Project Number- 9003-

Ambulance Services, Reliability Problems and Potential Technologies

An Interactive Qualifying Project

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Jono Graziosi

Lincoln Barber

Maciej Wojcik

Date: April 30, 2010

Approved by:

Mustapha S. Fofana, Ph.D.

Abstract

The goal of this IQP project was to understand ambulance services, reliability problems and potential technologies that can be used to advance patient-centered care. The IQP team conducted interviews, polling, and participated in data collection. Through these methods it was discovered that the main problems in ambulance services were associated with the road vibrations that were transmitted into the patient compartment. These vibrations were known to decrease the ability of paramedics to perform the tests and treatments needed while simultaneously increasing the stress experienced by patients. Potential technologies to improve ambulance services and suppress vibration were also investigated.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

When a life threatening accident requires an ambulance everyone wants the best care and the highest chance of survival on their journey to receiving advanced medical care. While proper training of ambulance workers can increase the success rate of trips, advancing the technologies that allow them to work safer and more efficiently provides a foundation for the advancement of the ambulance ride. Improving ambulance patient safety while simultaneously increasing the en route capability of the ambulance through technological advancement allows engineers a unique opportunity to increase the life saving capabilities of ambulances worldwide.

The most important part of an ambulance ride is the safety of the crew and patients with a focus on delivering the patient to the professional care they require. While ambulances are designed to make this as easy as possible there is room for improvement in certain areas of their performance. Improvements could increase the ability of the ambulance crew to provide a high level of care and perform all the necessary treatments to insure that the patient arrive at advanced treatment facilities. Once these areas in need of improvement have been identified, potential design flaws are attributed to the poor performance characteristics of the ambulance so that an engineering solution may be applied.

Determining how the desired improvements may be realized an engineering problem statement is formed outlining what is to be done. First the current safety issues and patient comfort problems associated with ambulances must be established. By consulting records on ambulance accidents and fatalities along with questioning current EMT personnel issues, preventing the best possible patient care may be identified and investigated further. These issues will allow current ambulance design to be analyzed highlighting potential areas for improvement. A physical design flaw derived from the need to improve a current area of patient care gives engineers the problem statement to which potential solutions and designs may be theorized and ultimately realized to resolve the issue.

Without any unifying research done, concluding the problems associated with ambulances and the level of patient care they can accommodate, the most up to date source is the working population who use the current machines on a daily basis. To insure a thorough insight multiple sources were contacted; EMS technicians were polled online as well as in person at local emergency facilities, both paramedic supervisors and dispatch operators were interviewed, and tours of local dispatch and management facilities were conducted.

Graduate research student Paul Cotnoir at Worcester Polytechnic Institute turned to the emergency medical technicians from the online forums of emtlife.com (Cotnoir, 2009). Choosing this site provided timely and sincere responses from professionals who are proactive and interested in the field. Through this forum it was discovered that a reduction in vibrations felt both by the technicians and patients could improve both the level of patient care and the ability to perform procedures. One emtlife.com user, “pdc,” registered with the web site as having both medical services and basic National Emergency Medical Technician certifications, commented on the availability of a scope of services possible in the patient compartment:

> You can't find it because it doesn't exist. Scopes of practice are based on the provider's level, not whether the provider is inside or outside of the ambulance. The simple fact is, everything would be easier and more accurate if the ambulance ride was smoother, including assessment, assessment tools (ECG, pulse ox, d-sticks, etc) and treatments. Furthermore, it would be much more comfortable for patients, especially when they are suffering from a skeletal injury or in spinal restriction. (EMTLife, 2009)

Another user, “djmedic913,” identified as having EMT and Paramedic certification, said, “Without vibrations everything we do would be safer with better results (EMTLife, 2009).” These along with other similar responses made it obvious that a reduction in the road induced vibrations transferred through the vehicle to patients and technicians could greatly improve degree of patient care.

The feedback from emtlife.com indicated the scope of services provided in an ambulance was based on many conditions. In response Paul constructed a technician questionnaire to get a quantitative analysis. Equipped with Paul’s questionnaire the IQP team arranged tours at local ambulance dispatch facilities. These tours provided a level of understanding to the inner workings of the emergency response system otherwise unavailable and the opportunity to qualitatively assess the scope of services provided in an ambulance. By interviewing paramedic supervisors and dispatch operators we revealed potential flaws and shortcomings within the navigation and triage electronics packages that are currently used.

With careful examination of these sources we were able to determine flaws within the current ambulance design and generate possible solutions which deserve further investigation. With this work as a guide future improvements in ambulance design may be realized and implemented in industry. Redesign of key ambulance components or adding additional components has the potential to impact the level of care provided to the patients, the ability of paramedics to diagnose patients, and the ability for a driver to safely deliver a patient.

Chapter 2 : Problems Identified with Ambulance Transportation

When on a call ambulance teams have two separate and equally important goals. In the back, patients must be treated with the optimal level of care so they arrive to their final destination in the best condition possible, while in the front the navigator and driver must insure that the ambulance gets there as quickly as possible in a safe manner.

When polling the paramedics online and at local dispatch facilities it was clear that certain factors greatly decrease both the patients comfort level and the ability of the paramedics to provide care en route. Road induced vibrations can be felt inside the patient compartment making it difficult to diagnose and treat patients. These vibrations can also cause pain and discomfort to patients being transported, especially those with spinal or neck injury and broken bones. Noise pollution hinders patient comfort level and the ability of the paramedics to communicate.

In the front ambulance drivers have a completely different set of issues. Often driving through traffic at high rates of speed these drivers need every bit of support they can get to make their intense job as easy as possible. Without up to date road construction information and GPS mapping support the drivers are not moving as efficiently as possible. Drivers must also know how the ambulance handles to drive as efficiently and safely as possible. Due to drivers changing vehicles and new drivers entering the field they don’t always know how the vehicle handle, especially at the high rates of speed ambulances are known for.

After polling ambulance workers through multiple sources, it was obvious that the reduction in vibrations would greatly increase patient comfort level and their ability to provide care. In light of this information our IQP team decided to research possible solutions to improve the shock absorbing capabilities provided to the patient compartment. Also a suite of programs is suggested for Ambulance Fleet systems to implement which would improve their current response time, ambulance routing capabilities, and decrease the amount of accidents caused by overdriving due to the driver being unfamiliar with the ambulances handling capabilities.

Chapter 3: Quantifying Road Surface Induced Vibrations

It has been well established that an ambulance ride has the potential to be a very traumatic and stressful experience for both the patient and the paramedic. Ambulances in the United States are typically built on Ford chassis (Appendix B) relying solely on the vehicles stock suspension to isolate the patient compartment from road surface induced vibrations, but the suspension does not succeed at complete vibration isolation. Ambulance manufacturers do nothing to decrease the vibrations induced upon patients by road surface conditions in addition to the stock suspension of the chassis they purchased.

Figure 1 Ambulance Patient Compartment in Use (Cotnoir, 2009)

Road Surface induced vibrations impact the patients care on two levels; it decreases the ability of paramedics to diagnose and treat. Additionally it has the potential to affect the body's vital functions, which may already be compromised. Specifically the cardiovascular system, skeleton, central nervous system, and respiratory system are all affected by road induced vibrations. The accuracy of EKG signals and blood pressure readings along with the ability to perform tests and treatments decrease as road vibrations increase.

To study the effects of road induced vibrations on the human body the expected vibrations experienced in an ambulance must first be determined. Road surfaces are typically categorized into four categories; dirt roads, rural paved roads, paved city streets, and paved multi-lane highways (a through d respectively) which can be seen below in Figure 2. (Cotnoir, 2009)

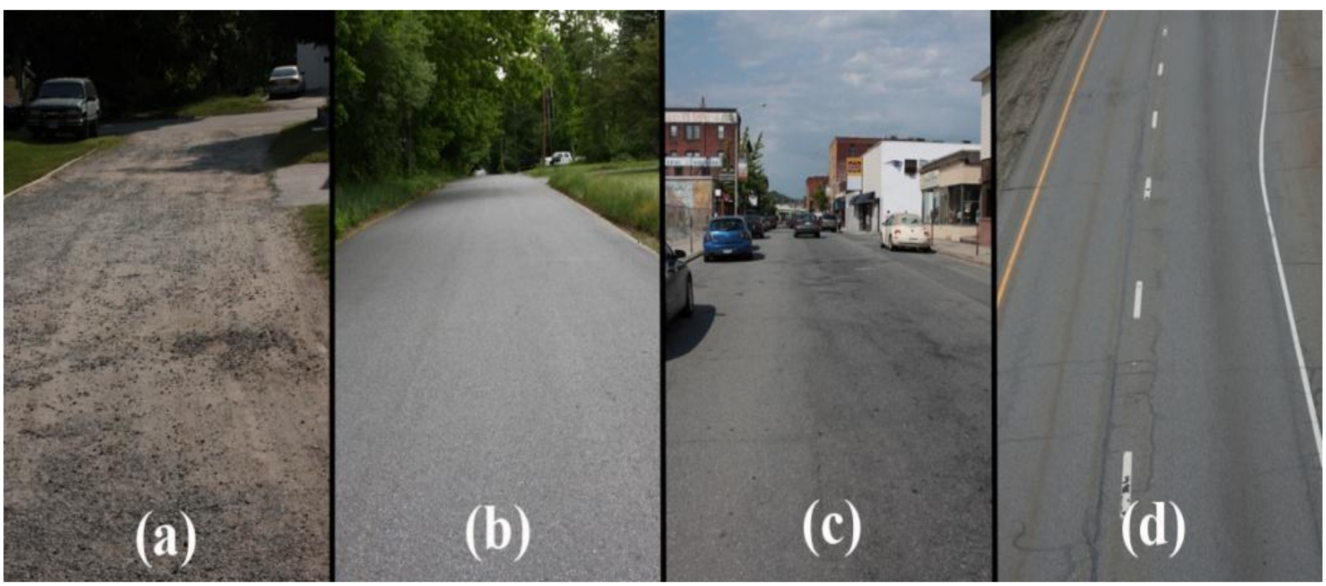


Figure 2 Road Surface Types (Cotnoir, 2009)

Each road surface is different and generalizations must be made about the frequency of vehicle response to the vibrations caused by each type. A sample of displacements recorded through actual highway (1) and city travel (2) is represented below in Figure 3.

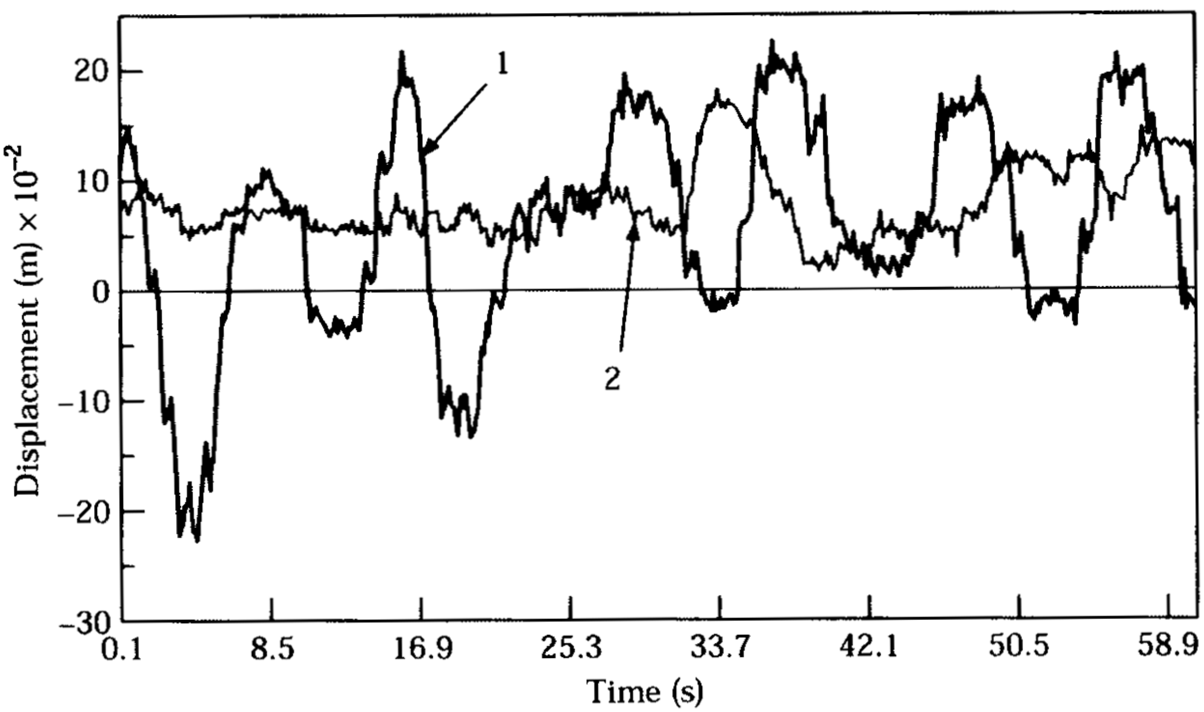


Figure 3 Displacement- Time History of (1) actual highway travel and (2) actual city travel. (Tamboli & Joshi, 1999)

In conjunction with this data the power spectrum density (PSD) vs. frequency was also recorded and may be seen below. The PSD shows the relationship between frequency and both amplitude of oscillations at that frequency and the number of oscillations occurring at that frequency. The graph shows a decrease in PSD as frequency increases, but it is still within

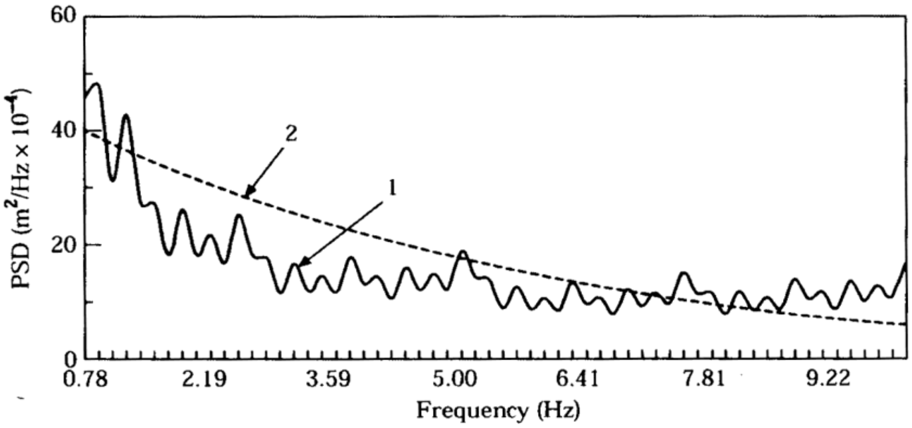


Figure 4 Frequency vs. Power Spectrum Density of (1) actual and (2) formulated road excitations. (Tamboli & Joshi, 1999)

Through experiments like this the root mean square of the acceleration along different axis can be determined. This allows for a quantitative analysis of the vibration magnitude and frequency experienced in a vehicle.

Table 1 Results of Road Surface Induced Vibration Analysis (Paddan & Griffin, 2002)

Typical frequency-weighted vibration magnitudes measured on various vehicles using both BS 6841 and ISO 2631 methods	BS 6841 (1987)		ISO 2631 (1997)
	Equivalent r.m.s. accel. (m s^{-2} r.m.s.)	Seat vertical accel. (m s^{-2} r.m.s)	Most severe axis accel. (m s^{-2} r.m.s)
	Maximum	Maximum	Maximum
Car	0.75	0.61	0.75
Truck (Lorry)	1.25	1.03	1.28
Van	0.61	0.53	0.57
Armored Vehicle	1.66	1.85	1.52

The results of the test that are tabulated in Table 1 show that with an increase in weight (i.e. trucks and armored vehicles) the route mean square (RMS) acceleration is much larger than that of a typical car with an increase of up to 60% shown. This means that the induced vibrations are harder to dampen due to the increase in weight. This shows that a secondary suspension of a much lighter platform within the patient compartment could greatly reduce the vibrations felt by patients.

