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An analysis and policy implications of comfort levels of diverse constituents with reported units for blast vibrations and limits: closing the communication gap

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AN ANALYSIS AND POLICY IMPLICATIONS OF COMFORT LEVELS OF DIVERSE CONSTITUENTS WITH REPORTED UNITS FOR BLAST VIBRATIONS AND LIMITS: CLOSING THE COMMUNICATION GAP

by

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ABSTRACT

Differences exist between public perception of construction blasting and quarry blasting. In general, people are able to tolerate short term inconveniences much better than long term ones.

Quarries and other long term mining operations utilizing blasting are coming under increasing public and legislative pressure in the United States. The question being posed for the blasting industry is, "Has our past haste in adopting complex scientific scales and units been detrimental to us?" In other words, are the most palatable things being reported? The goal of this dissertation is to determine whether current units create an atmosphere of discomfort among neighbors to quarries, putting the public relations efforts of the company at a disadvantage from the start.

Several Likert scaled surveys were distributed and analyzed across many constituencies. The surveys evaluate the decibel (dB) scale against millibar and pounds per square inch (PSI) as units for measurement of airblast pressure. Peak Particle Velocity (PPV) and frequency (Hz) were also compared to displacement in both inches (in) and millimeters (mm) for vibration measurement. Other qualitative data was gathered to direct future work in this area. Pilot surveys have been administered and their results published over the past three years. The thesis work is a much more comprehensive analysis of surveys modeled after the original survey described in the introduction.

The industry is already starting the process of rethinking how it handles the vibration issue. The past practice of treading softly as an industry has been proven to be a poor choice, and education of the public as well as lawmakers on all levels is necessary.

ACKNOWLEDGMENTS

Shannon, without you, this dissertation would have never been started. I would not have pursued this degree. Your complete support and encouragement were necessary (and sometimes unwanted) for its completion as well. You did more to help than you can ever know. Thanks.

Others were very helpful as well. Teresa Lusk was responsible for me coming to UMR in the first place. Without her, I'm not sure I would have even gone to college, and her continuing support has been greatly appreciated. My father and brother were also very supportive throughout the process.

I also need to thank Winco Windows and Gantt Miller for indirectly supporting this research effort. Through testing blast resistant windows, the author was supported to the extent he could pursue the research necessary for writing this dissertation.

Arlene Chafe and the rest of the staff at the International Society of Explosives Engineers (ISEE) were a great help in assembling a list for one of the survey pools, among other things. I also need to thank all of the survey participants.

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I would also like to thank my committee for helping me through a tight schedule towards the end. They each rose to the occasion to provide me with the ability to complete my dissertation on time. Dr. Grayson, Dr. Bullock, Dr. Baird, Dr. Tsoulfanidis, and Dr. Worsey all had an effect on my studies at UMR. Through classes, social interactions, conferences, and working together on my dissertation, I've grown to respect these men not only for their expertise, but for their exceptional personalities as well.

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1. INTRODUCTION

1.1. PROBLEM STATEMENT

Expanding urban environments are presenting new challenges for the explosives industry. When development of the larger cities in the United States began, quarries were strategically located to serve specific cities. By nature these quarries were located as close to the cities as possible while not interfering with development of commercial and residential land. As the cities have continued to sprawl into the countryside and suburbs have continued to grow, many established quarries are encountering challenging situations. Neighborhoods, shopping centers, and high tech industry are now common neighbors for suburban quarries. These quarries are now forced into public relations issues that were never a concern before.

In the past, extensive research has been undertaken on blast damage levels; however, this work has done little more than slow down the onslaught against the blasting industry. While it has been important work since it has provided the industry with certainty about what vibration and airblast levels are harmful to structures, a problem still remains. Although structurally safe levels have been met, complaints about blasting do not cease. At this point, the problem immediately transforms from a structural damage issue into one about abating complaints and fighting lawsuits. It should be obvious that the key or keys to this problem are somewhere else besides levels of vibration alone. Certainly the use of public relations in our industry is a relatively new idea and definitely making ourselves understandable to the public is a novel concept. Nearly twenty years ago, the blasting industry faced similar challenges as can be seen in a journal article by Petro and Anderson in 1986 (Petro, 1986). The abstract begins "Blast vibration problems are often a matter of neighbor complaints rather than compliance with regulations." (Petro, 1986). At the 2005 International Society of Explosives Engineers (ISEE) Conference on Explosives and Blasting Technique, Spathis (Spathis, 2005) states, "It is also interesting to note that in certain circumstances a person can feel levels of ground vibration that are lower than human comfort limits and thus be disturbed even though there has not been an exceedance (of regulatory limits)".

In order to clarify the problem faced at quarries forced to interface with numerous neighbors, background information is necessary. Disturbances like blasts from nearby quarries instill worry in people. In many cases, residents will start looking for damage following blasts. They may encounter damage or defects in their homes that occurred prior to any blasting activity nearby. Many times, lawsuits are initiated against the mining company or blasting contractor for damage not caused by blasting.

The use of confusing units may be the root of many problems associated with neighbors in close proximity to blasting. The simple fact that residents may not understand the units used to report ground vibration and airblast data has been overlooked to date when considering public relations for mining and blasting operations.

Warneke (Warneke, 2004) introduces the use of indicators to help in the creation of mining-related public policy. Through discussing the many definitions and characteristics of indicators, Warneke identifies a common thread among effective indicators. He states "characteristics necessary for effective indicators: ... Simple to interpret, accessible and publicly appealing." (Warneke, 2004). In the same way, blast reporting units are indicators of the success of a blasting program; thus, the units should follow the same characteristics.

The use of the decibel scale for airblast reporting can be shown as possibly detrimental when the logarithmic nature of the scale is considered. Figure 1.1 is a bar graph providing a visual comparison of the decibel scale and a linear PSI scale. The figure shows how a resident might be uncomfortable with the decibel scale because the values of a typical blast, the Office of Surface Mining (OSM) limit, and the threshold for damage appear to be very close relative to the scale. In contrast, the PSI scale shows that the actual pressure values of these items are farther apart. The safety margin appears to be much larger when using the PSI scale.

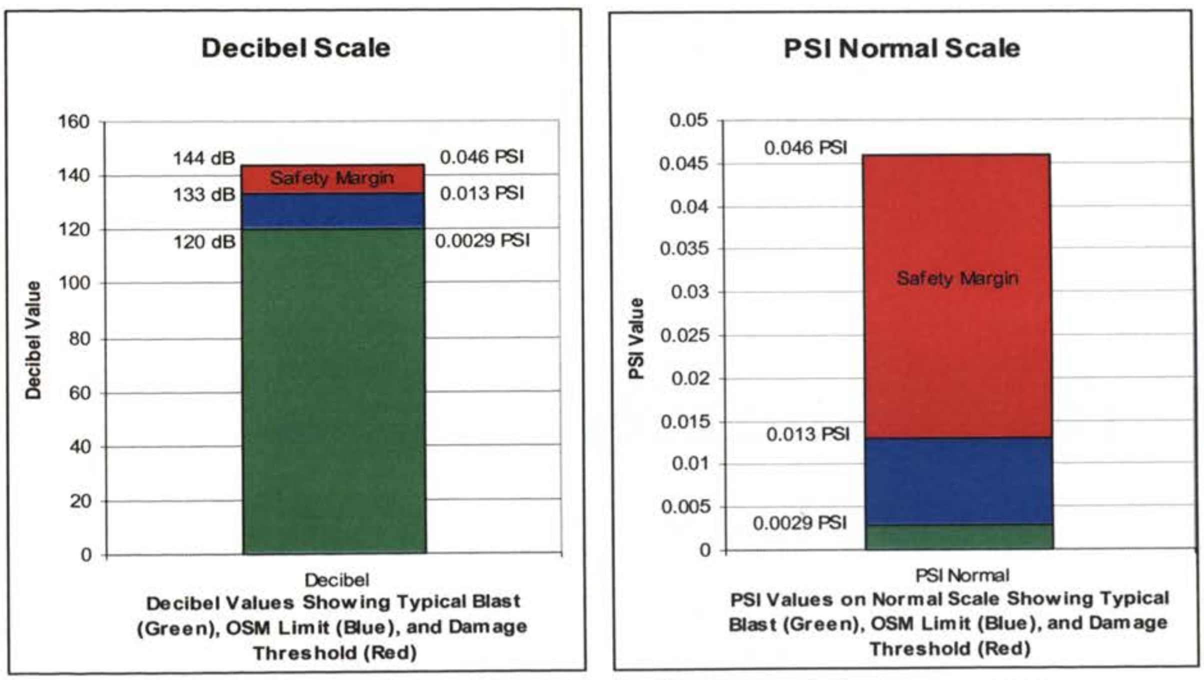

Figure 1.1. Comparison of logarithmic decibel scale and normal PSI scale.

In much the same way, ground vibration is reported using peak particle velocity (PPV) and frequency. This practice may also cause confusion and discomfort in residents close to quarries. Since ground vibration reporting is dependent upon two variables, visual representation is more difficult to assess. Nevertheless, through inspection of Siskind's (Siskind, et. al., 1980 A) Z curve, which has been adopted by OSM as well, possible alternative reporting units can be determined (Hopler, 1998). Figures 1.2 and 1.3 show two different representations of the Z curve on separate scales. The original curve shown in Figure 1.2 is a logarithmic frequency versus logarithmic velocity scale where the line represents a safety limit under which ground vibration is considered safe for structures. The points shown below the safety line are representations of typical blast vibration measurements from quarry blasts. Again, the logarithmic nature of the scales show that the typical blast data points fall relatively close to the safety limit line.

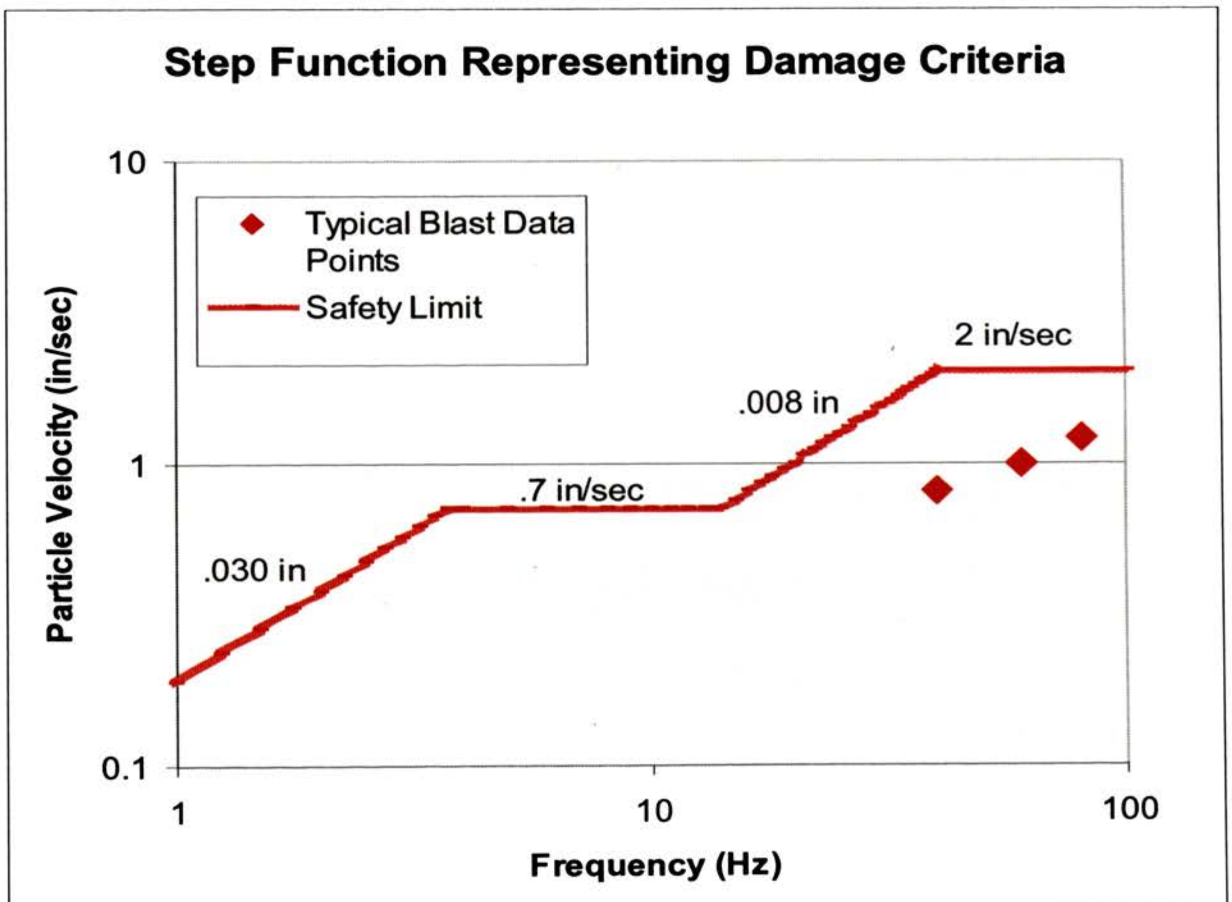

Figure 1.2. Step function representing damage criterion for blast vibration. Recreation of Hopler (Hopler, 1998).

Figure 1.3 shows the same step function represented in Figure 1.2, but the scales are normal as opposed to logarithmic. The typical blast data points are visibly further from the safety line in this representation although they represent the same values.

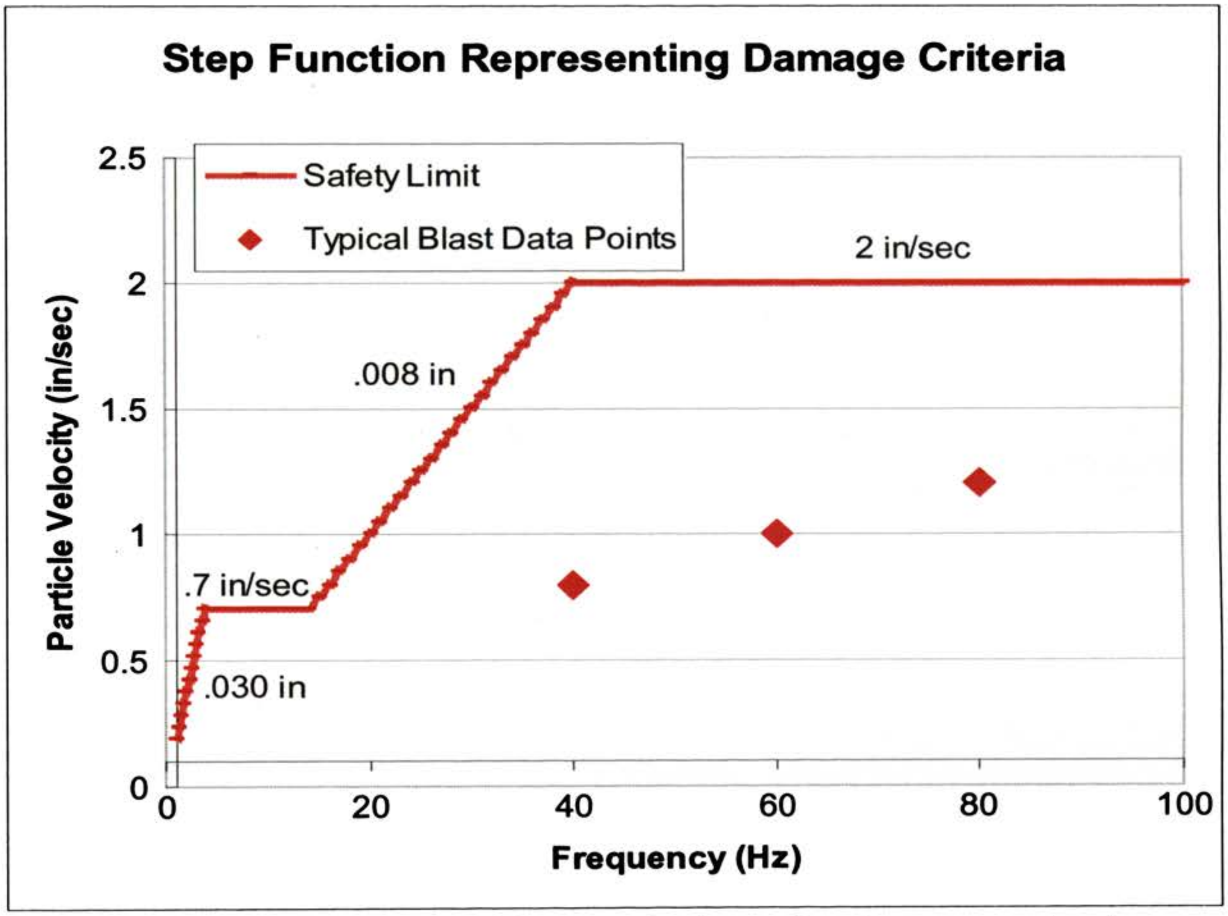

Figure 1.3. Representation of damage criteria step function on normal scales.

A possible alternative to PPV and frequency would be to report data in displacement, which can be derived from PPV and frequency. Not only would this allow for the reporting of a single term, but Figure 1.4 provides a visual representation of how displacement reporting might be perceived. The figure shows how displacements generated by the typical blast data points in Figures 1.2 and 1.3 compare to the displacement allowed by the safety limit at the same frequency. Again, the safety margin appears larger than the proximity of the points to the safety line in Figure 1.2 might suggest. While this visual representation is not as powerful as the decibel to PSI comparison in Figure 1.1, it does show evidence that displacement could be a better alternative for ground vibration reporting than PPV and frequency.

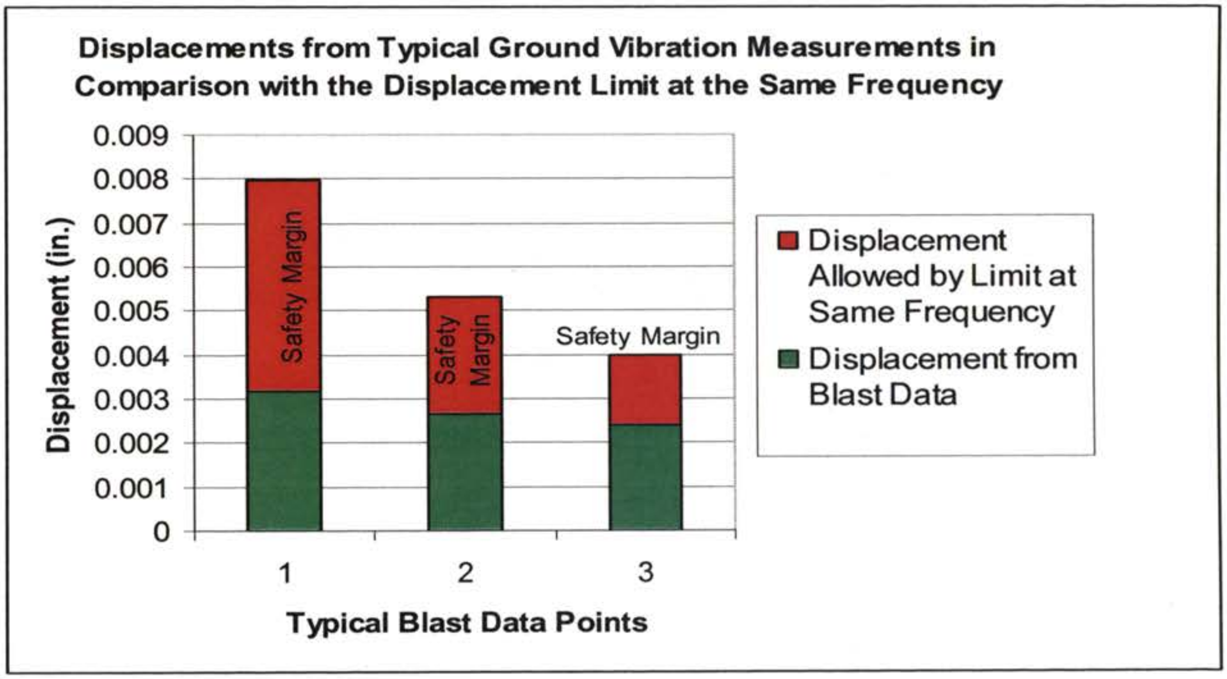

Figure 1.4. Bar graph showing comparison of displacement from typical blasts (1,2,3) and the displacement allowed by the OSM limit at the same frequency.

An example of the suburban growth situation described earlier can be found in St. Charles, Missouri. The first step in accomplishing the long standing, yet unearthed goal of public comprehension is to determine what is understandable to the public. The pilot survey described later in this introduction was an initial effort at determining public comfort levels with blasting and current reporting units. The survey asked questions about how comfortable people were with blast vibration and airblast levels and limits.

The pilot survey was performed prior to any advanced survey design research. It also cannot be used to create concrete conclusions from detailed statistical analysis. Its purpose was to gauge the possible usefulness of in-depth research and putting forth extensive effort in this area. Many more surveys would be required to complete the research initiated by this dissertation comprehensively, but the basic idea and approach is well documented in the description of the pilot survey and its results.

The problem at hand is the trend of restrictive local and state regulations regarding blasting. After the data from the pilot study was collected, several groups of people were surveyed to determine a suitable means for reporting airblast and ground vibration levels obtained through seismograph monitoring. The definition of these groups as well as the design of their surveys will be discussed at length in later sections.

There are four main goals for the research described in this dissertation. The major contributions are listed below.

- Survey data analysis will enable the selection of better reporting units for the airblast and ground vibrations produced in industrial blasting.
- The survey data will be shown to be an important part of the toolset for an effective public relations tool for mining companies.
- Recommendations for improvements in the public relations programs for the mining/blasting industry, and for that industry's relationship with regulatory authorities will be made.
- The determination of future research for the continuation of work in this area.

Absent from this list is the goal of changing or addressing the level of limits for airblast and ground vibrations that are based on quality scientific research. This is not one of the goals of this dissertation. In fact, limits in place that are based on USBM RI 8507 and USBM RI 8485 such as those adopted by OSM for the regulation of surface coal mining operations are based on sound scientific research (Siskind, *et. al.* A, 1980, Siskind, *et. al.* B, 1980). Since 1980, these limits have been proven to provide conservative limits for the protection of structures exposed to ground vibrations and airblast from mining blasts. Some limits in place, however, are not based on research of this kind. Examples of this are discussed in Section 1.3. The concept of creating new regulations, where none currently exist, with more uniform, scientifically backed limits will be addressed in the recommendations for regulators.

In accordance with the need to educate the non-blasting public and specifically regulators and policy makers, the Mississippi Valley Chapter of ISEE has been offering training to potential regulators, enforcement personnel, and governmental administrators. The chapter has held two eight-hour seminars and invited local regulators and city/county officials in 2004 in both the St. Louis area and the State Capitol. The training has been well received, and others are in the planning stages. With more effort such as this, officials will not only become better at proposing appropriate regulations but will also be better prepared for replying to complaints.

1.2. BACKGROUND PROMPTING RESEARCH

Beginning as nothing more than a curiosity, this research has evolved into a thorough examination of how the blasting industry interacts with the public, notably its neighbors. The curiosity began upon learning of the many attempts to embed restrictive legislation on a local level due to complaint levels. Past research has done much to enable mining operations to improve their blasting vibrations. A thorough review of this literature is discussed in later sections. Still, complaints persist. With the expanding development of urban communities, quarries are faced with neighbors multiplying at an alarming rate.

Quarry locations are somewhat predetermined based on geology and reserve availability. Deposits capable of producing aggregate can allow for placement outside current development, but over the life of a mining operation, development may envelop operations that were relatively remote in their early production stages. As development continues, quarries and residential development will have to coexist to prevent exorbitant costs for building materials. In most cases, transportation cost constitutes a major portion of the final price of any mined material. Coexistence will be difficult, if not impossible, if the blasting industry can not effectively communicate with the public in proximity to these operations. In order to facilitate proper communication, the industry must, among other things, determine effective and understandable tools for reporting ground vibration and airblast readings from seismographs.

During pilot research, many questions were raised concerning the validity of a Mining Engineer performing a study of this sort. These questions brought to light a very dominant feature of technical experts and engineers in the academic community. The belief that only social scientists should carry out surveys and studies of this nature places the mining and explosives industry in a very adverse situation. Social scientists have expertise in evaluating survey data and constructing robust surveys. Nevertheless, in most cases they lack the technical knowledge necessary to understand what measurements are important when it comes to ground vibrations and airblast produced through the use of commercial explosives in mining. This creates a predicament for research in this area as it proceeds. The solution lies in multidisciplinary research. This dissertation provides technical groundwork and enough quality data to prompt further research for both statistical experts and mining engineers to pursue jointly.

1.3. CURRENT AND IMPENDING BLASTING REGULATIONS

In 2002, county administrators issued a letter to many companies involved with the blasting and mining industry in St. Charles County, Missouri. The letter requested responses to proposed changes in blasting regulations for the county. The proposed changes were driven by complaint levels from residents in the county, and not damage criteria on which the previous regulations had been based. In an effort to appease residents and reduce complaint levels, the county proposed vibration and airblast limits well below federal regulations cited by The Office of Surface Mining (OSM) which are discussed at length in later sections. The letter suggested that the peak particle velocity (PPV) at the operator's property line was not to exceed 25 mm per second (~1.0 inches per second). The PPV at the nearest uncontrolled structure would be 13 mm per second (~0.50 inches per second). Finally, the 6 Hz, 2 Hz, and 0.1 Hz decibel limit would be reduced from 133 dB to 115 dB (apparently to conform to OSHA requirements for on-the-job noise levels). These proposed changes were extensive for the quarries operating in the county, and many operators and local industry experts responded to the letter (Hammond, 2002). The situation is not completely resolved to date. Current limits as of February, 2006 were 50 mm per second (~2.0 inches per second) PPV at the property line, 38 mm per second (~1.5 inches per second) at the nearest uncontrolled structure, and a much more reasonable 133 dB peak airblast for 2 Hz or lower (134 dB for 0.1 Hz or lower and 129 dB for 6 Hz or lower). However, if the proposed regulations were adopted, it would cause severe restrictions both in cost and practical application for blasting in St. Charles County.

The situation in St. Charles, not unlike many other escalating movements by local governments, was at the root of the decision to pursue this research. In fact, the quarry selected for the pilot survey was located in St. Charles County due to its proximity to Rolla. Also, many other local governments near St. Louis and St. Charles County are beginning to develop their own laws. The local governments in the St. Louis area have begun looking to St. Charles County for direction in creating their own policies. A simple internet search for "local blasting ordinances" can show that many other localities in the U.S. are facing the same issues.

On first inspection, many of the local laws reflect foresight and understanding of technical issues involved with vibration and airblast measurement. Woolwich, Maine, for example has a well written ordinance for blasting within the city limits. The ordinance allows for a range of peak particle velocities based on frequency. The limits for these velocities are closely related to those found in Siskind's work. The limits range from 0.5 inches per second under 30 Hz to 2 inches per second over 40 Hz. Airblast limits are also well defined and reasonable at 133 dB measured with a 2 Hz high pass system. The ordinance also covers pre-blast survey requirements, and measuring points are well defined. The permit fees are somewhat large at $100.00 per 1,000 cubic yards of material blasted; however, the ground vibration and airblast limits are within the limits of sanity (Woolwich, 2006). This type of local law is certainly not a problem worth an investigation of this type. However, realignment of this policy towards more restrictive limits in the future is a real possibility due to the volatility of local legislation.

For every sound Woolwich, Maine, ordinance however, there are any number of ordinances designed like that for Hobart, Wisconsin. This ordinance seemingly details blast reporting but does not include any limits for ground vibration or airblast. Limits on hole size and stemming are stated. Hobart limits the hole size to 3.5 inches, while requiring a minimum of 3.5 feet of stemming of minimum size 3/8" crushed stone. There are many problems with this type of language in a local ordinance. Since stemming depth and sizing are limited, serious damage could occur in some situations. The use of larger than 3/8" crushed stone as stemming material in a hole smaller than 3 inches is inadvisable. Also, 3.5 feet of stemming is not sufficient for most 3.5" blast holes (Hobart, 2006).

Windham, New Hampshire, does not regulate airblast limits, but the ground vibration limits are quite aggressive. Upon initial inspection, they are not very restrictive at 0.5 inches per second when frequency is below 40 Hz and 2 inches per second above 40 Hz. This ordinance is overly restrictive because of its definition of the measuring point. These vibration limits are to be met at 100 feet from the blast. This would be acceptable for a blast that was 100 feet from a structure, but overly restrictive for an operation that has thousands of feet to the nearest structure (Windham, 2006).

