (2009, March 18). Federal Highway Administration Interview. (W. Lyons, Interviewer)

Younie, B., & Pawlovich, M. (2009, March 12). Iowa DOT Interview. (J. Kirkland, Interviewer)

## 7 Appendix A: Interviews

### A1: Department of Transportation Interviews

#### Guardrail Survey Questionnaire:

1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?
2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?
3. What are the greatest drawbacks of the guardrails currently in use by the DOT?
4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?
5. Are you satisfied with the current guardrail options? If not, what improvement can be made to meet these deficiencies and better satisfy your desires?
6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?
7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)
8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?
9. What standards does your agency employ to determine if guardrail is warranted?
10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?
11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?



**Iowa DOT- Interview with Bob Younie and Michael Pawlovich:**

**1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?**

The Iowa DOT obtains most of the guardrail through construction projects that are done by contractors who are awarded projects through a competitive bidding process. Department designers prepare plans and specify the type and location for guardrail installations. The guardrail work is usually just a minor part of a bigger project that includes a broad range of work to be done. The attached file "Iowa DOT 2008 Contract Prices" reflects the departments guardrail price experience on those construction projects.

The file "qryGuardrail08" below tabulates the description, unit-price and quantity of guardrail repair parts bought by the department's Office of Purchasing for use in guardrail repairs made by field maintenance staff in 2008. Some repair items were purchased locally by maintenance forces and are not reflected in the file.

The references in both documents to "RE-12" and other similar identifiers are for a specific type of guardrail installation. You can find more information on this at the Iowa DOT's web site:

<http://www.iowadot.gov/projectdev/manual.html>

Within the web-site, click on the following for general guardrail design information:

- Road Design
- Design Manual
- Chapter 8
- Section 8B-1

Within the web-site, click on the following for specific guardrail design information:

- Specifications
- Electronic Reference Manual
- Start Here (just hover)
- October 21, 2008 (or any date you wish)
- Standard Road Plans
- RE



Iowa DOT 2008  
Contract Prices.pdf



qryGuardrail08.pdf

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

Guardrail must be crash tested and appropriate for the condition that requires guardrail. The DOT's Design Manual (link previously provided) provides further information.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

Time and cost to maintain.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year?**

See attachment; the information is from the department's Maintenance Management System. More years are available if needed.



Iowa DOT - Guardrail  
Repair.xls

**5. Are you satisfied with the current guardrail options?**

**If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

**6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

We have as part of our crash reporting form a possibility for indicating striking of guardrails. It is a simple enough exercise to pull the data indicating guardrail strikes out of the crash dataset.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

The Iowa DOT has not had injuries or deaths from department guardrail maintenance activities. Many maintenance activities are done on off-peak times using lane closures in order to provide a safe work zone.

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)?**

**Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

**9. What standards does your agency employ to determine if guardrail is warranted?**

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

The Iowa DOT's design staff adopts an aggressive position on construction projects relative to keeping old guardrail installations updated to current standards. So, old installations are either updated or removed and replaced with a guardrail system that meets current design standards.

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

Chris Poole, Roadside Safety Engineer - Methods Section - Office of Road Design, is available to review your guardrail presentation. Chris is the department's guardrail expert and is very knowledgeable about guardrail systems and their use. The Road Design Methods Section is responsible for updating road design standards and design details.

Chris Poole  
Roadside Safety Engineer  
Iowa DOT  
515-239-1864  
[chris.poole@dot.iowa.gov](mailto:chris.poole@dot.iowa.gov)

**Tennessee DOT- Interview with Joe Holt:**

**1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?**

We Contract all guardrail repair and installation. This office prepares contracts for bids.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

Typically would be the lowest bid meeting specifications.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

Expense and it can be unforgiving to vehicles that impact it.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year?**

That would be hard to find. I could give you a good estimate of total dollars spent.

**5. Are you satisfied with the current guardrail options?**

They seem to work fairly well.

**If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

If you could come up with a safe way to capture the vehicle impacting the guardrail instead of throwing it back into traffic.

**6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

We do collect accident data so repeat accident sections could probably be extracted.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

I think this would be available.

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)?**

We have thresholds in our contracts which tie down some of the other instances for repairing guardrail (when not destroyed).

**Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

I think there is work order data that you might be able to use.

**9. What standards does your agency employ to determine if guardrail is warranted?**

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

Total upgrade due to being out of standard are not financially feasible. We do upgrade end terminals to current standards as a practice.

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

We would not normally investigate new guardrails until they have passed the appropriate crash test required by the FHWA.

## Connecticut DOT- Interview with Monique Burns:

**1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?**

Yes. Project Engineers develop the engineers estimate and then processing reviews it form compliances with specs etc. and our contract unit puts all the boiler plate info for bidders together and advertises the project.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

We have a variety of guiderail systems that can be used based on deflection, warrant, grading, speed of road etc. (Refer to CTDOT Highway Design Manual Chapter 13 at the following web address <http://ct.gov/dot/cwp/view.asp?a=2288&Q=300688&dotNav=|> ) The designer stipulates the system being used in the project using a pre-established item number and unit cost and the contractors all bid on that item.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

We have a good number of systems we could use which in and of itself is a good thing. But, the drawback is that each location has to be looked at individually, Thus creating on any length of road a variety of systems to maintain. Not one product fits all locations.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year?**

**5. Are you satisfied with the current guardrail options?**

Real world application would be helpful.

**If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

Most often systems are developed that are proprietary which is a major problem, then it doesn't have simple repair or installation, then it doesn't have simple crash worthy ends and transitions to bridge parapet, and lastly they are often not aesthetic.

**6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

Not sure how to find it. I would go to the following web site and search for research reports performed by TRR <http://pubsindex.trb.org/default.asp?kw=roadside%20safety%20features&date1=1984&date2=2008&datetype=1&serial=&issue=&agency=&conference=&author=&terms=&code=&codename=> whatever you look to do the first thing I would ensure is that it is NOT proprietary. The next would be to break out a design by desired results. For example on an urban road the obstacle like hydrants intersecting roads and utility poles make it very difficult to install a proper

system. Cost to last longer really has no bearing. But on an interstate where the obstacles are not as many would need a generic system that minimizes cost and increases duration. Very complex question.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)?**

**Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

**9. What standards does your agency employ to determine if guardrail is warranted?**

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

We currently have a guiderail procedure found in the appendix of Chapter 13 noted in question 2.

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

That would be me.

## Michigan DOT- Interview with Carlos Torres:

### 1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?

The Michigan Department of Transportation (MDOT) has a guardrail blanket purchase order that is used by MDOT's maintenance forces for procuring guardrail. The blanket purchase order is prepared using the RFB process, and eligible bidders are able to submit bids for this contract. The document is prepared by the State of Michigan.

### 2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?

Guardrail used by MDOT has to meet all of the applicable requirements set forth in MDOT's 2003 Standard Specifications for Construction and MDOT's Standard Plan R-60 Series. MDOT's 2003 Standard Specifications for Construction is available online at the following address: <http://mdotwas1.mdot.state.mi.us/public/specbook/>

The latest version of MDOT Standard Plan R-60 is attached below.



R060g.pdf

### 3. What are the greatest drawbacks of the guardrails currently in use by the DOT?

That question is difficult to answer without comparing guardrail to other forms of barrier. In general, MDOT has a long history of working with guardrail and, in general, guardrail has performed very well in Michigan. However, guardrail is simply one form of barrier, with certain advantages and disadvantages. Other forms of barrier used by MDOT include concrete barrier and cable barrier (both low-tension and high-tension).

The greatest drawback of guardrail is maintenance, although cable barrier requires more maintenance than guardrail. Concrete barrier requires the least amount of maintenance, but is usually two to three times more expensive than guardrail.

In other words, the decision to use one form of barrier over the other is best handled on a case-by-case basis.

### 4. How much time, in man-hours, is required to maintain guardrails in a typical year?

See attachment below:



Iowa\_Mich DOT-  
Guardrail Repair.xlsx



**5. Are you satisfied with the current guardrail options?**

In general, MDOT is satisfied with guardrail. Guardrail has proven to be an effective means of shielding roadside hazards and preventing median crossover crashes.

**If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

**6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

The Department's maintenance staff might be able to identify high-impact areas. However, this information has not been published by the Department.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

Not to the best of my knowledge.

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)?**

In general, if the guardrail run consists of substandard guardrail (e.g., BCT terminal, etc.) or if guardrail in poor condition, only the damaged and/or substandard portion will be replaced. In most cases, when the Department develops a project, Department staff will review the corridor and upgrade any substandard or poor guardrail runs along that corridor. As a result, MDOT makes efforts to keep its existing guardrail up to current standards.

**Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

**9. What standards does your agency employ to determine if guardrail is warranted?**

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

Guardrail that doesn't meet current MDOT standards is usually upgraded through routine maintenance or as part of projects developed by the Department. Obsolescence, height, and updated/new standards are all valid reasons for upgrading and replacing guardrail.