Paddan and Griffen also conducted another test where the induced road excitations were recorded for several axis in 25 different cars. Two vibration standards were recorded during the test for a comparison. The methods for these vibration tests are outlined in the International Organization for Standardization 1997 ISO 2631-1 and the British Standards Institution 1987 BS 6841. A description of these basic standards may be seen in Appendix C and D respectively, explaining the goal of each standard in regards to whole body vibration experimentation and quantification. "Both standards require the vibration amplitude data to be calculated using a vibration dose value (VbV) which accounts for the frequency, the amplitude and the length of exposure to the vibration under investigation." (Cotnoir, 2009)

	BS 6841 (1987)								ISO 2631 (1997)			
	Equivalent r.m.s. acceleration (m s-2 r.m.s.)				Seat vertical. acceleration (m s-2 r.m.s.)				Most severe axis. acceleration (m s-2 r.m.s.)			
Vehicle type (#)	Med.	Min.	Max.	Std. Dev	Med.	Min.	Max.	Std. Dev	Med.	Min.	Max.	Std. Dev
Car (25)	0.45	0.32	0.75	0.14	0.37	0.25	0.61	0.10	0.39	0.26	0.75	0.14

Figure 5 Padden and Griffen Results tabulated in (Cotnoir, 2009)

The results of the test by Padden and Griffen were tabulated in a study by Paul Cotnoir. The results show a range of frequency related amplitudes ranging from .26 to .75 m/sec^2. This and other tests run by Padden and Griffen, 421 trials, it was observed that the vertical vibration was the most severe measured. It was also noted that while the frequency and amplitudes recorded vary based on location of measurement while the power spectrum density is fairly consistent, even across multiple studies.

While these previously mentioned test results for road induced vibrations gave us an idea of the kind of vibrations experienced inside an ambulance ride they were not conclusive, so the IQP team decided to work in conjunction with a PHD student Paul Cotnoir to perform our own road test in the back of actual ambulances. Paul arranged these tests to bolster his research on road surface induced vibrations and the goals outlined in his paper may be seen in Appendix E. Two photos may be seen below from one of these data collection sessions.

Both photos from left to right: Jono Graziosi, unknown, Paul Cotnoir

Figure 6 Photos from Data Collection

We recorded the vibrations caused by various road conditions at three different speed levels. The data was collected in 30 second intervals for each road condition at three separate speed ranges. The speeds ranged from 25 mph to 70 mph. Collecting the data was a sophisticated black box specifically designed to measure vibrations in three axes. A picture of the equipment used is seen above in Figure 6. After reviewing the data the ambulance ride was a success. It was evident that at high speeds similar to the speeds a patient would experience riding in an ambulance, considerable vibrations had occurred. We placed the data in the computer program in order to graph the measurements. The graphs prove that road induced vibrations on an ambulance are frequent and at times considerable.

Personally experiencing the ride it's easy to see how vibrations can have a negative impact on the patient care. It was difficult enough to sit still at times making it seem almost impossible to treat a dying patient. Physically experiencing the vibrations in an ambulance gave us a better understanding of the problem and the need for an alternative support system. A possible solution can be a force feedback system in which a force plate specially engineered to be retrofitted under the cab would suppress the vibrations. Although the Force Feedback system seems like a reasonable solution the reality is finding a way in order to design the system without having to build an entirely new ambulance. The cost of such a system comes into effect. Tests have to show the money being put into the construction of a feedback system would be greatly beneficial to the EMT's and patients.

Four vehicles were tested on highway road conditions and both the average and peak RMS acceleration values were compared between ambulances at different speeds. A list of the ambulances is tabulated below.

Table 2 Tested Ambulance Specifications (Cotnoir, 2009)

Ambulance #	Chassis Type	Ambulance Body Manufacturer
1	2005 Ford F450	Horton
2	2001 Ford E450	Lifeline
3	2008 Chevy C4400	Braun
4	2009 Ford F550	Lifeline

The results of the mean and peak RMS acceleration experienced from inside the Patient compartment at patient chest level are graphed below in Figure 7 (a) Mean RMS Acceleration (b) Peak RMS Acceleration. The graphs show a RMS acceleration average of about .75 $\frac{m}{s^2}$ with peak accelerations averaging well above $3\frac{m}{s^2}$. These have the potential to have negative effects on the human body, especially those patients with already compromised vital systems.

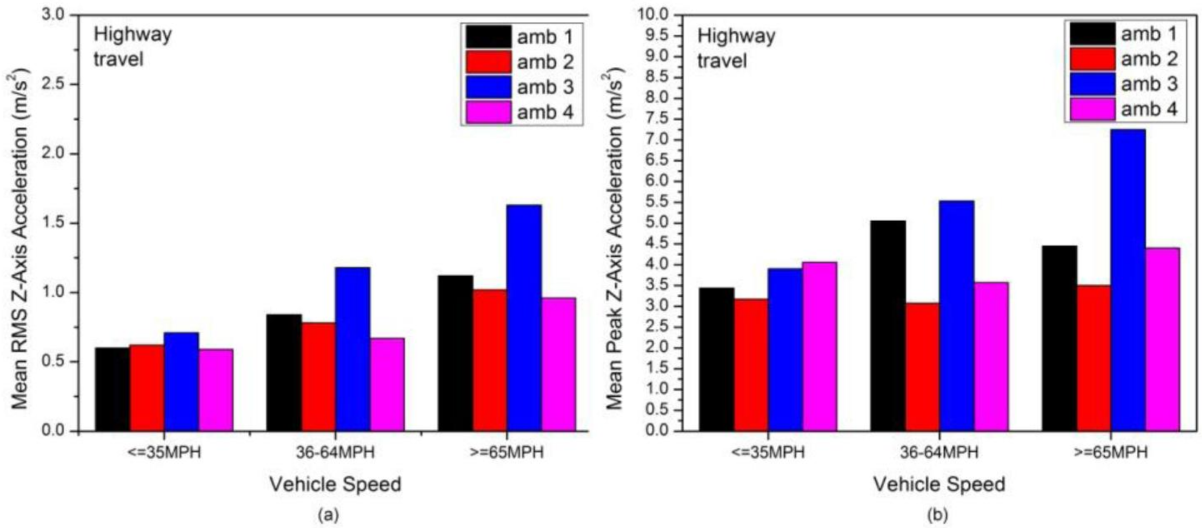


Figure 7 (a) Mean RMS Acceleration (b) Peak RMS Acceleration (Cotnoir, 2009)

These results were then compared with those from other studies for validation and confirmation that the problem with road surface induced vibrations experienced inside the patient compartment is not a problem localized to the Worcester County, where the test was conducted. The results, which are graphed below in Figure 8, show that the accelerations due to road conditions are not a localized problem or fluke in data recording. (Cotnoir, 2009)

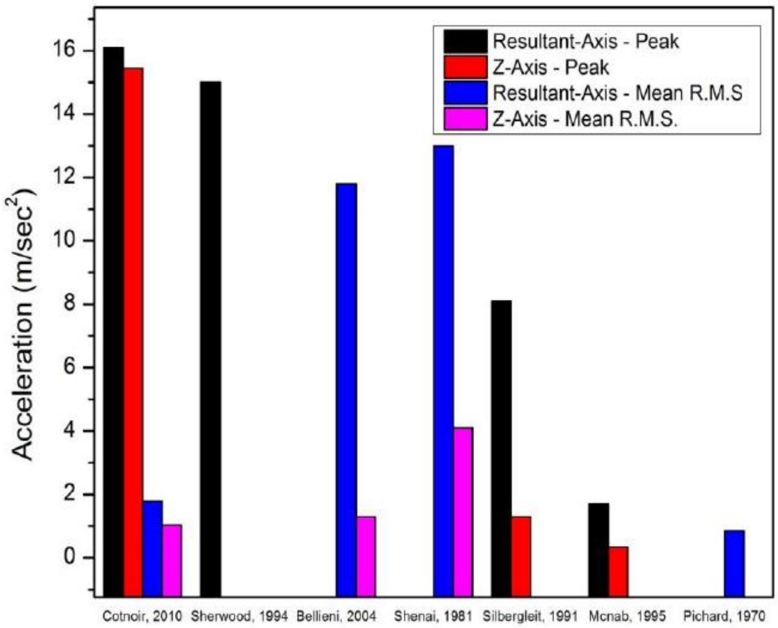


Figure 8 Road Surface Induced Vibration Measurement (Cotnoir, 2009)

The results were also graphed to compare the variation between ambulances, road surfaces and vehicle speed. This allowed a determination of the most important factors that affect the road surface induced vibrations experienced inside the patient compartment.

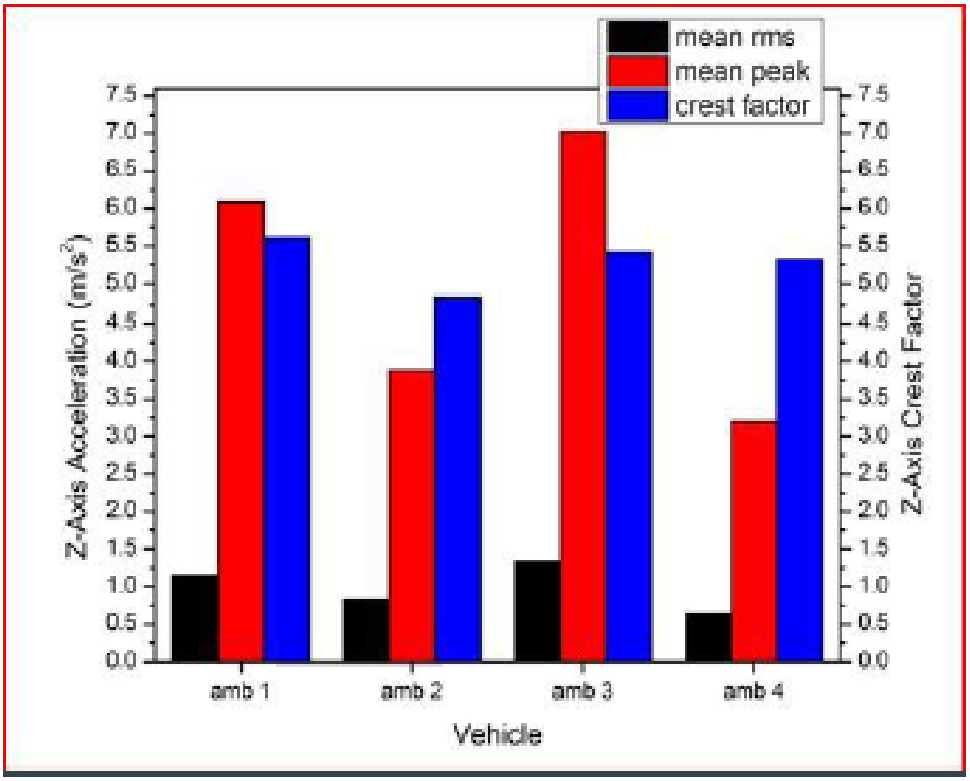


Figure 9 Vibration Variation Between Vehicles (Cotnoir, 2009)

This first graph shows the lack of variation between ambulances and crest factor. It also indicates a mean RRMS acceleration does not vary significantly between ambulances indicating the lack of an industry leader in vibration reductions. The graph below in Figure 10 shows almost a complete lack of change with respect to road surface condition. This shows that the corrections necessary to eliminate these problems would not be limited to the specific ambulance or road surface condition they were designed and tested in. This shows that an aftermarket component which could be added to or placed inside the ambulance body would have widespread market acceptance.

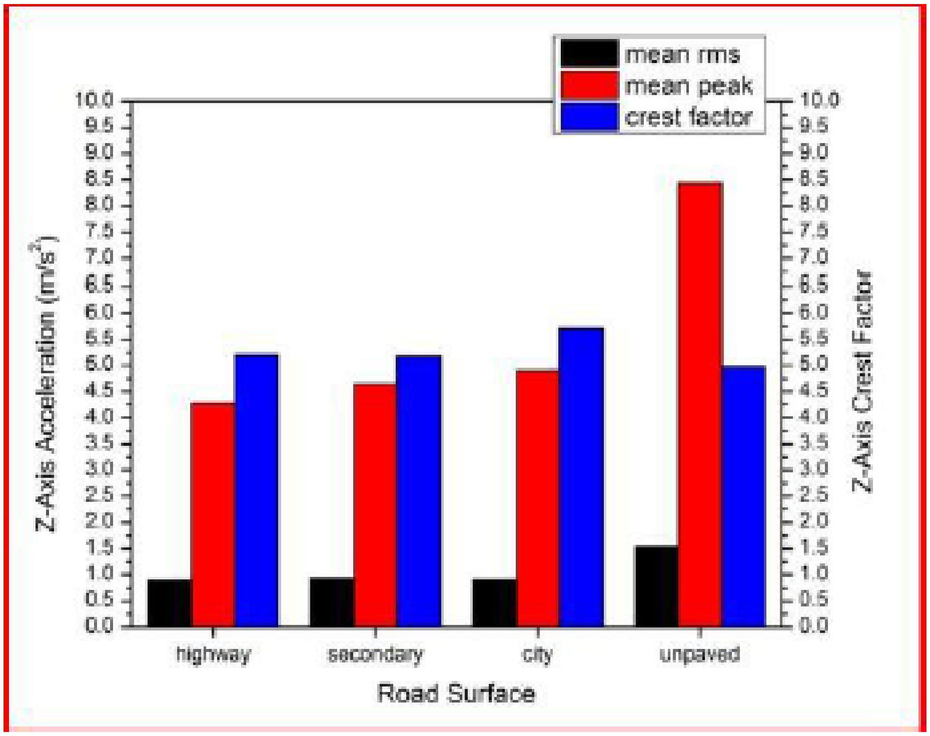


Figure 10 Vibration Variation With Respect to Road Surface Type (Cotnoir, 2009)

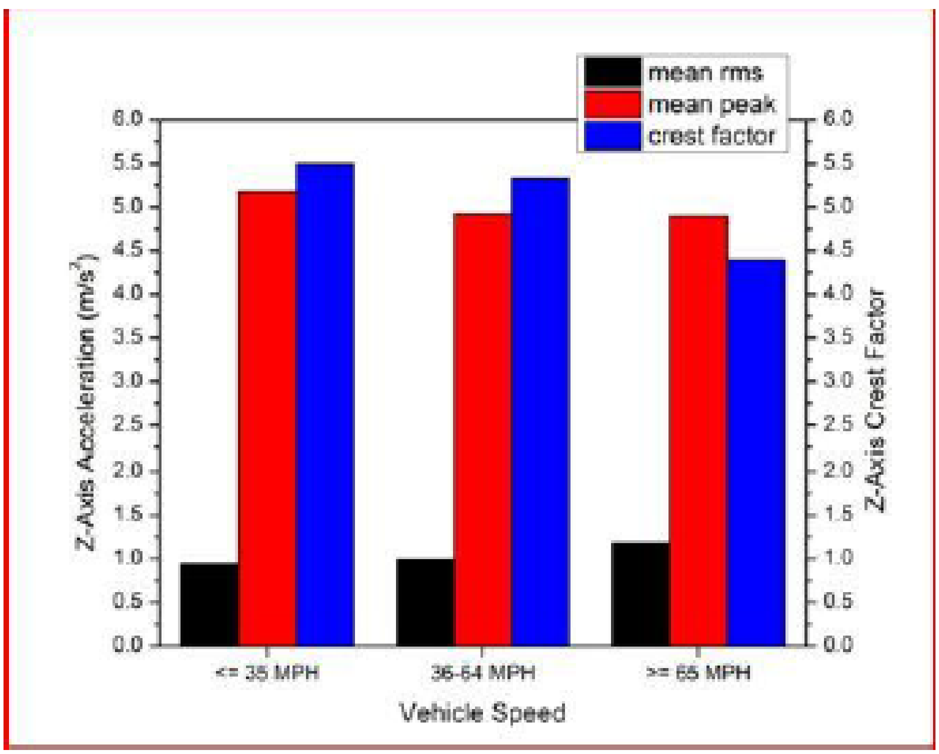


Figure 11 Vibration Variation With Respect to Vehicle Speed (Cotnoir, 2009)

The final graph indicates a lack of change in acceleration due to the vehicles speed. It is shown that while the mean peaks and crest factors decrease as speed increases, the mean rms acceleration increases slightly. After review of all three graphs it is evident that the most important characteristics pertaining to road induced vibrations experienced inside the patient compartment are the vehicle speed and road surface.

Chapter 3: The Effects of Road Surface Induced Vibrations on Patients

Now that the road surface induced vibrations have been quantified with respect to frequency and RMS acceleration the effects of these vibrations on the human body may be discovered.