Overland Park, Kansas, has set a 1 inch per second limit on peak particle velocity across the board. The stated reason for this level is "because it is one half of the level set by the federal government as being safe for frame houses." No airblast limits are set in this ordinance, nor are there any specifications for measurement. Had this locality taken the same approach for airblast limits, citizens would not be able to talk loudly for risk of breaking the airblast ordinance of 66.5 dB (Overland Park, 2006).

Many local laws governing blasting are well designed and appropriate for conducting business and providing safe and comfortable environments for citizens. Others create overly restrictive limits that would force operations out of business if forced to comply. Yet others still do nothing to protect citizens, and in fact allow for gross negligence on the part of blasters without breaking local laws.

Many states have adopted laws governing blasting within their borders. If well designed, this can virtually eliminate local governance of the industry. For instance, Missouri is currently considering legislation that would govern blasting operations and also preempt any local ordinances which may govern blasting. The Missouri Senate Bill 882 is well written and actually cites the USBM reports RI 8507 and RI 8485 for limits. The bill also encompasses licensing and record-keeping requirements. Currently, it is being reviewed by committees and is due to come to the floor for a vote in the near future. Other neighboring states have already passed state wide blasting policies, including Oklahoma and Arkansas. Illinois has a statewide licensing program but does not limit vibration and airblast levels (Missouri SB882, 2006).

1.4. ST. CHARLES, MISSOURI CASE STUDY

1.4.1. Survey Location, History and Politics. The following description of a survey and its results are the culmination of pilot work performed in the summer months of 2004. Much of the results of this survey have been published in various conference proceedings since that time. The survey targeted a specific quarry in St. Charles, Missouri (Lusk, 2005 A, Lusk, 2005 B).

The particular quarry in St. Charles is situated in a convenient location for commuters, and thus housing developments nearby are attractive to young working families. St. Charles is west of St. Louis, immediately west of the Missouri River. Many residents commute to St. Louis for work every day and use Interstate 70 as a primary travel route. The quarry is located only a few miles from I-70, and has been operating for many years. In the immediate vicinity (within one (1) mile) of the quarry, several neighborhoods are now established. There are basically two types of contrastingly different neighborhoods to be found in the area. There is a neighborhood that has been developed for nearly 40 years. This neighborhood's homeowners are typically older, and are approaching retirement or are already retired. The residents there have been living with the blasting at the quarry for many years. It is very likely that there were no efforts to educate the residents in this neighborhood as to the effects of blasting. The other neighborhood found near the quarry is a newer housing development that is still very actively building. Many homes overlook the quarry and rest on one of the high walls of the pit. This neighborhood is filled with younger people who typically work during the day and are new to the blasting at the quarry. This neighborhood was subject to a public relations letter sent to all residents early in its development. The letter has been attached as Appendix A.

Figure 1.5 shows an aerial view of the St. Charles quarry where pilot surveys were distributed. The figure highlights the quarry, the established neighborhood, and the newer development described above. The survey conducted for this paper highlights key differences in the two neighborhoods and an evaluation of differing perceptions of the quarry and blasting practices is made.

Figure 1.5. Aerial view of St. Charles quarry and surrounding neighborhoods.

1.4.2. Pilot Survey Introduction. Current reporting practices in the blasting industry utilize complicated scales for both airblast and ground vibration. For airblast, the regulatory limits report pressure according to the decibel scale, which is commonly used to represent how humans hear sound: the selection of the decibel scale for airblast pressure, however, is detrimental for several reasons. Considering that the majority of energy created from blast overpressure is of frequencies below the human hearing capabilities, and therefore is not sound, it is odd that decibels were chosen as the descriptor. Figure 1.6 shows the frequency response characteristics in the American National Standard Specification for sound level meters (SLM). OSM requires the use of a C-Weighted scale denoted by C in the Figure. Even at frequencies lower than 50 Hz, the C scale has little response reduction. This means that a SLM measuring on a C scale will capture the majority of energy even at low frequency. A web-based acoustics lecture from Cornell University states "The 'A' scale is that which most closely approximates the frequency-response scale of the human ear." (Cornell, 2006). According to Figure 1.6, there is a substantial reduction on the A scale in response to low frequencies beginning below 500 Hz. For example, at a frequency of 50 Hz, the A scale shows a reduction of approximately 30 dB. Since the pressure value is approximately halved for every 6 dB reduction. This means that at 50 Hz only about 3% of the actual energy would be recorded with an A scale. (The 3% is approximately calculated by taking the 30 dB and dividing by 6 dB, since the pressure is halved every 6 dB, which results in the original pressure value being halved 5 times. Therefore, starting with 100%: half of 100% is 50%, half of 50% is 25%, half of 25% is 12.5%, half of 12.5% is 6.25%, and half of 6.25% is approximately 3%.) Since the A scale most closely resembles human hearing, this suggests that most of the energy from airblast (which is typically of lower frequency) can not be heard. Even detonation of unconfined explosives at a relatively close range of approximately 100 feet would produce frequencies of well under 500 Hz. This information demonstrates that sound is not being measured in airblast measurements, but rather pressure is the object of these measurements. Also, the decibel scale is logarithmic making it very difficult for the public to understand.

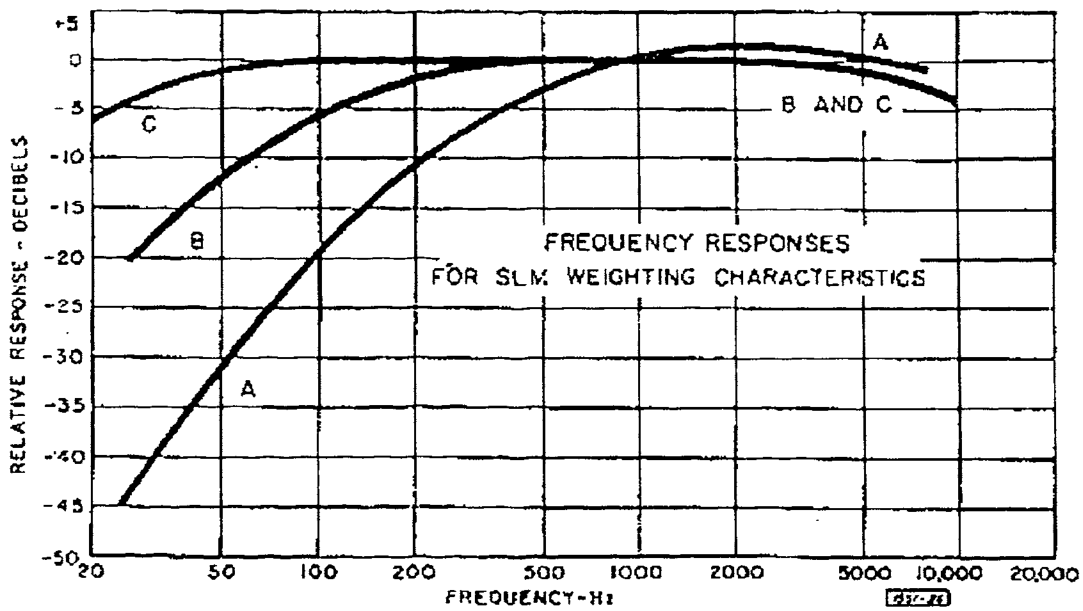

Figure 1.6. Frequency response characteristics in the American National Standard Specification for Sound Level Meters, ANSI-SI.4-1971 (Mining 402, 2005).

A closer inspection of the calculation of Sound Pressure Level (SPL) in decibels provides more evidence that it may not be the optimum scale for reporting airblast. The equation for decibels is as follows (Hopler, 1998):

$$SPL = 20 \times \log\left(\frac{P_e}{P_0}\right) dB \tag{1.1}$$

where

P_0 = Reference Pressure = 2.9e-9 PSI

P_e = Airblast Overpressure in PSI

Using Equation 1.1, it can be seen that a doubling of pressure occurs with an increase of 6.02 dB. With P_e = 0.0029 PSI, the SPL is calculated to 120 dB. Doubling the pressure so that P_e = 0.0058 PSI, the SPL rises only 6.02 dB to 126.02 dB. This logarithmic scale can represent unrealistic ideas about reducing the energy produced from airblast. A minimal reduction in SPL (dB) represents a substantial reduction in pressure.

From a perception standpoint, the decibel scale may be detrimental to the blasting industry. For example, the current OSM limit for blasting is 133 dB, while the damage threshold for poorly hung, large windows is approximately 144 dB (lowest level found in the literature). To the untrained eye, the limit is set at over 90% of the damage criterion. In actuality though, 133 dB (0.013 PSI using Equation 1.1) is less than 30% of the pressure represented by 144 dB (0.046 PSI). As discussed earlier, Figure 1.1 is a bar graph comparison showing the difference between the decibel scale and a linear pressure scale (PSI). The margin of safety represents the amount of space between the regulated limit and the threshold of window damage. Looking at Figure 1.1, which scale would be expected to give the most comfort to a non-technical person?

In blast vibration monitoring, particle velocity is measured and reported with an accompanying frequency. This may also be a poor choice of units from a public-perception standpoint. U.S. OSM regulations are based on a step function comparing frequency to velocity. Any vibration found below the step function shown in Figures 1.2 and 1.3 is considered to be at a level that will not cause damage to structures. Velocity alone does not cause damage to structures. Differential strain due to differential movement of two parts of a structure causes damage. Perhaps a better unit for reporting would be overall displacement. Displacement can be related to velocity and frequency in a sinusoidal wave with a simple equation as follows (Hopler, 1998):

$$D = \frac{V}{(2 \times \pi \times F)} \tag{1.2}$$

where
D = Displacement (mm)
V = Velocity (mm per second)
F = Frequency (Hz)

An example of how this might be more simple to understand and more well received can be drawn from a typical blast scenario. Vibrations from a typical blast using 100 mm (~4 inch) holes at a distance of 200 meters (~650 feet) should produce a PPV of approximately 10 mm per second (0.4 inches per second) at 35 Hz. Using equation 1.2, a displacement of 0.05mm (1.97E-3 inches) is experienced at the point of measurement.

This is approximately half the thickness of U.S. photocopy paper. Which measurement would be expected to give the most comfort to a non-technical person, a vibration of 10 mm per second or half the thickness of a piece of photocopy paper?

The survey described in the following pages was designed to determine whether there may be justification to consider changing the units used for reporting and regulating blast vibrations and airblast. With public relations becoming an increasing problem, public perception of the industry is an ever more important aspect of business.

1.4.3. Pilot Survey Description. In order to determine the public's perception of reporting practices in the blasting industry a pilot survey was developed. To be effective, the survey had to be relatively low impact and short. A total of ten questions were created to collect data on a few demographic points of each person, as well as various comfort levels with blasting in general and the reporting practices used by the industry.

Four questions were used to collect demographic data, including residence ownership, age, sex, and hours of work. The remaining six questions addressed the data needed for determining the public comfort level with blasting in the immediate vicinity of their residence. The use of different, less technically complicated measurement scales for vibration and airblast was considered as an alternative reporting system. Five of the questions were assigned comfort values by the person taking the survey as follows:

1-Very Uncomfortable
2-Uncomfortable
3-Neutral
4-Comfortable
5-Very Comfortable

This system is a widely accepted survey scaling technique known as the Likert Scale (Likert, 2005). The six questions asked concerning blasting reporting are as follows:

Q5. How comfortable do you feel having a blasting operation within 1 mile of your home?

Q6. When blasting commences, considering that 144 decibels begins damaging windows, how comfortable are you with setting a limit of 133 decibels for blast pressure?

Q7. When blasting commences, considering that 3.18 millibars begins damaging windows, how comfortable are you with setting a limit of 0.89 millibars for blast pressure?

Q8. What do you associate with the decibel scale?

Q9. When blasting commences how comfortable are you with ground vibrations at your home with velocity in the range of 0.5 inches/second (13 mm) at 35 Hz?

Q10. When blasting commences how comfortable are you with ground vibrations causing a displacement of 0.05 millimeters at your home?

From this point forward in the introduction, questions will be referred to by their corresponding number. The pilot survey has been attached as Appendix B.

This survey was administered to three groups of people for comparison and correlation. The first group consisted of residents of the "Established Neighborhood" near the quarry in St. Charles. Twenty surveys were administered in this neighborhood. A second group of 20 surveys was taken in the "New Development." The St. Charles surveys were gathered solely by knocking on doors of homes within 1 mile of the quarry. The third group (Control Group) included people who did not live in close proximity to a quarry and were taken both by knocking on doors and randomly at local retailers in Rolla, Missouri.

An informational flyer was given to all people who participated in the survey to explain the purpose and allow for them to contact the author if any questions would arise. This flyer is attached as Appendix C.

In all cases, it was expected that Question #6 would have lower comfort values than Question #7. It was also expected that subjects would associate the decibel scale with some sort of noise or sound. Finally, it was expected that Question #9 would have lower comfort values than those for Question #10.

1.4.4. Pilot Survey Results. Many conclusions could be drawn from the data collected in the pilot survey; however, the most important information gathered in the pilot survey was that it provided merit to continue with a broader, more scientific study with more statistical analysis. The pilot survey was evaluated only using simple averages. Later research of the statistical methods for analyzing ordinal categorical data (Likert type) has shown that averages tell only a portion of the story. A thorough review of literature covering statistical analysis can be found in later sections. The surveys that were administered after the pilot study were designed more scientifically, and their results were analyzed using recognized statistical methods.

The data collected from the pilot survey was not subjected to a robust statistical analysis. Nevertheless, the results prompted further research and are shown here as an introduction to the thought process involved with the research.

The following results have been tabulated for convenience. The demographic data was averaged across each survey group and across the entire pool. A few notable data points present themselves. Notice in Table 1.1 that the average age of the Established Neighborhood Group is 54 years, while the New Development is much younger, 35 years on average. Also notice that the "Established Neighborhood" group contains 55% retired persons against the 0% in the "New Development" group. All persons polled in St. Charles were home owners as well. The Control Group fell between the two St. Charles groups demographically with the exception of home ownership. There were three persons polled in the control group who were renters.

Table 1.1. Table of demographic averages for pilot surveys.

Demographics				
	Group			
	Established Neighborhood	New Development	Control Group	Overall
Average Age	54	35	50	46
Percent Polled Who Owned	100%	100%	85%	95%
Percent Polled Male	65%	50%	60%	58%
Percent Retired/Not Working	55%	0%	40%	32%

Table 1.2 shows average comfort levels of all three groups for all questions rated in the survey as well as the average rating for Question #5. Question #5 assesses the comfort level with a blasting operation within 1 mile of the subject's home. In St. Charles, the new development shows noticeably higher comfort levels with blasting

practices in general. This can be attributed to two factors. First, the public relations exercise administered before people purchased their new homes, and second, younger people may not be likely to complain as much as older people for a variety of reasons. This concept of different comfort levels among varying age groups is discussed further in later chapters.

Table 1.2. Table showing overall comfort with blasting. (Higher number means more comfortable 3=Neutral)

Average Comfort Level Across the Board				
	Group			
	Established Neighborhood	New Development	Control Group	Overall
Average Comfort Level On all Questions	2.09	2.41	2.91	2.47
Average Question 5	1.85	3.1	2.8	2.58

Question #6 and Question #7 were designed to find out if the public would be more comfortable with a linear millibar scale than with the more complicated decibel scale. The survey asks the same question using the same pressure values but expressed in different units. According to the survey results, all groups were significantly more comfortable with millibars than decibels as seen in Table 1.3. Question #9 and Question #10 were designed with a similar goal in mind. These questions compared equal values for vibration expressed in Velocity/Frequency and mm Displacement, respectively. The survey groups were marginally more comfortable with displacement as seen in Table 1.3 also. Several factors could have played a role in the marginality. First, the use of millimeters for the unit of displacement might have had some effect as generally many Americans do not prefer metric units and are more comfortable with traditional units such as inches. Also, it seemed that surveyed participants were not comfortable with displacement. In most cases subjects were very confused by Question #9 and in many cases did not know how to answer (many did not have any idea what velocity and frequency meant).

Table 1.3. Table showing average comfort levels on individual questions regarding reporting practices in pilot surveys.

Specific Comfort Levels				
	Group			
	Established Neighborhood	New Development	Control Group	Overall
Average Comfort with Decibel Scale Limit	1.75	2.15	2.3	2.07
Average Comfort with Millibar Scale Limit	3	2.95	3.8	3.25
Average Comfort with Velocity/Frequency	1.8	1.85	2.6	2.08
Average Comfort with mm Displacement	2.05	2	3.05	2.37

A few other points of interest can be drawn from the data collected. The points of interest are tabulated in Table 1.4. Most notably, in all 60 surveys there were zero persons less comfortable with millibars than decibels for airblast pressure. An average of the entire survey pool showed that only 22% were equally comfortable with millibar and decibels. There were substantially more subjects equally comfortable with displacement and velocity/frequency. One unexpected data point was the percentage of persons associating nothing with the decibel scale. On average, 28% of people surveyed did not have an answer for what they associated with the decibel scale. This is yet another reason for reconsidering the use of decibels as a reporting unit. The results of the pilot survey were published in 2005 by Lusk and Worsey (Lusk, 2005 A, Lusk 2005 B).

Table 1.4. Table showing interesting data points in pilot surveys.

Interesting Data Points				
	Group			
	Established Neighborhood	New Development	Control Group	Overall
Percentage With No Answer For Question 8 (Decibel)	50%	20%	15%	28%
Percentage less comfortable with Millibar than Decibel	0%	0%	0%	0%
Percentage less comfortable with Displacement than Velocity/Frequency	5%	0%	20%	8%
Percentage equally comfortable with Millibar and Decibel	20%	35%	10%	22%
Percentage equally comfortable with Displacement and Velocity/Frequency	65%	85%	30%	60%

1.4.5. Further Definition with Pilot Surveys. During the course of the St. Charles interviews, several questions arose as to the choice of wording and units of measurement chosen for the survey. The importance of choosing the correct wording and units became evident through further interviews. As discussed in earlier sections, the choice of millimeters as the unit for displacement may have forced lower comfort levels than would have been seen using the more common U.S. unit of inches. Other pilot surveys were administered to various employees of the University of Missouri at Rolla who did not have a technical background. These surveys replaced question #10 with the following question:

Q10. When blasting commences how comfortable are you with ground vibrations causing a displacement of 0.00197 inches at your home?

Although only a limited number of interviews were collected, a trend was starting to become evident. Comfort levels trended higher with inches than those with millimeters as the unit for displacement. Later surveys investigated the questions raised by this limited distribution.

Another set of data was collected at the beginning of an introductory explosives engineering class. This group had a strong technical background in engineering, as most students were in the third year of studies for a bachelor's degree in engineering. The group had not been exposed to vibration and airblast units in the class to this point, but the comfort levels were quite high relative to the averages for the results discussed to this point. This higher comfort level shows that familiarity with the units being used may have created higher comfort levels regardless of the knowledge of blast-induced vibration and pressure. To investigate further, surveys were later distributed to a group of technical people. These surveys are discussed in detail in later chapters of this dissertation.

The pilot surveys provided a base of information that prompted more research to discover what people are most comfortable with. Our industry has a great opportunity to harness the power of positive public relations, and taking steps to quell the public's discomfort with blasting in general can only help.

1.4.6. Conclusions from Pilot Survey. With the limited scope of the pilot survey, there were no definite answers. This characteristic is something typical when dealing with human subjects. Nevertheless, many strong relationships can be seen in the data. Without question, the surveys show that more research is necessary to determine what the correct path is concerning a public relations policy for the explosives industry. The overall low comfort values (all averages found to be Neutral or less) prove that more needs to be done in the way of educating the public on the mining and blasting industries' methods. Data also shows that using more easily understood units of measurement might help the public become more comfortable with blasting operations near their homes. Specifically in the case of using decibels for airblast pressure, not one person was less comfortable with the alternative linear unit of measurement. More research was also needed to determine whether millibars would be preferable to PSI or some other pressure unit. The same can be said for the use of velocity and frequency for vibration reporting. Average comfort levels were still marginally higher with the use of a simple displacement term. The use of inches instead of millimeters may be another way of increasing comfort levels in that respect. A final conclusion is that a small amount of public relations can increase comfort levels as well. The newly developed neighborhood in St. Charles, which was exposed to a public relations effort, showed higher comfort values than the established neighborhood where it is likely that little or no public relations were used in the beginning of the development there.

Throughout the remainder of the dissertation, comments regarding surveys will be in reference to the surveys designed and administered following the pilot survey discussed here. Pilot results provided evidence that this type of research is worthwhile to pursue. The pilot survey also provided critical direction for the later surveys. Finally, the pilot study provided preliminary indications of what may later be proven with the further research described in this dissertation. Later sections will provide detailed information regarding survey pool selection and distribution, statistical analysis of the collected data, and concrete conclusions drawn from the data. Spreadsheets containing unformatted data from the pilot survey are included on a CDROM in Appendix F.

2. REVIEW OF PREVIOUS WORK

2.1. MINING AND BLASTING RELATED LITERATURE REVIEW

There is no shortage of publications on the environmental effects of blasting. Many scientists and mining professionals have dedicated years of their lives to researching what effects are caused by the use of explosives. The same can be said for those who have studied the potential for damage to structures due to these environmental effects of blasting. The focus of this review has been to find publications related to airblast and ground vibration from typical rock blasting applications. The goal of the review was to determine the extent of research that has been performed on the subject of public perception of the reported values for airblast and ground vibration.

The majority of the literature over the past 20 years can be placed into five main categories. These categories are:

- Predicting ground vibrations and airblast readings through scaling and attenuation
- Structural response to airblast and ground vibrations
- Methods for reducing airblast and ground vibrations
- Human perception of vibration
- Interfacing with the public

The following subsections provide thorough reviews for each bullet item in the above list. Research in these areas has governed publications on ground vibration and airblast. Whereas the first three bullets have been widely researched to this point, work on the later two bullets has to date been very sparse. Wherever possible, the most current research is included in the literature review; however, much of the classical work has been proven through time and still represents the standards.

2.1.1. Predicting Ground Vibrations and Airblast Readings Through Scaling and Attenuation. A common practice for predicting ground vibration is to use scaled distance. This is an equation for predicting vibrations based on an explosive weight per delay basis. The Office of Surface Mining (OSM) utilizes a standard scaled distance formula when requiring the use of a seismograph for monitoring. OSM cites a scaled distance equation as follows:

$$W = \left(\frac{D}{D_s} \right)^2 \tag{2.1}$$

where:
W = Maximum Weight Per Delay (minimum 8 ms delay)
D = Distance to Nearest Structure
D_s = Scaled Distance

The scaled distance equation is a frequently used standard; however, the physical description of the equation is more subtle. The equation provides a weight per delay that would produce a PPV at a distance D from the blast equivalent to the PPV that would be generated by a 1 pound confined charge at the Scaled Distance, D_s (Worsey, 2005).

According to 30CFR Sec. 817.67, this scaled distance formula can be used as a guideline for the requirement for seismic monitoring. The regulations say that a scaled distance of 50 must be used when structures can be found between 0 and 300 feet. When structures fall between 301 and 5,000 feet, a scaled distance of 55 must be used. For structures at a distance of greater than 5,000 feet, a scaled distance of 65 must be used. Greater values for scaled distance are required when structures are further from the blast because the equation only scales PPV. As ground vibrations travel greater distances, the frequencies tend to become lower, and thus a lower PPV is necessary to ensure that the PPV and frequency produced still fall under the Z-curve in Figure 1.2.

These equations and values come from original research performed through the Bureau of Mines under Siskind and were published in 1980. Nicholls introduced the concept of scaled distance in Bureau of Mines Bulletin 656 (Nicholls, 1971). Siskind followed up on the initial work described in Bulletin 656 and expounded on it. He found that blast design differences had little effect on vibration, and that the most effective way to predict vibration was to use the maximum charge weight within any 8 millisecond delay. He proposed a similar scaled-distance formula which was the basis for the OSM regulations (Siskind, *et. al.* A, 1980). More currently, Kahriman (Kahriman, 2002) and Mclellan (Mclellan, 2001) both published their own case studies for using a modified scaled-distance formula. They utilized site-specific data to do so.

Many different locations around the world require the use of scaled-distance calculations for blasting operations. Most countries utilize either a square root law or cube root law. The United States follows a square root law as shown in Equation 2.1; however, many European nations employ a cube root scaled-distance equation (Lees, 2006).

Blair (Blair, 1999) published a wider applicable method for ground vibration predictions utilizing a statistical model. Much of the recent research has been defined by narrow scopes of site specific projects and, thus, is not reasonable for establishing global policy.

2.1.2. Structural Response to Airblast and Ground Vibrations. Many researchers have undertaken the task to understanding how different structures respond to airblast and ground vibration from blasting. It has long been known that structures have a resonant frequency at which the ground vibration is amplified. In the same work that prompted OSM regulations from 1980, Siskind (Siskind, *et. al.*, 1980 A) determined safe blasting levels for residential structures by testing and monitoring. He emphasized the relationship between Peak Particle Velocity (PPV) and frequency when considering damage criteria. He found safe PPV levels from blasting for drywall structures and plaster over wood for frequencies higher than 40 Hz and lower than 40 Hz. His study showed that for frequencies above 40 Hz, a PPV of 2 inches per second would be safe as a conservative estimate. He also found that for low frequencies (<40 Hz), a PPV of 0.5 inches per second was safe for plaster walled homes and a PPV of 0.75 inches per second would be safe for drywall structures (Siskind, *et. al.*, 1980 A). For a visual representation of the limit, refer to Figure 1.3. Again, these limits were utilized by OSM for regulations when seismic monitoring is required according to scaled distance.

Siskind (Siskind, *et. al.*, 1980 B) also published information concerning response and damage caused by airblast from surface mining. He concluded that safe levels of airblast also were frequency dependent. Siskind's recommendations for airblast limits are tabulated as follows: For 0.1 Hz or lower, flat response, the peak limit should be 134 dB. For 2 Hz or lower, flat response the peak limit should be 133 dB. For 6 Hz or lower, flat response, the peak limit should be 129 dB. For C-weighted, slow response, the peak limit should be 105 dBC (Siskind, *et. al.*, 1980 B). OSM adopted these limits exactly for 30CFR 816.67.

Other researchers have performed research about the vibration response of the actual structure. As opposed to earlier research involving vibration measurements of the ground near structures, Svinkin (Svinkin, 2003) suggests monitoring the vibration of the structure. Others have studied the factors that control structural response. Moore (Moore, 2003) discussed the response and damage criteria for brick veneered structures. He notes that even at PPV's in excess of 8 inches per second, damage is limited to interior drywall cracks that are "easily filled." Lucca (Lucca, 2006) discusses how other events such as slamming doors and thunderstorms cause structural response well in excess of what current blasting practices call for. He measured response from slamming a door at different locations in the house. The vibration levels recorded exceeded 7 inches per second three inches above the door, and were even over .6 inches per second on the floor near the door. He still advises a conservative PPV limit of 0.3 inches per second in the urban area discussed in the paper due to contractors' ability to achieve it without undue hardship.

2.1.3. Methods for Reducing Airblast and Ground Vibrations. In the blasting industry, methods for reducing airblast and ground vibrations are always of interest. There are two basic categories of research that focus on this goal. These methods are blast design and manipulation of seismic input through innovative use of timing.

Blast design is the first method. Petro (Petro, 1986), as quoted earlier, reveals that complaints do not always mean that a regulation was broken. In the same paper, he continues to describe an effort to reduce low frequency vibrations. There is no information included regarding the perception of the blasting by the complainants.

Starting in 1975, the ISEE began holding conferences on explosives and blasting technique. From the beginning these conferences served as a place for explosives engineers to share ideas on proper blast design for a variety of applications. There are a wealth of publications, too many to cover, which refer to hole size selection, pattern selection, hole loading, as well as a variety of other blast design factors. The basis for these publications come from specific applications, and each share similar scientific ideas for designing blasts to perform in a manner that suits the application. Other methods for improving blast design include using technology such as stemming plugs and more accurate drilling.