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

I would be the appropriate contact person for this purpose. My contact information is listed below.

**Nevada DOT- Interview with Warren Abbott:**

**1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?**

No. The majority of our guardrail is purchased as a designed safety product in road building or widening projects. Guardrail that is already on the roads being contracted is salvaged and that is our primary source for any maintenance we have to do.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

The lowest priced product that meets our specifications and installation requirements. Our specifications and installation requirements are many; any products that meet them are qualified to be bid. (If more information is needed on our Specifications & Installations, please contact Dennis Coyle at [Dcoyle@dot.state.nv.us](mailto:Dcoyle@dot.state.nv.us) or at 775 888-7598.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

Posts and panels are heavy and cumbersome and labor intensive to replace. With the price of steel continuing to increase, replacements are expensive.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year?**

Nevada Department of Transportation has a computer based Maintenance tracking program called the Maintenance Management System (MMS) that is input by the field crews and queried in many different ways to determine costs and amounts of work done.

See attached excel spreadsheet:



NDOT Guardrail  
Repair By Maintenan

**5. Are you satisfied with the current guardrail options?**

Yes, they do the job they were designed for more often than not.

**If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

**6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense**

**in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

One of the requirements of our Maintenance Management System (MMS) is for the Supervisor of a field crew to put a location for the work he has completed. So, each time guardrail is worked on it is put in the system by task, location, labor (man power), equipment and material used.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

The Safety Engineering Division of NDOT does keep records on injuries or deaths related to working on the roadways but it isn't broken out by task.

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)?**

Functionality is the biggest factor. If it has maintained its' integrity and continues to meet Federal Safety Standards it is generally NOT replaced.

**Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

Not within NDOT that I'm aware of.

**9. What standards does your agency employ to determine if guardrail is warranted?**

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

[a] Damage, [b] dilapidation, [c] obsolescence, or [d] a change in performance requirements (such as a need to accommodate larger vehicle types).

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

We have a four person Research Division that looks at all new or different products and determines whether or not they would fit within the Standard Products List used by NDOT. They are compared using both State and Federal guidelines for the product being evaluated.

A point of contact for Nevada DOT would be Roma Clewell 775-888-7894 or [Rclewell@dot.state.nv.us](mailto:Rclewell@dot.state.nv.us).

### **Massachusetts DOT- Interview with Richard Conard:**

Here is a web link to the Mass. Police crash form (i.e. the form that police use to fill out a crash report) from the NHTSA web site that has these forms for all States.

[http://www.nhtsa-tsis.net/crashforms/Pages/state/ma/MA\\_PAR\\_02\\_2005.pdf](http://www.nhtsa-tsis.net/crashforms/Pages/state/ma/MA_PAR_02_2005.pdf)

HOWEVER, PLEASE READ THIS: The data that the RMV and MassHighway receive from the crash reports is entirely dependent on the forms and computer data entry screens being filled out correctly and completely by whoever is filing the reports and entering the data. We can only report data using whatever has been entered. Sometimes this can present a significant obstacle to us and other potential users when the data are reviewed and analyzed.

For guardrails, see First Harmful Event, Sequence of Events, and Most Harmful Event. The first is for the entire crash, and the second and third are for each vehicle involved in the crash.

**Arizona DOT- Interview with Terry Otterness and Tom Donithan:**

**1. Who in your agency, or elsewhere, has authority in the areas of funding allocation for guardrails, management of guardrail inventories, and screening of wide geographic areas for guardrail needs?**

There is no separate funding program for guardrail. It is installed with new construction or reconstruction and then maintained as constructed. Maintenance has a budget that includes funding for guardrail maintenance. When a safety feature such as guardrail is installed with new construction, it is maintained with the same design standard until another project (normally pavement preservation) in the same area is initiated. At that time, the guardrail installations may be reviewed for the need to upgrade the guardrail system. At that time, the hardware, height of guardrail, end treatments, and placement are

reviewed to determine if revisions are needed. There was separate program statewide to upgrade older guardrail installations that did not have crashworthy end treatments- this was a program initiated by the Federal Highway Administration (FHWA). Also, ADOT initiated another separate guardrail program to replace older guardrail end treatments

(Breakaway Cable Terminals) that did not meet current crash test requirements.

**2. Does your agency keep an inventory/database of all guardrail installations? If so, is there a subsequent database in which accident reports involving guardrails can be pulled up?**

This should be referred to Tom Donithan, Phoenix District Maintenance Supervisor. I am copying Tom.

Tom Donithan-

Will, ADOT is currently working on a GIS based feature inventory system that would include guardrail. Unfortunately for both of us, that inventory does not exist as of yet. As for accident data, ADOT does maintain a data base for this but tracks it by Route, Mile Post and if the accident was a non injury, injury or fatal accident. It does not track property damage.

**3. What databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses does your agency use for managing its inventory and needs for guardrail?**

None

**4. What standards does your agency employ to determine if guardrail is warranted?**

We use the AASHTO Roadside Design Guide for guardrail warrants.

**5. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

Hardware, height, placement location, end treatment.

**6. Does the Dept. of Transportation, keep a record or database of where crashes occur? Is there a way to see where the highest concentration of accidents occur? Areas in which multiple crashes happened involving the guardrail and subsequent guardrail repair or replacement?**

This should be referred to Reed Henry, the State Safety Engineer. I am copying Reed also.

## Massachusetts Highway Department- Interview with Lisa Schletzbaum:

1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?

**Guardrail refurbishment or repair contracts are procured through the bid process. Typically, the District Maintenance Division will prepare the necessary bid documents for advertisement. These contracts are usually of a "maintenance type" and do not specify locations but rather are District wide repairs. The contracts consist of various guardrail items and the locations are determined by the Resident Engineer responsible for the contract and then assigned to the Contractor.**

**(Purchase? Generally speaking, MHD does not purchase "raw" guardrail for installation by MHD forces, but rather MHD "purchases" guardrail complete in place.)**

2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?

**MHD reviews several features during the bid process including; bid price, Contractor pre-qualification, Contractor past performance, Contractor's bond rating. During the actual work MHD is looking for a.) a timely response and completion and b.) conformance to standards with any repairs/replacement or upgrades. All guardrail must conform with MHD standards (web site?)**

3. What are the greatest drawbacks of the guardrails currently in use by the DOT?

**From a maintenance point of view – guardrail end treatments are a constant maintenance issue. Guardrail end treatments close to roadway (travel way) are "soft" and are frequently in disrepair due to hit and runs (good?) and plow damage.**

**Guardrail work cannot be routinely repaired by MHD due to lack of "specialty" equipment required to do the work.**

4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?

**The District typically expends about \$500K (very general estimate) per year for contracted guardrail work. Very little repairs are conducted by State Forces. MHD has a Accident Recovery Program (ARP) which conducts numerous repairs of guardrail. The guardrail repair contractors are reimbursed via the insurance company for the person(s) involved in the incident that caused the damage.**

5. Are you satisfied with the current guardrail options? If not, what improvement can be made to meet these deficiencies and better satisfy your desires?

**Numerous median (double face thrie beam steel guardrails) are being replaced with median (concrete) barrier in an effort to improve safety (cross over) and to reduce maintenance.**



6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?

**Due to the varying means for guardrail repair, this data is not easily compiled.**

**Institutional knowledge may be a resource.**

7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)

**I am unaware of any data available. Direct communications with Contractors (who perform this type of work) is suggested. Contractor contact info can be obtained on ComPass/Business directory/by category/Construction /horiz./Fencing /Guardrail**

8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?

**Primarily, visual inspections. Guardrail that has “minor” deficiencies (rust, minor surface dents, mis alignments, etc.) are prioritized lower.**

9. What standards does your agency employ to determine if guardrail is warranted?

**The MHD Project Development & Design Guide and the AASHTO Roadside design Guide are two resources.**

10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?

**Deteriorated guardrail, non standard guardrail and the implementation of new standards are all factors. Funding is a factor as the above needs to be prioritized. Depending on the severity of the issue, guardrail upgrades may not be performed until it can be included in the scope with adjacent roadway reconstruction or resurfacing.**

11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?

**There is a protocol for new product demonstration and evaluation. The initial starting point should be with MHD Research & Materials (R&M).**

**Colorado DOT- Interview with KC Matthews, Dave Wieder, and Ken Nakao:**

**1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?**

Purchases are governed by CDOT and Colorado purchasing rules. There is a bid document released, and suppliers bid on this document. The document is prepared by the CDOT purchasing agent with input from CDOT Maintenance and Operations.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

Compatibility with our existing systems, responsiveness (timely delivery) and low bid. We are governed by the purchasing rules requiring low bid.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

Cable rails are not interchangeable, there are several different systems installed throughout the state, and the parts are not interchangeable. Metal rails, require repair after most incidents. Concrete rail - installation cost.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year?**

We don't track man-hours, just dollars spent on repair which includes wages. Estimating an average of \$30.04/hour, we spent 40,928 hours in FY 2008. To date in FY 2009 we have spent 37,868 hours. Where could I find fairly precise data on that? This is precise as it gets, from the Maintenance and Operations Branch, the MLOS coordinator.

