University of New Haven

Department of Fire Science and Emergency Management

Emergency Management Plan to Increase Resilience in Transportation Sector Vehicles to an EMP Attack

Thesis Submitted in partial fulfillment of the requirements for the degree of

Master of Science in Emergency Management

By

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APPROVALS

I am sincerely grateful for the valuable comments from my advisor, the committee members, and the department chairperson in completion of this document. Their contributions were clearly an asset in the achievement of the goals of this Study.

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DEDICATION

I dedicate this thesis to my family, my loving wife Patricia, and daughters Alexandra and Theresa, son Matthew, daughter-in-law Lena, son-in-law Patrick, and grand-daughters Lilly and Esmae. Their continued love and encouragement in conjunction with this late-in-life career change from Engineering to Emergency Management was very much appreciated and cherished. I also dedicate this thesis to our pets who are part of all our families, in particular our cats Tweedledum, Cheese and Joey, and our dog Cassie who made numerous trips to my desk in the course of writing this thesis, offering their unending love and affection.

ABOUT THE AUTHOR

I enrolled in the Emergency Management M.S. program at University New Haven in January 2019 after retiring from full time employment at Roush Industries, Inc. as a Senior Engineer since 2007. Prior to joining Roush, I retired from Ford Motor Co. after 30 years of service since 1976 as a Principle Research Engineer and Product Development Supervisor. My background entering the program at UNH was a B.S. and M.S. in Mechanical Engineering, and a M.S. in Electronics and Computer Control Systems Engineering. My former work areas were in engine/powertrain systems design and development with Six Sigma black belt training. I deeply appreciate this opportunity offered to me at the University of New Haven to facilitate this career change in Emergency Management, and I hope it leads to many more years of work serving the public in disaster response, recovery and mitigation planning.

ABSTRACT

A vulnerability exists in the U.S. to an attack from a nuclear weapon of mass destruction (WMD) optimized to generate an electromagnetic pulse (EMP) with potential for widespread damage to electrical components in the critical infrastructure including non-military (non-MIL) transportation sector vehicles. The purpose of this study was to develop a plan on how hazard risks from an EMP attack can be better understood for modern-day, "electronics-heavy", transportation sector vehicles leading to affordable mitigation countermeasures that could be implemented as part of an emergency management plan. The FY2020 National Defense Authorization Act (NDAA) and preceding executive order signed by the President in 2019 supported this investigation to find ways to strengthen the transportation sector vehicle critical infrastructure from an EMP strike. A threat assessment analysis was used to identify capabilities of state actors and terrorist organizations that are of concern in national security forums. The hazards risk analysis utilized a hybrid emergency management/engineering approach to help visualize critical vehicle electronics sub-systems and components, and their respective potential failure modes. A comprehensive test plan was designed for modern-day, non-MIL transportation sector vehicles to identify the hazard risks which was accompanied by a failure modes and effects analysis template (FMEA) to quantify risks and prioritize mitigation countermeasures. Data from the literature from past testing, EMP resilience technical standards, and product information from expert suppliers who market EMP mitigation hardware were utilized to develop affordable mitigation countermeasure proposals for initial testing. The proposed emergency management plan was based on a strategic implementation of EMP mitigation countermeasures on non-MIL transportation sector modified to become resilient to EMP to support continuity in emergency services and delivery of lifeline supplies to the public after an EMP attack. A methodology was developed for enhanced logistics systems to address repair of un-modified, "as-built" vehicles damaged from the EMP attack. The results of this study will provide a foundation for future projects that can be executed to yield a transportation sector vehicle infrastructure more resilient to an EMP attack which is consistent with the FEMA National Preparedness Goal, and the recent FY2020 NDAA legislation and Presidential executive order.

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LIST OF ACRONYMS

Acronym	**Description**
1FAT	One Factor at a Time (testing terminology, alternative to design of experiments)
A/D	Analog to Digital Converter (component of microprocessors)
ABS	Vehicle Anti-lock Braking System
ADAS	Advanced Driver Assistance System
APP	Vehicle Accelerator Pedal Position
BC	Business Continuity
BCM	Business Continuity Management
BIA	Business Impact Analysis
C^4I	Refers to military ground-based systems that perform "critical, time-urgent command, control, communications, computer and intelligence (C4I) missions"
CBRN	Chemical, Biological, Radiological or Nuclear weapon
CIS	Critical Infrastructure Systems
CISA	Cyber Security and Infrastructure Security Agency
COVID-19	Corona Virus pandemic disease discovered in 2019
CPU	Central Processing Unit (component of microprocessors)
DC	Direct Current
DCS	Digital Control Systems
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOE	Design of Experiments (testing terminology)
DOE	U.S. Department of Energy
E1	1st part of Electromagnetic Pulse Waveform
E2	2nd part of Electromagnetic Pulse Waveform
E3	3rd part of Electromagnetic Pulse Waveform
ECU	Electronics Control Unit – microprocessor for vehicle controls
EMC	Electromagnetic Compatibility
EMGT	Emergency Management (University of New Haven)
EMI	Electromagnetic Interference
EMP	Electromagnetic pulse (used interchangeably with HEMP)
EMP SIG	Electromagnetic Pulse Special Interest Group (sponsored by Infragard)
EMS	Emergency Medical Services
ESF	FEMA Emergency Support Functions (U.S. Dept. of Homeland Security)

Acronym	**Description** *continued*
FEMA	Federal Emergency Management Association (part of U.S. Dept. of Homeland Security)
FMEA	Failure Modes and Effects Analysis
FY2020	Fiscal Year 2020
GDT	Gas Discharge Tubes
GEO	Geostationary Orbit, 36,000 km altitude
GMD	Geomagnetic Disturbance
HEMP	High Altitude Electromagnetic Pulse (used interchangeably with EMP)
HEO	Highly Elliptical Orbit
HMMWV	U.S. Military Vehicle - High Mobility Multipurpose Wheeled Vehicle
HOB	Height of Burst for nuclear weapon generating electromagnetic pulse
HPM	High Power Microwaves
HUMVEE	U.S. Military Vehicle - High Mobility Multipurpose Wheeled Vehicle
ICBM	Intercontinental Ballistic Missile
ICS	Incident Command System
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
Infragard	Non-profit organization serving as a public-private partnership U.S. businesses and FBI
INMA	InfraGard National Member Alliance (INMA)
ISIS	Islamic State of Iraq
Kv	Kilovolt (e.g. 50 Kv = 50,000 volts)
LEO	Low Earth Orbit, 200 – 2000 km altitude
LiDA	Logical in-Dept Analysis (used for emergency management logistics analysis)
MEHR	Iranian news agency
MHD	Magneto Hydrodynamics
MIL	U.S. Military (in reference to military vehicles and facilities hardened for EMP)
MIL STD	U.S. Military (in reference to military technical standards)
MIL-OBDII	Engine Diagnostics Malfunction Indicator Light for Onboard Diagnostics, II generation
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
MOV	Metal Oxide Varistor
MY	Model Year, in reference to when an automotive vehicle was produced.
NATO	North Atlantic Treaty Organization
NCC	National Coordinating Center for Communications
NDAA	National Defense Authorization Act

Acronym	Description *continued*
NIMS	FEMA National Incident Management System (U.S. Dept. of Homeland Security)
Non-MIL	Non-Military (in reference to transportation sector vehicles)
NOx	Nitric Oxide exhaust emissions
NRF	FEMA National Response Framework (U.S. Dept. of Homeland Security)
NS/EP	National Security and Emergency Preparedness (telecommunications systems)
OBL	Osama Bin Laden
OEM	Original Equipment Manufacturer (e.g., Ford, General Motors, FCA, Toyota, etc.)
PCM	Powertrain Control Module – Microprocessor for vehicle controls (Ford designation)
PLC	Programmable Logic Controllers
PLS	U.S. Military Vehicle - Palletized Load System
POE	Point of Entry (related to aperture openings in buildings or vehicles)
PRI	Priority Risk Index (emergency management metric used for FMEA risk analysis)
PSAPS	Public Safety Answering Point Service
RDD	Radiological dispersion device
RMA	Revolution in Military Affairs
RPN	Risk Priority Number (metric used for traditional FMEA risk)
RRCC	Regional Response Coordination Center
RS-105	Test standard defined in MIL-STD-461G to create laboratory version of E1 EMP pulse
RTG	Rubber Tire Gantrie
SASD	Silicon Avalanche Suppressor Diodes
SCADA	Supervisory Control and Data Acquisition Systems
SCR	Selective Catalytic Reduction emissions control system for diesel engines
SENT	Single Edge Nibble Transmission communications protocol
SLA	Spatially Localized Attack areas
TIVCT	Twin Independent Variable Cam Timing (engine controls for modern vehicle)
TVS	Transient Voltage Suppression (surge protection device)
UK (or U.K.)	The United Kingdom
UNH	University of New Haven
US (or U.S.)	The United States of America
WMD	Weapon(s) of mass destruction
WWII	World War II

1 INTRODUCTION

1.1 Overview

An electromagnetic pulse (EMP) can be generated by a man-made source such as a nuclear weapon, or a natural hazard event like a solar flare. EMP delivered by a nuclear weapon is one form of a CBRN attack executed most likely by a state actor due to the complexity of the technology required, and less likely by a terrorist organization. CBRN is an acronym used to describe a class of weapons of mass destruction (WMD) that could contain **C**hemical, **B**iological, **R**adiological or **N**uclear components deployed in a suite of attack mode situations. Per Silke (2018), the CBRN weapons suite are described as follows:

a) **Chemical Weapons**- Weapons that cause harm via toxic effects of chemicals interacting with the human body (example, aerosol release of nerve agent like Sarin).

b) **Biological weapons**-Weapons that act to infect a target population with a pathogenic micro-organism in the form of viruses or bacteria, and other pathogenic agents such as ricin and other microorganisms. Once introduced, either in person-to-person contact, the food supply or by direct atmospheric contact, the agent induces an infectious disease pandemic outbreak such as smallpox that can spread to others by direct or indirect contact, or more recently, the COVID-19 pandemic outbreak (Yong 2020).

c) **Radiological weapons** – Weapon devices that deploy radioactive materials is some form of radiological dispersal device (RDD) which harms the human body by means of ionizing radiation.

d) **Nuclear weapons** – In traditional scenarios, use of a fission or fusion nuclear reaction in a device close to ground-level yielding an immense explosion with subsequent thermal, kinetic, and radioactive contamination effects. When deployed at high altitude, 30-400 Km above the earth, the rapid release of gamma rays results in generation of an electromagnetic pulse (EMP) directed towards the ground, both vertically and radially, damaging electronics components without the thermal, kinetic impact and radioactive contamination effects of close-to-ground level explosions.

Numerous references in the literature discuss the vulnerability of the US to an EMP attack, the potential damage that could be incurred to critical infrastructure, and the subsequent potential for massive casualties caused by long term delay in delivery of lifeline supplies and emergency services to survivors. The EMP Commission Report (EMP Commission 2004, 2008) presented a comprehensive review of potential damage an optimized EMP device could incur in various sectors of critical infrastructure in the U.S.. The reports by Schneider (2007) prepared for the U.S. Congress Congressional Caucus on EMP, and Pry (2017) prepared for the Congressional Commission to Assess Threat to the U.S. from an EMP Attack elaborated on capabilities of technology-capable state actors and their associated attack scenarios. The InfraGard EMP Special Interest Group (INFRAGARD 2016) studied the impact of an EMP attack on critical infrastructure components in the U.S., with substantive mitigation proposals for the electric grid to bring the resilience to an acceptable level. Finally, the presentations by Radasky (2016, 2017) introduced further evidence on the vulnerability effects due to a High Altitude Electromagnetic Pulse (HEMP), Intentional Electromagnetic Interference (IEMI) and Geomagnetic Storms with substantive mitigation proposal concepts discussed to improve resiliency of the critical infrastructure for the electric grid and stationary electronics equipment. The information from these references and the results of a comprehensive literature review in this thesis support the recommendation that actions are needed to improve resilience of non-military transportation sector vehicles to an EMP attack for an emergency management response to be successful.

To support development of mitigation measures to improve resilience of critical infrastructure and national defense systems to an EMP attack, two legislative actions signed by the President were significant. In 2018, the White House issued a report and corresponding executive order titled *National Strategy for Countering Weapons of Mass Destruction Terrorism* (White House 2018). The executive order incorporated the following strategic objectives to reduce the likelihood of success for a terrorist group or violent non-state actor in deployment of a CBRN device:

- Eliminating accessibility of materials to produce or acquire CBRN/WMD weapons from terrorists or malicious non-state actors.

- Deterring states hostile to the United States from providing support to potential CBRN/WMD terrorists.
- Establishing an architecture to detect & foil terrorist CBRN/WMD networks.
- Enhancing US military and government personnel and facilities against CBRN/WMD terrorism.
- Developing the ability to identify and respond to new technologies that enable deployment of CBRN/WMDs.

The second significant piece of legislation was the FY2020 National Defense Authorization Act (NDAA) which originated with the Executive Order signed by the President on March 26, 2019 (White House 2019) and became law on Dec. 20, 2019 specifically addressing emergency response readiness to EMP ((Gertz 2020) and (Govtrack 2019)). The bill introduced "new measures requiring the federal government to protect the nation from the danger of nuclear-blast-produced electromagnetic pulse (EMP) attacks and similar solar-produced electronic disruptions", and specifically, it authorized development of capability to harden the critical infrastructure in the U.S. against an EMP strike.

1.2 Goals

The goals of this investigation focused on identifying the hazard risks, and developing plans to improve resilience of non-military (non-MIL) transportation sector vehicles to an EMP attack similar to the rigorous analysis completed for the electric grid and supporting critical infrastructure conducted by the EMP Commission Report (EMP Commission 2004, 2008), and the Infragard special interest group study "Powering Through (Infragard 2016)". By improving resilience of non-MIL transportation sector vehicles, the military can focus more fully on the strategic defense tasks that will be essential in defending our nation in the event of an EMP attack. Specific goals for this report were as follows:

- Develop a framework to categorize modern-day transportation sector vehicles and vulnerable electronics sub-systems and components exposed to an EMP/HEMP environment to enable a failure modes and effects analysis to be completed. This supported development of a more accurate hazards risk assessment due to exposure to an EMP, and a meaningful test plan.

- Develop a rigorous and comprehensive test plan with cost assessments for modern-day transportation sector vehicles at anticipated EMP/HEMP environments. This will generate data needed to quantify the damage scenarios and likely interaction effects from plausible deployment scenarios.
- Identify cost-effective mitigation design proposals to increase resilience of transportation sector vehicles. Considered were design actions that could be incorporated on as-built vehicles at a reasonable incremental cost to targeted groups of transportation sector vehicles to support Government EMP emergency preparedness directives.
- Define requirements for emergency management response and recovery plans that support delivery of emergency services and critical lifeline supplies to the public following an EMP attack including logistics in servicing vehicles damaged by EMP at automotive dealerships and 3rd party repair shops.

The accomplishment of the above goals will assist researchers, government agencies, and industry partners develop funding proposals for follow-up projects all of which are aimed at improved resilience of non-MIL transportation sector vehicles to an EMP attack. With better proof that particular mitigation measures are effective, the vulnerability of our nation to this national security threat will become diminished. Lessons learned will also apply to national security and emergency management plans for our allies world-wide.

2 BACKGROUND

2.1 EMP Physics

A high altitude electromagnetic pulse (HEMP) is produced when a nuclear weapon is detonated 30 to 400 km height above the earth (**Figure 1)** creating an electromagnetic pulse affecting a wide area radius beyond the point of deployment (**Figure 2)** depending on the height of burst (HOB), the size of the nuclear device, and how well the device is optimized for EMP (Pry (2017), (Radasky (2010), Emanuelson 2020-1). When a nuclear EMP device is detonated, gamma-radiation is generated interacting with the earth's magnetic field creating a near-instantaneous electromagnetic pulse without the kinetic energy, thermal effects and radiation of a near-ground deployed nuclear weapon. A high altitude electromagnetic pulse (HEMP) includes three fundamental waveform components E1, E2, and E3 shown in **Figure 3** from NCC (2019) and characterized by many references including Ostrich and Kumar (2017), MIL-STD-464C (2010), NCC (2019), Radasky 2010), Pry(2017) and Wilson (2008). From these references, the following description of the three components is presented. The E1 waveform component is the fast, nanosecond rise-time, broad-band pulse, ~100 ns in duration. The E1 pulse has the greatest

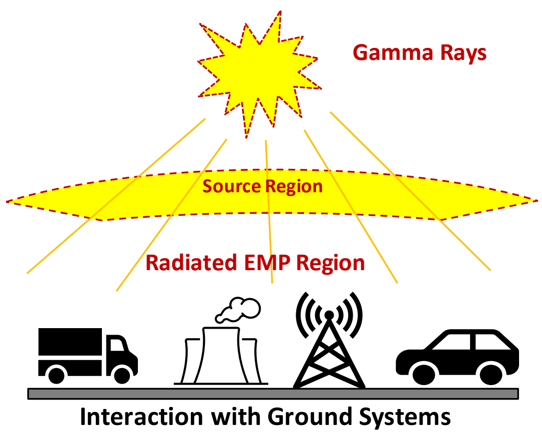

Figure 1 - High Altitude EMP (HEMP) Interactions (based on diagram from Emanuelson 2020-1)

Figure 2 - HEMP Coverage Area vs. Height of Burst (HOB) (Radasky and Savage (2010), Metatech, Corp.)

impact on “Individual Systems / Network” components as shown in **Figure 3**, and particular to this study, electronic sub-systems and components in transportation sector vehicles. The E2 pulse consists of two parts: E2A resulting from large-angle and multiple scattered prompt gamma radiation that take longer to

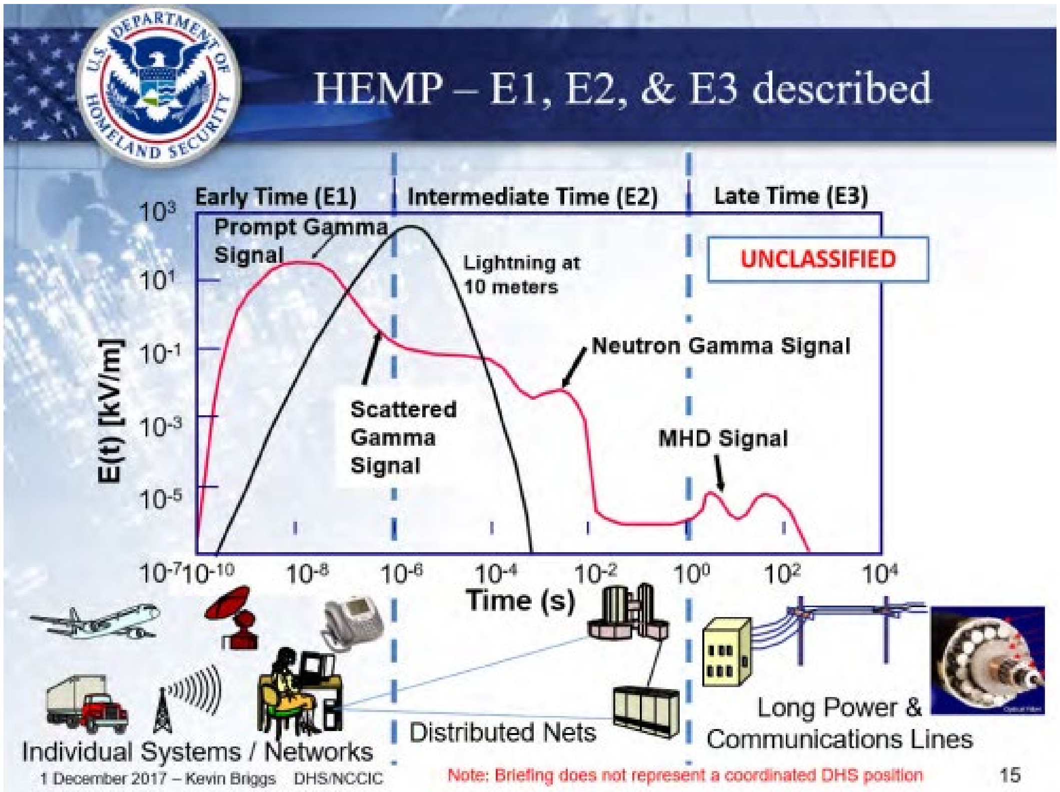

Figure 3 – Unclassified nominal HEMP Composite Environment, E1, E2, E3 (from NCC (2019), equivalent to Fig. a-5, MIL-STD-464C, Appendix A)

get to the source; and E2B caused by prompt neutrons creating secondary gammas through neutron scattering and capture with the air at ground level leading to secondary gammas. The E2 waveform is a longer, < 10 msec, lower amplitude pulse following the E1 waveform, having the greatest damage effects on “Distributed Network” components with frequency range that coincides with lightning strikes. The E3 waveform is a low-amplitude, long-duration pulse, persisting for 100’s of seconds inducing currents with most damage effects in long electric power grid distribution lines potentially damaging components like transformers and solid-state communication line drivers. E3 waveform effects are similar to solar geomagnetic disturbance effects. Geomagnetic effects do not have an E1 waveform component. The late E3 time pulse is caused by magneto hydrodynamic (MHD) effects which are very pronounced for high

altitudes above 200 Km. E3 can also be decomposed into two parts: E3 due to the blast originating from weapon debris generating a magnetic bubble propagating radially outward from the blast; and E3 due to the heave caused by heated ionized air produced by the blast rising through and distorting the geomagnetic field of the Earth. The potential damage effects of the E1, E2, and E3 HEMP waveform components are summarized in **Table 1** based on a similar table from Ostrich and Kumar (2017). For reference Geomagnetic Disturbance (GMD) effects are also included.

Table 1 - EMP vs. GMD Characteristics
(from information presented in similar table, Ostrich and Kumar (2017))

Attribute	EMP	GMD
Tactical Warning Time	None to Several minutes	20 to 45 minutes
E1, E2, E3 Effects (see **Figure 3**)	E1: High peak field, nanosecond rise time E2: Medium peak field E3: Low peak field	No E1 or E2 components E3: low peak field similar to EMP
Duration	E1: ~ 1 microsecond E2: ~ 10 milliseconds E3: 10 sec (blast) to 1-2 min. (heave)	E3: hours
Risks on equipment	E1: Telecommunications, micro-electronics equipment E2: Power lines, telecommunications tower components, transformers E3: Transformers, relays, long transmission lines, generator step-up transformers	E3: same as EMP E3 damage
Footprint	Regional to continental, depending upon the weapon characteristics, height of burst	Regional to worldwide, depending upon GMD event
Variability	Impact varies due to level of optimization and size of EMP weapon, height of burst, radial distance from ground zero	Intensity increases near large bodies of water & higher latitudes. Some events observed in southern latitudes

The physics on how the E1, E2, E3 EMP components are generated is further described by Andivahis et. al (2016). The source for a nuclear-generated EMP begins with the output from the nuclear weapon which generates neutrons, gamma rays and x-rays. The physical mechanisms responsible for generating various types of EMP depend on the height-of-burst (HOB) for a given nuclear EMP device, and how well the weapon is optimized for EMP. For high altitude bursts, HOB of 30– 400 km altitude, prompt gamma radiation interacts with air through Compton scattering (Parks 2015), the scattering of photons from electrons, generating a flux of high energy electrons called "Compton recoil electrons"

which transform into secondary electron-ion pairs. The Compton electrons move predominantly outward from the burst in a radial direction relative to the blast close to the speed of light giving rise to the Compton current. The secondary electron-ion pairs have no appreciable velocity relative to air compared to the Compton electrons, and as a result cause the air to be conductive as they drift within the electric field generated by the separation of charge formed by the Compton electrons moving radially away from the blast. The EMP is created as the electrons accelerate in a spiral path along the Earth's magnetic field lines creating transient electric fields and currents responsible for the electromagnetic pulse (EMP) at frequencies ranging between 100 KHz and 1 GHz traveling efficiently through the atmosphere. The large electric field in the range of 50-200 Kv/m can have devastating effects when coupled to electronic equipment components particularly those with semi-conductor components (Wilson (2008), Radasky and Savage (2010)), Radasky (2016, 2017).

The terminology for electromagnetic pulse (EMP) and high-altitude electromagnetic pulse (HEMP) are used interchangeably in this report. Both acronyms will be used per the reference material utilized and content in the particular section.

2.2 EMP Early History

The understanding of HEMP effects from high altitude nuclear weapon detonations began in the 1960's from tests conducted by the United States and the former Soviet Union (Radasky 2017 and NCC 2019). In 1962, the Fishbowl Starfish Prime HEMP test was conducted about 1400 km from Hawaii (**Figure 4**). A 1.4MT device was detonated 400 Km altitude HOB generating a ~14Kv/m electromagnetic pulse at Johnson Island, about 900 miles west of Oahu, HI. Fuses were damaged in ~300 streetlights in Oahu, telephone service microwave equipment were damaged, some car ignition systems failed, and burglar alarms were activated. Damage also occurred to the solar panels in many satellites, and high

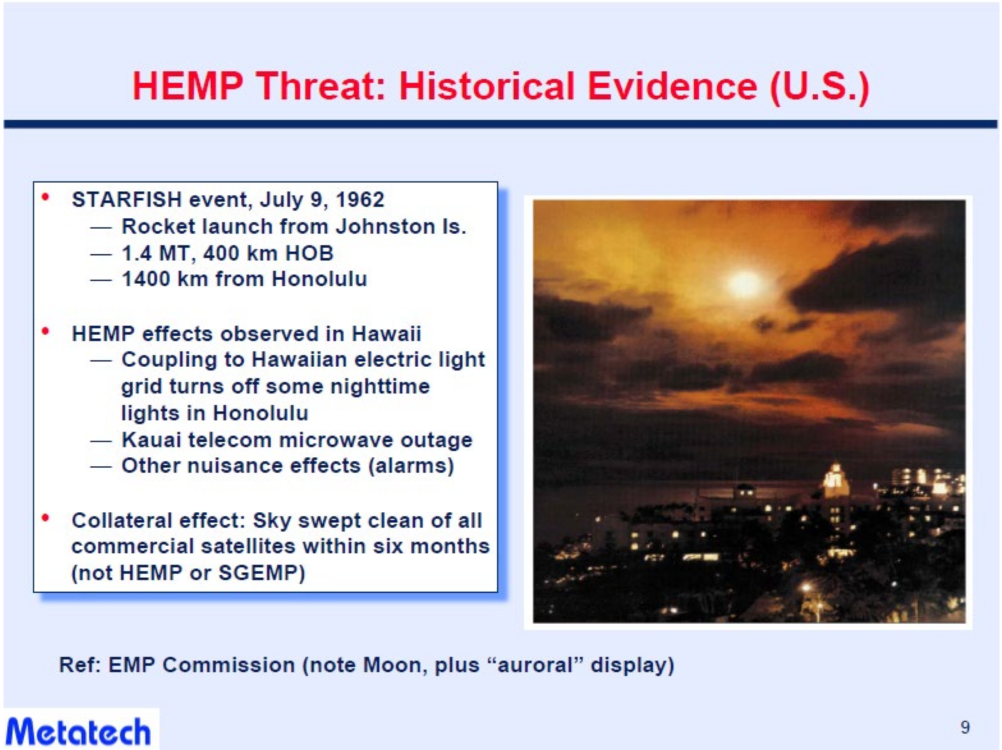

Figure 4 - U.S. Starfish Prime HEMP Tests, 1962
(from Radasky 2017, Metatech Corp.)

frequency radio communications were disrupted. The former Soviet Union also conducted HEMP tests in 1962 (**Figure 5**). A 300 kT nuclear weapon was deployed at 290 Km HOB. Overhead power and communications lines were damaged including puncture of high voltage transmission lines, damage to power supplies, damage to electric grid safety devices, and malfunction of radio equipment. Back-up diesel generators were also damaged.

More recent history has focused on the national security risk of state actors developing Super-EMP weapons with a variety of deployment scenarios. As discussed by both Pry (2017) and Schneider (2007), design and development of Super-EMP weapons focused on generation of gamma rays resulting in increased EMP E1 pulse amplitude, typically having low explosive yields in the range of 1-10 Kt. Peak EMP fields could reach 200 Kv/m at the center of the burst, and as high as 100 Kv/m at the radius margins (Pry 2017). The Congressional EMP Commission (2008) warned that Russia, China and likely North Korea have Super-EMP warheads. The 1-10 Kt size provides greater opportunity to package

compact size EMP weapons in a number of deployment devices such as an ICBM, short range missile, satellite, jet aircraft in zoom flight pattern, or a meteorological balloon.

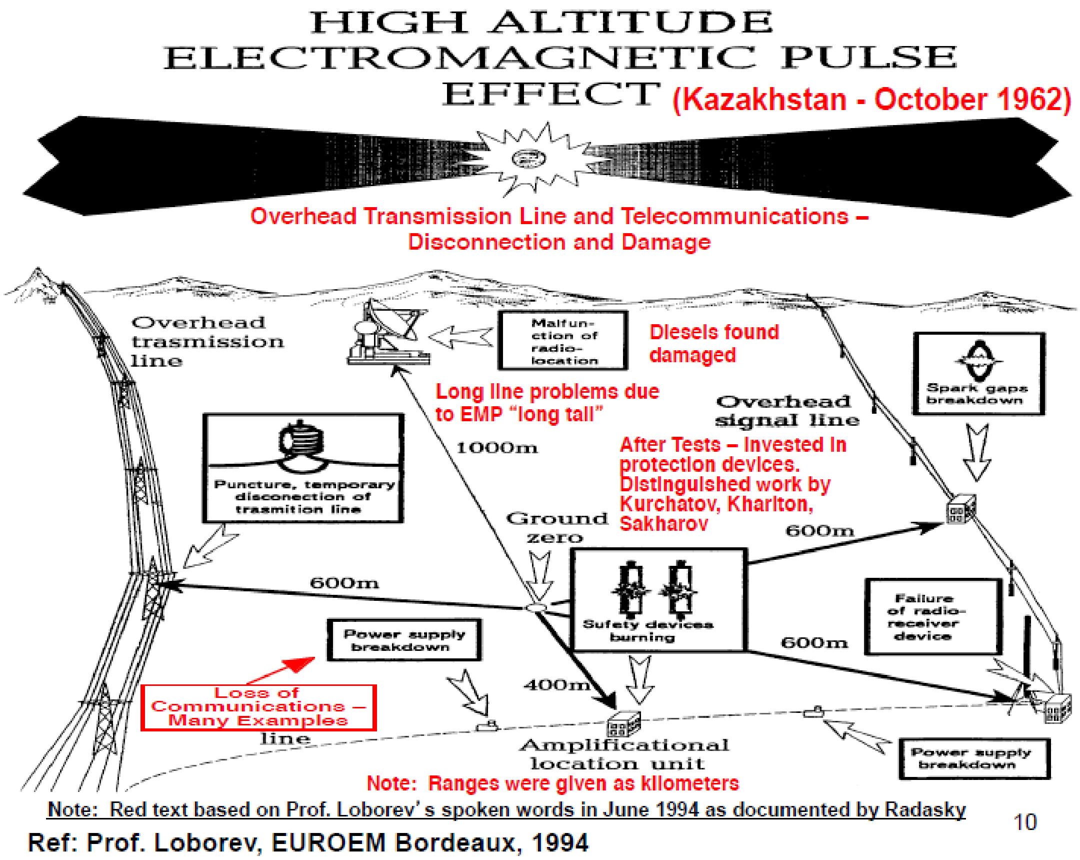

Figure 5 - Soviet K-3 Hemp Tests, 1962
(from Radasky 2017)

2.3 Threat Assessment

An EMP attack would be deployed with highest probability from a state actor whose ideologies or state policies desired to inflict damage and loss of life upon the United States or our allies. A lesser probability exists from terrorist organizations due to lack of technological capabilities for nuclear EMP WMDs, but not impossible per Pry (2017), Schneider (2007) and Allison (2010) if procurement or theft of the lower technology WMD devices and deployment means are considered. The threat assessment analysis was centered on the following topics:

- Who would initiate an attack, a terrorist organization or state actor?
- State actor EMP attack scenario generic description.
- State actor nuclear EMP capability summary.
- EMP attack example scenario summaries.

Although it is less likely a terrorist organization could deploy a nuclear weapon due to their inherent lack of the technological critical skill-sets, experts in national security forums conclude an EMP attack from a terrorist organization was not impossible and should be studied (Pry 2017, Schneider 2007). We are presently experiencing the 4th wave of terrorism in the world which is heavily focused on religious factors influencing the ideologies of terrorist organizations and their resultant political goals (Rasler and Thompson, 2009). The concern with terrorist organizations is their deeply rooted ideologies that can lead to future attack scenarios. For example, although al-Qaeda and ISIS have become dormant due to the strategic defense initiatives in the Mid-East over the past 20 years, patterns in communications from the past are important lessons learned for national security strategies in the future. Per Mowatt-Larssen and Allison (2010), the ideology of al-Qaeda always sought to find an improvised nuclear device (IND) that could yield a nuclear explosion in the form of a mushroom cloud over a US city with a sensational effect just like the 9/11 attack on the World Trade Center. Although the chance of al-Qaeda or ISIS obtaining a nuclear WMD was very small due to the complexities and cost in developing and delivering such a device, their continual desire to inflict such damage must be recognized. For example, the Fatwa issued

by Osama Bin Laden in 1998 (OBL 1998) that called for the killing of Americans, *"We -- with Allah's help -- call on every Muslim who believes in Allah and wishes to be rewarded to comply with Allah's order to kill the American and plunder their money wherever and whenever they find it."* This was known 3 years before 9/11, and our defense systems were not adjusted accordingly until the very unfortunate and tragic attack on September 11, 2001. Per House (2016), the brutality of ISIS and its underlying ideology was also a driving force to find and deploy CBRN weapons to expand its Caliphate with whatever means it can. Credible sources stated ISIS used chemical warfare agents in the past. Al Qaeda was experimenting with biological and chemical agents since the 1990's with social media posts documenting intentions to develop and deploy biological and chemical agents, and radiological dispersion devices (RDD)'s for dirty bombs. ISIS's ideology in employing CBRN weapons resembled the ideology of al-Qaeda that led to the 9/11 attack. Recently ISIS "sleeper cells" have undergone an insurgence against western forces and Iraqi soldiers taking advantage of the rising US-Iran tensions following the killing of Iranian General Soleimani, and in Syria against Kurdish fighters after Turkey began military operations against Kurdish forces in Northern Syria (Mroue 2020).

The points above show the strategies and end-effects of major terrorist organizations change, but their ideologies many times have similar underlying directives to kill Americans or our allies, inflicting damage with whatever resources can be made possible. Taken further, ideologies of terrorist organizations could be rooted in policies of state actors, or vice versa, creating dangerous situations where state actors have the technology to deploy complex weapons systems such as a nuclear EMP device with leaders in charge who have been infiltrated by radical ideologies of the terrorist organizations. Such ideologies and political goals could be rooted in a religious issue like the invasion of fundamental Islamic beliefs and customs by westerners, economic inequality and hardship caused by an adversary, or resentment from past political conflicts (Goodin 2009).

The primary focus in the threat assessment are scenarios where state actors would initiate an EMP attack based the understanding of present-day capabilities to manufacture the EMP optimized WMDs and multiple means of deployment. The diagram presented in **Figure 6** was created to illustrate the

arguments presented in the report by Pry (2017) and Schneider (2007) for EMP attack scenarios showing schematically how a state actor could potentially implement an EMP attack. For a particular regime and government leaders installed, the process begins to find paths to war and aggression versus paths to peace. Rationale is created for an EMP attack from a variety of political factors such as unification with a separated nation from a past conflict or political event. Some examples are:

- South Korea separated from North Korea after the Korean War;
- Taiwan separated from China; and,
- former Soviet states separated from Russia during the collapse of the former Soviet Union.

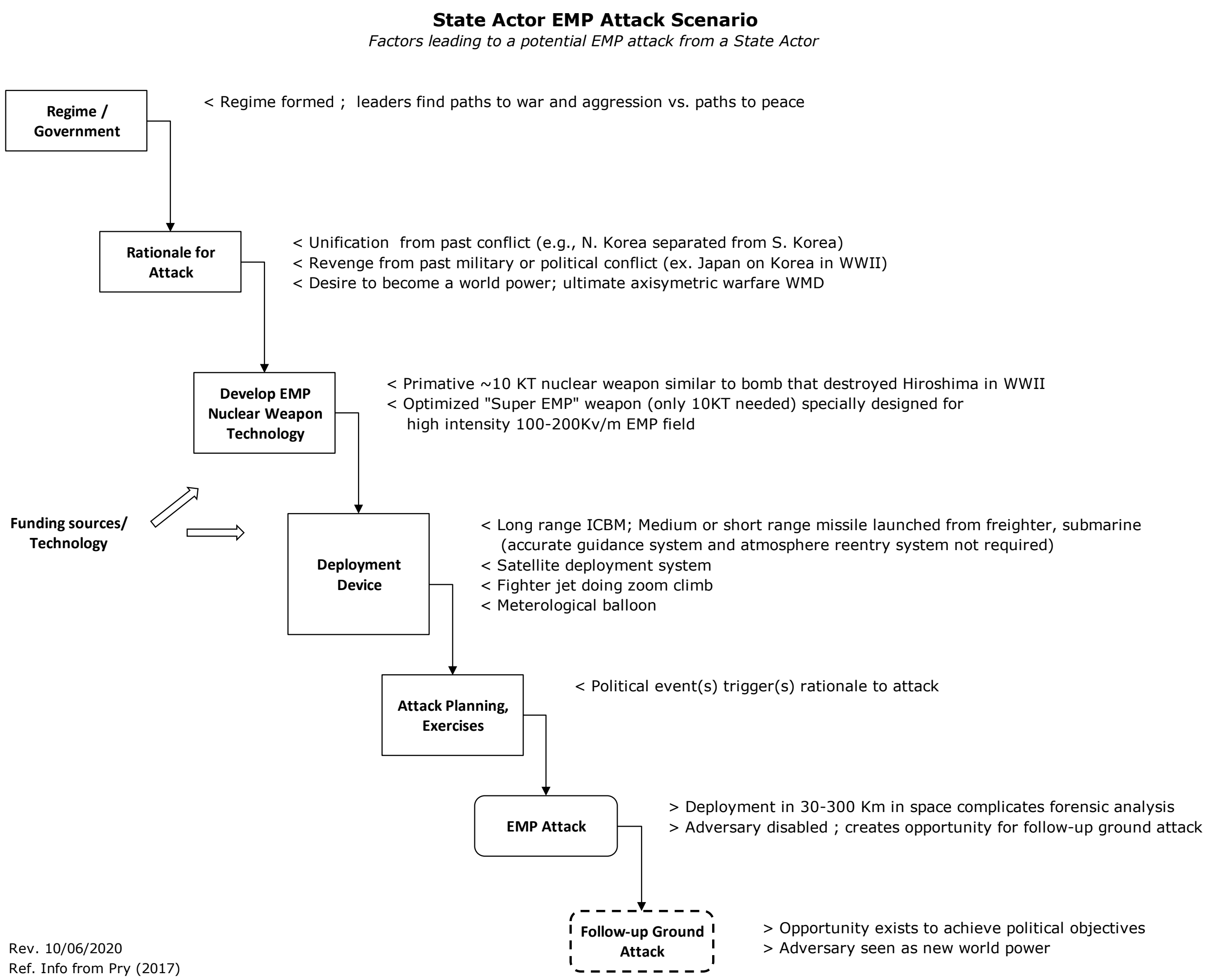

Figure 6 - State Actor EMP Attack Scenario
(based on Pry (2017) & Schneider (2007) reference info)

Other factors can also provide rationale such as revenge from past military conflicts such as the occupation of Korea by Japan during WWII, or the overall desire for a lesser nation to become a major world power. The technology is then developed for an EMP weapon and deployment device, all within the scope of a developed state actor regime having nuclear WMD manufacturing capability with means of deployment via inter-continental ballistic missiles (ICBMs), short range missiles, satellite deployment systems, meteorological balloons, or jet airliners placed on zoom-climb trajectories. The attack is planned with preceding exercises to assure success, for example, the north-south satellite trajectories presently exercised by North Korea over the U.S (Pry 2017). The EMP attack is then implemented disabling the critical infrastructure of the target nation leading the way to a successful ground attack and take over. Such a scenario offers an opportunity for a lesser status nation to inflict great damage on a super-power such as the United States or one of our allies, an asymmetric warfare ideal attack scenario. The attacking nation is then seen as a new world power.

Given the scenario discussed around the illustration presented in **Figure 6**, information from credible references (Schneider (2007), Pry (2017) and Albert (2019)) were used to summarize capabilities of potential state actors who could deploy EMP nuclear weapons as presented in **Table 2**. Additional support information on North Korea's capabilities was found in the report by Cordesman and Ayers (2017) to support information noted in **Table 2**. Capabilities to launch a nuclear EMP attack not only included the required technology to manufacture the weapons, but also a means of deployment. Results are illustrated for Russia, China, Iran, and North Korea. Not listed in the **Table 2** was Pakistan who also has nuclear weapons capability with some national security concerns. Pakistan, who nominally is a U.S. ally, has supported terrorist organizations in the past undermining U.S. policy objectives in the war on terrorism, in containing nuclear and missile proliferation, and in building positive relationships with Israel due to Israel's commercial and military cooperation with India (Pry 2017).