Much work has been published concerning the manipulation of seismic input through innovative timing design. Worsey (Worsey, 1983) began research on high accuracy electronic detonators in 1982 and was one of the first to patent such devices. He saw a need for better accuracy in blast design. The chemically delayed detonators commonly used still today have much deviation in timing that can be detrimental to blast design. Konya (Konya, 1987) discusses the use of electronic detonators to accurately design delay systems for the reduction of ground vibration and airblast. In reviewing this paper, one must keep in mind that it was published nearly 20 years ago. As the costs for electronic detonators continues to fall with mass production and less expensive components, more research is being performed to determine methods for causing wave interference for vibration reduction.

An interesting phenomenon is developing in the research as of late. Many researchers are beginning to once again investigate the possibilities of using high accuracy detonators to produce anti-resonant frequencies in production blasting.

Crenwelge (Crenwelge, 1988) introduced the concept in 1988. He discusses the use of single holes to characterize ground vibration transmission characteristics. Without the aid of highly accurate detonators, further research was limited until electronic detonators became more accessible. This practice is just now being realized as a valuable tool; however, there are problems with using the technique for overall blast vibration reduction. Often, if vibrations are reduced through this method at the measurement point, much higher vibration levels can be experienced at other locations not being measured. What this means is that protecting specific structures in close proximity to blasting is possible at the expense of higher vibrations elsewhere surrounding the blast area. Lusk (Lusk, 2006) revisited the concept for protecting a municipal water supply in Springfield, Missouri. He discusses the use of electronic detonators to create destructive wave interference and thus reduce ground vibration levels at the water supply towers. By optimizing the delay time through characterization of single hole traces, the vibration levels were reduced over 40% at the water towers which were 80 feet directly above the underground blasts.

Similar to Konyas's work, Blair and Armstrong (Blair and Armstrong, 1999) talk about controlling vibration through the use of electronic detonators in 1999. Rudenko (Rudenko, 2002) claims that many actions taken to reduce ground vibration actually cause them to be higher. He speaks of designing the timing of the shot to cause wave disturbance and thus reduce vibrations. Now that the breakthrough technology envisioned in the early 1980's is readily available, major advances in practical application of this technology are imminent. As blasting design undergoes the transformation to newer technology, realignment of regulations pertaining to its use should not be an afterthought.

2.1.4. Human Perception of Vibration. Consideration of how humans perceive vibration is an important concept in the realm of the proposed research topic. Research has shown that the response of humans to vibration is much different than the response of structures to the same vibration. Siskind's (Siskind, *et. al.*, 1980 A) work in 1980 discusses how human tolerance corresponds with structural response. He found that humans were more affected by high frequency vibration as opposed to the low frequency response in structures. A figure in an Army Corps of Engineers technical letter shows that humans find vibration of 1 inch per second at approximately 20 Hz intolerable. The intolerable line comes down to nearly 0.5 inches per second at 60 Hz (Department of the Army, 1989; Department of the Army, 1972). Both of these vibration levels fall well below the vibration limits set by OSM as safe to structures. Figure 2.1 shows how human tolerance and response follows a trend that is opposite that of Siskind's Z-curve. The figure is an approximate recreation of a figure in an Army Corps of Engineers Manual with Siskind's Z-curve overlaid (Department of the Army, 1972). The figure shows lines developed through steady-state vibration testing with humans and does not consider the transient nature of blast vibrations. According to the technical letter, these human tolerance levels were established in 1949. The idea presented here confirms that despite the blasting industry's best efforts to create vibration levels that are acceptable to neighbors, a paradox exists. In order to make vibrations safe for structures, frequency targets are high. This creates a human-tolerance problem and has subsequently created complaints of another nature. The answer to this intriguing problem must be to determine a proper method for educating all interested parties (public, regulators, administrators, blasters) on the nature of vibrations from blasting.

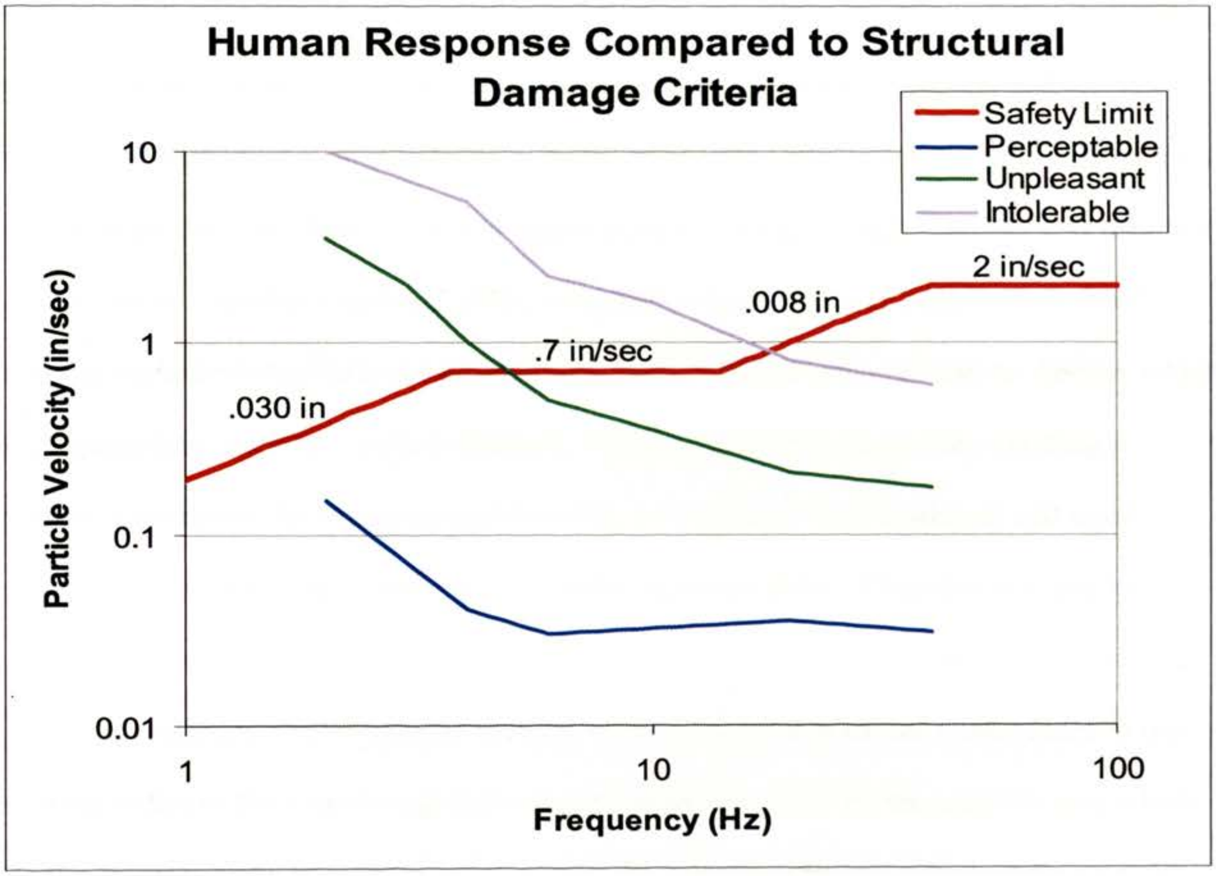

Figure 2.1. Human response compared to structural damage criteria.

2.1.5. Interfacing With the Public. There has been limited research on how to properly interface with the public. Even fewer have attempted to tackle the question of how blasting is perceived. Aimone-Martin (Aimone-Martin, 2000) published information in 2000 about a successful blast design, monitoring, and public relations effort. The paper discusses the successes of the operator in dealing with regulations and complaints, as well as reducing the effects of blasting. Also in the paper is an astounding, but questionable quote. "The 'annoyance' impact is one based on emotion and disposition and cannot be measured" (Aimone-Martin, 2000). However, "annoyance" impact can be measured by determining what causes people to complain. This is valuable information that cannot be discarded so easily. Barron (Barron, 2003) suggests that good public relations can be achieved in many ways through the everyday policies of the company. She also suggests that keeping ground vibration and airblast to an absolute minimum is imperative for quality relations. This is a key element to success since companies don't have to overly shake people's homes simply because it is legal for them to do so. Spathis (Spathis, 2005) published information and suggestions about creating consistent regulations and reporting units, but makes no attempt to discuss which are appropriate. In 1985, Siebert (Siebert, 1985) discussed a method for creating a positive experience for blasting operations by cooperation with regulators and open communication with the public and regulatory agencies alike. This idea is a quality concept. However, a two-way communication with the public could add to its validity.

A relatively new emphasis has been communicated in recent conferences in the blasting industry for a more aggressive public relations effort by the industry as a whole. On the frontier is the possibility of marrying the massive amounts of scientific research undertaken over the past 30 years with an effort to communicate intentions to the public. In order to accomplish this goal effectively, a robust medium for this communication must be developed.

In 2006, ISEE offered a public relations seminar at their annual conference for blasting related public relations. The topics covered included tips for meeting with property owners, face to face greetings during blasting operations, and insurance consequences of complaints (ISEE, 2006).

2.2. STATISTICAL METHODS FOR ANALYZING CATEGORICAL DATA

The process of analyzing and correlating data collected through interactive surveys poses several expected difficulties. Planning and forethought can help to curb the adverse effects of these problems, as detailed below.

When dealing with public perception, it is difficult to acquire absolute certainty about what the data means. In order to adequately understand the results of the surveys, a thorough statistical analysis of the data is necessary. To remedy this difficulty, the common methods for quantifying perception through surveys have been reviewed. During a seminar about research on teaching and learning in engineering in March, 2005, Felder (Felder, 2005) provided an excellent example of why surveys involving human perception can be difficult. One of the presentation slides says:

> Students are not like I-beams. They're not even like fruit flies. An infinite number of internal & external factors affect their performance (confidence, motivation, personality, learning style, prior background & experience ...). Therefore, there is no such thing as a clean controlled educational research study. Forget about $p<.001$: go with $p<.05$ or even $p<.1$ and rely heavily on replication with different populations. (Felder, 2005).

This idea can be easily applied to the public perception of blasting issue. The key to positive public relations is the education of the public, and this quote helps to identify the difficulties in quantifying perception and understanding. Teachers are forever striving for accurate and worthwhile assessments in classes. The effort should be no different for the blasting industry concerning its neighbors. Much of the survey data that was collected utilized the Likert scale for obtaining a quantitative value for a qualitative question. A search for appropriate scaling methods revealed that the Likert scale is appropriate for quantifying perception-type data (Likert, 2006). This is a widely accepted method for accomplishing this; however, analysis of the results is a much-debated topic.

Halpin (Halpin, 2002) defines categorical data as consisting of variables with a finite number of values, or rather a small number of discrete values. He also states that categorical data can only take a few forms. The forms he lists are nominal, ordinal, interval, and ratio.

Nominal data is that from open-ended questions where there are a limited number of responses that can be placed in categories. Examples of this would be questions of sex. There is no order to the data, but categories can be distinctly different.

Ordinal data is nominal data that is forced into ordered format. For perception type questions, the only way to obtain this type of data is to implement a scale such as Likert. Another example would be ordering political preference from left to right with a numbered scale (Schwarz, 2006).

Interval data is ordered as well, but this type of data will have no natural zero. A temperature scale would generate this type of data (Schwarz, 2006).

The final data type to discuss is ratio data. This type of data comes from questions like age, height, and weight. The scale for this data is also ordered, but has a natural zero point (Schwarz, 2006).

The data collected from the surveys distributed for this research mostly falls into the ordinal data group. The comfort level questions used a Likert scale ranging from 1 to 5, creating 5 categories for the values of the data. For the stated goals of this dissertation, advanced statistical analysis of the data for correlation purposes is not necessary. Trends can be drawn from descriptive statistics using means, distributions, and population percentages. A quote from a journal article by Clason (Clason, 2006) shows the acceptance of this approach. They compiled and analyzed several volumes of the *Journal of Agricultural Education* and found a multitude of articles covering Likert-scaled data. This quote shows the percentage of articles reporting only descriptive statistics:

> The Journal of Agricultural Education published 188 research articles in Volumes 27 through 32. Responses to individual Likert-type items on measurement instruments were analyzed in 95, or more than half, of these articles. After reviewing the articles analyzing individual Likert-type items, 51 (54%) reported only descriptive statistics (e.g., means, standard deviations, frequencies/percentages by category). Paired Likert-type items or sets of items were compared using nonparametric statistical techniques (e.g., chi-square homogeneity tests, Mann-Whitney-Wilcoxon U tests, Kruskal-Wallis analysis of variance tests) in 12 (13%) of the articles. Means for paired Likert-type items were compared using parametric statistical procedures (e.g. t-tests or analysis of variance F-tests) in 32 (34%) of the articles. (Clason, 2006)

The breakdown of articles described in the quote above places merit on data that is solely evaluated using descriptive statistics. Further research may look deeper into the correlations available in the data; but in this original case, advanced correlation equations are overkill.

One point does need to be addressed about the analysis of data for conclusions. With categorical data such as the Likert data collected here, averages are virtually meaningless without distributions. A simple example can show that this is the case. A population with average comfort of 3 could be obtained in several ways. The nature of the distribution can tell more about the data than the average alone. Consider a case where half of the responses were 1 and the other half were 5. This case gives an average of 3 but is entirely different from a population entirely made up of responses valued at 3

(Clason, 2006). Categorical data can also be analyzed efficiently through tabulation. Tabulation retains all the information in the data, and assures clearer presentation of the data structure (Halpin, 2002) Another quote from Adams, Fagot, and Robinson (Adams, 1965) regarding Likert-type data states that it is up to the researcher to determine what statistical means are required to fulfill the goals of the research:

> Nothing is wrong per se in applying any statistical operation to measurements of given scale, but what may be wrong, depending on what is said about the results of these applications, is that the statement about them will not be empirically meaningful or else that it is not scientifically significant. (Adams, 1965)

After a thorough review of literature concerning the analysis of Likert or categorical data, the decision was made to simply apply descriptive statistics to the data in order to serve the goals of the research. The remaining question was how to validate the data. Further review found that several methods are possible for doing so.

On initial review, it seems that validating data is as widely debated as analyzing it. Walonick (Walonick, 2000) regards the validity of data as a judgment by the researcher. A quote from his book shows his opinion on data validation.

> Validity refers to the accuracy or truthfulness of a measurement. Are we measuring what we think we are? This is a simple concept, but in reality, it is extremely difficult to determine if a measure is valid. Generally, validity is based solely on the judgment of the researcher. When an instrument is developed, each question is scrutinized and modified until the researcher is satisfied that it is an accurate measure of the desired construct, and that there is adequate coverage of each area to be investigated. (Walonick, 2000)

Others have also struggled with the concept of validating this type of data. Spector (Spector, 1981) explains, "Validity itself is a simple concept, but the determination of the validity of a measure is elusive" (Spector, 1981). Most sources recommend validation by some type of internal consistency. For single questions, this would mean that arbitrarily splitting the population would provide a similar percentage-wise distribution. For sets of data including a series of questions testing a single construct, internal consistency would include correlations between questions. This type of validation is known as the "split-half reliability." Problems associated with split-half reliability can be explained by considering the differences in how each data set could be split. There is a certain probability that the split creates the worst possible scenario for correlation. Likewise, the set could be split in a case creating the best possible correlation. Walonick (Walonick, 2006 B) suggests the use of a statistic known as Cronbach's Alpha. Based on average inter-item correlation, Alpha provides, in most cases, a lower bound for the validity of ordinal categorical data such as Likert (Carmines and Zeller, 1979). Methods such as test-retest and equivalent-form were also suggested by Walonick (Walonick, 2006 B), but both involve either running the entire survey a second time or developing an equivalent instrument for measuring the same construct. Both methods were deemed prohibitively expensive.

A similar statistic known as the KR-20 (Cronbach Alpha, 2006) can be used for dichotomous data. The KR-20 actually precedes and was the basis for Cronbach's Alpha, which is its non-dichotomous equivalent.

Kitchenham (Kitchenham, 2003) also suggests the use of Cronbach's Alpha for the assessment of reliability in ordinal data. The article goes on to discuss the fact that ordinal Likert-type data will often times not return normalized data; thus the results of analyzing data with statistical tools developed for handling normalized data can be misleading (Kitchenham, 2003).

Siegle (Siegle, 2006) from the University of Connecticut suggests that there are three statistical methods for measuring internal consistency as a component of reliability. Like the others above, he recommends the use of Cronbach's Alpha in conjunction with the Split-Half reliability test. Cronbach's Alpha and the Split-Half reliability test have been discussed at length above. Siegle published a formatted Excel spreadsheet on his website that allows for the analysis of Likert-type data. The spreadsheet calculates the values of all three statistics.

After evaluation with descriptive statistics, the data from this research was subjected to Cronbach's Alpha analysis and the Split-Half reliability test using Siegle's spreadsheet. Detailed coverage of the descriptive statistics as well as the results of the Alpha calculations can be found in sections 4 and 5 of this dissertation.

Perceptual mapping was discovered as a possible tool for evaluating perception type data. It is a tool that has been used for many years for marketing purposes where consumer data can be plotted to show how consumers feel about certain products. An example can be shown for car companies. Through data collection a company might determine that consumers feel that the company's vehicles are conservative and practicle. If the car company wishes to market a high performance vehicle, they may want to target marketing to shift this perception to sporty and classy to capture a different market (Perceptual mapping, 2006). A similar idea could be applied to reporting units in future studies.

2.3. SIMILAR RESEARCH

Review of current literature yielded very little information regarding work that is similar to what is discussed in this dissertation. While this shows that the work is indeed original, the absence of other similar work causes difficulty in comparing results to other studies. One group of British researchers at the University of Leeds, United Kingdom are undertaking research that will provide some correlations to how blasts are perceived from within homes near blasting operations. The research will consist of placing instrumentation for measuring response to blasting in the living areas of homes but will also consider a psychological component of the perception. The researchers are obtaining good data through the use of detailed interviews with residents. The interviews are being conducted and analyzed by psychological and social-science experts within the University of Leeds. No information has been published to date, but the study is ongoing and plans for publications in 2007 are set (Pegden, 2006).

3. RESEARCH PROCESS

3.1. APPROACH TO AND PLAN FOR RESEARCH

A well defined approach was required for the research topic. Figure 3.1 shows the research flow diagram outlining the tasks required to obtain the goal of determining the best possible reporting methods, and their subsequent effects on regulations. The process began with topic selection and progressed through the writing of this dissertation. The following section describes the individual components of the research flow diagram as a process for performing research.

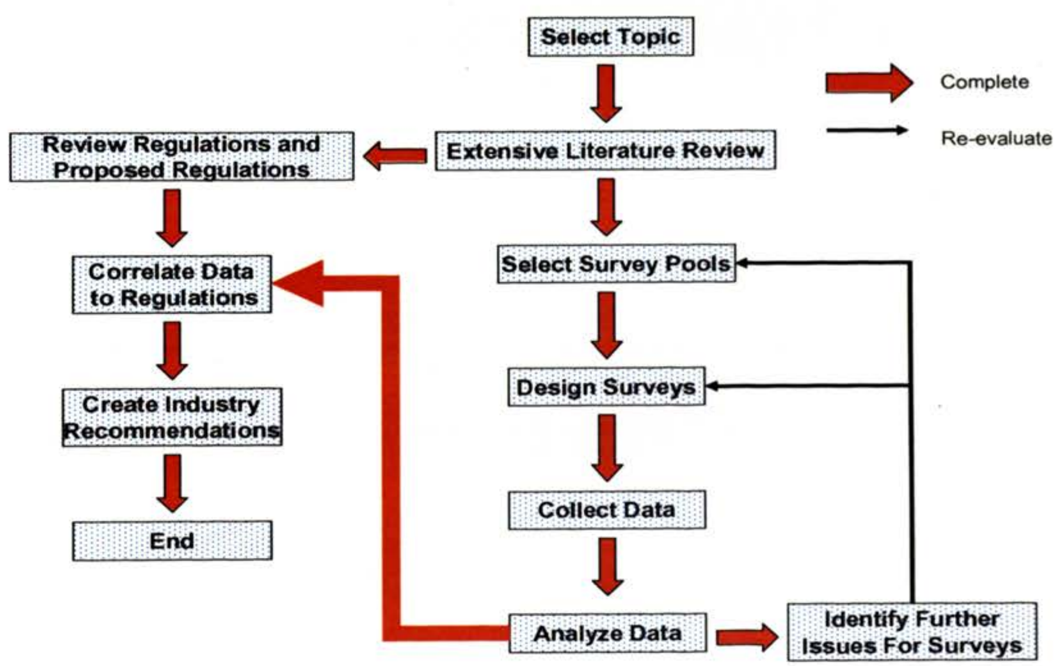

Figure 3.1 - Research flow diagram.

The following section headings directly refer to the research flow diagram in Figure 3.1. Sections describe items in the order shown in the figure.

3.2. EXTENSIVE LITERATURE REVIEW

A comprehensive literature review was completed using publications covering ground vibrations and airblast in several different categories. A review of statistical methods for analyzing and validating data similar to that collected for this research was also performed. While there were numerous publications covering all technical aspects of ground vibration and airblast, there is a definite shortage in the area of the selected dissertation topic. Considering the importance of this subject and with so little research completed, the topic is an ideal candidate for a thesis which is hoped will lead to a positive difference in industry practices as well as facilitate a great advance in this area. The complete literature review can be found in Chapter 2 of this dissertation.

3.3. SURVEY POOL SELECTION

A critical step in the research process was to determine appropriate survey pools. Five distinct pools were identified. They are as follows:

- Alpha Group – Public in proximity to blasting operations
- Beta Group – Control groups of the public who are not exposed to blasting
- Gamma Group – Civil Engineers
- Delta Group – Blasting Professionals
- Epsilon Group – Local and State regulators and administrators

These survey pools were selected in order to obtain a view from each perspective involved in the regulation process. The residents living in close proximity to blasting operations were surveyed in order to find possible reasons for low comfort levels with blasting. A control group of residents who are not exposed to blasting were surveyed as a control group that is not affected by blasting. This could provide insight as to how certain public relations policies are working. Civil engineers are included to provide a strong scientific basis for damage criteria as these are the people who design and build the structures. A group of blasting professionals was also subjected to a survey to identify differences in their responses to the other groups as these are the individuals who would likely be the most comfortable with all units for reporting blast vibrations. Local and State regulators and administrators are a separate group because they will have different perspectives on the issues. They are ultimately responsible for politically dealing with citizens that complain about blasting. An attempt to quantify Regulators' lack of understanding through surveying a group comprised completely of Regulators is discussed in further chapters.

Results of analysis of the different groups shows that each group has a very different perspective concerning blasting. These differences are discussed at length in chapter five. These differences affect the way each constituent group interacts with the other groups and, thus, creates a communication barrier. This research is a completely novel approach in blasting, and therefore, potential for positive impact is high. Sample selection of each group will be specifically discussed in later subsections, but the overall methodology for selecting samples is discussed immediately below.

Prior to discussing the selection of survey pools, a review of pertinent sampling methods is in order. Sampling methods can be classified as either probability or nonprobability. For probability sampling, there must be a known probability of each member of a given population being selected (Walonick, 2006 C). For the case of the research discussed in this dissertation, probability sampling simply was not possible. There was no way of identifying an entire population of subjects for each of the groups, much less assigning a probability to their selection. This leaves non-probability sampling for the selection of survey pools. Non-probability sampling occurs in any case where the researcher introduces non-randomness to the sampling. By nature, survey pools for specific groups trend towards non-probability sampling (Walonick, 2006 C). A random sample would require the awareness of every member of the population of that group. As an example, consider local and state legislators. The task would be daunting to collect a list of every person involved with this kind of position in the U.S., or even the State of Missouri. The other groups listed above would require similar lists to achieve true random probability sampling.

One advantage for using probability sampling is the ability to calculate sampling error. The sampling error is generally stated as plus or minus the resulting measured value. “Sampling error is the degree to which a sample might differ from the population” (Walonick, 2006 C). “In non-probability sampling, the degree to which the sample differs from the population remains unknown” (McDaniel and Gates, 1991). For this reason, no sampling errors were calculated for the data collected. For closure on this issue, a quote from Taylor (Taylor, 1998) closes things nicely:

> "random sampling error" -- or the likelihood that a pure probability sample would produce replies within a certain band of percentages only because of the sample size -- is one of the least of our measurement problems. The main problems of survey measurement, or more accurately mismeasurement, include...

The article continues to discuss various nonsampling errors such as survey design and sample selection (Taylor, 1998).

Only a few types of non-probability sampling methods can be characterized. Convenience sampling is often used for researchers wishing to determine an approximation for the truth. The sample is selected in this method due to convenience. Judgment sampling is truly a form of convenience sampling where the researcher makes a judgment concerning the representative nature of the selected sample. In this case, the survey pools were selected using both convenience and judgment sampling. The survey pools selected came mostly from the states surrounding Missouri for convenience, and judgments were made as to the representative nature of the samples by the researcher. The survey pool selection is outlined in detail in the following sections.

3.3.1. Alpha Survey – Public in Close Proximity to Blasting Operations. In order to select survey pools for the Alpha Survey, quarries within a few hours drive of Rolla, Missouri, were selected based on internet searches of aggregate operations, as well as from first-hand knowledge of the nearby quarry locations. Three target geographical locations were selected as a starting point, and two quarries from each area were located. Quarries near St. Louis, Missouri; Springfield, Missouri; and Little Rock, Arkansas, were identified, and neighborhoods were targeted through the use of "Google Earth"©. "Google Earth"© is a free software program that supplies aerial photos of much of the United States. The following figures will show the locations of the survey pools for the Alpha Survey.

3.3.1.1 Alpha Survey – St. Louis, MO. Figure 3.2 is an aerial view of the St. Louis area pointing out the locations of the two quarries surveyed there. Both quarries were in the southern portion of the St. Louis area.

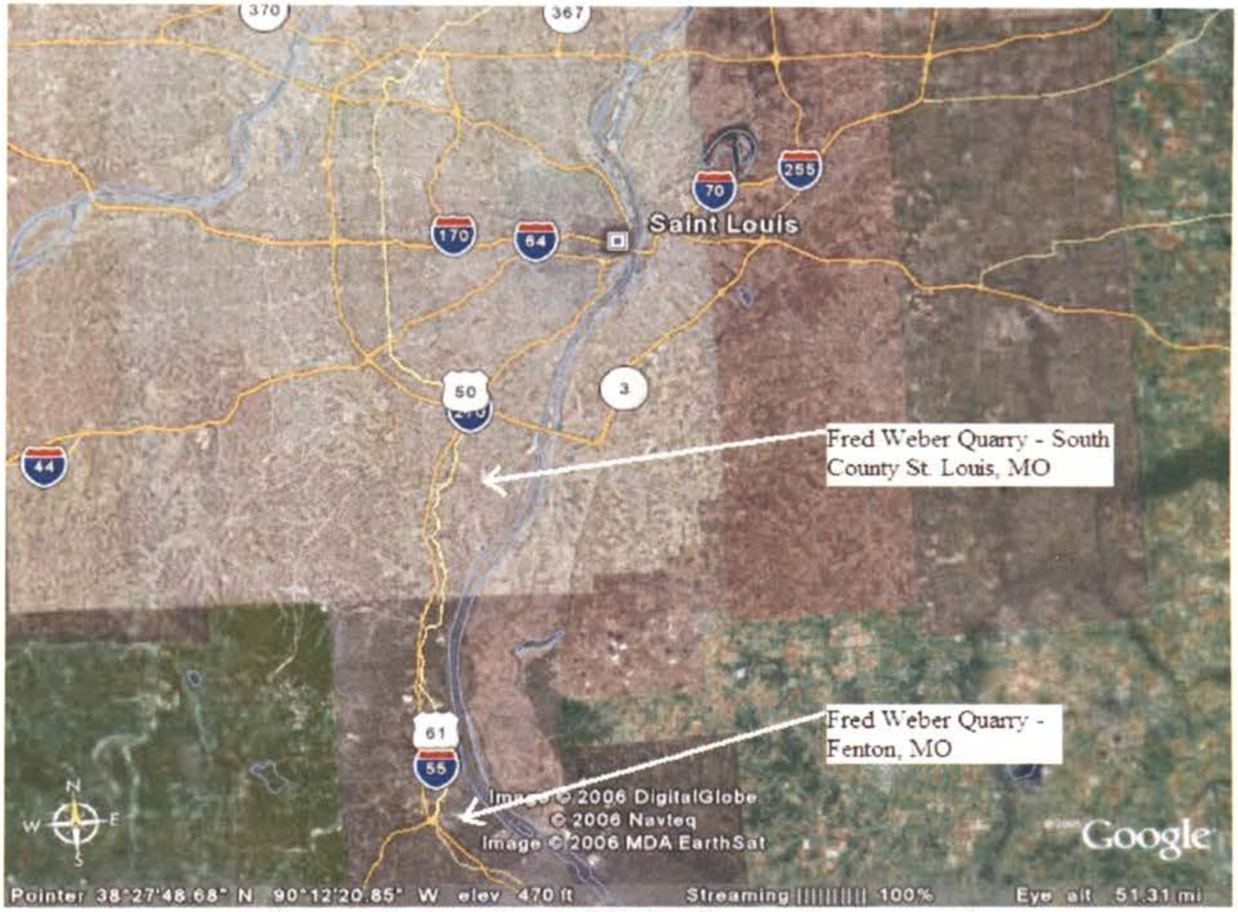

Figure 3.2. Locations of St. Louis quarries surveyed.