**5. Are you satisfied with the current guardrail options?**

While we are always looking forward to new innovations, we are satisfied with our current selections of NCHRP 350 approved guardrails.

**If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

**6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

CDOT has a highway maintenance division that keeps track of damaged guardrails in the form of Damage Reports; where the damaged guardrails are located, and what section(s) of guardrail need to be

replaced. Sometimes, the the damaged guardrails are transcribed from accident reports, but most of the reports are generated from drive-by inspections, statewide.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

Is yes this is tracked as part of a larger injury database by the Risk Management section

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)?**

We replace them during construction of projects in which they lie if they do not meet current design standards, or are so worn out as to be ineffective. This is a decision by the design engineer. Our division prepares Safety Assessment reports for each project during the early stages of the design phase. As a standard comment in every report, the engineer should adjust, repair and upgrade existing guardrail to meet current standards.

**Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

Not that I am aware of.

**9. What standards does your agency employ to determine if guardrail is warranted?**

Attached are URL links leading to CDOT's guardrail standard plan sheets.

<http://www.dot.state.co.us/DesignSupport/MStandards/2006%20M%20Standards/2006%20M%20Standards%20pdfs/33%20Guardrail%20Type%203%20W%20Beam/Guardrail%20Type%203%20W%20Beam%20M-606-1%20All.pdf>

<http://www.dot.state.co.us/DesignSupport/MStandards/2006%20M%20Standards/2006%20M%20Standards%20pdfs/34%20Guardrail%20Type%207%20F%20Shape%20Barrier/Guardrail%20Type%207%20F%20Shape%20Barrier%20M-606-13%20All.pdf>

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

Factors that CDOT considers for replacing or upgrading guardrail includes guardrail height, damaged guardrail, and new guardrail standards. Usually, when a guardrail is replaced, the end terminals are also replaced.

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

You should present to the traffic section, KC Matthews can give you the contact information.

**Florida DOT- Interview with Dale Cook:**

1. We prepare a contract for competitive bid for our in-house maintenance. The contract is prepared in our office.
2. That the parts meet our specs and whoever is the low bidder.
3. I'm not aware of any drawbacks.
4. We track our in-house crew production but 80% of our routine maintenance is now done by contract so we do not have the overall man-hours.
5. Yes,
6. Don't track that information.
7. Don't track that information.
8. Through field inspections.
9. They must meet the NCHRP 350 crash test criteria.
10. Usually replace only damaged or deteriorated sections.
11. Andy Keel, Roadway Design Office. [Andy.keel@dot.state.fl.us](mailto:Andy.keel@dot.state.fl.us).

### **Federal Highway Administration- Interview with Timothy White:**

Generally, the Highway departments, either State or locals (as owners of the highways) are responsible for installing and maintaining guardrail. Massachusetts, as well as most other States, have standards for different types of guardrail that they use. The highway designers will specify which guardrail type is to be used at which location. It would vary based on left side vs. right side, anticipated impact angles, available deflection distance, whether the barrier can be struck from one side only or two sides. The steel rail “W” beam that Massachusetts uses is a very common type used by many States throughout the country.

How much it costs to maintain guardrail naturally depends on how often it is struck. Generally, most guardrail (strong posts) can take some hits without needing to be replaced and/or repaired. There is really no criteria as to how much damage can be sustained before replacement or repair is needed. In Massachusetts, the cost of repairing and/or replacing damaged guardrail is the responsibility of the vehicles operator or his/her insurance company. If the operator of the vehicle is identified by the police their insurance company is contacted by the State and charged for the cost of the repairs.

All the various guardrail types that are used throughout the country are required to be tested (by the manufacturer) and are approved for use by the FHWA (Federal Highway Administration). These approved systems are on the FHWA Safety web site.

[http://safety.fhwa.dot.gov/roadway\\_dept/road\\_hardware/nchrp\\_350.htm](http://safety.fhwa.dot.gov/roadway_dept/road_hardware/nchrp_350.htm)

Guardrail warrants are covered by the AASHTO Roadside Design Guide.

Factors that are considered for replacement or upgrade of guardrail are age, height, and generally its ability to perform as originally intended. Over time the rail may be compromised by rust, damaged by vehicle hits, and the effective height may be reduced by roadway overlays.

Guardrail standards and average bid prices for guardrail can be found on the MassHighway website.

<http://www.mhd.state.ma.us/>

## Washington State DOT- Interview with Rod Erikson:

### **1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?**

Answer: Within WSDOT we follow two processes for the purchase of guardrail. Both processes will need to follow WSDOT specifications and standards when selecting and constructing barrier systems.

#### (1) New Construction

The majority of barriers used on our highways are supplied through construction projects. The barrier needed on a project is generally presented as an individual pay item(s) within the plans, specifications, and estimates for each project as the project is developed. After a is developed, it goes out for competitive bidding and is generally awarded to the lowest qualified bidder. At this point the successful bidder will become the contractor and the contractor or designated subcontractor will purchase the needed project barrier from suppliers that provide barrier systems that meet WSDOT specifications.

#### (2) Maintenance

WSDOT maintenance personnel are able to purchase barrier from a Washington State Barrier Contract. Again, the barrier items on this contract need to meet WSDOT specifications. This type of contract is awarded to suppliers on a complete basis. The barrier items and their cost are agreed on for a designated period of time when Washington enters into a contract of this type with a barrier supplier. Additional limited items can be added to these contracts as necessary during the life of the contract.

### **2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

Answer: WSDOT develops standard or general specifications that state the requirements that need to be met when supplying a barrier system. These specifications are not based on initial cost alone.

Anticipated performance is also a very important factor that is considered in the decision making process.

### **3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

Answer: I do not of any specific drawbacks. However, WSDOT is in the process of continually improving the way we do business. For example, we are currently working on improvements to our cable barrier systems. Also, we are exploring barrier post material options using life cycle cost analysis.

### **4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?**

Answer: Maintenance expenditures for guardrail repairs are running from 44,968 to 49,635 hours per fiscal year.

### **5. Are you satisfied with the current guardrail options? If not, what improvement can be made to meet these deficiencies and better satisfy your desires?**

Answer: We are reasonably satisfied with the options we have. However, we are open to considering other options. We try our best to be aware of new developments on the local and national level that will have merit for WSDOT use. In addition, we have individuals that are involved with national research efforts to try and stay informed. Also, our staff members are involved with such groups as Task Force 13, and TRB Committee AFB20 (Roadside Safety Design).

### **6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense**

**in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

Answer: Unfortunately I am not able to obtain this information from a central data base. Local maintenance areas are responsible for the repair of barriers under their jurisdiction. In the future WSDOT would like to have a statewide barrier inventory that would help more easily track this information. To find answers to your question, local maintenance area representatives would have to compile this information and it would have to be analyzed by WSDOT researchers. Because of other priorities it is not advisable to request or engage in this type of research effort at this time.

**7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

Answer: The WSDOT safety office keeps these types of records. There were no known injuries from errant vehicle, unsecured loads etc. The injuries on record were sprains, strains, etc. that were incurred as part of the daily work activities.

**8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

Answer: To begin, WSDOT has written policy relating to the replacement of some types of older guardrail systems. In addition, WSDOT designers and maintenance personnel evaluate the general condition of existing barrier systems. Considering these factors, systems are replaced as part of contracted construction projects or by WSDOT maintenance personnel. Also, many barrier systems are replaced during roadway improvement projects that necessitate the removal of existing systems for widening, new alignments etc.

**9. What standards does your agency employ to determine if guardrail is warranted?**

Answer: We develop policy that is incorporated into the WSDOT Design Manual. Much of this policy is a reflection of AASHTO guidance found in the AASHTO Roadside Design Guide. In addition, WSDOT is involved with new barrier developments through involvement with other states and committees on a national level that influences our policy development. Attached for your information are links to applicable WSDOT policy, standards, and standard plans.

<http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/700.pdf>

<http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/710.pdf>

<http://www.wsdot.wa.gov/Design/Standards/Plans.htm#SectionC>

<http://www.wsdot.wa.gov/Design/projectdev/>

**10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?**

Answer: All of the factors mentioned above are considerations for guardrail replacement. In addition, WSDOT is involved with the roadside safety community locally and nationally. We strive to stay current with recent developments in traffic barrier testing, design, installation, and maintenance. The information we gather influences our policy development for the selection, installation, and maintenance of roadside safety hardware.

**11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

Answer: Our established process for the review of new products is currently undergoing change. I am currently the contact for new barrier products in the Design Office. If you would like, you can begin by sending me information concerning your barrier design. It will be helpful to include with this submittal analysis and crash test information. Also, if one is available include an acceptance letter from FHWA.