The information from the references is clear that capabilities exist which could be utilized in the deployment sequence described in **Figure 6**. The contents of **Table 2** present the capabilities summary.

Table 2 - State Actor Nuclear EMP Capability Summary
(from Pry (2017), Schneider (2007) and Albert (2019))

State Actor	**Capability Claimed**	**Evidence** *(Reference / Comments made)*	**Ref. No.***
Russia	Super EMP Weapons	• Russian Gen. Vladimir Slipchenko in military textbook Non-Contact Wars: ○ "nuclear EMP attack … a new way of warfare … greatest revolution in military affairs (RMA) in history…renders obsolete modern armies, navies and air forces." ○ "For the first time in history, small nations, even non-state actors can humble the most advanced nations on Earth."	2
		• Aleksy Vaschenko, "A Nuclear Response to America is Possible", Zavtra (Nov. 1, 2006): ○ "The Russian nuclear component relies on Super-EMP factor" ○ "Russian response to U.S. Nuclear blackmail" ○ Described effect of 300-400Km 10-MT detonation over U.S.	1, 2
		• Dr. Lowell Wood, U.S. House of Representatives Armed Services committee (intelligence information & published documents: ○ "Russia has continued to maintain the ability to launch a massive EMP attack on the United States…. " ○ "Soviet strategic strike forces characteristically have featured weaponry well-suited to efficient EMP generation over exceptionally wide areas…." ○ "EMP strike component exists today …. at its maximum Cold War strength".	1
China	EMP/Super-EMP Weapons	• Congressional Commission on the Threat to the United States from Electromagnetic Pulse (EMP): ○ "China and Russia have considered … nuclear attack options that …employ EMP as primary or sole means of attack." ○ " U.S. naval force coming to aid Taiwan against Chinese attack would have to be prepared for nuclear weapons/EMP"	1
		• Chung Chien, Taiwan Defense Review: ○ "China's PLA (People's Liberation Army) possesses matured vehicle carrying [a] low-yield nuclear weapon to detonate at the appropriate height, … battle-tested, Dong Fong-15 (M-9 for export) short range ballistic missile (SRBM)" ○ "Tandem nuclear EMP attack over Taiwan, could knock out an OISR system island wide…"	1
		• China's National Security Policy Committee article, "General Trend of the Worldwide Revolution in Military Affairs" (2016): ○ "electromagnetic pulse bombs …the new disruptive technologies ...can change the 'rules of the game …disrupting U.S. precision military capabilities"	2
		• PLA newspaper article: ○ "The U.S. is more vulnerable than any other country in the world" to attacks by EMP and Cyber Warfare" ○ "Could be the 'Pearl Harbor Incident' of the 21st century, surprise attack against enemy's crucial information systems of command, control, and communications"	1
Iran	EMP Weapons	• Military textbook, Passive Defense (2010): ○ Endorses the theories of Russian General Slipchenko and decisive effects of nuclear EMP attack to defeat an adversary	2

		• Iranian political-military journal, Electronics to Determine Fate Of Future Wars: ○ "key to defeating the United States is EMP attack …if world's industrial countries fail to devise effective ways to defend themselves….they will disintegrate within a few years"	2

		• International Atomic Energy Agency (IAEA) briefing (2005):
		  ○ "Iran designing Shahab-3 missile to deliver 'black box', … U.S. Nuclear weapons experts believe is a nuclear warhead"
		  ○ "…size, shape, weight and detonation height …make no sense for conventional explosives."
			1

		• The Daily Telegraph [U.K.] (2007):
		  ○ "Defense officials monitoring the growing co-operation between North Korea and Iran"
		  ○ "Iranians could be in a position to test fire a low-grade device — less than half a kiloton — within 12 months."
		  ○ "South Korean press reported that Iranians were invited to view the effects of the North Korean nuclear test."
			1

		• Jan. 2007, Major Gen. Amos Yadin, Chief of Israeli Intelligence: ○ "Iran will have a nuclear bomb within 2/1/2 years."	1
		• Report by Iranian news agency MEHR: ○ "Iran is violating international sanctions and going full bore to protect itself from a nuclear EMP attack."	
		• Ambassador Henry Cooper, former Director of the Strategic Defense Initiative: ○ "Iranian satellite launches appear to be practice for nuclear EMP attack on the U.S."	2

North Korea	EMP/ Super EMP Weapons	• Pry (2017) – Washington Post & Wall Street Journal refs.:
		  ○ On April 9, 2013, North Korea's KMS-3 satellite orbited the U.S. on a south to north polar trajectory to evade U.S. early warning radars and National Missile Defenses at optimum altitude and location for an EMP attack
		  ○ On April 16, 2013, the KMS-3 again orbited over the Washington, D.C.-New York City corridor where if armed with a nuclear warhead, the peak EMP field could impact the U.S. political and economic capitals and collapse the Eastern Grid (75 percent of U.S. electrical power)
		  ○ N. Korean satellites continue similar orbits over N. America today on trajectories optimized to evade U.S. Ballistic Missile Early warning systems for a surprise EMP attack.
			2

		• Statement, Office of the Director of National Intelligence (2006): ○ N. Korea's detonation of low-yield nuclear device October 2006, 1st rogue state with nuclear weapon capability.	1

		• Council on Foreign Relations (Albert 2019): o U.S. Intelligence officials believe N. Korea possesses as few as 10-30 nuclear weapons, some believe they have 30-60. o Regime has tested ICBMs capable of carrying large nuclear warhead. o Between 2006 to 2017, N. Korea has conducted 6 nuclear weapon tests. o Regime has know-how to produce bombs with weapons grade uranium or plutonium, core components of a nuclear weapon. o N. Korea's nuclear program has evolved internally with some assistance from China, Russia and Pakistan over the years	3
*Reference No. (see **Section 12** REFERENCES for complete listing): 1) Schneider (2007) 2) Pry (2017) 3) Albert (2019)			

Assuming the capabilities exist as illustrated in **Table 2**, specific examples of attack scenarios are presented in **Table 3** which were derived from the information from Schneider (2007) and Pry (2017) following the process illustrated by the diagram shown in **Figure 6.** For the specific examples presented, all nations in threat of being attacked likely-have national defense plans for traditional warfare and ground deployed CBRN WMDs. It is not clear what national security preparedness plans exist for a nuclear attack, and the vulnerability presented by an adversary having the nuclear EMP mode of attack in their military arsenal. It's the foundation of this report, building on the concerns raised by Pry (2017) and Schneider (2007), if the U.S. and its allies are to become prepared for an EMP attack, plans are needed to first understand the hazard risks associated with an EMP attack with modern-day transportation sector vehicles followed by proposals for mitigation measures that can be applied to ensure emergency management plans for EMP are successful.

Table 3 - EMP Attack Example Scenario Summaries
(based on information from Pry (2017) and Schneider (2007))

Scenario Example	Description	Comments	Ref. No.*
Iran Strikes Israel	Iran centers EMP attack on Jerusalem to destroy Israel enabling conquest of its territory and the Holy City.	Nuclear weapon detonated 30 Km over Jerusalem with extending EMP field to a 600 Km radius. Parts of Egypt (Cairo), Syria, Northern Saudi Arabia Western Iraq and nearly all of Lebanon and Jordon affected. Military ground attack on Israel follows.	2
		Schahab-3 short range ballistic missile could be used for deployment	1
Iran Strikes Israel and Egypt	EMP attack over Cairo results in knockout of Egypt and Israel sparing impact on most of Lebanon, Syria, Iraq, Saudi Arabia and Jordon.	Similar 30 Km HOB deployment as 1st scenario w/600 Km radius. EMP attack paralyzes Iran's enemies and spares its important allies.	2
Iran Strikes Saudi Arabia and the Gulf States	Iran centers EMP attack over Riyadh, Saudi Arabia,	Iran's main ideological rival in the Muslim world in the struggle between Shiites (Iran) and Sunnis (Saudi Arabia) is destroyed. Military ground attack follows.	2
Pakistan Strikes Israel	Similar deployment scenario as Iran attacking Israel.	Pakistan government hostile to Israel due to Israel's military and commercial cooperation with India, Pakistan's archenemy.	2
N. Korea Strikes S. Korea and Japan	N. Korea initiates EMP attack on Japan and S. Korea	3 Policy goals achieve: 1) reunification w/S. Korea; 2) revenge on Japan for its occupation of Korea during WWII; 3) recognition of N. Korea as a world power	2
N. Korea Strikes the United States	N. Korea initiates EMP attack on the continental U.S. via ICBM, short range ballistic missile or satellite	Taepo Dong missiles well known to the Washington national security community. Kim Jong-Un can no longer tolerate economic sanctions, and military exercises between U.S. and South Korea. Optimized nuclear EMP weapon delivered w/400 Km HOB with EMP field extending 2200 Km covering the US, most of Canada and Mexico. In 1 year, 9 out of 10 Americans dead from starvation, disease, and societal collapse.	1, 2
China Strikes Taiwan and the Philippines	China initiates EMP attack on Taiwan and the Philippines. 30 Km HOB spares China from the blast.	Three EMP pulse bombs from the mainland would cover the entire land area of Taiwan, destroying air defense in just a few minutes. A 4th bomb deployed 1200 miles east would keep the US forces at bay.	1, 2

		Military ground attack follows to reunify Taiwan to Mainland China, and to expand China's claim to the Philippines and the S. China Sea.	
Russia Strikes European NATO	Russia makes EMP attack on European NATO to paralyze military capabilities	US and European governments are deterred to interfere while Moscow annexes Ukraine and the Baltic States to reconstitute the former Soviet Union. Putin contends the disintegration of the former Soviet Union was "the greatest geopolitical catastrophe of the century"	2
Russia Strikes the United States	Russia attacks the U.S. in retaliation for U.S. retaliation against Russia for attacking NATO to all0w for annexation of the Baltic states	Russian submarines deploy super EMP warheads to paralyze US strategic and general purpose forces and black-out the national grid. 14 EMP bursts at 30-100 Km HOB to maximize EMP field strength centered on 14 U.S. strategic military targets.	2
EMP World War Against the West	Russia, China and No. Korea and Iran issue coordinated EMP attack on all western nations.	Coordinated EMP attack to disable the US, Canada, Mexico European NATO, Israel and Egypt.	2
ISIS Strikes Italy (2017 scenario)	ISIS or a future well funded terrorist organization purchases an EMP weapon from N. Korea and deploys via a crude Scud missile	Attack on the Vatican, consistent with the ISIS apocalyptic worldview to destroy the world's false religions, Catholicism a icon of Western Christian religions	2
* Reference No. (see **Section 12** REFERENCES for complete listing): 1) Schneider (2007) 2) Pry (2017)			

Although unlikely due to lack of technology, Pry (2017), Schneider (2008) and Allison (2010) contend the probability for a terrorist organization initiating a WMD EMP attack is small, but not zero, and should be considered. The diagram presented in **Figure 7** was created to illustrate the arguments presented by Pry (2017) in the report "The (Congressional) Commission to Assess the Treat to the United States from Electromagnetic Pulse (EMP) Attack" on how a state actors or terrorist groups could potentially implement an EMP attack. Following the staircase flowchart in **Figure 7,** the terrorist group is formed with their ideologies and political goals, the desire for attack is created, and the planning process begins utilizing any means possible consistent with asymmetric warfare principles. If sufficient wealth is possessed by the terrorist group such as ISIS in the 2014-2019 timeframe, a state actor in grave financial need who has the nuclear EMP capability such as North Korea sells the EMP weapon to the

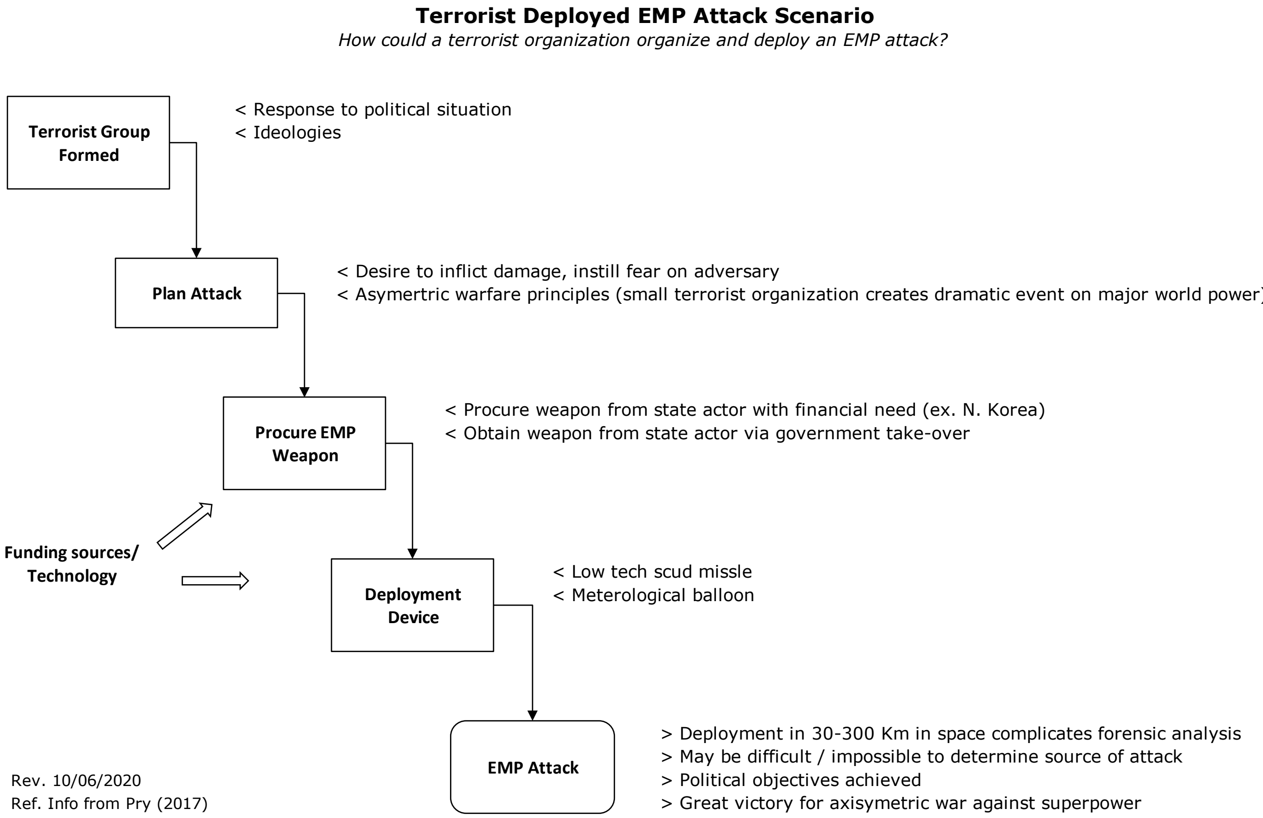

Figure 7 - Terrorist Deployed EMP WMD Attack Scenario

terrorist group. A deployment device is obtained (purchased or stolen) having technology compatible with the terrorist group such as a low-tech Scud missile, or a meteorological balloon. The EMP device is then deployed at least 30 Km above the earth to inflict damage on a potential adversary yielding great victory in axisymmetric warfare against a superpower.

The threat and vulnerability analysis discussed above, and the recent Presidential executive order (White House 2019) and FY2020 NDAA legislation (Gertz 2020) illustrate the importance in this investigation on how the transportation sector vehicle critical infrastructure should be improved to become more resilient to an EMP attack from potential adversaries.

3 LITERATURE REVIEW

The literature review provided information on the impact of EMP to the overall critical infrastructure in the U.S. that served as the foundation for the hazards risk analysis and proposed mitigation measures for transportation sector vehicles. Logistics factors in the emergency management plan discussed in **Section 8.0** depended on many elements of the overall critical infrastructure to assure success of mitigation measures for transportation sector vehicles supporting emergency services and delivery of lifeline supplies to the public in the event of an EMP attack. Focus areas reviewed included the following:

- Overview of EMP impact to critical infrastructure in the US;
- Key reference review of literature on EMP; and
- Response-readiness assessment for transportation sector vehicles.

3.1 Overview of EMP Impact to Critical Infrastructure in the US

The review of EMP impact to critical infrastructure helped place the impact of EMP to transportation sector vehicles into perspective with the remainder of the critical infrastructure. One of the most significant reports were the EMP Commission Reports issued to the United States Government assessing the impact of EMP to critical lifeline infrastructure in the U.S. (EMP Commission (2004, 2008)). For different segments of critical infrastructure, the reader is encouraged to relate non-transportation sector infrastructure components to those in the transportation sector since many times interactions will exist where one section of critical infrastructure is mutually dependent on another components. For example, with transportation vehicles, gasoline and diesel fuel supplies needed to keep the transportation vehicles operating require electrical power to pump the gasoline out of the ground at fuel filling stations which could be compromised, in the case of an EMP attack, by a multi-day, multi-week or multi-month power outage.

3.1.1 EMP Impact on Critical Infrastructure Components (EMP Commission Report)

In sections **3.1.1.1** to **3.1.1.13** the results of the EMP Commission Report (EMP Commission (2008)) are be presented. Although not directly addressing transportation vehicles other than section **3.1.1.6**, transportation vehicles support all critical infrastructure components in some way, and lessons learned on vehicle damage assessments and mitigation measures may be applicable to the particular infrastructure area. Conversely, sections of the critical infrastructure also support operation of transportation sector vehicles such as the electric grid for electrical power, and petroleum refineries to maintain fuel supplies and means of delivery to customers at fuel stations.

3.1.1.1 Infrastructure Commonalities

The EMP Commission (2008) were the first to point out that many parts of the infrastructure contain similar or common subsystem elements. For example, microprocessor-based process control systems such as SCADA systems, an acronym for Supervisory Control and Data Acquisition Systems, Digital Control Systems (DCS), and Programmable Logic Controllers (PLCs) reside in nearly all aspects of the U.S. critical infrastructure. SCADAs are used in the electric grid to adjust for load demands. SCADAs are also used for process controls in the natural gas and liquid fuel delivery distribution systems, manufacturing systems for petroleum and natural gas, water treatment and delivery systems, and sewage treatment systems. If sufficient commonality exists among the variants of SCADA systems used for process controls, and if these systems by design are vulnerable to an EMP attack, then the imposition of the E1/E2/E3 waveform described previously could have disabling effects on the SCADA systems supporting process control equipment within the U.S. critical infrastructure.

3.1.1.2 Electric Power

The electric grid infrastructure consists of power generation equipment, transmission system equipment (high voltage lines for long distances), and distribution systems.

- Generation systems in the power plants or even alternative sources of energy supply have increased reliance on electronics and microprocessor components. The E1 pulse can upset protection systems, and the SCADA grid control systems.
- Transformers and relays are likely to be vulnerable to EMP power surges. The E1 pulse is likely to disrupt and damage relays. E3 can inflict damage in the high value transformer equipment which are often unique with few spares in storage, and long lead times to manufacture taking months or years to replace.
- In the Distribution system, the E1 pulse from EMP can induce arcs across insulators separating power lines from supporting wood poles and trees causing shorts and fires.

The efforts to understand the impact of EMP to critical U.S. infrastructure, and the development of proposed mitigation measures has been most active and mature for the electric grid. The EMP Commission (2008) report developed significant recommendations. The InfraGard EMP Special Interest Group (INFRAGARD 2016) conducted a similar study with a very thorough set of EMP mitigation proposals for the electric grid to bring the resilience of the grid to an EMP attack to an acceptable level.

3.1.1.3 Telecommunications Systems

All modern civilian communications devices are at risk due to an EMP attack. The following recommendations were introduced to improve resilience in telecommunications equipment to EMP.

- Evolve critical National Security and Emergency Preparedness (NS/EP) telecommunications to incorporate new technologies that improve EMP resilience to an acceptable level.
- Improve the ability of services to function for extended periods without primary power in the event of extended down-time from the electric grid.
- Address infrastructure interdependency impacts in contingency planning, i.e. interdependencies affecting telecommunications systems; develop business continuity plans to improve resilience of these systems to disruptions.

- Identify critical telecommunications applications that must survive an EMP attack and address shortfalls with mitigation measures.

3.1.1.4 Banking and Finance

Business continuity (BC) plans in the banking and finance organizations must include EMP attack as one of the risks that can impact continuity of the business. BC principles such as those discussed by Hiles (2014) need to consider EMP in addition to cyberattacks in the analyses and business impact analyses (BIAs). Once these risks are understood, the principles of business continuity planning can assist organizations in designing business continuity management (BCM) plans that will incorporate EMP attack as a risk with appropriate mitigation measures.

3.1.1.5 Petroleum and Natural Gas

37 % of domestic energy usage in the United States is derived from Petroleum, and 31% from Natural Gas (EIA 2019). Per EMP Commission (2008), the infrastructure to support petroleum and natural gas refining vulnerable to an EMP attack is shown in **Figure 8** with the following components:

1) The petroleum supply consists of oil wells, and delivery of petroleum crude via sea or by land (pipeline) to the refineries;
2) The refinery infrastructure to process crude oil contains many SCADA controllers.
3) Storage systems exist to retain processed fuel prior to delivery to the customers; and,
4) The distribution system delivers processed petroleum products to customers via land by commercial trucks, or by sea via freighters. Processed petroleum products include jet fuel, home heating oil, off-road diesel fuel, gasoline and diesel fuel for over the road transportation vehicles, propane and petrochemicals.

Similarly, per EMP Commission (2008), the natural gas infrastructure vulnerable to EMP is shown in **Figure 9** and has the following components:

1) The natural gas supply originates wells delivered to refineries by pipeline.

2) Infrastructure within refineries to process the natural gas also contains many SCADA controllers similar to petroleum refining.

3) Storage facilities to satisfy customer demands; and,

4) A pipeline distribution system exists to deliver natural gas to the various residential, commercial, industrial and electric power generation customers.

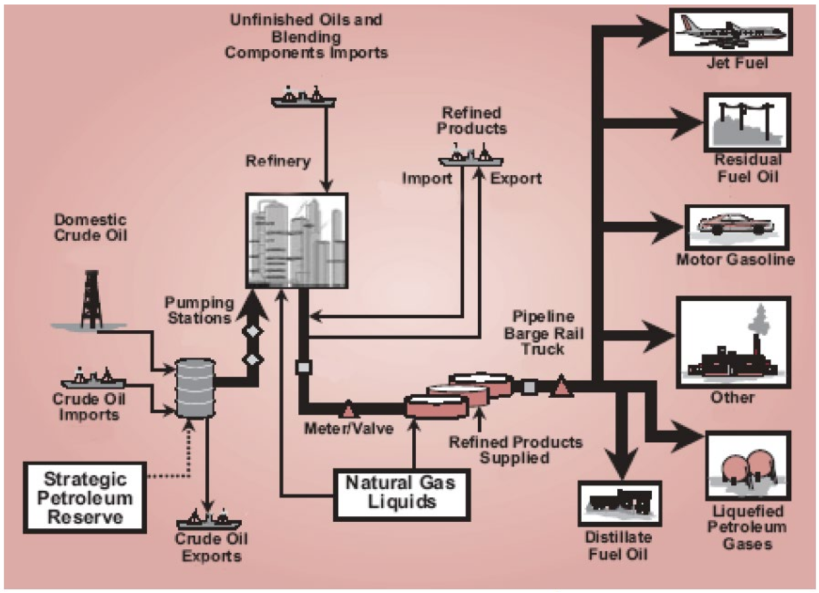

Figure 8 - Schematic of Petroleum Infrastructure (Fig. 5.1 from EMP Commission (2008))

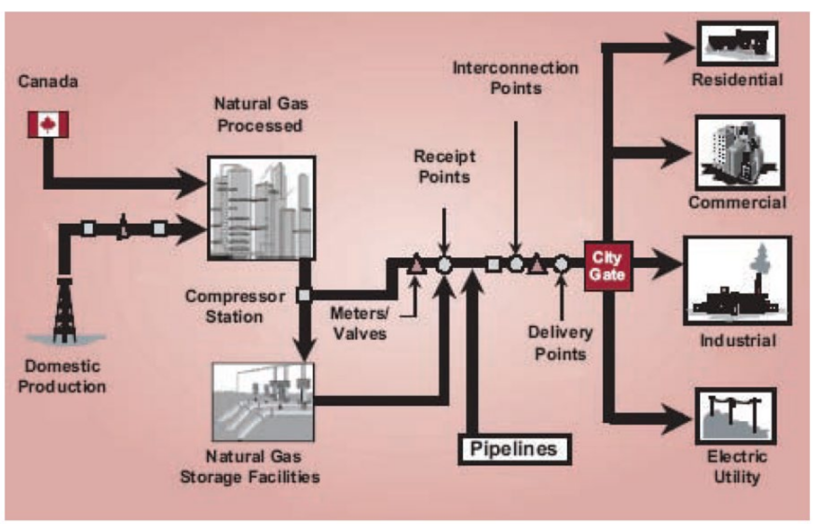

Figure 9 - Natural Gas Infrastructure (from EMP Commission (2008))

Petroleum and natural gas infrastructure are both vulnerable to an EMP attack in areas interrelated to each other (EMP Commission (2008)):

- EMP damage to processing equipment inside facilities such as pumps, SCADA systems, various microprocessor based sub-systems, sensors, and plant processing control data centers.
- Interruption of supplies and raw materials delivered to the refineries due to damage to the transportation system infrastructure.

Because the refineries are damaged, processed fuel delivery to customers could also be interrupted which will affect how fast the transportation infrastructure can be rebuilt after an EMP attack.

3.1.1.6 Transportation Infrastructure

Vulnerability of the transportation infrastructure was investigated in the EMP Commission (2008) report. The following components were studied:

- Long Haul Railroad- responsible for shipment of coal, chemicals, farm products, minerals, food products and other lifeline supplies.
- Locomotives – for personal transportation, e.g., AMTRAK, etc.
- Commuter Trains (not part of EMP report) – present in most major metropolitan areas of the US
- Automobile and Trucking Infrastructure (focus area for the **5.0** Methodology, **6.0** Test Plan and Risk Analysis, **7.0** Mitigation, and **8.0** Emergency Management sections):
    - Trucking industry:
        - Delivery of lifeline supplies to distribution centers, warehouses, and grocery stores;
        - Fuel delivered to metro areas to service stations and homes for home heating oil, propane; and,
        - Specialty vehicles for garbage removal, utility repair trucks, fire equipment.
    - Automobiles:
        - Personal transportation vehicles.

    - Traffic signals and the associated traffic controller electronics.

EMP Commission (2008) highlighted the following areas of vulnerability due to an EMP attack.

- Long Haul Locomotives/Locomotives vulnerabilities:
    - Damage to railroad control centers, e.g., CSX Corporation control centers, that rely on IT equipment and current-off-the-shelf (COTS) equipment not hardened for EMP;
    - Controls components for diesel generators used for back-up power;
    - Railroad control signal hardware not hardened for EMP (only 20% of population are pre-microprocessor era designs); and,
    - Microprocessor hardware for traction control and electric brakes used in 80% of modern locomotives (20% are pre-microprocessor age).
- Automobile and Trucking Infrastructure vulnerabilities:
    - Damage to numerous microprocessors, sensor and actuator components used for the engine and transmission powertrain electronic control unit (ECU), and numerous peripheral microprocessors used for other vehicle functions; and,
    - Failure of electronic traffic signals and subsequent traffic congestion (80% of signalized intersections utilize a Type 170E controller not hardened for EMP).

Tests were conducted in an EMP simulation laboratory in 2004 for automotive vehicles, the only significant test data set to date. The tests were conducted with the following parameters and corresponding observations:

- Automobile model years from 1982 to 2002;
- Automobiles subjected to EMP environments up to 50 Kv/m in both turned-on and turned-off running states;
- No effects observed in vehicles turned-off;
- For vehicles turned-on, 3 cars stopped running after field strength of 30 Kv/m was applied; and,
- Dashboard in one vehicle was damaged and required repair.

Tests were also conducted on 18 trucks for model years 1991 to 2003:

- Of the trucks not running during the EMP test, none were affected by the 50 Kv/m electric field;
- 13 of the 18 trucks exhibited a response while engine was turned-on;
- Two could be restarted immediately; and,
- One required towing to a garage for repair.

Since 2003, there has been a significant increase in the level of electronics and microprocessor-based systems present in automobiles and trucks. The prior tests were conducted up to 50 Kv/m (EMP Commission (2008)). Data in the literature suggest EMP levels up to 200 Kv/m could be experienced by an optimized EMP nuclear device per national security reports by Wilson (2008), Schneider (2008), and Pry (2017). Future EMP lab tests are needed to assess damage effects of EMP by varying EMP strength levels, employing more recent model year, "electronics-heavy" vehicles, and imposing EMP consistent with the latest 50-200Kv/m range discussed in recent national security reports. Discussion on the future proposed testing will the subject area in the **Section 6.0** Test Plan and Risk Analysis section.

3.1.1.7 Maritime Shipping

Maritime shipping infrastructure consists of the maritime shipping vessels, and the port operations infrastructure. Vulnerability should exist in the ship's control rooms which have significant electronics content for propulsion control, navigation and communication. The greatest concerns are in the ports that contain the following components that could be vulnerable to EMP (EMP Commission (2008)):

- Cranes in seaports that utilize over 100 microprocessors and sensors are not hardened for EMP;
- For spare parts, no plans are in place in anticipation of an EMP attack;
- Terminals that utilize an assortment of diesel and diesel/electric powered equipment called Rubber Tire Gantries (RTGs) to move containers; and,
- Central computer server information systems or local microprocessor based systems that store information on shipping container content.

3.1.1.8 Commercial Aviation

Per the EMP Commission (2008) report, the commercial aviation infrastructure could also be vulnerable to EMP. Briefly, areas of vulnerability are noted below:

- For the aircraft, increased use of microprocessors and electronic components for flight control could result in failures in aircraft while in flight or while being staged for flight on the ground;
- Ground based support equipment will be vulnerable; and,
- Air traffic control equipment may not be fully hardened to EMP and may be vulnerable.

3.1.1.9 Food Infrastructure

Per the EMP Commission (2008) report, the vulnerabilities in the food infrastructure are in the following areas:

- Potential damage to off-road transportation vehicles: tractors, harvesters, planters, etc.;
- Food processing equipment that could contain SCADA or similar controllers.
- Refrigeration warehouses; and,
- Distribution systems to get food to grocery stores which is heavily dependent on over-the-road commercial truck transportation infrastructure.

As one can imagine, disruption to the food infrastructure system will create great chaos in the US, resulting in violence, deaths, starvation, and loss of government control. Additional discussion on the food infrastructure and logistics in response and recovery will be discussed in **Section 3.2.5** on vehicle usage logistics for delivery of lifeline supplies and in **Section 8.0** on Emergency management plans.

3.1.1.10 Water Infrastructure

Drinking water infrastructure is dependent on the electric grid for running water purification equipment, i.e. pumps and miscellaneous machinery (EMP Commission (2008)). SCADAs which are not hardened are used extensively in water treatment systems, and as discussed previously, will likely be

affected by an EMP attack. Additional components that can be vulnerable include any electrically driven pump, valves, filters, and process control systems (includes SCADAs).

3.1.1.11 Emergency Services.

Emergency services system's vulnerabilities could involve many different components due to significant dependency on electronics. Shown in **Figure 10** are the major components of a typical emergency services response and communication system. Vulnerabilities to EMP exist in the following areas (EMP Commission (2008)):

- Police vehicles;
- Fire trucks;
- EMS vehicles;
- The Public Safety Answering Point (PSAPS) dispatch and radio network systems; and,
- Computer and communication equipment that's part of the city or township's emergency operations system.

In light of major components involved, EMP vulnerabilities and concerns with emergency service systems are highlighted as follows:

- Majority of emergency service equipment is not hardened for EMP; and,
- Even though emergency service equipment have been designed for dense electromagnet environments from radio, television, wireless communications, radar and other man-made sources, they do rely on radios to transmit and receive voice and message traffic using many frequencies contained in EMP radiation fields.

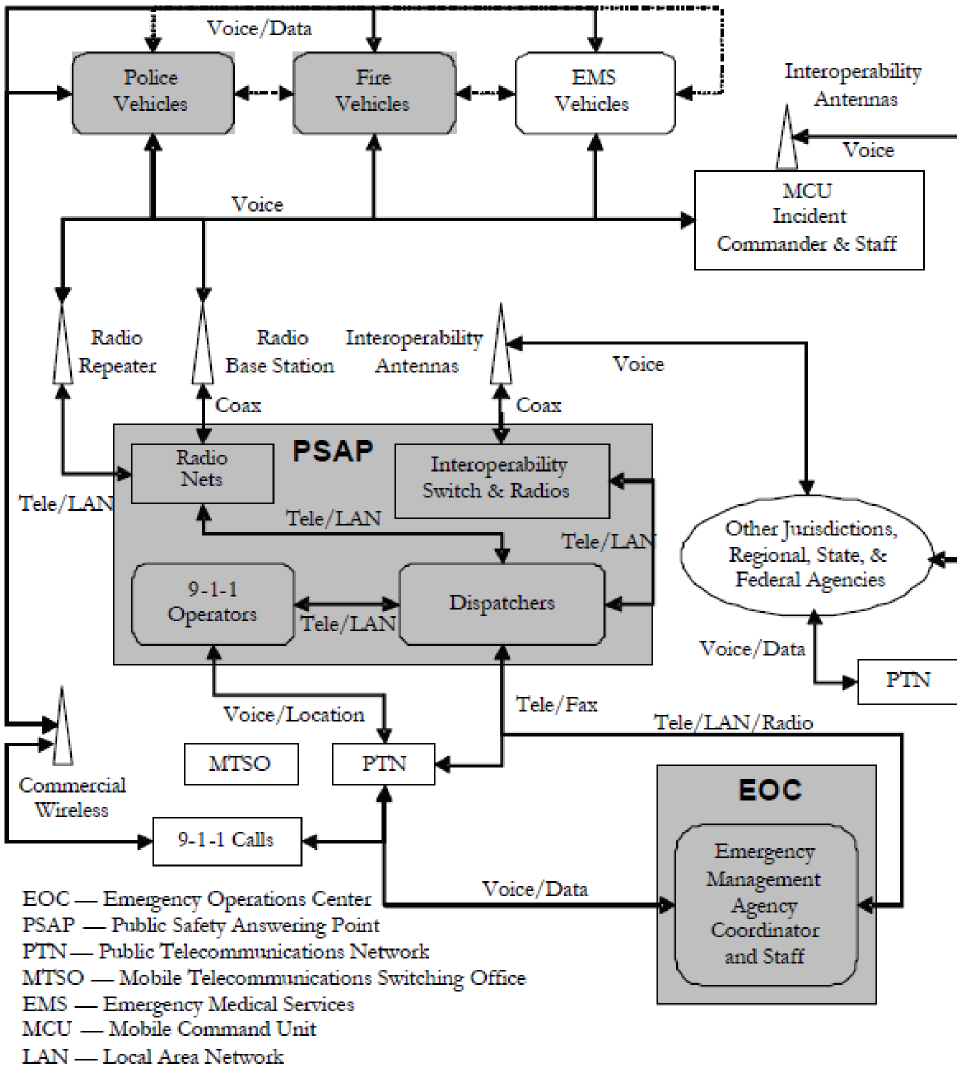

Figure 10 - Generic Modern Emergency Services System
(Fig. 9-1 from EMP Commission (2008) Report)

3.1.1.12 Space Systems

Two classes of EMP effects that are primary threats to satellites in space (EMP Commission (2008)):

- Direct line of sight exposure to nuclear radiation pulses, i.e. x-rays, ultraviolet, gamma rays, neutron pulses; and,
- Chronic exposure to enhanced high energy electrons trapped in the Earth's magnetic field.

The first high altitude nuclear tests were conducted in the 60's where 1st insights were obtained to a high altitude EMP device. The U.S. detonated a 1.4-megaton (MT) STARFISH2 device on July 9, 1962, at 400

km altitude **Figure 11** shows photographic images of each explosion which showed very different phenomena and enhancements of the radiation belts.

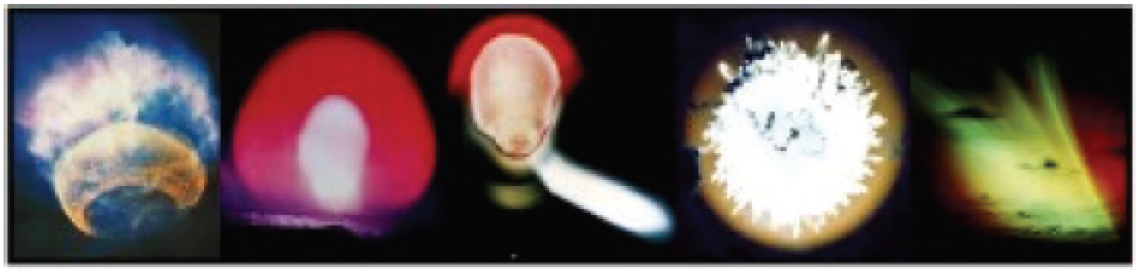

Figure 10-1. From left to right, the ORANGE, TEAK, KINGFISH, CHECKMATE, and STARFISH high-altitude nuclear tests conducted in 1958 and 1962 by the United States near Johnston Island in the mid-Pacific. *Burst conditions for each were unique, and each produced strikingly different phenomena and different enhancements of the radiation belts.*

Figure 11 - High Altitude Nuclear Tests by the US in the 60's
(Fig. 10-1 from EMP Commission (2008) Report)

Satellite's orbits are optimized for intended missions:

- LEO orbit satellites, 200-2000 km altitude; satellites enable remote sensing, weather data collection, and telephony.
- GEO orbit satellites, 36,000 km, in the equatorial plane; satellites' 24 hr orbit matches rotation of the Earth; used for communications & monitoring of large-scale weather patterns
- HEO orbit satellites, highly elliptical orbits; perform specialized functions, wide area communications for several hrs. at a time

An adversary possessing lift and orbiting control capability can destroy a satellite. Any combination of hardening and mitigation measures can be selected to achieve the required degree of survivability. An EMP attack on any of the several key geographical regions could cause serious damage to LEO satellites. It was recommended in the study that the government agency or commercial customer that acquires the particular satellite assess the significance of the space system, particularly in LEO orbits, and apply the appropriate hardening and mitigation measures for EMP to protect the assets at the desired level for that particular satellite device and its mission.

3.1.1.13 Government, Keeping Citizens Informed

It is essential that Government continues to function through an electromagnetic pulse (EMP) emergency. The EMP Commission (2008) issued the following recommendations to the US Government:

- The Department of Homeland Security (DHS) prioritize measures that to ensure the President and other senior Federal officials can exercise informed leadership in the aftermath of an EMP attack.
- The President and other senior Federal officials must be able to manage national recovery in an informed and reliable manner.
- The DHS, working through the Homeland Security Council, should give high priority to identifying and achieving the minimum level of robust connectivity needed for recovery following an EMP attack. By working with state authorities and the private sector, DHC should draft protocols for implementation by emergency and other government responses following an EMP attack, “Red Team” these extensively, and validate through development and issuing of standards, training, and exercises.

In retrospect, the manifestation of these recommendations have been elevated in importance to the Government via the 2019 Executive Order and FY2020 National Defense Authorization Act (NDAA) (Gertz 2020). In support of the investigation for the transportation sector vehicles in this report, it was encouraging to see the results of the EMP Commission and other related EMP studies were recognized, and at least now a firm direction has been instituted by the Government to address the EMP threat more seriously.

3.1.2 HEMP and HPM Device Threat Assessment (CRS Report for Congress)

The report to Congress from the Congressional Research Service by Wilson (2008) offered more insight to the high altitude EMP (HEMP) threat assessment with added comments regarding threats from High Power Microwaves (HPM). The report was intended to complement the EMP Commission (2008) report. US Military weapons and control systems are becoming more complex and more reliant on U.S. civilian infrastructure which is not hardened for EMP. Depending on the targeted area and power of the EMP attack, recovery times could take years for the US to recover if widespread damage is incurred to electronics systems and the electric power grid.

Wilson (2008) provided a more complete perspective of the physics of HEMP and HPM explosions and various deployment scenarios related to a national security threat. Per earlier discussions in **Section 2.1**, high altitude nuclear explosions create an electromagnetic pulse (EMP) with 3 components, the E1 < 1 usec energy shockwave, the E2 component similar to a lightning strike, and a third E3 long lasting magnetohydrodynamic (MHD) signal lasting from 1 msec to many seconds in duration. A HPM pulse can be generated by a powerful chemical detonation transformed through a special coil device called a flux compression generator to generate an intense electric field. HPM devices tend to be mechanically simpler than HEMP devices, and compact suit-case size that could more easily be deployed by less sophisticated actors such as terrorist groups who do not have the skillsets and facilities to product and deliver a HEMP nuclear device. A HEMP attack on the U.S. continent via a 10-1000 Kt nuclear warhead, centrally deployed 300-400 km over the US would require a ballistic missile for widespread damage area. A 1 to 10 Kt warhead launched from the deck of a freighter using a short range ballistic missile to an altitude of ~30 km could be used to target a smaller coastal area of the U.S.. Both HEMP and HPM weapons have the capability to immobilize vehicles with modern electronics ignition and control system equipment.