Figure 3.3 shows a quarry in south St. Louis County, Missouri. This quarry location has a massive amount of development surrounding it. Surveys were distributed throughout the neighborhoods surrounding this quarry.

Figure 3.3. Aerial photo showing a south St. Louis County quarry operation and its surrounding neighborhoods.

Figure 3.4 shows a second quarry selected for survey targeting south St. Louis. This quarry is located in Fenton, Missouri, which is only a few miles outside of St. Louis. The aerial photo shows that this quarry is somewhat more remote than the quarry in Figure 3.3. Only a limited number of surveys could be distributed around this quarry, but there were still a number of neighbors within 1 mile of the property.

Figure 3.4. Aerial photo showing quarry in Fenton, Missouri.

3.3.1.2 Alpha Survey – Little Rock, AR. The next set of figures will show the location and orientation of selected quarries in Little Rock, Arkansas. In this case, two quarries sandwich a neighborhood, but each has other neighbors that aren't shared. The two large quarries/mining operations are separated by less than two miles. Figure 3.5 shows the locations relative to major highways in Little Rock.

Figure 3.5. Locations of Little Rock quarries surveyed.

Figure 3.6 shows the Granite Mountain Quarry and its proximity to surrounding neighbors. Many surveys were distributed among the neighbors of this operation.

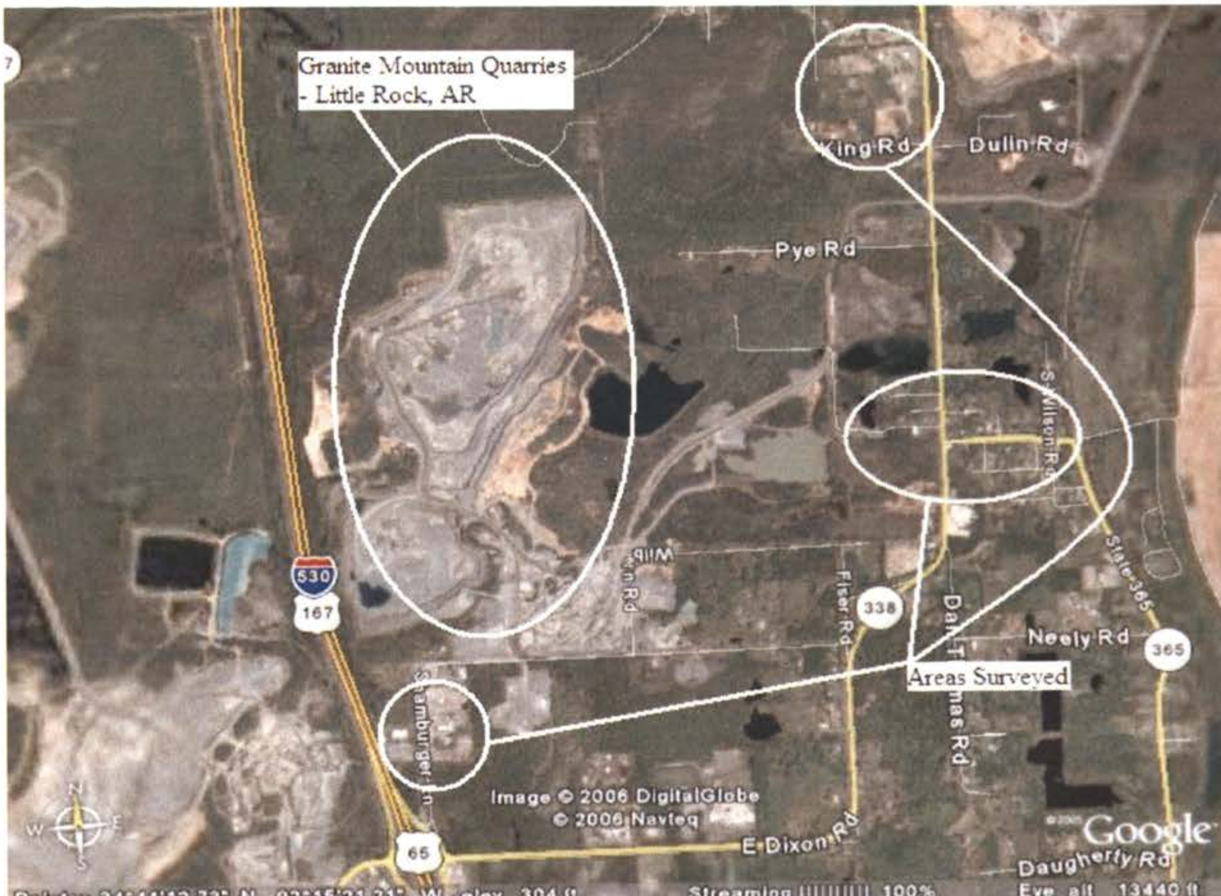

Figure 3.6. Aerial photo of Granite Mountain Quarries and surrounding neighborhoods in Little Rock, Arkansas.

In Figure 3.7 a 3M quarry less than two miles northeast of the GMC quarry in Figure 3.6 is shown with its orientation to surrounding development. A number of the neighbors shown in Figure 3.7 are less than one mile from both GMC and 3M.

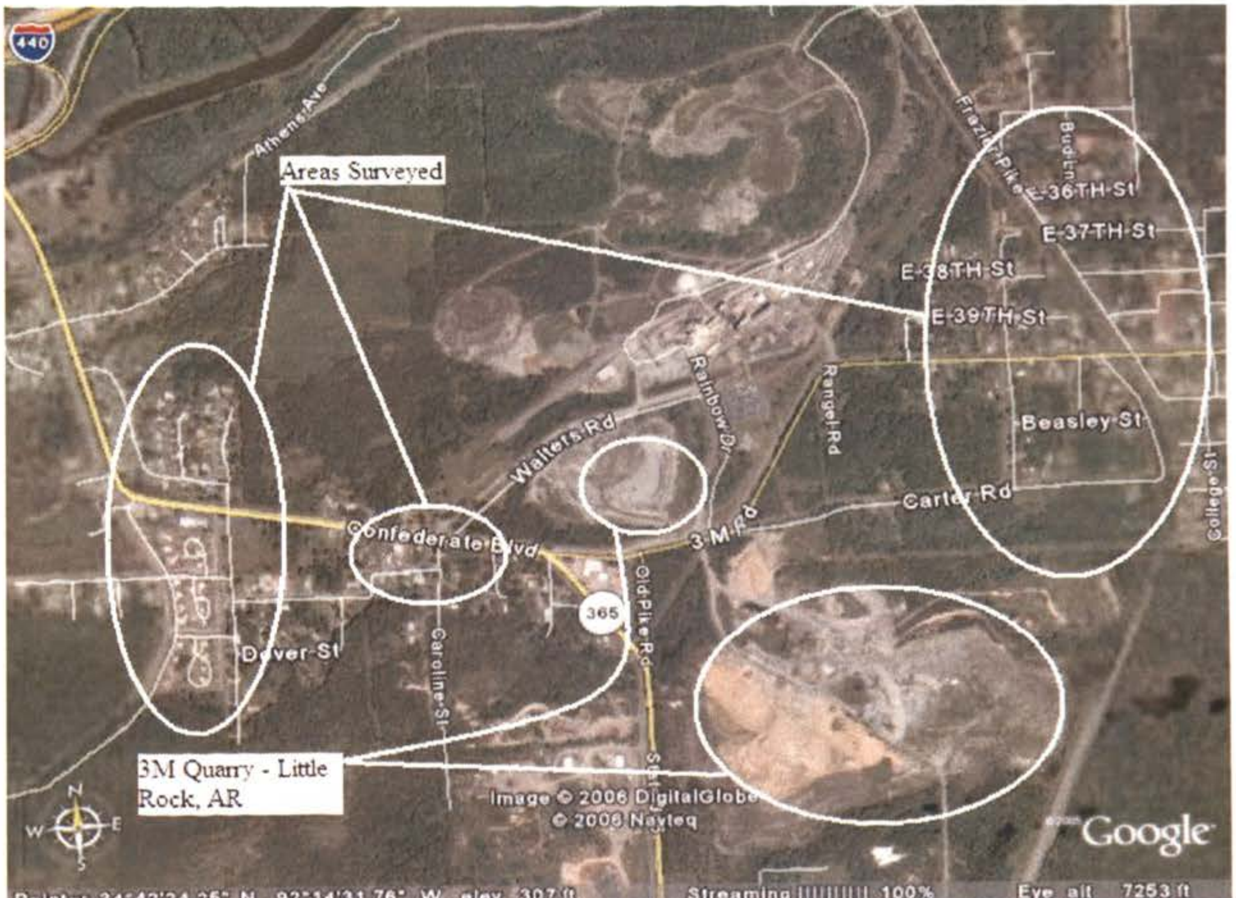

Figure 3.7. Aerial photo of 3M quarry in Little Rock, Arkansas.

3.3.1.3 Alpha Survey – Springfield, MO. The final geographic location selected for Alpha Surveys was Springfield, Missouri. Figure 3.8 shows the relative locations of the two quarries surveyed there.

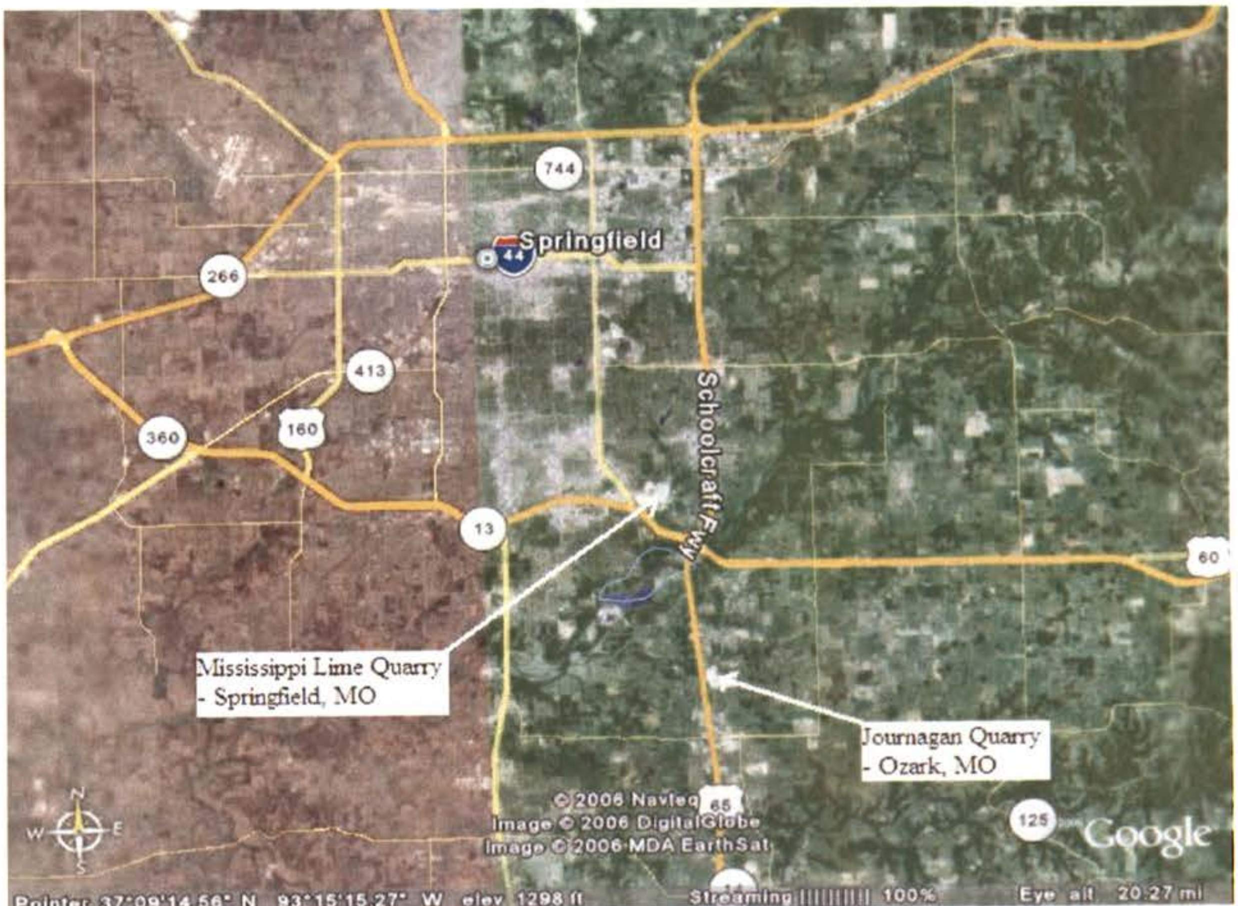

Figure 3.8. Locations of Springfield quarries surveyed.

Figure 3.9 is an aerial photo of a Journagan Quarry in Ozark, Missouri, which is only a few miles south of Springfield. This quarry was relatively remote; however, there was a fairly recent development just north of the operation. Also, several rural neighbors were included in the survey.

Figure 3.9. Aerial photo of Journagan quarry in Ozark, Missouri.

The final quarry selected for the Alpha Survey pool was in Springfield, Missouri. Figure 3.10 shows the aerial photo of the quarry with surrounding neighborhoods. The figure also shows the amount of development surrounding this Mississippi Lime operation. Many surveys were distributed among the neighbors of this quarry as well.

Figure 3.10. Aerial photo of Mississippi Lime operation and surrounding neighbors in Springfield, Missouri.

The quarries selected for the Alpha Survey pool were chosen due to their proximity to residential areas and suburban development. This type of interaction is precisely the scope of research defined by the goals in the introduction. Detailed information about the actual collection of data is provided in later sections of Chapter 3.

As discussed earlier, this sample selection utilizes components of both convenience and judgment sampling, as do the remaining survey pools to be discussed. The quarries were all within driving distance of Rolla for convenience, but they were selected as a representative sample of suburban quarries across the United States. Most quarries near metropolitan areas would have similar types of developments. The Alpha Survey was targeted as the key group for comparison of all other survey pools. The members of the population sampled are the target of this research effort. The other survey groups were consciously selected with internal bias (technical people, regulators, blasting professionals) for the reason of comparison to the Alpha group.

The differences found during data analysis are the basis for conclusions and recommendations. In order to support the stated goals of this research, the analysis would be used to create recommendations for populations represented by the other survey groups, provide public relations tools for the mining industry, and to lead the way into future research in this area.

3.3.2. Beta Survey – Public Not Exposed to Blasting Operations. Survey pool selection for the Beta Survey was closely associated with the Alpha Survey pool. Areas not exposed to ongoing blasting operations were selected in each geographical location. Neighborhoods were selected in St. Louis, Missouri, Little Rock, Arkansas, and Springfield, Missouri that were aesthetically similar to the neighborhoods surrounding the corresponding quarries from the Alpha Pool. Aerial photos would not add value to the selection of the beta survey, so only a description of each sample from the three geographical locations follows.

The area surveyed for the Beta Pool in the St. Louis area was located several miles north of the south St. Louis quarry shown in Figure 3.3. The aesthetics of the Beta neighborhood in St. Louis were matched as closely as possible to the areas surrounding the quarries chosen for the Alpha Pool in St. Louis. The homes were seemingly upper middle-class homes that were well kept and predominantly single-family houses.

Similar to the St. Louis area, developed areas of Little Rock, Arkansas, were chosen to replicate conditions and lifestyles found surrounding the two quarries surveyed there for the Alpha Pool. The neighborhood was mostly well kept, but the homes were visibly in worse condition than those chosen in St. Louis. The specific area canvassed was located several miles west and just south of I-30 on the western portion of Little Rock. Again, these homes were typically single-family dwellings; however, in an attempt to remain consistent with the Alpha surveys, the neighborhood was fairly aged in construction styles and showing signs of neglect or deterioration.

In Springfield, the Beta Pool was selected in accordance with the process stated above. The area selected lies several miles north of the Mississippi Lime operation shown in Figure 3.10. The majority of the homes in this area matched what could be found around both quarries surveyed in Springfield. Most of the developments were newer construction with some areas of upper economic-level homes. Again, the Beta Pool for Springfield was chosen with consistency in mind. Discussion of actual data collection for the Beta Survey pool can be found later in Chapter 3 in Section 3.5 titled Data Collection.

3.3.3. Gamma Survey – Civil Engineers. Obtaining an adequate pool of civil engineers for the Gamma Survey proved to be quite challenging. Initial attempts to obtain a mailing list from the American Society of Civil Engineers (ASCE) failed. ASCE did not return several phone calls in attempts to work out an arrangement to either advertise the survey on their organization website or purchase a select mailing list for the Midwest. This left personal contacts with civil engineering firms as the only alternative. The main goal for the Gamma Survey was to determine if distinct differences could be noted between the general public (Alpha and Beta Surveys) and people with technical backgrounds that would be familiar with technical scales and units. Also, civil engineers are professionally responsible for construction design and evaluation of structures that could be affected by blasting. With this in mind, several engineering companies were contacted and a limited number of surveys were administered. To add to this survey pool, civil engineering professors at UMR supplemented the list.

3.3.4. Delta Survey – Blasting Professionals. Through contacts at the International Society of Explosives Engineers (ISEE), a mailing list was obtained containing active members in the states surrounding Missouri. The list ensured that blasting professionals would be reached with a broad range of background and experience. Many types of people associated with blasting from explosive manufacturers' technical and sales representatives to field blasters were included. The group adequately represented a population of blasting professionals that would communicate with residents near blasting operations. Information from the Blasting Professionals provided insight as to how people who deal with technical ground vibration and airblast units on a daily or at least regular basis felt about blasting near their homes. It was thought that the results would hopefully give merit to education of the public by showing that professionals who understand the units would be comfortable with vibration and airblast limits for their own homes. The results would also show how differently this group perceives blasting when compared to the other groups.

3.3.5. Local, County, and State Regulators – Epsilon Survey. Determination of the Epsilon Survey pool was relatively simple; however, locating the required information to populate the sample proved much more difficult. Since all levels of government were needed, the population was defined as follows:

- Missouri State Senators
- Missouri State Representatives
- County Regulators from all three geographic regions targeted by the Alpha and Beta Survey pools (St. Louis, MO, Little Rock, AR, and Springfield, MO)
- City Regulators from all three geographic regions targeted by the Alpha and Beta Survey pools

There were no expectations for the results of this survey group. The individuals in this group would have wide ranging backgrounds, and the characteristics of the sample would most likely follow that of the Alpha and Beta Survey groups.

The difference between the public survey groups and the Epsilon Survey group lies in the fact that many regulators are responsible, on some level, for the well-being of their constituents. They may also be faced with political pressure to take an active role in regulating blasting activities. These officials may welcome the idea of standardized regulations to reduce the burden of responsibility on them to protect their constituents. Currently in the United States, local lawmakers often reference OSM standards as benchmarks. This type of reference is a dangerous trend for the blasting industry for several reasons. First, many local officials wish to exceed the level of protection in their communities. In an effort to accomplish this and a lack of understanding of measurement units, they may put in place highly restrictive limits. Examples of this activity have been shown in the introduction. The implementation of more simple units and standards could aid in curbing this problem. The purpose of collecting data from this group was to determine a benchmark level for regulators' comfort levels with blasting units, as well as to note any differences between the Epsilon group and other survey pools.

3.4. SURVEY DESIGN

Careful design of the surveys was imperative to the success of the project. Much care was taken to understand the impact of each question and its wording. Each group selected utilized a set of common questions, as well as carefully designed questions specific to that group. The committee and other UMR professors with experience in survey data collection and analysis were consulted. Several issues were discussed at length with them concerning the surveys including question wording, survey administration method, survey length, and number of surveys.

Using the survey described in the introduction as a pilot study, questions were redesigned with helpful input from the research committee and social-science professors with expertise in survey data here at UMR. Gentry and Martin (Gentry, 2005) offered their experience to the research process. They recommended using mailed surveys rather than administering them orally. More information about this can be found in the following section titled Data Collection. They also recommended not changing any wording between survey pools. There can be a few questions that are solely for a particular group, but overall the surveys should be similar in all cases (Gentry, 2005). Consistency is the key to acquiring quality data.

Most problems with questionnaires are born in the design phase of the project. Well defined goals are the best way to assure a good questionnaire design (Bartholomew, 1963; Freed, 1964). One important way to ensure a quality survey is to include other experts and relevant decision-makers in the survey design process (Walonick, 1993). Their input will improve the questionnaire and they will subsequently have more confidence in the results.

An excerpt from another of Walonick's (Walonick, 2006 B) publications provides a method for final survey approval. The following method was used by submitting the surveys to the committee as well as subjecting other people in Rolla prior to its distribution:

> Instead, we recommend the following method to get the kinks out of your survey. It's fast, costs nothing, and you'll get immediate and valuable feedback that can be used to improve your instrument.
>
> 1. Find someone who will act as a respondent. They do not need to be someone from the actual pool of potential respondents. You can ask a spouse or friend to "pretend" they are from the target population. Do not use someone who helped create the survey.
>
> 2. Give them a "final" copy of the survey and say something like, "Please complete this survey as if you were a real respondent. You can just make up the answers. Feel free to ask me any questions while you're completing it". Then give them the survey and sit there quietly while they take the survey. The survey you give them should be a "final" copy... exactly the way it will appear on the paper when it is printed. If it's an internet survey, have them take it on the internet. If you use this method while the survey is in "draft" form, do it again after the survey is in final form.
>
> 3. Any question they ask you about the survey indicates a defective item. Real respondents will not have an opportunity to ask questions, so you must fix these items now. Modify all items that

> were mentioned. Then begin the process again with a new respondent, and continue until there are no questions. Usually, you'll be done after two or three "pretend respondents." (Walonick, 2006 B)

Much care was taken in the design phase of the surveys in order not to inadvertently bias the results through wording of particular questions. Each question followed similar formatting so as not to enter differences other than those being specifically sought. The respondents who were used to ensure there were no questions generally only had comments about the different units. The following sections describe the specific surveys used for each pool.

3.4.1. Alpha Survey. The Alpha Survey was designed for distribution to members of the public who reside within 1 mile of an ongoing blasting operation. In all cases for this research, the participants were selected who lived adjacent to surface aggregate quarries. The survey consisted of seventeen questions total. The initial five questions asked for general demographic data including home ownership, age, sex, working hours, and duration at the current residence. This information was used to partition the data into further groups. Not all of the information gathered here proved useful for this research; however, in future studies it may provide answers for questions not asked here. The remainder of the survey asked questions regarding blasting and reporting practices for ground vibration and airblast. Question #6 asked:

6. How comfortable do you feel having a blasting operation within 1 mile of your home?

1	*2*	*3*	*4*	*5*
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

This question was designed to determine how comfortable respondents were with blasting close to their home in general. For reading simplicity through the analysis of the data each question will be assigned a short name for reference throughout the remainder of the dissertation. The above question #6 will be referred to as Alpha General Likert from this point forward.

Question #7 asked:

7. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

This question (Alpha Decibel Likert) begins a series of questions regarding airblast reporting. The series contains two more questions which are identical to Alpha Decibel Likert but utilize direct conversion of units to millibar and pounds per square inch (PSI). The other three questions in the series ask what the respondent associates with each unit. The questions followed by their abridged names are as follows:

8. What do you associate with decibels?
(Alpha Decibel Association)

9. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

(Alpha millibar Likert)

10. What do you associate with millibars?
(Alpha millibar Association)

11. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (PSI). How comfortable are you with a blast producing 0.0029 PSI of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

(Alpha PSI Likert)

12. What do you associate with PSI?
(Alpha PSI Association)

The above series of questions was designed to determine whether residents would be more comfortable with a reporting unit other than decibels. The qualitative association questions were an attempt to begin explaining why.

Three questions followed which addressed ground vibration reporting units. The following series of questions were identical except for the direct unit conversions using sinusoidal wave equations.

13. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable are you with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1	*2*	*3*	*4*	*5*
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

(Alpha VF Likert)

14. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable are you with ground vibrations of 0.00227 inches at your home?

1	*2*	*3*	*4*	*5*
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

(Alpha Inches Likert)

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable are you with ground vibrations of 0.06 millimeters at your home?

1	*2*	*3*	*4*	*5*
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

(Alpha mm Likert)

Again, these questions were used to assess the respondent's preference for reporting units, but these questions targeted ground vibrations. Questions eight through fifteen constituted the major scope of this research, and the majority of the data analysis is based on these questions. All five survey pools were asked these questions. Other group-specific questions were asked for the reason of looking forward to future research. The Alpha survey contained two more questions as follows:

16. Have you ever lodged a complaint against a blasting operation?
Yes *No*
(Alpha Complaint)

17. Federal safety limits are reasonable for public safety.

1	2	3	4	5
Very Uncomfortable	*Uncomfortable*	*Neutral*	*Comfortable*	*Very Comfortable*

(Alpha Federal Likert)

While analysis of the final two questions in the Alpha Survey is not necessary for reaching the goals of research, they do provide insight when planning for future studies. With these questions, evaluating relationships between comfort levels, complaints, and the potential use of federal blast vibration limits can be achieved. A copy of the actual survey distributed can be found in Appendix D, where all of the surveys are located.

3.4.2. Beta Survey. Since the Beta Survey was targeted for individuals residing more than 1 mile from quarry operations, only one change was made from the Alpha Survey to the Beta Survey. Alpha General Likert was changed from "how comfortable do you feel" to "how comfortable would you feel." Otherwise the surveys were identical and were designed for the same goals. In further sections, all shortened names will follow the format outlined in the description of the Alpha Survey above, only the names will begin with Beta as opposed to Alpha. For example, Alpha General Likert will refer to Question 6 from the Alpha Survey while Beta General Likert refers to Question 6 from the Beta Survey. Appendix D contains a copy of the actual Beta Survey that was distributed.

3.4.3. Gamma Survey. Following in suit with the Alpha and Beta surveys, the Gamma Survey asked very similar questions. Gamma was designed to be taken by civil engineers. Civil engineers were selected as a survey pool in hopes of determining whether a technical background would increase comfort levels with reporting units. Only one change was made to the Gamma layout. The question asking for duration at current residence was replaced with a question asking for professional title. The remainder of the survey is identical to Beta. Shortened names for later reference to the questions follow the standard format previously discussed. For clarification, Gamma General Likert refers to Queston 6 of the Gamma Survey and so on. A copy of the actual Gamma Survey that was distributed can also be found in Appendix D.

3.4.4. Delta Survey. A fourth survey was designed to be taken by blasting professionals. The technical content of the Delta Survey is again identical to the previous surveys. The question regarding professional title from the Gamma Survey was replaced with a question asking for years of experience with explosives and blasting. Questions regarding airblast and ground vibration units are retained in their entirety on the Delta Survey and will be referred to according to the standard format from here forward (Using Delta as the first term). Two additional questions were asked of the Delta pool and are as follows:

17. Have you ever been involved in a blasting complaint in any way?
Yes *No*
(Delta Complaint Resolution)

19. Would you describe your companies [sic] public relations policy concerning blasting as proactive, reactive or not applicable?
(Delta PR)

These additional questions were again asked outside the scope of this research; however, they will help in determining possible directions for future work. A copy of the actual Delta Survey has been appended in Appendix D.