Vibrations have been shown to have an effect on the vital signs of healthy young adults. In a study conducted by Captain James G. Clark three young men, aged 19, 23, and 25, were subjected to horizontal vibrations for three minute periods at frequencies from 4 Hz to 12 Hz. The vibration inducing apparatus and one of the trial participants may be seen below in Figure 12. The results indicate a raise in heart rate, mean arterial blood pressure, and Cardiac index shown below in Table 3. This shows that experiencing induced sinusoidal vibrations increases the strain placed on the body's vital systems.

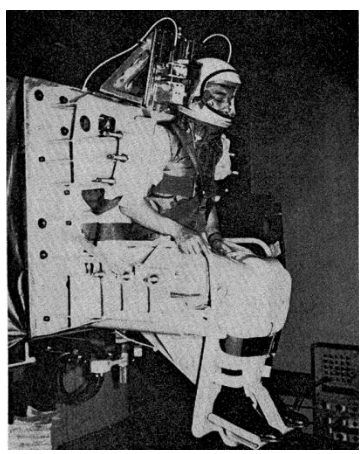


Figure 12 : Vibration Inducing Chair and Experiment Test Equipment (Clark, Williams, Hood, & Murray, 1967)

Table 3: Initial Effect of Whole Body Vibration on Cardiovascular System in Humans at 1G and Varying Frequencies

(Clark, Williams, Hood, & Murray, 1967)

Frequency (Hz)	Increase in Heart Rate $\left(\frac{Beats}{Minute}\right)$	Increase in Mean Arterial Blood Pressure ($mm\ Hg$)	Cardiac Index $\frac{Liters}{Minute * M^2}$
4	13 ± 4	8 ± 15	1.28 ± 0.03
6	11 ± 3	9 ± 2	1.86 ± 0.04
8	18 ± 6	5 ± 2	1.76 ± 0.06
10	24 ± 6	14 ± 3	2.47 ± 0.07
12	22 ± 8	17 ± 4	1.14 ± 0.05

This is one of many tests done which shows a correlation between the frequency of vibrations induced inside the patient compartment and a change in the vital systems due to said vibration. An adaptation of this data may be seen below in showing the direct relationship between the increases of heart rate with the increase in frequency of induced road vibrations.

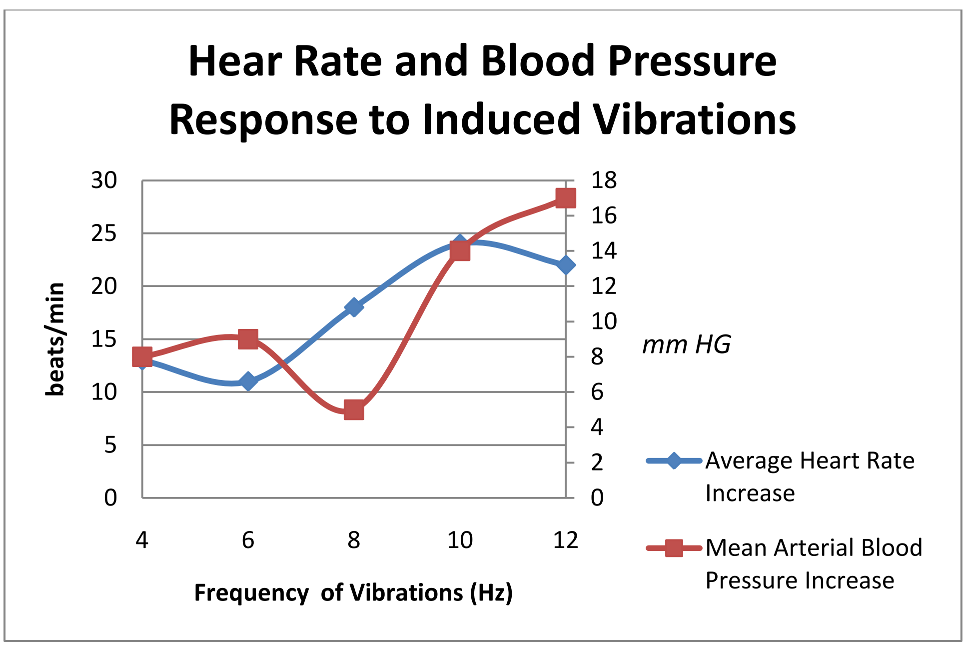


Figure 13 Vital Response to Induced Vibrations

Respiratory function has also been shown to be affected by induced vibrations. The graphs below show the machine settings from a roll oscillation motion simulation test. The graph on the left indicates the acceleration at chest level of a person riding in a rolling vibration inducing device pictured above in Figure 14. The study was designed to prove that these induced vibrations had an effect on the respiratory system. The results are shown below.

Figure 14 Roll Oscillation Motion Simulator

(Green, et al., 26 February 2008)

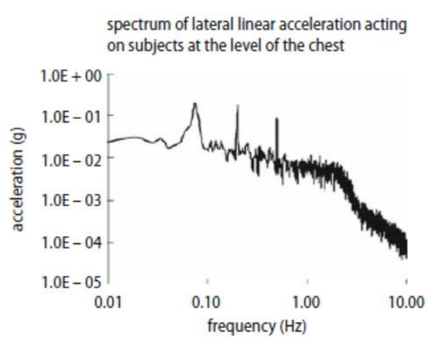


Figure 15 Roll Oscillation Test Settings
(Green, et al., 26 February 2008)

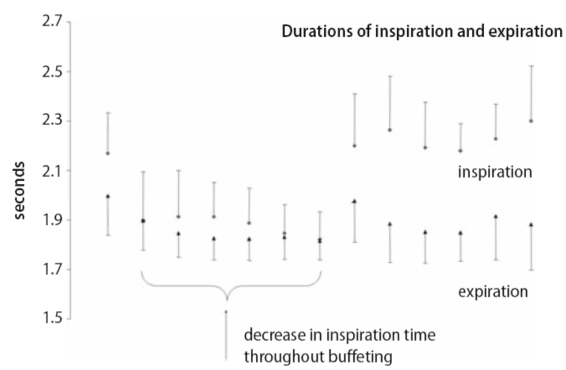


Figure 16 Duration of Inspirations and Expirations
(Green, et al., 26 February 2008)

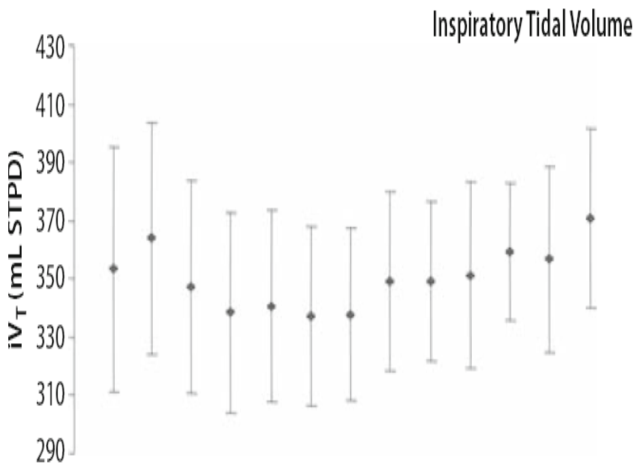


Figure 17 Inspiratory Tidal Volume (Green, et al., 26 February 2008)

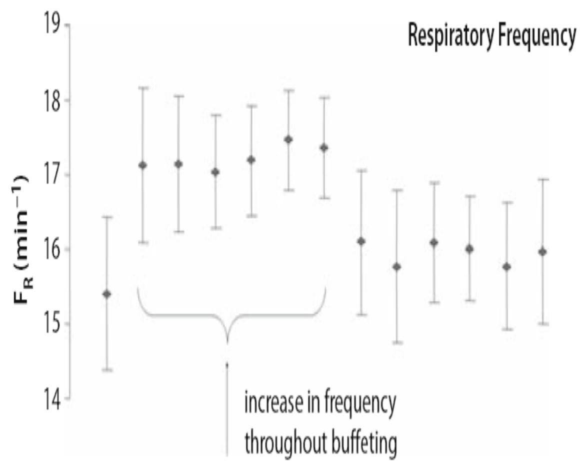


Figure 18 Respiratory Frequency (Green, et al., 26 February 2008)

The results clearly show that the buffeting oscillations had an effect on multiple characteristics of the test subject's normal respiratory function. It can be directly seen that while oscillations were induced inspiration times decreased which is directly related to the increase of respiratory frequency.

These previous studies are just a few of those proven to show changes in biological systems due to induced vibrations. A table showing multiple resources outlining experiments where humans undergo induced vibrations while certain vital characteristics are measured can be seen in Appendix A is it appears in Ambulance Vibration Suppression Via Force Field Domain Control (Cotnoir, 2009).

While the patient's increase in stress and vital statistics is a major concern with the road induced vibrations transferred to the patient compartment, the ability of the emergency medical support crew to perform the lifesaving tasks necessary is also hindered. Road surface induced vibrations play a huge role in the ability of a worker to perform even the most standard tasks.

Reading numbers from vital equipment, reading and writing of information, taking vital measurements, and performing treatments can become almost impossible while traveling over some road surfaces.

The effect of vibration on vision can be detrimental to the emergency personnel. Blurred vision effects due to vibration exposure result from movement of perceived images on the retina of the eye and is the cause of confusion and inability to read a book or the computer monitor inside a moving vehicle. Vibrations below approximately 2 Hz typically do not result in any major loss of visual acuity as the eye is able to accommodate with its own pursuit eye movement function which helps the eye follow moving subjects. As the vibration frequency increases, the ability of the human visual system to keep pace lessens. This starts at around 10 Hz and is very pronounced by 20 Hz. Above 20 Hz there may be resonances present in the eye muscles which lead to even greater deficiencies (Cotnoir 2009). The frequency of vibrations observed within an ambulance can sometimes exceed amounts that affect the ability to perform important medical procedures. The graph below represents the reduced amount of reading capabilities as both the reader and the material they are reading are vibrated at the frequencies we recorded in the ambulance experiments.

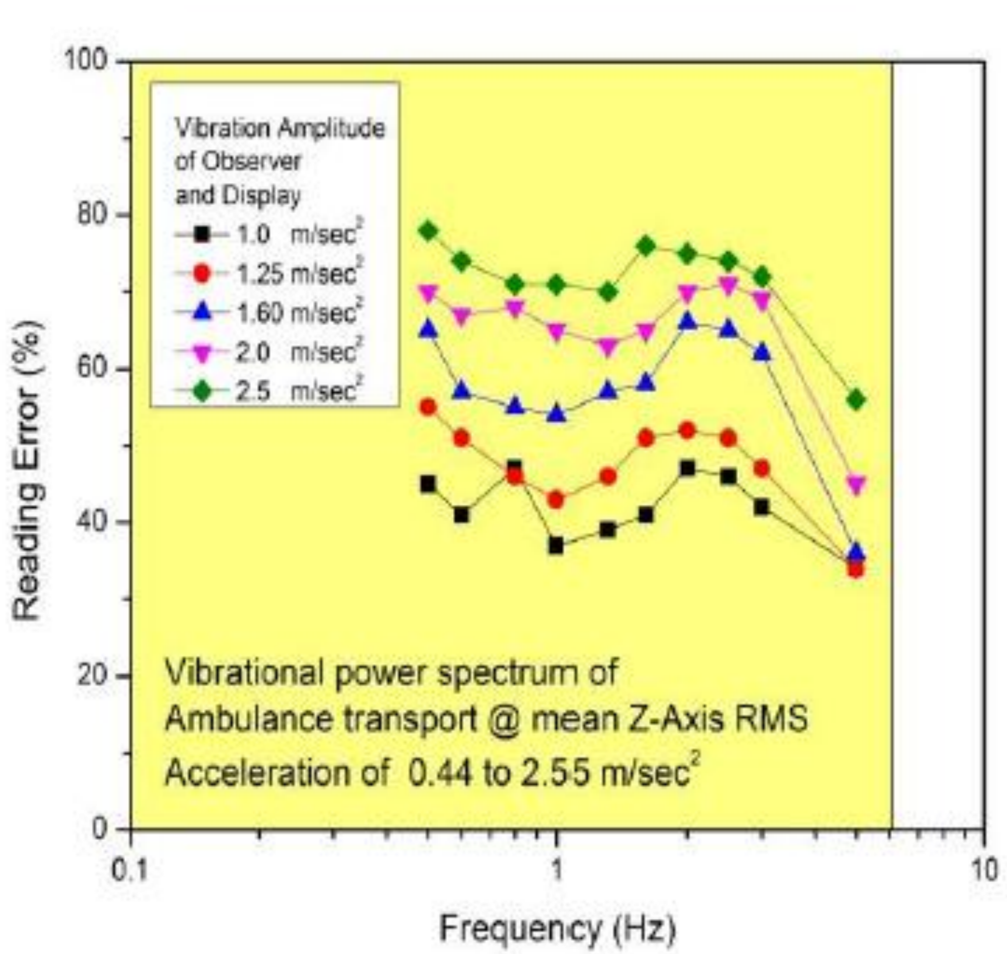


Figure 19 Reading error due to Induced Vibrations (Cotnoir, 2009)

The vision of a paramedic is crucial to their ability to diagnose and treat a patient's symptoms. Other Studies have shown that induced vertical vibrations have the ability to decrease the visual acuity of a person with frequencies as low as six or seven hertz depending on the distance between viewer and subject. A table showing the limits of a person's ability to see based on the frequency and RMS of the induced vibrations is shown in Figure 20. The line for each respective distance shows at what frequency and RMS acceleration vision becomes impaired at. This experiment explains the difficulty of a paramedic to see what is happening within the patient compartment with a max viewing distance approximately 1.2 meters away corresponding to the maximum data line recorded on the graph. While it has been shown ambulances do not always reach frequencies and acceleration magnitudes which would deny sight to the passengers they can be reached in the modern ambulance.