Unique data were also presented in the report by Wilson (2008). A study by Sage et al (2007) created damage assessments shown in **Table 4** for a HEMP device deployed over the Baltimore-Washington-Richmond area based on estimates accepted by a broad range of EMP experts. Depending

on whether a “Mid-Case” or “High-Case” scenario is assumed, damage estimates for Electric Grid, communications systems, SCADAs and misc. electronics equipment such as vehicle electronics range from 20-70% of the population with 5-33 months for repairs or replacement times. For repairs, Wilson (2008) commented it’s recognized that given sufficient wide area damage, available spare parts supplies can be exhausted quickly, and availability of skilled labor and spare parts to conduct the repairs will be in short supply with significant ranges of replacement times as shown in **Table 4**.

Table 4 - Estimated Damage and Recovery Times After HEMP Attack on Washington D.C. Area (Table 1 from Wilson (2008))

	Percentage of Capacity Damaged			Midpoint of Replacement Times (months)		
Infrastructure	**Low Case**	**Mid Case**	**High Case**	**Low Case**	**Mid Case**	**High Case**
Electric grid						
Transformers	10%	40%	70%	2.5	13.5	33.0
Other	30%	40%	50%	1.5	5.0	10.0
Communications systems						
Large	10%	20%	50%	4.0	18.0	27.0
Small	5%	20%	50%	2.0	12.0	17.0
SCADA						
All types	5%	20%	50%	1.5	5.0	10.0
Electronics						
Large	20%	45%	70%	4.0	12.0	17.0
Small	1%	2%	3%	1.5	5.0	10.0

Source: Instant Access Networks and Sage Policy Group, “Initial Economic Assessment of Electromagnetic Pulse (EMP) Impact upon the Baltimore-Washington-Richmond Region,” September 10, 2007, Exhibit 2, p. 5, at [http://www.pti.org/docs-safety/EMPecon_9-07.pdf].

The nature of EMP damage was also discussed along with mitigation measures (Wilson 2008, p. crs-13). The EMP surge from a powerful nuclear blast could yield an electric field of 200 Kv/m, 4x the level used in the hardening tests conducted by the 2008 EMP commission for transportation vehicles suggesting when tests are re-run, higher field strengths at these levels should be part of the test matrix. Wilson (2008) commented a recent Russian report in the literature on “Super-EMP Weapons” confirmed the 200 Kv/m EMP levels.

Wilson (2008) provided a useful description of the EMP field and its impact on electronics systems were also discussed. For example, an EMP field of 200 Kv/m will generate 200 Kv for every 1 meter of exposed electrical conductive object. If an object is 2 m long, 400 Kv will be generated; for a 0.5 m object, 100 Kv will be generated. These comments were relevant when considering mitigation actions particularly for vehicles utilizing microprocessor engine and transmission controls and electronic actuators and sensors. If a Faraday cage shield is used surrounding the microprocessor, any conductors running in and out of the cage could act as antennae and conduct a shockwave through the equipment. Specially designed surge protectors, termination procedures and isolated transformers may be required to serve as electrical filters. More discussion on surge protection will be introduced in **Section 7.0** on Methodology.

The report to Congress, Wilson (2008) also reinforced the threat assessment that several potential US adversaries such as Russia and China are capable of launching a crippling HEMP strike against the US. Other nations such as North Korea were developing the capability. Iran in 2005 reportedly purchased several medium and intermediate range ballistic missiles from North Korea with a range of 2500 miles. HPM weapons are simpler in design and can be built with materials and chemical explosives easy to obtain. Suitcase sized HPM devices powerful enough to destroy electronic facilities are available through catalogue sales via commercial vendors. Such smaller scale microwave HPM devices could be deployed by terrorist groups but without the widespread damage capability of HEMP.

3.1.3 InfraGard EMP Special Interest Group Report

The Infragard (2016) published a report "Powering Through, from Fragile Infrastructure to Community Resilience". The report sponsored by the InfraGard National Member Alliance (INMA) and the FBI formed the EMP special interest group (EMP SIG) to study for the purpose of studying information about catastrophic, long-lasting threats to the nation's infrastructure from EMP, cyber-attacks, coordinated physical attacks, pandemics, and extreme space weather conditions such as solar storms. Specific focus was directed towards the electric grid in the U.S. and critical infrastructure inter-

dependencies with regards to threats that could cause widespread and long term failure, and plans that are required to enhance the capability of these systems to become more resilient to these threats to avoid extended service outages. Critical infrastructure addressed included: the electric power grid; water and waste treatment systems; communications systems; transportation mass transit and vehicles; agricultural and food processing equipment; public health and medical facilities; finance institutions; and emergency services.

Table 5 - Threats to Critical Infrastructure, Infragard Study (from "Powering Through-From Fragile Infrastructure to Community Resilience" Infragard (2016)) with permission to publish, this document only, by M. Lasky, 9/24/2020)

THREATS TO THE POWER GRID – EXAMINED IN DETAIL IN CHAPTER II

Equipment at Risk	EMP (Nuclear)	Solar Storm	Cyber	Physical Attack	Radio Frequency Weapons
Transformers	R	R		R	R
Generator Stations	R	G	R	R	R
SCADA / Industrial Controls	R	R	R	R	R
Utility Control Centers	R	R	R	R	R
Telecommunications including cell phones	R	R	R	Y	Y
Radio Emergency Communications	R	P	Y	Y	Y
Emergency SATCOM Communications	R	P	Y	Y	Y
Internet	R	R	R	Y	Y
GPS	R	P	Y	Y	Y
Transportation	R	Y	Y	Y	Y
Water	R	Y	R – Y	Y	Y

Legend: Red = direct permanent effects. Yellow = Cascading effects if no backup power. Pink = temporary effect (.5- 36 hours) assuming backup power. Gray = direct effects uncertain. Red-Yellow = potential permanent effects plus cascading effects.

The threat assessment summarized in **Table 5** from Infragard (2016) shows EMP has the most widespread effects among all the power surge threats affecting all parts of the U.S. critical infrastructure. Solar storms, for example, affect more of the fixed infrastructure components, but not transportation systems like automotive with the onboard computers, and the electronic sensors and actuators. As

discussed previously from the EMP commission (2008) report, the interdependencies among critical infrastructure elements must be considered.

Infragard (2016) discussed proposed actions for response and recovery addressing the threats that could affect critical infrastructure noted in **Table 5**. Specifically for EMP, the following mitigation actions presented in **Table 6** were proposed, some of which are relevant to actions possible to make transportation vehicles more resilient to EMP. More information is needed regarding status of implementation particularly considering the recent legislation and Presidential executive order on EMP.

Table 6 - Mitigation Actions Proposed for Electric Grid, Infragard Study (from "Powering Through-From Fragile Infrastructure to Community ...", EMP SIG(2016), p. 51)

Mitigation Action (from INFRAGARD 2016)	**Description** (from from INFRAGARD 2016)	**Relevant to Transportation Vehicles?**
Transformer protection	Neutral ground blockers and transient voltage suppression devices (Metal oxide varistors (MOVs or spark gaps) used for E1 & E3 protection	Possible (suppression devices); need to investigate
Mobile command centers	EMP protected command centers provide back-up to damaged units	Applicable for "garage parked" Fire and EMS emergency vehicles
SCADA systems	Used for load controls. EMP and cyber protected, replaced former SCADA systems vulnerable to EMP and Cyber attacks	Indirectly applicable to any microprocessor based controller used for vehicle peripherals, i.e. dashboard displays, climate controls, etc.
Digital Relays	Digital relays use for (??)**. Mitigation actions: apply shielding, house relays in Faraday cages, store spare relays in Faraday cages; replace solid conductor control cables with fiber optic cables	Unlikely applicable.
Protective relays	Usually redundant w/primary protection schemes. Protect for EMP by shielding, or consider replacement w/electro-mechanical relays	Not sure.
FLEX Warehouses	EMP protection on support equipment for nuclear power plants or hardening spare equipment.	No
Manual Generator Restart Procedures	Many generator systems depend on electronic industrial controls (SCADAs ?) to operate and restart generators. Implement options for manual restart procedures for generators; regularly practice restart protocols	No
Large Load Centers	Used because generators cannot restart unless large loads are connected. EMP protection via identification and protection of large load centers like pumping stations, factories, etc.	No

Other mitigation actions proposed to protect the electric grid from EMP from Infragard (2016) are presented in **Table 7**:

Table 7 - Additional Mitigation Actions Proposed for Electric Grid EMP Protection (from "Powering Through-From Fragile Infrastructure to Community ", Infragard (2016), p. 52-58)

Mitigation Action (from INFRAGARD 2016)	**Description** (from from INFRAGARD 2016)	**Relevant to Transportation Vehicles?**
Black-start equipment and procedures	Make sure black-start equipment are EMP protected; conduct practice exercises to assure procedures work	No
Backup power generators for critical infrastructure	Important concept but dependent on diesel, propane or natural gas fuel delivery	No
Stocking of spares	Important concept, since predicted recovery times is lengthy. Use spares as a buffer for normal replacement of parts via regular maintenance programs.	No
Mutual Assistance	Adjacent power companies assist each other in providing service based on no. of units that are operational after a disaster.	No
Resilient Micro-grids	Local power generation and storage via solar, wind turbines. Equipment must be EMP protected via MIL-STD 188-125-1 and MIL-STD-188-125-2.	No

A number of response and recovery scenarios were discussed in from Infragard (2016) to deal with the outages to the electric grid caused by the various attack modes. Information in the report would be valuable for electric companies and municipalities to develop mitigation action plans in the event of a major grid outage caused by the threats presented in **Table 5**.

3.1.4 Risks and Strategies Involved with An EMP Attack – Eversource Report

The presentation by Dr. Ed Goldberg (2019) inspired this thesis report. Eversource is a major electric transmission and distribution operator in Connecticut, Massachusetts and New Hampshire as well as a major distributor of natural gas. Like many excellent overview documents on EMP, Dr. Goldberg reviews the physics of EMP, the potential threat from our adversaries, and the impact on the electric grid. As stated in the report, the nuclear detonation and subsequent EMP generated induces near instantaneous rise destructive currents in "any and all conductors" including those part of the hardware infrastructure

associated with potential to destroy nearly all electronics and electrical devices. Two classes of mitigation actions were identified:

- Mitigate the risk of damage and effects caused by an EMP
- Mitigate the consequences of EMP damage and effects that do occur

To mitigate the risk, and reduce the likelihood of damage, the following actions were proposed (Goldberg 2019):

- Faraday cage/shielding – conductive metal enclosure allowing electromagnetic energy to induce current on the surface of the cage; hence, protecting the equipment within the cage
    - Electromagnetic energy radiated from the surface of the cage into the cage is equal and opposite, so there is a cancellation effect.
- "Active electronic protective devices." – likely for the longer time scale E2/E3 EMP components damaging to the electric grid.
- "Voltage clamps (MOVs, Varistors, etc.), fast current protection, neutral blockers, etc. ("who cares WHAT they are – the technology exists").
- "Segmentation and isolation, either all the time or just in time."
    - "Some equipment will survive, but if it's all interconnected, it does little or no good".
- 'Spares, especially for long lead items in conjunction with investigating extra protections for these components.

To mitigate the consequences, Goldberg (2019) discusses the following:

- Survivability, what can be done in advance to preserve core infrastructure?
- Business Impact Analysis (BIA), can the supply chain become more robust given the threat of EMP?
- Adjust emergency operations plans to consider threats from EMP.
- Increase stockpiles of lifeline necessities vs. relying on "just in time" delivery concepts.
- Introduce micro-grids with protected infrastructure, i.e. wind, solar, energy, back-up generators, batteries.

The comments for mitigation actions to reduce risks and consequences were useful and will assist in development of mitigation plan proposals for transportation sector vehicles, particularly Fire and EMS emergency vehicles that could be protected by the building enclosures (via MIL STD 188-125-1) vs. the vehicles themselves. Similarly, the electric utility repair vehicles could also be protected via storage in Faraday Cage protected buildings vs. modifying the vehicles themselves. More discussion is needed on this latter concept.

3.1.5 Electromagnetic Defense Task Force Reports

A significant reference source with regards to EMP were the two reports published by the Electromagnetic Defense Task Force (Maj. Stuckenberg et. al, 2018, 2019). The reports focused on critical infrastructure in the US and how the function of that infrastructure is coupled to the ability of the Department of Defense to conduct their mission to protect our country from their adversaries. The 2018 report (Maj. Stuckenberg et. al, 2018) addressed the following priorities:

- Nuclear power resilience.
- Installation command posts.
- Exercise and training realism.
- Competitor control of digital information.
- Machinery, Equipment and Critical Assets.
- Physical and Biological Impacts.
- Complexity, ownership and investments.

The 2019 report (Maj. Stuckenberg et. al, 2019) was a follow-up report on actions addressed in the prior year task force. More research is warranted on reviewing the findings of both these reports in context of improving resilience of the transportation sector to EMP. One point to make is that the more the public infrastructure is prepared with regard to resilience to EMP, the less the public will be dependent upon the US Military for survival of lifeline supplies in the event of an EMP attack, thus giving more time and focus for the US Military to execute their mission.

3.1.6 Other References

Other references were utilized in context of completing the threat assessment (Schneider (2007), Pry (2017), Albert (2019), discussion of mitigation design proposals (Radasky (2010, 2016, 2017), and discussion of the emergency management plans (Austin (2017), FEMA (2013, 2015, 2016, 2017, 2019)). These references were introduced in other sections and serve as additional valuable reference information for this report.

3.2 Response-Readiness Assessment –Transportation Vehicles

In regards to response and recovery readiness assessments for transportation sector vehicles utilizing available data from the literature, concerns existed from lack of data and the dependence on non-Military transportation sector vehicles for delivery of emergency services and critical lifeline supplies to the public in the event of an emergency such that would result from an EMP attack. Modern transportation sector vehicles employ significant use of electronics components and microprocessors for critical vehicle functions. Emergency vehicles are typically after-market conversions of these same vehicles incorporating the same electronics for the vehicle functions, and additional electronics for communications or whatever special functions that particular vehicle must perform. Military vehicles are in two classes (U.S. Army 2020): a) combat vehicles which are usually hardened for EMP; and b) non-combat and combat support vehicles where full EMP protection has not been applied.

To perform an accurate readiness assessment, introducing the following classifications yielded a more informed assessment vs. a generalized analysis attempting to cover all vehicle types:

- Military vehicles.
- Emergency vehicles.
- Commercial vehicles.
- Personal vehicles.

The previous tests to assess damage impact to vehicles from EMP were conducted by the EMP commission as described in **Section 3.1.1.6** on *"Transportation Infrastructure"* from the EMP

Commission (2008) Report. It was valuable the tests were conducted, and as one would expect, more data are needed to more accurately create a damage assessment status report to enable the mitigation planning to proceed in the most cost effective and strategic manner. Specially, additional data are needed due to the following rationale:

- Class of vehicles tested since the EMP Commission test in 2004 were conducted with 1982 to 2002 Model Year (MY) passenger cars, and 1991 to 2003MY trucks. Since that time, significant additions have been made to electronics in modern passenger cars and trucks.
- EMP field strength of 50Kv/m was used in the past EMP commission tests. More recent data in the literature and reports obtained from Russian journals suggested that modern optimized nuclear EMP weapons could easily delivery an E1 EMP pulse strength up to 200Kv/m (Wilson (2008), Pry (2017)).

3.2.1 Military Vehicles

Although not directly part of the public transportation sector, military vehicles support the response and recovery efforts in the event of a major disruption to the vehicle population due to an EMP attack. Military vehicles must also be designed to be resilient to EMP in combat scenarios to effectively complete their mission in the areas of conflict. To complete the readiness assessment, it is assumed military vehicles are divided into two classes of vehicles (U.S. Army 2020): tanks and combat vehicles; and, support vehicles.

Tanks and combat vehicles are vehicles (U.S. Army 2020) such as the M1 Abrams Tank, the M2/M3 Bradley Fighting Vehicle (BFV), the Cougar, the Stryker, the M1117 Guardian, the M-ATV and the RG-21 Nyala. Based on reports in the literature (Freedberg 2017), it will be assumed tanks and combat vehicles have been hardened to EMP via three standards:

- MIL-STD-125-2 (2005) for High Altitude EMP Protection for Ground-based systems that perform "critical, time-urgent command, control, communications, computer and intelligence (C^4I) missions";

- MIL-STD-461-G (2015) for DOD Interface Standard: Requirements for the control of Electromagnetic Interference Characteristics of Subsystems and Equipment; and
- MIL-STD-464-C (2010) on Electromagnetic Environmental Effects Requirements for Systems.

In these vehicles, use of electronics for various powertrain and vehicle functions is minimized. Faraday cage concepts are applied for any centralized controller present for vehicle function, and microprocessors utilized for auxiliary systems related to the mission support equipment installed. Per MIL-STD-125-2 (2005), the following are key components of the technology leads to an EMP resilient vehicle:

- Protected volume – a 3D space enclosed by an electromagnetic barrier also referred to as a Faraday Cage;
- Point-of-entry (POE) protective devices- Devices such and such as waveguides below cutoff and closure plates for aperture POEs, electronic filters, electric surge arrestors, and penetrating conductors;
- HEMP Harness – Information in MIL-STD-125-2 does not directly describe the HEMP Harness and associated requirements. Therefore, it will be assumed the HEMP Harness connects the primary vehicle microprocessor for engine and transmission controls to the peripheral actuators and sensors; and
- Mission critical equipment for communications and other purposes must be enclosed in a protected volume to be resilient to EMP.

Other standards are also utilized for military tanks and fighting vehicles to become resilient to EMP. MIL-STD-464C (2010) provides basic requirements for electromagnetic environmental effects (E3) for DOD systems. MIL-STD-461G established interface and associated verification requirements for the control of electromagnetic interference (EMI) and electromagnetic compatibility (EMC) for electronic, electrical, and electromechanical sub-systems supporting vehicle functional requirements. The standard is best suited for items having electronic enclosures, are no larger than an equipment rack, and have

electrical interconnections via discrete wiring harnesses between enclosures, and electrical power derived from prime power sources.

Military support vehicles (U.S. Army 2020) consist of a family of medium tactical vehicles likely used for transport of supplies and personnel. This includes Heavy expanded Mobility Tactical trucks, High mobility multi-purpose wheeled vehicle (HMMWV or HUMVEE), Heavy Equipment Transport vehicles, Palletized Load System (PLS) vehicles, and Buffalo vehicles used to clear explosives. It is unclear from the literature what fraction of support vehicles are hardened for EMP.

Important comments on the response and readiness assessment for military vehicles are as follows:

- Vehicle design technologies are established for EMP protection in military vehicles.
- MIL vehicles do tend to minimize the use of electronics for powertrain controls to reduce modes of failure in the field, and to facilitate designs that are EMP resilient without the significant complexity required for the control system hardware in commercial or passenger car transportation sector vehicles.
- Contractors and component suppliers familiar with these designs would be a valuable asset in developing design proposals for an EMP resilient non-military vehicle.
- It is unclear what fraction of military support vehicles are hardened for EMP based on information in the literature.

3.2.2 Transportation Sector Emergency Vehicles

Transportation sector emergency vehicles, except for Fire Engine Trucks, are traditionally commercial or personal transportation vehicles converted to be emergency vehicles. The electronics in emergency vehicles are identical to the parent commercial vehicle or passenger car vehicle. For a response and recovery readiness assessment, we should assume all these vehicles are vulnerable to an EMP attack providing they are exposed to the environment without any special metal enclosure that could serve as a Faraday cage. The only data that provides insight to the potential damage an EMP attack would

incur on these vehicles was from the 2004 testing conducted by the EMP commission discussed in **Section 3.1.1.6** on *"Transportation Infrastructure"*. Additional tests with modern day vehicles are needed to properly assess the risk and to assess the magnitude of the task to develop mitigation design features to reduce those risks.

A special class of emergency vehicles are fire engine trucks used by municipal fire departments. Laracy (2012) conducted a thorough investigation of EMP impact on Fire and EMS vehicles in relationship to how such an attack would affect the Walpole, MA Fire Department. In the report, Laracy (2012) discussed how communications systems in the vehicles would be affected, and the powertrain system (engine plus transmission) components of the trucks could be damaged due to failures in the electronics and microprocessor components resembling those used for passenger cars and trucks. Mitigation actions applied to the fire engines to become resilient to EMP were discussed.

As a result of reviewing this report by Laracy (2012), an additional proposal could be considered for fire and EMS emergency vehicles since the vehicles reside in the fire houses and EMS garages prior to deployment, and likely will not be on the road in the event of an EMP attack. Specifically, could Faraday shields and transient voltage isolation concepts be applied to the fire houses and EMS garages where the trucks reside using principles in MIL-STD-188-125-1/2 and IEC TS 61000-5-10 (2017) providing a cost effective means of improving the resilience of these vehicles to an EMP. Better shielding of the buildings, and installation of surge protection devices for power lines connected to the trucks while waiting for calls, and any antenna systems that feed to communications systems will go a long way in improving resilience of fire truck emergency vehicles to an EMP attack. Mitigation actions on the fire engine and EMS vehicles themselves as proposed by Laracy (2012) would further improve resilience.

3.2.3 Transportation Sector Commercial Vehicles

An important class of transportation sector vehicles are over the road trucks used for delivery of materials for manufacturing, food products to grocery stores, purchased items to distribution centers and many more lifeline supplies to the public and regional businesses. Without over the road trucking, major interruptions would occur to the food supply industries and businesses in the U.S. Powertrain systems

used in these vehicles primarily utilize diesel engines and some form of electronic transmission system. Both the engines and the transmissions utilize a significant number of electronic actuators, sensors and central microprocessors for engine and transmission control. In addition to the engine and transmission controls, quite sophisticated emissions control systems are also utilized based on systems containing an oxidation catalyst, a particulate trap, and a selective catalytic reduction (SCR) Nitric Oxides (NOx) control system (Johnson 2011). All these components, including the electronic fuel injection equipment used on diesel engines would be vulnerable to an EMP attack due to the presence of sensors, injectors and actuators if proper shielding and surge protection devices were not employed. More data would be needed to define the level of impact to predict the percent of vehicles damaged, and the nature of the failures so effective risk reduction mitigation measures can be applied.

3.2.4 Transportation Sector Personal Vehicles

Transportation sector personal vehicles, i.e. cars and light trucks, have extensive utilization of electronic actuators, sensors and microprocessors for engine and transmission controls, and a number of micro-control systems in the body system for climate control, electronic steering, vehicle entry and security systems, etc. Testing vehicles for vulnerability to EMP with this level of electronics has never been done in history, and is required if plans are to be developed to improve designs to be more resilient to EMP. The testing will also assist in defining repair scenarios and service procedures for vehicles that have been EMP hardened but must be repaired in the automotive dealerships and other garage repair bays.

3.2.5 Vehicle Usage Logistics Systems for Delivery of Lifeline Supplies

Transportation sector vehicles play a critical role in delivering lifeline supplies to retailers, grocery stores, and manufacturing operations for every aspect of business in the US. If a significant population of the commercial truck delivery vehicles are damaged, then we are presented with a logistical challenge on delivering these supplies to their desired destination. The logistics response systems will need to identify what delivery type vehicles were not damaged so the vehicles that are running can retrieve supplies from warehouses and deliver them to the distribution centers, retail stores and grocery stores themselves.

4 REFLECTION ON GOALS AND RESEARCH QUESTIONS

The goals of this study support the National Preparedness Goal (FEMA 2015), to build and sustain core capabilities to achieve:

> *"A secure and resilient Nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from threats and hazards that pose greatest risk."*

From the analysis in prior sections devoted to understanding the characteristics of EMP optimized nuclear weapons, the national security threat assessment, and the impact of an EMP attack to the overall critical infrastructure, it's evident a vulnerability exists in the U.S. and our allies worldwide. If left in present status without investment in mitigation measures, an EMP attack via a nuclear weapon deployed 30-400 Km altitude could lead to widespread disruption of critical infrastructure that could in-turn result in massive casualties long-term if national security and emergency management mitigation measures are not implemented. To provide authorization to develop EMP mitigation measures, the March 2019 Presidential Executive Order (White House 2019) and subsequent FY2020 National Defense Authorization Act (Gertz (2020) and Govtrack (2019)) were issued addressing all aspects of the critical infrastructure. For transportation sector vehicles, an emergency management plan proposal that would at least allow an effective emergency management response and recovery plan to be executed with continuity in delivery of lifeline supplies to the public in the event of an EMP attack will require investment to implement EMP mitigation proposals.

Reflecting on the above, the following goals are summarized for this study to improve resilience of modern-day transportation sector vehicles to an EMP attack:

- Develop a framework to categorize vulnerable under-hood electronics sub-systems and components exposed to an EMP/HEMP environment to enable a failure modes and effects analysis to be completed and a more accurate hazards risk assessment.

- Develop a comprehensive test plan with test cost assessments to quantify the risk damage assessment from sub-systems and components exposure to anticipated EMP/HEMP environments and likely deployment scenarios.
- Identify cost-effective mitigation design proposals to increase resilience of transportation sector vehicles.
- Define logistical requirements for repair scenarios for vehicles that have not incorporated EMP mitigation design actions.
- Define requirements for an emergency management response and recovery plan that support delivery of emergency services and critical lifeline supplies to the public following an EMP attack.

In support of the achievement of these goals, two research questions will also be addressed:

- How can a mitigation plan be developed that is affordable to implement nationwide?
- What segment of non-MIL transportation sector vehicles should employ mitigation design changes versus rely on the logistics to repair vehicles after the EMP event occurs?

5 METHODOLOGY

5.1 Overview and Strategy

For transportation sector vehicles, the methodology approach applied to understand the risks and improve resilience to EMP must support generation of the following information:

- A clear visualization of modern-day transportation sector vehicle electronics sub-systems and components and their potential failure modes to support a meaningful risk analysis.
- A test plan that will quantify the hazard risks and build on what was tested by the EMP Commission testing in 2004 in two areas:
    - Generation of test data with modern-day, electronics-heavy, transportation sector vehicles.
    - Test lab procedures capturing simulated EMP conditions representative of the 50-200Kv/m EMP pulse levels expected from optimized EMP weapon technology, and noise factor effects representing variability present at the time of an EMP attack.
- Mitigation design proposals that are affordable to implement nationwide on at least the portion of the vehicle population supporting emergency services and delivery of lifeline supplies to the public.

The methodology utilized to achieve the goals and answer the research questions is summarized in **Table 8**. Lessons learned from the threat analysis and literature review provided the rationale to pursue this project, and foundation information for the reliability analysis, risk analysis, and mitigation proposals for transportation sector vehicles. The emergency management response and recovery proposed plans assume investments will be made to make transportation sector vehicles for emergency services and delivery of lifeline supplies to the public resilient to an EMP.

Table 8 - Transportation Sector Vehicle EMP Resilience Methodology Strategy

Methodology Component	Category	Description	Desired End Results	Section
Threat Analysis	National Security	Develop understanding of national security threat due to EMP optimized weapons and associated deployment scenarios from state actors and terrorist organizations	Justification for study EMP test conditions for lab tests	**2.0**
Literature Review	National Security	Conduct literature review to understand impact of EMP on critical infrastructure, and in particular, for transportation sector vehicles	Summary of past work Direction of study defined.	**3.0**
Reliability Analysis	Engineering/ Emergency Management	Develop vehicle classification breakdown to understand the hazard risks Develop framework to categorize automotive vehicle sub-systems and components for EMP vulnerability assessment Define process to visualize potential failure modes in relationship to the coupling to the EMP, the EMP control countermeasures, and the noise factors uncertainty due to EMP weapon types and deployment scenarios	Identification of critical sub-systems and components for modern vehicles Framework to address potential failure modes	**5.0**
Risk Analysis	Engineering/ Emergency Management	Develop comprehensive test plan for cars and light trucks, and medium and heavy-duty trucks to yield a more accurate list of hazard risks	Test plan enabling critical data to be generated on EMP failure modes for modern vehicles	**6.0**
Mitigation	Engineering/ Emergency Management	Define cost effective mitigation countermeasures that could be applied based on failure modes discovered during testing. Develop countermeasure implementation strategy supporting application to vehicles supporting delivery of emergency services and critical lifeline supplies.	Design actions that can be applied to emergency vehicles, selected heavy duty trucks, and medium duty delivery trucks nationwide.	**7.0**
Response and Recovery	Emergency Management	Define emergency management and logistics plan assuming transportation sector vehicles supporting emergency services and delivery of critical lifeline supplies to the public have incorporated EMP mitigation countermeasures.	Emergency management plan to avoid massive casualties due to EMP. Logistics defined for remaining vehicle repairs.	**8.0**

5.2 Vehicle Classifications

A vehicle classification system for MIL and Non-MIL transportation sector vehicles was developed to assist in test planning for hazards risk assessment and development of design mitigation proposals. The following vehicle classifications were defined. **Section 3.2** in the literature review presented additional reference information on the vehicle types described below.

- Military vehicles – In reference to use for combat, military vehicles are assumed to be already resilient to EMP with design configurations conforming to MIL standards. For EMP design mitigation features, combat military vehicles serve as a technology reference for other vehicle classes. Non-combat support vehicles may not yet incorporate EMP resilient design features. However, proposals developed for non-MIL transportation sector vehicles could be applied to non-combat military vehicles since in many cases they share the same technology platforms. Military vehicles are typically diesel engine powered with simplified powertrains containing as little electronics as possible.
- Emergency vehicles – Fire, Police, and EMS emergency vehicles are critical to delivering emergency services. EMP mitigation actions must address the vehicle sub-systems and components, and in some cases, the significant addition of safety, communications, and medical equipment contained on-board. Emergency vehicles are primarily a mix of gasoline and diesel-powered vehicles.
- Commercial vehicles- Commercial trucks are used for delivery of lifeline supplies to businesses and ultimately to the public. Buses are used for public and school transportation. Utility vehicles service the electric grid and natural gas delivery infrastructure. Commercial vehicles are typically diesel powered.
- Personal vehicles- Passenger cars and light trucks consist of gasoline engine powered vehicles, hybrid vehicles, and electric vehicles. Personal vehicles are typically gasoline powered and recently, incorporate hybrid-electric powertrains, and a limited number of electric vehicles.

5.3 EMP Mitigation Plan Scenarios

Given the above proposed classifications of transportation sector vehicles, the process to describe plans to improve resilience to EMP was initiated. In the flow chart presented in **Figure 12**, two scenarios for mitigation actions are described, one based on implementation of a “modified vehicles” mitigation plan to improve resilience to EMP, the other for “as-built vehicles” is based on understanding the impact of EMP from the risk analysis and testing, and then having emergency management plans in place to efficiently address the surge in repairs at the automotive dealership repair bays and private repair garages. Both scenarios are dependent on execution of a new laboratory test plan to be described in the following section that will aid in defining the hazards risk assessment for modern transportation sector vehicle sub-systems and components exposed to EMP, and the various deployment scenarios described in the Threat Analysis section.

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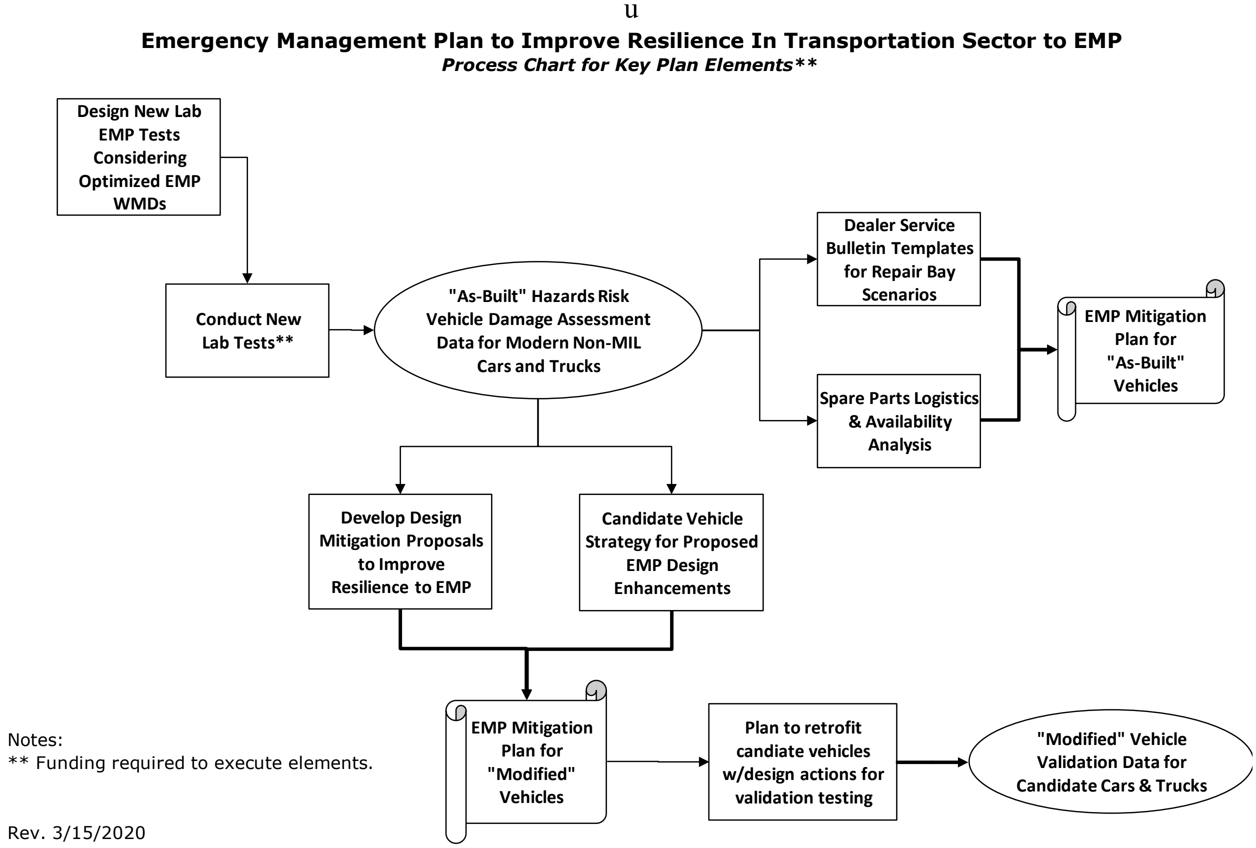


Figure 12 - Process Chart: Key Plan Elements to Improve Transportation Vehicle Resilience to EMP

The new set of laboratory tests, the first step in the process, is essential to define the "as-built vehicles" hazards risk damage assessment. From the test data, failure modes and damage levels will be better understood for modern "electronics-heavy" automotive cars and trucks while exposed to EMP field levels characteristic of Super-EMP weapons that are of concern today in national security forums. It's well recognized in these forums per comments from the EMP commission (2008) report and the InfraGard "Powering Through" report (INFRAGARD 2016) that more data are needed to more accurately assess the damage to non-military transportation vehicles due to EMP attack for the variety of potential attack scenarios.

Once the "as-built vehicles" hazards risk damage assessment data are generated, the EMP mitigation plan will be developed in one of two scenarios as illustrated in **Figure 12**:

- The "As-Built Vehicles" repair scenario will rely on an efficient repair process established with sufficient spare parts to repair vehicles damaged from an EMP attack. This path would assume the cost to convert all these vehicles to become EMP resilient would be cost prohibitive, and if the repair process can be addressed to become more efficient and timely, the fraction of vehicle population not employing mitigation design measures can be repaired in a reasonable period of time. The logistics of this scenario will be discussed further in the Emergency Management **Section 8.0**.
- The "Modified Vehicles" mitigation scenario relies on proposed design mitigation measures implemented to improve resilience of non-MIL transportation sector vehicles to EMP. The vulnerable components and their failure modes will be analyzed via the process outlined in the **Sections 5.4** to **5.7**, and **7.0** with the goal of identifying cost effective design proposals that could reduce or eliminate the EMP risk for that particular vulnerable sub-systems or components. In **Section 8.0**, a strategy will be proposed for candidate vehicles to be converted to become more resilient to EMP with the goal of providing lifeline supplies and emergency services to the public while the repair processes are being implemented for "as-built vehicles" due to damage created by the EMP attack.

5.4 Process for Reliability Analysis

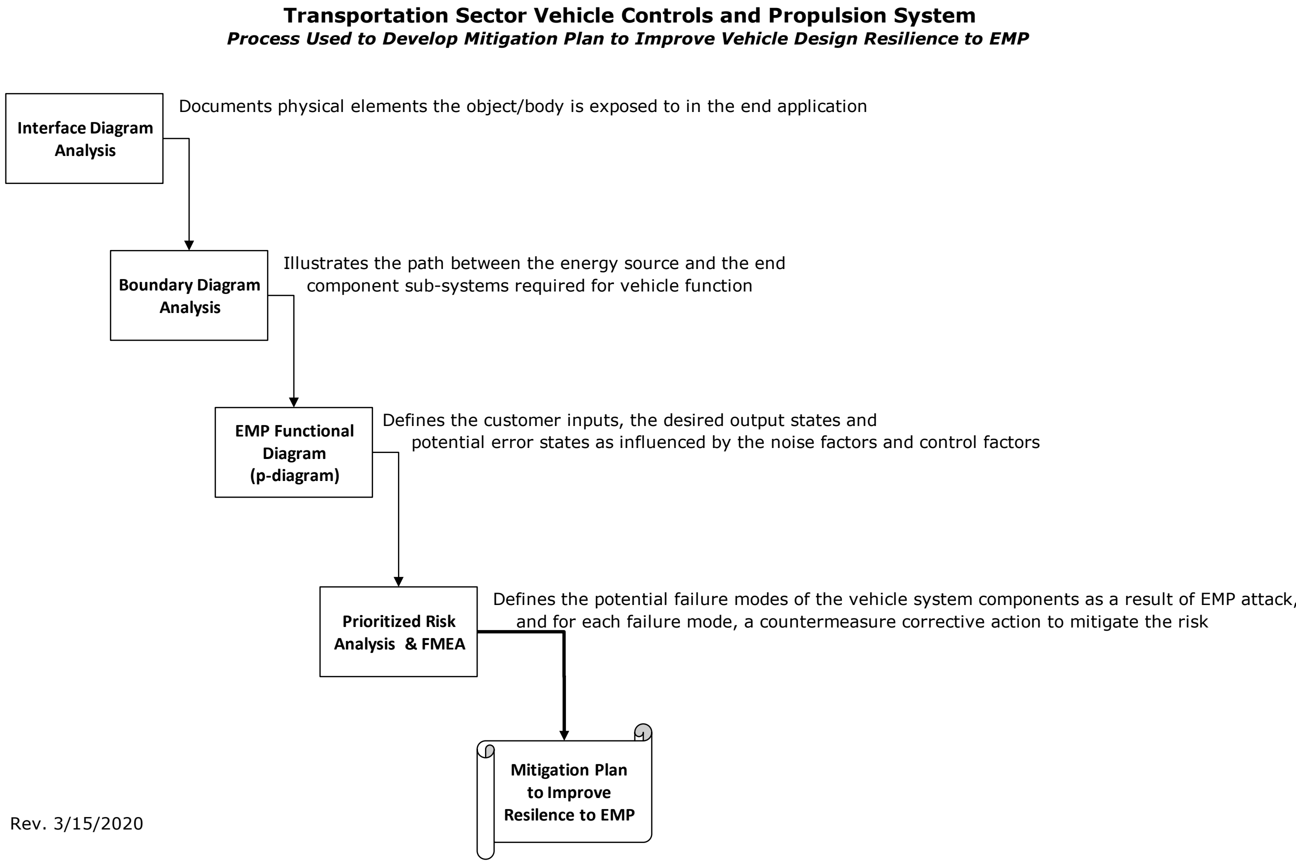


Figure 13 - Process Used for Reliability Analysis to Improve Resilience to EMP

The process for reliability analysis used to improve resilience to EMP is presented in **Figure 13**. The goal was to develop a methodology to visualize critical components and potential failure modes vs. tools that directly attempted to predict reliability of a system. To start the process, the Interface Chart Analysis presented in **Section 5.5** describes the physical elements the vehicle exposed to in the end environment, i.e. the EMP electric field generated as a result of the attack. The Boundary Diagram Analysis presented in **section 5.6** illustrates the path from the EMP device energy source to the components and sub-systems in the vehicle. In **Section 5.7**, the EMP Functional Diagram (p-diagram) will be used to define the customer inputs, the desired output states and potential error states as influenced by the noise factors one of them being the actual EMP field generated as a result of the attack. In **Section 7.0**, a failure modes effects analysis (FMEA) borrowed from the engineering world will assist in

visualizing potential failure modes, their corresponding mitigation measures, and their relative rank in importance relative to the suite of possible failure modes envisioned. A new round of tests described in **Section 6.0** is proposed for a suite of modern-day transportation sector vehicles ranging from passenger cars and light trucks, to medium duty delivery and over the road, heavy duty diesel tractor style vehicles. Once the new test data are available, the risk analysis metrics in the FMEA can be used to define mitigation plans for logistics supporting repair of "as-built" vehicles, and strategic implementation of mitigation retrofit plans for "modified vehicles" to improve resilience to EMP. The above process described in **Figure 13** is similar, in principle, to the process described by Campean and Henshall (2012) on "Functional Basis for Failure Mode Avoidance in Automotive Systems Engineering Design".

The summation of these steps will become the framework of the hazard mitigation plan aimed at improving resilience of transportation sector vehicles to an EMP attack. Although this multi-step graphical method seems extensive, the point is to develop a plan that is supported by a comprehensive analysis of potential failure modes in the critical vehicle sub-systems and components to enable a reliable and cost effective mitigation plan to be proposed. It is assumed this will better-enable budget proposals to be created in a manner that optimizes the end result for the given budget dollars available knowing with better confidence the dollars invested will yield genuine improvements in resiliency with greater chance of success in the emergency management plans supported by the non-MIL vehicle critical infrastructure.