3.4.5. Epsilon Survey. The final survey was designed for local, county, and state regulators. The technical questions remained unchanged from the previous surveys; however, a few additional questions were asked. The initial list of qualitative questions for the Epsilon Survey included office held, what type of jurisdiction (state, county, city), age, sex, existence of blasting operations within jurisdiction, blasting complaints, and elected vs. appointed. Technical questions were identical to the Beta Survey and were supplemented with two further questions as follows:

20. Rank these factors from 1 (most important) to 4 (least important) when you are considering a new policy.

( ) Constituent complaint about a problem.
( ) Pre-established federal limits.
( ) Importance of effected parties.
( ) Pressure from other regulators (nearby counties etc.).
(Epsilon Factor Rank)

21. Have you ever discussed or received a complaint about blasting from a constituent?
Yes *No*
(Epsilon Complaint Reciept)

These two questions were again not needed to complete the research goals stated earlier but were useful in determining how regulators would react to blasting complaints. A copy of the actual Epsilon Survey that was distributed can be found in Appendix D.

3.5. DATA COLLECTION

As discussed in earlier sections, much consideration was taken when selecting a data collection method. The pilot survey described in the introduction was administered orally on a door-to-door basis. Martin and Gentry (Gentry, 2005) suggested the use of mailed surveys or written questionnaires. For the Alpha and Beta pools, surveys were hand-delivered to mailboxes in the selected areas to ensure proximity to or distance from the quarries. The surveys were placed in envelopes with a business reply envelope and introductory letter. The introductory letter can be seen in Appendix E. The letter does not give specific information about the research, only that it is part of a research project. An incentive program was also mentioned in the letter. Survey participants were encouraged to submit surveys to be entered in to a drawing for $100. The incentive was an effort to increase response rates as suggested by Gentry and Martin (Gentry, 2005). A winner was selected after all surveys were collected. Nearly 1,700 surveys were delivered in all, with 900 delivered for the Alpha pool, and 800 for the Beta pool. The Alpha pool returned 152 surveys for a total response rate of nearly 17%. The Beta pool returned only 51 surveys for a return of just over 6%. Dr. Gentry and Dr. Martin advised to expect return rates between 10% and 30% with this type of survey (Gentry, 2005). While the Beta response rate is lower than expected, a small portion of the non-return rate can be explained by the postal service drawing surveys out of mailboxes, and returning to sender. Nearly 200 surveys were returned at which point they were mailed to the address corresponding with the number coded on the envelope. Other calls were fielded from postal service workers in the various geographic locations claiming that many surveys were thrown away. Even with the low response rate, there was plenty of data to analyze, and all of the groups targeted were populated. The specific numbers of surveys delivered to each area as well as response rates are discussed in Chapters 4 and 5.

The Gamma pool was populated by civil engineering firms in Rolla, Missouri; Kansas City, Missouri; Wichita, Kansas; and Fort Lauderdale, Florida. These surveys were administered by e-mail directly, and utilized a letter similar to the one sent with Alpha and Beta surveys. No incentive was offered for response for this group. To supplement the civil engineering pool, professors in the civil engineering department were surveyed as well. In total nearly 100 civil engineers were contacted, and 20 surveys were returned for a return rate of 20%. This return rate was acceptable and populated the pool for analysis.

The Delta pool was generated through the use of a mailing list obtained from the International Society of Explosives Engineers. The mailing list included 206 names and addresses of all active members of the organization in Missouri, Kansas, Oklahoma, Arkansas, Illinois, and Iowa. This group returned 53 surveys for a return rate over 25%. Already a trend was forming from the response rates alone. Each group that would be expected to be more familiar with ground vibration and airblast reporting units recorded a higher response rate.

For populating the Epsilon pool, e-mail addresses were gathered from online sources for local and county regulators in St. Louis, Little Rock, and Springfield. Also, e-mail addresses for State Representatives and Senators from Missouri were obtained.

Over 200 legislators were surveyed, and only 5 responded with completed surveys (2.5%). Nearly twice that amount responded saying that they were not able to complete the survey. Relationships of data points between this group and the others could not be determined, but the trends found in local and state regulations were suitable for determining recommendations.

In total, nearly 300 surveys were collected and analyzed. The samples have been validated through internal consistency using Cronbach's Alpha and the Split-Half reliability test. Also, it is felt that the sample sizes are adequate for accomplishing the stated goals for the research.

3.6. ANALYZE DATA

Once data had been collected, systematic interpretation of the results provided information for further steps in the process. The statistical reduction and analysis of the data had been validated by the review of accepted methods in Chapter 2. The data was analyzed using descriptive statistics only. Further analysis was seemingly overkill, and the interpretation of such results could be called into question. Most statistical analysis tools were developed for continuous data and normalized distributions. While some tools are available for nonparametric data, the majority of these still require dependent and independent variables and continuous data. Kitchenham (Kitchenham, 2003) supports this statement in a journal article by saying, "if we do not have an approximately Normal response, the results of analyzing the data may be misleading. We believe it is important to understand the scale type of our data and analyze it appropriately" (Kitchenham, 2003).

In the case of the Likert questions in the surveys used for this research, a comparison of distributions between questions and among each survey pool is a more reasonable approach to drawing conclusions from the data. The remaining task was to validate the data or determine its level of reliability. Again, typical statistics can not handle ordinal data similar to that collected for this research. As discussed in Chapter 2, testing the data for internal consistency can validate the surveys use as a psychometric instrument for measuring a single latent variable. The single latent variable in the case of these surveys is the perception or comfort level with blasting and reporting units for ground vibrations and airblast. Cronbach's Alpha can be a very useful statistic for determining validity or reliability (Kitchenham, 2003; Walonick, 2006 B). Alpha is defined as the mean correlation across the items. Each pool of data was subjected to two separate calculations for internal consistency. As mentioned previously, Siegle from the University of Connecticut offers an Excel spreadsheet formatted for performing Cronbach's Alpha calculations and Split-Half reliability tests on Likert-scaled data like that collected in the surveys (Siegle, 2006). Results of the calculations are discussed in Chapters 4 and 5, and Appendix F contains files with Siegle's spreadsheet filled with the survey data from this research.

3.7. IDENTIFY FURTHER ISSUES FOR SURVEYS

Throughout the research process, the successful design of the survey was apparent. Survey results were easily formatted and placed into spreadsheets for analysis. There were some issues with missing data from unanswered questions, but overall, the surveys returned seemed genuine and complete. As the data was compiled, it was obvious that future surveys could be useful. Nevertheless, the amount of data obtained was immense, and complete analysis was necessary prior to designing further surveys. To date, no questions were raised about the data that could be answered by a limited extension of the current survey design. Based on the data analysis described in the previous section, questions regarding what individual or collective survey results mean were identified that may necessitate further study. These questions are addressed at length in Chapter 8.

3.8. CORRELATE DATA TO REGULATIONS

Once the data analysis was completed, the data was qualitatively correlated to the trend of local regulations shown in the introduction. The discomfort with reported values for ground vibrations and airblast is potentially what is driving the overly restrictive regulations. Furthermore, misunderstanding the technical units used for reporting amplifies the problem at the local level. Combining the analysis of survey results with the review of regulations will provide some answers as to why overly restrictive regulations have been implemented. This step was necessary in order to facilitate the next step of creating industry and regulatory recommendations.

3.9. CREATE INDUSTRY AND REGULATORY RECOMMENDATIONS

Once all data analysis and correlation to policy was completed, scientific and logical recommendations were developed as to the appropriate actions required. Recommendations were created for both the blasting and mining industry and for regulatory officials.

The majority of the questions in the surveys centered on the comfort levels of individuals about several reporting units for ground vibrations and airblast. Current reporting practices have shown to be ineffective for both communication and creation of sound policy. Since these reporting practices are interwoven into public policy, recommendations will need to be made as to the requirements listed in the regulations. It is hoped that the results of this work will be utilized to create an open and candid relationship with the public, regulators and administrators, and the blasting industry. A subsequent goal is to reduce the amount of complaints from residents in proximity to blasting operations by creating an understanding of the process involved, through the implementation of the recommendations of this work.

The recommendations created here will be presented to the industry through conferences, journals, and other publications. Already, the limited work done in the pilot survey has been very well received by industry members. Publications already include the 2005 International Society of Explosives Engineers annual conference paper, and a paper for the 2005 European Federation of Explosives Engineers conference in Brighton, United Kingdom (Lusk, 2005 A, Lusk, 2005 B). Hopefully, the process can continue through implementation; although, this will be a long process over many years.

3.10. END GOALS

The end goals of the process were identified in the introduction and are revisited here. Four primary goals were defined as:

- Survey data analysis will enable the selection of better reporting units for the airblast and ground vibrations produced in industrial blasting.
- The survey data will be shown to be an important part of the toolset for an effective public relations tool for mining companies.
- Recommendations for improvements in the public relations programs for the mining/blasting industry, and for that industry's relationship with regulatory authorities will be made.
- The determination of future research for the continuation of work in this area.

Later chapters describe in detail how the goals of the research were met specifically. The final chapter of the dissertation describes conclusions related to the goals of the research.

4. SURVEY DATA

4.1. ASSESSMENT OF DATA RELIABILITY

The challenge of addressing the reliability of the survey data collected has been discussed at length in Chapters 2 and 3. In summary, validation of the data is achieved through a few distinct methods. First, the data has been validated by the researcher through qualitatively analyzing responses and returns of surveys. The vast majority of surveys returned were complete and responses seemed sincere with many comments littering the return sheets.

The majority of sources recommended any of three methods for establishing reliability levels for data similar to that collected here. While the alternate-form and test-retest methods were deemed cost prohibitive, the internal-consistency method was chosen to assess the reliability of the surveys for use as a psychometric instrument for measuring comfort levels with blasting and reporting units for ground vibrations and airblast. Numerically, the data was subjected to robust calculations proving internal consistency. Using Siegle's Excel spreadsheet, the formatted data from each survey pool returned excellent values for internal consistency based on two statistics. The two statistics chosen for reliability calculations were Cronbach's Alpha and the Split-Half reliability coefficient (Siegle, 2006). In agreement with Walonick and Kitchenham, Siegle suggests that a widely accepted cutoff value for Cronbach's Alpha and the Split-Half reliability coefficient is 0.7. This means that the values for these statistics should be higher than 0.7 before the instrument can be considered reliable (Kitchenham, 2003, Siegle, 2006, Walonick, 2006 B). For all five survey pools, Cronbach's Alpha was over 0.9 and the Split-Half reliability was above 0.88. This provides proof the survey resulted in very good internal consistency in all cases. Table 4.1 shows the actual calculated values for Cronbach's Alpha and the Split-Half reliability coefficient for each survey pool.

Table 4.1. Calculated values for Cronbach's Alpha and Split-Half reliability coefficient for each survey pool.

Survey Pool	Cronbach's Alpha	Split-Half Reliability
Alpha Survey	0.951	0.898
Beta Survey	0.968	0.914
Gamma Survey	0.952	0.911
Delta Survey	0.938	0.881
Epsilon Survey	0.969	0.986

Even though the Epsilon Survey only returned 5 completed forms, the internal consistency was adequate for analysis. The high values for the statistics in Table 4.1 provide evidence that the survey was well designed and that the responses recorded can be used to draw conclusions with descriptive statistics. All of the statistical reliability analysis spreadsheets have been included on the CD of files found in Appendix F. A word document is also included in Appendix F with the equation for Cronbach's Alpha.

4.2. COMPILATION OF CONSTITUENT GROUPS

A systematic approach to data analysis was necessary for determining what information could be inferred from the collected data. Once initial data entry was completed for all of the survey pools described in Chapter 3, the decision on how to proceed through data analysis was pivotal. The review of literature for methods of analyzing Likert type data showed that averages alone would not provide the level of detail required to draw concrete conclusions. Nevertheless, average Likert values for the individual questions was an optimum starting point to determine which questions merited further review. The data was already naturally partitioned by the Survey Pools, so initial analysis did not require further partitioning.

The process for reviewing the data was laid out in the following steps:

- Calculate average comfort (Likert) values for each question for entire set of survey pools.
- Determine which questions required distributions to draw conclusions.
- Calculate distributions for selected questions on a percentage basis for comparison reasons. (Not all pools contained the same number of subjects.)
- Visually inspect data to determine what other statistical tools and values would be valuable.
- Draw conclusions for best available reporting units.

The first step in analyzing the large amount of data produced from the five survey pools was to calculate average comfort values for each question in the survey. This calculation was performed for each survey pool, and Table 4.2 provides a summary of the results.

Table 4.2. Average Likert values for each survey question from each survey pool.

Survey Pool	General Likert	Decibel Likert	millibar Likert	PSI Likert
Alpha	2.39	2.36	2.58	2.65
Beta	2.13	2.37	2.86	2.92
Gamma	2.32	2.50	3.28	3.44
Delta	4.10	4.20	4.19	4.25
Epsilon	3.00	2.80	3.20	3.80
Survey Pool	**VF Likert**	**inches Likert**	**mm Likert**	**Federal Likert**
Alpha	2.37	2.41	2.50	3.06
Beta	2.45	2.51	2.61	3.12
Gamma	2.78	3.22	3.28	3.37
Delta	4.28	4.10	4.08	4.14
Epsilon	3.00	3.00	3.00	2.80

Several trends begin to emerge by simply viewing Table 4.2. Notice that in nearly all cases, comfort levels are higher for millibar Likert than for Decibel Likert, and likewise PSI Likert is higher than millibar Likert. This begins to show that across the board, people are most comfortable with PSI as a reporting unit for airblast. Remember that Decibel Likert, millibar Likert, and PSI Likert are identical questions with only the units changed. The pressure values cited in the questions remained exactly the same. Also, in all groups except Delta (blasting professionals) comfort values were for the most part on the uncomfortable side of neutral. The ground vibrations did not show results as promising as those for selection of an airblast unit. Nevertheless, the averages show that people were marginally more comfortable with inches displacement than velocity and frequency. Comfort levels were also higher for millimeter displacement than inches displacement. The low comfort levels overall for ground vibration questions shows that there is some sort of barrier with the concept.

Visually, a bar graph of the average results tells a story about what units were preferred. Figure 4.1 is a bar graph of average comfort values for the Alpha Group. It clearly shows that comfort values trend higher towards Alpha PSI Likert and Alpha mm Likert. While differences in average comfort values could be perceived as marginal, consider the benefits of achieving higher comfort levels. Other disciplines such as finance would claim victory in such improvements. An improvement of 10%, which is approximately the improvement from decibels to PSI, in profit margin is incredible and would be considered substantial. A closer look at the distributions of responses for these questions further supports this idea. The majority of analysis in this chapter will be for the Alpha group because these are the individuals with whom quarries would actually be dealing. Further analysis and comparisons of the other groups can be found in Chapter 5.

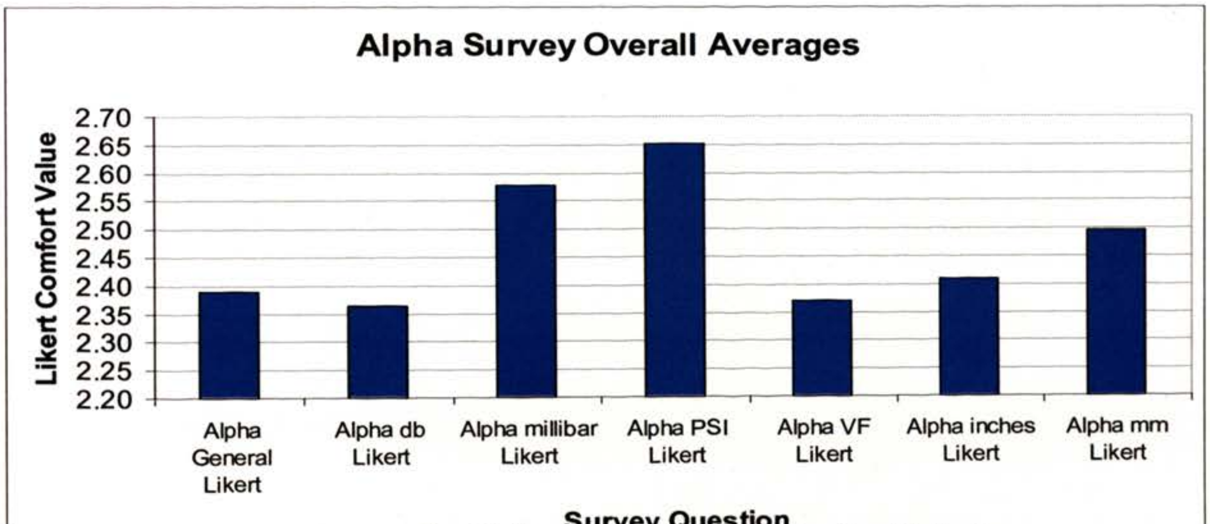

Figure 4.1. Bar graph of Likert comfort values for the Alpha Survey.

Looking at the distributions of responses for Alpha dB Likert, Alpha millibar Likert, and Alpha PSI Likert shows that there is a distinct distribution shift towards higher comfort levels. Figure 4.2 shows the distributions. This distribution shift along with the significant increase in comfort level for PSI, which provides evidence that PSI is a better unit for airblast reporting than decibels.

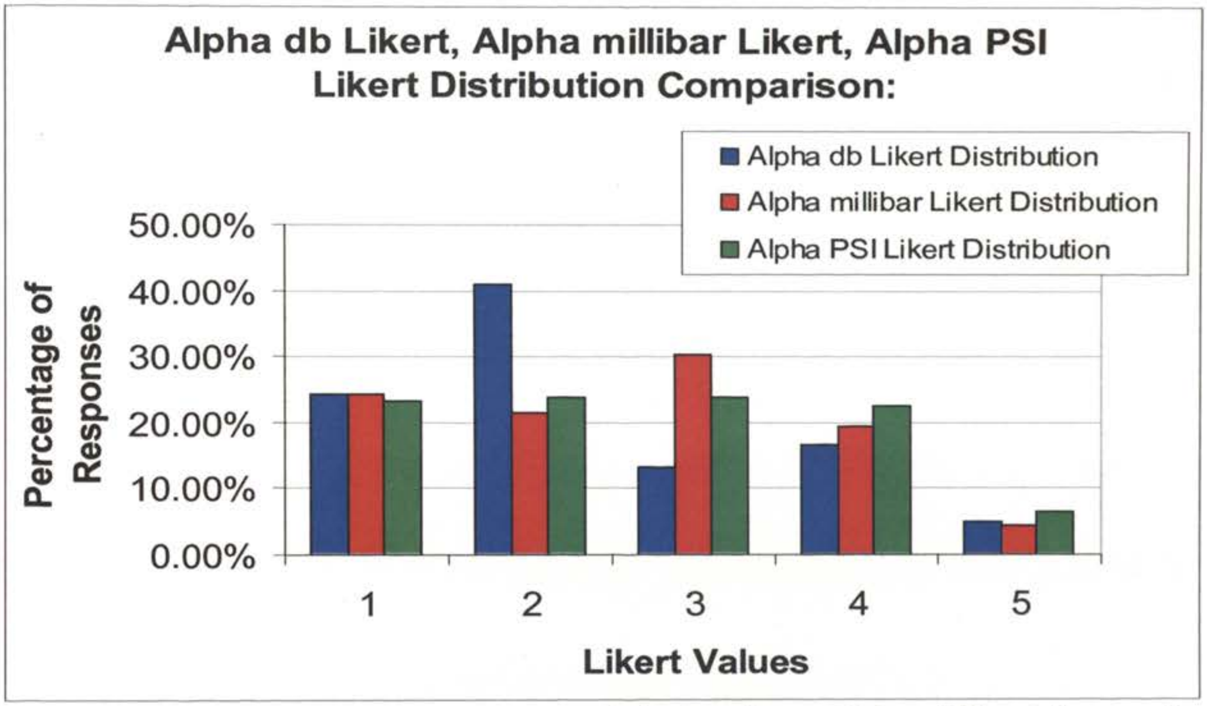

Figure 4.2. Distribution comparison for Alpha dB Likert, Alpha millibar Likert, and Alpha PSI Likert.

To begin understanding what causes higher comfort levels with pressure units such as millibar and PSI over the same values reported in dB, a short analysis of the qualitative association questions from the Alpha Survey was performed. Table 4.3 is a summary of responses found for the three association questions regarding airblast units. The percentages tell a story about how comfortable respondents were with each unit. Total percentage values for each group may not add up to 100% due to a small number of answers that didn't fall into the major categories. The vast majority of respondents associated decibels with sound. Only 2% of respondents associated decibels with pressure. For millibar, only 2% associated the unit with sound while 27% associated with pressure and 57% replied "Don't Know" or had no answer. Finally, PSI had 61% of respondents associated the unit with pressure. As a side note, 13% of respondents mentioned tires when asked what they associated with PSI. This suggests that some respondents may have felt more comfortable with the unit since they were comfortable with using it in their daily lives, for example while maintaining tire pressure on their vehicles. In comparison, the value for an airblast pressure measurement pales in comparison to what is required to inflate a personal vehicle tire (30-40 PSI). This reference point may have allowed respondents to associate blasting with something that they were comfortable.

Table 4.3. Summary of responses for Alpha dB Association, Alpha millibar Association, and Alpha PSI Association questions.

Alpha dB Association Responses	Alpha millibar Association Responses	Alpha PSI Association Responses
74.3% Sound	2% Sound	1.3% Sound
2% Pressure	27% Pressure	61.2% Pressure
19% No Answer or "Don't Know"	57.2% No Answer or "Don't Know"	28.3% No Answer or "Don't Know"
	5.3% Weather	13% Mentioned Tires
	8.6% Other	

A similar analysis was performed for the ground vibration unit questions VF Likert, inches Likert, and mm Likert. Figure 4.3 shows the distributions of the questions asked for determining a best unit for ground vibration measurement reporting. Average comfort levels suggest that mm displacement is preferred to inches displacement and peak particle velocity and frequency; however, the distributions look very similar. Since the averages were marginally higher for mm displacement, no concrete conclusions can be drawn from the data without further research and additional surveys. Future surveys could ask how respondents feel about words like "vibration," "displacement," or "movement."

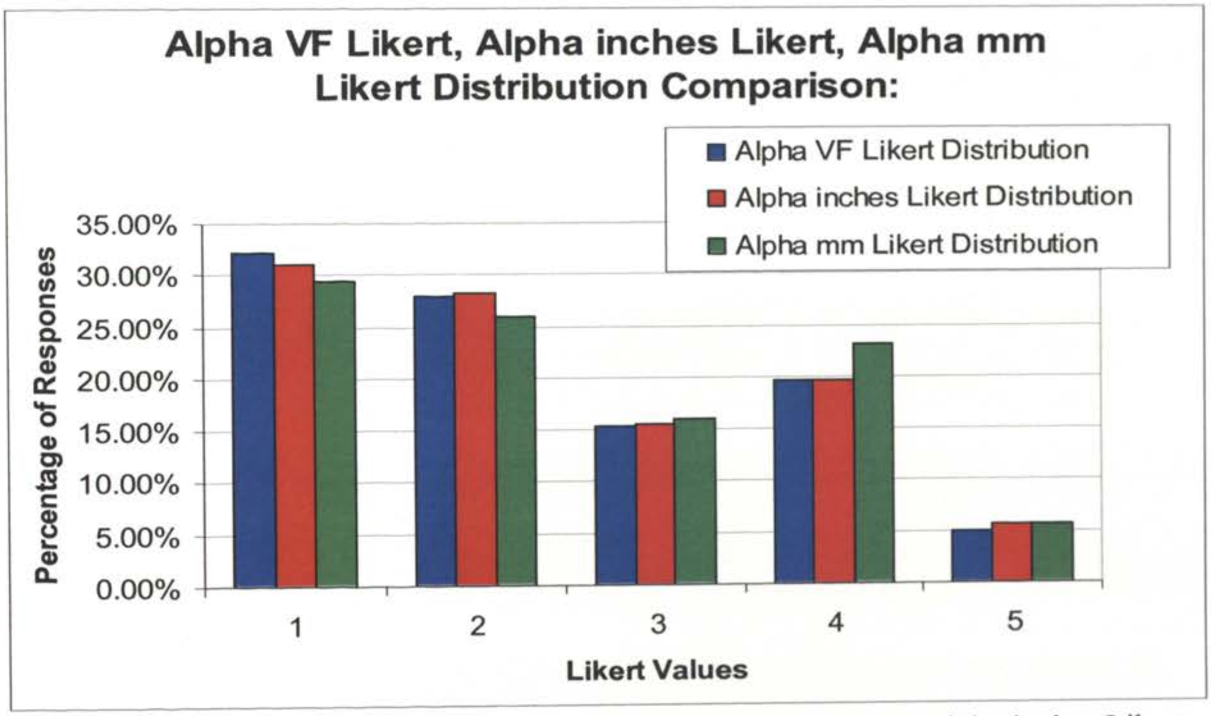

Figure 4.3. Distribution comparison for Alpha VF Likert, Alpha inches Likert, and Alpha mm Likert.

Without further research, analysis of which reporting unit is best among peak particle velocity and frequency, inches displacement, and mm displacement is inconclusive. Nevertheless, the use of simpler units is advisable. Thus, even though the data does not solidly support mm displacement as an optimum unit for ground vibration reporting, it is advisable to use such units for simplicity when communicating with quarry neighbors. Appendix F contains a CD with Excel spreadsheets of the unformatted raw data for all survey pools.

4.3. CONCLUSIONS FROM INDIVIDUAL SURVEY POOLS

PSI was the conclusive choice of the three units selected in this study to report airblast measurements. The average comfort values were higher for PSI than for the other two units, and in all cases except for the Delta Survey Pool, it was preferred by more than 10% over decibels. Closer inspection of the distributions of the Alpha Survey Pool supported this conclusion. It is believed that the higher comfort values for PSI may have been generated by the fact that many people are familiar with the unit, and indeed use it on a regular basis for tire maintenance on their personal vehicles.

Results for analysis of questions involving units for ground vibration measurement were not as conclusive. Average comfort values were highest for mm displacement as opposed to peak particle velocity and frequency or inches displacement; however, the distribution shift was marginal suggesting that there is perhaps another variable which causes lower comfort levels. Future studies could ask qualitative questions about the descriptors for the units to provide insight as to why comfort levels were low. For instance, respondents may have been uncomfortable with the word displacement or vibration or movement. Perhaps there is a better term that would not cause such anxiety.

5. CROSS ANALYSIS OF RESULTS

5.1. COMPARISON OF DIFFERENT CONSTITUENT GROUPS

Significant differences can be seen between the varying survey pools. The following figures (Figures 5.1 through 5.7) show distributions from each question compared across all of the survey pools. Collectively, the figures show that the Delta Survey pool had distributions that were vastly different than those for the Alpha, Beta, and Epsilon pools which trended to lower comfort levels. The Gamma pool more closely resembled the Delta Survey pool, showing that a technical background and possibly a familiarity with technical units allowed for higher comfort levels with the units used to report blast vibrations.

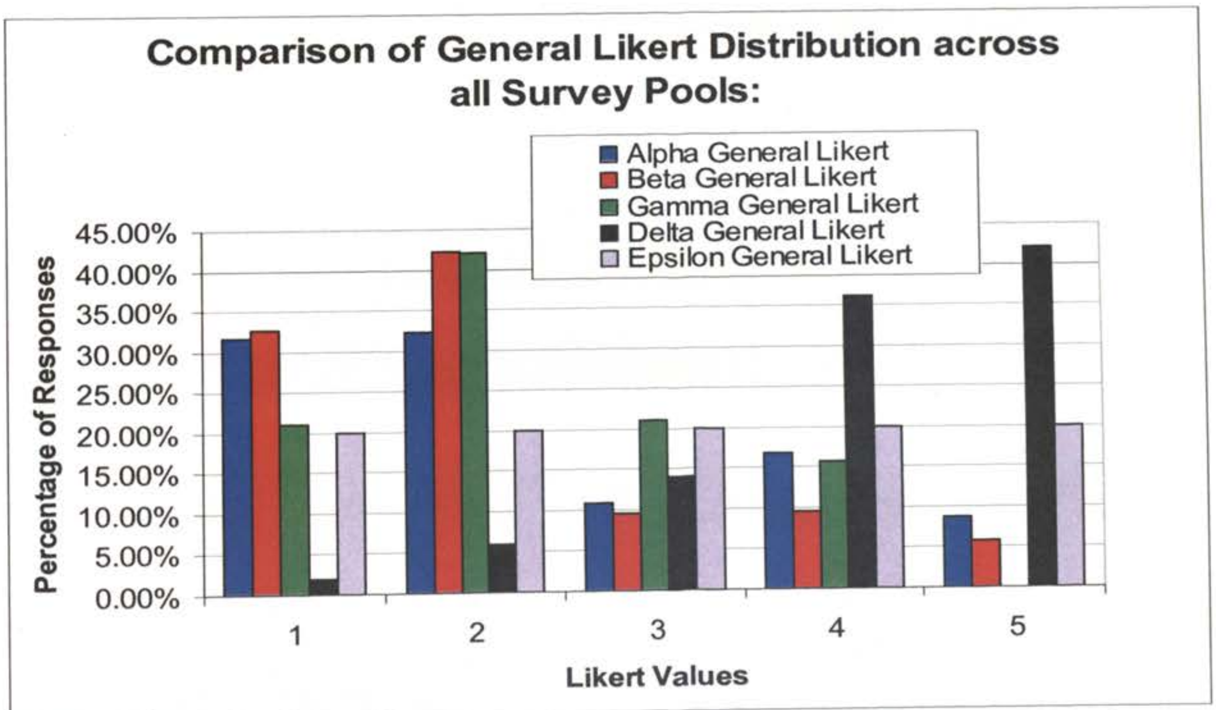

Figure 5.1. Comparison of distributions from all survey pools for General Likert question.