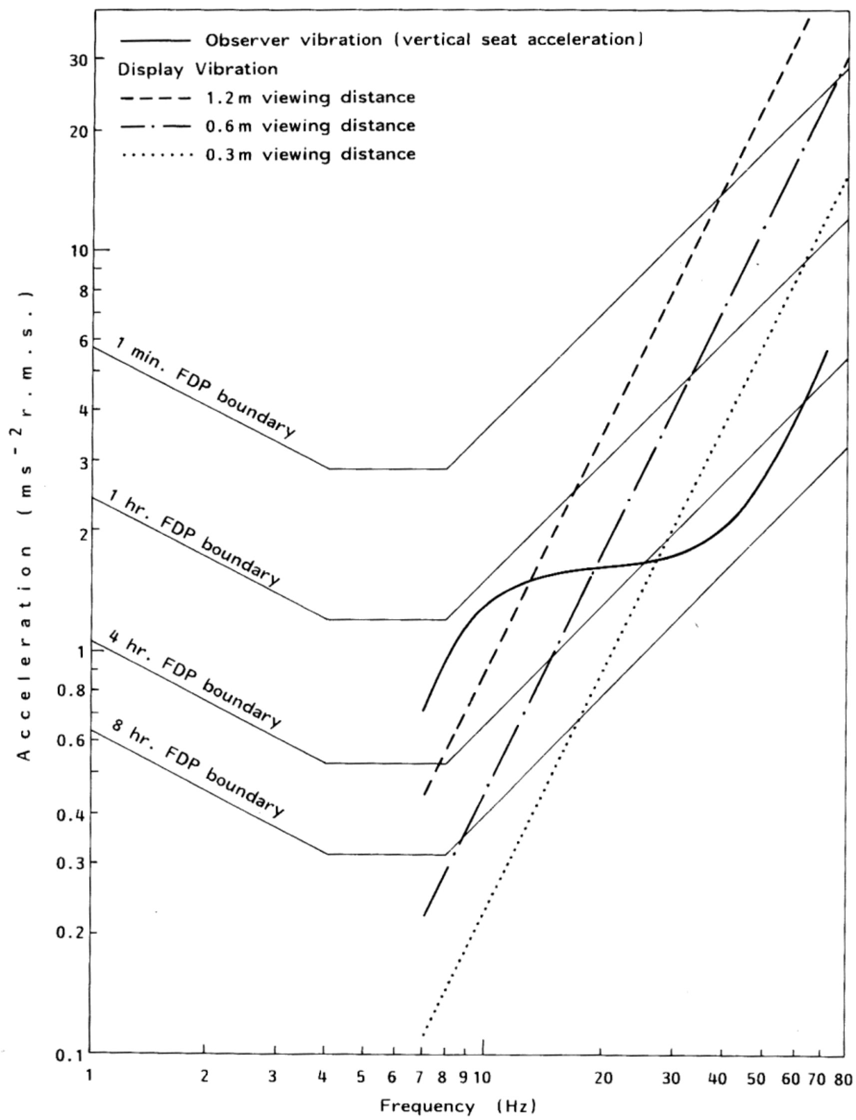


Figure 20 Vision Impairment (Griffen, 1990)

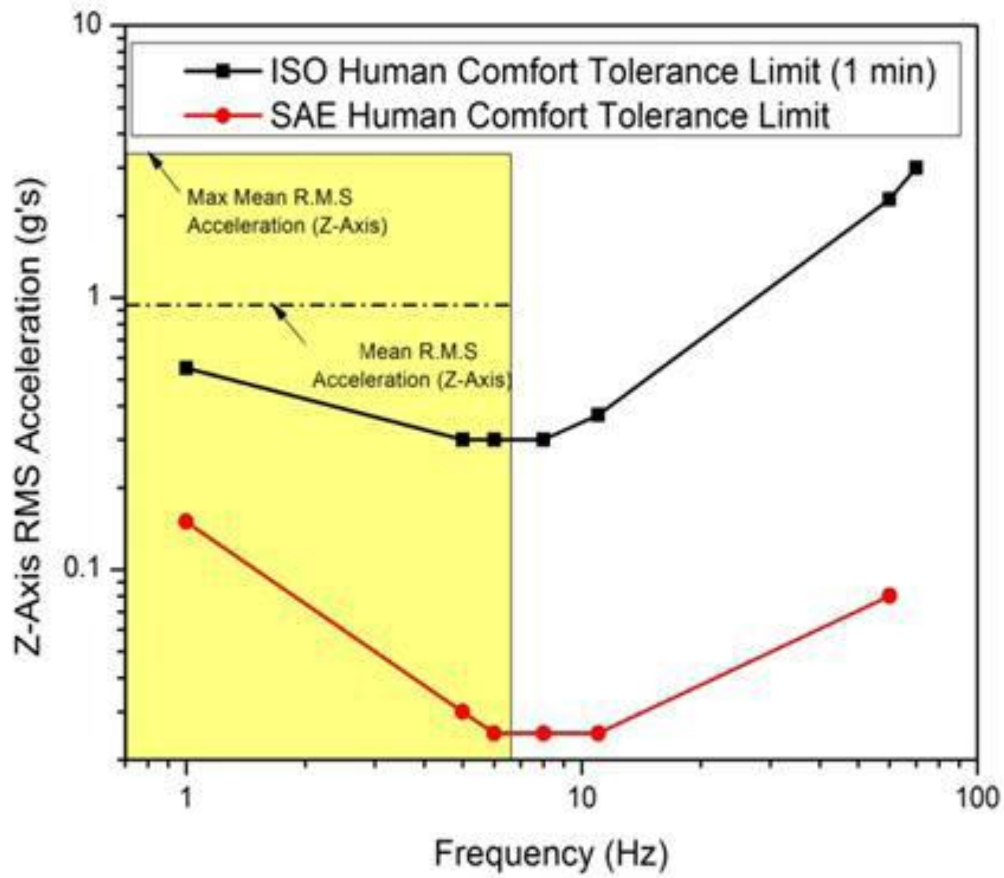


Figure 21 Mean RMS vibration amplitudes encountered in our ambulance tests along with comparison against standards of vibration tolerance limit. (Cotnoir, 2009)

The test clearly indicated acceleration values above ISO/SAE standard levels associated with human comfort.

Another interesting test reported by Cotnoir involved writing with different Power spectrum Densities at the same frequency. This meant that only the amplitude of the RMS acceleration in the z axis was changed. The results clearly indicate an increase in the difficult to write legibly at RMS accelerations. It can be seen that the writing clearly becomes impossible to read when the rms acceleration rises above 1.95 m/s^2.

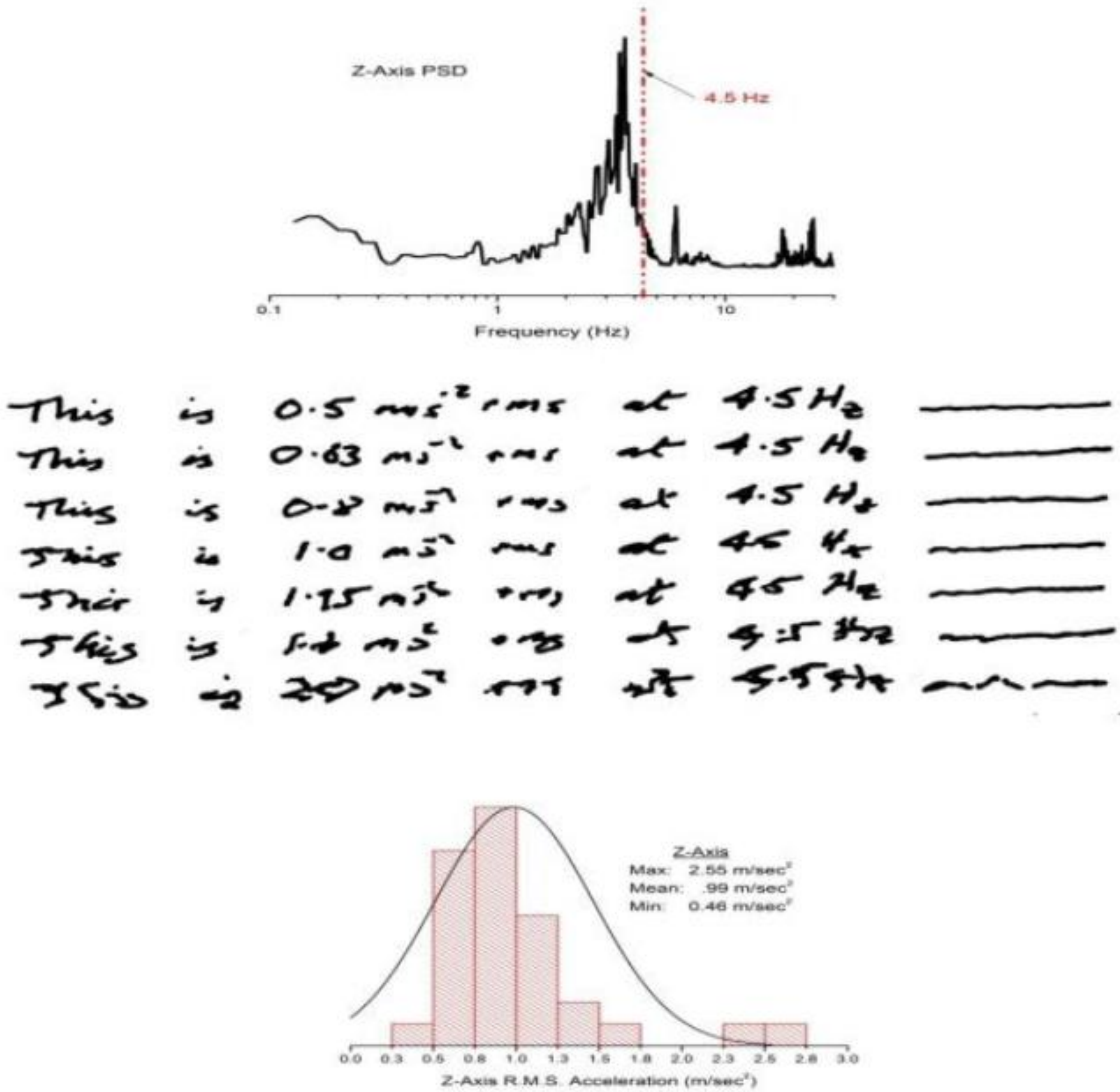


Figure 22 Mean RMS vs. Qualitative Handwriting Evaluation (Cotnoir, 2009)

The ability to perform standard tests of motor function may also be seen below graphed against Z axis mean acceleration values. The results from the vibration amplitudes and frequencies are also graphed showing they were well within the ranges experienced inside an ambulance. (Cotnoir, 2009)

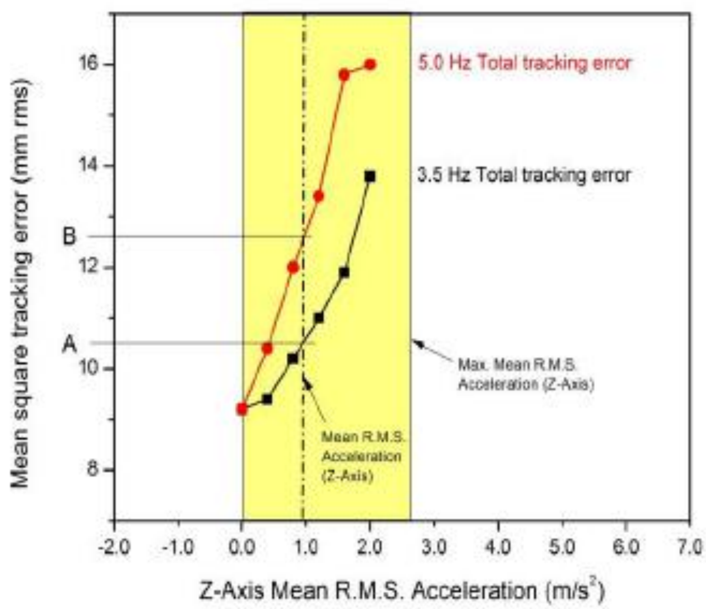


Figure 23 Tracking error caused by Induced Vibrations (Cotnoir, 2009)

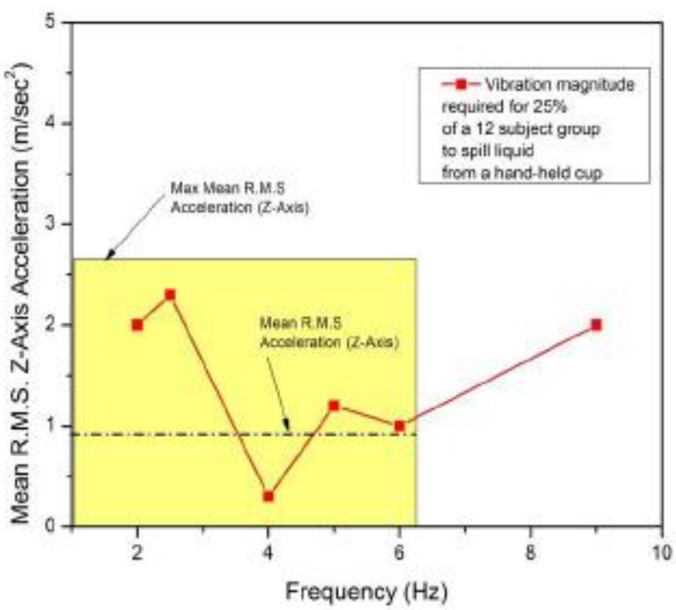


Figure 24 A test indicating a loss of the ability to maintain a steady hand (Cotnoir, 2009)

The vibrations experienced inside the patient compartment make it more difficult for paramedics to perform virtually every task. Some tasks become impossible while others are only increased in difficulty. Simple tasks which are routine in hospitals, such as starting an IV, become very difficult in the back of a moving ambulance. A graph of the Power Spectrum Density of the recorded vibrations in the experiment mentioned previously conducted by Paul Cotnoir may be seen below in Figure 25. The graph also indicates the frequencies and required power spectrum densities of the natural frequency of multiple body parts. This shows what combined frequency and RMS acceleration of vibrations induced on the body to achieve the resonant frequency of different body parts.

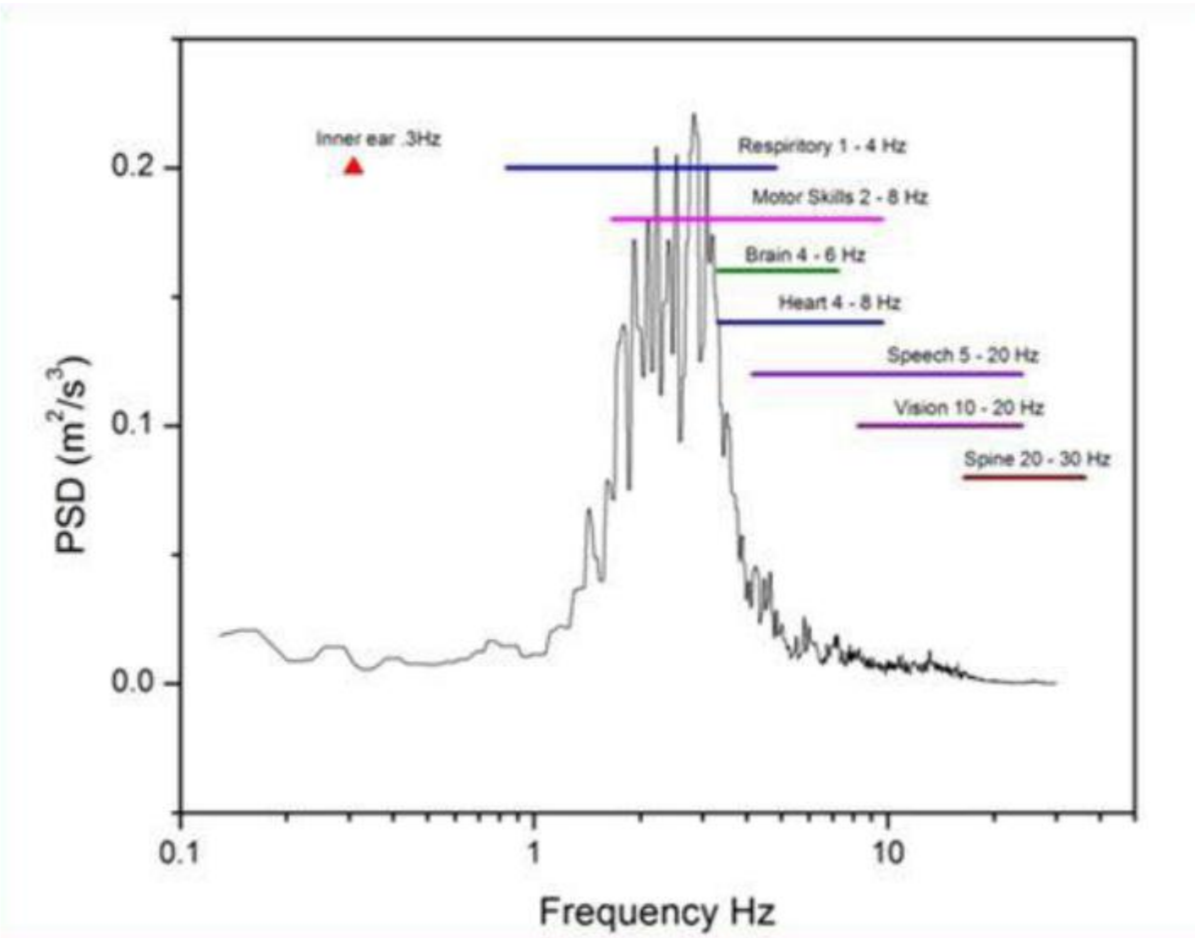


Figure 25 Power Spectrm Density of recorded frequencies and Body Parts (Cotnoir, 2009)

Whole body vibrations can affect the movement and motor skills of patients and emergency personnel. Vibrations are transmitted through the ambulance into the individual's body including arms and legs. This is an important fact because even the smallest degree of vibration-induced disturbance can become the deciding factor in the ultimate success or failure of a task. Referring to Paul Cotnoirs research there are three sources, categorized by Griffin, of error associated with vibration-affected manual tasks: (1) vibration-correlated (or breakthrough) error, (2) input-correlated error, and (3) remnant.

Vibration-correlated errors are vibrations transmitted through the body to the arm and hand or to an object which may be controlled by the subject. According to Griffin an individual in a ridged seated position would have the greatest amount of hand motion in the x and z axes caused by vibrations. Below is a graphical representation of the physical affects vibrations have on hand movement.