5.5 Vehicle EMP Interface Diagram

The EMP Interface diagram presented in **Figure 14** was developed to help illustrate the sub-systems and components in the vehicle controls and propulsion system for a modern transportation sector vehicle in relationship to the EMP environment imposed. The diagram served as a starting point for a reliability analysis of the vehicle sub-systems and components as impacted by an EMP attack. Shown at the center of the diagram is the "Vehicle Controls and Propulsion System" surrounded by satellite elements, the primary components potentially vulnerable to EMP, and the EMP input itself. This diagram

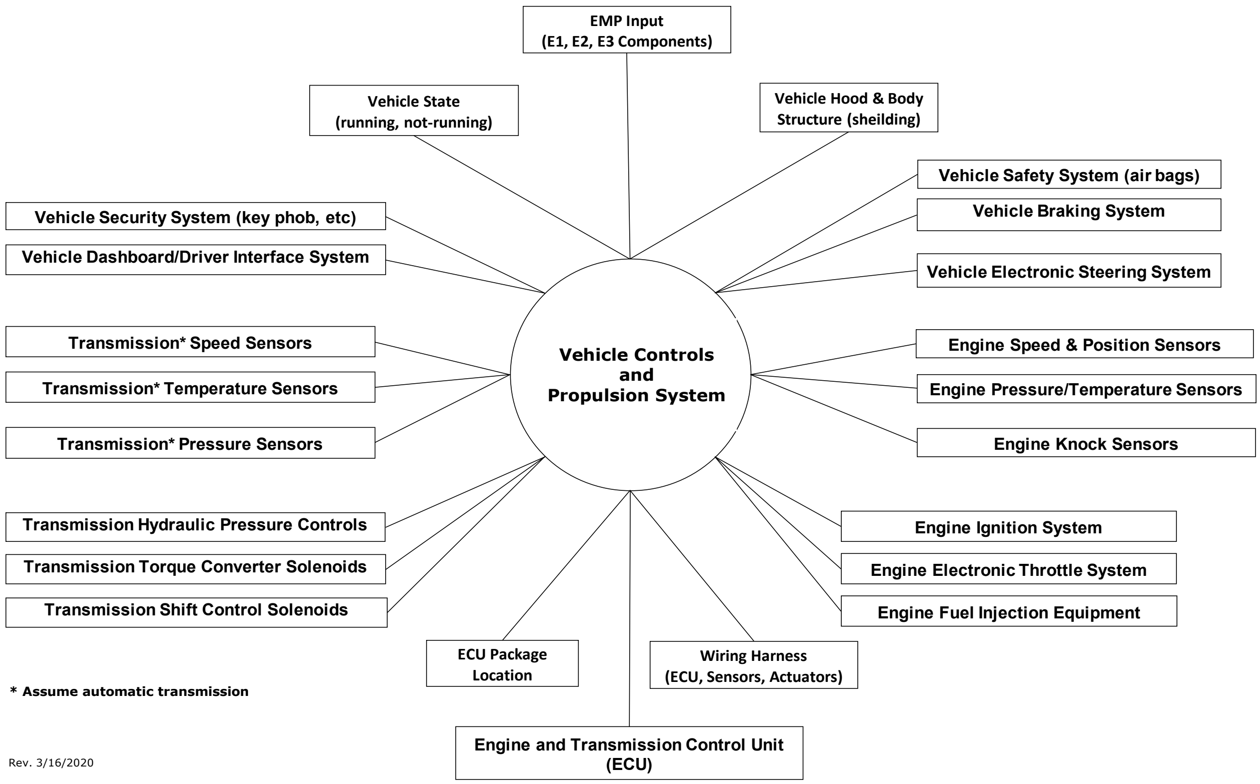


Figure 14 - Vehicle Controls and Propulsion System EMP Interface Chart
(intended to document the physical elements the system is exposed to in the end application environment)

served as the first step in developing a comprehensive picture of what's involved in the function of the system that could be disrupted by an EMP disturbance. From inspection of the component breakdowns presented, the following components were considered vulnerable and common to the majority of modern Non-MIL vehicles:

- Electronics control unit (ECU), the microprocessor that controls engine load, transmission shift schedules and other vehicle functions. The ECU utilizes sensor inputs and then issues output functions to actuators for control of the engine-transmission powertrain system.
- Electronic throttles which were formerly mechanically actuated via the driver's foot pedal input, now are electronically controlled governing the air flow to the engine and power output.
- Electronic fuel injection equipment, the electric fuel pumps and the fuel injectors which are located in the intake manifold (port injection) or in the engine cylinder (direct injection).

- Electronic ignition system components, coils, high voltage wires creating the high voltage, ironically in a similar Kilovolt (Kv) range as EMP, for spark ignition.
- Various sensors to control engine function such air flow sensors, manifold pressure sensors, oil pressure sensors, oil, coolant and air temperature sensors, engine speed and position sensors, and knock sensors.
- Solenoids that control automatic transmission gear shifting and lock-up clutch functionality, pressure control valves for the hydraulics that provide the actuation force for gear shifting.

Unique components for different vehicle classifications deserve special considerations:

- Fire and EMS emergency vehicles – Vehicles containing not only the sub-systems and components in the powertrain and dashboard systems common to passenger cars and commercial trucks, but also contain significant electronics communications and lifeline support equipment which are just as vulnerable to EMP as the parent vehicle driveline components (see **Figure 10**). For migration actions, the following facts should be considered:
    - Fire and EMS emergency vehicles reside in fire houses or garages prior to deployment for emergencies with electronics communications and life support equipment powered by building power sources to be ready for an emergency.
    - Mitigation proposals need to protect not only the vehicle powertrain components, but also communications and life support equipment via the various EMP mitigation approaches as referenced in the technical standards by the International Electrotechnical Commission via IEC TS 61000-5-10 (IEC (2017)), and the military standards MIL STD-188-125-1&2 (2005). Whatever is applied to protect communications and life support equipment will also protect the vehicle powertrain controls components if the vehicles reside in the garages and fire houses at time of an EMP attack.
    - EMP protection of the vehicles themselves would offer additional protection.
- Police vehicles – Police vehicles are basically production vehicles with conversions for performance, and a significant addition of electronics equipment for communications purposes.

Since police vehicles are special conversions of production vehicles, unique opportunities exist for early application of mitigation design changes to improve resilience to EMP. It will be assumed police vehicles are vulnerable to EMP at the time of attack, i.e. out on the street or in open parking lots, not in garages.

5.6 Boundary Diagram

The boundary diagram presented in **Figure 15** helped create the walk from the energy source, i.e. the nuclear EMP device, to the subsystem components in a modern transportation sector vehicle vulnerable to EMP. **Figure 16** to **Figure 19** based on service manual information (Ford Motor Co (2018)) provide expanded versions of the wiring diagram illustrations shown to the right of **Figure 15.** The "Source Region" diagram and "High Altitude EMP (HEMP) Interactions" diagram in **Figure 15** based on figures from Emanuelson (2020-1) and Radasky (2017) show the source of the burst above the earth's surface where gamma radiation is transformed into an electromagnetic pulse that interacts by coupling to vulnerable electronics components in the critical infrastructure as described in **Section 3.2.1** on "EMP Impact on Critical Infrastructure Components." The effect of the burst is directed downwards towards the ground above the location of the detonation propagating outward radially at distances determined by the height of the blast (HOB) (recall **Figure 1** and **Figure 2**). The vulnerable sub-systems and components impacted by the EMP environment are shown in the wiring harness illustrations on the right side of **Figure 15.**

Once reaching ground level in the vicinity of the vehicle, the under-hood effective electromagnetic pulse is attenuated by the enclosures consisting of the vehicle's hood, body structure and aperture openings, i.e. the front grill and underbody openings, with varying attenuation depending upon vehicle model design details. The wiring harness connects the actuator and sensor components to the engine control unit (ECU) which Ford refers to as the "Powertrain Control Module" shown in the **Figure 18** "Under-hood Wiring Harness Illustration". The wiring harness sections leading to the actuators and sensors act like antennas to the EMP pulse directing voltage input to the components and the ECU. The electric field attenuated by the shielding present in the vehicle will become coupled with the wiring

harness sections and find their way to the ECU, the path to ground, the sensor/actuator components, and the battery junction box, i.e. multiple paths for a short period of time. For example, a 200 Kv/m pulse imposed on a 0.5 m section of wiring harness, unshielded, unattenuated, would impose a 50K voltage pulse for a ~5-10 ns time period.

Figure 16 to **Figure 19** for the example 2014 Taurus Ford vehicle illustrate the summation of the electronics components that are vulnerable to an EMP attack as oriented in the vehicle relative to the engine control unit (ECU). In a typical vehicle installation, the ECU is located either under-hood or somewhere in the vehicle cowl behind the firewall inside the vehicle. The wiring harness connects to the processor and delivers control signals to solenoids and actuators for fuel and air/fuel ratio control to the engine, and ignition signals to the coils that provide the ignition source for combustion. The sensors provide feedback on the engine state such as crank position, engine speed, and the thermodynamic state of the intake mixture for fuel air metering. Sensors are also present for detection of engine knock. Monitors, the combination of sensor outputs plus computer algorithms, are present in the ECU for the exhaust system (not shown) for monitoring and safe operation of the emissions control system for protection of the catalytic converter and other exhaust system emissions control components.

Relative importance of the various components shown in **Figure 16** to **Figure 19** would logically focus first on components related to propulsion and safety systems including the "Engine and Transmission Components", the components from the "Under-hood Wiring Harness Illustration" including the ECU (Ford refers to as the "Powertrain Control Module"), the accelerator pedal position sensor (APP), and the ABS brake system. Components from the "Dashboard Display & Body Functional Components Illustration" including the dashboard system and instrument cluster components may not appear important to allow the propulsions system components to operate properly. Experience in engine testing of competitive vehicle engines at Roush (Roush 2020) has many times shown the entire dashboard needed to be installed in the test room due to the security interlock systems in the vehicle that are interfaced to the ECU. EMP damage to the interlock system could cause a "no-start" condition for the vehicle. **Figure 17** is a generic engine sub-harness illustration for a V6 engine with intake port fuel

Vehicle Controls and Propulsion System EMP Boundary Diagram *(source to response)*

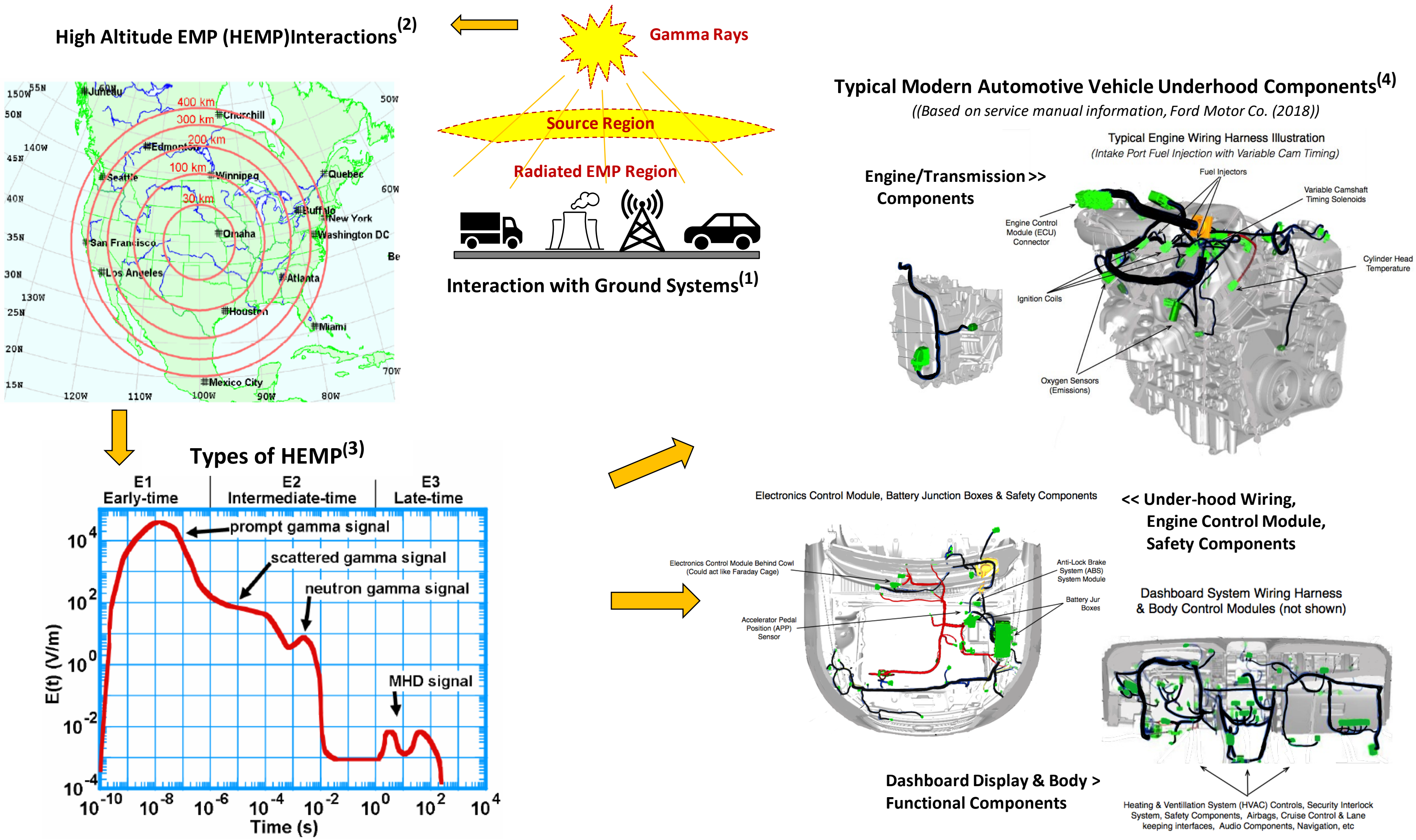


Figure 15 - EMP Boundary Diagram: Path from EMP Energy Source to End-Component Subsystems

((1)-Diagram based on info. from Emanuelson (2020-1); (2,3) Diagrams from Radasky (2010), and (4) Diagrams based on info from service manuals, Ford Motor Co. (2018))

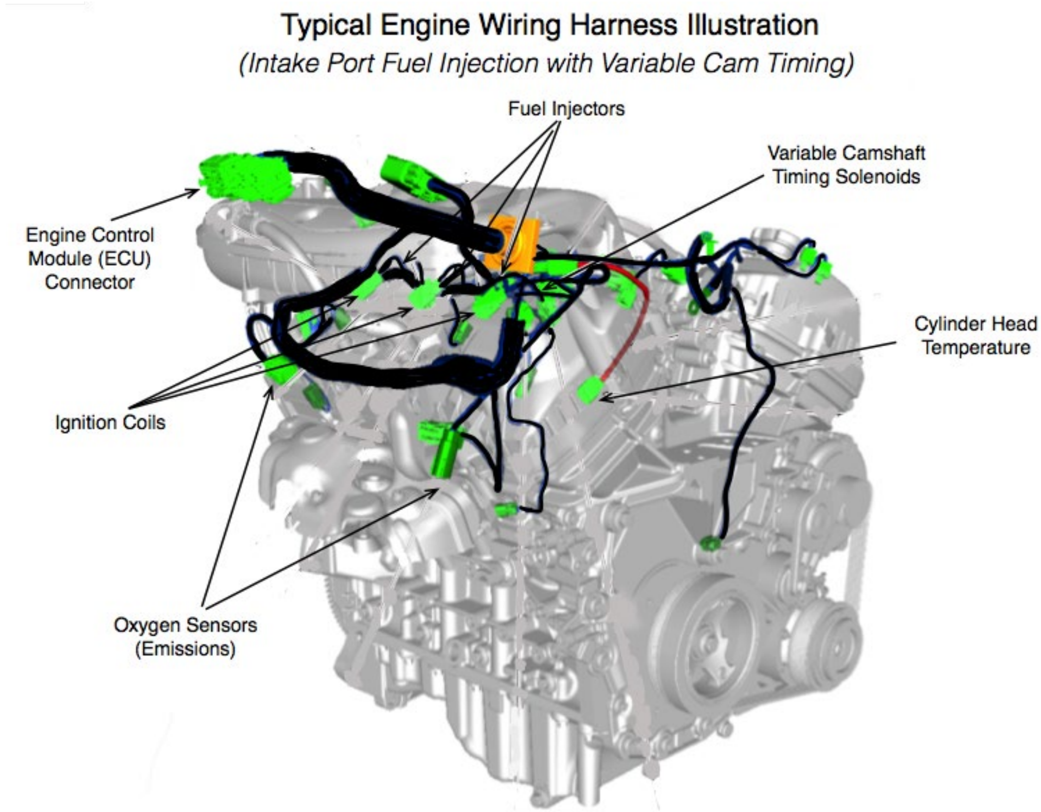


Figure 16 - 2014 Ford Taurus 3.5/3.7L TIVCT Engine Wiring Harness Illustration*
**Non-Turbocharged w/Twin Independent Variable Cam Timing (TIVCT)*
(Based on service manual information, Ford Motor Co. (2018))

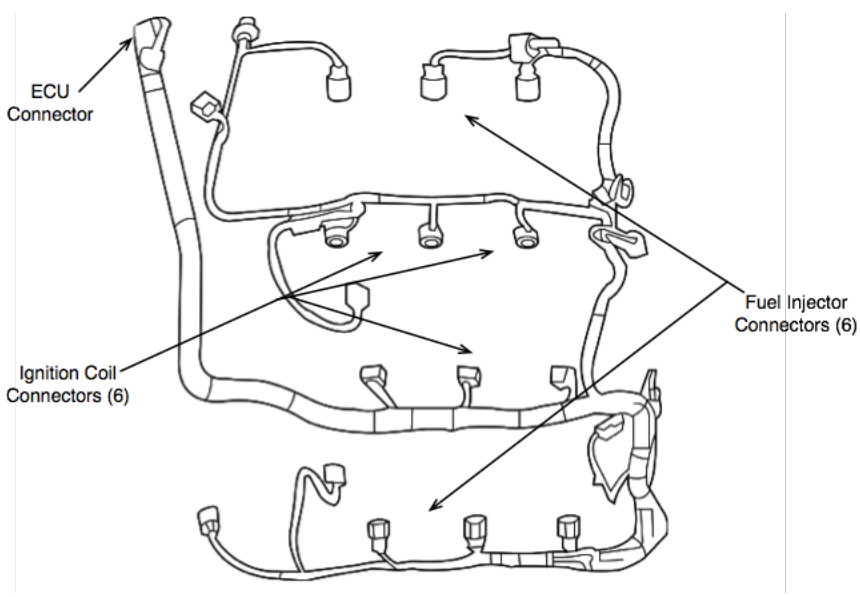


Figure 17 – Typical V6 Engine Wiring Sub-Harness Illustration
(Intake Port Injected Engine)
([FordDiscountParts.com (2020)](FordDiscountParts.com))

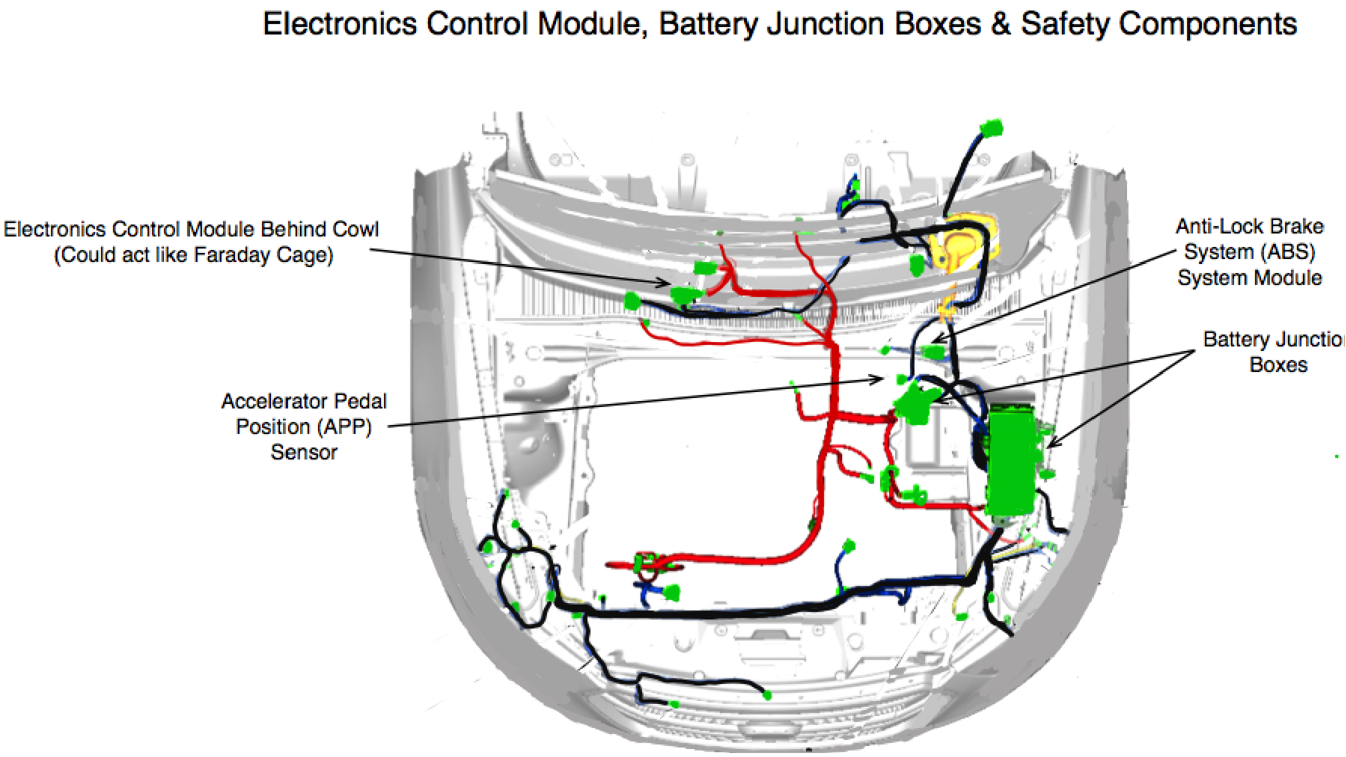


Figure 18 - 2014 Ford Taurus 3.5/3.7L TIVCT Under Hood Wiring Harness Illustration (Based on service manual information, Ford Motor Co. (2018))

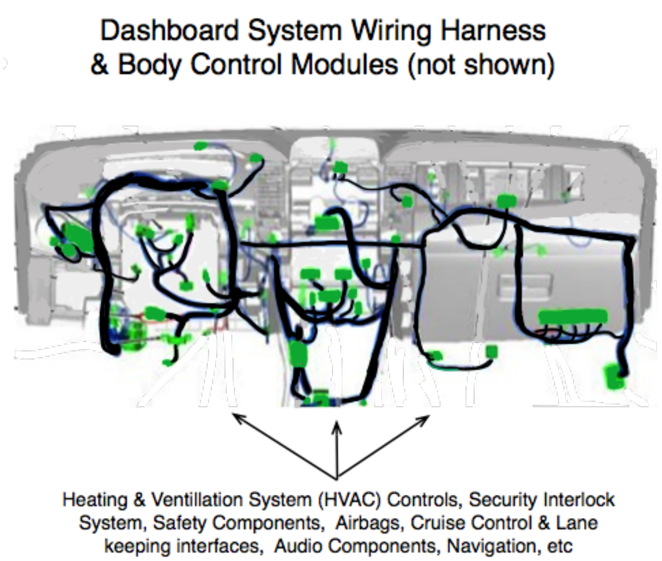


Figure 19 - 2014 Ford Taurus 3.5/3.7L TIVCT Dashboard System Wiring Harness Illustration (Based on service manual information, Ford Motor Co. (2018))*

injection. The illustration was included to show how supply and return conductors to and from the actuators, in this case the ignition coils and the fuel injector coils are equal length. This could aid in equalizing the EMP differential voltage impose on the actuators which could reduce the severity of the voltage surge and subsequent damage that could be imposed. Nearly all the sensors and actuators in an automotive vehicle have this "equal-length" supply / return conductor characteristic. This could provide one explanation as to why the EMP Commission (2008) tests conducted on at least the 2002 MY vehicles did not create catastrophic effects in the vehicle electronics components which could aid in mitigation design proposals discussed in **Section 7.0**.

5.7 EMP Functional Diagram *(p-diagram)*

The "EMP Functional Diagram" presented in **Figure 20** commonly called a "p-diagram" (Systems2Win 2020) serves a front-end to the hazards risk analysis and complementary failure modes

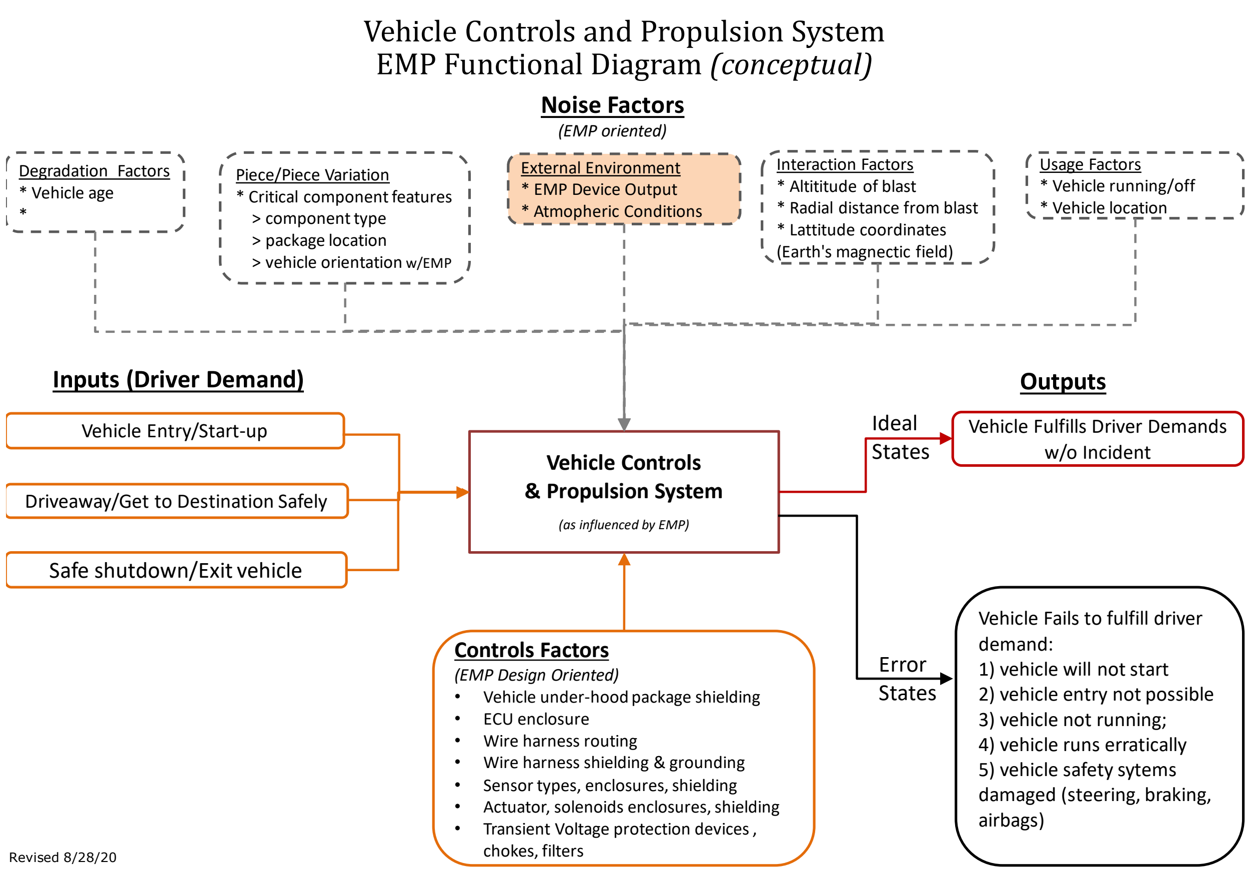


Figure 20 - EMP Functional Diagram for Vehicle Controls and Propulsion System

effects analysis (FMEA) borrowed from the reliability engineering world (U.S. Army 2006) to be discussed in **Section 7.0**. The diagram serves as a tool to assess the impact of EMP on the vehicle functional components which will become the foundation for the transportation vehicle mitigation plan to be discussed in a later section. The heart of the p-diagram is the "Vehicle Controls & Propulsion System" as influenced by EMP. Use of the error states to become potential failure modes in the FMEA will be discussed in the Mitigation **Section 7.0**. The p-diagram "Inputs" represent the "Driver Demand" with three basic functions:

- Vehicle entry and start-up;
- Vehicle drive-away and reach the required destination safely; and
- Safe shutdown and exit from the vehicle.

Two types of outputs are shown in the p-diagram. The "Ideal States" show the desired output that the vehicle fulfills the driver demands without incident. The "Error States" show some examples on how the vehicle would fail to deliver the driver demands if impacted by EMP:

- Vehicle entry not possible due to issues w/security system
- Vehicle will not start
- Vehicle not running due to damage to one of the components or the ECU
- Vehicle runs erratically due to damage of components or the ECU
- Vehicle safety systems damage such as electric braking and steering systems, air bag systems, security interlock systems leading to loss of vehicles control and accidents while driving, or loss of vehicle function causing vehicle to be undriveable.

The Noise factors contribute to variability in how the EMP pulse interacts with the vehicle. Related to deployment scenarios, noise factors could be associated with atmospheric conditions, height of the blast, radial distance from the blast, and latitude coordinates which govern how the EMP field generated from the device interacts with the Earth's magnetic field. The vehicle characteristics will also contribute noise factor variables such as age of the vehicle, vehicle body materials such as steel vs aluminum or steel

vs. composite fiberglass materials, factors that affect the "faraday cage" attenuation factors. A noise parameter related to "usage factor" would be the state of the vehicle at the time of the EMP attack, e.g. is the engine running or off.

The mitigation design features that impact resilience to EMP will reside in the control factors in the p-diagram, some incorporated in the production vehicle to address EMI/EMC concerns, and other residing in potential mitigation upgrades:

- Vehicle under-hood shielding;
- Enclosure for the main ECU, i.e. the Faraday cage;
- Enclosures for the remainder of microprocessors utilized for various vehicle functions;
- Wire harness routing;
- Harness shielding and grounding;
- Sensor types, enclosures and shielding applied;
- Actuator types, their enclosures and shielding of the harness sections leading to those components;
- Transient voltage suppression devices, chokes and low-pass filters.

5.8 Methodology Summary

The purpose of the reliability planning diagrams shown in **Figure 13** to **Figure 20** was to provide a comprehensive picture of the problem to assure the essential elements of the vehicle electronics sub-systems and components are captured in the identification of potential failure modes to enable development of cost-effective mitigation design actions. The analysis will also assist in developing repair scenarios for "as-built" production vehicles. This information will serve as the foundation to develop a meaningful test plan for data to define the hazard risks from EMP which will be essential developing mitigation plans to make the transportation sector vehicles more resilient to EMP. The mitigation plans will embody one of two scenarios with an emergency management plan that will support continued

delivery of emergency services and lifeline supplies to the public immediately after the attack (discussed in **Section 8.0**). The two mitigation scenarios to be defined area as follows:

- Identify and engineering design changes that can be implemented strategically to increase resilience of vehicle to EMP supporting the emergency management plan with cost-effective EMP protection devices that can be implemented on select vehicles in the critical infrastructure.
- Development of logistics plans to address repair of damaged "as-built" vehicles in a reasonable period, i.e. within 4-12 weeks after the EMP event.

6 TEST PLAN AND HAZARDS RISK ANALYSIS PROPOSAL

6.1 Overview

To assess hazard risks in modern transportation sector vehicles resulting from the various modes for an EMP attack, additional tests are needed in EMP simulation laboratories. The EMP Commission reports (EMP Commission 2004, 2008) orchestrated the previous set of tests that provided early insight to potential problems that could arise from an EMP attack on transportation sector vehicles (see **Section *3.2.1.6*** in Transportation Sector Infrastructure). The EMP Commission did the best they could at the time with the budget available for testing of 37 passenger car vehicles between 1982 and 2002MY with EMP environments up to 50 KV/m with engine-on vs. engine-off operational states. Per the reports, the most serious effects observed were on cars with running engines causing the cars to glide to a stop requiring re-start, and in one vehicle the dashboard system was damaged requiring repair. Most vehicles exhibited malfunctions considered a nuisance such as blinking dashboard lights, all of which could be likely repaired in a dealership repair bay. In similar tests conducted on 18 trucks ranging from gasoline powered pickup trucks to large diesel powered tractors, model years 1991 to 2003, three of the truck engines stopped, two were re-started successfully, and one needed to be towed to a garage for repair. 10 of the trucks exhibited minor temporary responses, 5 trucks did not exhibit any anomalous response up to 50 KV/m.

Given the results of the past EMP simulation laboratory testing, why would one propose to run additional tests to assess the hazards risk level? The answers reside in two factors:

- Significant increase in electronics content since the 1982-2003 MY vehicles tested in 2002 that can lead to additional hazard failure modes and new risks.
- Optimized EMP weapons have been reported in the literature to delivery EMP field levels beyond the 50 KV/m tested in 2002 approaching levels up to 200 KV/m.

For passenger cars and light-trucks, the new technologies introduced in modern-day vehicles since the 1982-2002 model year vehicles were tested are:

- Drive by Wire systems (Wikipedia (2020)):
    - Throttle by wire (electronic throttles) for load control
    - Brake by wire (electronic braking systems)
    - Steer by wire (electronic steering systems, lane keeping monitors)
    - Park by wire (electronic parking brakes)
- Failures in Advanced Driver Assistance Systems (ADAS) customers are becoming more accustomed to in modern vehicles for various driving tasks (Bisen 2019) such as autonomous drive systems, adaptive cruise controls with electronic braking, lane keeping systems and others. Failures in these systems could lead to accidents if active during the EMP event.
- Increased complexity emissions control systems with electro-mechanical actuators and multiple sensors
- Technologies to improve fuel economy such as direct cylinder fuel injection, variable cam timing, cylinder deactivation

Similarly, for medium and heavy-duty truck applications, the new technologies introduced in modern-day trucks since the 1993-2003 model year vehicles were tested are:

- Modern automotive diesel engines utilizing high pressure common rail fuel injection systems with solenoid or piezoelectric fuel injectors, and electronically controlled fuel injection pumps.
- A similar introduction of electronic throttles, and electronic actuators and sensors in the emissions control systems.
- Significant increase in complexity in the emissions control systems including for diesel engines: numerous sensors; diesel particulate traps; and, Selective Catalytic Reduction (SCR) systems for Nitric Oxide exhaust emissions controls.

The proposed test plan will incorporate elements described in the remainder of this section to allow for an EMP hazards risk analysis to be completed with a new set of test data that will become the starting point for development of proposals for mitigation countermeasures and repair scenarios. Once the

damage impact is better understood, a sub-system component development program could be initiated where design mitigation measures are defined and tested to determine if the original issues discovered during EMP testing could be eliminated. Finally differentiating across the important categories of transportation sector vehicles and including those variations in the test plan will also add value to the investment for the new test program.

6.2 As-Built Vehicle Test Plan

Cars and light trucks have their own unique contribution to the transportation sector vehicles critical infrastructure. If the severity of EMP impact on this sector of transportation sector vehicles repeated the observations from the 2004 EMP Commission tests, then the problem would be resolved with vehicle re-starts, service bay repairs or no action for EMP mitigation measures required at all. In contrast, with the significant increase in electronics content in the modern automotive cars and trucks combined with the increased EMP field level intensity possible with Super-EMP optimized weapons, the assessment of severity on infrastructure will require more data. Similar comments can be made for the Medium Duty – Heavy Duty (MD-HD) truck market vehicles. The test plan was developed with the following strategy:

- Construct two test plans:
    - a) test plan for cars and light trucks; and
    - b) test plan for medium duty (MD) and heavy duty (HD) trucks.
- For cars and light trucks, cover cars, SUVs, and pick-up truck vehicle classes.
- For MD-HD trucks, cover Ford Transit or Dodge Ram style delivery vehicles, MD delivery and school bus trucks, and over-the-road Heavy Duty trucks.
- For drive systems cover non-hybrid, electric-hybrid, and electric drive systems.
- For SUVs, cover models utilized by Police emergency vehicles, a class of passenger cars and light trucks that would be desirable to develop design mitigation actions for EMP.

- For pickup trucks, cover the effect of aluminum/composite vs. all steel body, a potential significant control variable in attenuating the EMP signal prior to being absorbed by the under-hood wiring harness elements.
- Utilize a core design of experiments (DOE) multi-vehicle test to understand interaction effects from the various x-factor control and noise factor variables (discussed next).
- Utilize a supplemental set of vehicle tests at worst case one factor at a time (1FAT) test conditions since wiring harness designs, actuators, and sensors, although similar in function for all vehicles could incorporate subtle differences with varying sensitivities to EMP.

6.2.1 EMP Functional Diagram *(P-Diagram)* – Test Parameter Opportunities

To understand the opportunities for test parameters in an EMP laboratory setting, the EMP Functional p-diagram presented in **Figure 21** describes parameters that could be exercised during lab testing for as-built vehicles. For reference, parameters described in the original p-diagram presented in **Figure 20** are included but are highlighted white since use of these parameters would only be possible in an actual deployment situation with or without design mitigation actions implemented.

For inputs, the following are the desired driver operational modes that can be accommodated in a laboratory EMP test following exposure to various EMP pulse environments:

- Vehicle Entry/Start-up - Driver expects to successfully enter the vehicle and start the engine to an idle state before and after the EMP event.
- Drive State: Idle- After start-up, engine idles successfully after EMP event; no anomalies observed in vehicle sub-systems and component functions (will require checklist).
- Drive-state: Engine loaded/Drive-away – In coordination with the test lab procedures, it is desirable between EMP tests to engage the transmission in drive, and drive the vehicle over a short drive route to verify engine and transmission function, and proper function of the vehicle steering, braking, vehicle speed control systems, and other safety systems.

- Safe shutdown/Exit vehicle - After the Drive Idle and Drive-away states, the driver should be able to safely shut-down and exit the vehicle engaging the security interlock system.

The outputs in the p-diagram first point to the Ideal Function implying "Vehicle Fulfills Driver Demands w/o Incident". The Error states would involve "Vehicle Fails to Fulfill Driver Demand" anomalies:

- vehicle entry not possible
- vehicle will not start
- vehicle not running or runs erratically
- vehicle safety systems damaged (steering, braking, airbags, security inter-lock system)
- vehicle advanced driver assistance systems (ADAS) systems operating erratically

The test parameters that can be varied in a laboratory setting are the Control Factor and Noise Factor x-parameters. For control parameters, since this phase of testing involves evaluation of as-built vehicles, the variations in parameters shown in green in the p-diagram will be accomplished by testing different vehicle types which will inherently involve a suite of variations shown in the p-diagram. The design mitigation actions will be investigated after the initial as-built vehicle test program is complete. For Noise Factors, the factors noted in the p-diagram are opportunities for testing:

- Degradation factors, vehicles with low vs. high mileage
- Piece to Piece variation, testing multiple copies of the same vehicle type
- External EMP environment, 50 KV/m plus higher peak values per information on lab capabilities vs. expected EMP levels from optimized EMP weapon design.
- Repeat pulses of EMP, simulating a multi-pulse attack deployment scenario.
- Orientation of vehicle relative to EMP field grid
- Usage factor, vehicle running at time of EMP or shut-off.