## Illinois DOT- Interview with Dave Piper:

1. Do you purchase guardrails through a request for bid? (RFB) process? Who prepares the document that goes out to prospective bidders?

Guardrail is generally purchased as part of construction projects, including furnishing and installing the systems. Other means of purchasing guardrail include repair contracts, which also include furnishing and installing the needed repair parts.

2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?

Guardrail is specified by IDOT under the Standard Specifications for Road and Bridge Construction and by the Highway Standards. These are available at:

<http://www.dot.il.gov/desenv/hwyspecs.html>

Guardrail is in Section 630 of the specifications, and terminal treatments are in Section 631. Related Highway Standards are those beginning with these same section numbers, 630, and 631. The latest Highway Standards are included in Revision 210 Effective 1/1/2009 at the link noted above.

Roadside Hardware is required to meet the crash testing criteria of National Cooperative Highway Research Program Report 250 (NCHRP 350). This document describes crash test conditions for vehicles, roadside hardware, impact conditions and speeds, and evaluation criteria for vehicles, occupants, and the roadside hardware. NCHRP 350 is available at:

[http://safety.fhwa.dot.gov/roadway\\_dept/road\\_hardware/road\\_policies.htm](http://safety.fhwa.dot.gov/roadway_dept/road_hardware/road_policies.htm)

Guardrail is required to meet Test Level 3.

It is also important to us that the guardrail provide a complete system, including end terminals, transitions to bridges, and parameters for use with curbs, maximum cross slopes allowable, maximum impact angles/barrier flare rates, variable post spacing for reduced impact deflection, methods for allowing posts to be skipped at shallow obstructions, design criteria near the break to steep front slopes, and so on. The guardrail system shown in Highway Standard 630001 reflects Illinois' adoption of the Midwest Guardrail System developed by a Pooled Fund Group of States and FHWA through the University of Nebraska, Midwest Roadside Safety Facility at Lincoln (MwRSF). At <http://engineering.unl.edu/specialty-units/MWRSF/> You can find some information about MwRSF.

3. What are the greatest drawbacks of the guardrails currently in use by the DOT?

There is no proven crashworthy guardrail application for a short radius application, such as is often needed at side roads or entrances, especially where a side road or entrance is near the corner of a bridge. The bridge corner scenario makes the design even more demanding as both a crashworthy radius treatment plus a transition to a rigid bridge rail are needed.

4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?

For both questions 4 and 7, I am making an inquiry to our Bureau of Operations. I think they have an annual report that will help. As with number 6, I will follow up with this information.

5. Are you satisfied with the current guardrail options? If not, what improvement can be made to meet these deficiencies and better satisfy your desires?

See 3 above.

6. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?

We are developing a Safety Datamart that would facilitate such a search. I am working to try to wring some information out of it, but the large number of crashes involved is taking a while. Rather than slow down this response, I will follow-up with this if it works out.

7. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)

8. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?

Guardrail is replaced based on its condition. This requires engineering judgment, but the main criteria is that the system be crashworthy. District Operations personnel make routine inspections of the highway system for such needs. Where damage is related to a specific crash, a claim is made against the driver

for repair of the damage to the State-owned property. Where the damage is hit-and-run, repairs are made from a line item provided in the annual program of construction funds.

9. What standards does your agency employ to determine if guardrail is warranted?

This is covered in our Bureau of Design and Environment Manual:

<http://www.dot.il.gov/desenv/bdemanual.html>

Chapters 38, 49, and 50 include roadside hardware warrants for various conditions. Chapter 38 generally applies to new construction. Chapters 49 and 50 apply for 3R (resurfacing, rehabilitation, and restoration) projects. On other lower scope projects (resurfacing only work), decisions on guardrail work are on a case-by-case basis.

10. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)?

See 9 above.

11. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?

Please start with me. I could share this with a number of contacts at IDOT. We have addressed many guardrail needs as noted in the answers above, but some important challenges remain. Changing guardrail systems is a major decision, but good information exchange is a good step for both sides.

## Ohio DOT- Interview with Dean Focke:

**1. Do you purchase guardrails through a request for bid (RFB) process? Who prepares the document that goes out to prospective bidders?**

Guardrail is purchased by the contractor for new construction, and through a prebid parts contract for maintenance and repair.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

Our parts contracts specify our standard guardrail 12 gauge W beam strong post systems based on our Construction and Materials Specifications. We rely on NCHRP and MASH crashworthiness.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

Standard w-beam is not engineered to be a barrier system, but in reality just common components which were available.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?**

I'll try to mine that data, which I'll send at a later date.

**Are they satisfied with the guardrails? If not, what improvement can be made to better satisfy them?**

Field staff would like easier systems to maintain. A lot of our staff are not as well equipped as some contractors, so they do not have the proper tools to do the job. Lighter systems are a plus.

**5. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

You are talking about Life-cycle cost, something we have a difficult time to get a handle on too. There are a lot of factors to consider to have meaningful life-cycle cost data, but state DOT's don't have the resources to calculate that data. And in Ohio, the costs could vary drastically between our various districts, due to factors like equipment, crew experience, work priorities and amount of guardrail in their jurisdiction.

**6. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

I've seen national figures for work zone accidents from ATSSA. I'd imagine they could filter out guardrail accidents.

**7. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

Ohio has Maintenance guidelines, like a percentage torn or flattened, or the number of posts or blockouts missing. These numbers however, are only numbers and not based on any meaningful research. We are waiting for NCHRP Research 22-23 to be completed for this information.

**8. What standards does your agency employ to determine if guardrail is warranted? (isn't this fairly standard?)**

We rely on the AASHTO Roadside Design Guide.

**9. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)? (is this covered in #2?)**

For pure maintenance, see answer #7. For guardrail projects, we'll look at upgrading old guardrail to NCHRP 350 standards.

**10. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

Contact Mike Bline at 614-644-1203 or at [michael.bline@dot.state.oh.us](mailto:michael.bline@dot.state.oh.us).

## **New York DOT- Interview with Terry Hale:**

### **The Bidding Process:**

Idea of generic vs. proprietary owners of technology- generic would fall under a nonexclusive patent where many companies can buy the technology, proprietary falls under exclusive patents where only one company owns the technology. NY DOT tries to avoid bidding to proprietary owners because they can charge huge prices. NY DOT offers a list of needs that can be met by many proprietary products.

### **As Far As HDPE IS Concerned:**

NY DOT would need to know if it is equivalent to steel as far as price, strength, physical properties, etc. They would need to know if this would be a weak or strong post system. They would need to know how the new system addresses the issue of tire snagging. Also, they would want to know how it stands up to environmental deterioration.

### **Other Discussions:**

We talked about what factors would be most important when deciding to purchase this new technology. The largest concern to them was price. I then asked if they would save on the long run in repair costs then would it be worth it to them, even though they would spend more initially. Terry then brought up the point that not all guardrails get hit. If this were to be setup and never hit, then it would be a loss of money because it wouldn't have incurred maintenance costs anyway. I then asked about frequent hit areas and that this could be a nice option for such hot zones. I then asked if there was a way to determine such areas. He said that this was hard information to come by as these records are usually kept on a local basis. Not only are they local, but they include damage to all roadside equipment and not just guardrails. In order to determine these hot zones, data from guardrail accidents along would have to be separated out of all the local records and then consolidated.

**Kansas DOT- Interview with David Marshall:**

**1. Do you purchase guardrails through a request for bid (RFB) process? Who prepares the document that goes out to prospective bidders?**

Yes, they do use a bid process. They bid to qualified contractors. Usually the guardrail bid is part of an over project.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

Presuming that the proper specs are met, then price is the only criteria. The proper specs fall under NCHRP Report 350 and MASH 08.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

The problem is that vehicles are constantly changing. There could be a whole new type of vehicle fleet in five years. The change in the vehicle fleet is met in updated crash test standards (MASH 08). A key component of change is the bumper height. Therefore, the problem with current guardrails is that they may become obsolete before their life cycle is done.

**4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?**

Not easily determined.

**Are they satisfied with the guardrails? If not, what improvement can be made to better satisfy them?**

Pretty satisfied with current systems, as long as it meets Report 350 standards.

**5. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

This type of data can be pulled from police reports involving guardrails that are hit. Unfortunately, this information is not open to the public.

**6. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

We do have a database for this. Contact safety engineer Steve Buckley. 785-296-1148 or 785-296-3618

**7. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are**

**supportive of benefit-cost-risk analyses relating to guardrail replacement?**

They have a maintenance manual that gives guidance on when to replace a damaged guardrail.



**Delaware DOT- Interview with Greg Hainsworth:**

**1. Do you purchase guardrails through a request for bid (RFB) process? Who prepares the document that goes out to prospective bidders?**

There are bids given out to contractors for construction projects. The contractors are free to choose the products from the manufacturer of their choice, as long as they meet given specifications.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

The Contractor must buy equipment that meets NCHRP Report 350 standards.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

No drawbacks

**4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?**

It depends on how many times the guardrails are hit. This data is not easily determined.