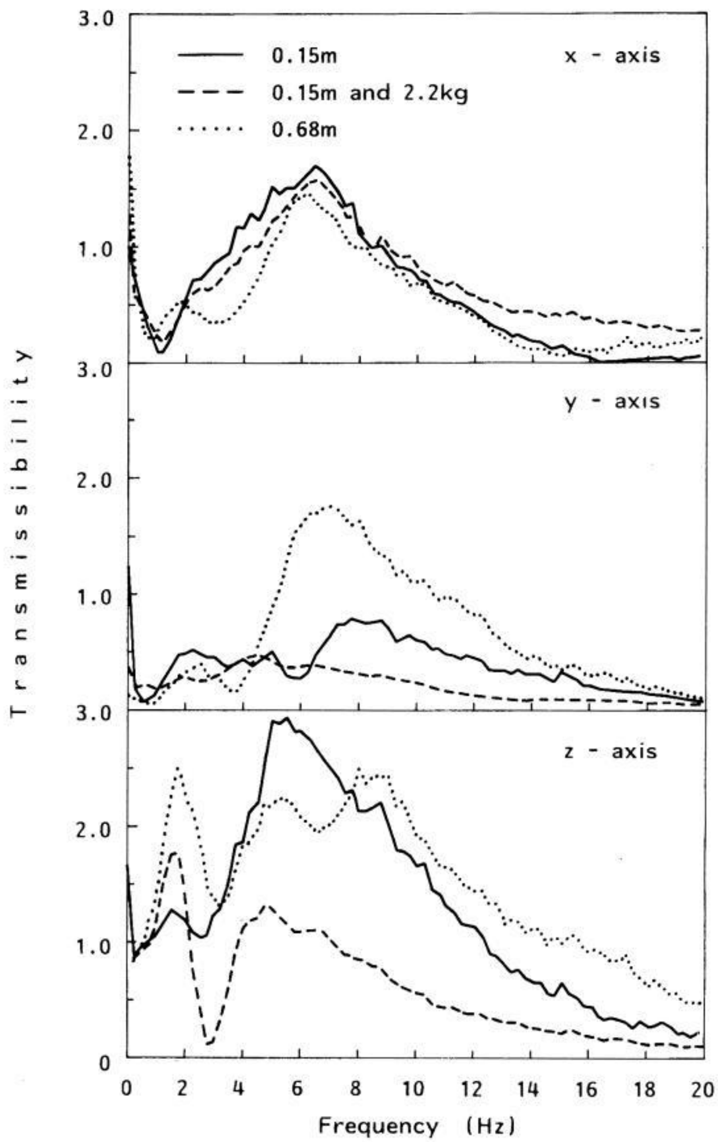


Figure 26 Transmissibility to the hand of vertical vibrations applied to a seated subject as measured by (Griffen, 1990)

The second error described by Griffin is input correlated error. This error is simply due to the normal limitations of the human visual and motor system to perform such a task. The error is attributable to neuromuscular lag time, tracking strategy, or a host of other variables as prescribed by Paul Cotnoirs work. The third component of task error are remnants.

Figure 25 shows that during ambulance rides the body is subjected to vibrations which can clearly affect the bodies performance in certain areas. While the graph does show that hearing is not generally affected by these vibrations the road noise created by the ambulance may.

The ability of a paramedic to be able to clearly hear is crucial to be able to diagnose and treat patients. As seen in a study, conducted by the US Army Center for Health Promotion and Preventive Medicine, the road surface induced noise level inside of a patient compartment of military ambulances can reach up to 94 dB. The results of the test may be seen below in Figure 27.

Photo	Model	Name, Condition	Location	Speed km/hr or (mph)	Sound Level dB(A)
	M966, also: M996 M997 M998 M1037 and other non-heavy	High mobility multi-wheeled vehicle (HMMWV), at 2/3 payload	Crew positions	0(idle) 48(30) 88(55)	78 84 94
	M996 M997	HMMWV mini and maxi ambulance, at 2/3 payload	Patient areas	up to 88 (55)	less than 85

Figure 27 Ambulance Noise Levels

(US Army Center for Health Promotion and Preventive Medicine)

In conjunction with the graph below it is shown that the 85 dB which may be present in the patient compartment of an ambulance at high speeds would require paramedics to at least raise their voice above normal level and potentially require shouting if road conditions and speed increase the noise level too high.

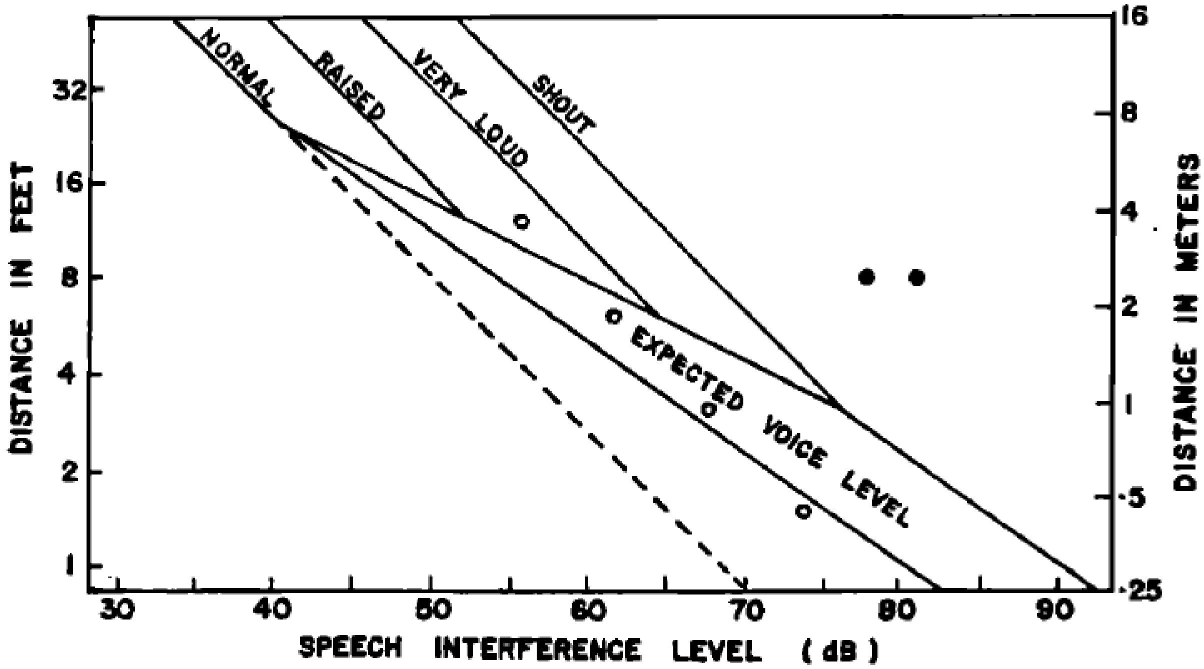


Figure 28 SIL vs. Coherent Face to Face Communication Distance (Waltzman & Levitt, 1978)

Speech interference level (SIL) versus distance for various voice levels. The region below each curve shows the SIL-distance combination for which reliable face to face communication is possible. (Waltzman & Levitt, 1978)

This experiment shows the potential noise level inside the patient compartment to reach a level where communication is difficult, yet this experiment only accounts for the road surface induced noise while in actuality an ambulance will have sirens wailing. According to the Ambulance Manufacturer's Division standards ambulance sirens must meet the following sound level requirements.

> Shall be capable of producing a continuous warning sound at a minimum level of 123 dB, A-weighted, at 3 meters (10’) on axis in the “wail mode” with “yelp” falling within 1 dB with 13.6 volts +/- 1% input, at a fundamental frequency in the range of 500–2,000 Hz maximum. (Ambulance Manufacturers Division of the National Truck Equipment Association, 2007)

Sound levels this high are in the range reported by the American Speech-Language-Hearing Association to be harmful to human hearing as seen above in Table 4. The AMD siren requirements mandate that sirens be as loud as jet plane taking off. While this probably does not cause permanent hearing loss to occur while riding inside the ambulance, the levels of sound produced will certainly contribute to the speech interference level experienced inside the patient compartment.

Table 4 Sound Levels with Qualitative Examples

(American Speech-Language-Hearing Association, 2010)

Painful

150 dB = rock music peak
140 dB = firearms, air raid siren, jet engine
130 dB = jackhammer
120 dB = jet plane take-off, amplified rock music at 4-6 ft., car stereo, band practice

Extremely Loud

110 dB = rock music, model airplane
106 dB = timpani and bass drum rolls
100 dB = snowmobile, chain saw, pneumatic drill
90 dB = lawnmower, shop tools, truck traffic, subway

Very Loud

80 dB = alarm clock, busy street
70 dB = busy traffic, vacuum cleaner
60 dB = conversation, dishwasher

As shown road surface conditions play a large part on the level of ambient noise and vibrations experienced inside the patient compartment. A reduction in the transmissibility of sound and vibrations into the patient compartment could greatly improve the ability of paramedics to provide quality care, and decrease the stress experienced by the patient due to unwanted stimulation.

Chapter 4: Potential Engineering Solutions

Now that the road surface induced vibrations have been identified as a source of discomfort for patients and decreased ability of paramedics to perform. A problem is outlined for engineering solutions to be applied: The desire for a reduction of road surface induced vibrations transmitted to the patient and paramedic crew inside the patient compartment.

The first step is to analyze the current measures taken to reduce the amount of vibrations transmitted from the ground to the patient compartment. This requires an analysis of the standard ambulances used today and the vibration reducing systems they employ.

In the United States most ambulances are composed of an aftermarket ambulance body attached to a Ford F series truck body. These trucks offer ambulance prep packages which equip them with all of the required components needed to satisfy Ambulance Manufacturers Division Standards. These packages also offer beefed up suspension to account for the heavy Patient Compartments added on the back. Below in Table 5 some examples from Braun, a leading manufacturer of ambulances, show how close the curb weight, the completed ambulance weight, is to the gross vehicle weight specified by the manufacturer of the chassis. These weights do not include any medical equipment, fuel, or passengers. These things will easily add a few thousand pounds to the curb weight pushing the vehicle closer to the gross vehicle rating of the chassis. While this keeps the vehicle within the legal requirements, a GVW so close to that of the chassis manufacturers limit has negative effects on suspension function and handling.

Table 5 Total Usable Payload in Braun Ambulances

(Braun, 2008)

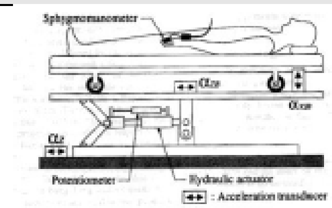
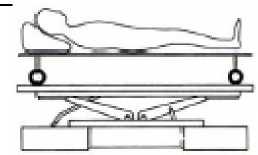
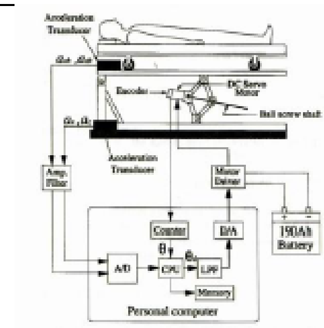
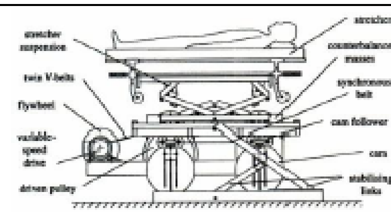
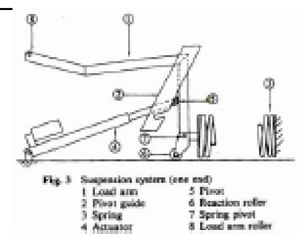
Vehicle	GVW (lbs) (rated)	Curb Weight (lbs)	Total Usable Payload (lbs)
Braun Super Chief	20000	15,993	4,067
Braun Chief XL E-450	14,500	10,881	3,689
Braun Chief XL F-450	16,000	12,554	3,446
Braun Chief XL G-4500	14,200	10,778	3,442
Braun Raider G-3500	12,300	10,005	2,295

When a vehicle is loaded to the GVWR of the manufacturer that is the maximum payload the chassis was designed to carry. This is calculated by factoring in the durability and size of all major suspension and drive train components. However the vehicle is not designed for optimal handling or function at this weight, it is only a maximum limit. The suspension system of the Ford chassis used in most ambulances today is a passive system. This means that there are no sensors to adjust the amount of spring force or dampening force. The system simply rides out any road induced oscillations until the damping of the system eventually returns it to normal. The amount of time the suspension system takes to return to equilibrium is directly related to the mass of the ambulance that it has to stop. As the vehicle approaches the GVWR the suspension system is moving towards an under damped model situation where it is very difficult to arrest road induced vibrations of the patient compartment.

Since most ambulances in the United States are a combination of a stock chassis and custom made ambulance body there are only three obvious solutions: ambulance bodies should be designed to reduce weight, Ford and other manufacturers could design and implement a better suspension system for higher weights, or a secondary vibration reduction method could be implemented. While redesigning the ambulance bodies to be lighter in weight may benefit the handling it could reduce the protection of the passengers inside the patient compartment in the case of an accident. This procedure could also prove very costly with the need to implement newer composite materials as the lightest of affordable alloys are currently used now. This makes implementing a secondary vibration reduction mechanism between the ground and the passengers inside the patient compartment a logical choice to reduce the transmitted vibrations.

To this end multiple shock absorbing stretchers have been designed and manufactured over the years. An assortment of shock absorbing stretchers was tabulated in a paper by Paul Cotnoir. While these stretchers all attempt to reduce vibrations they suffer from similar problems "high cost, high maintenance, high bulk and weight, high power consumption, and a non-universal fit" (Cotnoir, 2009). When comparing these stretchers to others used in the field the disadvantages greatly outweigh the advantages. While this design solution does have the potential for valid and applicable outcomes the current available attempts have failed to recognize the needs of ambulance consumers, the private and commercially owned ambulance fleets. These needs primarily being that the stretcher is light weight, of standard size, reliable, comes with a warranty, and that the manufacturer has a reputation for timely and reliable service.

Table 6 Vibration Reducing Ambulance Stretchers (Cotnoir, 2009)

Study authors	Stretcher/suspension design	
Sagawa, et. al., 1997 (manually control)	This design succeeded in using pitch angle of the stretcher to help stabilize the patient's blood pressure. Success at controlling vibration was inconclusive.	
Snook & Pacifico, 1976	Double electrically controlled electric motors in concert with compression springs produced reductions of up to 66% in peak acceleration values over a normal stretcher in the 3 to 10 Hz range	
Sagawa & Inooka, 2002 (actively controlled)	The authors claim this servo-controlled electric design maintains the patient at .45 m/sec^2 +/- 1.32 m/sec^2 within a frequency range of 0 – 70 HZ	
Henderson & Raine, 1998	In the 0 – 12 Hz range, this servo-controlled hydraulic design reduced r.m.s. accelerations from 64% to 85% depending on road surface.	
Leyshon & Stammers, 1986	With a mattress in place, this design attenuates ambulance floor vibrations by 7 db @ 1.5 Hz and 9 db @ 4 Hz	

Another vibration reduction concept being researched and designed by Paul Cotnoir is a dampening plate with Force Field Domain System Control. This system implements a plate retro fitted to the inside of any ambulance compartment. A conceptual drawing showing the construction of the plate may be seen in Figure 29. Below that is a schematic drawing of one possible solution for the active damping control system.