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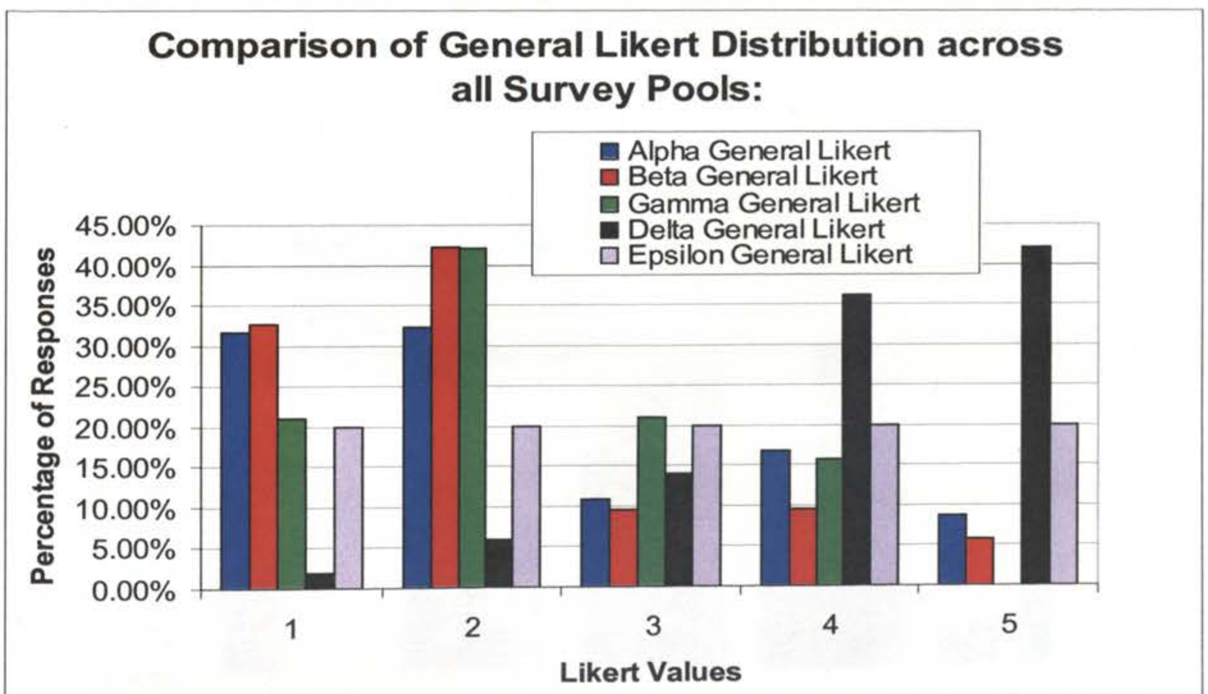

Figure 5.1. Comparison of distributions from all survey pools for General Likert question.

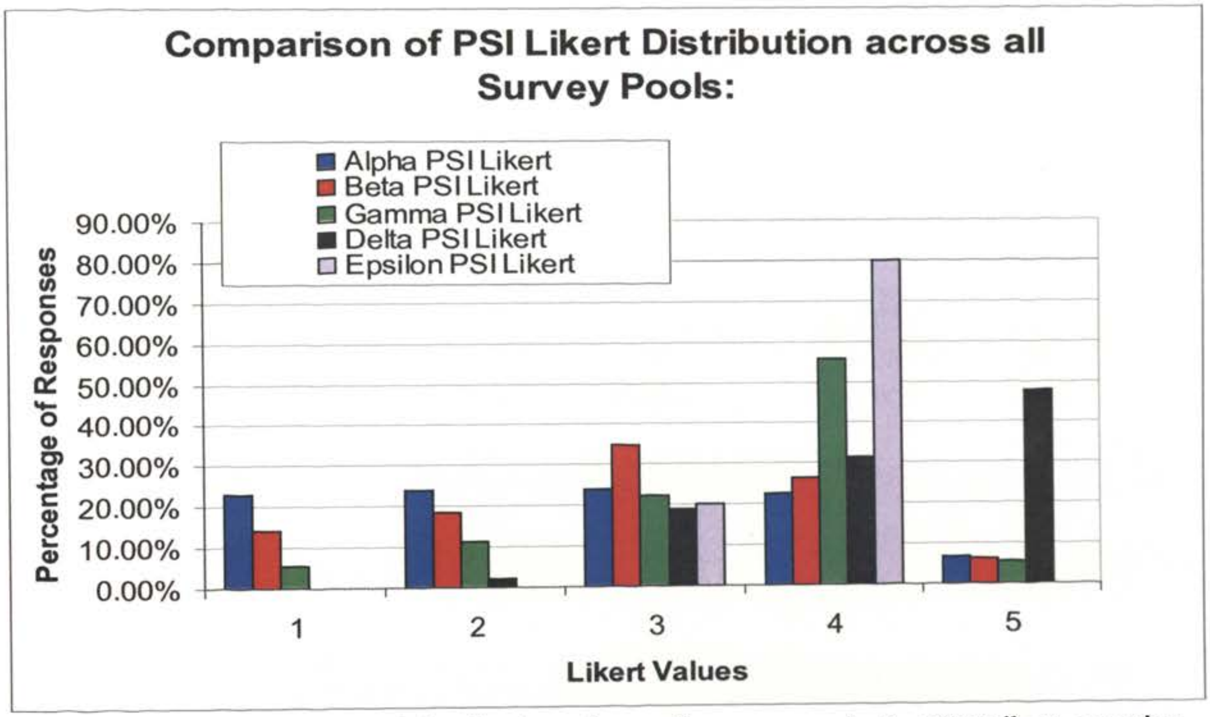

Figure 5.4. Comparison of distributions from all survey pools for PSI Likert question.

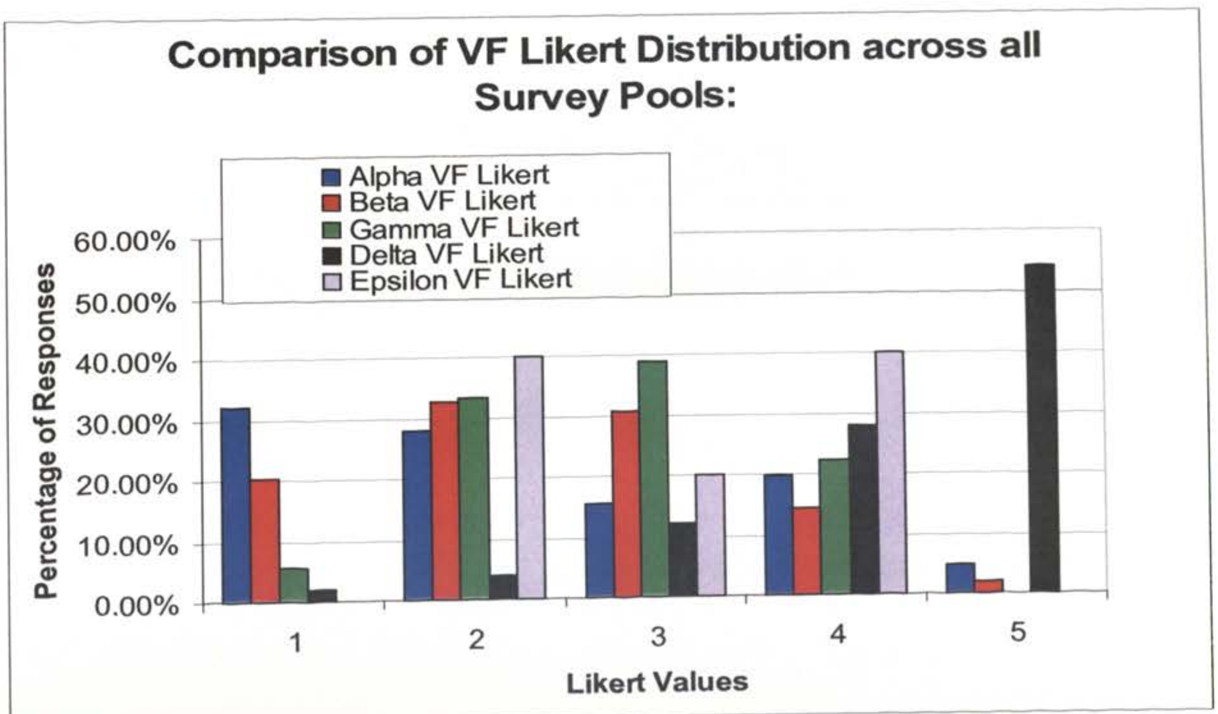

Figure 5.5. Comparison of distributions from all survey pools for VF Likert question.

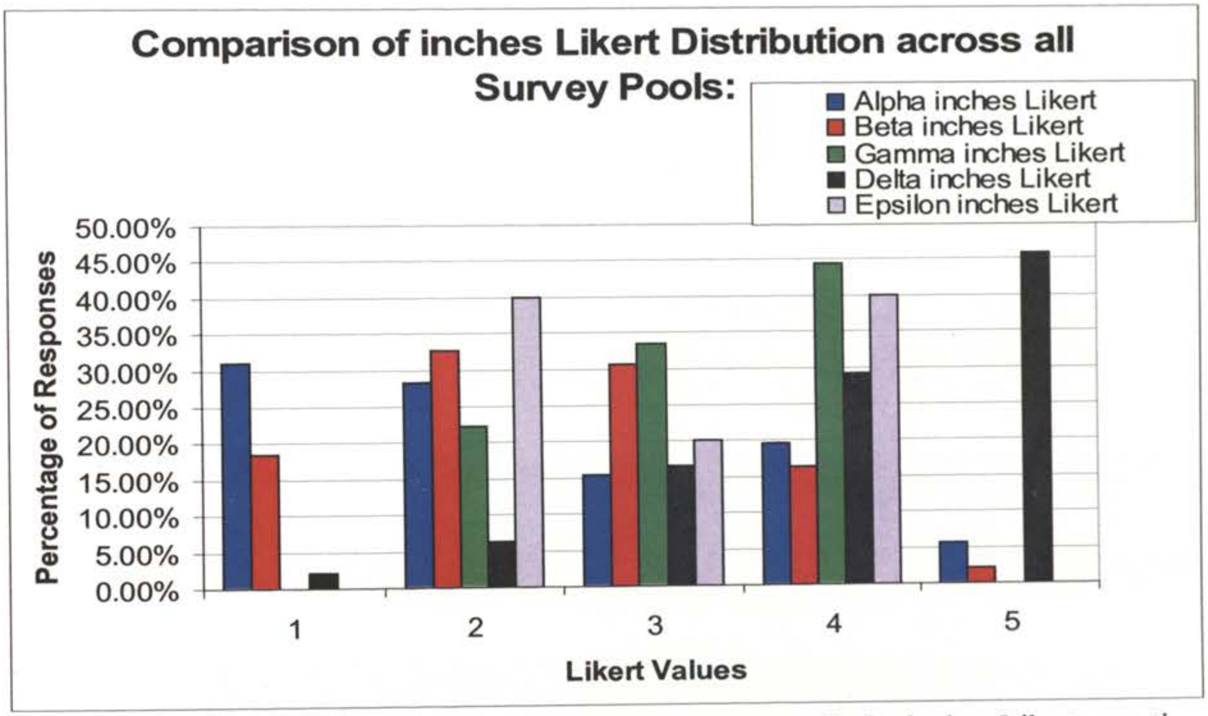

Figure 5.6. Comparison of distributions from all survey pools for inches Likert question.

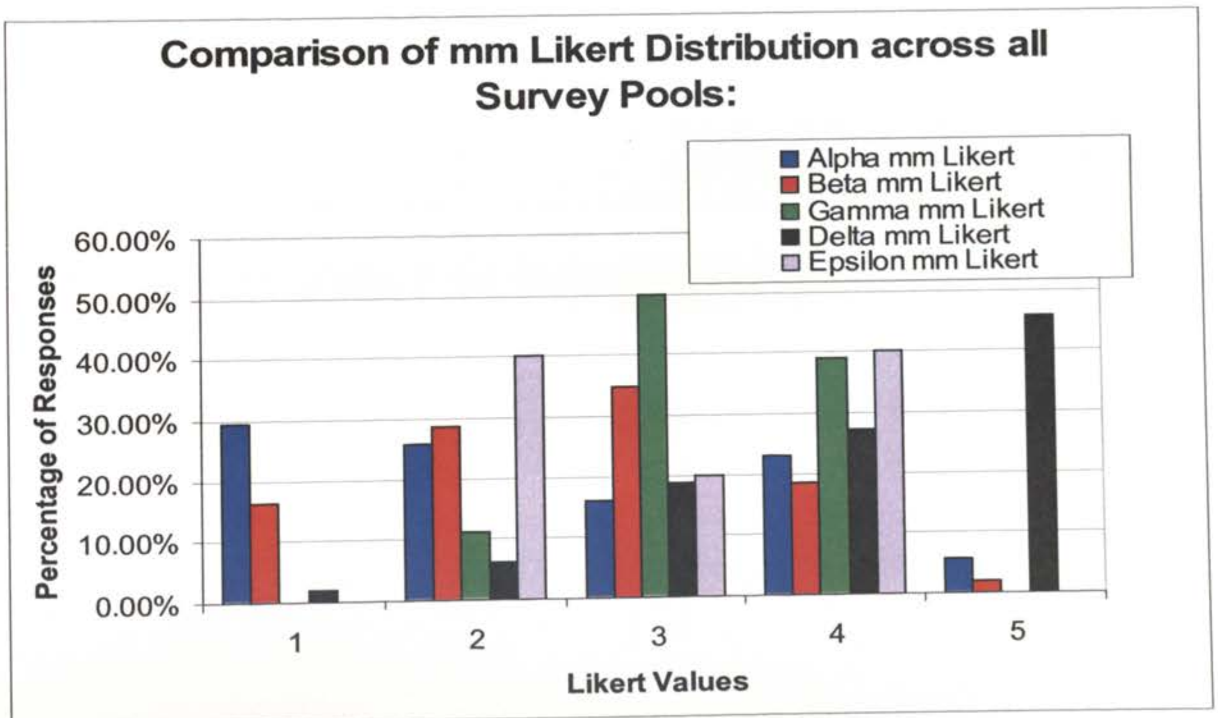

Figure 5.7. Comparison of distributions from all survey pools for mm Likert question.

Using the distributions shown in Figures 5.1 through 5.7 and the averages for each survey group from Table 4.2, many conclusions can be drawn. First, a logical selection of groups to be compared must be made in order to avoid endless cross comparisons of groups that represent similar populations. For example, although the Alpha Group contains people residing within 1 mile of a quarry, the population it represents is similar to the Beta Group (public). Likewise, Gamma and Delta represent similar populations (technical people). The Epsilon group is seemingly the most independent from any other group; however, with such a small return of only 5 surveys, comparison to other groups must be approached cautiously.

After logical qualitative assessment of the survey groups, three comparisons were selected. First, a comparison of the Alpha and Beta groups was selected to show that the populations are similar, but that the average comfort values may differ slightly. Another useful comparison would be the combined averages of Alpha and Beta in comparison to the combined averages of Gamma and Delta. This comparison would show the difference between the public and people with technical backgrounds. Finally, the Epsilon Group can be compared to other groups to determine how they may be different.

5.1.1. Alpha – Beta Comparison. Visual comparison of the distributions of Likert comfort values from all questions for both Alpha and Beta can be seen in Figures 5.1 through 5.7. Overall, the distributions are very similar. This suggests that the populations are similar, and thus the selection of pools was correct. A closer look at the averages for Alpha and Beta in Table 4.2 shows that the Beta Group has average comfort values that are slightly higher than those for the Alpha Group. This may mean that the contact with blasting has been a contributing factor in making residents less comfortable with it. Perhaps members of the Alpha Group have become annoyed or aggravated with the blasting that they experience. It is hoped that positive public relations and education can reverse this trend.

5.1.2. Public – Technical People Comparison. Figures 5.8 through 5.14 show distributions for each Likert question from the surveys. The Alpha and Beta Groups were combined on a percentage basis so as not to skew the distribution towards the larger sample size. This combination provides the distributions for the Public series. The Gamma and Delta Groups were combined in the same way for the Technical distributions. The comparisons in Figures 5.8 through 5.14 provide an analysis of differences between people who have a technical background and those pooled from the general public.

In every case, the technical distribution is focused more towards the higher comfort values than the corresponding public distribution. The evidence drawn from these distributions proves that there is a significant difference in comfort levels dependent upon a higher level of technical education with regards to ground vibration and airblast reporting units. The use of simpler units for blast vibration reporting will allow quarries and mining operations to more easily provide technical background for neighbors, through educating them on the technical concepts. Note that once a technical background is established, even the ground vibration questions (VF, inches, mm Likert) start to show a distribution shift towards higher comfort levels with the simpler units.

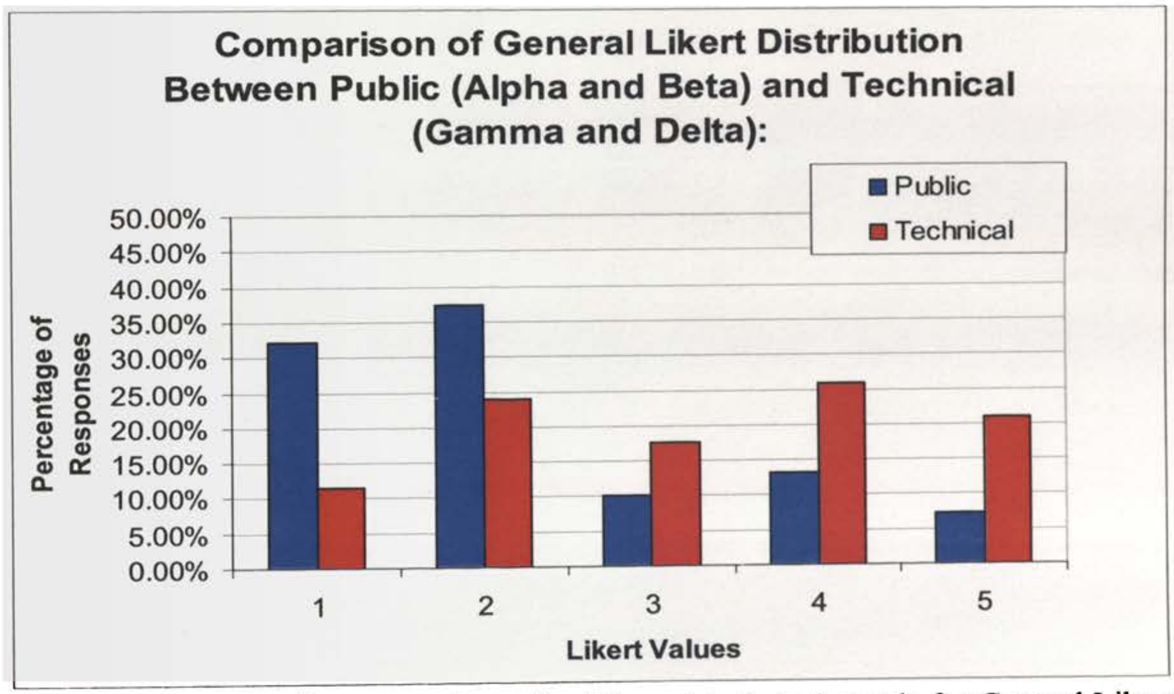

Figure 5.8. Distribution comparison of public and technical people for General Likert question.

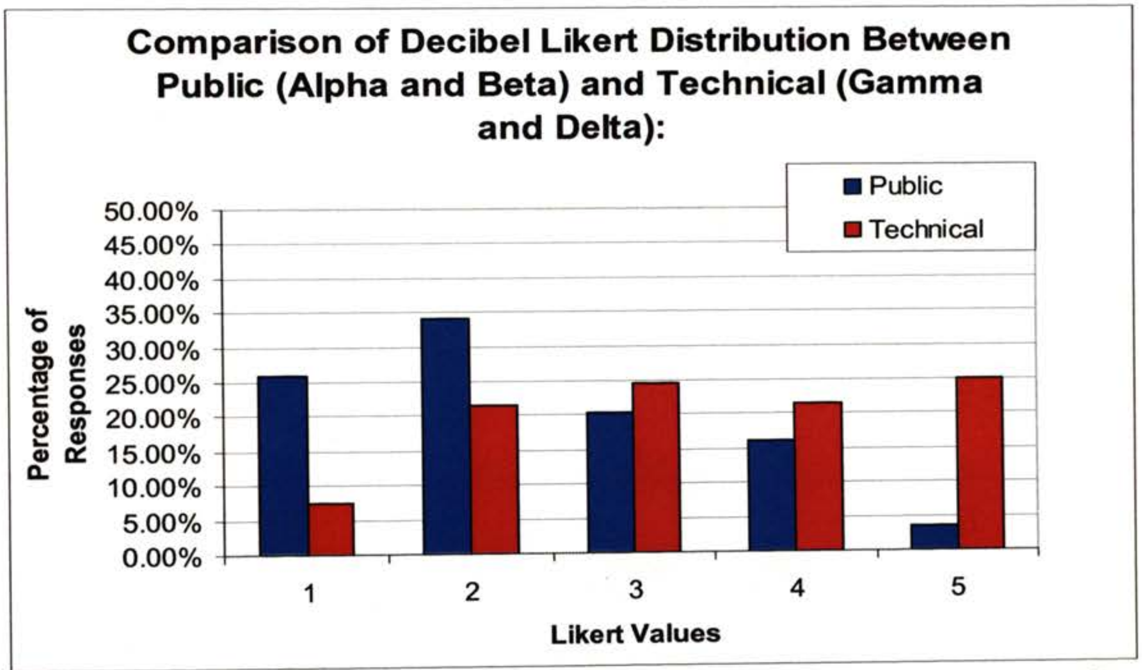

Figure 5.9. Distribution comparison of public and technical people for Decibel Likert question.

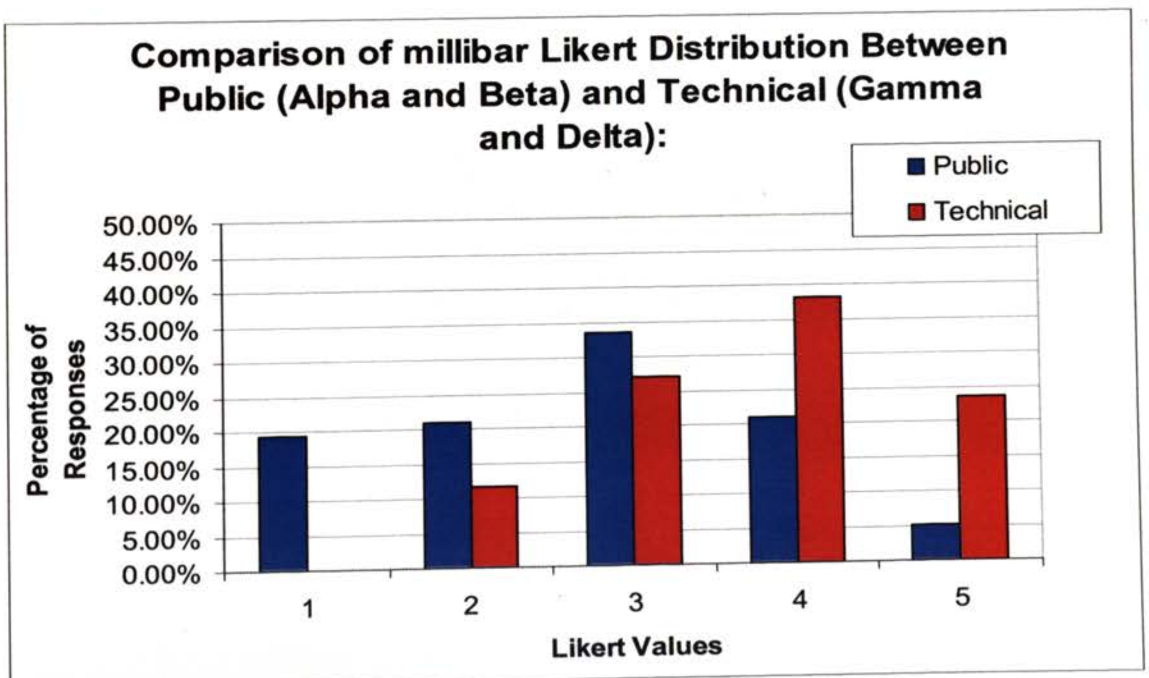

Figure 5.10. Distribution comparison of public and technical people for millibar Likert question.

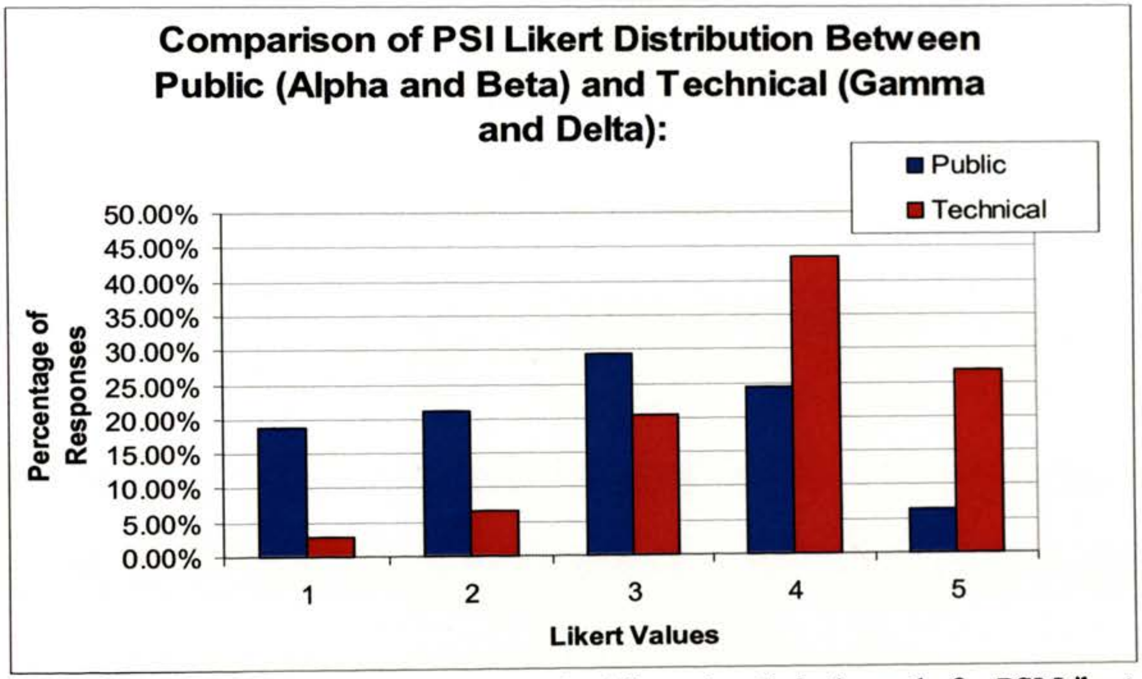

Figure 5.11. Distribution comparison of public and technical people for PSI Likert question.