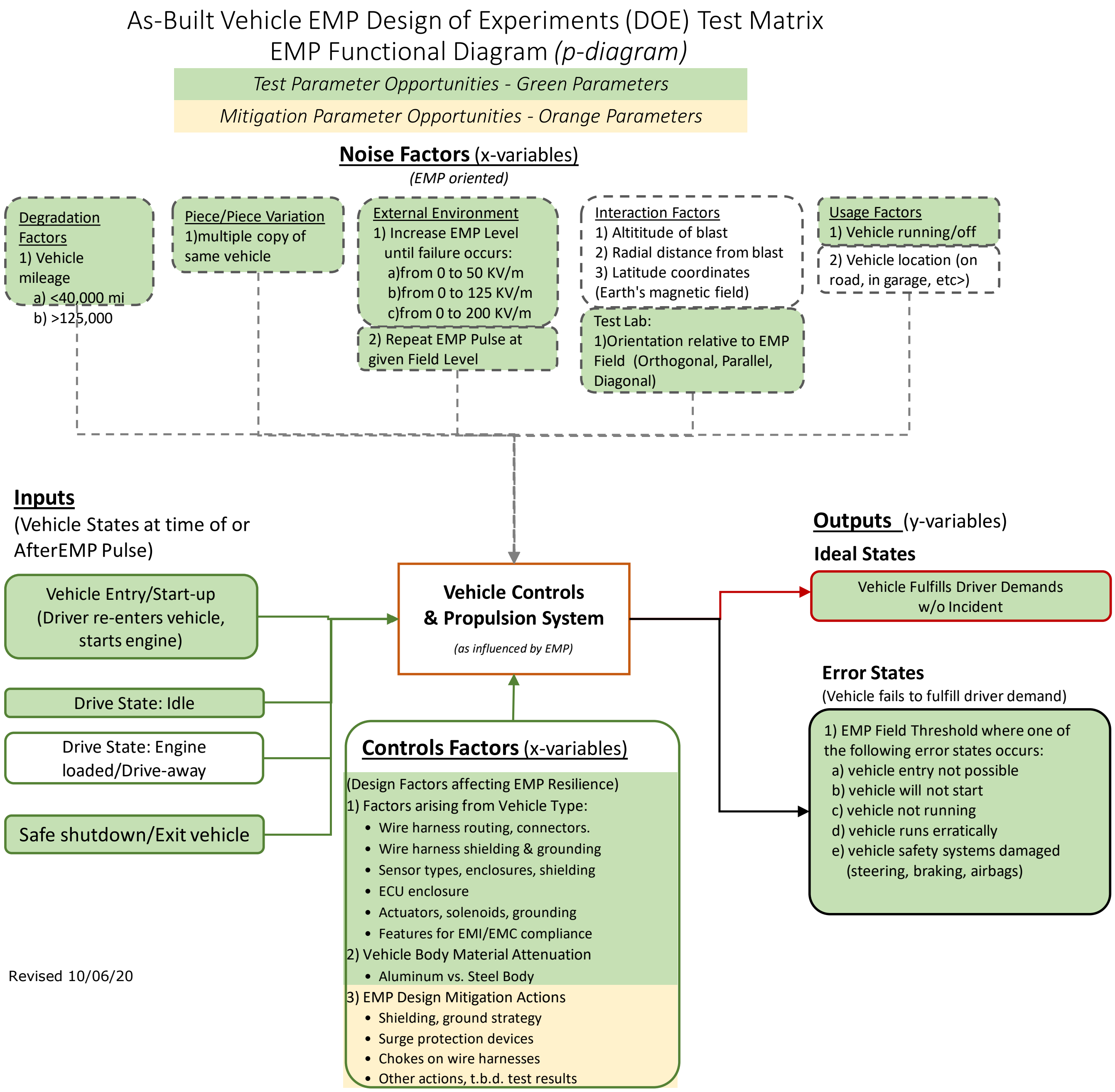


Figure 21 - EMP Functional p-Diagram For Test Planning
(Test Parameter Opportunities for EMP Laboratory Testing – Highlighted Green; Mitigation parameters, Orange)

Noise factors unavailable for lab testing would be factors related to the deployment of the EMP weapon such as height of burst, radial distance from the blast, and the earth's latitude coordinates as related to the interaction with the Earth's electric field.

6.2.2 Test Laboratory Summary

To support the test plan proposals, a survey of available test labs was conducted as presented in **Table 9**. Cost per shift for the DOE test matrix discussed in **Section 6.2.4** and **6.2.5** were based on ranges of costs across all the test labs. Actual test costs would have to be determined at the time of a formal grant proposal. Based on the information gathered from the labs, lab costs per shift (test day) ranged from $2000 to $4800/shift. For planning purposes, in the test matrix section, a cost of $2500 was assumed. Additional costs would include preparation costs for the test articles, and engineering support from the requestor and the lab operations personnel. Based on the survey of test labs, the existing facilities that could accommodate a full vehicle are the White Sands, NM Missile Range and the Patuxent River, MD test facility, both US Government Military affiliated test facilities that accommodate testing from commercial customers. The Keystone Compliance, Elite, Dayton Brown and NTS test labs presently conducts component and sub-system testing for EMP and full vehicle EMI/EMC testing. Such facilities could be converted to test full vehicles for EMP if there was a grant funding opportunity.

Table 9 - EMP Test Laboratories for Vehicle and Component Sub-System Testing

EMP Test Labs for Vehicle and Laboratory Sub-System Testing					
No.	**Laboratory**	**Type of Tests Supported**	**Location**	**Contact/Website:**	**Capabilities/Comments**
1	White Sands Missile Range	• Vehicle, Sub-System and Component Level Testing	White Sands Missile Range, New Mexico	Usarmy.wsmr.pao@mail.com 575-678-1134 https://www.wsmr.army.mil/testcenter/testing/landf/Pages/ElectromagneticTestFacilities.aspx https://www.wsmr.army.mil/PAO/Pages/Home.aspx https://www.wsmr.army.mil/testcenter/services/neee/eme/pages/default.aspx https://www.wsmr.army.mil/testcenter/testing/landf/Pages/ElectromagneticTestFacilities.aspx	• Two test areas for EMP • Horizontal and vertical simulators • Rotational platform in one facility for orientation test • Simulated water tank for marine simulation • Anechoic chamber capability • Extensive EMP test history w/MIL vehicles, aircraft, naval vessels • Provides test engineering support services • Cost / shift ~ $
2	Keystone Compliance	• Sub-system, Component Level Testing • Willing to build vehicle test chamber to customer specs	New Castle, PA (outside Pittsburg)	Tony Masone (EMC Lab Mgr.) (724) 657-9940 tonyjr@keystonecompliance.com www.keystonecompliance.com	• RS-105 (MIL-STD-461-G) HEMP testing • EMP test chamber, parallel plate antennas capable of RS-105 50 KV/m • Anechoic chamber test chamber • Device Under Test (DUT) ~2-3 ft x 2-3 ft x 2-3 ft • Test chamber can be modified for larger DUTs including full test vehicle • Worked on Ford Motor Co vehicles to validate FMC 1280 EMI/EMC standards (BIC designs, connectors, shell design) • Can provide design services

3	Elite Electronic Engineering, Inc.	Component level, sub-system testing	Downers Grove, IL	Steve Laya
				Sales and Marketing Manager
				sglaya@elitetest.com
				Desk: (630)495-9770 x119
				Cell: (630)805-1809
					Elite Existing Test Capabilities:
					• MIL-STD-461-G RS-105 testing
					  ○ 50kV/m, (1.8-2.3)nsec x 23+/-5nsec
					• IEC 61000-4-25
					  ○ 50kV/m, (2.0-2.5)nsec x 25-30nsec

				www.elitetest.com https://www.elitetest.com/testing-services/emiemc-testing/lightning-hirf-emp/emp-testing	• 1.2m parallel plates, anechoic chamber • Number of waveforms tests supported • Plate area 1m x 2m, separation 1.2m ○ DUT max • Recommended contacting Dr. William (Bill) Radasky for more info on HEMP testing
4	Patuxent River (Pax River)	Full Vehicle level testing	Patuxent River, Maryland	https://federallabs.org/labs/naval-air-warfare-center-nawc-aircraft-division-patuxent-river?page=0%2C0%2C0%2C3 https://federallabs.org/labs/electromagnet-environmental-effects-e3-facilities https://virtualglobetrotting.com/map/electro-magnetic-pulse-emp-test-range/view/google/ https://apps.dtic.mil/dtic/tr/fulltext/u2/a606571.pdf	• Limited Web Information • PS-6 pulse generator capable of EMP levels from 15KV/m (single ended) to 77 KV/m (double ended) • Test pad accommodates large test articles • Need to contact (Dr. Bill Radasky recommendation)
5	NTS Test Services	Component level, sub-system testing	McKinney, Texas	Jeffrey Viel Chief Engineer EMI/EMC/E3 Regional Sales rep for New England Jeffrey.Viel@nts.com https://www.nts.com/services/testing/emc/electromagnetic-pulse-testing/	• EMP testing, 50 KV/m per RS-105 for MIL-STD-461G • Large semi-anechoic EMI chamber (~ 10m measurement chamber), 65ft long x 40 ft wide x 26 ft tall w/chamber door 12ft x 12 ft. equipped to test full size vehicles for EMI/EMC testing • For EMP, pulse transmission hardware limits DUT to approximately 3ft x 3ft x 3 ft • EMP testing for vehicle size DUT's will require new investment
6	Dayton T. Brown	Component and sub-system testing	Long Island, NY	Tom Volpe 516-901-2270 https://www.dtb.com/testing-electrical-EMP.php	• 50 KV/m per RS-105 for MIL-STD-461G • Dayton T. Brown cannot test full vehicles ○ DUT Max size= 4ft x 4ft x 6 ft
7	Holland Shielding Systems	EMP Mitigation Design, limited testing	The Netherlands	https://hollandshielding.com/EMP-Protection	• Mitigation design solutions • Building mitigation concepts

6.2.3 Design of Experiments (DOE) Test Plan– Overview

Two design of experiments (DOE) test plans are proposed, one for cars and light trucks, and another for medium duty delivery and heavy-duty commercial trucks. A DOE test plan takes a set of x-factors deemed important, and then a factorial test matrix is created to vary the input x-parameters systematically in an orthogonal manner so the main effects of the parameters and the interactions are quantified. To understand why a DOE test plan is proposed, the concepts of interaction vs. non-interaction parameters will be described. In **Figure 22,** factors recommended for the DOE test matrix are presented along with the rationale. Once the DOE tests are conducted with the parameters described in **Figure 22,** sufficient information should be generated to provide a basis for worst case on additional vehicles as described in **Section 6.2.6** without the DOE test format. Providing additional budget and

DOE Interaction Test Parameters	**(Rationale)**
X1 - Vehicle Type	(Vehicle design could interact w/EMP
X2 - Peak EMP Field Level	(Optimized EMP weapons produce EMP > 200 KV/m; EMP level varies by location from blast, HOB, etc.)
X3 - No. of Repeat EMP Pulse Inputs	(Optimized EMP deployment could be via multiple warheads sequenced, yielding multiple EMP pulses)
X4 - Steel vs. Aluminum Body	(Attenuaton factor; Ford introduced Alumimum body panels on F150 in 2015 and the Expedition in 2018 which could be an important factor in under-hood attenuation of the EMP pulse
X5 - Vehicle Orientation	(Orientation of vehicle in test lab relative to the parallel plate grid. A diagonal or orthgonal orientation could yield a larger EMP pulse in the wiring system vs. a parallel orientation.)

Figure 22 - Parameters for DOE Tests to Understand Interactions

Single Factor Test Parameters	**(Rationale)**
X1 - Multiple copies of same vehicle	(2nd vehicle may respond differently than 1st vehicle)
X2 - More vehicle types	(Different manufacturer for same vehicle types, example, additional SUVs used for police vehicles)
X3 - Diesel vs. Spark Ignited	(For selected vehicles, both gasoline and diesel engines are offered providing an opportunity for back to back engine-type comparison)
X4 - Electric vs IC Engine	(Adding 1-2 electric vehicles would be valuable given the recent increased interest in electric cars for zero emissions green vehicle markets)
X5 - Vehicle Mileage	(A test of mileage and multiple copies of same vehicle, combined (could a higher mileage vehicle respond differently than a lower mileage vehicle)

Figure 23 - Vehicle Type Test Parameters Not Requiring DOE Testing
(run at worst case DOE Test Conditions)

interest is available to conduct additional vehicle tests, valuable test data will be generated with additional vehicle types to improve the fidelity of the hazards risk assessment for EMP imposed on various transportation sector vehicles.   Parameters summarized in **Figure 23** could be considered**.**

In **Figure 24**, illustrations were created to show interaction vs. no-interaction effects with hypothetical data. Given a measure of failure rate, failure severity or other metric developed, the left two diagrams show different response rates across vehicles for increases in EMP field levels (upper left diagram) and orientation in test chamber (lower left diagram), i.e. the lines are not parallel. In the right

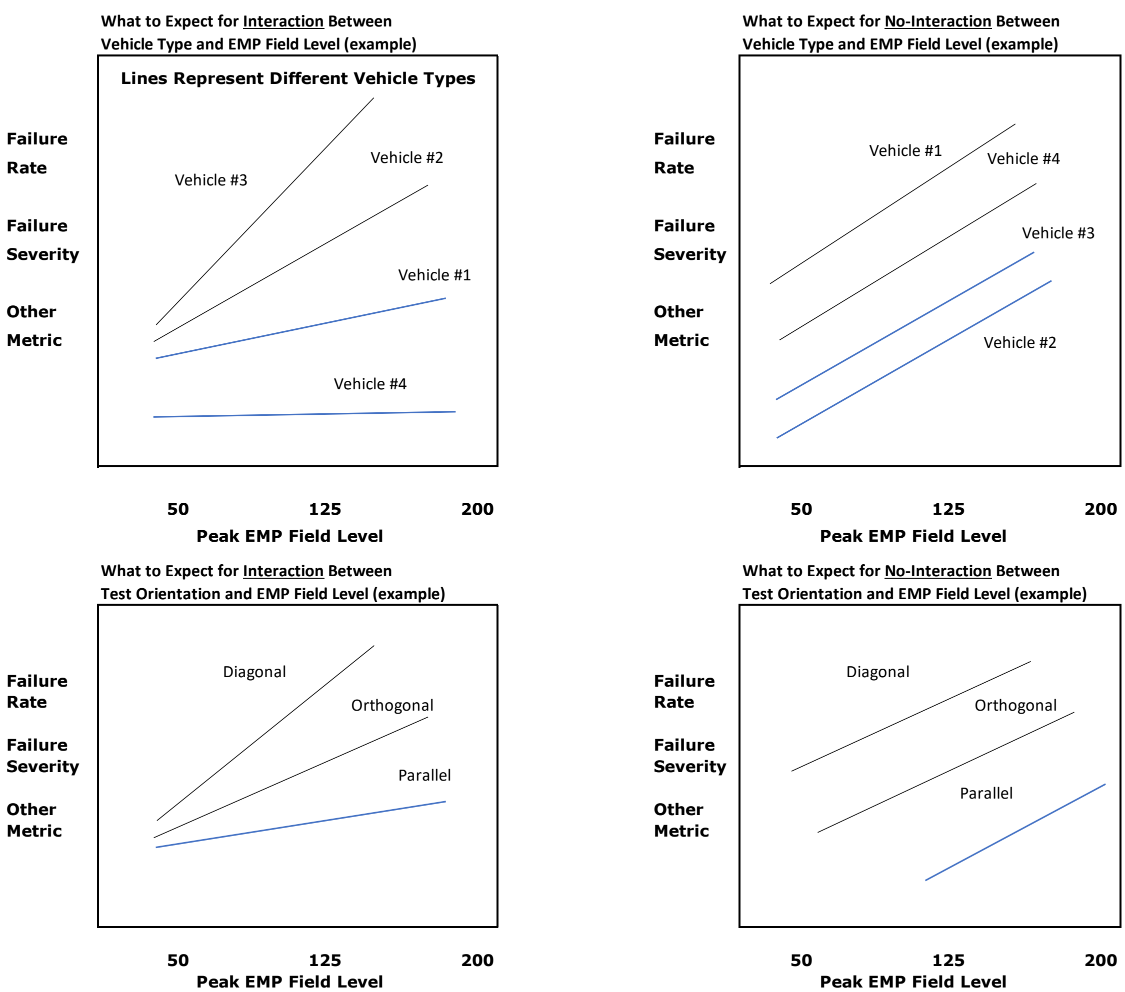


Figure 24 - Illustrations, Interactions vs. No Interactions in a DOE Test

two diagrams in **Figure 24**, the response rates are equal, i.e. the lines are parallel. With a properly designed orthogonal DOE, such information will be obtained as a result of the testing.

6.2.4 Proposed Test Plan– Cars and Light Trucks

The objective of the proposed test plan for cars and light trucks is to support creation of a hazards risk assessment based on test data which will drive the development of a cost effective mitigation plan to improve resilience of modern transportation sector vehicles to an EMP attack. Without the new data, the risks will not be understood. If an unfortunate attack occurred and the impacts to transportation sector vehicles were significant, then major disruptions will occur in delivering lifeline supplies to the residents in affected areas, and corresponding loss of public services will also be impacted such as police protection, emergency services, etc. The proposed test plan is composed of two segments:

1) Full factorial DOE test matrix to allow for understanding the important main effects and interactions associated with factors leading to failure modes due to exposure to the EMP pulse.

2) Follow-up vehicle tests for the wider range of vehicle types conducted at worst case conditions discovered in the DOE to supplement data for the hazards risk assessment.

The data will be used to create projections of how the transportation sector is disrupted, what can be expected in loss of lifeline supplies, how capable are dealership repair bays in repairing the vehicles, will there be sufficient spare parts, will there be a significant loss in critical public services such as police protection, fire and EMS response, etc.

The DOE Test plan for cars and light trucks is presented in **Table 11**. The test matrix is a full factorial DOE test matrix which will allow for determination of the main effects and interactions among the x-factors. The 1st x-factor is the vehicle type with 4 vehicle types chosen covering a wide range of characteristics, capturing hybrid vs. conventional powertrain, aluminum body vs. steel body, SUV vs. car or truck. The rationale on vehicle type selection are as follows:

- Passenger car- Toyota Camry, popular passenger cars sold in North America, reasonably electronics heavy, hybrid option adds a future wide-spread technology mix for future passenger cars
- SUV – Ford Explorer, direct injection spark ignited engine configuration with variable cam timing, electronics heavy, powertrain platform same / similar as Police car package, lessons learned can be addressed in mitigation design actions for potential implementation in future police packages.
- Pickup-Steel Body, Chevy Silverado LTZ, steel body pickup, electronics heavy, similar content as Ford F150 Lariat, different actuator components for fuel economy improvement (cylinder deactivation w/port injection)
- Pickup-Aluminum Body, Ford F150 Lariat, aluminum body, possible significant factor affecting attenuation of EMP to under-hood component impact, electronics heavy similar to Chevy Silverado LTZ, different actuator components for fuel economy improvement (variable cam timing w/direct injection)

The 2^{nd} x-factor is the EMP Field with two levels chosen.

- The 50KV/m level is carry-over from the standard described by RS-105 per MIL-STD-461-G, with waveform shape utilized in all EMP test labs.
- The higher 200/max KV/m level represents the max EMP level reliably achieved in the EMP test lab that approaches the worst-case conditions expected with optimized EMP nuclear devices discussed in the literature.
    - Note: The "200/max" KV/m EMP level is assumed to be a separate run in the DOE vs. combining the effects for 50 and 200/max KV/m into a single run with progressively increased EMP levels. The reason is the 50 KV/m level has been established as an industry standard worldwide for EMP testing per MIL STD 461G (RS-105) with established test equipment. 200/Max KV/m will need to be generated with new test equipment and methods simulating Super-EMP weapons; hence, introducing another variable in the experiment. It's recommended these equipment sets be used discretely to enable a historic reference to be

created with the 50 KV/m equipment while new data can be obtained with what was created to achieve higher EMP field test conditions. It's likely the facility will not be able to reach the 200 KV/m level; hence, once a formal test program commences, discussions with the laboratories and technical experts are suggested to reach an agreed upon EMP level for the 200/max KV/m setting in the DOE.

The 3rd x-factor is the Vehicle Orientation parameter with two levels indicated in the FF (full factorial) DOE in **Table 11**. Vehicle orientation is the nose-to-tail relationship of the vehicle relative to the EMP field grid plates used to impose the EMP pulse in the test chamber. There could be a sensitivity due to how the wiring harness system and components are arranged in the under-hood environment relative to how the grid imposes the EMP pulse on the vehicle. The most severe condition would have to be

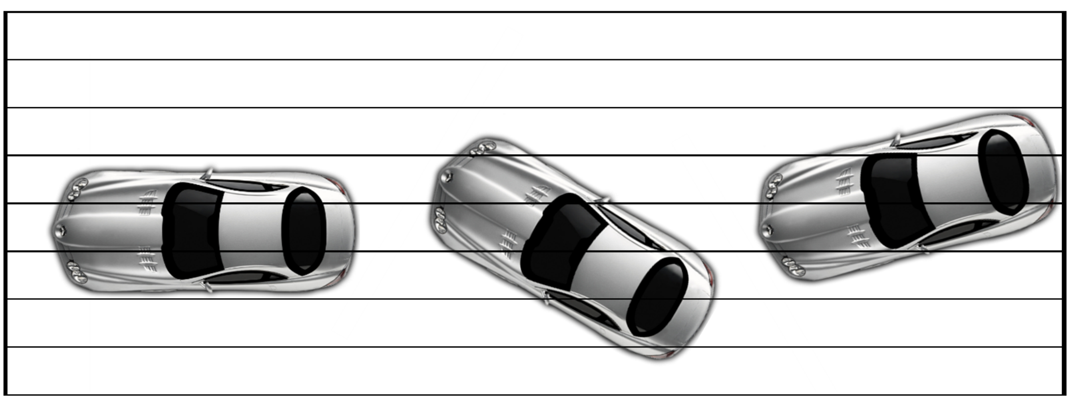


Figure 25 - Parallel Orientations Relative to EMP Grid (0, +30, -30 deg)

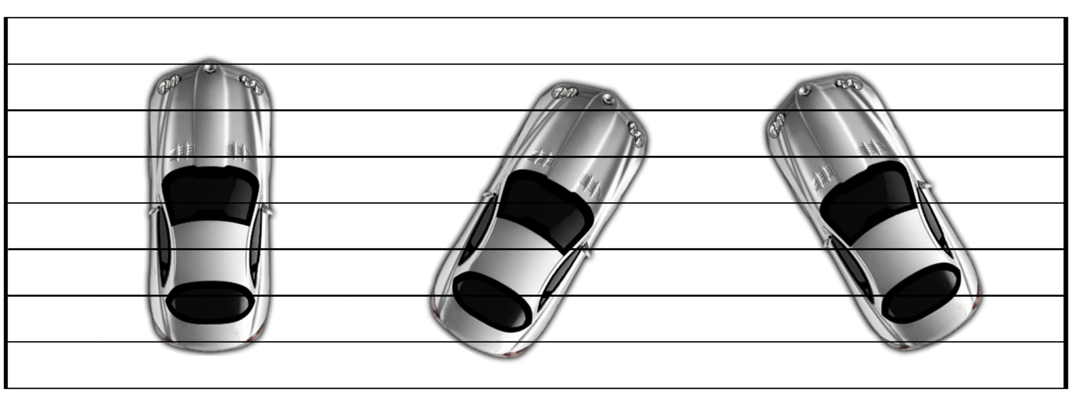


Figure 26 - Perpendicular Orientations Relative to EMP Grid (90, 120, 60 deg)

determined experimentally and could yield positions that are not exactly parallel or perpendicular to the grid. To resolve this issue without introducing more vehicles into the test matrix, the vehicle is proposed to be rotated in conjunction with the 3 repeat pulses for each EMP level with is part of the proposed test procedure. Referring to **Figure 25** and **Figure 26**, the DOE setting designated as parallel in **Table 11** will run the 3 pulse test at 0, +30 and -30 deg. Similarly, for the DOE setting of Perpendicular, the 3-pulse test at 90, 120 and 60 deg.

Test procedure details and work instructions will be refined at the time of test. The proposed test sequence described at a summary level in **Table 11** and clarified below will be the basis for the procedure. The test sequence summary described **Table 10** combined with the DOE test matrix presented in **Table 11** are designed to achieve the following objectives:

1) Exercise 4 vehicle types through plausible EMP scenarios to provide data for risk assessment.
2) Run the prior art MIL-STD-461G (RS-105) Standard 50KV/m EMP level as well as an elevated level (200/Max KV/m) closer to the maximum threat expected for an EMP attack
3) Cover effects of vehicle orientation relative to the EMP grid
4) Progressively increase EMP level to define the threshold for failure for both engine off and engine running operational modes.
5) Provide data from vehicle manufacturer diagnostic scan tools as well as subjective drive evaluations to quantify anomalies discovered caused by EMP pulse exposure.
6) Due to the Full Factorial DOE test matrix design, interaction effects will be quantified across the x-variables for vehicle type, EMP field level and orientation, as well as the main effects.
7) The results of the test will assist in establishing worst case conditions if budget is available to test additional vehicles at the worst-case settings for EMP level and orientation.

The matrix plot presented in **Figure 27** helps illustrate the main effects captured in the DOE presented in **Table 11**. The DOE test plan included 4 vehicle types tested, 2 EMP levels, 50 and 200 Kv/m, and two orientations, parallel and perpendicular.

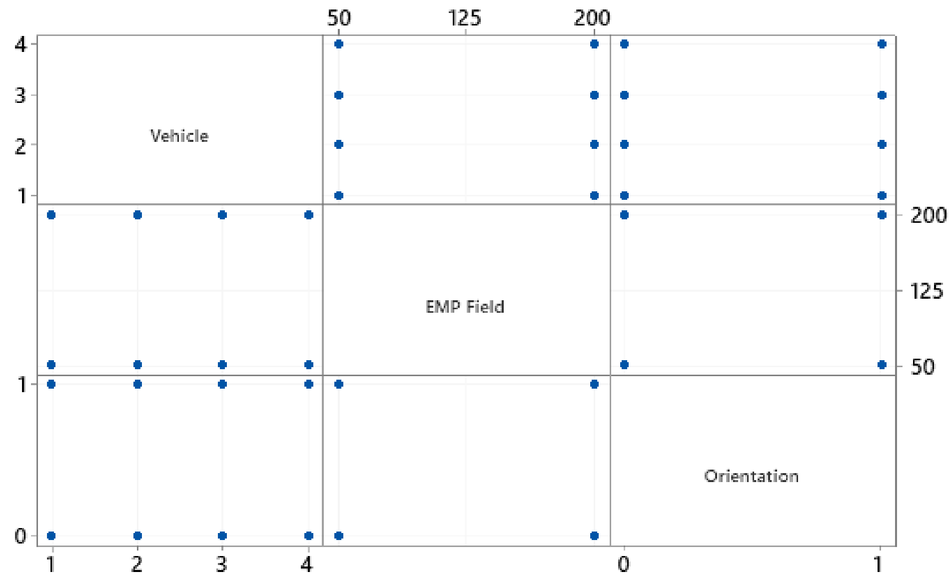


Figure 27 - Matrix Plot of Test Parameters for 3 Factor 3x2x2 Level DOE (Minitab (2020))
(Vehicle, 4 types tested; EMP field, 50, 200/max KV/m; Orientation; 0-parallel, 1-perpendicuclar)

Table 10 - Test Procedure Sequence for DOE Test Matrix

1) Run baseline vehicle diagnostic tests with manufacturer's scan tool, establish drive evaluation metrics on short drive route close to test site, and conduct baseline drive evaluation.
2) Setup instrumentation and lab equipment in test chamber, install vehicle for testing.
3) a) Set EMP Pulse generator to **10%** of desired setting (for example, if EMP Field setting is 50 KV/m, set EMP level to 5 KV/m).
   b) Run EMP test w/engine OFF; Run Diagnostic Tests
   c) Run 3 EMP tests w/engine ON at 3 Vehicle Orientations noted in **Figure 25** and **Figure 26**, per orientation specification in **Table 11**. Run diagnostic tests with vehicle drive evaluation if possible.
4) a) Set EMP Pulse generator to **20%** of desired setting (example, for 50KV/m, set EMP level to 10 KV/m).
   b) Run EMP test w/engine OFF; Run Diagnostic Tests
   c) Run 3 EMP tests w/engine ON at 3 Vehicle Orientations per notes in (3c). Run diagnostic tests with vehicle drive evaluation if possible.
5) a) Set EMP Pulse generator to **50%** of desired setting (example, for 50KV/m, set EMP level to 25 KV/m).
   b) Run EMP test w/engine OFF; Run Diagnostic Tests
   c) Run 3 EMP tests w/engine ON at 3 Vehicle Orientations per notes in (3c). Run diagnostic tests with vehicle drive evaluation if possible.
6) a) Set EMP Pulse generator to **max%** of desired setting (example, for 50KV/m, set EMP level to 50 KV/
   b) Run EMP test w/engine OFF; Run Diagnostic Tests
   c) Run 3 EMP tests w/engine ON at 3 Vehicle Orientations per notes in (3c). Run diagnostic tests with vehicle drive evaluation if possible.
7) Run detailed vehicle diagnostic tests with vehicle manufacturer scan tool, conduct drive evaluation to identify anomalies in vehicle functions.

e

Table 11 - Design of Experiments (DOE) Test Plan Proposal: Cars and Light Trucks

EMP Design of Experiments (DOE[1]) Test Planning Worksheet | **Vehicle Class: Passenger Cars & Light Trucks** | 5/29/2020 Rev.

Full Factorial DOE Design Test Plan Matrix

2022 <== Assumed year of test

Vehicle Costs (assume purchase & scrap after test)				
Est. Cost[8]	**Type**	**Ref.[2]**	**MY Desired for Test[3]**	**MY for Cost Est[4]**
$ 21,000	Passenger Car	Toyota Camry Hybrid	2020	2018
$ 32,000	SUV	Ford Explorer Sport[5]	2020	2018
$ 31,000	Pickup - Steel Body	Chevy Silverado (LTZ V8)[6]	2020	2018
$ 30,000	Pickup - Alum. Body	Ford F150 (Lariat 5.0L V8)[7]	2020	2018

EMP Lab Costs & Test Engineering		
EMP Test	Lab Costs/Test	$2,500
Engineering	% of Veh Cost	4%
Test Prep	% of Veh. Cost	3%

Projected Test Costs	
A) Procurement	$ 456,000
B) Prep for Test	$ 13,680
C) Lab Charges	$ 40,001
D) Test Engr.	$ 18,240
Totals (ROM Est)	**$ 527,921**

		x-factors		Cost Estimates			
Run No.	**Vehicle***	**EMP Field (KV/m)**	**Vehicle Orientation[9,10]**	**Est Veh Cost**	**Est. Prep Cost**	**Est. Lab Cost**	**Est. Test Engr. Cost**
1	SUV	50	Perpendicular	32000	960	$ 2,500	$ 1,280
2	Pickup-Alum	200/max	Perpendicular	30000	900	$ 2,500	$ 1,200
3	Pickup-Alum	50	Perpendicular	30000	900	$ 2,500	$ 1,200
4	PassCar	50	Perpendicular	21000	630	$ 2,500	$ 840
5	Pickup-Alum	200/max	Parallel	30000	900	$ 2,500	$ 1,200
6	Pickup-Steel	50	Perpendicular	31000	930	$ 2,500	$ 1,240
7	Pickup-Steel	200/max	Parallel	31000	930	$ 2,500	$ 1,240
8	PassCar	50	Parallel	21000	630	$ 2,500	$ 840
9	Pickup-Steel	50	Parallel	31000	930	$ 2,500	$ 1,240
10	SUV	200/max	Perpendicular	32000	960	$ 2,500	$ 1,280
11	Pickup-Steel	200/max	Perpendicular	31000	930	$ 2,500	$ 1,240
12	PassCar	200/max	Parallel	21000	630	$ 2,500	$ 840
13	SUV	50	Parallel	32000	960	$ 2,500	$ 1,280
14	Pickup-Alum	50	Parallel	30000	900	$ 2,500	$ 1,200
15	PassCar	200/max	Perpendicular	21000	630	$ 2,500	$ 840
16	SUV	200/max	Parallel	32000	960	$ 2,500	$ 1,280

#	**Proposed Test Sequence Per Run No. Configuration[10]**	**Est Time (min)**
1	Install vehicle; setup instrumentation	30
2	Run diagnostic system prior to test.	10
3	Set EMP Pulse generator to **10%** of desired setting	15
3a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
3b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientations	45
3c	Run diagnostic tests w/vehicle evaluation if possible	30
4	Set EMP Pulse generator to **20%** of desired setting	15
4a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
4b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientations	45
4c	Run diagnostic tests w/vehicle evaluation if possible	30
5	Set EMP Pulse generator to **50%** of desired setting	15
5a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
5b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientations	45
5c	Run diagnostic tests w/vehicle evaluation if possible	30
6	Set EMP Pulse generator to **max%** of desired setting	15
6a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
6b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientations	45
6c	Run diagnostic tests w/vehicle evaluation if possible	30
7	Run detailed vehicle diagnostics & drive evaluation	20
	Totals (480 min total per 8 hr shift)>>	**480**

Notes:

(1) DOE Generated by Minitab (Minitab (2020))
(2) Proposed plan is purchase 2 yr. old vehicles to save purchase costs. Example, test run in 2020, purchase 2018 vehicle.
(3) Desired model year for test based on assumed year of test
(4) Model year for cost estimate based on assumed year of test, and desired model year for test (assume 2 yr old vehicle)
(5) Ford Explorer Sport, most similar to Ford Explorer Police Package (possible future design mitigaton project)
(6) 2020 Chevy Silverado LTZ, steel body, electronics-heavy, similar to the F150 w/different actuator & controls components
(7) 2020 Ford F150 Lariat, aluminum body, electronics-heavy similar to Silverado w/different actuator & controls components.
(8) Estimated Costs from www.cars.com
(9) Vehicle orientation relative to EMP Electric Field Antennas (perpendicular or parallel)
(10) Prior to test, run special screening test to determine worst case parallel, perpendicular or diagonal orientation

6.2.5 Proposed Test Plan– Delivery Vehicle, and Medium/Heavy-Duty Trucks

Similar to the test plan developed for cars and light trucks, a test plan was also developed for delivery vehicles and Medium to Heavy Duty Trucks as presented in **Table 12**. Since this vehicle class is more costly than the cars and light trucks, it is proposed to only test 3 vehicle types:

1) **Delivery Van** style commercial delivery van popular for local deliveries. The Ford Transit was selected for the DOE, but other manufacturers produce similar vehicles such as Chevrolet Express/ GMC Savana, Mercedes-Benz Sprinter, Nissan NV, and the Dodge Ram ProMaster.
2) **Medium Duty Delivery/School Bus** style truck would be a popular powertrain platform for school buses and local box style delivery trucks.
3) **Heavy duty over the road tractor style truck** would represent the trucks used for the commercial truck infrastructure for delivery of lifeline supplies to the nation.

All three vehicle classes have experienced the same evolution of increased electronics content as passenger cars and trucks whereas in 2002 when the EMP commission tests were run with 1991 to 2003 vehicles, electronics were present in the vehicles but not to the level of modern day commercial trucks. The tests are aimed to help establish the risks to enable the most cost-effective hazard mitigation plan to be developed similar to cars and light trucks. For this vehicle class, will the damage levels be solvable in the dealership repair bays with sufficient level of spare parts, or should selected vehicles be modified to become more resilient to EMP? The test data will enable these questions to be answered.

The test procedures for trucks will be similar to the car test procedure described in **Table 10** with the exception that we're dealing with a much larger vehicle which could require more time to maneuver in and out of the test pad area. The intra-test evaluations that are proposed to incorporate both diagnostic scan tool tests as well as short vehicle drive evaluations are important. There are many systems in the vehicles that involve micro-processors and some failure modes may not be quantified via the scan tools alone vs. the drive evaluation tests. This will require efficient entry, positioning and exit from the test pad area.

The objectives for the DOE tests for the Delivery Van and Commercial trucks described in **Table 10** will be the same as the objectives for cars and light trucks. Similar to cars and light trucks, once the DOE is complete, and worst case conditions are defined, additional vehicles can be purchased or borrowed to run through the test pad to increase sample size for a given set of test conditions for EMP level and vehicle orientation. This could include certain classes of emergency vehicles such as fire trucks, additional over-the-road tractor style vehicles, actual school buses, and local transportation city buses. Testing a hybrid vs. gasoline or diesel powertrain could also be considered.

6.2.6 Supplemental Vehicle Testing

If additional budget is available for the car and light truck testing, additional vehicles cold be considered for testing at worst case conditions once the DOE tests are complete. A procedure could be considered as follows:

1) From the DOE testing, determine a suitable worst-case test condition for peak EMP level and vehicle orientation.
2) Select and procure additional vehicle types for test beyond what was tested in **Table 11**. Examples:
    a. Pickup truck with diesel vs. gasoline engine.
    b. Electric car
    c. Non-hybrid passenger car
    d. Alternate to Explorer for vehicle popular as police car (potential mitigation project)
    e. Higher mileage (>100,000 miles) versions of cars tested in **Table 11**.
    f. Repeat of 1 vehicle tested by the EMP Commission in 2004 (EMP Commission (2008)) for cross-reference.
3) Run test procedure outlined in **Table 10** at worst cast test conditions determined in (1).

6.2.7 Estimated Costs for Testing

Included in the DOE test plans for both Cars and Light Trucks (**Table 11**) and Delivery Trucks and Heavy Duty Trucks (**Table 12**) are cost estimates for the test programs. The cost numbers should be considered as Rough Order of Magnitude (ROM) cost estimates subject to refinement once an actual grant proposal is pursued. The cost numbers could be considered conservative on one hand since the assumption was made that all the vehicles would be non-saleable after testing was completed. For the truck test matrix in **Table 12**, it's likely at least the more expensive Medium Duty delivery and Over-the-Road Tractor style vehicles could be repaired or rebuilt and become saleable which should reduce vehicle purchase cost by 30-60%. Depending on the source of funding, likely the Federal Government, it may also be desirable to quarantine these vehicles for future design mitigation projects. Assuming there is a significant failure rate for the vehicles, various research and academic organizations could pursue a project to develop a design solution for that particular vehicle yielding a divide and conquer approach to solve the mitigation problem. Original Equipment Manufacturers (OEMs) could support such projects at close to zero cost supplying production hardware for testing, and production subsystem to build on their knowledgebase particularly if the Government provides incentives to participate which could come in the form of fuel economy or emissions credits for their high-volume manufactured customer vehicles.

The costs for testing as noted in **Table 11** and **Table 12** were ~$500K for the cars and light trucks, and ~$700K for the delivery vans and Medium-Heavy Duty trucks. If additional vehicles are tested at worst case conditions, this could add $100-200K for the cars, and $300-500K for the trucks. In developing a test plan proposal, the costs for preparation of the vehicles, engineering support while running tests, and lab costs must be considered. Hopefully, these estimates are useful in placing our objectives into perspective. Finally, the cost estimates do not include the costs of any design work for hazard mitigation. This would be a separate endeavor which could be similar in magnitude 0.5 to 1x to the original multi-vehicle DOE tests costs, depending upon how production ready the design solutions must be to provide mitigation measures for the EMP levels that caused damage during the testing.

Table 12 - Design of Experiments (DOE) Test Plan Proposal: Delivery & Medium/Heavy Duty Trucks

EMP Design of Experiments (DOE[1]) Test Planning Worksheet	Vehicle Class:	Medium - Heavy Duty Truck	5/29/2020	Rev.
Full Factorial DOE Design Test Plan Matrix				
2022	<== Assumed year of test			

Vehicle Costs (assume purchase & scrap after test)				
Est. Cost[6]	Type	Ref.[2]	MY Desired for Test[3]	MY for Cost Est[4]
$ 20,000	Transit Style-Commercial	Ford Transit	2020	2018
$ 60,000	MD Delivery/School Bus[5]	International 4300	2020	2018
$ 80,000	OverRoad-Cab	International LT625	2020	2018

EMP Lab Costs & Test Engineering		
EMP Test	Lab Costs/Test	$2,500
Engineering	% of Veh Cost	4%
Test Prep	% of Veh. Cost	3%

Projected Test Costs	
A) Procurement	$ 640,000
B) Prep for Test	$ 19,200
C) Lab Charges	$ 30,000
D) Test Engr.	$ 25,600
Totals (ROM Est)	**$ 714,800**

	x-factors			Cost Estimates			
Run No.	Vehicle	EMP Field (KV/m)	Vehicle Orientation[7,8]	Est Veh Cost	Est. Prep Cost	Est. Lab Cost	Est. Test Engr. Cost
1	MedDelivery	50	Perpendicular	60000	1800	$ 2,500	$ 2,400
2	LightDelivery	50	Perpendicular	20000	600	$ 2,500	$ 800
3	OverRoad	50	Perpendicular	80000	2400	$ 2,500	$ 3,200
4	OverRoad	200/max	Parallel	80000	2400	$ 2,500	$ 3,200
5	LightDelivery	50	Parallel	20000	600	$ 2,500	$ 800
6	OverRoad	50	Parallel	80000	2400	$ 2,500	$ 3,200
7	MedDelivery	200/max	Perpendicular	60000	1800	$ 2,500	$ 2,400
8	OverRoad	200/max	Perpendicular	80000	2400	$ 2,500	$ 3,200
9	LightDelivery	200/max	Parallel	20000	600	$ 2,500	$ 800
10	MedDelivery	50	Parallel	60000	1800	$ 2,500	$ 2,400
11	LightDelivery	200/max	Perpendicular	20000	600	$ 2,500	$ 800
12	MedDelivery	200/max	Parallel	60000	1800	$ 2,500	$ 2,400

#	Proposed Test Sequence Per Run No. Configuration[10]	Est Time (min)
1	Install vehicle; setup instrumentation	30
2	Run diagnostic system prior to test.	10
3	Set EMP Pulse generator to **10%** of desired setting	15
3a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
3b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientatio	45
3c	Run diagnostic tests w/vehicle evaluation if possible	30
4	Set EMP Pulse generator to **20%** of desired setting	15
4a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
4b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientatio	45
4c	Run diagnostic tests w/vehicle evaluation if possible	30
5	Set EMP Pulse generator to **50%** of desired setting	15
5a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
5b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientatio	45
5c	Run diagnostic tests w/vehicle evaluation if possible	30
6	Set EMP Pulse generator to **max%** of desired setting	15
6a	Run EMP test w/engine OFF; Run Diagnostic Tests	15
6b	Run 3 EMP tests w/engine ON at 3 Vehicle Orientatio	45
6c	Run diagnostic tests w/vehicle evaluation if possible	30
7	Run detailed vehicle diagnostics & drive evaluation	20
	Totals (480 min total per 8 hr shift)>>	**480**

Notes:

(1) DOE Generated by Minitab

(2) Proposed plan is purchase 2 yr. old vehicles to save purchase costs. Example, test run in 2020, purchase 2018 vehicle.