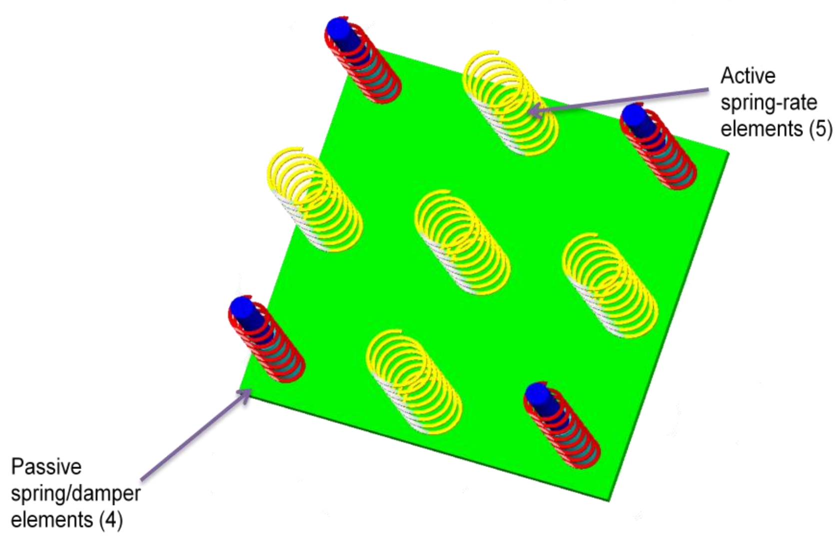


Figure 29 Force Plate (Cotnoir, 2009)

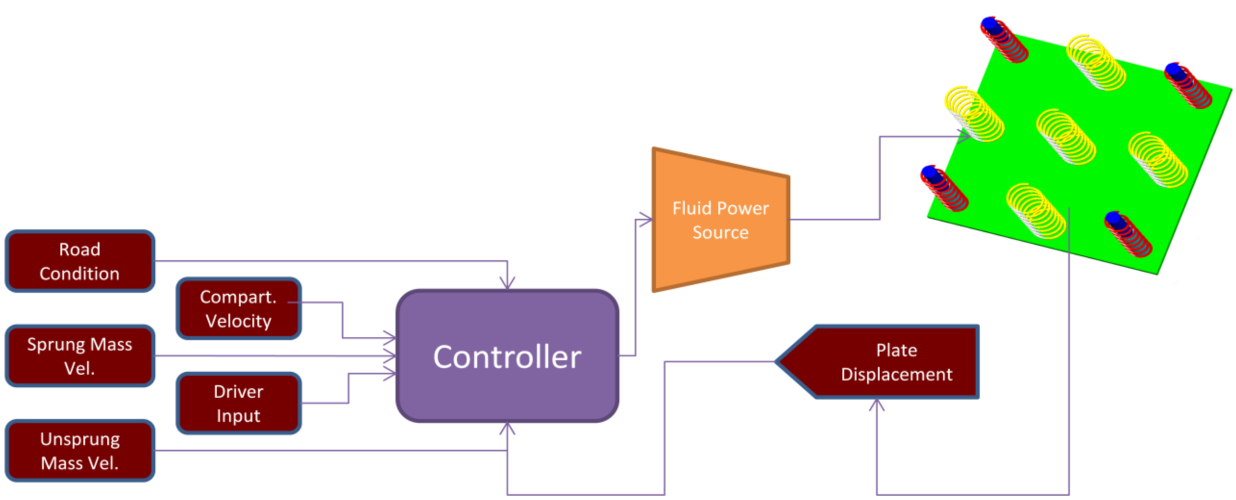


Figure 30 Schematic of Active Feedback Control System (Cotnoir, 2009)

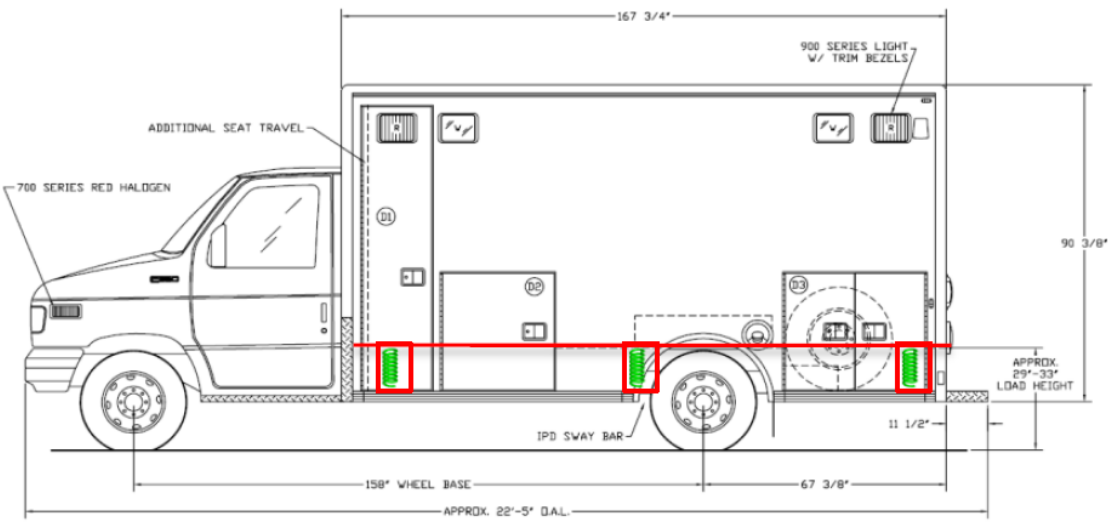


Figure 31 Ambulance schematic with force plate installed (Cotnoir, 2009)

As the vehicle drives along the road accelerometers attached to the axels, chassis, and ambulance body would read the road surface vibrations being transmitted from the road into the ambulance. Then in real time the dampening springs force could be adjusted to provide optimal damping of the vibrations to anything resting on the pad. This allows for the dampening of vibrations transmitted to the patient and emergency medical personnel to be reduced without attempting to control the movement of the entire patient compartment, only the people inside. This would improve the ability of ambulance personnel to perform all procedures necessary, especially those mentioned before; i.e. IV needle insertion.

The next step in the study conducted by Paul is to model an ambulance with a Cad system, including material properties to allow for an accurate estimate of the center of gravity. This model can then be used in conjunction with analysis software and a model of the force plate to test sample control methods and simulate road induced vibrations.

Modeling of the ambulance will be done using Solidworks and drawings of a German ambulance that the team was able to acquire. The drawings are almost dimensionless so a reference will be made to wheel base, one dimension available for the model. The scale drawings of the ambulance will be loaded into a program called ByteScout graph digitizer where other dimensions may be inferred by pinpointing the location of the axis and entering the dimensions. A picture of the German ambulance drawing open in ByteScout may be seen in Appendix G.

The high sound interference level inside the patient compartment decreases the ability of paramedics to communicate and perform certain diagnostic tests. For example the use of a stethoscope in the back of an ambulance is all but impossible. With a reduction in road surfaced induced vibrations transmitted to the cab the amount of noise from loose equipment would be lessened. In addition it is recommended that sound proofing material be integrated into the patient compartment floor, ceiling, and side walls. Decreasing the sound interference level experienced inside the patient compartment through a reduction in transmitted road and siren noise along with vibration reduction will increase the ability of paramedics to communicate and diagnose effectively. This could be done by adding a layer of Dynamat or other material like it. Dynamat is a sound deadening material marketed to high end car audio enthusiasts. IT advertises the ability to decrease road noise greatly allowing you to hear the full capability of your sound system, or in our case the lack of noise desired inside an ambulance. A picture of the material may be seen below.

Figure 32 Dynamat (Dynamat, 2010)

Chapter 4: Electronics Advancements in Emergency Medical Response Technology

Improving ambulance efficiency can be achieved by integrating a GPS system into the ambulance cab. Many crews have portable GPS systems (TomTom or Garmins) but are rarely used due to time constraints. While some rescue fleets already implement newer integrated systems, not all are aware of the benefits and still work with older outdated software.

One such new system is called fleet eyes and was established to help paramedics find locations and receive updates from the hospital. Fleet Eyes is interconnected with the dispatch system. A picture of the fleet eyes system in use at the UMASS Memorial Dispatch Headquarters may be seen below in Figure 34. This system allows the dispatcher to see the location of all rescue vehicles in the fleet they are responsible for. This makes the managing of a large rescue fleet much easier by enabling real time positioning of all units allowing a dispatcher to choose where to send which ambulance in case of multiple emergency situations. Dispatchers may select which ambulance and where it should go on a program integrated with Google Maps. The Route will then be sent to the ambulance driver appearing on his Fleet Eyes GPS Unit in the cab of the ambulance. These maps also contain as up to the date information as possible on construction and heavy traffic situations.

Fleet Eyes also provides smart phone applications so real time monitoring of an entire fleet may be done from anywhere at any time. Dispatch Supervisors at multiple dispatch centers could not say enough good things about the app. In addition rescue personnel not riding in an ambulance but near a call could be alerted to it and automatically have a route set on the GPS from their current location to the scene of the call. A photo of an I-phone running the software may be seen below in Figure 33 along with a list of the features the software boasts on the Fleet Eyes website.

- Individual secure login
- Available on the App Store
- One click keyword search
- Embedded Google map
- Complete details of vehicles
- Complete details of every pending and active incident
- Filtered view by group/call type
- Route yourself to any incident or vehicle
- Live traffic feed
- Satellite, hybrid, and traffic map layers

Figure 33 Fleet Eyes Iphone App and a List of its Features (FleetyEyes, LLC., 2009)

Using this software dispatch can relay directions from the ambulance's location to the site of the patient in need of help. The network can update crews with real time traffic conditions and is capable of sending directions to the GPS systems inside the ambulance as well. In a lifestyle where seconds can mean the difference between life and death Fleet Eyes is another step in the right direction in improving ambulance efficiency and the ability to save a lives.

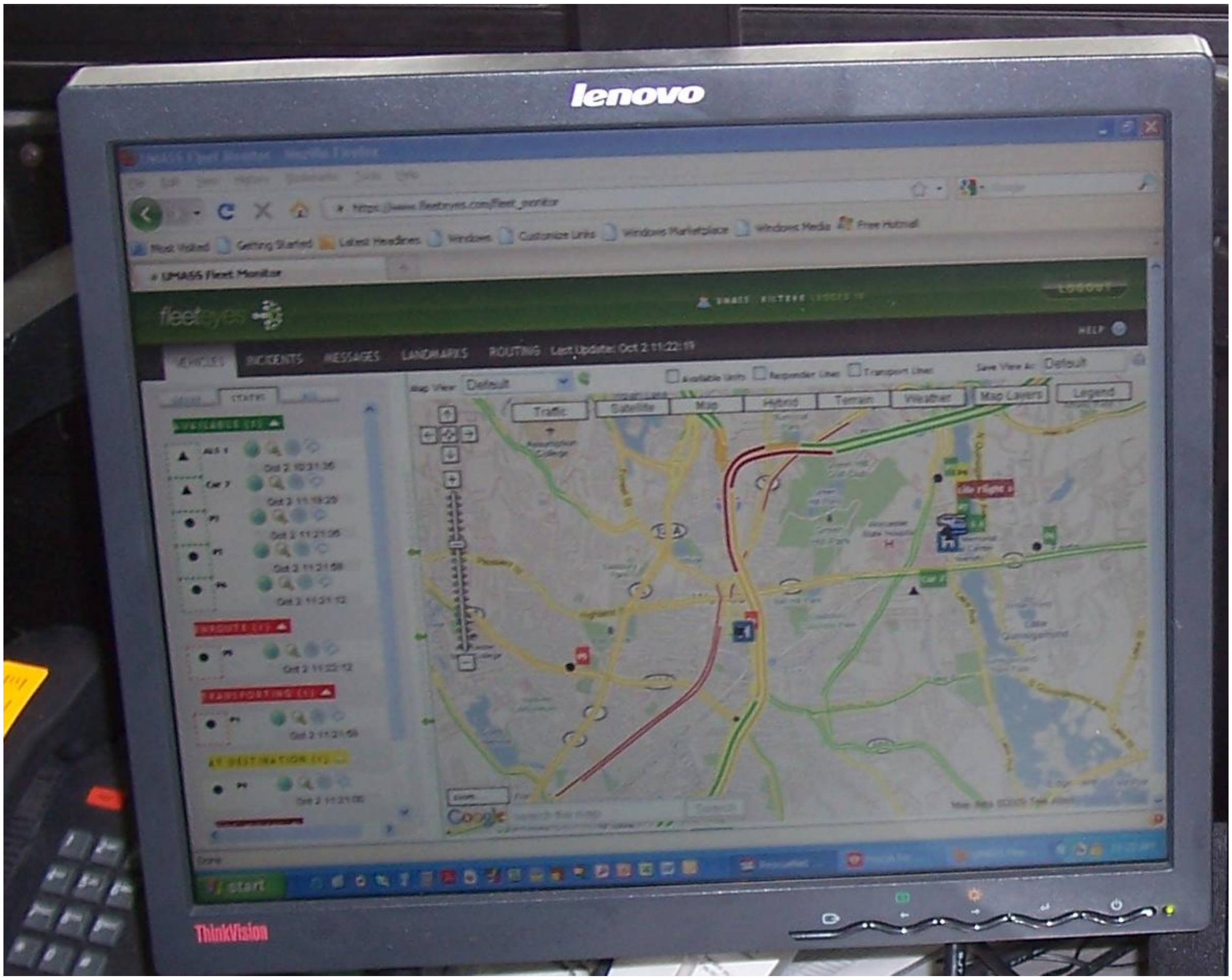


Figure 34 Fleet Eyes Rescue Vehicle Tracking System

While this software has many beneficial features some dispatchers when questioned in the field did have some small complaints. Mostly the reporting of road closings were not given to them until it was too late and a vehicle had to reroute during a call. This could be easily corrected by adding a computer module at the police dispatch center. They could then easily report any road closings or road work on a daily basis.

A feature which was not included but could be added to future GPS mapping programs is the ability of the ambulance to record road vibrations as an ambulance travelled. The roads could then be categorized by the frequency of oscillations, RMS acceleration induced on the vehicle body, and incline of the road. These quantitative numbers could then be organized into qualitative categories for instance roads which should be avoided with heart attack patients. This information could then be added to a local database of road surface conditions and be utilized in conjunction with RescueNet software to plan ambulance routes from emergency call sites to the ambulance. If it is entered into the RescueNet system that a patient has had a heart attack, roads that should be avoided while carrying the patient could be highlighted in red on the GPS map viewable both to the driver and dispatcher. This allows for routes to be created by the software or dispatcher, for example in blue, while still showing the red roads that should not be taken with the current patient's condition taken into account. By showing these roads at all times the driver can make decisions quickly if the route must be changed due to circumstances unknown to anyone but the driver. This cheap to implement technology advancement could decrease the amount of road surface induced vibrations transmitted to the patient compartment without any major mechanical alterations to the ambulance.

Rescue Net is a computer software suite made by ZOLL which greatly enhances the ability of a paramedic team to safely and proficiently transport a patient. The Rescue Net Software Suite has a host of different applications all tailored to increase the speed and efficiency of which the ambulance team operates by collecting data from multiple sources organizing that information and making it available to the dispatcher, ambulance crew, and hospital. Amy Smith, director of integration for ZOLL, said. "The power of RescueNet Link is the 'Sense and Sync' technology that allows the medic to focus their attention on the patient without having to worry about managing technical data collection while providing care." (Bruner, 2010) The system integrates a GPS tracking System, a ZOLL E series defibrillator, and the RescueNet ePCR Suite and puts all of the information into a concise and intuitive software screen.

By connecting a patient to the E Series Defibrillator, pictured below in Figure 35, all vital signs are automatically displayed for the EMS crew in the Patient compartment and simultaneously sent via Bluetooth communication to the RescueNet software Suite which sends the information to both the hospital and dispatcher. The E Series Defibrillator also boasts several other advantages over its competitors which may be seen below in Figure 35.

- ZOLL's Real CPR Help®, which measures chest compressions and rate and depth in real time, and provides visual and optional audible feedback. All CPR data can be recorded and reviewed using RescueNet Code Review software.
- See-Thru CPR®, unique to ZOLL, which allows CPR artifact to be filtered, letting you see organized rhythms without pausing compressions.
- Built-in GPS clock, allowing users to synchronize dispatch, defibrillator, and intervention call times, improving overall data accuracy.
- E Series® allows rescuers to easily and accurately diagnose CO poisoning with the simple push of a button.
- Integrated optional Bluetooth® functionality to provide data transmission capability to a variety of destinations.

Figure 35 ZOLL E Series Defibrillator and Highlighted Important Features (ZOLL Medical Corporation, 2009)

The information gathered by the RescueNet software suite is displayed in the back of the ambulance on a touch screen data terminal seen below in Figure 36. This terminal streamlines the ability of the ambulance crew to quickly record and send data cutting down the time previously needed for cumbersome paperwork via the ePCR suite. The software insures that all of the proper forms are filed and filed correctly.

RescueNet touch screen data terminal being used in a demonstration by Amy Smith, Director of Integration for ZOLL Medical Corporation.