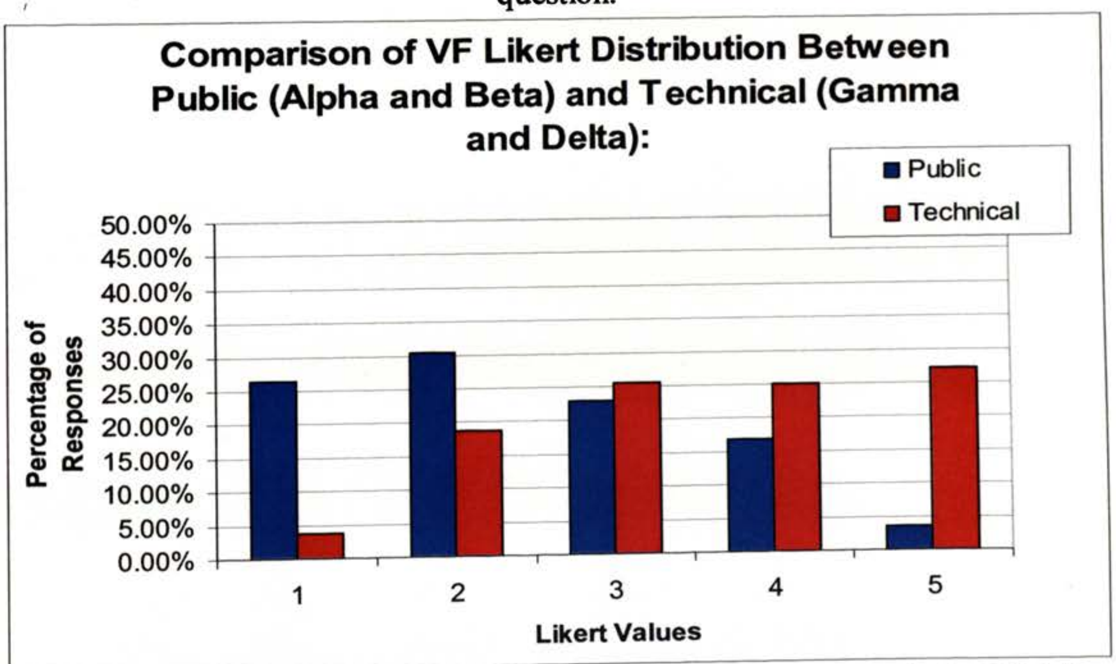

Figure 5.12. Distribution comparison of public and technical people for VF Likert question.

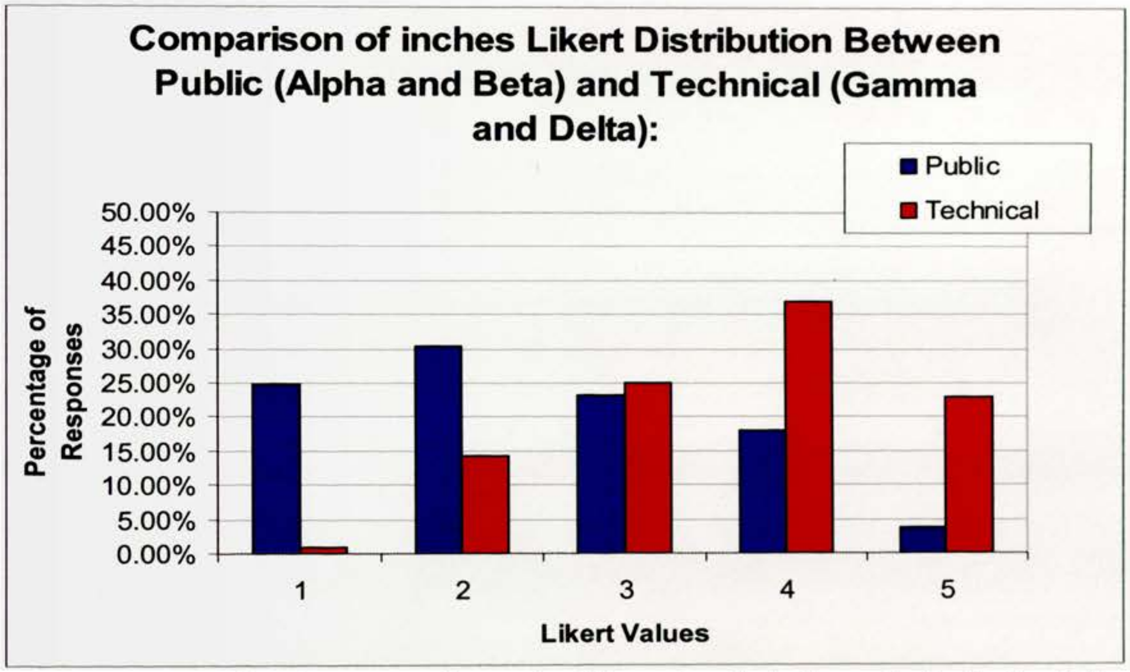

Figure 5.13. Distribution comparison of public and technical people for inches Likert question.

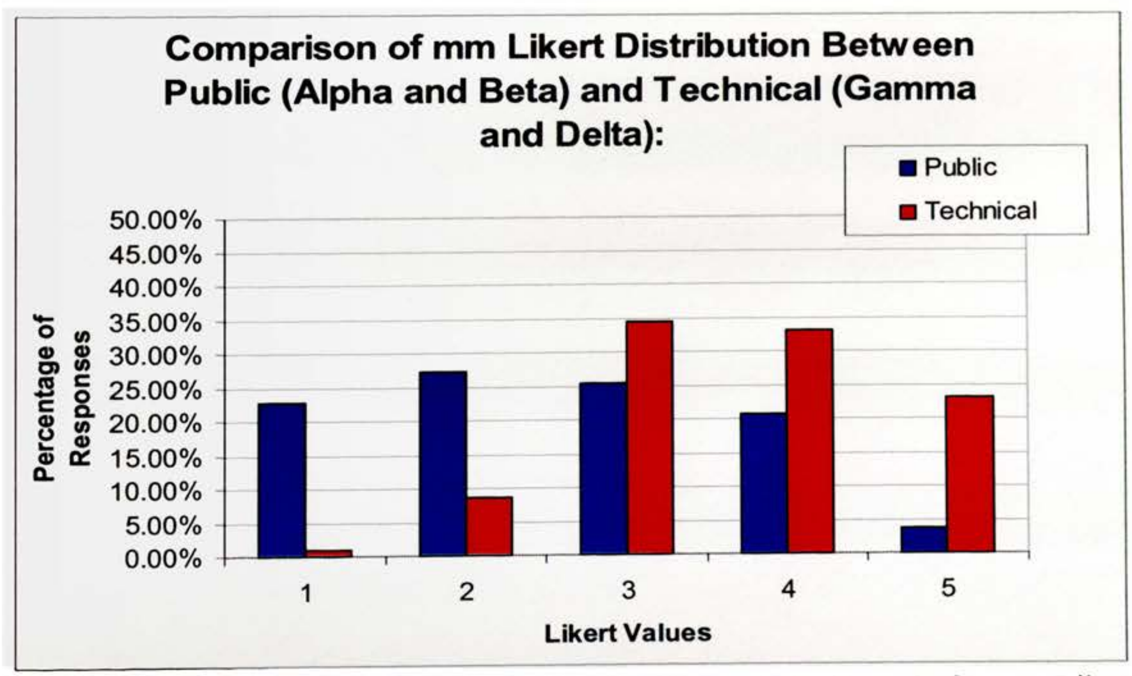

Figure 5.14. Distribution comparison of public and technical people for mm Likert question.

5.1.3. Epsilon – Other Groups Comparison. In Figures 5.1 through 5.7, the distributions for the Epsilon Group are significantly different than any of the other groups. Using Table 4.2, averages from the Epsilon Group generally fall between the lower valued Alpha and Beta Groups and the higher valued Gamma and Delta Groups. This is appropriate considering that regulators are often responsible for interacting regularly with all of the other groups. Future surveys will be needed to define methods for communicating effectively with regulators. The small size of the sample may have had an effect on the analysis of this group. Unformatted data for all survey groups can be found in files on the CDROM media located in Appendix F.

5.2. CONCLUSIONS FROM CROSS ANALYSIS

Through comparing the distributions and averages for the Alpha and Beta Groups, it was discovered that the Beta Group had slightly higher comfort values but similar distributions. This means that the Alpha Group, which has been exposed to blasting on a regular basis, is generally less comfortable than the Beta Group, which has had limited exposure to blasting.

Cross analysis has shown that respondents with technical backgrounds tend to be more comfortable with reporting units for airblast and ground vibrations. The Gamma Survey (Civil Engineers) pool more closely resembled the distributions from the Delta Survey (Blasting Professionals) pool, both of which were the most comfortable with all questions. The Gamma group averages fell between those for the Delta group and those from the Alpha and Beta groups, which were fairly similar. This suggests that technical background or education enables higher comfort levels with units used for reporting blast vibrations.

It is worth noting from Table 4.2 that the Delta group was the only group that had average comfort levels for the mm Likert and inches Likert questions that were lower than averages for the VF Likert question. While the difference was very slight and all average values from the Delta group were above 4, this may suggest that the blasters were more comfortable with units that they use everyday as opposed to displacement.

Further evidence is presented in Figures 5.8 through 5.14. The combined averages for the technical distributions trended towards the comfortable side, while the public distributions were closer to the uncomfortable side. In Chapter 7, recommendations to industry will utilize this information to suggest education of the public in proximity to mining operations.

6. PUBLIC RELATIONS TOOL

6.1. SURVEY DATA AS A PUBLIC RELATIONS TOOL

It is technically and scientifically proven that blast vibrations already have accepted limits that are safe and preclude damage from blasting. The problem of complaints about blast vibrations is now one of annoyance levels and public relations. Public relations overall offers the most fruitful path as zero annoyance will only occur when blast vibrations are almost eliminated. Mining operations should create proactive public relations policies especially concerning the use of explosives at their mines. Surveys could be a pivotal tool for determining what types of information neighbors might like to see regarding blast vibration and airblast data. Baseline surveys could determine a level of education that is currently found amongst the majority of its neighbors. This provides an excellent starting point for developing quality public relations. A short example of how survey data could be used to target issues follows.

A simple comparison of average comfort values at two separate quarry locations shows that the survey information could be used as an effective public relations tool. Table 6.1 shows average comfort values for a partitioned data set for the Ozark, Missouri, quarry shown in Figure 3.9 as compared to the partitioned data set for the Little Rock, Arkansas, quarries shown in Figure 3.5. The Ozark quarry was one of the quarries surveyed in the Springfield, Missouri geographic location. These two locations were chosen for the example analysis due to a visible difference in the aesthetics of the neighborhoods. In Ozark, the homes were newer construction and higher property-value homes than those around the Little Rock quarries. The averages summarized in Table 6.1 show that there is a difference in comfort levels for the two locations.

Table 6.1. Summary table for comparison of Ozark quarry and Arkansas quarries.

Partitioned Location	General Likert	dB Likert	millibar Likert	PSI Likert
Ozark	2.00	2.00	2.44	2.50
Little Rock	1.67	1.83	2.00	2.50

Partitioned Location	VF Likert	inches Likert	mm Likert	Federal Likert
Ozark	2.24	2.34	2.28	2.90
Little Rock	2.09	2.00	2.18	2.64

It can easily be seen that comfort levels are much lower from the Little Rock respondents. Notice the trends found in the analysis of the entire Alpha Survey group continue here with PSI as the preferred unit for airblast and mm displacement the preferred unit for ground vibration. The values themselves do not provide any aid as to how to handle the distinctly lower comfort values; however, taking a closer look at both the demographic information and the answers to the qualitative questions in the survey provides some direction. Table 6.2 shows the results of a simple analysis of the association questions asked in the survey about units for airblast measurement. The table values do not add up to 100% for each question due to the fact that some answers did not fall into the major categories summarized.

Table 6.2. Summary table of association analysis of partitioned data for Ozark, Missouri quarry and Little Rock, Arkansas quarries.

Partitioned Location	dB Association	millibar Association	PSI Association
Ozark	72% Sound	32% Pressure	69% Pressure
	25% Don't Know or No Answer	44% Don't Know or No Answer	25% Don't Know or No Answer
Little Rock	**83% Sound**	**83% No Answer or Don't Know**	**83% No Answer or Don't Know**
	17% Don't Know or No Answer	8% Pressure	17% Pressure

The summary table above provides insight for the lower comfort values from respondents in the Little Rock area. Specifically, 83% of respondents did not have an answer or replied "Don't Know" for the questions regarding what they associate with both millibar and PSI. This is particularly higher than the percentages responding "Don't Know" in the Ozark area. This suggests that education of the neighbors on something as simple as the units for pressure might help raise their comfort levels with reporting units for airblast.

Much could be learned about what residents find annoying about any specific operation with quality surveys. Findings could reveal that blasting is not the most annoying factor involved in the mining process. Crusher noise, dust, backup alarms, and truck traffic could all have adverse effects on the image of an operation. Expansion of the survey questions could address many of these issues.

Determining characteristics of quarry neighbors who are likely to complain would allow for specific targeting of public relations efforts. The data collected shows that age is a contributing factor to comfort levels with blasting. Figure 6.1 is a histogram showing average comfort levels on all of the Likert questions from the Alpha Survey for different 10-year age groups. The histogram shows that the age group 51-60 consistently returns the lowest comfort values on Likert questions. For consistency, Figure 6.2 is the same histogram for the Beta Survey. It also shows that the 51-60 age group averaged the lowest comfort levels.

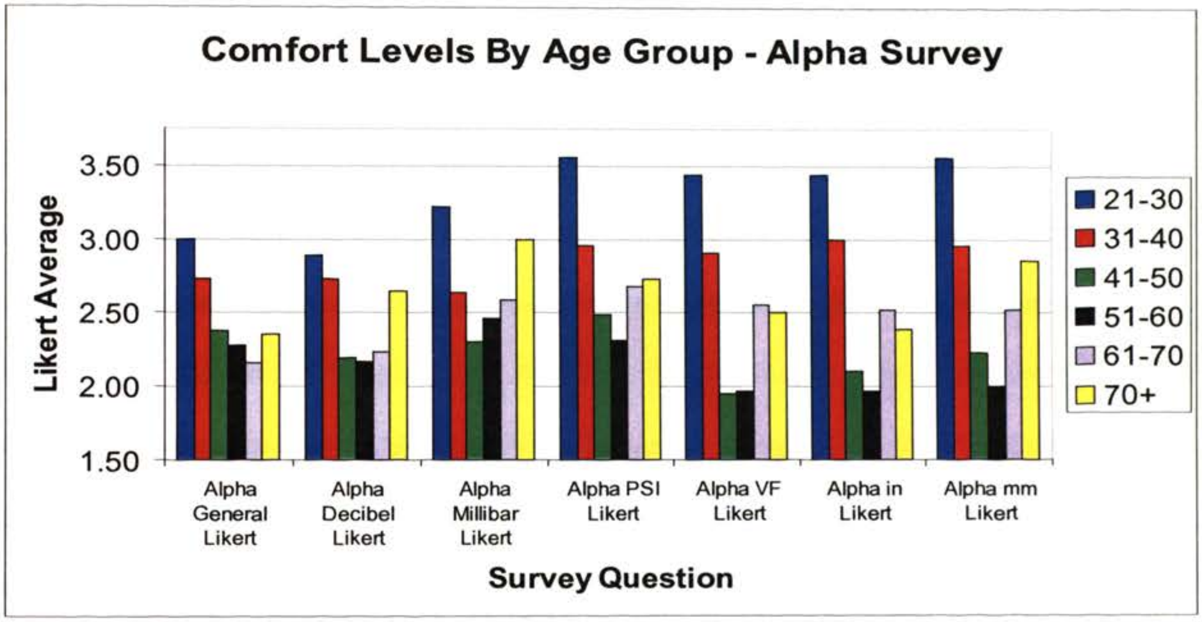

Figure 6.1. Histogram showing average comfort levels from different age groups on Likert questions. Alpha Survey.

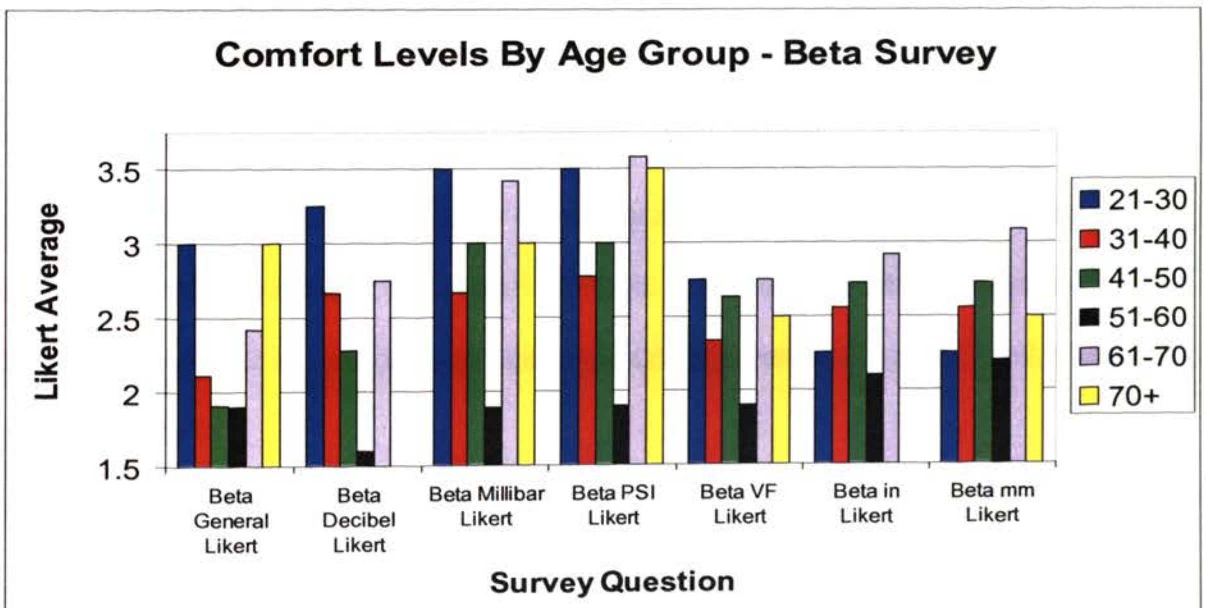

Figure 6.2. Histogram showing average comfort levels from different age groups on Likert questions. Beta Survey.

The information is Figures 6.1 and 6.2 can be utilized on a site basis to determine reasons for public relations problems. Shortly after the Alpha Surveys were distributed, it was learned that the Fred Weber quarry shown in Figure 3.3 was experiencing heavy complaints and public relations issues. After analyzing the Alpha surveys from this quarry, it was determined that education was not as large a factor as it may be in Little Rock. Most respondents had sensible answers for the qualitative airblast reporting questions. This suggests that another issue may be driving the problems. Considering age distribution of the surrounding area was a selected as the next step in determining what was at the root of the quarry's public relations problems. The respondents from the neighborhoods surrounding the Fred Weber quarry in south St. Louis County had an average age of slightly over 50 years old. Furthermore, 63% of the respondents fell between the ages of 45 and 62. It is important to consider a small amount of ages immediately around the age ranges shown in the histograms because the age ranges are arbitrarily selected at natural breakpoints of 10 years.

Looking further into the averages from Alpha surveys generated near the Fred Weber quarry it was discovered that comfort levels were indeed lower than the overall averages for the Alpha Group. Table 6.3 shows that the averages are noticeably lower at the Fred Weber quarry than the overall averages. This table and the histograms in Figures 6.1 and 6.2 suggest that the age group driving complaints at the Fred Weber quarry is 51-60.

Table 6.3. Average comfort levels on Likert questions for Fred Weber South Quarry and overall Alpha Group.

Partitioned Location	**General Likert**	**Decibel Likert**	**millibar Likert**	**PSI Likert**
Fred Weber South	2.02	2.05	2.37	2.29
Alpha Averages	2.39	2.36	2.58	2.65

Partitioned Location	**VF Likert**	**inches Likert**	**mm Likert**	**Federal Likert**
Fred Weber South	1.98	2.00	2.12	2.91
Alpha Averages	2.37	2.41	2.50	3.06

A final example showing age difference as a factor in comfort levels comes from the Alpha Survey and data from the Pilot Survey discussed in the introduction. A simple comparison of averages from Alpha General Likert and Question 5 from the Pilot Survey (which are the same question regarding general comfort with a blasting operation) shows an interesting anomaly. The average age of the Established Neighborhood in the Pilot Survey was 54 years, and the average age of the Newer Development was 35 years. Taking the averages from Alpha General Likert for the 31-40 age group (2.73) and the 51-60 age group (2.28) gives a difference of 16.5% in comfort levels. The average for Question 5 in the Pilot Survey from the Newer Development was 3.1, while the average for the Established Neighborhood was 1.85. This is a difference of 40.3%. Logically, the higher comfort level in the Newer Development was partially due to the age difference, but such a large difference suggests that another factor was involved. As mentioned in the introduction, the Newer Development was subjected to a mailing as a public relations effort. It could be that the difference in the two neighborhoods in the Pilot Survey was driven by both age differences (16.5%) and public relations or education efforts (23.8%). An alternative way of looking at this fact is to say that the research results were biased by the public relations efforts.

Gathering demographic and qualitative data will enhance an operator's ability to communicate and, thus, circumvent complaints. The key to positive public relations is to give neighbors what they want without creating undue financial burden on the operation. For example, learning that the majority of neighbors do not understand anything about blast vibrations could prompt local meetings to discuss these issues. Likewise, surveys could show that neighbors are well educated in terms of blast vibrations and airblast, and thus another avenue must be chosen.

6.2. ADVANCES IN PROACTIVE PUBLIC RELATIONS

Many situations where quarries are surrounded by development can be found all over the United States today. Favorable public relations are an increasing problem for quarries and mines in areas of rapid growth. In the past, the explosives and blasting industry has taken a soft-spoken approach with the public. The idea of ignoring public relations in hopes that complaints will eventually go away is no longer effective.

Already, many people harbor ill feelings toward blasting operations. Positive public relations are necessary. However, the blasting and mining industries in general are way behind in creating a positive image in their communities. It is imperative that over the next several years, the aggregate industry follows the lead of industries, such as plastics, in educating the public about the good things that are created through the use of explosives and mining. Already, the mining industry is well versed in public relations regarding environmental concerns with mine closures and pollution. The expertise obtained through cleaning up the mining industry's environmental image could be directly applied to the issues with blasting complaints.

The first step in achieving positive public relations is educating the public on how blasting operations conduct business, and how these operations affect the public. People are naturally uncomfortable with events that they perceive as potentially dangerous to their homes. Current reporting practices leave much to be desired when considering that the public must understand what is actually happening when blasting takes place. In order for the blasting industry to sustain positive public relations, the information that is reported about each particular blast not only must be easily understood by the public, policy makers, and explosives users alike, but it is imperative that they also have a good comfort level with these numbers. The survey results found in this dissertation are a first attempt at locating a proper medium for transferring seismograph data to the public in an easily understandable format.

Another necessary step in positive public relations is determining the characteristics of people who are likely to complain about or be uncomfortable with blasting operations. As discussed earlier, the age group from 51-60 years old consistently provided the lowest average comfort values on Likert questions. This might suggest that this age group is most likely to complain. More research will be required to determine how comfort values correlate to complaints, but at least a target group for public relations has been identified. The data cannot positively determine whether this difference in comfort levels among age groups is a function of age only, or if generational factors are involved. Generational differences may have created the discrepancy in comfort values for the different age groups. If this is the case, then as the 51-60 age group grows older, their lower comfort values will follow them into the 61-70 age group in future surveys. If age alone is responsible for the difference, then later surveys would show similar results with the 51-60 age group recording the lowest averages.

Many life factors could explain a difference in comfort levels with age. For example, perhaps younger respondents were more resilient to blasting and, thus, were more comfortable with it. As the age rises, stress from work or "mid-life" issues could cause individuals to be more easily bothered by blasting. Upon retirement, perhaps a lower stress environment allows people to be more resilient to blasting once again. This sequence is only an example and is not supported by the data; however, future surveys could attempt to evaluate reasons for lower comfort levels in the 51-60 age groups.

There may be philosophical differences between generations as well. Some generations could be overall more sensitive to environmental issues or just have reservations about mining in general.

Recently the Mississippi Valley chapter of the ISEE entertained discussions about appointing or electing a public-relations representative. The idea has not been totally accepted by all members; however, the idea is intriguing. Many times media coverage will interview neighbors of blasting operations and make statements that are unchecked and for the most part wrong. A public-relations representative for the chapter would be responsible for quickly responding to such media. Once the media is informed that such a person exists, it is hoped that their opinion would be solicited when coverage of such events are imminent. The use of such a representative would allow the blasting industry an opportunity to protect its image when slandered by angry residents during media coverage. While this public-relations effort is somewhat reactive, it does present an interesting idea of creating publicity for the positives produced from explosives and blasting.

Creating industry standards for discussing ground vibrations and airblast with easy-to-understand terms and units would make public-relations efforts much easier. Consider the compound effect of communication. While discussing this research with industry members, one vibration consultant claimed to be very capable of explaining the technical aspects of blast vibrations to any quarry neighbor during seismograph setup and measurement. The question is: can the quarry neighbor then effectively explain the issue to other neighbors? The use of simple units would increase this neighbor's ability to do so.

In general, the blasting industry will have to be very creative and novel in order to deal with this emerging problem effectively. Major changes will need to take place in order for quarries and residential neighbors to continue living together without serious issue. The mining and blasting industry will be ultimately responsible for bridging the communication gap.

7. RECOMMENDATIONS FROM RESEARCH

7.1. RECOMMENDATIONS TO INDUSTRY

The data collected and subsequent analysis provided direction for creating quality recommendations for the blasting industry. Specifically, the quarry blasting industry can glean positive information from this dissertation. With ever-expanding urban areas, quarries are being enveloped by residential neighborhoods at an alarming rate. Positive relationships with neighbors are paramount in the success of these quarry operations. The data from all of the Survey Groups as well as the Pilot Survey supports the following recommendations for quarries that utilize blasting as their primary excavation method:

- Embrace the idea of reporting ground vibration and airblast data in the most easily understandable format. Analysis in Chapter 4 shows that PSI would be a better reporting unit than decibels.
- Start asking why when residents are unhappy with blasting at the quarry. The Pilot Survey began showing trends that explained why respondents were uncomfortable with blasting. Further data from the additional survey groups (Alpha through Epsilon) supports the concept of starting by asking why residents are unhappy and complain.
- Implement a proactive public-relations program which includes surveying adjacent neighborhoods to determine comfort values and "hang-ups" with the quarry operation. Chapter 6 discusses how information from surveys could be used as a tool for directing public-relations efforts and is supported by data from the Pilot Survey and other Survey Groups.
- Follow public-relations efforts with education of neighbors in areas where a survey shows a need. This idea was discussed in Chapters 5 and 6.

Most importantly, the blasting industry should quit its past practice of avoiding issues with the public. By embracing the idea of changing the way business is done (specifically reporting practices), quarries stand to build sustainable relationships with nearby developments. The idea is no different than opening mining operations in undeveloped nations. The mining industry has learned through practice the idea of obtaining a "social license to operate." The concept should not be isolated from companies that are only involved with domestic mining operations. A social license to operate is obtained when local customs allow for the development of reserves because of a local understanding of the benefits of such operations. While many operations are facing neighbors for the first time due to new developments, there is still a need to coexist.

The data obtained through surveys has shown that airblast could be more effectively reported using PSI as opposed to decibels. The general public does not understand the logarithmic nature of the dB scale, and further it has connotations of sound rather than pressure. The blasting industry should begin to take advantage of what people already understand. For example, many people would associate PSI with the pressure in their tires. They may already have a number in mind for comparison to the reported levels. Since most people think in terms of relationships, considering a blast producing 0.0029 PSI doesn't seem overly harmful when compared to the 32 PSI required to fill their tires. The concept may seem remedial, but public relations should be designed as simple as possible.

More research will be required to determine the correct unit for reporting ground vibrations, but the low comfort levels overall point to education as a potential tool for improvement. Once blasting practices have been established that produce vibrations at levels well below the threshold of damage, the job becomes less technical and more towards public relations. Neighbors must be comfortable with the operation, including its blasting practices. One source of discomfort comes from a lack of education in the area of blast effects. Residents are often frightened unduly by vibrations because they fear harm to their homes. Complicated scales and measurements do nothing but further the adverse effects of ignorance.

The first question to be answered when assessing a blasting program is: Are the blast vibrations produced harmful to nearby structures? Once the answer to this question is no, operations must begin to question why complaints are still happening. In most cases the answer falls into two categories which are annoyance and fear. Annoyance is much more difficult to deal with because even the slightest vibration could be perceived as a nuisance to residents. However, fear can be overcome through education.