**5. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

Contact the safety division – Adam Weisner, 302-659-4062

**6. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

See answer 5

**7. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

See answer 5

## Rhode Island DOT Interview:

**1. Do you purchase guardrails through a request for bid (RFB) process? Who prepares the document that goes out to prospective bidders?**

Yes, the guardrail jobs are contracted out as part of an overall project.

**2. What is the Dept. of Trans. looking for when it puts out an RFB for guardrails? Are there particular features, characteristics, and/or attributes that affect the decision to purchase, or is it only a matter of price?**

RIDOT is looking to see that the contractor meets material specs, design criteria, and also looks at the installation method for required guardrails.

**3. What are the greatest drawbacks of the guardrails currently in use by the DOT?**

There are no visible drawbacks to current systems. They follow the AASHTO (NCHRP Report 350).

**4. How much time, in man-hours, is required to maintain guardrails in a typical year? Where could I find fairly precise data on that?**

They don't have the time, but they spend approximately 1.2 million dollars per year on maintenance and repairs, of which, RIDOT recoups 60% from insurance claims.

**5. One of the things we are investigating is how this new guardrail, which will be more expensive but last much longer, can save money for transportation departments. We think it makes the most sense in high impact areas where guardrails are frequently replaced because of accidents. However, we are unsure how to find such data about which guardrail sections are hit and replaced repeatedly. How can we find that information?**

They do not have a database for this information. The best place to look is the Resident Engineers of guardrail contracts.

**6. One point that has been made to us is the danger to human workers who replace or install guardrails. Are data kept on injuries and deaths to highway workers involved in guardrail replacement or installation? (Perhaps it is part of a larger state database)**

There are only data kept on death/injuries for all maintenance crews and not just guardrails.

**7. How do you determine when a guardrail section needs to be replaced (assuming it is not completely destroyed in an accident)? Are there databases, reports, methodologies, etc., that are supportive of benefit-cost-risk analyses relating to guardrail replacement?**

Generally, if the structure is compromised, they replace it.

**8. What standards does your agency employ to determine if guardrail is warranted? (isn't this fairly standard?)**

See answer 3

**9. What are the factors you consider for replacement/upgrade of guardrail (e.g. obsolescence, height, new standards, etc.)? (is this covered in #2?)**

See answer 2

**10. If someone from WPI wanted to make a presentation on this guardrail to get feedback, to whom should we present? How can I get his/her contact information?**

They do not object to a presentation.

## **A2: Guardrail Industry Interview**

### **Trinity highway Products- Interview with Don Johnson**

#### **How big is the current guardrail market?**

- It depends on what you mean. You could be referring to the guardrail itself or the guardrail with all the crash cushions and end treatments included. The answer is I don't know. The market is big, in the hundreds of millions per year range.

#### **Is it a growing market?**

- It's actually been a shrinking market in the past couple of quarters. Guardrail purchasing is a function of federal funding. Usually the federal government funds about 80-90% of the money needed for a road project and the individual state pays the other 10-20%. Even so, sometimes the states still can't come up with their share, thereby freezing the federal dollars which are waiting to be spent. Other times, the federal dollars allotted for road projects in transportation bills get contested in Washington. However, generally we believe the Obama stimulus package will turn funding back on. The last three months of 08 and 09 thus far have shown a scarce guardrail market. Also keep in mind that winter is typically the slow season for road construction projects. Summer usually picks back up. So work is not constant, but rather, it comes in spurts.

#### **Do you know any of the specifics included in the stimulus bill that would apply to road side safety?**

- It looks as if each state will be getting a substantial number of dollars for road improvement. It is then up to the states to decide where they need improvement and to then get federal approval to spend the money on it. On a side note, all the safety features such as guardrails, cushions, end treatments, etc., only make up about 5% of the cost of building a road and generally are the last thing to be done.

#### **Does Trinity manufacture guardrails?**

- We manufacture with all of our six guardrail manufacturing plants around the country. We have plants from southeast South Carolina, Kentucky, Ohio, Texas, Utah, and Mississippi.

#### **Who are other manufacturers?**

- All of our only manufacturers are typically one plant companies. Trinity is the predominant manufacturer in the country. We have several plants in order to give small contractors a localized feeling. This is practical because the subcontractors who deal with the big contractors of the road projects take more comfort in dealing on a localized basis rather than with a big national source. This use of several plants also reduces freight and increases service to the job site. Generally, each of the six plants has an adequate amount of precast guardrails and end treatments ready to be shipped at a moment's notice. Each plant is capable of delivering materials to job sites within days of an order, as subcontractors don't usually plan that far ahead. If they were not to keep guardrails in storage, they would lose out on the business opportunities with the subcontractors. Some other manufacturing companies other than Trinity are the more localized companies usually located in Ohio, Connecticut, Virginia, Utah, Texas, and Tennessee. These are small privately owned companies while Trinity is a large publicly owned conglomerate.

#### **Are the other small manufacturers tied into competitors of Trinity or are they on their own?**

- There are very few guardrail suppliers that have exclusive customers that they serve.

#### **How much of the market does Trinity own?**

- Well over two thirds

#### **What are the names of Trinity's primary competitors?**

- Kothman, Gregory Galvenizing in Ohio, Elder Lee The best way to get a list of competitors is to go on the web and type in guardrail manufacturers.

**What are the current prices on the guardrail market?**

- This is a hard number to determine. It all depends on the price of the steel at a particular point in time. Manufacturers buy their materials from steel mills, so however much the steel is worth, the price is reflected in the price the manufacturer charges to the contractors. There is a yoyo effect in that steel tends to rise really high one year and then plummets the next. So Trinity's policy is to not offer a set price for too long a period of time because they can't control the basic material. The more you can stay away from locking on a specific price, the more timeless the set of information you'll have to work with.

**Thrie-beam?**

- This guardrail is 50% taller than w-beam and 50% heavier. This is not a new product, but rather it has been around for several years. This is commonly used to transition from standard w-beam into bridges. In the thrie-beam guardrail the posts are spaced closer together for a stiffer transition. The thing that Trinity likes about the thrie-beam is that only one or two other suppliers produce this product. Of our six plants, we have two or three plants that produce the thrie-beam. The reason not all of our plants produce thrie-beam is that the demand for it is only a fraction of what it is for w-beam. Generally the length of guardrails sold is 25' or 12.5'.

**What are you looking for in order to license a technology?**

- Trinity has developed a standard approach over the years. We look for inventors and researchers to be the idea men. We do not have an R&D department. We look for bright guys with bright ideas that have a practical use. We typically look for an exclusive license. We do this because inventors usually like to know that the company which they sell their idea to is doing everything they can to put the technology into use as soon as possible and for as long as possible. This can be done in two ways. One way is for the people who invented the technology to fully develop and crash test their invention and then sell it to us for us to market. The other way is for the inventors to sell us their idea and use us to sponsor the crash testing and then market it. Trinity has undergone both processes in the past. Once you come with the HDPE design you must run it through full scale crash tests. The crash test it must pass is the NCHRP Report 350 crash test. There has also been a coming shift to the new and improved MASH 08-09 crash test. The tests average around 35-40 thousand per test. Guardrails commonly have two tests, one being conducted with a pick-up truck and the other with a small car. Factoring all costs, figure to spend about 100,000 for the two tests.

**Does the fact that there are only two test for guardrails make it more attractive to Trinity when compared with other safety products like crash cushion which have eight required crash tests of similar cost?**

- Yes in that aspect, but it would still have to be determined if there were a real need for your product in the market place as opposed to the need of a new crash cushion. Usually, in this business, the low initial cost of the product is the major selling point. Let's say that a typical guardrail costs 12 dollars per foot, and your product costs 15-20 dollars per foot. You would then have to determine why anyone would pay a premium for your product. The self restoring capabilities of guardrails, is a hot topic on the market right now. So this property could have some attractiveness due to less maintenance money spent. You will have to determine how much is spent to keep current guardrails maintained. This amount will probably vary. I kind of think that the initial cost will be enough to be a hindrance to the market even when compared to savings on maintenance costs. This will be your challenge.

**What would be the benefit to Trinity of licensing our technology?**

- Basically it would be another product to put in our arsenal. I would have to think that plastic has a much longer shelf life than steel.

**How long does it take to conduct the tests and get approval?**

- Typically with a lead time of a month or two, it shouldn't be a problem to get a test. In the U.S. the test place is in charge of the test set-up. In Europe, you must bring a contractor to set up the test.

**How are these products marketed to highway departments?**

Guardrails are typically included in a contract to rebuild a road. It goes through a bidding process at the state DOT level. The overall job is contracted out to a large contractor and from there the safety equipment is contracted of to a smaller subcontractor. The recent trend has been to outsource maintenance work. It would be in your best interest to show that your design is over the minimum accepted safety capacity without significantly increasing the cost. This would make to purchase of your system more attractive to Contractors and DOT's which are at constant risk of being sued over structural failures.