Figure 36 RescueNet Touch Screen Data Terminal (Bruner, 2010)

The last component of the RescueNet software suite is the GPS system which tracks all vehicles. While the FleetEyes system already tracks the vehicles the information is only available to the dispatchers and ambulance drivers to facilitate easy routing and tracking of the ambulance fleet. The purpose of the GPS component of the RescueNet system is to provide the estimated time of the ambulances arrival at a hospital. At the hospital one concise program displays all of the information for all incoming ambulance patients; patient information collected from the dispatcher, information entered into the touch screen located in the patient compartment of each ambulance, the patients current conditions including real time vital statistic monitoring and recording, and the location and estimated time of arrival for all ambulances currently en route to the hospital. This system makes the triage of patients coming into a hospital with high ambulance call volume streamlined and easy. The hospital can be ready at the exact time of patient arrival with the proper facilities prepped and faculty waiting and ready to save the lives of even the most critically wounded patients. No time is wasted when a RescueNet software system is implemented into an ambulance fleets dispatch centers, ambulances, and hospitals. A photo of a computer running RescueNet software at the UMASS Memorial Medical Center dispatch room may be seen below in Figure 37. Some portions of the screen were blocked out to protect the privacy of patients and comply with the UMASS Memorial confidentiality regulations.

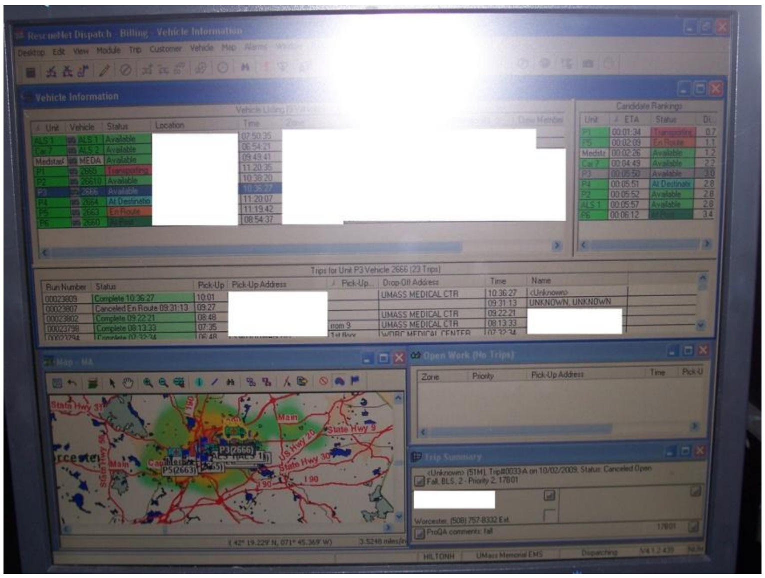


Figure 37 RescueNet Software

Through the implementation and use of these hardware and software systems produced by ZOLL and FleetEyes complete integration and sharing of any data involved in a medical emergency response call is achieved. This software is already helping save lives in some dispatch departments and should be implemented in all large ambulance fleets. A picture of a dispatchers work station at UMASS Memorial Medical Center may be seen below.

Figure 38 Dispatcher Work Station

As shown above there is a third monitor at the dispatcher's statement whose function has not been discussed. This monitor displays the program Pro QA which guides a dispatcher through the correct line of questioning during an emergency call. When a caller is distressed the situation is heightened and a dispatcher must remain calm try to collect all of the pertinent information. With Pro QA the dispatcher is guided through the proper line of questioning with the next question decided upon by the previous answers. This can ease the situation and require the dispatcher to focus on one less thing while still insuring all of the correct information is collected. Previously this was done with question guiding books which could be cumbersome and easily ignored. When the data entry system is requesting the correct information dispatchers are more likely to inquire about the necessary information required to determine what the skill level of emergency medical respondents and what equipment will need to be sent to the scene of the call. A screen shot of the Pro QA software open at the beginning of a call may be seen below. The answers are entered into the fields of this page when a call is initially made, and based on these answers the next questions are correlated and the dispatcher is prompted to enter the answers.

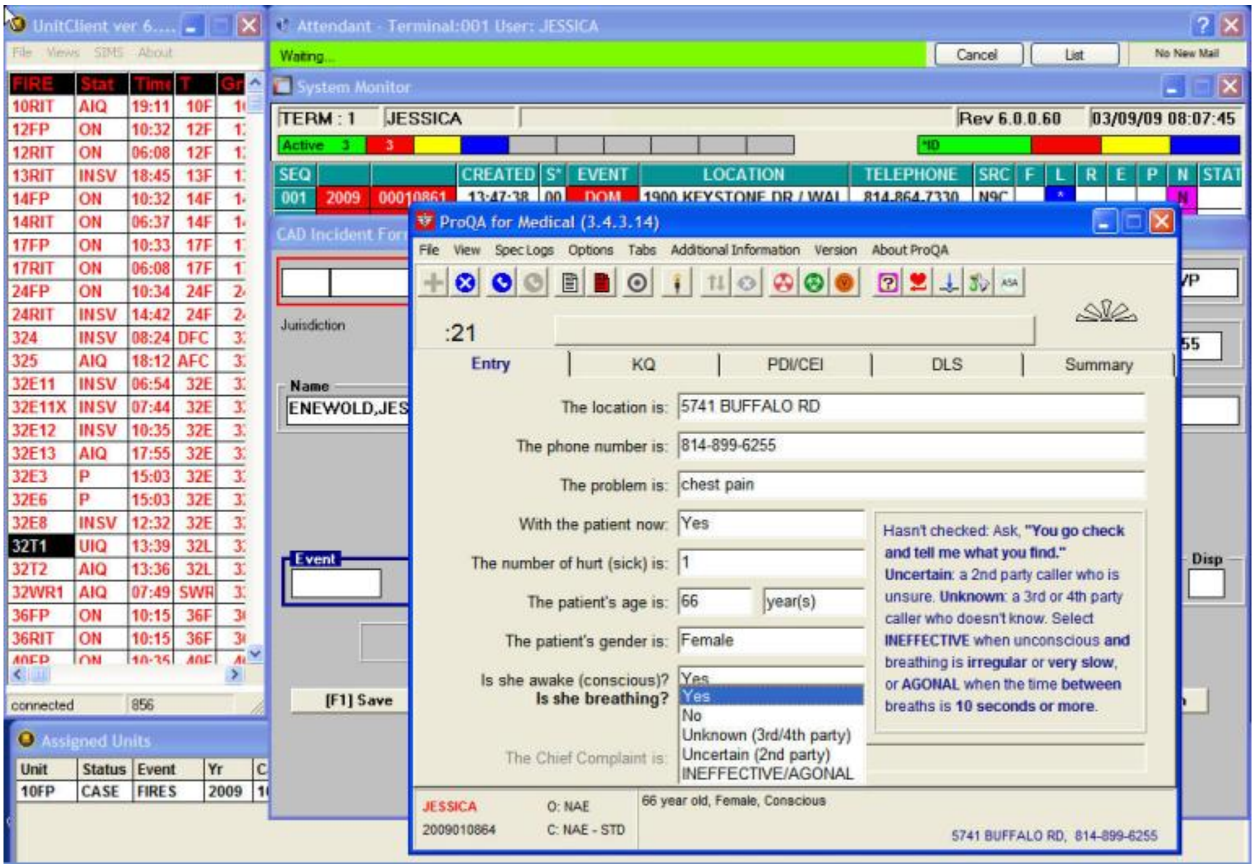


Figure 39 Pro QA Initial Questioning Screen (PRWeb, 2009)

Another piece of equipment that could be added to improve the safety of ambulance operation is a black box driving habit trainer. The box is mounted inside the ambulance and may be hooked up to several detectors and a beeping alarm. These systems have the potential to detect speed, acceleration, radial acceleration, breaking forces, seatbelt use, and even require a button to be pushed on the back of the ambulance while backing down to guarantee there is someone watching behind the ambulance. When the system detects that the driver is driving outside of the optimal performance zone of the vehicle a beep starts sounding. If the driver does not correct the action the beep will continue to sound louder and faster, increasing with time or if the driver pushes the vehicle farther after the alarm has started sounding. This gives the driver real time feedback on their driving which could easily get out of control in high stress emergency situations without a real time driver feedback. The system also prevents smaller accidents like backing over bikes and other things by requiring the navigating EMS personnel to exit the vehicle and depress a button on the back silencing the alarm inside the cab that is otherwise sounding when the vehicle transmission is set to reverse. The system also records when the alarm was sounding and for what reason to be reviewed after the fact. All drivers interviewed in the field liked the system due to the reduced number of accidents they saw after implementing the system. They felt as long as it was not used in a “big brother” manner to report bad driving to a supervisor, or to use against them in court in case of an accident.

Chapter 6 Conclusions

As a result of this project many areas of potential improvement in ambulance design have been identified and their source derived from careful analysis of the ambulance structure. Methods for a reduction in road surface induced vibrations, a reduction in patient compartment sound interference level, and a host of modern electronics which increase ambulance efficiency and safety have been discussed. It is the IQP teams hope that this project will allow future advancement of ambulance design to emerge from the research and ideas which have been brought together in this paper.

Working on the project where such an in depth insight of a problem had to be gained was a great experience. The team didn't usually go to events together due to busy scheduling, but we all arranged and conducted information gathering meetings, either for interview purposes or data collection. The team went to Hospitals, dispatch centers, EMS trade shows,and went for data collection rides on ambulances.

At the EMS trade show in Connecticut we took some pictures of one of the newest ambulance designs currently available in the US. The group thought it almost laughable that the newest designs are still mounted on standard truck chassis. All other fields of public service have specialized automobiles. Police forces have the interceptor package added to all cars. This greatly improves the handling and performance of the cars to allow officers to perform their duties at the maximum possible level while not being limited by any of their equipment. Fire fighters have custom made fire trucks. They are 100% manufactured for that purpose and all aspects of design from the ground up are integrated with the sole purpose of fighting fires in mind. Below are some pictures and a few brief sentences about the new ambulance we photographed.

Figure 40 One of the newest McCoy Miller Ambulances

New ambulance designs have been presented with improvements in specially designed infrastructures. The cabs have been modified to provide emergency personnel with enough space to comfortably treat and respond to the patients needs. However the latest ambulance in production was just introduced by McCoy Miller was still an aftermarket body attached to a Ford E-350 chassis.

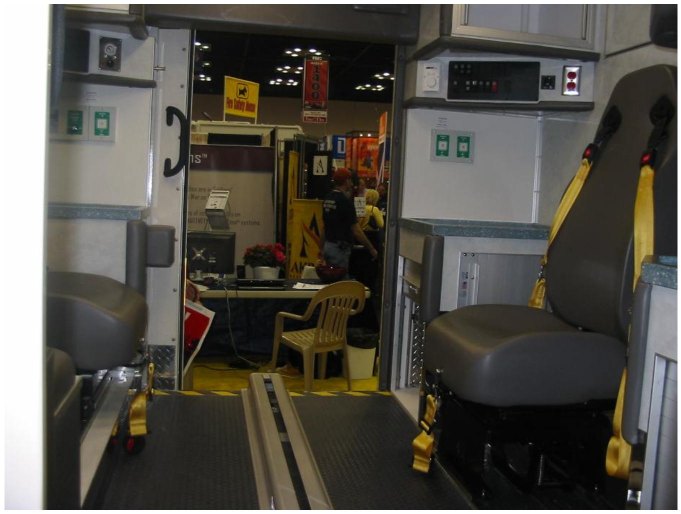


Figure 41 McCoy Miller Ambulance Compartment

It can be seen that there is a track inside the new ambulance for aligning the stretcher. While this may make loading certain specially designed heavy stretchers into the ambulance easier it eliminates the possibility of loading any ordinary stretcher in and securing it place. The lack of backwards compatibility of this patient compartment is a definite design flaw. In an emergency this ambulance would be unable to transport a patient safely without a stretcher designed to work with this ambulance.

Figure 42 Ambulance Seeting

The seats for paramedics working on patients inside the patient compartment are pictured above. They provide four point harnessing, essentially securing the workers within their seats for even the worst of accidents. They also slide from side to side increasing the access to the patient.

After seeing where the ambulance market is today the group concluded that there lay a large opening in the ambulance manufacturer's market. There are currently no manufacturers designing ambulances from the ground up with patient care in mind every step of the way. The needs of ambulance workers are there to listen to if the manufacturers would open their ears. Ambulance crews want a quieter smoother ride in the patient compartment. This issue will not be completely fixed until ambulances are no longer aftermarket boxes strapped to a stock chassis. The suspension must be specially designed to provide the performance and handling desired by drivers while making it smooth and quite enough for a baby to sleep in the back. The team believes this could be achieved through careful thought and planning if the needs of the customer are kept in mind.

References

Ambulance Manufacturers Division of the National Truck Equipment Association. (2007). *AMD Standards.*

American Speech-Language-Hearing Association. (2010). *Noise and Hearing Loss*. Retrieved 04 02, 2010, from asha.org: http://www.asha.org/public/hearing/disorders/noise.htm

Barber, L., & Jones, M. (1999). *How shit works.* Millville: Linc Inc.

Braun. (2008). *Chief XL*. Retrieved 2010, from Braun Industries Incorporated: http://www.braunambulances.com/products/products-detail.php?cart=34169545403439&n=home&sku=33196237491167

Bruner, S. M. (2010, March 9). Rescue solution: ZOLL's RescueNet LinkEmergency data integration system looks to streamline fire and EMS data. *EMS Comunications* .

Clark, C. J., Williams, C. J., Hood, W. B., & Murray, R. H. (1967). Initial Cardivascular Response to Low Frequency WHole Body Vibrations in Humans and Animals. *Aerospace Medicine* , 464 - 467.

Cotnoir, P. (2009). *Ambulance Vibration Suppression Via Force Field Domain Control, PHD Thesis.* Worcester Polytechnic Institute, Mechanical Engineering, Worcester, Ma.

Dynamat. (2010). *Dynamat Custom Cut*. Retrieved 2010, from dynamatstore.com: http://www.dynamatstore.com/

EMTLife. (2009). *Moving Ambulance Scope of Service*. Retrieved 2010, from EMTLife.com: http://www.emtlife.com/archive/index.php/t-13271.html

FleetyEyes, LLC. (2009). *Mobile*. Retrieved 2010, from fleeteyes: http://www.fleeteyes.com/products-iPhone.html

Ford Trucks. (2007). *Body Builders Layout Book.*

Green, D. A., Golding, J. F., Mandip, A., Faldon, M. C., Murphy, K. G., Bronstein, A. M., et al. (26 February 2008). *Adaptation of ventilation to 'buffeting' in vehicles.*

Griffen, M. J. (1990). *Handbook of Human Vibrations.* New York, New York: Harcourt Brace Jovanovich.

International Organization for Standardization. (1997, May 01). *ISO 2631-1:1997 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements.* Retrieved 2010, from Thomson Reuters: http://www.techstreet.com/cgi-bin/detail?doc_no=ISO|2631_1_1997&product_id=22795

Paddan, G., & Griffin, M. (2002). Evaluation of whole-body vibration in vehicles. *Journal of Sound and Vibration , 1* (253), 195-213.

PRWeb. (2009, March 9). *All Releases for March 9, 2009*. Retrieved 2010, from prweb.com: http://images.google.com/imgres?imgurl=http://www.prweb.com/prfiles/2009/03/09/191029/CADProQA.png&imgrefurl=http://www.prweb.com/releases/2009/03/prweb2214734.htm&usg=___cVQtuFQc9fzXOtLRO5lNqCC1KE=&h=529&w=768&sz=365&hl=en&start=2&um=1&itbs=1&tbnid=iF7QJ

Tamboli, J. A., & Joshi, S. G. (1999). Optimum Design of a Passive Suspension System of a Vehicle Subjected to Actual Random Road Excitations. *Journal of Sound and Vibration* , 193 - 205.

US Army Center for Health Promotion and Preventive Medicine. (n.d.). *Noise Levels of Common Army Equipment.* Retrieved April 2010, from U.S. Army Center for Health Promotion and Preventive Medicine : http://chppm-www.apgea.army.mil/HCP/NoiseLevels.aspx

Waltzman, S. B., & Levitt, H. (1978). Speech interference level as a predictor of face-to-face communication in noise. *Journal of Acoustic Society of America* , 581-590.