(3) Desired model year for test based on assumed year of test

(4) Model year for cost estimate based on assumed year of test, and desired model year for test (assume 2 yr old vehicle)

(5) Powertrain and engine compartment for school bus and medium duty delivery box trucks are similar, assumed to be equivalent; hence, covered by single vehicle class

(6) Estimated Costs from www.Cars.com and www.Internationalusedtrucks.com

(7) Vehicle orientation relative to Electric Field Antennas (perpendicular or parallel)

(8) Prior to test, run special vehicle orientation screening test to determine if perpendicular or diagonal orientation produces most severe EMP pulse within the vehicle wiring system.

6.3 Modified Vehicle Test Plan

Modified Vehicle test scenarios will encompass plans to validate design mitigation actions to address issues discovered during testing. Assuming a particular component failed during the tests outlined in **Section 6.2.4** and **6.2.5,** a design mitigation action would be developed per the engineering subject matter experts, a prototype would be built, and the test sequence outlined in **Table 10** would be re-run to determine if the design action made the vehicle component resilient to EMP. Once the prototype was built and tested yielding a concept ready status, the next step would pursue the design and manufacturing plan for production. Prototypes would be built with representing the product-intent design manufactured with production tooling, and then the validation tests would be repeated. Extending the test matrix to more customer / attack mode test conditions would also be advised to build confidence the design action will result in a transportation sector vehicle more resilient to potential EMP attack scenarios.

7 EMP MITIGATION PLAN

7.1 Overview

The mitigation plan was built upon the reliability analysis presented in **Section 5.0** to define mitigation countermeasure design proposals for validation testing that could be implemented following the "as-built" vehicle test plan presented in **Section 6.0**. First, the vulnerable sub-systems and components identified in the Methodology section were analyzed for potential failure modes. When incorporated into the proposed failure modes and effects analysis (FMEA) template, the EMP risk analysis can be completed with metrics to prioritize risks. Second, based on the potential failure modes and prioritized risks, plausible mitigation countermeasure proposals were developed for validation testing that could be incorporated in target segments of non-MIL transportation sector vehicles to increase resilience to EMP, and enable an effective emergency management plan to be implemented. Concepts presented in the literature were considered in development of vehicle EMP mitigation countermeasure proposals (Emanuelson (2020-2)), Laracy (2012), Transtector (2017a)). The fundamentals how the HEMP environment interacts with electrical components in stationary facilities, and technical specifications for mitigation design actions (Radasky (2010), IEC TS 61000-5-10 (2017)) were also considered. The risk assessment and mitigation plans were developed with the following elements:

- Develop an understanding of how the HEMP environment and coupling modes that could lead to excess voltage and current flow in the vehicle sub-system components.
- Utilize the hazard risk and damage scenarios described by the interface chart, boundary diagram and p-diagram reliability analysis presented in **Section 5.5** to **5.7** to assist in visualizing plausible mitigation measures.
- Provide some examples of how mitigation countermeasures can be implemented for testing in a representative late-model, "electronics-heavy" non-MIL transportation sector vehicle to reduce the impact of the EMP pulse on the sub-systems and components affecting vehicle function.

- Provide a means of systematically addressing the potential failure modes and the potential countermeasure mitigation design action proposals utilizing a Failure Modes and Effects Analysis (FMEA) template borrowed from the engineering world with rating metrics familiar to emergency management hazards risk assessment reports.

7.2 HEMP Environment and Coupling

The HEMP environment described in **Sections 2.1 and 5.6** has been shown to with vehicle wiring and electronics components which in turn can lead to potential damage to vehicle controls, actuator and sensor components (EMP Commission (2008)). In **Figure 28,** the nominal HEMP composite waveform describes the E1, E2 and E3 components (Radasky and Savage (2010)). For transportation sector vehicles heavily appointed with micro-processors, electromagnetic actuators, solid state sensors, and wiring

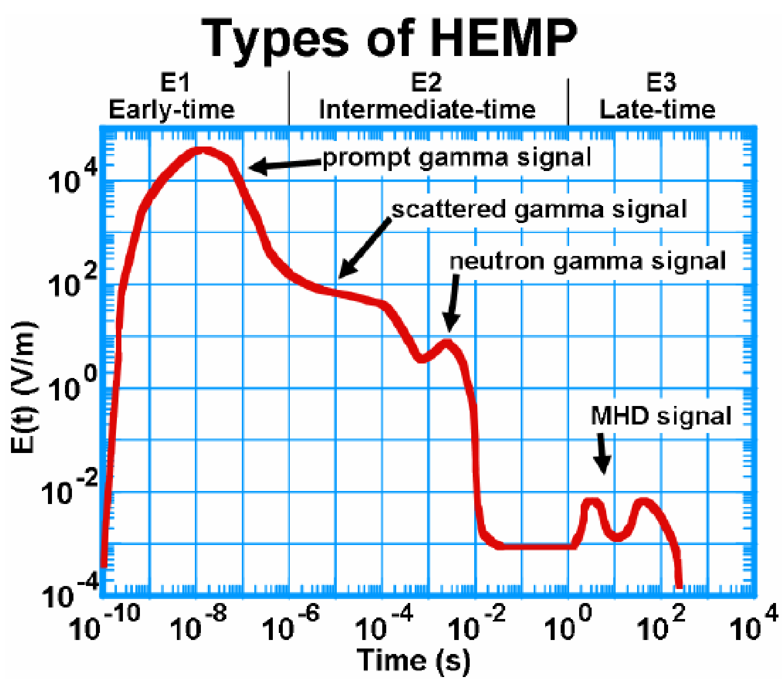


Figure 28 - Unclassified Nominal HEMP Composite Environment E1, E2, E3 (Radasky and Savage (2010), Metatech Corp. and MIL-STD-464C (2010))

harness components, the E1 waveform has been identified as the most severe with regards to the array of electromagnetic actuators and solid state microprocessor based electronics subsystems and components. In **Figure 29,** the idealized composite waveform presented in **Figure 28** is transformed into a laboratory

waveform for the E1 HEMP component as defined by MIL-STD-461G via the RS-105 test (MIL-STD-461-G, 2015). The waveform has a peak EMP amplitude of 50 KV/m, a standard in laboratory validation testing of components, sub-systems, full vehicles, aircraft and watercraft for resilience to EMP. As discussed in the Literature Review **Section 3.0** and the Test Plan **Section 6.0,** an optimized EMP weapon could deliver a HEMP level approaching 200 Kv/m suggesting laboratory tests should be conducted at the 50Kv/m EMP level to compare to past data, but also test to a higher level as close to 200 KV/m as possible per the capabilities of the test equipment. Procedures were developed and described in **Section 6.0** to incorporate both EMP levels in DOE testing and validation of proposed design mitigation actions. A fundamental research question is what is the impact on the modern-day vehicle electronics sub-systems and components as compared to the past EMP Commission testing (EMP Commission 2008)?

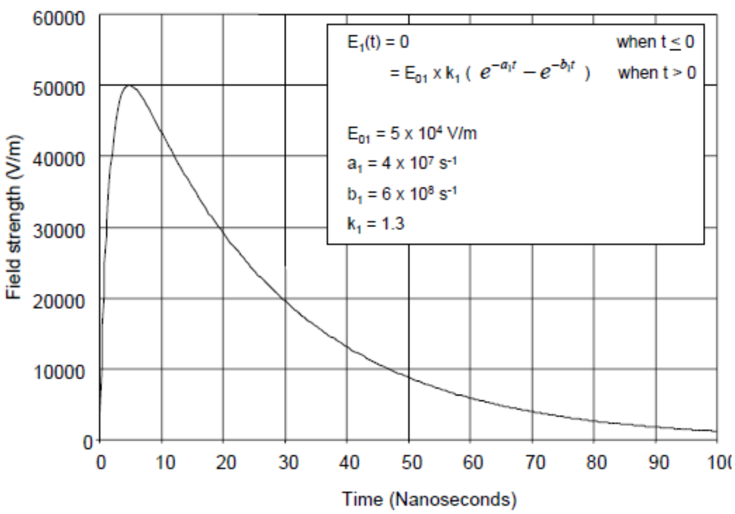


Figure 29 - E1 HEMP RS-105 Laboratory Waveform (from MIL-STD-461G (2015))

In **Figure 30**, the coupling mechanisms for an EMP pulse to induce voltage and current spikes into electronics components is described by Radasky and Savage (2010). In an under-hood vehicle environment, both modes of couplings are present, electric/capacitive and magnetic/inductive. The wiring harness sections of an automotive vehicle act as antennas to transmit the EMP electric field to the adjacent vehicle electronics components. For capacitive coupling, the EMP electric field rearranges

electric charges on the conductors causing charge movements (currents) and voltages. For magnetic/inductive coupling, the high frequency wave coupled to the wiring harness section conductors cause a voltage spike rise depending upon which way the EM wave is propagating and the E & H field polarization. Based on the discussion of Radasky and Savage (2017), a reasonable hypothesis assumes both forms of coupling described in In **Figure 30** would exist in an under-hood environment for transportation sector vehicles. The electric field will be attenuated to some degree by the vehicle body structure, and once attenuated, the coupling interaction would induce a voltage in the wiring harness sections from the electric field. This is one reason why the test plan discussed in **Section 6.0**, both parallel and orthogonal orientations, and +/- 30 degree offsets relative to the electric grid were proposed in the test matrix in the laboratory that generated the EMP pulse. This could be analogous to different location effects for latitude relative to ground zero location of the burst, or simply the orientation of the vehicle relative to the source of the burst.

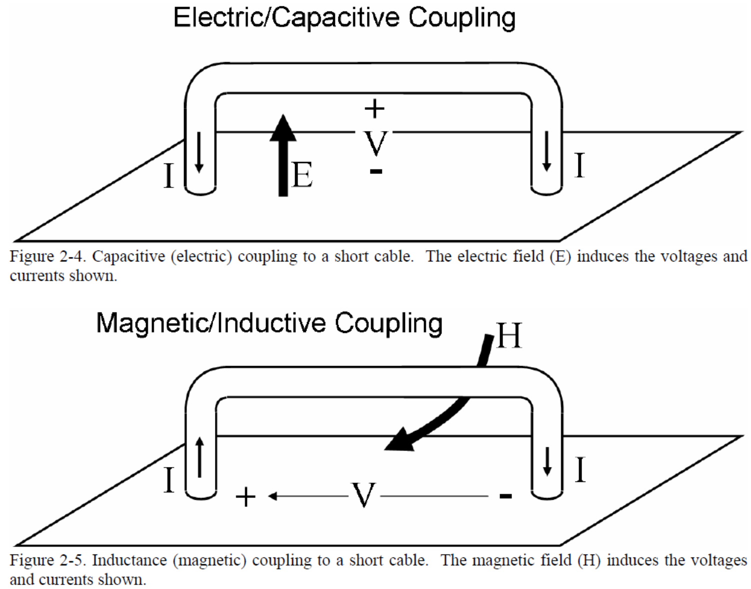


Figure 30 - Electric/Capacitive and Magnetic/Inductive Coupling (from Radasky and Savage (2010), Metatech Corp.)

To relate the EMP electric field strength to induced voltage in the wiring harness sections Wilson (2008, p. crs-13, end-note 31) presents a useful explanation.

> *"Kilovolts per meter is the standard measure for describing the strength of an EMP field. In layman's terms, the statement that a Russian Super-EMP weapon could generate 200 kilovolts per meter means that a conductive object exposed to the EMP field will experience a surge of 200,000 volts for every meter of its length. So if the object is 2 meters long, it gets 400,000 volts.*

If 3 meters long, it gets 600,000 volts, and so on."

Translating this explanation to a vehicle under-hood environment, a 100 KV/m EMP pulse attenuated to an under-hood EMP level of 60 KV/m imposed on a 0.5 M wiring harness segment would result in a 30 KV voltage spike imposed on the electronics components connected to that wiring harness segment. Since all actuators, sensors and drive motors have more than one conductor for supply and return power, or excitation voltage supply and return with signal return, the voltage spikes imposed on these conductors could be balanced offering an inherent protection to the vehicle components if the voltage difference is close to zero, and the current flow due to difference in voltage is minimal. The engine injector and ignition coil sub-harness illustration presented in **Figure 17** illustrates how the supply and return conductors to these actuators are equal in length when connected to the ECU by the main connector at the end of the wiring sub-harness. Since all actuators and sensors are connected to the Electronics Control Unit (ECU) in a similar manner along with numerous microprocessors with conductor paths to ground, this could be the area where the majority of component failure modes would be observed which was an important hypothesis proposed in the development of the 1st design mitigation measures to improve resilience to EMP.

7.3 Vulnerable Components

7.3.1 Wiring Diagrams

In **Figure 15,** the path from the energy source to system failure was illustrated in the boundary diagram. In **Figure 31,** the composite under-hood environment for sub-systems and components are illustrated with expanded views presented previously in **Figure 16, 18 and 19** based on vehicle service manual information (Ford Motor Co. (2018))**.** The illustrations show areas in the engine compartment where the conductors within the engine, transmission and vehicle wiring harness sections could act like antennas transmitting the EMP pulse to the vulnerable components.

Based on the discussion of coupling from Radasky and Savage (2017) and the illustrations of the under-hood environment, the interactions of the EMP pulse to the vehicle electronics components are

Typical Modern Automotive Vehicle Underhood Components

((Based on service manual information, Ford Motor Co. (2018))

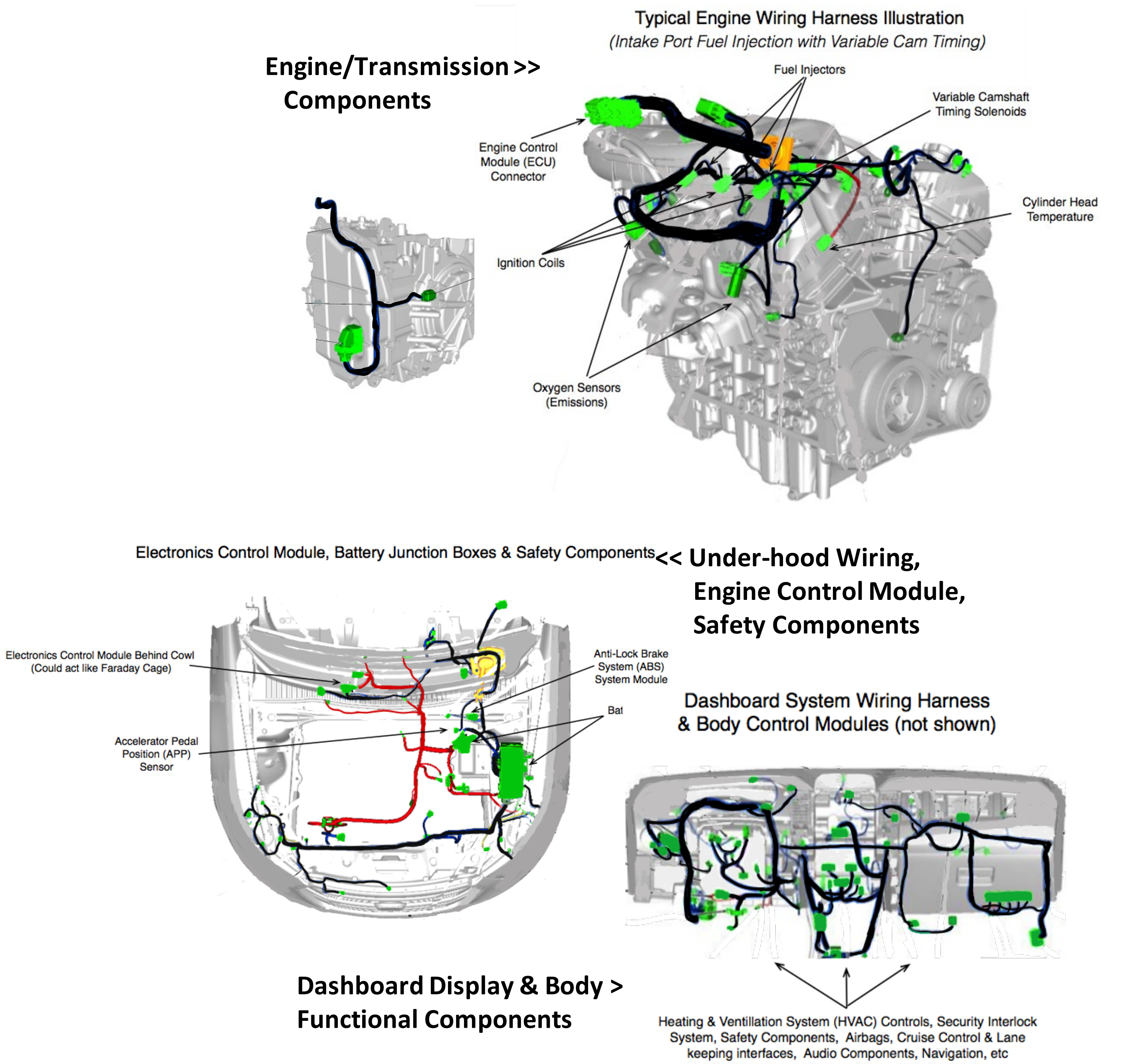


Figure 31 - Illustrations of typical vehicle wiring harness diagrams (for expanded views see Figures 16-19)

Notes: 1) Wiring harness segments act like antennas transmitting the EMP pulse to vulnerable components
2) Wiring harness creates equal length conductors to and from sensors, actuators, and motors suggesting equalized voltage difference, reduced current pulse amplitude.

(Illustrations based on service manual information, Ford Motor Co. (2018))

hypothesized as follows. The HEMP environment existing outside the vehicle is attenuated by the vehicle body structure which is usually steel (good), and recently more aluminum and composite materials (not as good). Once attenuated by the body structure, e.g., reduced in peak voltage level relative to the outside HEMP environment, the resultant under-hood EMP pulse is coupled to the conductors inside the vehicle wiring harness segments via the electromagnetic coupling physics discussed in **Section 7.2.** The wiring sub-harness sections for the engine and transmission contain trunks of conductors feeding the actuator components such as fuel injector coils, ignition coils, turbocharger waste gate actuators, engine and transmission electro-hydraulic control solenoids, and DC motors for the electronic throttles, and emissions control devices such as evaporative emissions purge valves. The Electronics Control Unit (ECU) is usually located under the vehicle cowl behind the firewall. This will assist in creating a Faraday Cage effect for the ECU which is a desireable EMP resilience feature as part of a typical transportation sector vehicle design.

7.3.2 Vulnerable Components and Potential Failure Mode Scenarios

The Interface Chart presented in **Figure 14** was one tool used to help visualize the major categories of components shown in the illustrations of the electronics components in the under-hood environment. Since vehicle electronics components and microprocessor based sub-systems and sensors share many features, the categories of components binned by sub-system in the interface chart were consolidated by function in **Table 13** for engine, transmission and other vehicle control functions. In **Table 14,** a preliminary list of potential failure modes due to EMP is presented which will assist in visualizing potential mitigation measures for EMP. The Electronics Control Unit (ECU) is utilized for engine and transmission controls, adaptive speed control, and numerous other vehicle functions. Internal to the ECU, the microprocessor, memory, analog to digital (A/D) converters, digital to analog (D/A) converters, signal conditioning circuitry, and numerous power MOSFETs (metal oxide field effect transistors) exist collectively for program software instructions, sensor signal conditioning, electronic throttle motor control, and control of numerous actuators such as ignition coils, fuel injectors, engine and

transmission electrohydraulic control solenoids, and emissions control valves. The book by Ribbens (2017) on Automotive Electronics provides a detailed description of automotive electronics components providing a valuable reference in any follow-up engineering design and test program for EMP damage assessments and proposed mitigation measures.

Software interrupts indicated in **Table 14** relate to the potential failure mode where ECU microprocessor Central Processing Unit (CPU) instructions are interrupted by the power surge. Interrupts in microprocessors are caused by conditions that halt the microprocessor temporarily to work on a different task and then return to its previous task halting peripheral devices to access the CPU (GeeksforGeeks 2020). With EMP, a soft ECU interrupt could be resolved by a simple key-on/key-off sequence as was noted in the EMP Commission report 2004 test program (EMP Commission 2008). A more serious form of interrupt could result in the EMP pulse flashing or removing the ECU's memory requiring reflash of the processor to restore program instructions and the calibration data. Such a process

Table 13 - EMP Vulnerable Components (examples)

- Electronics Control Unit (ECU)
    - Microprocessor, memory instructions
    - Analog -to-Digital (A/D) and digital-to-analog (D/A) converters
    - Power MOSFETs for actuator controls
    - H-Bridge MOSETs for DC motor controls
    - Sensor excitation and signal conditioning circuits
- Actuators (driven by electromagnetic coils or piezoelectric actuators)
    - Electronic throttle drive motor
    - Fuel injectors
    - Ignition coils (port injection, direct injection, gasoline vs. diesel)
    - Engine/transmission electrohydraulic control solenoids
- Sensors
    - Traditional - Temperature, pressure sensors
    - Speed sensors - crank/ cam position
    - Engine knock sensors.
    - SENT Protocol, SAE J2716, sensors (TI (2010))
- Security inter-lock systems, dashboard displays
- Exhaust emission systems monitors and sensors.
- Numerous Microprocessors, ~30-100 for a modern automotive vehicle.
- Antilock braking, electric braking systems
- Electronic steering, driver assist lane keeping and adaptive cruise

would have to be conducted by a dealership since such repair tools are not available to the public in aftermarket parts distributors.

Table 14 - Potential Component Failure Modes

Failure modes caused by voltage/current surge due to EMP environment:

- Software and hardware interrupts requiring ECU restart or CPU memory reflash (soft failures)
- Internal ECU MOSFET / Zener Diode hardware failures (used to control all actuators)
- Actuator component failures, electromagnetic coil burn-out
- Wiring harness shorting due to over-current
- Sensor failures
    - Traditional sensors -- signal conditioning hardware or sensor failures
    - SENT Protocol (SAE J2716) sensors
- Security inter-lock system, dashboard display system, body control module (micro-processor interrupts)
- Failures in vehicle safety systems such as electric steering, electric braking, anti-lock braking, adaptive cruise control systems.

Internal to the ECU electronics, numerous power MOSFET drivers are used to control the actuators with generic function described in the Infineon Technologies technical bulletin (Infineon 2020). Examples actuators are the electronic fuel injectors, the ignition coils, the electrohydraulic control valves used for engine variable cam timing and transmission controls. A special class of MOSFET called an H-bridge MOSFET is used to control DC motors used for the electronic throttles, emissions control device actuators, and other miscellaneous DC motor drives utilized for powertrain controls or other vehicle control functions.

A typical component and conductor layout for actuator components is presented in **Figure 32** for electronic fuel injectors used for control of engine air/fuel ratio and engine power. The wiring harness layout would be similar to what is shown in the lower left side of **Figure 31** with an expanded view for the engine previously presented in **Figure 16,** and a generic engine sub-harness illustration for an intake port injected engine as shown in **Figure 17.** The diagram in **Figure 32** shows one side of the fuel injector solenoid actuators connected to the +12V battery control module, and the return conductors connected to

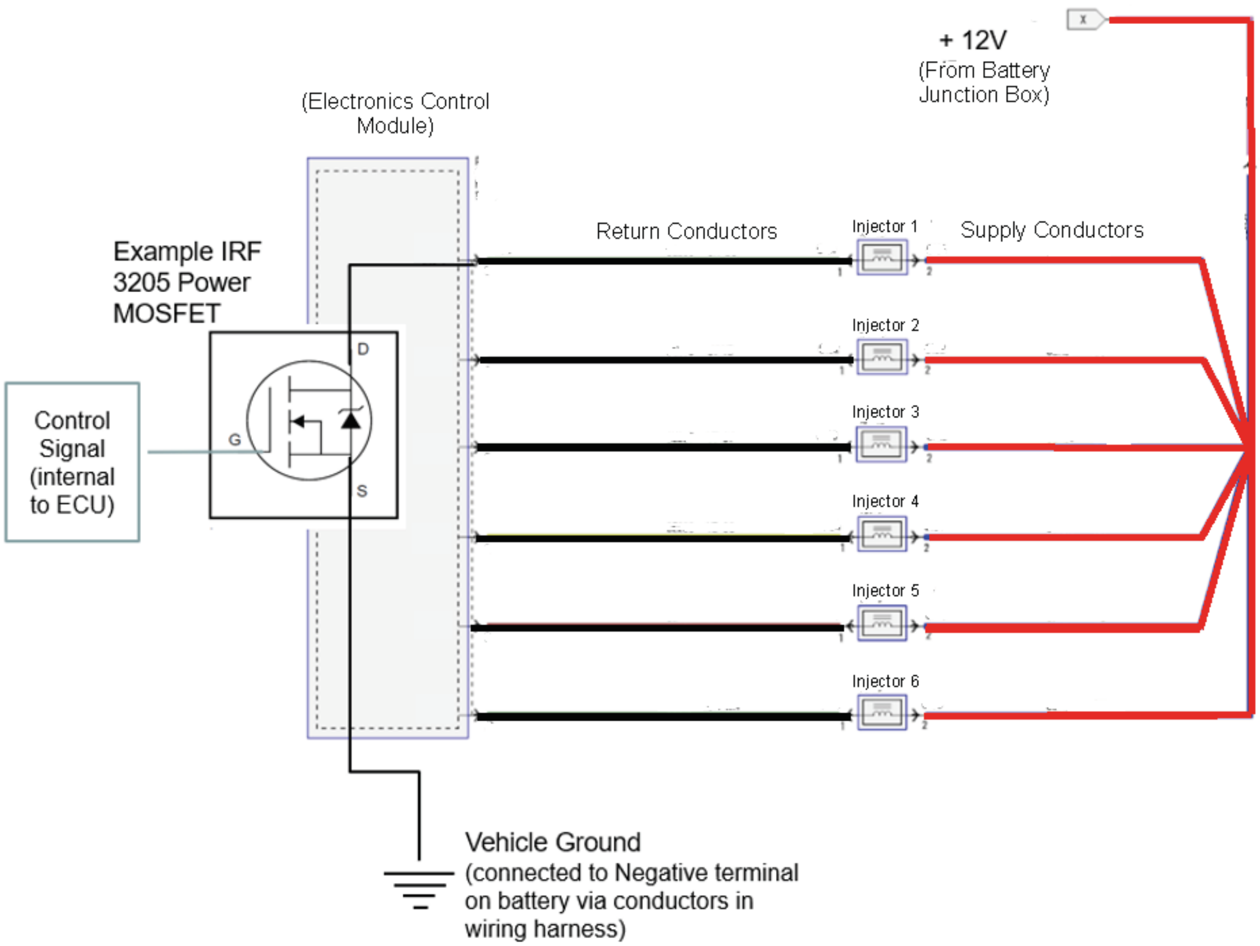


Figure 32 - Fuel Injector Actuator Wiring Diagram Typical for Automotive ECU Applications (Based on service manual information, Ford Motor Co. (2018))

the ECU. The battery junction box delivers +12V power to the ECU, which in turn routes the power to the supply conductors within the wiring harness bundle of conductors shown by the "black" segments in **Figures 16**, **18** and **19**. Internal to the ECU, the example Texas Instruments IRF3205 Power MOSFET (Infineon 2020), typical for control of solenoid actuators, creates the path to ground via the control signal connected to the Gate (G) internal to the microprocessor which in turn creates a connection from the fuel injector solenoid return conductor to ground via the D to S gate once the gate switch (G) in the MOSFET is closed. This gate (G) closed switch (D-S) sequence is repeated every engine cycle increasing in frequency as the engine speed (RPM) is increased. The Zener diode path between D and S shown at the right-hand side of the IRF3205 MOSFET is to protect the MOSFET for over-voltage due to current surges once the injectors are turned off from residual inductance in the coils. This is analogous to a water

hammer effect in a hydraulic line when a valve is turned off suddenly causing a pressure surge and possible damage to the fluid line. Per the Infineon (2020) data sheet for the IRF3205 MOSFET, the Drain-to-Source (D-to-S) breakdown voltage via the Zener diode is 55v. If the surge voltage exceeds 55v, then an additional path to ground would be created for current flow until the pre-MOSFET voltage is reduced below the 55v threshold.

During an EMP surge, the process for inducing high voltage to the actuator components is hypothesized as follows. When coupled to the wiring harness sections under-hood of an automotive vehicle, the surge voltage would be applied to both the supply and return conductors of the injector actuator due to the nature of how the wiring harness sections are constructed. If this is the case, we could assume the voltage, although exceeding the 55v threshold in the Kv range, for a 0.2m section of wiring harness exposed to a 30Kv/m EMP surge, a 6Kv surge voltage peak would be introduced similar in time response as displayed in the laboratory RS-105 EMP pulse presented in **Figure 29.** Since conductors are of similar lengths on each side of the injector (+12V side likely 25% larger), the voltage could be near-balanced on each side of the injectors. Subsequently, the path to failure would be surge voltage imposed on the return conductors of the actuator connected to the ECU resulting in a surge in voltage imposed internal to the ECU through the Power MOSFET, either via the normal D-S conduction path created by the Gate G via the control signal, or drain to source (D-S) breakdown via the Zener diode. The voltage surge will also be seen on the negative side in the wiring harness in conductors from the ECU being routed to the battery and vehicle chassis ground. If by some miracle all these wiring harness sections are perfectly balanced in length, then the voltage surge would be equalized everywhere, and no component damage would result. It will be assumed this is a false hypothesis and sufficient surge voltage would be imposed on the ECU via coupling in the wiring harness placing the internal MOSFETs used for control of fuel injection, ignition, cam timing control solenoids, transmission control solenoids and electronic throttle drive motors at risk. This hypothesis provided a basis for one of the primary design mitigation measures proposed in **Section 7.4.**

In a modern-day transportation sector vehicle, multiple sensors exist contributing to fail-safe

operation in engine controls, transmission controls, vehicle safety functions including electronic braking and lane departure control systems, dashboard displays, and numerous body control functions. Example sensors include: temperature, pressure, and mass air flow sensors; exhaust oxygen sensors for engine fuel/air control, engine knock sensors, engine speed sensors, and camshaft position sensors; and finally, more recently sensors for safety and body control such sensors to support lane departure, autonomous vehicle operation, and adaptive cruise control systems. The ECU wiring diagram presented in **Figure 33** represents a small subset of these sensors. Nearly all traditional sensors contain some form of excitation voltage from the ECU, and after the physical condition changes related to the sensor measurement, like temperature with a thermistor, the sensing voltage will change, and via the internal A/D converter in the ECU, the physical measurement and data will be available digitally for control algorithm computations and decisions in the ECU.

Recently, SENT protocol, SAE J2716, sensors (TI (2010)) have been introduced and are presently being utilized extensively in modern automotive vehicle sensor functions. The processing protocol is very similar to a computer CAN (controller area network) bus protocol where measurement values are interpreted among pockets of digital data as shown in **Figure 34**. The waveshape similar to the example presented in **Figure 34** is broadcast by the sensor. The 1st two packets of data contain the calibration and header sensor ID information, the remaining pulses contain the data, all identified via the pulse width for the subsets of the data packets. Although this may appear more complex than a traditional excitation voltage and sensor response type sensor, the goal was to create a protocol that could reduce the cost of the multitude of sensors in modern automotive vehicles with improved accuracy. Vulnerability to EMP could occur due to damage to the broadcast circuitry on the sensor, or the decoder circuitry inside the ECU that interprets the signature of the data packets to infer a sensor measurement.

In addition to the multiple sensors and actuators, a number of microprocessors are present in a vehicle for various functions, all of which are subject to interrupts from the EMP pulse, or physical damage due to internal exposure to the voltage spike with the resultant current spike that could

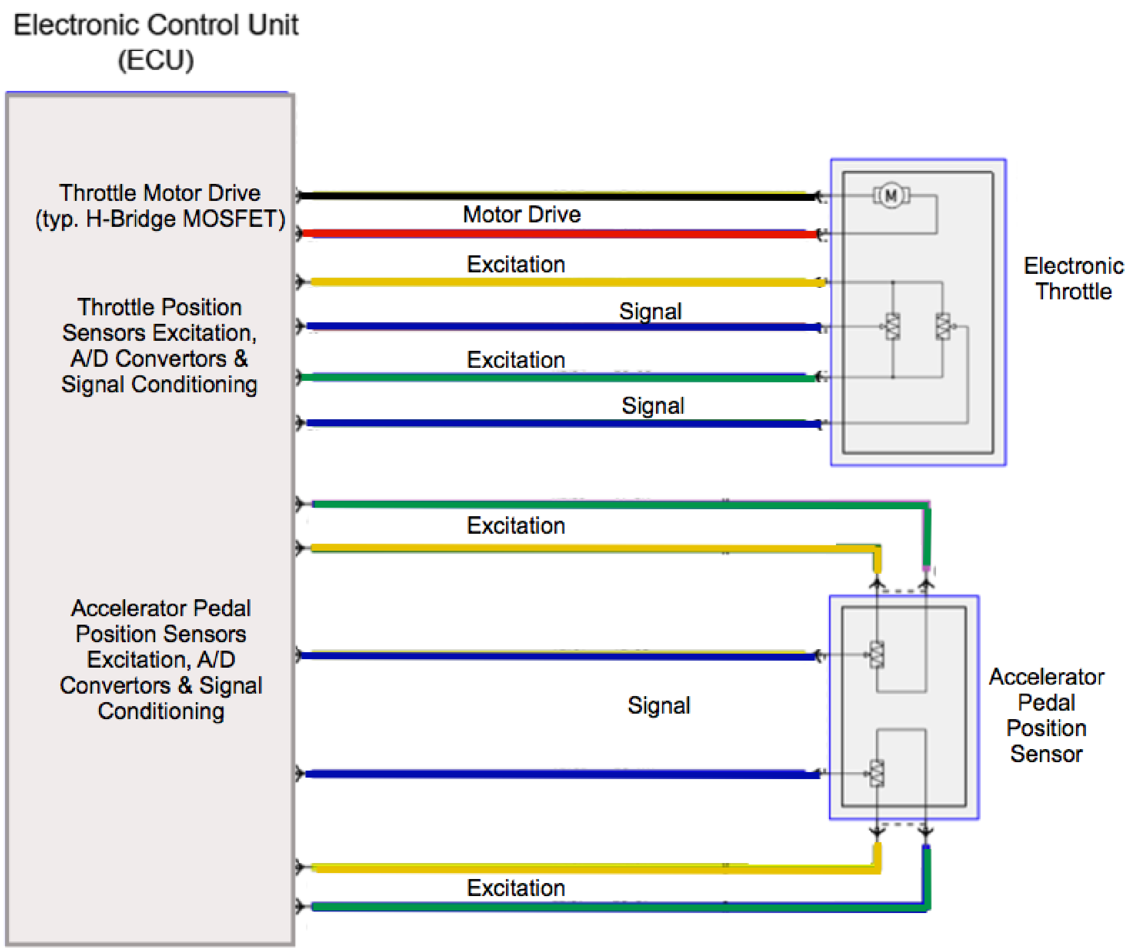


Figure 33 - ECU Wiring Diagram for Electronic Throttle Control and Selected Sensors (sensors shown are throttle & accelerator pedal position sensors)

(Based on service manual information, Ford Motor Co. (2018))

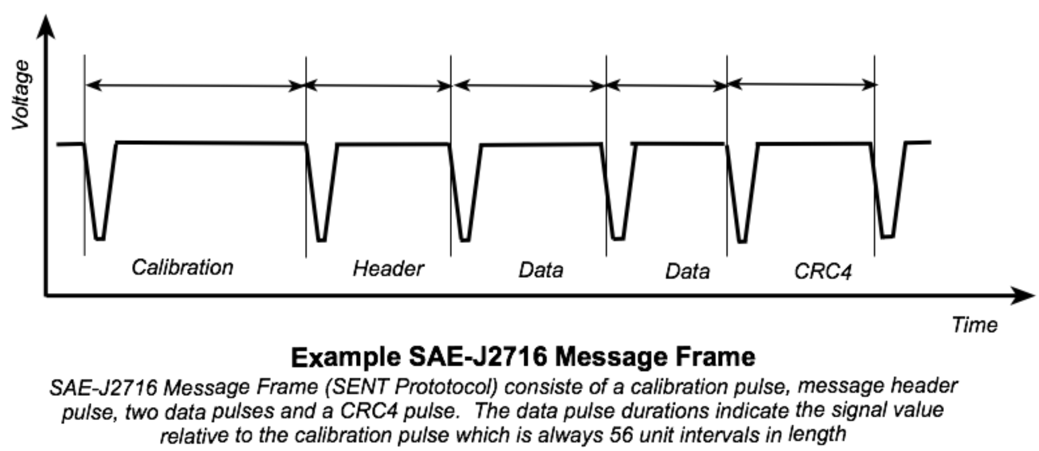


Figure 34 – Example SAE-J2716 (SENT Protocol) Signal Message Frame

(Information from TI (2010), Texas Instruments Corp.)

damage internal components (Motavalli 2010). Even though these may not seem important for proper vehicle function, microprocessor-based components in the dashboard display and perimeter security systems could be damaged preventing access to the vehicle after exposure to an EMP pulse.

7.3.3 Comments on 2004 EMP Commission Test Results

The 2004 EMP Commission report included a section on automotive vehicle test results for cars and trucks (EMP Commission 2008). Although test budgets were limited, the results were important in light of the fact the later model vehicles tested included 2002-2003 model year cars and trucks, all of which incorporated electronic fuel injection and in the case of gasoline engines, electronic ignition with a significant content of emissions control equipment requiring various sensors, actuators and motor drives. EMP environments up to 50 Kv/m were tested with vehicles in the on (running) vs. off (turned off) states. 3 cars stopped running for EMP field levels 30 Kv/m or higher, one vehicle's dashboard display was damaged, and only one of the trucks required towing to a garage. The damage observed was very modest given the magnitude of the EMP pulse which may imply there was significant faraday cage attenuation of the EMP pulse from external to the vehicle to the internal under-hood environment. It may also imply that although a voltage spike was imposed on the wiring harness, the nature of how the conductors are arranged in-route to actuators and sensors could lead to a balancing effect for applied voltage which would reduce the current flow through the sensor (see discussion in **Section 7.2** and **Figure 17**). The lessons learned imply that more data are needed to assess the hazard risks with modern transportation sector vehicles that will drive engineering data based, cost-effective, design mitigation proposals.

7.4 Mitigation Opportunities and Plans

For non-Military vehicles which will have limited budgets for incremental features for EMP protection, it will be important to develop proposals that are cost effective and function in a manner to prevent massive shutdown of the transportation sector critical infrastructure for weeks and months in the

event of an attack. One assumption with non-Military transportation sector vehicles is some disruptions can be allowed after an EMP attack, unlike MIL vehicles that are required by designed to be robust and resilient under all EMP conditions to avoid a disruption in the middle of a mission that could result in significant loss of life, and loss of the military objective for that particular engagement. In contrast, non-MIL transportation sector vehicles could tolerate some disruption providing the recovery time to get the infrastructure up and running again in a reasonable time, for example 1-12 weeks after an EMP attack. This is an assumption which is basis of the emergency management plan proposed in **Section 8.0**.

As we recognized very early in the course of this research paper, the lack of more accurate hazard risk assessment data from testing modern day transportation sector vehicles at expected EMP levels anticipated from optimized EMP nuclear weapons should be viewed as a critical shortfall in understanding the risk to the transportation sector vehicle critical infrastructure, and the subsequent disruption to society as we know it today if such an attack would occur on our nation utilizing an optimized EMP nuclear weapons. The potential of loss of human life due to lack of lifeline supplies could be significant as discussed in detail by Pry (2017) where it was suggested that 9 out of 10 lives could be lost in the US if such an orchestrated attack by state-actor adversary was successful and extensive per the land area impact diagram presented in **Figure 2**. Given the recent Presidential executive order to find ways to increase resilience of our critical infrastructure to EMP ((Gertz (2020) and Govtrack (2019)), the recommendations from this research report will assist in better understanding the risks via the test program proposed in **Section 6.0**, and the success of mitigation measures to help make transportation sector vehicles more resilient to EMP per the concepts proposed in this present section.