## Highway Safety Corp. - Interview with John Roy

WL: Can you tell me about standard guardrail length?

JR: Standard guardrail length by definition is 6'3", but that is simply a regulation. All sections of guardrail are sold at either 12'6" or 25". The latter is usually sold in more southern states where long stretches of highway are more commonly seen. Here in the northeast almost all sections are sold at 12'6".

WL: What is the greatest indicator of guardrail price today?

JR: The Scrap Metal Price Index is the leading indicator of steel price. A great percentage of the price of guardrails is tied to the price of steel, more so than labor.

WL: What would the typical cost of guardrails be per section?

JR: The sections of guardrails would range from \$52-60 for the guardrail and \$30-35 for posts, on a 12'6" section. For a 25' section you would be looking at \$85-90 for the guardrail and \$60 for the posts.

WL: So per foot, the cost of a complete guardrail system, including posts would be around?

JR: Between \$10-12, and sometimes ranging to \$15 on very small or tough orders. This can of course range on the SMPI (Scrap Metal Price Index), but today those are very accurate numbers.

WL: Thank you John. Would it be alright to contact you in the future if further questions about pricing came up?

JR: No problem. Contact me anytime.

### **A3: Insight from Dr. Malcolm Ray**

#### **Guidelines for talking within the Industry:**

“I don’t have a problem with you talking to either Randy or Mike Kempen **BUT I don’t want you to disclose that we are working on an HDPE guardrail and/or that we are talking to trinity**. You can tell them you are working on an MQP regarding the market potential for guardrail products in general.”

#### **HDPE guardrails reformation ability:**

“The number of impacts that HDPE can sustain is based on experiments. We did experiments where we still got 90+% restoration after six strikes. An HDPE crash cushion in the market (the REACT 350 developed by former provost Carney) has experienced similar results. HDPE has to strain a lot (and by a lot I mean 80% or more) so the HDPE essentially will not fracture. What is more likely is that the connections will fail.”

#### **Comparative Crash Testing:**

“Unfortunately, the full-scale crash tests haven't been done so it is hard to say how much more or less severe and HDPE crash would be. I think the number of crashes the system can accommodate with no or little repair is actually more interesting. To be able to use a guardrail you need the FHWA approval but they don't distinguish between performance (one is presumed to perform as well as any other that meets the test criteria). Therefore, we know HDPE guardrails can sustain at least five or six crashes and self-restore with little or no repair. So, for example, it takes on average \$1000 to repair damage to a typical strong-post w-beam guardrail using HDPE would avoid \$5000 of life-cycle repair cost. Thus, the best place to use the HDPE is in locations where there is a high likelihood of crashes and/or many repeat crashes.”

#### **Regarding the HDPE Technology In General:**

- wants to deal exclusively with Trinity Industries (TX)
- preliminary testing shows the rail restoring to 90% after six hits
- this would only be applicable in what would be called “high crash areas” which I estimate would be “two to three percent of the guardrail market”
- potential savings that could be associated with this include: costs of human life, traffic/congestion costs, repair/maintenance/replacement costs
- there is an existing patent which coincides with the WPI IP policy
- the licensing agreement for this technology would likely involve less royalties due to the high development costs
- the technology still needs to pass the two NCHRP Report 350 tests (expensive- \$50,000 ea.)
- the price of the HDPE rail will be closely tied to the price of petroleum since HDPE is a petroleum product
- implementing this rail would require entire sections to be replaced, it would not have the ability to be plugged in with the steel rails. There is also no HDPE end terminal



## A4: Benchmarking

### Incite Innovation- Interview with President John Kirwan

- 1) How does Incite go about finding new projects? (i.e. new technology development, customer needs, failing technology)

JK: Incite mainly finds potential projects through the use of what we call “Idea Generators”. These individuals are in the medical device industry, and can include individual surgeons or surgeon groups, established and independent medical device distributors, as well as medical and technical college programs.

Each of these avenues has their own take on the medical device market, which can lead to a variety of new ideas and potential products. For example surgeons are in the operating room. They know what they have, what they like, and what they need. With this point of view, they have ideas to improve on what they have in their hands, as well as new products which could make their jobs easier. From the standpoint of a distributor, they can evaluate sales patterns and determine where a need is not being met. With this knowledge they may have ideas for products which can fill a need, but may not know how to fully develop the product and get it approved for use.

- 2) Does Incite apply a formula or framework for evaluation of these projects?

JK: Absolutely. We usually start with an introductory meeting so the idea or new product can be pitched. In this meeting the idea can be as simple as a sketch on a napkin, or a full blown presentation with the potential for the product to be developed from the Idea Generators point of view.

- a. Does this formula take in to account testing costs which medical devices would need to pass in order to become commercially available?

JK: Spelled out, the evaluation process that Incite utilizes has four main criteria. These evaluation areas are: Technology, Intellectual Property, Regulatory, and Market Analysis. In Technology, we look at the potential for the idea to be developed into a full scale product. Materials and manufacturing methods are considered in this area. The Intellectual Property review is a critical aspect of the evaluation process. We conduct in depth patent searches to determine if a patent is needed, if one exists, and if there is an existing patent if we have “freedom to operate” without infringing on it. In terms of Regulatory, we look at the actual product and the potential development costs it may incur. Has there been tests run on it, or does it need to be put through a 510k or clinical study. The Market Analysis comprises of Incite looking and estimating the current and future competition, estimated return on investment, reimbursement, potential acquirers and potential acquisition value. We definitely look at the potential costs associated with projects. Some may simply not project to be profitable enough to move forward with development.

- b. What are the characteristics of a project that is accepted? Passed on?

JK: If the idea meets a standard score from the evaluation process that I mentioned above, we will usually accept that project. Of course we need to be comfortable with the idea in general, have some understanding of the technology and have a clear IP path (in depth patent search to make sure there aren't existing patents which will prohibit the development). The regulatory approval pathway for most projects at this company will usually be a 510k. This means that the potential product can be shown to be substantially equivalent to something already in the market and not a completely new product

category. This would be different from a completely new product which would need to be tested in clinical studies in order to ascertain its safety and efficacy. The cost of a clinical study can be in the millions of dollars, which is far more than we would be willing to spend unless the project was a home run. A 510k requires 90 days for approval from the FDA which enables a faster monetization of the idea.

Incite passes on some projects because: we are unsure of the market and its potential for growth as well as its stability, the project is a new technology which would be too costly for us to undertake, the IP field is crowded and difficult to maneuver around, and the time and money to test and develop may be too much.

- 3) Does Incite look, on an individual project basis, for a specific amount of revenue which that project could achieve?

JK: The foremost concern we look at in terms of making money from the project, is that we can cover the costs of development. The development costs to get the product to the acquisition stage need to be well understood. If the potential acquisition value is not higher than the development costs, there is no value in undertaking the project. To project these costs we look at similar products that have been developed and launched in the market. Incite looks to, at least, double the investment we've made in development.

- 4) Are some projects passed over because they are simply too costly?

JK: As I have addressed above, yes. There are some projects that may be great ideas, but project out to being too much for us to potentially develop and turn around. There are great ideas that can be revolutionary but simply not meet enough demands to make back what they take to develop.

- 5) Does the company history who is pitching the project come in to play?

JK: Absolutely. The relationships we have built with others allow us to market ourselves to the idea generators. In turn our credibility allows us to market the products once we have developed them. With this reputation and these relationships we can sell the products to the big players in the market, or at least have them listen to our product pitch. We need our reputation to get into the market, and then use our reputation to finish what we've started.

**Spine Corpectomy Mode Testing in a Comparative setup- Interview with Matthew Lyons**

**Target Market:** Pedicle Screw Fixation of the Spine between T1 – S1.

**Size of Market:** US Market Value 1b 2007, ROW: 500m

**Test Standard Model:** ASTM F17-17 “Spine Corpectomy Model”

- **Test Material Requirements:**
  - Qty (100) 4.5mm x 60mm Long Multi-Axial Pedicle Screws
  - Qty ((25) Cross Links
  - Qty (50) 5.5mm Titanium Rods
- **Test Set-Up**
  - Qty (5) Static Compression – Max Load to failure
  - Qty (5) Static Tension – Max Load to Failure
  - Qty (5) Static Torsion – Max Load to Failure
  - Qty (8) Dynamic Fatigue Compression- Max Load Tension/Compression to 5 million cycles run-out
- **Comparison of Competitive Products:**
  - Same Quantities of all components and test set-ups
- **Test Machine** – MTS Static - Dynamic Compression Machine
- **Costs of Materials**
  - All BMI Components – \$25,000 - \$40,000
  - Competitive Product - \$50,000
  - Run Test at Competitive Product at Accepted Testing Supplier - \$40,000
  - Travel Costs for Company Engineers - \$5,000
  - Company Employee Costs - \$50,000\* (\*These costs assume 12 months of development time to design the products and perform and manage the testing process).
  - FDA 510(k) Submission Costs \$5,000
- **Time to complete Tests**
  - Produce Test Pieces – 12 weeks Minimum
  - Perform Test – 6 weeks Minimum
  - Submit Test and Await Acceptance from FDA of Test – 12 weeks Minimum
- **Summary Of Costs**

<b>Action</b>	<b>Costs</b>
All BMI Components	\$40,000
Competitive Product	\$50,000
Run Test	\$40,000
Travel Costs for Company Engineers	\$5,000
Company Employee Costs	\$50,000*
FDA 510(k)	\$5,000
<b>Total</b>	<b>\$190,000</b>

**Closing comments:**

Keep in mind that these estimated coasts assume getting the test correct on the first try. This rarely happens. Any company might do some preliminary tests to understand general performances. However, this can become costly. Generally, BMI would undertake these tests and required two cycles before completing the test satisfactorily.