Weber, U., Reitinger, A., Scusz, R., Hellmich, C., B Steinlechner, H. H., Mora, B., et al. (2009). Emergency Ambulance Transport Induces Stress in Patients with Acute Coronary Syndrome. *Emergency Medical Journal* (26), 524-528.

ZOLL Medical Corporation. (2009). *E Series Defibrillator*. Retrieved 2010, from ZOLL.com: http://www.zoll.com/medical-products/defibrillators/e-series/

Appendix A

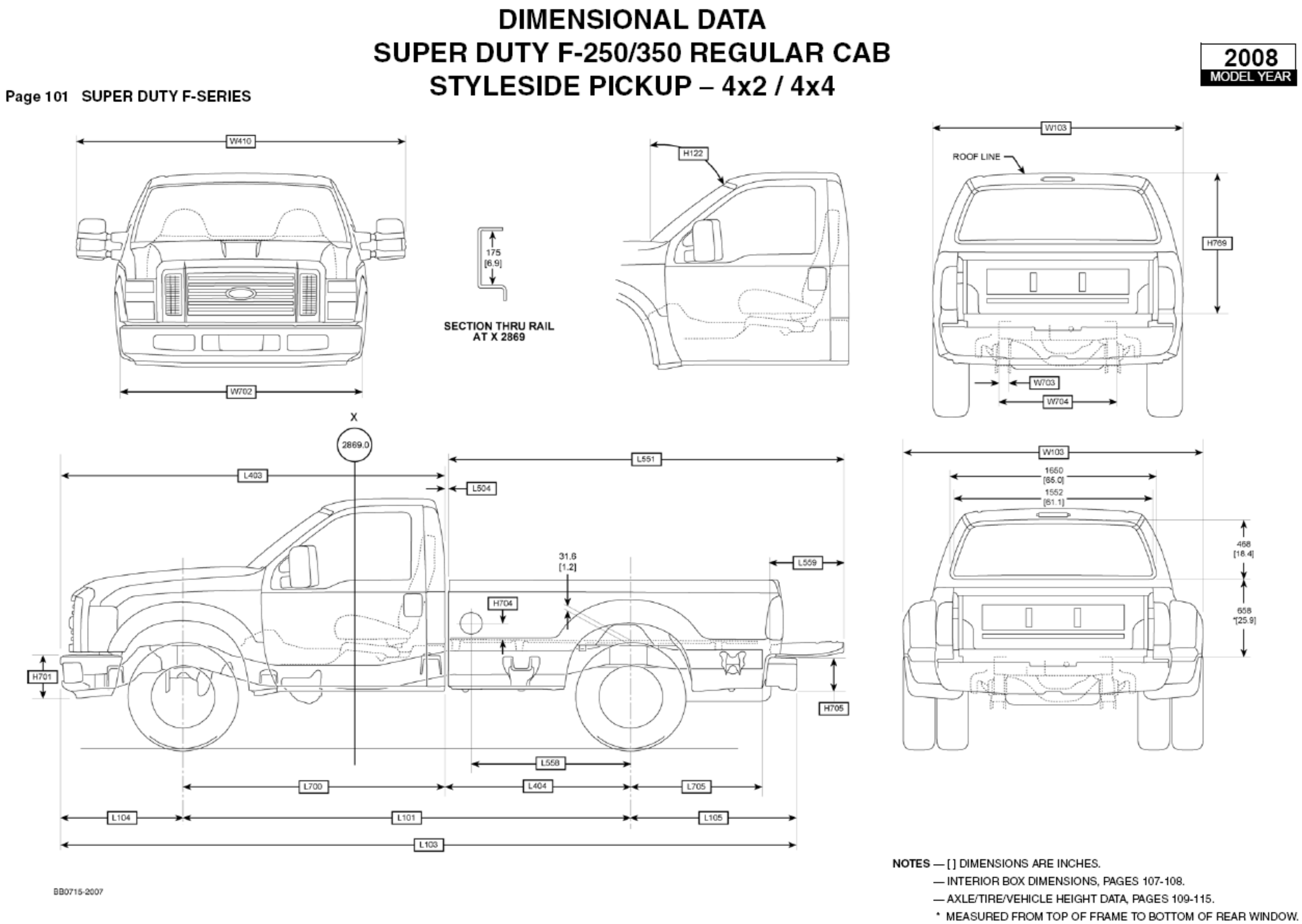
(Cotnoir, 2009)

Systemic Category	Study Authors	Findings
	Griffin, 1990, p174	In the range of 2 – 20 Hz, moderate to high magnitudes of vertical vibration produce a cv response similar to moderate exercise including elevated heart and respiration rates as well as an increase in cardiac output, mean arterial blood pressure, pulmonary ventilation and oxygen uptake. All these effects increase with increasing vibration magnitude around major body resonant frequencies.
Cardiovascular (cv)	**Uchikune, 2002, p 203-206**	A 4% increase in heart rate was measured when seated subjects in a high speed vehicle were exposed to vertical vibrations in the range of 1.6-2.3 Hz and magnitudes of .26 - .43 m/s^2 r.m.s., a 4% increase in heart rate. Subjects were seated and vibration measurements were made at their heads.
	Yue & Mester, 2007a, p. 107	The authors of this study, associated with vibration assisted conditioning, found that human exposure to vibrations in the 40-50 Hz range resulted in an increase in the maximum shear stress at the walls of major coronary arteries and veins at even at local amplitudes as small as 50 µm. This vessel dilation phenomenon has potential benefits for athletes due to the increased blood flow capacity, but may present health risks for individuals with existing cardiovascular conditions.
Cardiovascular (cv)	**Yue & Mester, 2007b,p. 123**	• The results of this study suggest that whole body vibrations which produce local vibrations in excess of 40 µm lead to the dilations of small blood vessels, particularly arterioles of up to 30%. This dilation led to a significant observed reduction of total peripheral resistance – an important ability of the human body to prevent the blood pressure from getting too high during high levels of exertion. • The distribution of local vibrations is dependent on the vibration amplitude and body transmissibility. • Transmissibility depends on vibration frequency and location as well body posture and muscle state. • Vibrations are transmitted through both muscle and skeleton separately and in concert. Transmissiblity through muscle tissue varies with muscle activation.

(cont'd)	**Green, et. Al., 2006**	In simulated rides over rough road surfaces, subjects displayed prolonged mild hypocapnia (lower than normal levels of CO_2 in the blood stream brought on by tachypnea (elevated respiratory frequency) along with initial increases in heart rate and blood pressure. The authors feel this could be significant for individuals with impaired cardiovascular function who must travel in an ambulance over rough roads, or in evacuation from a combat or disaster zone.
Respiratory	**Green, et. Al. , 2008**	This study included simulated rides over rough road surfaces identical to the authors' 2006 study. Subjects displayed prolonged mild hypocapnia (lower than normal levels of CO_2 in the blood stream brought on by tachypnea (elevated respiratory frequency) which the authors feel could be significant for individuals with impaired respiratory control who must travel in an ambulance over rough roads, or in evacuation from a combat or disaster zone.
	Ernsting, 1961	The author reported hyperventilation and increased oxygen consumption on exposure to high frequency vibration.
	Dupuis, 1969	The author reported decreased respiration frequency, but increased respiration volume on exposure to vibrations in the 2-10 Hz range at a weighted magnitude of 1.25 m/s^2.
Respiratory	**Sharp, Patrick, & Withey, 1975**	This study found that constant-displacement sinusoidal vibration in the 2-10 Hz range resulted in increased oxygen uptake due to hyperventilation and muscle tension. The effects were greatest at the highest frequencies.
Endocrine and metabolic	**Litta-Modignani, Blivaiss, Magid & Priede, 1964**	The authors reported small, but significant changes to steroid levels in blood and urine samples of human subjects exposed to short term whole-body vibrations. All readings were within normal levels.
	Pushkina, 1961	This study reported hypoglycemia (low blood sugar), hypocholesterinaemia (low blood cholesterol) and low blood levels of ascorbic acids after exposure to vibration.
Motor processes	**Roll & Roll, 1987**	The authors found that vibration applied to the muscles of the eye influenced proper orientation of the eye relative to posture control.
	Eklund, 1972	The author found a variety of adverse effects to balance due to exposure to whole-body vibration
Sensory processes	**Moseley & Griffin, 1987**	This study points to a possible link between vibration and and biodynamic eye reflex movement. Evidence is also presented vibration effects on vestibular systems which can result in instability, disorientation of body, and disruptions of vision.

Central nervous system	**Ullsperger & Seidel, 1980**	The authors found that 4 Hz whole-body vibration produced significant decreases in EEG amplitudes which may have an effect on perception thresholds.
Skeletal	**Klingenstierna & Pope, 1987**	This study found a temporary reduction in body height of around 10-20mm upon exposure to whole body vibration
Other	**Roman, 1958**	The author found that whole-body vibration tests at 25 Hz and +/- 1g to +/-10g amplitude ratings with exposures of 3 to 15 minutes produced severe chest pain and gastrointestinal bleeding at the highest settings and exposure times.
	Loeckle, 1950	The author reported traces of blood in the urine of a man with a kidney stone at 30 Hz and +/- 9g accelerations
Other	**Gratsianskaya, 1974**	The results of this study indicates menstrual disorders, internal inflammation, and abnormal childbirth in women exposed to 40-55 Hz vibration.

Appendix B



(Ford Trucks, 2007)

Appendix C

(International Organization for Standardization, 1997)

This part of ISO 2631 defines methods for the measurement of periodic, random and transient whole-body vibration. It indicates the principal factors that combine to determine the degree to which a vibration exposure will be acceptable. Informative annexes indicate current opinion and provide guidance on the possible effects of vibration on health, comfort and perception and motion sickness. The frequency range considered is

- 0,5 Hz to 80 Hz for health, comfort and perception, and
- 0,1 Hz to 0,5 Hz for motion sickness.

Although the potential effects on human performance are not covered, most of the guidance on Whole-body vibration measurement also applies to this area. This part of ISO 2631 also defines the principles of preferred methods of mounting transducers for determining human exposure. It does not apply to the evaluation of extreme-magnitude single shocks such as occur in vehicle accidents.

This part of ISO 2631 is applicable to motions transmitted to the human body as a whole through the supporting surfaces: the feet of a standing person, the buttocks, back and feet of a seated person or the supporting area of a recumbent person. This type of vibration is found in vehicles, in machinery, in buildings and in the vicinity of working machinery.

Appendix D

Title	Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock
Standard Number	BS 6841:1987
Abstract	Methods of quantifying vibration and shock in relation to human health, interference with activities, discomfort, the probability of vibration perception and the incidence of motion sickness. Tentative guidance is given on the possible effects of vibration.
Cross References	BS 6472, ISO 2041, ISO 2631, ISO 5805, ISO 8041, SAE J1013, SAE 770253
Descriptors	Vibration effects (human body), Mechanical effects (human body), Physiological effects (human body), Vibration, Vibration hazards, Vibration measurement, Occupational safety, Occupational medicine, Weighting functions, Frequencies, Position, Motion, Vibration testing, Testing conditions, Visual perception, Sensory perception, Estimation, Transportation

Appendix E

Data from instrumented vehicles indicated that a standard ambulance chassis suspension is incapable of adequately and reliably attenuating some of the harmful road excitations commonly encountered by these emergency vehicles. A secondary vibration attenuation system to augment the standard ambulance suspension could provide a workable solution.

Therefore, it was the goal of this study to:

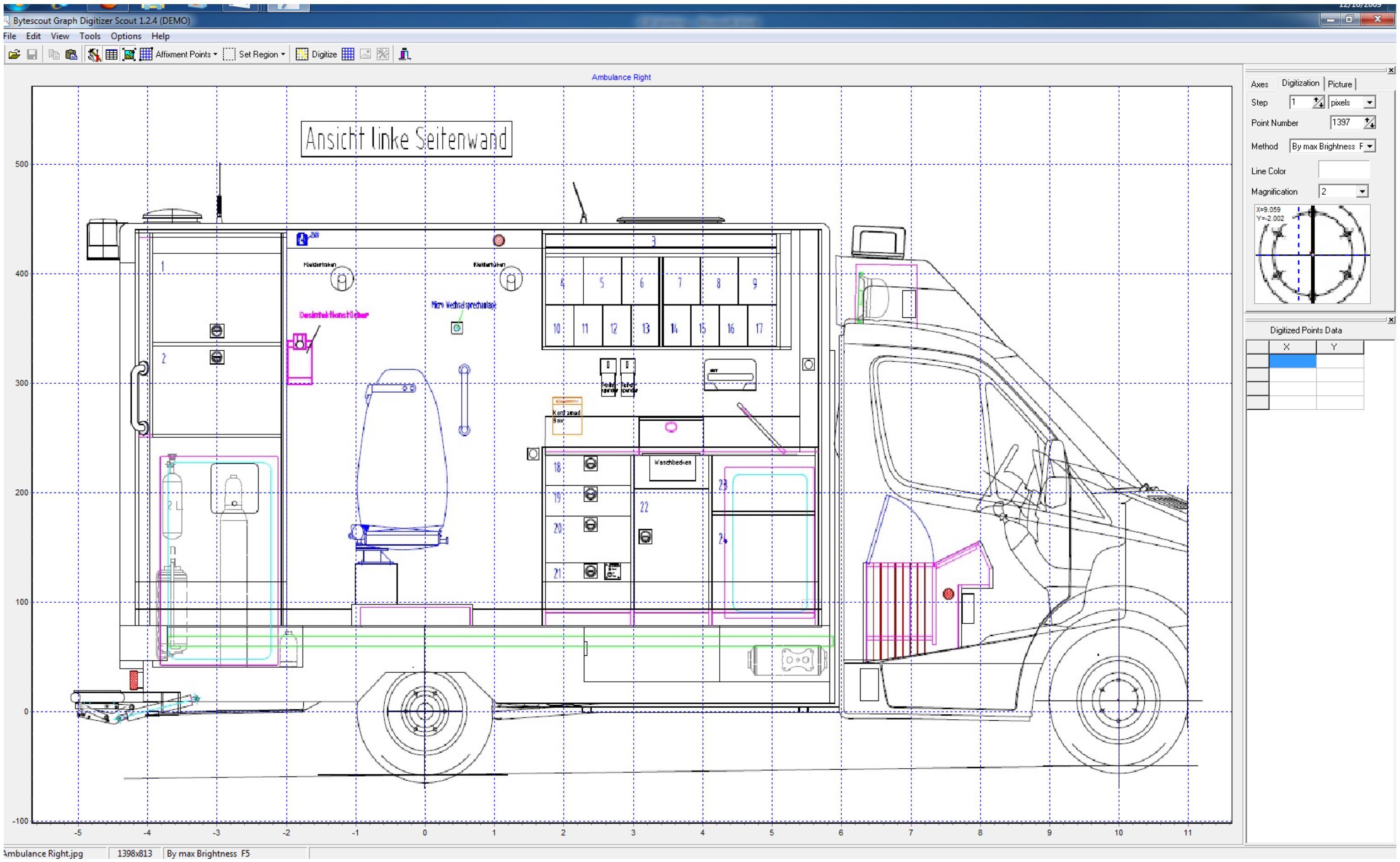
1. **Experimentally determine** the vibrational amplitude, frequency and energy of a typical ambulance ride, and correlate those vibrational characteristics to human physical impacts on ambulance passengers and EMT crews.

2. Use the vibrational parameters to **characterize** road forcing functions to simulate typical ambulance travel over the undulating surface of a variety of common road surfaces at a broad range of frequencies to create a computational model of a vibration attenuation solutions.

3. **Model** a force field domain control system (FFDCS) embodied in a force plate design capable of working in tandem with a standard ambulance suspension system to attenuate the most harmful vibrations encountered by such a vehicle in normal service.

The broader significance of this study lies in enhancing the patient-centered care associated with ambulance travel by improving patient comfort and safety through the assessment and administration of mobile medical interventions with improved precision, accuracy and safety.

Appendix F


Bytescout Graph Digitizer Scout 1.2.4 (DEMO)
File Edit View Tools Options Help
Affixment Points
Set Region
Digitize
Ambulance Right
Ansicht linke Seitenwand
Axes
Digitization
Picture
Step
pixels
Point Number
1397
Method
By max Brightness
Line Color
Magnification
Digitized Points Data
X
Y
Ambulance Right.jpg
1398x813
By max Brightness F5