Overall, it is up to the mining operations and the blasting industry to extend the olive branch to its neighbors and begin building a solid foundation of trust and candor. It is not a simple task, yet dedication to the issue will allow for years of incremental improvements. Eventually, the majority of public-relations issues could be handled on a long-term basis. There will always be a certain number of people who are just not comfortable with the idea of blasting near their homes, no matter what effort is put into quelling their annoyance. This is shown by the fact that through all of the distributions for the Alpha and Beta Groups there were some percentage of residents who answered "very uncomfortable." It is not certain how many of these respondents could be more comfortable with public relations or educational efforts by the mining company. In this case, constant feedback should be encouraged, and problems will have to be handled on a case-by-case basis. While not every complainant could be quelled through open communication and simple, easy-to-understand units, at least other residents would be less likely to rally around these people in complaining.

Another variable to consider when determining public relations and neighbor complaints is the potential advantages for residents complaining enough to force quarries to move. The property owners stand to profit in two ways from this situation. First, the resale value of their homes will likely increase when there is no longer an industrial quarry in the back yard. Secondly, the price of all aggregate will likely increase, forcing the construction cost of new homes higher. Both of these advantages must be considered when designing and implementing public relations programs. This concept also may be a driving factor in the lower comfort values for residents living in proximity to quarries. Although the effect would be difficult to quantify, it must be considered. Even if this effect could not be quantified, the concept definitely supports the idea of using simpler units for reporting. If units are difficult to understand, blasting becomes an easy target for people to complain about. Regulators will not be prepared to reply to complaints, and will have no other option than applying pressure to the operations responsible for the blasting.

Before education of neighbors can be effective, a baseline level of understanding must be established. Performing a survey similar to the ones described in this research could provide direction for a proactive public-relations program and in fact could be an integral part of it. Chapter 6 discusses in depth the concept of utilizing surveys for public relations.

Once a baseline for a particular operation is measured through surveys, an aggressive education campaign can be pursued. The education could come in the form of educational mailings, local meetings, and simply personal contact.

Education should not be confined to neighbors. The mining industry must also reach out to local and state regulators. This effort will go far into preventing ridiculously restrictive regulations from being proposed. The Mississippi Valley Chapter of ISEE has begun to conduct seminars to this end. An educational seminar has been offered for officials and lawmakers in St. Louis, Missouri, and Jefferson City, Missouri, and others are in the planning stages.

As local and state regulations become more restrictive to blasting activities, the problems associated with blast vibrations and airblast are becoming more of a public-relations problem rather than a technical issue with respect to blast damage. It is necessary to shift focus from blast-damage limits, which have been extensively researched, to quantifying and controlling annoyance. This can be said only with a qualifying statement. Technically sound regulations must be created with public relations in mind. This seemingly simple task will provide lawmakers with an easily understandable standard by which to base local regulations. To date, a limited amount of work has been performed in this area, but the United Kingdom study discussed in the literature review and this dissertation are a start.

7.2. RECOMMENDATIONS FOR REGULATORS

Reporting units and regulations must be considered together. Regulators are advised to question all details of blasting regulations that are proposed. When laws are created that are based on federal precedence set by OSM regulations, these laws should follow the regulations exactly. Changing the values of limits arbitrarily could be detrimental to the livelihood of many operations within the jurisdiction and may result in costly lawsuits filed by mining companies as blasting is the only economic means of breaking hard rock in quarrying. If the blasting industry is true to the recommendations stated above, the layman should be able to understand what is being reported and what levels are safe and not overly restrictive.

Local regulators are encouraged to strive for uniform limits across regions. Statewide regulations could be effective if designed properly. Another benefit of uniform limits is the release of burden for local regulators. They may prefer to refer constituents to regulations that are already in place as opposed to developing new ones. In general, local policies are much easier to pass and apply than state and federal regulations. For this reason, developing local legislation for blasting limits brings the risk of creating overly restrictive limits that could effectively close operations and create unnecessary political pressure at the local level. Regulators should keep in mind that forcing operations to move farther away will only serve to raise material costs for development of their cities as well as reducing the tax bases. Roads will cost more to build and maintain. Housing costs will increase as well, not to mention the loss of quality employment for the area affecting mainly the population represented by the Beta Group. The majority of the workforce for the quarries might not live within 1 mile of the operation. Similar to the recommendations for industry, regulators should promote coexistence.

Research in other areas has provided much insight as to the development of public policy. Warneke (Warneke, 2004) discusses at length the use of indicators to help in the creation of public policy. Through discussing the many definitions and characteristics of indicators Warneke identifies a common thread among effective indicators. He states "characteristics necessary for effective indicators: ... Simple to interpret, accessible and publicly appealing." (Warneke, 2004). As discussed in Chapter 1, the blasting industry needs to define good indicators for public relations and complaint levels involving blast vibrations. These indicators should be utilized to guide public policy in regards to blasting. The survey described in this dissertation could be utilized as a beginning for this process as well.

In order for regulations to be easily understood, the units of measurement utilized within them must be familiar and understandable to legislators, government administrators, and the public. Data from surveys, such as the one discussed in this dissertation, and others to follow, will speak volumes as to what the general public is most comfortable with when discussing units of measurement for blast vibrations and airblast.

The units must be sufficiently simple for non-technical enforcement personnel to explain to the public. This is especially true for small towns and political subdivisions that have limited numbers of technically-educated personnel resources.

8. CONCLUSIONS AND FUTURE RESEARCH

8.1. CONCLUSIONS

Over the past several decades, extensive research has been undertaken involving airblast and ground vibrations due to blasting. While much quality work has been done, a key piece to the public-relations puzzle has been left out of the research. This key piece is "What does the public think about blasting?" This generalized question has been answered qualitatively thousands of times at the informal discussions of many conferences. However, the question has never been answered quantitatively, and further, it has never been correlated to reporting practices within the blasting industry until the research for this dissertation was performed. The research discussed here provides new concepts for the blasting industry.

With the data collected and recommendations created, the industry stands to seize an opportunity to take public relations to a new level. The data begins to tell a story about what people want to know about blasting. It also shows that quarry neighbors are not comfortable with blasting near their homes. By utilizing the most easily understandable units for reporting ground vibration and airblast data to the public, there is potential for improving comfort levels with blasting in general.

The data gathered during this research allows for the design of public-relations efforts for mines and blasting operations in general. It also provides some new ideas for literature and media to build from, through new publications.

The following specific conclusions were drawn from the data collected:

- Overall people are not comfortable with blasting near their homes. Only the Delta Group (blasting professionals) produced an average above 3 (neutral), proving that all other groups were less than comfortable with blasting.
- The use of the decibel scale is misleading to the public and creates greater discomfort with the blasting that produces the airblast.
- PSI would be a better choice of unit for reporting airblast measurements based on higher comfort levels and distribution shifts in all cases. The aggregate increase in comfort level was over 10% in all cases except for the Delta Group (blasting professionals), who were more than comfortable with all units.
- While a conclusion for better ground vibration units could not be reached adequately with the data, questions to be answered by future research were raised. The survey provided a baseline to build on for determining how to handle this complex issue.
- Individuals with technical backgrounds or blasting experience (Gamma and Delta) were much more comfortable than the "general public" (Alpha, Beta, and Epsilon) across the board. This shows that a level of education could make quarry neighbors more comfortable with the vibration information reported to them. Simpler units could only make this an easier task.

The conclusions reached through this research are groundbreaking in the fact that no one else has considered this type of method for helping the blasting industry with its public-relations issues. Even the author of this dissertation has intermittently fallen into the trap of following engineering instincts rather than focusing on simple, easy-to-explain communication. The key to progress in this area is to remember that the blasting industry has a very technical background, and items taken for granted as common knowledge are unknown to the public.

Other more subtle conclusions were also drawn from the data analysis. Age group distributions discussed in Chapter 6 showed that in nearly all cases that the comfort levels decreased with age until they reached a minimum at the 51-60 age group. The 61-70 and 70+ age groups trended towards higher comfort levels, but not as high as the youngest groups. This U-shaped distribution raised questions about why the comfort levels among different age groups differed so regularly. Learning more about this issue could aid in developing public relations programs in the future.

Analysis of the survey results from the Delta Pool provided interesting information. The average comfort levels were higher than any other group for all questions. This is to be expected since the Delta Pool consisted of blasting professionals; however, the Delta Pool was also the only group which preferred PPV and frequency to mm displacement or inches displacement. It is possible that the blasting professionals simply prefer to use the units that they have been using for many years. More information would be needed to determine exact reasons for this occurrence.

Consider the idea that neighbors initiate complaints in order to potentially raise the value of their homes as discussed in Chapter 7. It is apparent that the mining/blasting industry must utilize all tools necessary to combat frivolous complaints. Using reporting units and methods that are not easy-to-understand is definitely not the answer. This has been proven through years of mining in urban areas. Implementing more easily understood scales and units for reporting airblast and ground vibrations is certainly a step in the right direction.

8.2. FUTURE RESEARCH

Continuation of this research effort is paramount in order for it to provide a positive impact for the mining industry. Currently proposals are being written by the author for research funded by the Office of Surface Mining (OSM) to look into how the ideas addressed here can help surface coal mining. Since the majority of regulators use OSM standards, most if not all surface mines could be helped through OSM funded research. Hopefully, OSM will be open to exploring the possibility of changing the units they require for airblast and ground vibration reporting based on research similar to what is presented here.

The mining industry would serve itself well by implementing the recommendations outlined in Chapter 7. Further surveys at all types of mining operations will help build a database of information that could provide dividends to all of the mining industry.

Specific research projects that should be proposed in the near future are addressed in closing here. Future surveys can be utilized to determine what words create high levels of anxiety such as “house moving” or “displacement” in regards to ground vibration. There is still an unknown concern with ground vibration that causes uncomfortable reactions from individuals living near mining operations. This is the issue at heart of a debate as to whether a better ground vibration unit could be selected. Future surveys could also determine whether PSI is the optimum unit for airblast. This research has established that it is superior to decibels, but perhaps percentage of damage thresholds could be even more effective in creating comfort with respondents. By using percentage limits, no units would be necessary. For example, consider that the damage threshold for windows is 0.046 PSI, a typical blast might produce 0.0029 PSI at a nearby structure, and the OSM limit for airblast is 0.013 PSI. By using percentage reporting and limits, the damage threshold would be 100%. This would mean that the limit would be 28%, and the typical blast would represent 6% of the damage threshold. It could be that using percentages instead of units would help to clarify the issue in the mind of the public by installing a reference point automatically. The same idea could be applied to vibration as well through the development of safety factors.

Future survey items have been identified in consideration of the difference in comfort values across varying age groups. Future surveys could be designed to determine the cause for this phenomenon. The questions would be designed to determine whether the U-shaped distributions are a function of age only, or if generational differences were more of a factor. It would be very useful to know why the comfort levels are lower for the 51-60 age group than any other.

Other surveys could be designed to partition the Delta group in order to determine why they prefer PPV and frequency to displacement. One way to partition the group would be to select a pool of blasters who actually drill, load, and fire the blasts and compare their results to a pool of vibration specialists. As discussed earlier, the reason could be that blasting professionals are more comfortable with a familiar unit, but more data is necessary to draw specific conclusions.

In order to more clearly define the possible advantages to educating quarry neighbors for public relations efforts, more surveys should be administered. The study could include two groups that reside away from any blasting operations. One group could be exposed to educational efforts followed by a survey asking about blasting and reporting units. The other group would then be administered the same survey without any educational efforts. This study would potentially quantify the positive effects of educating quarry neighbors on blasting and how it is reported. It could also allow for honing public relations and educational efforts for the best results.

While reviewing literature on surveys and analysis methods, perceptual mapping was discovered. It is a marketing tool used by companies for product development. Perceptual mapping is a very powerful and easy-to-use technique for studying the relationships between two or more categorical variables. It is frequently used in marketing research to understand consumer perceptions of a product and to determine the potential effectiveness of an advertising campaign designed to modify their perceptions. There is a possibility that this method could be useful since mining operations are essentially marketing their blasting programs to neighbors.

Further study of the data already obtained could also prove useful. Correlations between individuals who have filed complaints with their comfort levels with units or their demographic information could help answer more questions about what drives people to formally complain about blasting. The author plans to reach out to the operators of the quarries where neighbors were surveyed to determine if their public-relations efforts have been effective and if there are ways that the results of this work can help them achieve their goal of coexisting with suburban neighbors.

The results of the research described here have only begun to scratch the surface of how to optimally interact with the public. Continued efforts over many years will hopefully show how useful this information can be for the mining and blasting industry.

APPENDIX A.

PUBLIC RELATIONS LETTER TO ST. CHARLES NEIGHBORHOOD

December 16, 2002

Hello,

My name is Paul Worsey and I would like to introduce myself. I am the current examiner for the Missouri state blasting certification programs and a Professor at the University of Missouri. You may have seen me on the Discovery, Learning or most recently History channels on TV. I've been asked to write a short piece on blasting for those people who are purchasing a home in a new development next to the St. Charles rock quarry.

Materials in your house such as the aggregate in the concrete and black top outside on your street probably came from this quarry. The aggregate is used because it is strong. It has to be blasted from the ground so it can be loaded into trucks and taken to a crusher for further breakage. If you could just dig it from the ground it wouldn't be strong enough for the job. Because of this quarries blast their rock. Over five billion pounds of explosives are used each year in the United States in mining, and because of this, raw materials like those used to construct your house are relatively inexpensive.

Homeowners are often startled by blasts because they are sudden. However, they rarely cause damage to buildings because the blasting is usually too far away, or when close the blasting crews take special precautions to avoid high vibration levels.

There are two types of blast vibration that cause homes to shake. These are air blast and ground vibration. Often times it is difficult to distinguish between the two when inside a home.

Government studies show the safe limit for ground vibrations from quarry blasting is 2 in/sec. The usual limit for air blast is 133 decibels (dB). Most of the energy is at frequencies below human hearing, so it's hard to judge the noise level of a blast without using a special blasting seismograph. I like to use the following analogy: have you ever wondered why dogs hear dog whistles but we don't? That's' because we are bigger so we don't hear the higher frequencies a dog does. Similarly because a house is very large compared to a person it "hears and responds to" only low frequency noise, rather than the "medium" frequencies that people hear the best.

The first thing to be damaged by air blast is a window. It takes over 140 dB before poorly installed windows and large picture windows start to crack. St. Charles County has regulated limits for blasting ground vibrations and air blast to prevent damage.

Virtually every house develops cosmetic flaws as it ages, no matter where it is located - next to a quarry or in the middle of the country side. These flaws include nail pops, cracks in sheet rock around doors, window corners and joints (especially at wall corners) and cracks in large concrete slabs and foundation walls. My current house in particular has a lot of nail pops and cracks in the sheetrock, which are fixed each time we redecorate, and my concrete patio and garage floor also have cracks in them. I know they are annoying when you see them but they are like wrinkles, which are inevitable as you age, and that's life I'm afraid. No one has ever blasted any rock anywhere near my house. The reasons these cosmetic defects commonly occur in Missouri are the tremendous changes in temperature (below zero to 100 degrees plus) and humidity, along with the tremendous shrinking and expansion of typical Missouri clays. Both the US government, and independent university and international studies show that the stresses from normal weather changes are far greater on a house than those caused by typical blasting vibrations, which only last for a few seconds.

The US government (Office of Surface Mining) has established safe blasting vibration limits. They use a special equation that limits the amount of explosives that can be shot on a single delay within a blast. The numbers used in this equation are very conservative and if the mining operator stays below the maximum pounds it calculates, he is not even required to use a seismograph because the ground vibrations will be low (although still noticeable). Rather than give the equation I have put together a simple table with the pounds of explosive that can be used per delay for various blasting distances to a house.

Distance (ft)	Max explosive (lb/delay)
400	64
500	100
600	119
800	212
1000	331
1500	744
2000	1322

The numbers in the table typically give ground vibrations less than a third of the St. Charles County limits, so if you are using a seismograph you can use 3 times as much.

You may have noticed that I talk about pounds per delay rather than the total explosives used in the shot. In blasting we normally separate the firing of neighboring holes by a small delay of a few milliseconds. This allows the rock in front of the first hole to move enough out of the way before the next hole fires, giving it an easier job, and as a result significantly improves rock breakage. Using delays in a blast saves quarry operators a lot of money because they get much better rock breakage, which means less oversize and quicker crushing. A useful side effect is that ground vibrations are substantially reduced. This is because the ground is hammered in lots of small blows rather than one BIG ONE. The time it takes for a blast to fire is around a half second or so.

It is very unlikely that a house neighboring the quarry will suffer any damage due to blast vibrations. This is because of the St. Charles regulations that set the maximum blast vibration levels allowed for the protection property, and the strict enforcement of these regulations by County officials.

Dr. Paul Worsey
Worsey & Associates
Explosives Industry Consultants.

APPENDIX B.

PILOT SURVEY

PILOT SURVEY

Survey for Public Perception of Blasting and Reporting Practices

General Questions

1. Do you own or rent your residence?
2. What is your age?
3. What is your sex?
4. What hours do you work?

Technical Questions

For the following questions, rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

5. How comfortable do you feel having a blasting operation within 1 mile of your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

6. When blasting commences, considering that 144 decibels begins damaging windows, how comfortable are you with setting a limit of 133 decibels for blast pressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

7. When blasting commences, considering that 3.18 millibars begins damaging windows, how comfortable are you with setting a limit of .89 millibars for blast pressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

8. What do you associate with the decibel scale?

9. When blasting commences how comfortable are you with ground vibrations at your home with velocity in the range of .5 inches/second at 35 Hz?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

10. When blasting commences how comfortable are you with ground vibrations causing a displacement of .05 millimeters at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

APPENDIX C.

PILOT SURVEY INFORMATIONAL FLYER

How do explosives affect you?

Many of the products that you use or need on a daily basis are produced through the use of explosives in mining. For example, you might not know that limestone from quarries much like the ones in your neighborhood can be used in household goods such as toothpaste and hand soap. It is more likely that you would be familiar with the construction uses of the aggregates mined nearby. A few facts that you may not be aware of are as follows. (courtesy of Missouri Limestone Producers Association web page)

- Construction of a typical home requires 300 to 400 tons of aggregate.
- Up to 80% of the concrete in roads and other structures is comprised of crushed stone; up to 95% of asphalt roads and parking lots is crushed stone. One mile of two-lane concrete highway requires 7,200 tons of aggregate; one mile of two-lane asphalt highway requires 10,300 tons of aggregate.
- About one-half of all crushed stone production is used for publicly-funded projects such as highways, bridges, water/sewer systems, public buildings, airports, etc.
- Most aggregates are used within 40 miles of where they are extracted and are typically hauled by dump truck. After a truck loaded with aggregate travels about 20 miles, freight charges usually begin to exceed the cost of the material it carries.
- Limestone is mined in 92 of Missouri's 114 counties, and the industry employs more than 2,500 people with a combined payroll of more than $60 million.
- More than 75 million tons of crushed limestone products are produced in Missouri each year--roughly 10 tons for each resident.

With these facts in mind, some of the positive impacts of the use of explosives can be seen. Limestone quarries in St. Charles County are responsible for maintaining low prices for aggregates to support the development of new homes and roads. These operations use explosives that are necessary for the extraction of the rock. Federal guidelines govern the blasting practices; however, many city and county ordinances have been established which are not based on science and damage criterion. For many years, the explosives and mining industries have sustained quiet reputations concerning the effects of their practices. Currently the explosives industry is specifically targeting communities such as St. Charles for educating the public about the use and effects of explosives. Typical blasts from these quarries will cause vibration displacement at nearby homes of only about the thickness of a piece of photocopy paper. Likewise, the pressure level is measured in Decibels which is generally considered a sound measurement. The pressure created from blasting is generally of lower frequency than can be heard. Limits are generally set to approximately 133Decibels, which is 30% of the level proven to begin damaging windows at 144Decibels. The Decibel scale is logarithmic which means that numbers cannot be compared directly.

The purpose of the survey that you have just taken is to identify the needs of the public from a reporting standpoint. What is the best way for blasting operations to report their seismograph information? Ideally the reporting would be straightforward and easy to understand for residents and policy makers alike. If you would like more information concerning this survey or about blasting and explosives in general, feel free to contact Braden Lusk at the University of Missouri-Rolla. Phone number – (573) 341-7584. Thank you for spending this time to aid in our research.

APPENDIX D.

COMPILATION OF ACTUAL SURVEYS: ALPHA, BETA, GAMMA, DELTA AND EPSILON

ALPHA SURVEY

Survey for Public Perception of Blasting and Reporting Practices

General Questions

1. Do you own or rent your residence?
2. What is your age?
3. What is your sex?
4. What shift do you work?
5. How long have you resided in your current residence?

Technical Questions

For the following questions, rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

6. How comfortable do you feel having a blasting operation within 1 mile of your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

7. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

8. What do you associate with decibels.

9. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

10. What do you associate with millibars?

11. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (psi). How comfortable are you with a blast producing 0.0029 psi of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

12. What do you associate with psi?

13. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable are you with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

14. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable are you with ground vibrations of 0.00227 inches at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable are you with ground vibrations of 0.06 millimeters at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

16. Have you ever lodged a complaint against a blasting operation?

Yes		No

17. Federal safety limits are reasonable for public safety.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

BETA SURVEY
Survey for Public Perception of Blasting and Reporting Practices

General Questions

1. Do you own or rent your residence?

2. What is your age?

3. What is your sex?

4. What shift do you work?

5. How long have you resided in your current residence?

Technical Questions

For the following questions, rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

6. How comfortable would you feel having a blasting operation within 1 mile of your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

7. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

8. What do you associate with decibels.

9. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

10. What do you associate with millibars?

11. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (psi). How comfortable are you with a blast producing 0.0029 psi of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

12. What do you associate with psi?

13. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable would you be with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

14. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable would you be with ground vibrations of 0.00227 inches at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable would you be with ground vibrations of 0.06 millimeters at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

16. Have you ever lodged a complaint against a blasting operation?

Yes No

17. Federal safety limits are reasonable for public safety.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

GAMMA SURVEY

Survey for Public Perception of Blasting and Reporting Practices

General Questions

1. Do you own or rent your residence?

2. What is your age?

3. What is your sex?

4. What shift do you work?

5. What is your title?

Technical Questions

For the following questions, rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

6. How comfortable would you feel having a blasting operation within 1 mile of your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

7. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

8. What do you associate with decibels.

9. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

10. What do you associate with millibars?

11. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (psi). How comfortable are you with a blast producing 0.0029 psi of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

12. What do you associate with psi?

13. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable would you be with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

14. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable would you be with ground vibrations of 0.00227 inches at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable would you be with ground vibrations of 0.06 millimeters at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

16. Have you ever lodged a complaint against a blasting operation?

Yes   No

17. Federal safety limits are reasonable for public safety.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

DELTA SURVEY

Survey for Public Perception of Blasting and Reporting Practices

General Questions

1. Do you own or rent your residence?
2. What is your age?
3. What is your sex?
4. Is your residence within 1 mile of a blasting operation?
5. How many years of experience do you have with explosives and blasting?

Technical Questions

For the following questions, rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

6. How comfortable would you feel having a blasting operation within 1 mile of your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

7. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

8. What do you associate with decibels.

9. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

10. What do you associate with millibars?

11. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (psi). How comfortable are you with a blast producing 0.0029 psi of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

12. What do you associate with psi?

13. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable would you be with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

14. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable would you be with ground vibrations of 0.00227 inches at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable would you be with ground vibrations of 0.06 millimeters at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

16. Have you ever lodged a complaint against a blasting operation?

Yes No

17. Have you ever been involved in a blasting complaint in any way?

Yes No

18. Federal safety limits are reasonable for public safety.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. Would you describe your companies public relations policy concerning blasting as proactive, reactive or not applicable?

EPSILON SURVEY

Survey for Public Perception of Blasting and Reporting Practices

Please answer questions 1-7, 10, 12, and 14 in text immediately below the question.
Please answer questions 8, 9, 11, 13, 15-21 by placing a capital X immediately following your selection.
Example: If you want to select 3…

1	2	3X	4	5

General Questions

1. What office do you hold?

2. Where does your jurisdiction lie? (City, County, etc.)

3. What is your age?

4. What is your sex?

5. Do you regulate any active blasting operations?

6. Have you ever dealt with a blasting complaint?

7. Were you elected or appointed to your position?

Technical Questions

For the following questions, rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

8. How comfortable would you feel having a blasting operation within 1 mile of your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

9. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

10. What do you associate with decibels.

11. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

12. What do you associate with millibars?

13. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (psi). How comfortable are you with a blast producing 0.0029 psi of air blast overpressure?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

14. What do you associate with psi?

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable would you be with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

16. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable would you be with ground vibrations of 0.00227 inches at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

17. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable would you be with ground vibrations of 0.06 millimeters at your home?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable

18. Have you ever lodged a complaint against a blasting operation?

Yes No

19. Federal safety limits are reasonable for public safety.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

20. Rank these factors from 1 (most important) to 4 (least important) when you are considering a new policy.

( ) Constituent complaint about a problem.
( ) Pre-established federal limits.
( ) Importance of effected parties.
( ) Pressure from other regulators (nearby counties etc.)

21. Have you ever discussed or received a complaint about blasting from a constituent?

Yes No

APPENDIX E.

ALPHA AND BETA SURVEY INTRODUCTION LETTER

University of Missouri Rolla
Braden Lusk
1006 Kingshighway
Rolla, MO 65401
August 24, 2005

Dear Resident:

My name is Braden Lusk and I am a graduate student at the University of Missouri Rolla. I am requesting your help in completing my research. I am performing groundbreaking research on the public opinion of blasting (the use of industrial explosives). Many constituencies of people are being surveyed to determine what they think of blasting, and how industry practices could best be improved. I've enclosed a short questionnaire that should not occupy more than just a few minutes of your time to complete.

If you are generous enough to assist, please answer all questions on the survey (front and back) and place the completed survey into the enclosed business reply envelope. No stamp is required. Place this envelope in the outgoing mail and it will find its way back to me. Your survey results will be added to a pool of surveys and we need lots of responses to create a statistically sound average. Your help in this research will be greatly appreciated, and the relationship between the general public and the blasting industry will improve because of your participation.

In addition to my gratitude, an incentive program will hopefully encourage more participation in the program. Two completed questionnaires will be selected at random, and the person filling out this survey will be sent $100. Currently 2000 surveys are being distributed. This means that your odds of winning are 1 in 1000 if every person returns a survey. Out of 2000 surveys, past experience shows that 600 surveys are likely to be returned. This means that odds of winning are closer to 1 in 300. If you would like to participate in this drawing, please place your name and address in the top right corner of the front page of the survey next to question 1. Your name and address will only be used for this drawing and will not in any way find its way on to a mailing list for junk mail.

If you have any questions regarding this research or blasting in general, please feel free to contact me at any time. My e-mail address is braden@umr.edu, and my phone number is 573-341-7584. Thanks for your participation in this research.

Sincerely,
Braden Lusk
Graduate Student – University of Missouri Rolla
Enclosure – Questionnaire, Business Reply Envelope

APPENDIX F.

CD WITH STATISTICAL RELIABILITY SPREADSHEETS AND UNFORMATTED DATA FROM ALL SURVEY POOLS

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VITA

Braden Trex Lusk was born on December 11, 1977 in Walsh, Colorado. He received the degree of Bachelor of Science cum laude in Mining Engineering at the University of Missouri-Rolla, Rolla, Missouri, in 2000.

After graduation he went to work for Cargill Salt where he performed as a production supervisor and mining engineer at the Cleveland Mine, an underground salt mine in Cleveland, Ohio. He also worked as a department supervisor at the Hutchinson, Kansas, evaporation salt facility for Cargill.

In 2003, he was awarded a Chancellor's Fellowship from the University of Missouri-Rolla and a Graduate Research Assistantship from the University of California through Los Alamos National Laboratory, allowing him to complete a Doctor of Philosophy degree in Mining Engineering with a graduate minor in Explosives Engineering. During his Ph.D. candidacy he worked on numerous projects involving the use and effects of explosives for both Los Alamos National Laboratory, industry supporters, and the University of Missouri-Rolla.

He also acted as a Graduate Teaching Assistant to Dr. Paul Worsey, who was his advisor. He assisted teaching numerous courses on explosives engineering related topics.

Upon completion of the doctoral degree, Braden has been appointed as an assistant professor of mining engineering at the University of Kentucky in Lexington, Kentucky. His appointment begins in August, 2006.

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