Time is money. Any company needs to consider the time required to develop, test and submit a product to FDA for the purposes of Clearance into the US market. In most cases these test (not including development time) six months to complete. That is because the time to produce parts and run tests can become time consuming. Many times tests can become delayed due to machine breakdown or in some cases we had power-outages that destroyed whole runs of data. Delays in completing acceptable tests can delay product launches which in turn create losses in sales that were anticipated.

### **Blackstone Medical- Interview with William Lyons III**

“In regards to the conversations you had with Mr. K and Uncle Matt, remember, we were in very high margin, low volume, medical businesses that generally carried a huge gross profit because our R&D expense was huge. The R&D expense does not show up in the Cost of Sales line on an income statement. So, because guardrails are pretty much what they are and there is little if any real R&D expense going on, the GP number reflects it. Said another way, we had a lot of guys working in product development that don't fall into the cost of sales line item. So when you have that you need to make sure your gross profit is very high to be able to cover this R&D expense. When Uncle Matt said that generally he would price products at 2X, that was because he needed that extra money in GP (the second X) to cover the heavy R&D expenses. Hope this helps.”

## A5: Technology Transfer

### Intellectual Property- Interview with Mike Manning

Any patents or IP's associated with the HDPE guardrail technology?

*Yes, two. 6,637,971 does not have a license associated with it, 6,962,245 had previously been licensed to Energy Absorption Systems a division of Quixote. There are not current operating licenses. Any licensing could be made to be "exclusive" to an extent.*

If it is determined that there is a viable marketplace for this technology, what is the licensing process?

*Trinity and WPI would engage in a licensing agreement. WPI has a IP policy already showing at 50/50 split of profit between the university and inventor. The licensing agreement would last for the age of the patent the product was associated. Normal patent life is about 20 years. The patent must incur annuity costs from the filing date to keep the patent enforced.*

Is there a patent process?

*Yes. First there is a disclosure document describing the invention. Next an evaluation process happens to evaluate the patent potential. The inventor has one year to obtain a patent after his/her disclosure is published. Overall the patent gives you the right to tell other people they can or cannot make something which would entail your invention. Any agreement we would have with Trinity they would understand that licensing this technology from WPI wouldn't mean that they could run with it and do whatever they want.*

## 8 Appendix B: Maintenance Life Cycle Savings

### B1: Life Cycle Savings

Nevada DOT Maintenance Savings for 1% of Market

<b>Maintenance Savings over a six hit life cycle (1%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$696	\$1,392	\$2,087	\$2,783	\$3,479	\$4,175
2007	\$578	\$1,156	\$1,734	\$2,311	\$2,889	\$3,467
2006	\$616	\$1,231	\$1,847	\$2,463	\$3,078	\$3,694
2005	\$453	\$907	\$1,360	\$1,813	\$2,266	\$2,720
2004	\$421	\$841	\$1,262	\$1,683	\$2,103	\$2,524
2003	\$502	\$1,003	\$1,505	\$2,006	\$2,508	\$3,010
2002	\$460	\$920	\$1,380	\$1,840	\$2,300	\$2,760
2001	\$280	\$560	\$841	\$1,121	\$1,401	\$1,681
2000	\$398	\$796	\$1,194	\$1,592	\$1,990	\$2,388

Nevada DOT Maintenance Savings for 2% of Market

<b>Maintenance Savings over a six hit life cycle (2%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$1,392	\$2,783	\$4,175	\$5,566	\$6,958	\$8,350
2007	\$1,156	\$2,311	\$3,467	\$4,623	\$5,779	\$6,934
2006	\$1,231	\$2,463	\$3,694	\$4,926	\$6,157	\$7,388
2005	\$907	\$1,813	\$2,720	\$3,626	\$4,533	\$5,439
2004	\$841	\$1,683	\$2,524	\$3,365	\$4,207	\$5,048
2003	\$1,003	\$2,006	\$3,010	\$4,013	\$5,016	\$6,019
2002	\$920	\$1,840	\$2,760	\$3,680	\$4,600	\$5,520
2001	\$560	\$1,121	\$1,681	\$2,242	\$2,802	\$3,362
2000	\$796	\$1,592	\$2,388	\$3,184	\$3,980	\$4,776

Nevada DOT Maintenance Savings for 4% of Market

<b>Maintenance Savings over a six hit life cycle (4%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$2,783	\$5,566	\$8,350	\$11,133	\$13,916	\$16,699
2007	\$2,311	\$4,623	\$6,934	\$9,246	\$11,557	\$13,868
2006	\$2,463	\$4,926	\$7,388	\$9,851	\$12,314	\$14,777
2005	\$1,813	\$3,626	\$5,439	\$7,253	\$9,066	\$10,879
2004	\$1,683	\$3,365	\$5,048	\$6,731	\$8,413	\$10,096
2003	\$2,006	\$4,013	\$6,019	\$8,025	\$10,032	\$12,038
2002	\$1,840	\$3,680	\$5,520	\$7,360	\$9,200	\$11,040
2001	\$1,121	\$2,242	\$3,362	\$4,483	\$5,604	\$6,725
2000	\$1,592	\$3,184	\$4,776	\$6,368	\$7,959	\$9,551

Nevada DOT Maintenance Savings for 6% of Market

<b>Maintenance Savings over a six hit life cycle (6%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$4,175	\$8,350	\$12,524	\$16,699	\$20,874	\$25,049
2007	\$3,467	\$6,934	\$10,401	\$13,868	\$17,336	\$20,803
2006	\$3,694	\$7,388	\$11,082	\$14,777	\$18,471	\$22,165
2005	\$2,720	\$5,439	\$8,159	\$10,879	\$13,599	\$16,318
2004	\$2,524	\$5,048	\$7,572	\$10,096	\$12,620	\$15,144
2003	\$3,010	\$6,019	\$9,029	\$12,038	\$15,048	\$18,057
2002	\$2,760	\$5,520	\$8,280	\$11,040	\$13,799	\$16,559
2001	\$1,681	\$3,362	\$5,043	\$6,725	\$8,406	\$10,087
2000	\$2,388	\$4,776	\$7,164	\$9,551	\$11,939	\$14,327

Nevada DOT Maintenance Savings for 10% of Market

<b>Maintenance Savings over a six hit life cycle (10%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	\$6,958	\$13,916	\$20,874	\$27,832	\$34,790	\$41,748
2007	\$5,779	\$11,557	\$17,336	\$23,114	\$28,893	\$34,671
2006	\$6,157	\$12,314	\$18,471	\$24,628	\$30,785	\$36,941
2005	\$4,533	\$9,066	\$13,599	\$18,132	\$22,664	\$27,197
2004	\$4,207	\$8,413	\$12,620	\$16,827	\$21,033	\$25,240
2003	\$5,016	\$10,032	\$15,048	\$20,063	\$25,079	\$30,095
2002	\$4,600	\$9,200	\$13,799	\$18,399	\$22,999	\$27,599
2001	\$2,802	\$5,604	\$8,406	\$11,208	\$14,010	\$16,811
2000	\$3,980	\$7,959	\$11,939	\$15,919	\$19,899	\$23,878

Michigan DOT Maintenance Savings for 1% of Market



<b>Maintenance Savings over a six hit life cycle (1%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$1,383	\$2,766	\$4,149	\$5,532	\$6,915	\$8,297
2006	\$1,449	\$2,897	\$4,346	\$5,794	\$7,243	\$8,691
2005	\$996	\$1,992	\$2,988	\$3,984	\$4,981	\$5,977
2004	\$1,650	\$3,300	\$4,950	\$6,600	\$8,250	\$9,900
2003	\$1,171	\$2,342	\$3,512	\$4,683	\$5,854	\$7,025
2002	\$919	\$1,839	\$2,758	\$3,678	\$4,597	\$5,517
2001	\$895	\$1,790	\$2,685	\$3,580	\$4,475	\$5,370
2000	\$987	\$1,974	\$2,960	\$3,947	\$4,934	\$5,921
1999	\$829	\$1,658	\$2,487	\$3,316	\$4,145	\$4,973