The test results from the 2008 EMP Commission report were puzzling (EMP Commission (2008)). If one reviews the MIL standards, i.e. MIL-STD-125-1 (2005), MIL-STD-125-2 (2005), MIL-STD-461G (2015), MIL-STD-464C (2010), the IEC Technical specifications IEC TS 61000-5-10 (2017), and the associated technical reports, a significant investment would be required to improve resilience of transportation sector vehicles to EMP. In contrast, the test data did not support this hypothesis based on the vehicles tested, particularly the later model vehicles close to 2002/2003 model year that employed

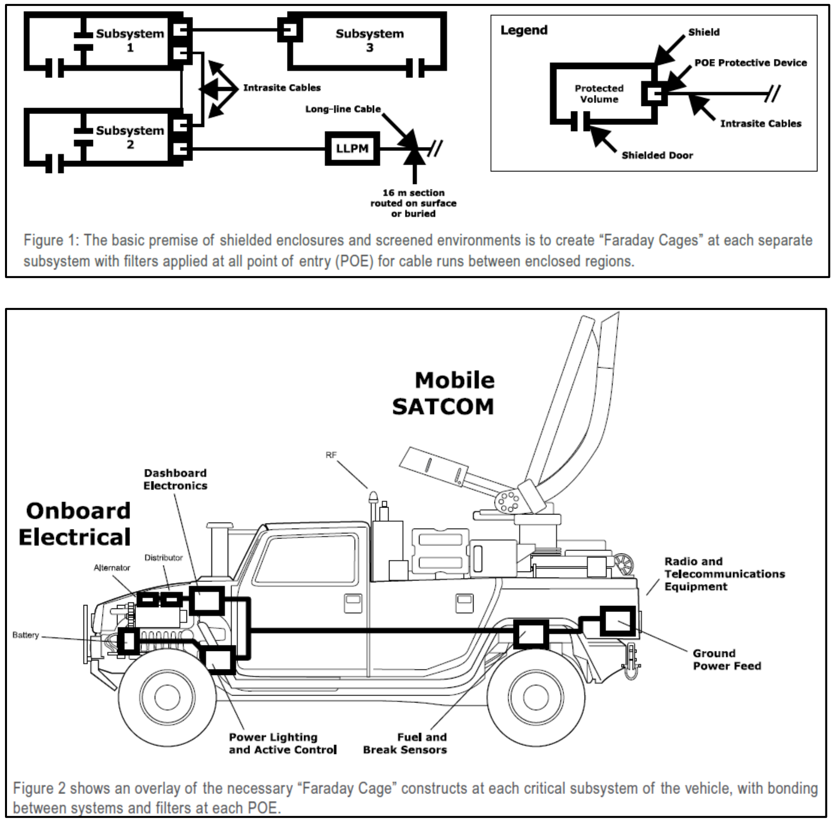
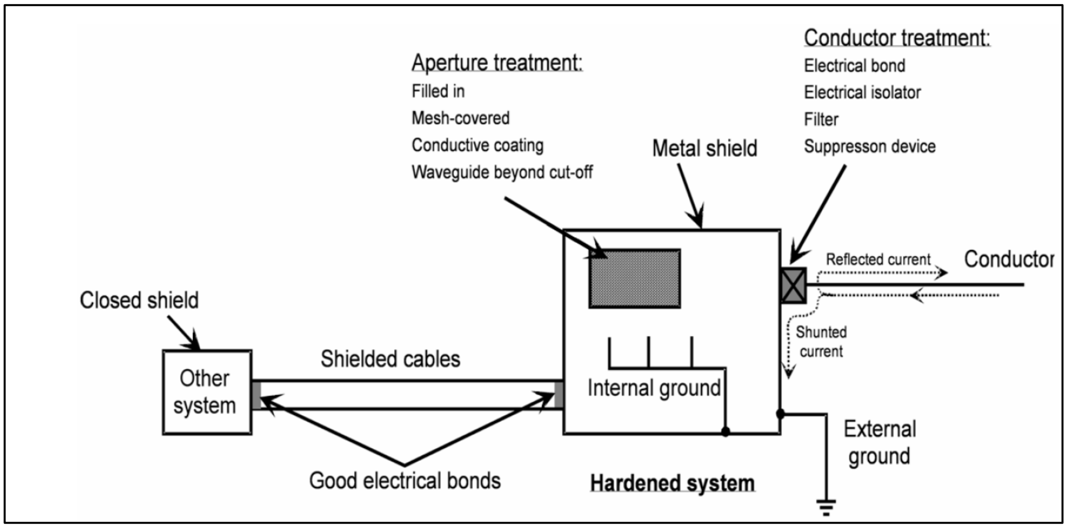


Figure 35 - Faraday Cage, Inter-Cage Surge / Filter Concept for EMP Protection (ref. Figs. 1 & 2 from Transtector (2017a))

electronic fuel injection and ignition systems and ECU architecture similar to what was presented in **Figure 32**. What is proposed below is the most pragmatic approach to the problem, driven by the likely failure modes and the most cost-effective initial approaches to mitigate failure. Once new vehicle data are obtained via a rigorous test program like the plan proposed in **Section 6.0**, the mitigation design solutions can be more strategically developed to minimize cost implementing effective design changes to minimize disruption to the transportation sector critical infrastructure following an EMP attack. Design Mitigation Approaches from MIL and IEC Standards

EMP resilient design standards from MIL and IEC standards provide a foundation for the actual design actions proposed for transportation sector vehicles. The report from Transtector (2017), a supplier of EMP surge and filter devices, refers to the MIL-STD-125-1&2 (2005) and MIL-STD-464C (2010) standards with proposals for the following (**Figure 35**):

- Construction of Faraday shield environments (EMI tight boxes) surrounding all critical electronics system components
- Bounding all metallic structures to a single point ground system.
- Surge or filter protection of all entry/egress points that provide electronic connections between Faraday cage shielded environments.



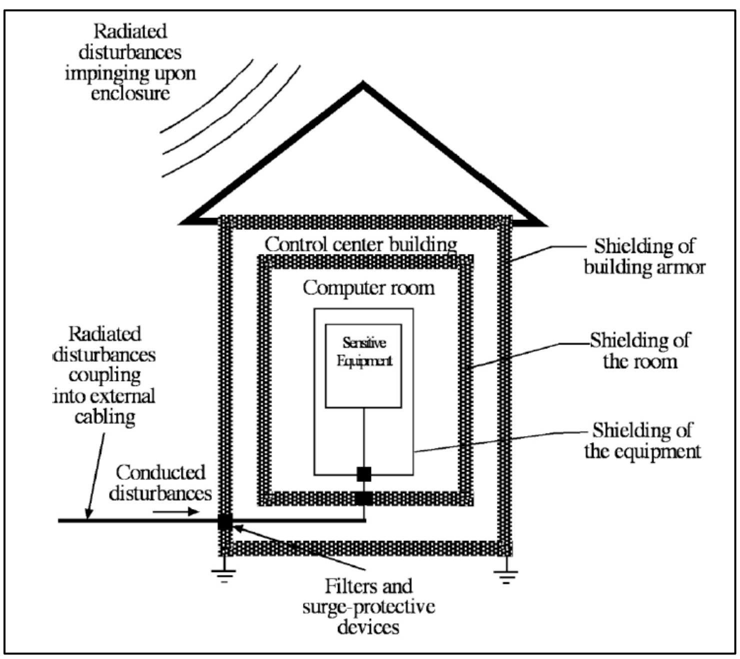


Figure 36 - Basic High Frequency Shielding Filtering Approaches for Equipment Protection in Buildings (Upper diagram, Fig. 4-8 from Radasky & Savage (2010), similar to Fig. 2 from IEC TS 61000-5-10 (2017) (Lower diagram, Fig. 5 from Radasky (2010)

The IEC TS 61000-5-10 (IEC 2017) technical specifications guideline describes the fundamental concepts one would apply to a facility housing electronics components to improve resilience to EMP (**Figure 36**). It is clear a transportation sector vehicle is not a building, but many of the concepts from IEC TS 61000-5-10 (2017) provide some important analogies that can be introduced for automotive vehicle mitigation opportunities. For example:

- The closed metal shield surrounding the building would function as a Faraday cage which is created in part by the vehicle's body structure, particularly when steel sheet metal is used for the body structure. Recent automotive vehicles that utilize aluminum or composites for the body structure should be inferior to the traditional steel body. However, EMP resilient cloth could be applied to the under-hood surfaces to re-create or improve upon the closed metal shield faraday cage concept (Tech Protect 2019).
- The element labeled conductor treatment in **Figure 36** is where electrical isolation filters and surge suppression devices could be applied, a concept that will be further described in the next sections on low cost mitigation design approaches. The surge pulse current is either reflected or shunted during an EMP surge event preferably to an earth ground reference. For an automotive vehicle, earth ground does not exist, only a floating chassis ground presenting unique challenges for surge power absorption.
- Electrical connection of external systems would be accomplished by shielded conductors with good electrical bonds to the outer shield faraday cage structure. In a transportation sector vehicle, these external electronics systems with multi-conductor interfaces is not typical since most electronics in vehicles is self-contained not interacting physically with the outside world. One exception would be with Police, Fire and EMS vehicles, or electric utility trucks that could incorporate electronics for support systems that reside outside the vehicle Faraday cage. If such is the case, the shielding concepts noted in IEC TS-61000-5-10 (2017) should be applied.
- Apertures need to be considered with waveguide mesh with features that filter below cut-off

frequencies for the EMP waveforms. In an automotive vehicle, the grill openings and access from the bottom of the vehicles could be a source of EMP pulse exposure under hood which needs to be studied experimentally if the EMP impact of the vehicle grill and underbody apertures is determined to be significant.

- Finally, grounding is extremely important. As shown in the diagram, external earth grounding of the closed metal shield to earth ground, and connection of internal components to earth ground is a desirable characteristic. In an automotive vehicle, the chassis ground is floating with no practical option to connect to earth ground unless it's a feature added to a military vehicle like dragging chains or installing a temporary earth ground while the vehicle is parked in an attempt to avert severity in an EMP attack.

As a starting point, it is recommended a sub-set of the features described in this section should be considered for initial testing once the baseline tests with un-modified production vehicles are completed. The cost/potential benefits trade-off chart presented in **Table 15** assists in placing the potential EMP mitigation measures into perspective. Particularly, the focus for 1st mitigation design proposals will reside in the low cost/significant benefit category taking advantage of the existing industry standards for bonding metallic structures to a single point ground, and connecting grounds to the outer body structure

Table 15 - EMP Mitigation Acton Cost-Benefits Chart

Cost / Benefit Chart for Potential EMP Design Mitigation Concepts		
• Shielding cables from external electronics devices for specialized vehicles (need to study for emergency vehicles to assess risk).	• 12 V Power source EMP transient voltage suppression surge protection devices • Bonding metallic structures to single pt. ground system (present industry standard) • Connecting internal grounds to the outer closed metal shield (present industry standard)	**Low Cost**
• External earth ground (nearly impossible to achieve, vehicles moving) • Aperture treatment (modifications to existing apertures affects cooling system design which incurred extensive validation testing; need to first determine if this is important)	• Individual Faraday cage enclosures for under-hood electronics components and sub-assemblies • Filters for data lines, sensor conductors (more costly, would require individual filters per sensor or data line)	**High Cost**
Moderate Benefit	**Significant Benefit**	

metallic shield. In this same category are the power source EMP surge transient voltage suppression surge protection devices to be discussed in **Section 7.4.3**.

7.4.1 As-Built Vehicle Mitigation Plan – Repair Scenarios

If the failure mode results from the new EMP test program presented in **Section 6.0** repeat what was observed in the EMP Commission tests of 2004 (EMP Commission 2008), this will be categorized as an idealized damage scenario where component failure modes would be minor and efficiently addressed by a low cost trip to the dealership. In this idealized scenario, component failure rates would occur on a small fraction of the vehicle population during an EMP attack, the cost to replace damaged components would be affordable (e.g., <$500-1000), plenty of spare parts would be available for all vehicle repairs nationwide, and the critical infrastructure in the U.S. is up and running within 2-4 weeks.

In contrast, a non-idealized damage scenario which is more realistic per the viewpoints of recent EMP forums (Pry 2017), multiple component failures would be incurred on a significant fraction of the vehicle population. This would include high cost repairs or replacement of the Electronics Control Units (ECUs), the wiring harness sections, multiple actuator and sensor components, all combined hours to weeks to repair, costs for repairs are expensive (e.g., > $2000), and potential delays in repairs are incurred due to shortage of spare parts requiring 3 months to 3 years to get the critical transportation sector infrastructure up and running again to the level prior to the attack. In this latter scenario, there's real trouble in store for the public far exceeding shortages of lifeline supplies experienced with COVID-19 in 2020 (Yong 2020). Experts claim significant crime, starvation and death could result with as much as 9 out of 10 lives lost in the US (Pry 2017) if this latter scenario occurs. This supports the desire to study the problem, obtain the correct data to assess risk, and develop the most cost effective mitigation actions to protect at minimum, a targeted sub-set of the vehicle population to be resilient to EMP, and have plans in place to produce sufficient stockpiles of spare parts rebuild the remainder of the transportation sector critical infrastructure to a status equivalent to what existed prior to the attack.

In the **Section 7.4.3**, cost effective proposals will be presented for mitigation actions, and in **Section 8**, the emergency management plan to deliver lifeline supplies to the public will be discussed.

7.4.2 Modified Vehicle Mitigation Design Proposals

Implementing a design change to an automotive vehicle will always be scrutinized for relative to the benefits of the incremental investment vs. the cost. The results of the test program outlined in **Section 6.0** will be infinitely valuable in understanding the magnitude of hazard risks in conjunction with modern "electronics heavy", transportation sector vehicles when exposed to an EMP attack. One low-cost high value approach to EMP mitigation outlined in the Cost-Benefits chart presented in **Table 15** is power source EMP transient voltage suppression (TVS) surge protection. In **Figure 37,** this concept is illustrated. The vulnerable components potential failure modes outlined in **Section 7.3.2** and **Table 14** are all as result of voltage surge in the wiring harness conductors caused by coupling between the EMP electromagnetic field and the under-hood vehicle electronics components and wiring harness elements. If a device could be installed to clip the voltage during the EMP event with sufficient response time, the voltage throughout the electronic circuitry could be reduced to a safe level avoiding significant disruption and component damage. This hypothesis must be tested experimentally, and it is recommended TVS mitigation hardware be prepared for testing immediately after the baseline damage assessment tests are complete as described in **Section 6.0**. Regarding coupling, there is always a chance sections of the electronics package could act independently with their own antenna, coupling and component damage effects. The proposal is to investigate power surge EMP surge protection devices first, and for any remaining components requiring shielding, filtering, or additional surge protection devices, address those mitigation actions separately after the initial power surge protection switches are installed.

In **Figure 37** the transient voltage suppression (TVS) surge protection concept is illustrated. The TVS surge protection device is connected on the positive side of the battery between the battery and the battery junction box which feeds the ECU and all the actuators for a typical automotive powertrain configuration. The negative side of the switch is connected between the processor ground return and the negative terminal of the battery, and then connected to chassis ground in the vehicle. It should be noted the vehicle chassis is not a true earth ground, it is a floating ground during an EMP surge would have a

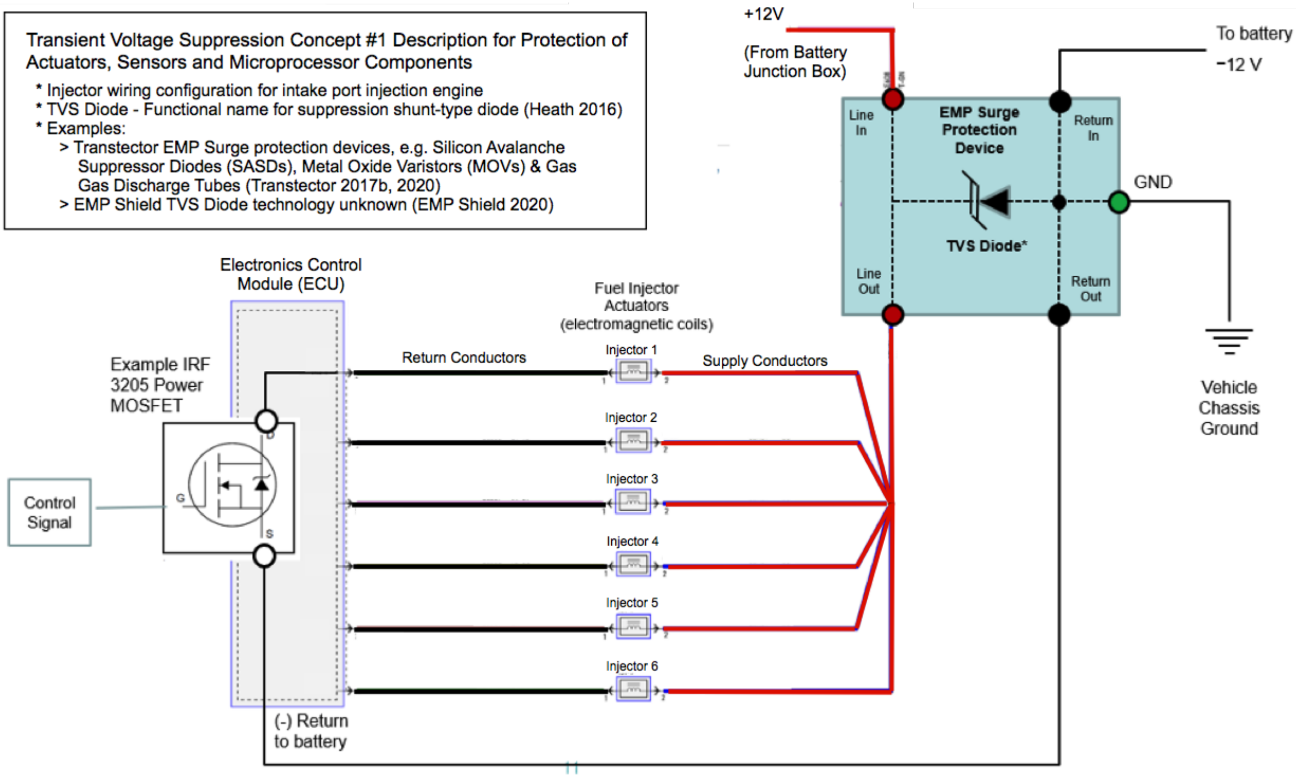


Figure 37 - Power Source EMP Surge Protection, Concept to Protect Vehicle Electronics
(Injector Circuit Example, parent diagram based on service manual information, Ford Motor Co. (2018))

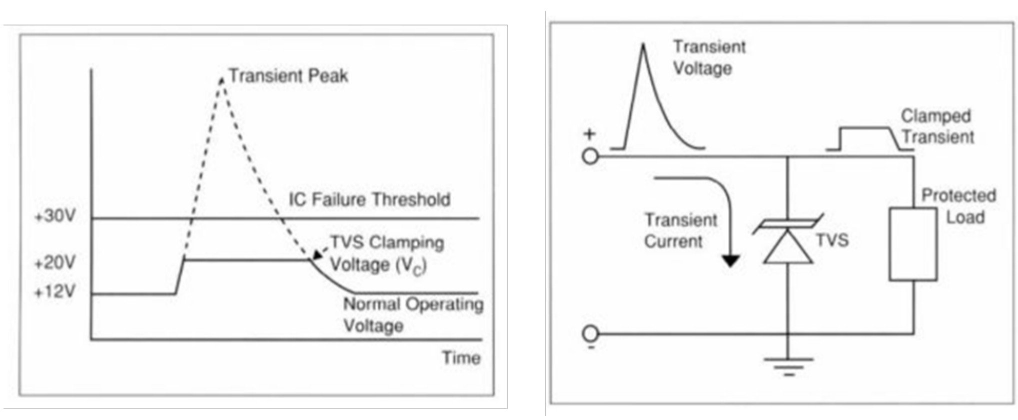


Figure 38 - Illustration of Transient Voltage Suppression Diode Function
(Figs. 1& 2 from Heath (2016))

voltage potential between the vehicle chassis ground and earth ground. During the EMP surge event, the fast acting Transient Suppressor Diode circuit would trigger passively creating a shunt (short) from the positive side of the battery to ground and the negative terminal; hence, reducing the magnitude of the voltage spike during the EMP event. Such devices are marketed commercially by Transtector (2017b), Transtector (2020), and EMP Shield (2020). The fast acting surge protection switch can utilize a number of technologies Transtector (2017b, 2020) such as Silicon Avalanche Suppressor Diodes (SASDs), Metal Oxide Varistors (MOVs), or Gas Discharge Tubes (GDTs) depending upon the application and degree of protection required. The concept should be viewed as something that could be implemented as a high volume after-market add-on device costing possibly <$500 for materials, something that could be affordable for applying mitigation actions to police vehicles for instance to improve resilience to EMP. **Figure 38** illustrates the concept of transient voltage suppression as discussed by Heath (2016).

In **Figure 39**, a similar power surge EMP surge protection concept is shown with the addition of an absorption circuit on the negative return side if the circuit. Since the vehicle chassis connected to the negative terminal of the battery is a floating ground, it would be advantageous to find a way to absorb the power surge similar to the function of a true earth ground. The power absorption circuit would contain a capacitor with sufficient charge absorption capability to absorb the voltage surge on the negative side, and with the diodes, prevent surge from the negative side to be reflected back to the positive side if the vehicle wiring system which would reduce the effectiveness of the power surge protection device. Both configurations proposed in **Figure 38** and **Figure 39** are easy to test at low cost. It’s recommended these hardware configurations be prepared and be ready to test immediately following the test plan outlined in **Section 6.0** combined with low EMP, non-destructive diagnostic tests with high voltage probes and current monitors to determine the levels of voltage and current imposed on various sections of the electronics sub-systems and wiring harness sections.

In the event the EMP power surge protection hardware presented in **Figure 38** or **Figure 39** does not fully protect the vehicle electronics components, and it’s discovered that particular sensors, actuators or wiring harness segments need additional protection, selective implementation of filters, inductive

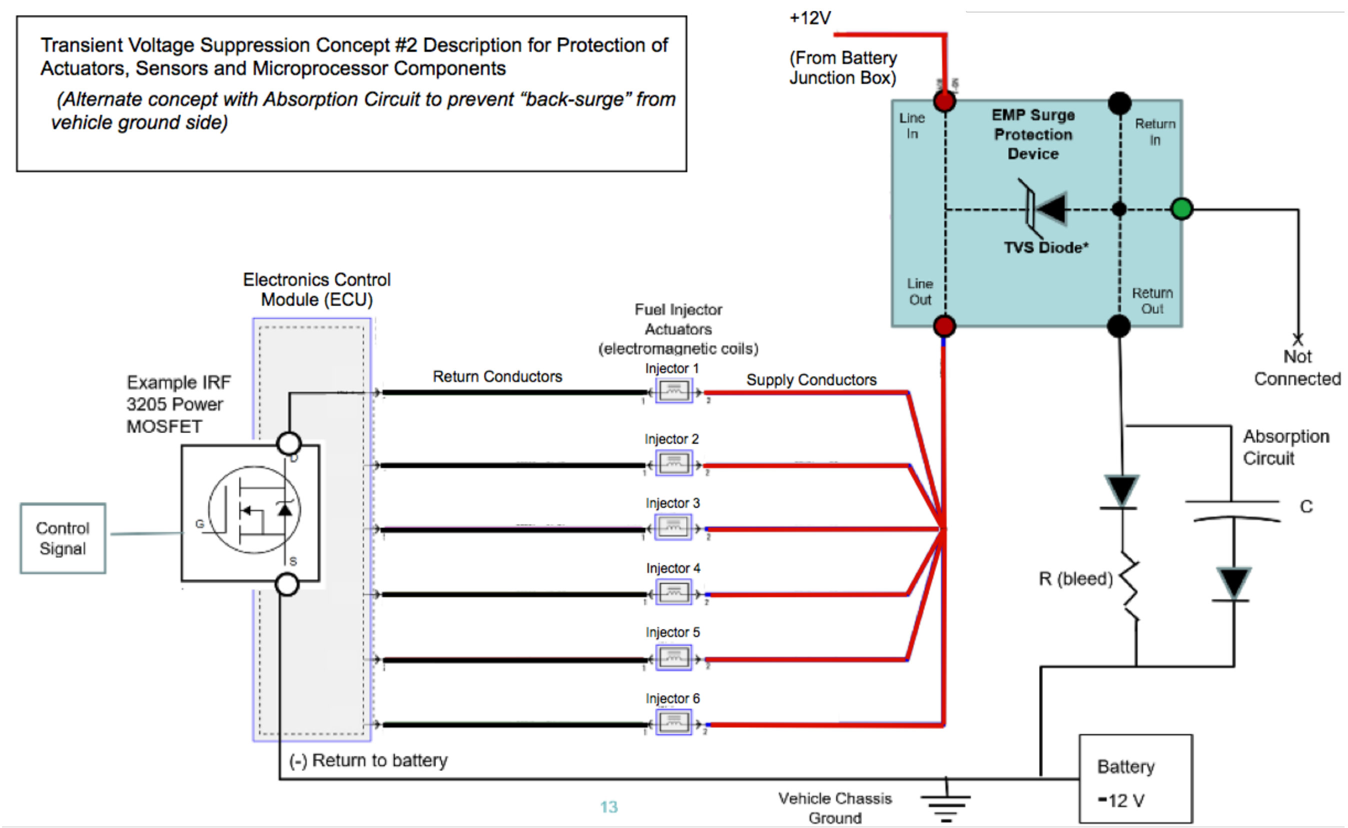


Figure 39 - Power Source EMP Surge Protection with Absorption Circuit, lower right (Injector Circuit Example, parent diagram based on service manual information, Ford Motor Co. (2018))

choke ferrites, and if required, additional surge protection hardware can be implemented. The question anyone would ask when viewing under-hood complexity of a modern transportation sector vehicles is how could an array of protection devices be installed without significant tear-up to the wiring harness assembly or even more impossible changes to the ECU processor. Typical to all vehicle calibration development testing prior to production release of a vehicle, tests are conducted to populate the processor with data specific to the vehicle application, and breakout boxes similar to what is shown in **Figure 40** are installed to access the signals to and from the actuator and sensor components for diagnostic purposes. There are commercial units as shown in **Figure 40** (Bosch 2020), but the majority are custom made for the original equipment manufacturer (OEM) ECU architecture configuration (not shown). The wiring harness connector(s) that normally insert into the vehicle bulkhead to connect to the ECU processor would be inserted into the breakout box sub-harness which is then routed to the breakout box for testing

with a return harness bundle connected to the bulkhead for connection to the ECU. Inside the breakout box, additional filters, ferrite inductive chokes, surge protectors could be installed per requirements identified during testing. The breakout box and the additional harness sections would employ a Faraday Cage enclosure concept as shown in **Figure 35** and **Figure 36,** and the shielding scenarios relative to the harness and vehicle floating ground per the IEC TS 61000-5-10 (2017) technical specification document. The breakout box concept solution could be used for validation testing to prove the EMP mitigation design changes are effective, and possibly for small volume production implementation programs for targeted vehicle segments such as police emergency vehicles or any vehicles supporting delivery of emergency services and critical lifeline supplies to the public. Production Manufacture of Record (MOR) for the vehicle conversion could be the same MORs used for the original police vehicle fleet conversions.

The break-out box filter and surge protection could employ commercial products such as those from Transtector (2020) or custom circuit hardware for the particular component or internal ECU circuitry area being protected. For example, for the electronic throttle DC motor drive shown in **Figure 33**, the concepts discussed in **Figure 37 or Figure 39** could be implemented. Simple R/C circuits are integral to nearly all ECUs for filtering analog data prior to internal conversion via the analog to digital (A/D) converter. Additional filtering could be incorporated into the breakout box such as the low pass filter shown in **Figure 41** (Electronics Notes 2020)**.** The addition of ferrite beads or ferrite chokes surrounding conductors have also been used to suppress high frequency noise in electronic circuits (Altium 2017). The procedure will be to run the tests, have EMP surge protection hardware ready to test utilizing the transient voltage suppression principles. Then if any components continue to fail under the test conditions outlined in **Section 6.0**, then measurements will be made to characterize the noise frequency spectrum to enable a corresponding filter design to be implemented inside the breakout box for validation testing.

EMP Filter Implementation Concept

Example – Sensors and Actuators

- Example shown for electronic throttle motor drive, throttle and accelerator position sensors
    - Traditional sensors – Excitation voltage, signal return
    - New generation sensors – utilize SENT Protocol (SAE J2716)
- Wiring harness comments – equal length conductors to and from sensors and drive motors from ECU suggest coupling could be equalized, reducing peak EMP voltage imposed on components.
- For all traditional sensors, ECU provides:
    - Excitation voltage, 5-15 V
    - Input filter circuit (R/C)
    - A/D Converter
- Proposed Mitigation measures
    - Custom filters, Ferrites, Transient Voltage Suppressor diodes installed per test data
    - Break-out Box Installation w/Faraday Cage shielding

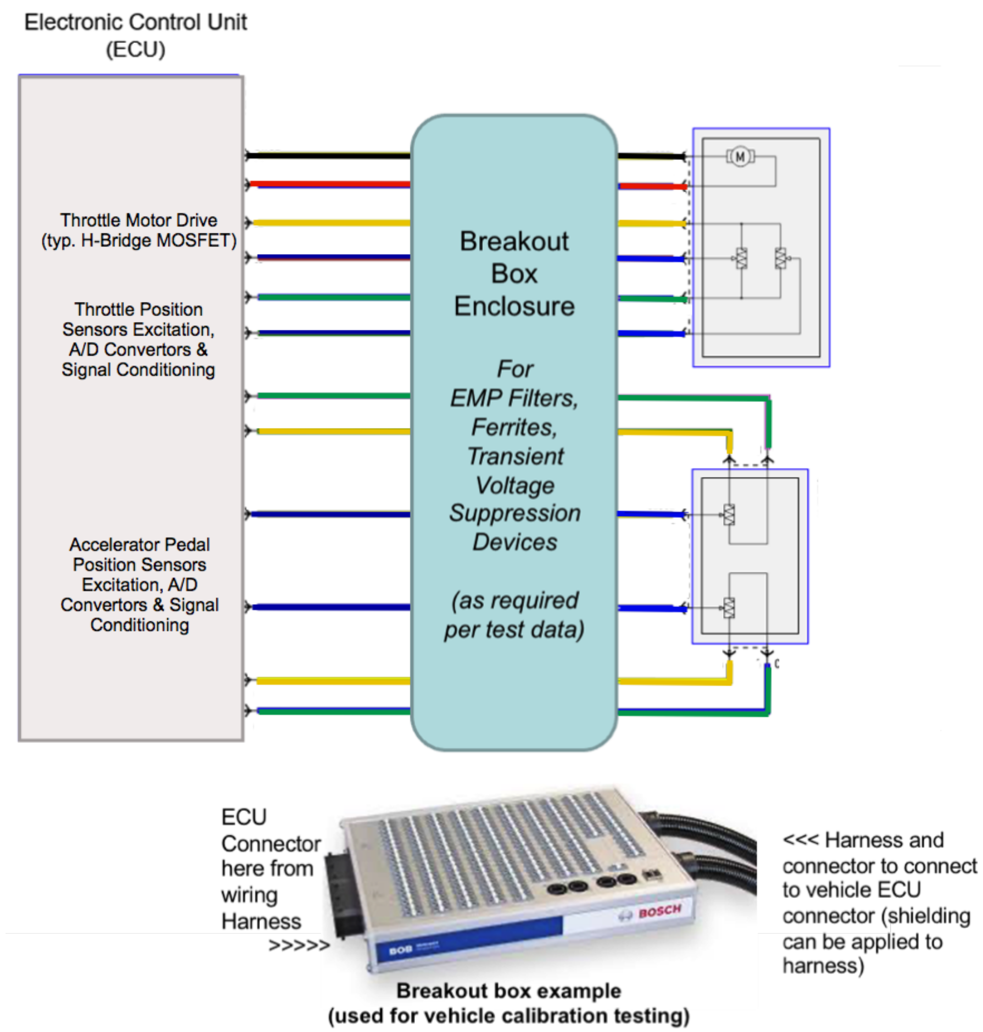


Figure 40 - EMP Mitigation Development & Implementation Concept for Sensors, Selected Actuators (Injector Circuit Example, parent diagram based on service manual information, Ford Motor Co. (2018), Breakout Box, sales photo from Bosch (2020))

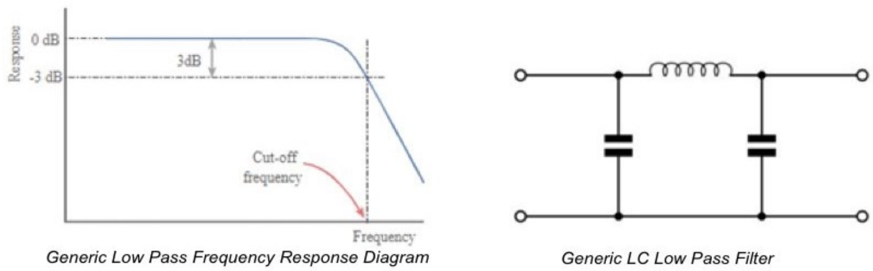


Figure 41 - Low Pass Filter Generic Frequency Response Curve & Example L-C Circuit (based on information from Electronics Notes (2020))

7.5 Failure Modes Effects Analysis (FMEA) for EMP Hazards Risk Assessment

After a new set of test results are obtained per the test plan presented in **Section 6.0** and the associated failure modes engineering analysis is complete for the risk analysis, emergency management and national security personnel can begin the hazards risk assessment to predict damages to the present-day transportation sector critical infrastructure, and begin the process of sponsoring contracts for validation testing of cost-effective mitigation measures. With or without regulations for non-Military transportation sector vehicles to improve their resilience to EMP, costs of hardware and software changes will always present a challenge. Automotive design engineers will need to become creative to develop cost effective design changes that provide opportunity for the greatest protection from EMP at the lowest cost so after a potential attack by an adversary, the critical infrastructure associated with transportation sector vehicles does not create life threatening disruptions in delivery of emergency services and critical lifeline supplies to the public. Allowing a scenario to occur creating months and months of shutdown due to lack of robust EMP resilient designs for non-MIL cars and trucks is simply not acceptable, and inconsistent with the FEMA National Preparedness Goal (FEMA 2015). It is assumed no US Citizen or permanent resident would ever want to be placed in such a situation which could be far worse than any supply chain disruption experienced with the 2020 COVID-19 pandemic (Yong 2020).

Conducting a failure modes effects analysis (FMEA) based on the reliability analysis presented in

Section 5.0 and the potential failure mode discussion in this section will enable design changes to improve resilience of vehicles to EMP to be implemented in the most cost effective manner. FMEAs, a process initiated by the Military in the 1940s, is a step by step approach for identifying failure modes, mitigation design measures, and validation tests to confirm the performance of the design countermeasures (ASQ 2020). FMEAs have also been used in risk assessment in emergency management as described by Stamatis (2019). Stamatis utilized a similar approach to what was done in this report utilizing the FMEA process for hazards risk assessment to:

1) Identify and characterize the threats (potential failure modes, potential causes of failure)
2) Assess the vulnerability of critical assets to the treats identified (risk assessment metrics system)
3) Determine the likelihood and consequences of the specific types of attacks on specific assets (effects of failure)
4) Identify mitigation measures to reduce risks (current control measures, recommended actions)
5) Prioritize risk mitigation measures (risk assessment metrics).

7.5.1 Example FMEA for Transportation Sector Vehicles

The Interface Chart, Boundary Diagram and P-diagram presented in the Methodology **Section 5.0** all supported analysis steps to help visualize the critical sub-systems and components in a modern transportation sector vehicle, and the error states due to EMP that become the potential failure modes for an FMEA. These analyses combined with what will be learned from the test plan proposed in **Section 6.0** will provide the foundation for an FMEA to assess the hazard risks for EMP if no design mitigation actions are executed, and also help prioritize the most promising and cost effective solutions to make the transportation sector vehicles sufficiently resilient to EMP to avoid major disruptions to the critical infrastructure.

The FMEA presented in **Table 17** was created considering six likely failure modes for a modern transportation sector vehicle. Although the 2004 EMP Commission test (EMP Commission (2008)) did

not experience failures of this magnitude, a re-run of the tests as described by the test plan in **Section 6.0** will be conducted with EMP field levels up to 200 Kv/m versus the original 50Kv/m levels, and all vehicles will be late-model year transportation sector vehicles, heavy with electronics for nearly all vehicle functions. Different orientations of the vehicle relative to the EMP pulse generator, and variation in the peak amplitude of the EMP pulse with multiple EMP pulses will be run at progressive percentages of the target max EMP level. The likelihood of failure will be much greater, and the magnitude and extent of failure to the vehicle population tested is unknown.

The metrics used in the FMEA utilized the Priority Risk Index (PRI) metrics similar to the metrics used for hazards risk assessment in emergency management (New Hanover 2010) vs. the more traditional engineering FEMA's Severity, Occurrence, Detection and Risk Priority Number (RPM) metrics (ASQ 2020). The Priority Risk Index Metrics (PRI) are presented in **Table 16**. For the failure modes presented in **Table 17**, all *Probability* and *Spatial Extent* values for calculation of PRI index in the middle of the chart are assumed to be equal to 4.0 since no test data are available to suggest otherwise. The two parameters would be very similar in magnitude per test data results. In other words, if any of the failures occurred as noted, in predicting what would happen large scale to the transportation sector vehicle population would be tied directly to the data. If 50% of the vehicles tested exhibited an ECU failure for hardware interrupt, then it would be assumed that 50% of the vehicle population in the EMP affected area would exhibit the failure mode and the subsequent disruption to personal transportation and delivery of lifeline supplies would result. *Warning Time* for all cases is a level 4 due to the surprise nature of an EMP attack. *Duration* would be defined based on the particular failure mode. Variation in this parameter is illustrated by the three types of ECU failures noted in the FMEA.

To illustrate how the PRI index results would change based on test data, a hypothetic test data results summary will be assumed for the components failure modes presented in **Table 17**. For the purposes of illustrating how the FMEA can be used as a tool in risk assessment and mitigation planning, the following assumptions will be made for test results from the test program described in **Section 6.0**:

- 75% of the vehicles experienced ECU software and hardware interrupts.

- 50% of the vehicles experienced ECU hardware failures requiring with two scenarios: one with sufficient spare ECUs available; one, with shortage of spare ECUs.
- 50% of vehicles experienced fuel injector or actuator failure requiring replacement.
- 50% of the vehicles experienced a throttle or accelerator position sensor failure.
- 75% of the vehicles containing sensors utilizing the new SENT protocol experienced failure requiring replacement of the sensor or parent sub-assembly.

The scenario above was used to create the PRI metrics at the far-right hand side of the FMEA form in **Table 17**. If mitigation measures were employed and another set of test data were generated, the PRI Metrics numbers would be adjusted accordingly to show the decreased probability of failure if application of the mitigation measures was successful.

Once the test program commences and real failure mode data are obtained, this type of analysis is proposed for all failure modes observed to assess hazard risks if no actions are taken for mitigation measures, and once test data are obtained on potential cost effective mitigation countermeasures, then the chart can be used to illustrate the reduction in risk, indicative of improvements in delivery of lifeline supplies to the public, minimizing hardship, loss of life and crime.

Table 16 - Priority Risk Index (PRI) Index Definition

The Priority Risk Index (PRI) was utilized by New Hanover (2010) for their hazards risk analysis. The metrics and formula to calculate a composite PRI Index are presented below. The higher the PRI index, the greater the hazard risks. The highest PRI index score is value of 4.0.