Michigan DOT Maintenance Savings for 2% of Market

<b>Maintenance Savings over a six hit life cycle (2%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$2,766	\$5,532	\$8,297	\$11,063	\$13,829	\$16,595
2006	\$2,897	\$5,794	\$8,691	\$11,588	\$14,485	\$17,382
2005	\$1,992	\$3,984	\$5,977	\$7,969	\$9,961	\$11,953
2004	\$3,300	\$6,600	\$9,900	\$13,201	\$16,501	\$19,801
2003	\$2,342	\$4,683	\$7,025	\$9,366	\$11,708	\$14,050
2002	\$1,839	\$3,678	\$5,517	\$7,356	\$9,195	\$11,034
2001	\$1,790	\$3,580	\$5,370	\$7,160	\$8,950	\$10,741
2000	\$1,974	\$3,947	\$5,921	\$7,894	\$9,868	\$11,842
1999	\$1,658	\$3,316	\$4,973	\$6,631	\$8,289	\$9,947

Michigan DOT Maintenance Savings for 4% of Market

<b>Maintenance Savings over a six hit life cycle (4%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$5,532	\$11,063	\$16,595	\$22,127	\$27,658	\$33,190
2006	\$5,794	\$11,588	\$17,382	\$23,176	\$28,970	\$34,764
2005	\$3,984	\$7,969	\$11,953	\$15,938	\$19,922	\$23,907
2004	\$6,600	\$13,201	\$19,801	\$26,401	\$33,001	\$39,602
2003	\$4,683	\$9,366	\$14,050	\$18,733	\$23,416	\$28,099
2002	\$3,678	\$7,356	\$11,034	\$14,712	\$18,390	\$22,068
2001	\$3,580	\$7,160	\$10,741	\$14,321	\$17,901	\$21,481
2000	\$3,947	\$7,894	\$11,842	\$15,789	\$19,736	\$23,683
1999	\$3,316	\$6,631	\$9,947	\$13,262	\$16,578	\$19,894

Michigan DOT Maintenance Savings for 6% of Market

<b>Maintenance Savings over a six hit life cycle (6%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$8,297	\$16,595	\$24,892	\$33,190	\$41,487	\$49,785
2006	\$8,691	\$17,382	\$26,073	\$34,764	\$43,455	\$52,146
2005	\$5,977	\$11,953	\$17,930	\$23,907	\$29,883	\$35,860
2004	\$9,900	\$19,801	\$29,701	\$39,602	\$49,502	\$59,403
2003	\$7,025	\$14,050	\$21,074	\$28,099	\$35,124	\$42,149
2002	\$5,517	\$11,034	\$16,551	\$22,068	\$27,585	\$33,101
2001	\$5,370	\$10,741	\$16,111	\$21,481	\$26,851	\$32,222
2000	\$5,921	\$11,842	\$17,763	\$23,683	\$29,604	\$35,525
1999	\$4,973	\$9,947	\$14,920	\$19,894	\$24,867	\$29,840

Michigan DOT Maintenance Savings for 10% of Market

<b>Maintenance Savings over a six hit life cycle (10%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$13,829	\$27,658	\$41,487	\$55,316	\$69,145	\$82,974
2006	\$14,485	\$28,970	\$43,455	\$57,940	\$72,425	\$86,910
2005	\$9,961	\$19,922	\$29,883	\$39,844	\$49,806	\$59,767
2004	\$16,501	\$33,001	\$49,502	\$66,003	\$82,504	\$99,004
2003	\$11,708	\$23,416	\$35,124	\$46,832	\$58,540	\$70,248
2002	\$9,195	\$18,390	\$27,585	\$36,779	\$45,974	\$55,169
2001	\$8,950	\$17,901	\$26,851	\$35,802	\$44,752	\$53,703
2000	\$9,868	\$19,736	\$29,604	\$39,472	\$49,341	\$59,209
1999	\$8,289	\$16,578	\$24,867	\$33,156	\$41,445	\$49,734

Michigan DOT Maintenance Savings for 1% of Market (Contracted)

<b>Maintenance Savings over a six hit life cycle (1%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$2,945	\$5,891	\$8,836	\$11,781	\$14,727	\$17,672
2006	\$3,823	\$7,646	\$11,469	\$15,292	\$19,115	\$22,938
2005	\$3,490	\$6,981	\$10,471	\$13,962	\$17,452	\$20,942
2004	\$3,379	\$6,758	\$10,137	\$13,516	\$16,896	\$20,275
2003	\$3,427	\$6,855	\$10,282	\$13,710	\$17,137	\$20,565
2002	\$3,000	\$6,000	\$9,000	\$12,000	\$15,000	\$18,000
2001	\$2,639	\$5,279	\$7,918	\$10,558	\$13,197	\$15,836
2000	\$2,624	\$5,248	\$7,872	\$10,497	\$13,121	\$15,745
1999	\$2,023	\$4,047	\$6,070	\$8,093	\$10,116	\$12,140

Michigan DOT Maintenance Savings for 2% of Market (Contracted)

<b>Maintenance Savings over a six hit life cycle (2%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$5,891	\$11,781	\$17,672	\$23,563	\$29,453	\$35,344
2006	\$7,646	\$15,292	\$22,938	\$30,584	\$38,231	\$45,877
2005	\$6,981	\$13,962	\$20,942	\$27,923	\$34,904	\$41,885
2004	\$6,758	\$13,516	\$20,275	\$27,033	\$33,791	\$40,549
2003	\$6,855	\$13,710	\$20,565	\$27,420	\$34,275	\$41,129
2002	\$6,000	\$12,000	\$18,000	\$24,001	\$30,001	\$36,001
2001	\$5,279	\$10,558	\$15,836	\$21,115	\$26,394	\$31,673
2000	\$5,248	\$10,497	\$15,745	\$20,993	\$26,241	\$31,490
1999	\$4,047	\$8,093	\$12,140	\$16,186	\$20,233	\$24,279

Michigan DOT Maintenance Savings for 4% of Market (Contracted)

<b>Maintenance Savings over a six hit life cycle (4%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$11,781	\$23,563	\$35,344	\$47,125	\$58,907	\$70,688
2006	\$15,292	\$30,584	\$45,877	\$61,169	\$76,461	\$91,753
2005	\$13,962	\$27,923	\$41,885	\$55,846	\$69,808	\$83,770
2004	\$13,516	\$27,033	\$40,549	\$54,066	\$67,582	\$81,099
2003	\$13,710	\$27,420	\$41,129	\$54,839	\$68,549	\$82,259
2002	\$12,000	\$24,001	\$36,001	\$48,001	\$60,001	\$72,002
2001	\$10,558	\$21,115	\$31,673	\$42,231	\$52,788	\$63,346
2000	\$10,497	\$20,993	\$31,490	\$41,986	\$52,483	\$62,979
1999	\$8,093	\$16,186	\$24,279	\$32,372	\$40,465	\$48,558

Michigan DOT Maintenance Savings for 6% of Market (Contracted)

<b>Maintenance Savings over a six hit life cycle (6%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$17,672	\$35,344	\$53,016	\$70,688	\$88,360	\$106,032
2006	\$22,938	\$45,877	\$68,815	\$91,753	\$114,692	\$137,630
2005	\$20,942	\$41,885	\$62,827	\$83,770	\$104,712	\$125,655
2004	\$20,275	\$40,549	\$60,824	\$81,099	\$101,373	\$121,648
2003	\$20,565	\$41,129	\$61,694	\$82,259	\$102,824	\$123,388
2002	\$18,000	\$36,001	\$54,001	\$72,002	\$90,002	\$108,002
2001	\$15,836	\$31,673	\$47,509	\$63,346	\$79,182	\$95,019
2000	\$15,745	\$31,490	\$47,234	\$62,979	\$78,724	\$94,469
1999	\$12,140	\$24,279	\$36,419	\$48,558	\$60,698	\$72,837

Michigan DOT Maintenance Savings for 10% of Market (Contracted)

<b>Maintenance Savings over a six hit life cycle (10%)</b>						
	1 hit	2 hits	3 hits	4 hits	5 hits	6 hits
2008	N/A	N/A	N/A	N/A	N/A	N/A
2007	\$29,453	\$58,907	\$88,360	\$117,813	\$147,267	\$176,720
2006	\$38,231	\$76,461	\$114,692	\$152,922	\$191,153	\$229,384
2005	\$34,904	\$69,808	\$104,712	\$139,616	\$174,520	\$209,424
2004	\$33,791	\$67,582	\$101,373	\$135,164	\$168,956	\$202,747
2003	\$34,275	\$68,549	\$102,824	\$137,098	\$171,373	\$205,647
2002	\$30,001	\$60,001	\$90,002	\$120,003	\$150,003	\$180,004
2001	\$26,394	\$52,788	\$79,182	\$105,576	\$131,970	\$158,365
2000	\$26,241	\$52,483	\$78,724	\$104,965	\$131,207	\$157,448
1999	\$20,233	\$40,465	\$60,698	\$80,930	\$101,163	\$121,395