PRI Category	**Degree of Risk**			**Weighting**
	Level	**Criteria**	**Index**	
Probability	Unlikely	Less than 1% probability of occurrence	1	30%
	Possible	Between 1 and 10% probability	2	
	Likely	Between 10 and 100% probability	3	
	Highly Likely	100% annual probability	4	
Impact	Minor	Very few injuries, if any. Only minor property damage and minimal disruption on quality of life. Temporary shutdown of critical facilities.	1	30%
	Limited	Minor injuries only. More than 10% of property in affected area damaged or destroyed. Complete shutdown of critical facilities more than one day.	2	
	Critical	Multiple deaths/injuries possible. More than 25% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for more than one week.	3	
	Catastrophic	High number of death/injuries possible. More than 50% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for 30 days or more.	4	
Spatial Extent	Negligible	Less than 1% of population affected	1	20%
	Small	Between 1 and 10%<. of population affected	2	
	Moderate	Between 10 .and 50% of population affected	3	
	Large	Between 50 and 100% of population affected	4	
Warning Time	More than 24 hours	Self-explanatory	1	10%
	12 to 24 hours	Self-explanatory	2	
	6 to 12 hours	Self-explanatory	3	
	Less than 6 hours	Self-explanatory	4	
Duration	Negligible	Duration < 24 hours	1	10%
	Small	24 hours < Duration < 1 week	2	
	Moderate	1 week < Duration < 6 weeks	3	
	Large	Duration >> 6 weeks	4	

PRI VALUE = [(PROBABILITY x .30) + (IMPACT x .30) + (SPATIAL EXTENT x .20) + (WARNING TIME x .10) + (DURATION x .10)]

Table 17 - Failure Modes and Effects Analysis (FMEA) for Example EMP Failure Modes
(hypothetical component failures & corresponding recommended actions)

EMP Failure Modes and Effects Analysis
Examples, Transporation Sector Vehicles
Prepared By: Jules LoRusso | Rev. 9/27/2020

<<<< Based on severe damage scenario (Pry 2017) >>>

					Priority Risk Index (PRI) Metrics							Adjusted PRI Metrics					
System / ***Component*** **/** Function	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Potential Causes of Failure**	**Current Control Methods / Comments**	**Probability**	**Impact**	**Spatial Extent**	**Warning**	**Duration**	**PRI Index**	**Recommended Action(s)**	**Probability**	**Impact**	**Spatial Extent**	**Warning**	**Duration**	**PRI Index**
Engine System / ***Engine Control Unit (ECU)*** **/** Control Engine Speed and Load per Driver Demand	Hardware Failure / ECU requires re-build or replacement, significant fraction of vehicles tested.	Driver allowed vehicle to coast to safe location; Vehicle not driveable	EMP voltage surge damages internal MOSFETs &/or Zener Diodes	None. / Processor requires replacement. Possible shortage of spares complicates recovery period. Lack of repair shop capacity caused 6-12 mo recovery period.	3	3	4	4	4	3.40	Enhanced logistics systems to increase repair shop capacity (DFA Presidential directives), recovery period 1-3 mo.	3	1	4	4	3	2.70
											Mitigation actions implemented to address issues discovered in testing (Transient voltage suppression (TVS) devices, filters, etc.).	2	1	2	4	2	1.90
Engine System / ***Engine Control Unit (ECU)*** **/** Control Engine Speed and Load per Driver Demand	Software Interrrupt / Vehicle requires re-start	Driver allowed vehicle to coast to safe location for restart; Possible accident	Voltage surge causes interruption in microprocessor program instructions	Existing ECU protections for EMI/EMC	3	1	3	4	1	2.30	Vehicle requires re-start is only action required to clear software interrupt. Same PRI metrics.	3	1	3	4	1	2.30
Engine System / ***Engine Control Unit (ECU)*** **/** Control Engine Speed and Load per Driver Demand	Hardware Interrrupt / ECU requires re-flash at dealership	Driver allowed vehicle to coast to safe location; Vehicle not driveable	EMP voltage surge causes memory in ECU to be wiped	Take vehicle to dealership to reflash memory in ECU	3	3	3	4	3	3.10	Enhanced logistics systems to increase repair shop capacity (DFA Presidential directives), recovery period 1-3 mo.	3	1	3	4	1	2.30
											Mitigation actions implemented to address issues discovered in testing (Transient voltage suppression (TVS) devices, filters, etc.).	2	1	2	4	1	1.80
Engine System / ***Fuel Injectors (actuators)*** **/** Sequential, pulsed delivery of fuel to engine cylinder, once/2 rev/cylinder	Injectors failed after EMP pulse; no fuel delivery to cylinders w/failed injectors; Injectors require replacement	Loss of engine power; Emission system MIL-OBDII light	Injector coil failure due to EMP voltage surge, excessive current in actuator coils	None. Injector sub-harness acted like antenna during EMP pulse.	3	3	4	4	3	3.30	Replace Injectors/sub-harness if reqd. Enhanced logistics systems to increase repair shop capacity (DFA Presidential directives), recovery period 1-3 mo.	3	1	3	4	1	2.30
											Mitigation actions implemented to address issues discovered in testing (Transient voltage suppression (TVS) devices, filters, etc.).	2	1	2	4	2	1.90

Table 17 - Failure Modes and Effects Analysis (FMEA) for Example EMP Failure Modes (continued) (hypothetical component failure modes & recommended actions)

EMP Failure Modes and Effects Analysis
Examples, Transporation Sector Vehicles
Prepared By: Jules LoRusso | Rev. 9/27/2020

<<<< Based on severe damage scenario (Pry 2017) >>>

					Priority Risk Index (PRI) Metrics							Adjusted PRI Metrics					
System / ***Component*** **/** Function	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Potential Causes of Failure**	**Current Control Methods / Comments**	**Probability**	**Impact**	**Spatial Extent**	**Warning**	**Duration**	**PRI Index**	**Recommended Action(s)**	**Probability**	**Impact**	**Spatial Extent**	**Warning**	**Duration**	**PRI Index**
Engine System / ***Throttle Position Sensor (TPS, Traditional)*** **/** Typically twin redundant sensor, provides angular position feedback to ECU	Sensor failed, does not provide feedback signal to ECU (Traditional TPS (3-wire potentiometer; hall effect sensors; inductive sensors)	Vehicle not driveable; Electronic throttle body must be replaced.	EMP voltage surge coupled to wiring harness caused over-voltage and current flow to excitation circuits	None. Engine sub-harness connected to throttle body acted like antenna transmitting EMP pulse to throttle body	4	3	4	4	3	3.60	Replace Sensors/sub-harness if reqd. Enhanced logistics systems to increase repair shop capacity (DFA Presidential directives), recovery period 1-3 mo.	3	1	3	4	1	2.30
											Mitigation actions implemented to address issues discovered in testing (Transient voltage suppression (TVS) devices, filters, etc.).	2	1	2	4	2	1.90
Engine System / ***Throttle Position Sensor (TPS, SENT SAE J2716 Protocol)*** **/** Typically twin redundant sensor, provides angular position feedback to ECU	Sensor failed, does not provide feedback signal to ECU (Sent Protocal TPS sensor, internal failure)	Vehicle not driveable; Electronic throttle body must be replaced (not sure if sensor can be replaced).	EMP voltage surge coupled to wiring harness caused over-voltage and current flow to excitation circuits.	Engine sub-harness connected to throttle body acted like antenna transmitting EMP pulse to throttle body. According to Hella (2009), SENT protocol sensors are more robust to EMI.	4	3	4	4	3	3.60	Replace Sensors/sub-harness if reqd. Enhanced logistics systems to increase repair shop capacity (DFA Presidential directives), recovery period 1-3 mo.	3	1	3	4	1	2.30
											Mitigation actions implemented to address issues discovered in testing (Transient voltage suppression (TVS) devices, filters, etc.).	2	1	2	4	2	1.90

7.6 Discussion – Risk Assessment and Mitigation Plan

The fundamentals of how an EMP attack could influence the electronics in a modern transportation sector vehicle were analyzed and discussed. Potential failure modes were discussed in more than one format to facilitate an understanding to be developed on how the EMP electric field is coupled to the vehicle electronics wiring harness sections and in-turn, the internal electronics sub-systems and components. Potential design mitigation proposals were proposed which could be prepared at low cost and tested after the original **Section 6.0** test program is completed. Finally, the failure modes and effects analysis (FMEA) was presented assuming example failure modes for the Electronics Control Unit (ECU) microprocessor, and selected actuator and sensor components. The FMEA methodology was exercised to show how failure modes observed during testing could be addressed in a systematic manner to identify or validate what components are vulnerable, and the projected damage to the entire transportation sector vehicle fleet if a widespread EMP attacks was successful. The FMEA also showed with metrics documenting the impact of EMP if no mitigation measures are applied, and the effectiveness of potential mitigation measures to reduce the hazard risks of EMP to vehicles for transportation sector vehicles supporting emergency services and delivery of critical lifeline supplies to the public.

8 EMERGENCY MANAGEMENT PLAN

8.1 Overview

The literature contains numerous reports on the potential devastating consequences of an EMP attack on the critical infrastructure, including transportation sector vehicles. As discussed by Pry (2017), an optimized EMP weapon deployed 30 to 400 Km above the earth imposing EMP fields up to 200 Kv/m for an optimized EMP nuclear weapon could cover a significant fraction of the U.S. and North American continent. The burst would have no prompt kinetic damage or injuries to humans, but damages to the electronics infrastructure supporting all critical infrastructure aspects of society is the risk. Potential adversaries understand that millions could die from long-term collateral effects of an EMP attack resulting from damage to the electric grid, disablement of a significant fraction of transportation sector vehicles, and other crippling damage to critical infrastructure interrupting delivery of lifeline supplies to the public in a manner never seen in the history. The report by Pry (2017) presented to the U.S. Congress portrays one of the most devastating impacts of an EMP attack by a potential adversary consistent which is consistent with the majority of reports presented in congressional national security forums (EMP Commission (2008), Schneider (2007)). There are reports stating more optimistic projections that such an attack may not be so severe such as the report from the Electric Power Research Institute's 2019 report (Patel 2019). The conclusion from this research study supports the concerns raised by Pry (2017) and others that the hazard risks from an emergency management perspective could be significant, and more study is needed on risk analysis and cost effective, strategic mitigation plans. The test plan proposed in **Section 6.0** is intended to quantify the hazard risks for non-MIL transportation sector vehicles. The proposed mitigation measures proposed in **Section 7.0** offered low cost upgrades that could be applied to vehicles strategically to mitigate the risks which could be validated by follow-up test programs.

The foundation of the proposed emergency management plan was to identify requirements for an emergency management infrastructure that could provide emergency services and community lifeline supplies to the public consistent with the FEMA National Preparedness Goal (FEMA 2015) in the event

of an EMP attack. It is well known that implementing EMP mitigation actions will be an financial investment; hence, the focus here will be to find a strategic solution where sufficient investment in EMP mitigation actions will result in the emergency management infrastructure to function, lifeline supplies will be delivered to the public, and in a reasonable time period, enable repairs to be completed on the remainder of non-MIL transportation sector vehicles to minimize significant hardship and casualties to the public.

8.2 EMP Situation Severity Analysis

Prior to describing the proposed emergency management plan, a brief discussion on severity analysis will assist in justifying mitigation actions and associate cost analysis proposals. Since a major EMP attack and associated damage to a targeted area never occurred in history, only predictive simulation tools can complement the hazards risk analysis already presented to estimate the level of disruption transportation sector vehicles which are one element of a collection of inter-connected critical infrastructure systems (CIS). The questions are what is the severity of an EMP attack on the critical infrastructure, low long should we expect the disruption and loss of function to occur, and what does this present as a national security problem in protecting our nation to avoid significant hardship and casualties.

In the report by Adams (2013), the treat to critical infrastructure was analyzed due to cyber-attacks, a threat with end-effects similar to an EMP attack if deployed on a large scale. Cyber-attacks on communications systems and SCADA controllers used for control of the electric power grid controls, petroleum refining, and water treatment plants could be implemented in a surprise cyber-Pearl Harbor type attack that could lead to weeks and months of disruption to the critical infrastructure and subsequent loss of life. In a report by Keller (2009), the aftermath of an EMP attack was specifically analyzed. The damage due to the E3 component of EMP (**Section 2.1**) could yield damage to the electric grid taking up to 18 months to repair, consistent with the findings of the EMP Commission (2008) and the Infragard (2016) EMP special interest group. The initial shock from widespread grid failure due to EMP should resemble the widespread power outage caused by the December 2008 Ice Storm that shut-down the

electric grid in the Northeastern United States for 6-14 days. When the power failure occurred, there was disorientation and silence, and everything relying on electrical power was shut down with no knowledge of when power would be restored. Some communications existed via the news media when back-up power generators were available. An EMP attack would be more severe since the electrical equipment at the sources of communication would not only loose electrical power due to the grid failure, but also be damaged by the EMP attack causing loss of function when temporary generator power was restored. The power outage resulting from December 2008 ice storm near the Christmas holiday affected nearly 2 million residents and businesses in New England. With a successful EMP attack, the population effected could be two orders of magnitude larger than the 2008 December power grid outage, with outages in electrical power alone lasting for weeks to months with many elements of the critical infrastructure that depend on electrical power damaged. In the case of this report, the transportation sector vehicles themselves could be damaged due to exposure to the HEMP environment damaging critical electronics components in the vehicles. The casualties resulting from weeks to months disruption to the critical infrastructure of this magnitude would be unimaginable from any past experience our society had to endure from natural or man-made disasters.

In the report by Lieutenant Colonel T. Riddle (2004), the impact of an EMP attack on critical infrastructure was studied. Unlike localized effects of a hurricane or "traditional" low altitude nuclear weapon detonation, the instantaneous widespread scope over a large land area of the US would make recovery attempts lengthy, taking months placing the country in a 19th century environment until electrical equipment and components became available. Strategic nuclear military forces have been hardened to EMP, but some general purpose military vehicles, aircraft and naval vessels could be vulnerable particularly with greater use of lower cost, commercial-off-the-shelf (COTS) hardware that has little or no EMP protection. Jump start of the critical infrastructure would require significant portions of the overseas military returning to the U.S. making areas they were protecting abroad vulnerable to regional conflicts. Lieutenant Colonel T. Riddle (2004) further stated it's the responsibility of the DHS to build and maintain a complete critical infrastructure assessment as related to national security, and

continuation of the economy and delivery of lifeline supplies to the public following an EMP must be achieved to avoid significant hardship or casualties. Hardening the critical infrastructure to the vulnerabilities from a HEMP attack are essential to this mission to support the National Response Plan (FEMA 2019) for emergency preparedness including reliable communications among Federal, State and local responders.

Mathematical models have been developed to study the interdependency of critical infrastructure systems to predict various scenario effects due to disruption from natural hazards and malicious activity from potential adversaries. Dueñas-Osorio et. al. (2007) created models of interdependent critical infrastructure systems (CIS) for electric power, water distribution, transportations and telecom communications systems disrupted for seismic events using concepts and methods from graph tools. The response of networked systems was modeled for simultaneous failure of several elements and sequential removal of critical elements. Mitigation scenarios were studied by accounting for the contribution of every node to facilitate flow of critical infrastructure systems via mitigation actions to reduce overall vulnerability. In the paper by Lu et. al. (2018), a mathematical model was created to study the functionality of modern cities and their reliance on interdependent infrastructure systems such as for electrical power, water, fuel supply, and transportation. Disruptions often propagate across infrastructure systems resulting in catastrophic consequences. The math model could be useful in predicting long term damage scenarios for EMP which will assist in justifying investment in mitigation actions. Finally, a mathematical study from China by Ouyang et al (2018) studied mathematically the vulnerability of inter-connected critical infrastructure systems in localized areas when multiple spatially localized attack areas (SLAs) were considered. The IEEE 24-bus reliability test system (Ordoudis et. el. 2016) was used in the analysis utilizing power transmission systems and associated CIS elements in Shelby County and Harris Counties in the U.S. The results showed how sections of the CIS could be disabled due to random failures, natural hazards, malicious attacks, or combinations of these factors. The math model could predict the severity of the disruption due to various combinations of CIS elements that were affected. Mitigation measures were also investigated to reduce the vulnerability from the particular cause of

disturbance. The methodology of Ouyang et al (2018) could be useful in predicting the impact of EMP on critical infrastructure in the U.S. if the hazard risk assessment impact on elements of the critical infrastructure CIS components were understood. For the electric grid, a significant knowledgebase has been developed for the electric grid as presented by Infragard (2016). The EMP Commission Reports (2004, 2008) analyzed hazard risks on not only the electric grid but other components CIS components. The math model method of Ouyang et al (2018) could be used in National Security forums to establish damage and casualty predictions from possible attack scenarios with results used to justify investment in mitigation measures.

The remainder of the emergency management section is devoted to the description of one possible plan for emergency preparedness for an EMP attack assuming the impact to CIS systems is significant, including transportation sector vehicles. To improve resilience, investing in mitigation actions for transportation sector vehicles maintaining emergency services and delivery of lifeline supplies to the public with enhanced logistics systems to repair damaged vehicles that have not employed mitigation measures should minimize significant disruptions to CIS components, and the associated long-term casualties.

8.3 Emergency Management Recovery Continuum Scenarios

The Recovery Continuum presented in **Figure 42** from the FEMA National Response Framework (FEMA (2019) shows 3 of the 4 phases of emergency management in the preparedness, response and recovery phases from any natural or man-made disaster or catastrophe. The impact of an EMP attack on the three periods will depend upon the hazards risk severity of EMP to the critical infrastructure, and the mitigation measures implemented prior to the attack. Presently the hazard risks for non-MIL transportation sector vehicles is unknown for modern "electronics-heavy" vehicles exposed to a 50 to 200Kv/m HEMP environment from an optimized nuclear EMP devices. The test plan presented in in **Section 6.0** was designed to quantify these hazard risks to better plan what mitigation actions are required

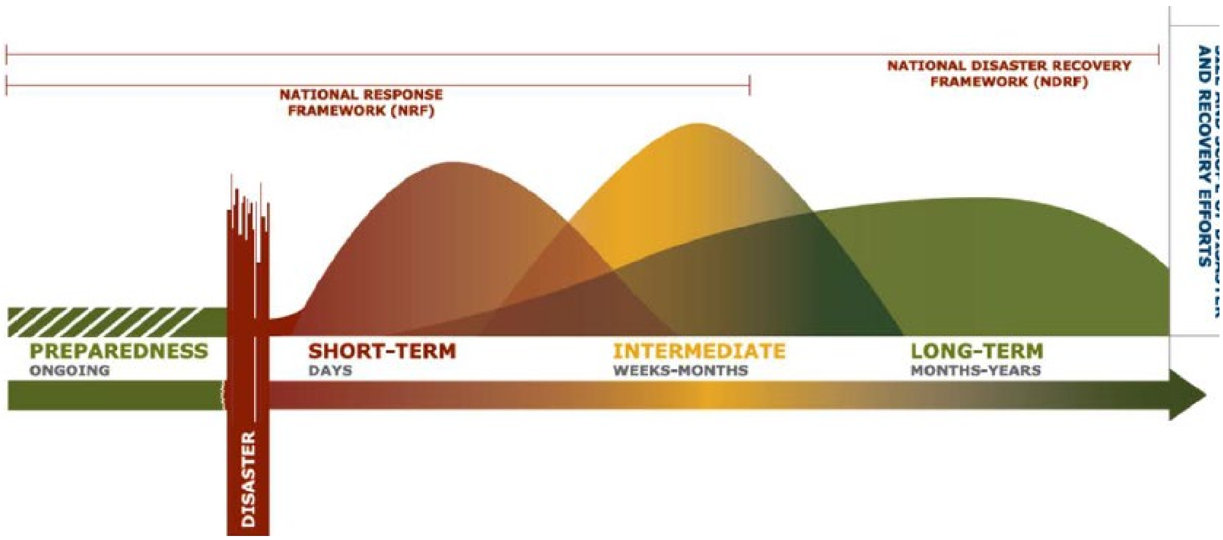


Figure 42 – Emergency Response and Recovery Continuum
(from FEMA, Fig. 1, National Response Framework (FEMA (2019))

Table 18 - Disaster Response and Recovery Continuum Extreme EMP Scenarios

Scenario	**Short Term** ***(days)***	**Intermediate** ***(weeks – months)***	**Long Term** ***(months – years)***
1) Mitigation Measures Applied (the goal)	* Limited electric grid failures. * Most emergency, delivery, and utility vehicles functional. * Damaged personal vehicles transported for repairs. * Lifeline supplies to distribution sites	* Emergency services restored. * Power restored. * Personal vehicles repaired. * Lifeline supplies available.	* Transportation vehicle infrastructure restored. * Minimal casualties.
2) No Mitigation Measures Applied (present status)	* Major damage to electric grid * Widespread power outages * Numerous emergency, delivery, and utility vehicles non-functional. * Numerous stranded personal vehicles unable to be transported for repairs. * Lifeline supplies in short supply.	* Continued widespread power outages. * Shortage of repair shops & spare parts for repairs. * Lifeline supplies begin to be exhausted. * Massive casualties begin.	* Electric grid and remainder of critical infrastructure slowly being repaired. * Lifeline supplies in short supply. * Military resources limited due to national defense needs. * Massive casualties (Pry 2017).

to enable the emergency management plans for Short Term, Intermediate Term, and Long Term response and recovery periods to become effective. To support the discussion leading to the proposed emergency management plan, two extreme scenarios can be visualized as presented in **Table 18** with many intermediate situations in between. Assuming the hazard risks due to EMP on the critical infrastructure

are significant per discussions by (Pry 2017) and others in national security forums, the end-result damage scenarios will be different depending upon the investment in mitigation measures. **Table 18** presents a high-level overview of two extreme scenarios. The goal will be to implement EMP mitigation measures strategically to transportation sector vehicles enabling the 1st scenario for continuity in emergency vehicles and delivery of lifeline supplies which will in-turn enable a reasonable level of functionality in the emergency management infrastructure to support the public and minimize casualties.

8.4 Strategy

The functional p-diagram presented in **Figure 43** was created to help visualize the possible outcomes of an EMP attack as a function of the input, the EMP attack itself, the noise factors representing the uncertainties due to the nature of the state-actor's nuclear EMP device and how it was deployed, and finally the control factors in place from mitigation measures, the emergency management infrastructure tools, and the assets of the military. Similar to the disaster response and recovery continuum extreme scenarios presented in **Table 18**, the p-diagram developed in **Figure 43** elaborates further on the output states showing two ideal states and two error states. Ideal state "y1" assumes a heavy investment in mitigation measures prior to an EMP attack for close to zero disruption and casualties. The second ideal state "y2" assumes a more strategic investment in EMP resiliency measures to avoid widespread downtime and minimize casualties. Error state "y3" assumes limited investment critical infrastructure, massive disruption to lifeline supplies, and significant casualties. Error state "y4" assumes no investment in critical infrastructure, catastrophic disruption to lifeline supplies, massive casualties.

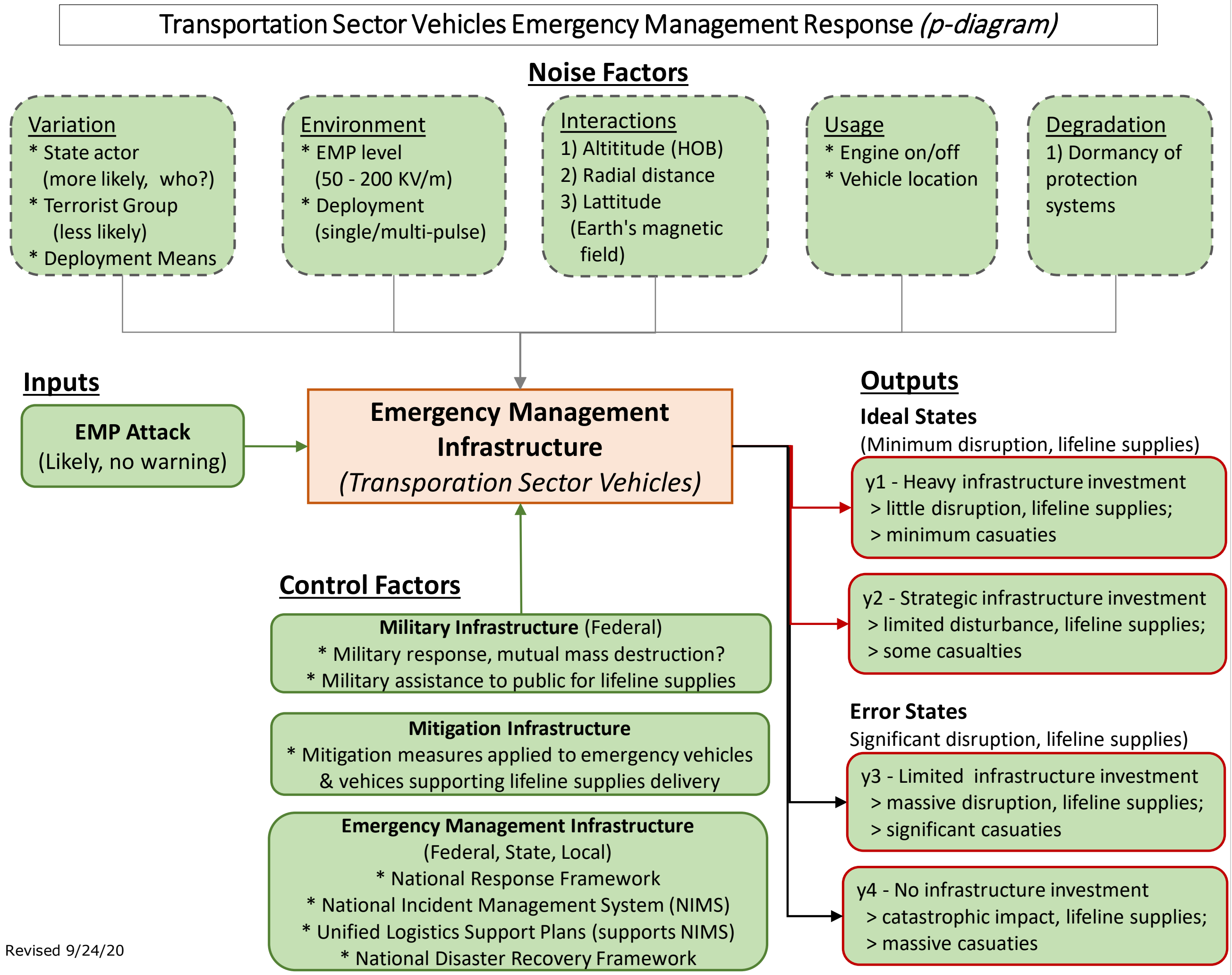


Figure 43 - Emergency Management Response to an EMP Attack Functional Diagram (p-diagram)

The control measures to influence the outcome of a high risk EMP attack are shown at the center bottom of the p-diagram. The Military Infrastructure at the Federal level will play an important role in the response, and if the adversary, state actor, terrorist organization is known, it should be assured the principle of mutual mass-destruction will be attempted similar to the scenarios during the cold war. However, what if the device is deployed in a manner where the state actor cannot be identified, a problem recognized in the literature for EMP devices (Pry (2017), Schneider (2008)), then the military response to the responsible party who initiated the attack will be compromised. The military can assist to deliver lifeline supplies to the public; however, for widespread damage over a significant portion of the US, use

of military resources for delivery of needed lifeline supplies will be limited. The Mitigation infrastructure will represent the end-result of the testing and mitigation measures successfully applied per the recommendations presented in **Sections 7.0**. The goal would be to determine from the Emergency Management Infrastructure the critical assets needed to keep the transportation sector vehicles running at least to a point to provide emergency services and delivery of lifeline supplies to the public while any damaged vehicles are being repaired in the dealerships and repair shops.

8.5 Requirements to Restore Community Lifelines

Let's assume the scenarios presented by Pry (2017) are correct, transportation sector vehicles are vulnerable, and the **Section 6.0** test programs and potential mitigation measures presented in **Sections 7.0** are validation tested and implemented strategically in a manner that is affordable. A breakdown analysis of the key emergency management infrastructure key elements should yield a list of strategic recommendations on what should be invested in for mitigation measures to yield at least one the "y2" ideal state scenario described in the p-diagram in **Figure 43,** and the 1st response and recovery continuum scenario presented in **Table 18**.

8.5.1 National Response Framework and National Incident Management System

The FEMA National Response Framework (NRF) (FEMA (2019)) is the foundation emergency management doctrine for how the nation should respond to any disaster event. NRF was built utilizing scalable, flexible, and adaptable concepts identified in the FEMA National Incident Management System (NIMS) (FEMA (2017)) to align key roles and responsibilities across the nation in the event of a national disaster or catastrophe. The goal for this study was to identify the critical parts of the non-MIL transportation sector vehicle infrastructure that would be needed to support a coordinated emergency management response to an EMP attack to avoid the possible catastrophic aftermath effects discussed by knowledgeable authors on this subject such as Pry (2017) and Mabee (2017).

The first areas of focus were the foundational components of the emergency management infrastructure required to support delivery of community lifelines for incident stabilization noted in **Figure 44** from the FEMA National Response Framework (FEMA 2019). The p-diagram shown in **Figure 43** provided a means of visualizing the input versus output functions of the emergency management infrastructure supported by transportation sector vehicles, the noise factors that created variability and uncertainty to the incident, and the control factors that could facilitate either an ideal state or error state situation. Achieving either of the ideal states was the goal with a successful emergency response for the public with emergency services available following the EMP event, and continued delivery of lifeline supplies to the public with minimum casualties.

Figure 44 - Community Lifelines for Incident Stabilization
(from FEMA National Response Framework (FEMA 2019), Fig. 1)

In **Figure 45** also from the NRF, the process employed today on how our emergency responders respond to a natural or man-made disaster catastrophe is presented. In the pre-incident stage shown by the blue box, the mitigation measures and preparedness drills are executed. Then the incident occurs, and a disruption to critical services results. To establish community lifelines for incident stabilization presented in **Figure 44**, functional transportation sector vehicles will be required to support the actions shown in the orange boxes for the emergency management infrastructure shown in **Figure 45** to be functional leading to the final ideal state in the green box, “Stabilize all Lifelines”. For any variation of the Incident Command System (ICS) from the single incident commander shown in **Figure 46** to the Unified Command shown in **Figure 47**, vehicles supporting continuity of emergency services and delivery of community lifelines will require non-MIL transportation sector vehicles that have been made resilient to EMP; hence, the purpose of this report. In the p-diagram from **Figure 43,** one control factor was the U.S. Military supporting the emergency management response which may be one scenario to

exercise in theory, but given the national security situation created by such an attack, it is more reasonable to assume the military's focus after such an attack should be to protect the nation from a follow-up attack by the potential adversary, and not be consumed with keeping the lifeline supplies and emergency services delivered to the public. Such an assumption is very clear for our allies at risk from such an attack such as S. Korea, Taiwan, Israel, and the NATO countries in Western Europe per the national security attack scenarios discussed in **Section 2.3** of this report.

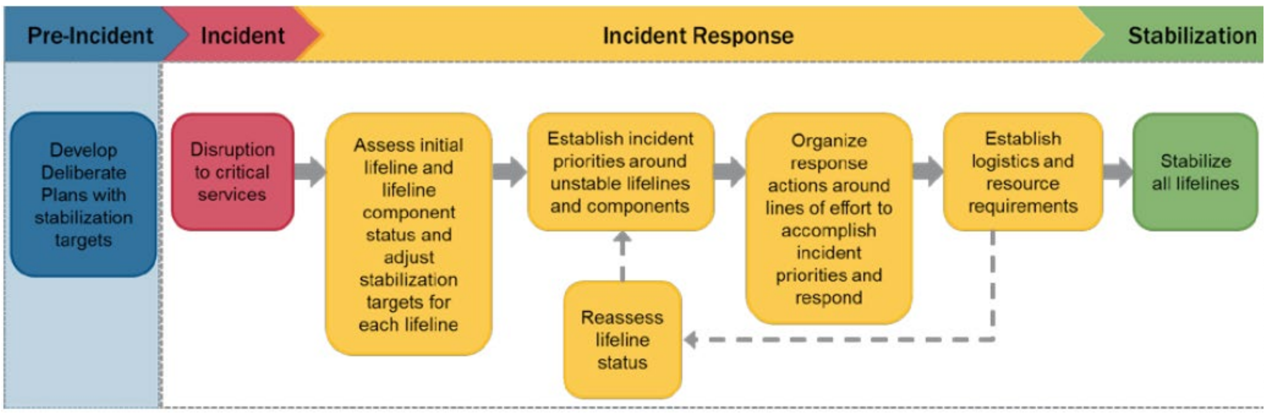


Figure 45 - The Application of Community Lifelines to Support an Emergency Response (from FEMA National Response Framework (FEMA (2019)), Fig. 2)

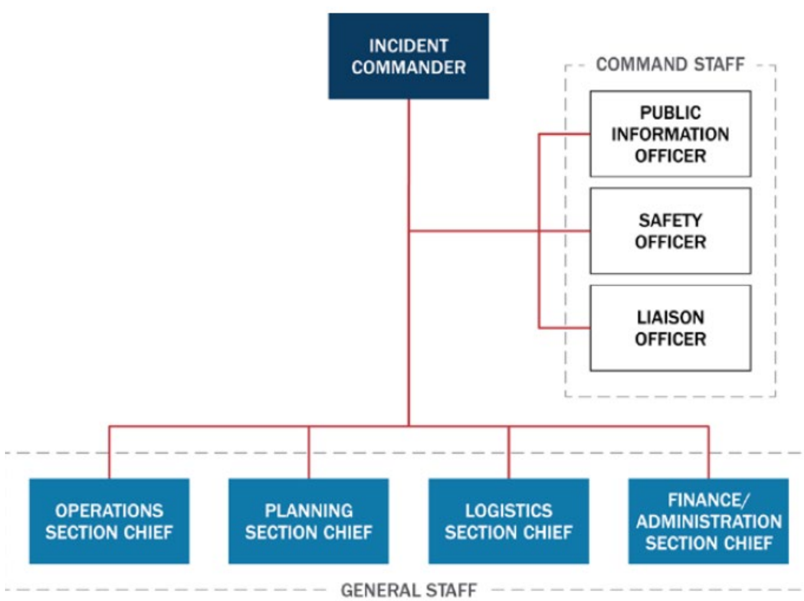


Figure 46 - Incident Command System (ICS) Organization w/Single Commander (from FEMA National Response Framework (2019), Fig. 3)

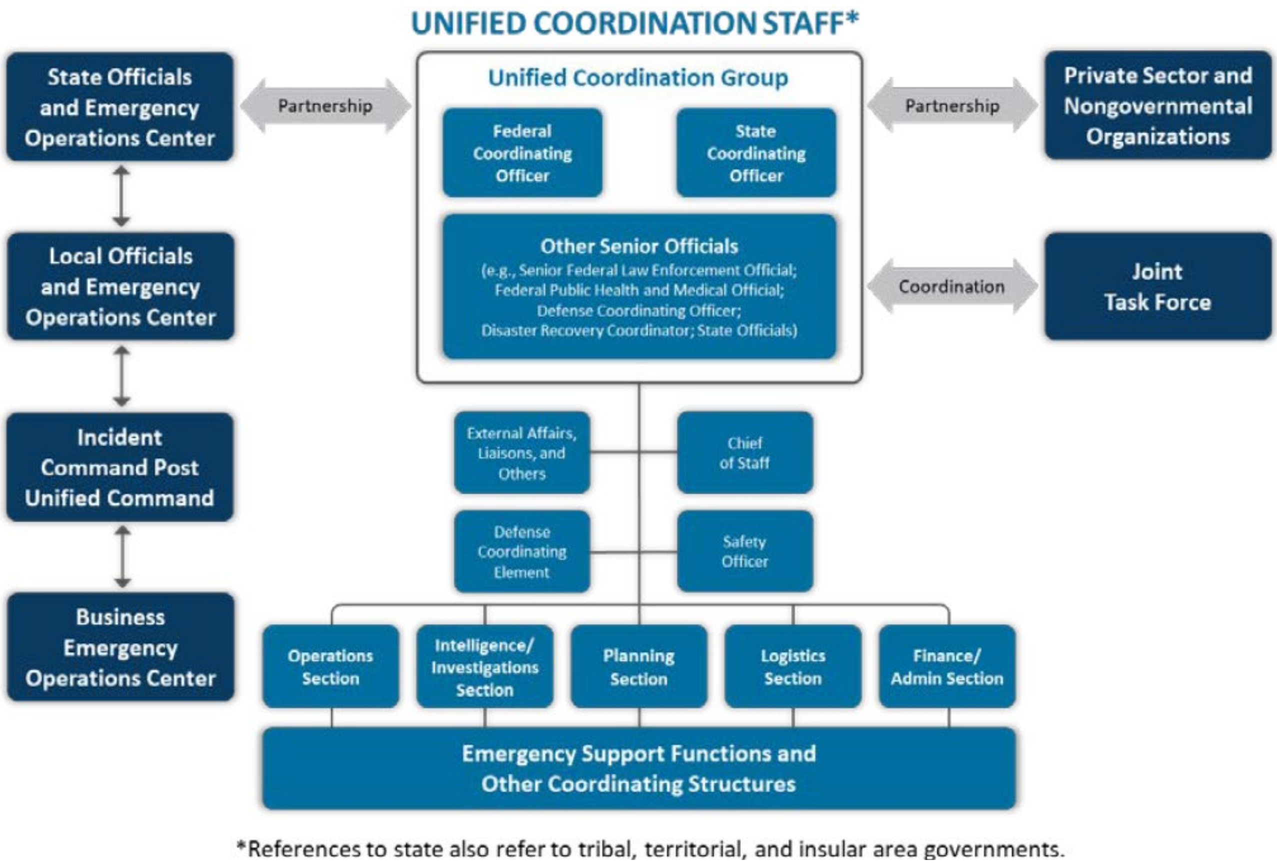


Figure 47 - Incident Command System (ICS), Unified Coordination
*(from FEMA National Response Framework (2019), Fig. 4: "**Unified Coordination**")*

In order for the Emergency Support Functions (ESFs) to deliver their core capabilities to stabilize community lifelines described in the NRF (FEMA 2019) following an EMP attack, the requirements presented in **Table 19** were identified as minimum strategic investments in the critical infrastructure for EMP resilience to achieve the "y2" ideal state in the p-diagram from **Figure 43**; otherwise, the NRF response structure would be compromised and ineffective leading to many lives lost due to long-term delay in delivery of emergency services and lifeline supplies to the public (Pry 2017).

*Table 19 - Transportation Vehicle & Infrastructure Requirements to Stabilize Community Lifelines**

No.	Requirement	Type	Description
1	Police vehicles	Vehicle	All police vehicles and vehicles used for critical security services for the public and in industry
2	Fire trucks	Vehicle	All fire truck emergency vehicles**
3	Commercial trucks and Delivery vehicles	Vehicle	Vehicles responsible for delivery of food and water supplies to the public, namely the over the road heavy duty trucks and local medium duty delivery vehicles
4	EMS vehicles	Vehicle	EMS vehicles**
5	Electric Grid	Infrastructure	Sufficient electric grid infrastructure to support restoration of community lifelines
6	Electric Grid	Vehicles	Electric utility vehicles needed for immediate repair needs
7	Fuel Refineries	Infrastructure	Fuel refineries: raw crude to finished products
8	Fuel Refineries	Vehicle	Fuel refineries: a) Heavy duty truck, distribution to fuel stations; b) internal vehicles needs to support infrastructure
9	Communications systems	Infra-structure	Sufficient continuity in the communications systems to coordinate delivery of lifeline supplies
10	Communications systems	Vehicle	Utility vehicles, short term repair of communications systems
11	Hazmat Response	Vehicle	Specialized emergency vehicles to respond to Hazmat incidents caused by power grid failures, other reasons.

Notes:
* Requirements support restoration of critical lifelines during short term response and recovery period (**Figure 42**)
** For fire and EMS vehicles, it may be more cost effective to apply mitigation measures to the firehouses and buildings where they reside vs. the vehicles themselves

8.5.2 Logistics – Unified Logistics Support Plans

A further analysis of the emergency response was conducted regarding logistics that yield more insight to the mitigation measures required prior to an EMP attack to support delivery of emergency services and community lifelines. In **Figure 48**, the logistics planning sequence of events following a disaster are described from the State of Florida Unified Logistics Support Plan (SERT 2015). In **Figure 49** also from SERT (2015), an illustration is presented for a "Type I Distribution Point Following a Natural or Man-made Disaster". By inspection of the actions and activities in **Figure 48** and **Figure 49,** additional requirements for transportation sector vehicles and support systems in the critical infrastructure were derived and presented in **Table 20** which were in addition to the 1st level requirements to support the FEMA NRF and NMIS presented in **Table 19** for delivery of critical lifeline supplies to the public after a disaster. EMP resilience of these critical infrastructure assets presented in **Table 20** will directly relate to

the successful execution of the logistics planning sequence shown in in **Figure 48**, and also allow distribution centers such as that shown in **Figure 49** to be functional.

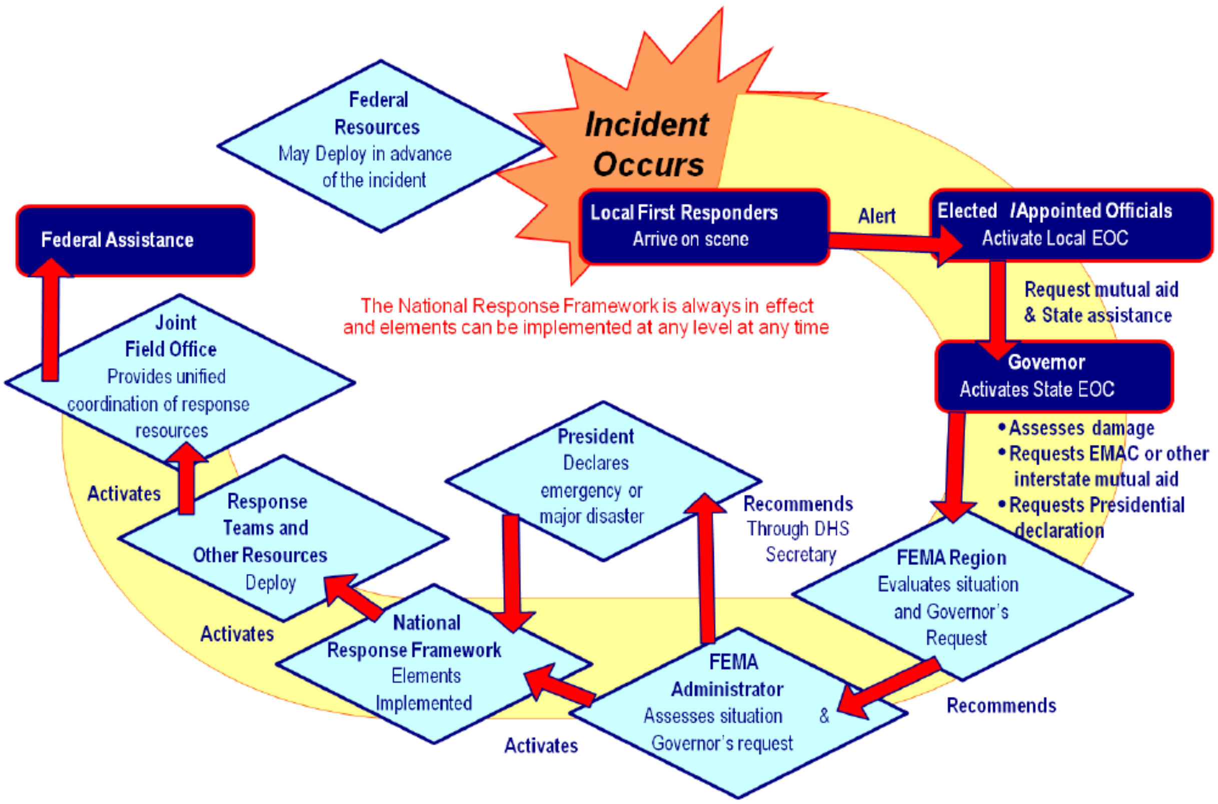


Figure 48 - Logistics Planning Sequence of Events Following a Disaster (from the State of Florida Unified Logistics Plan (SERT 2015))

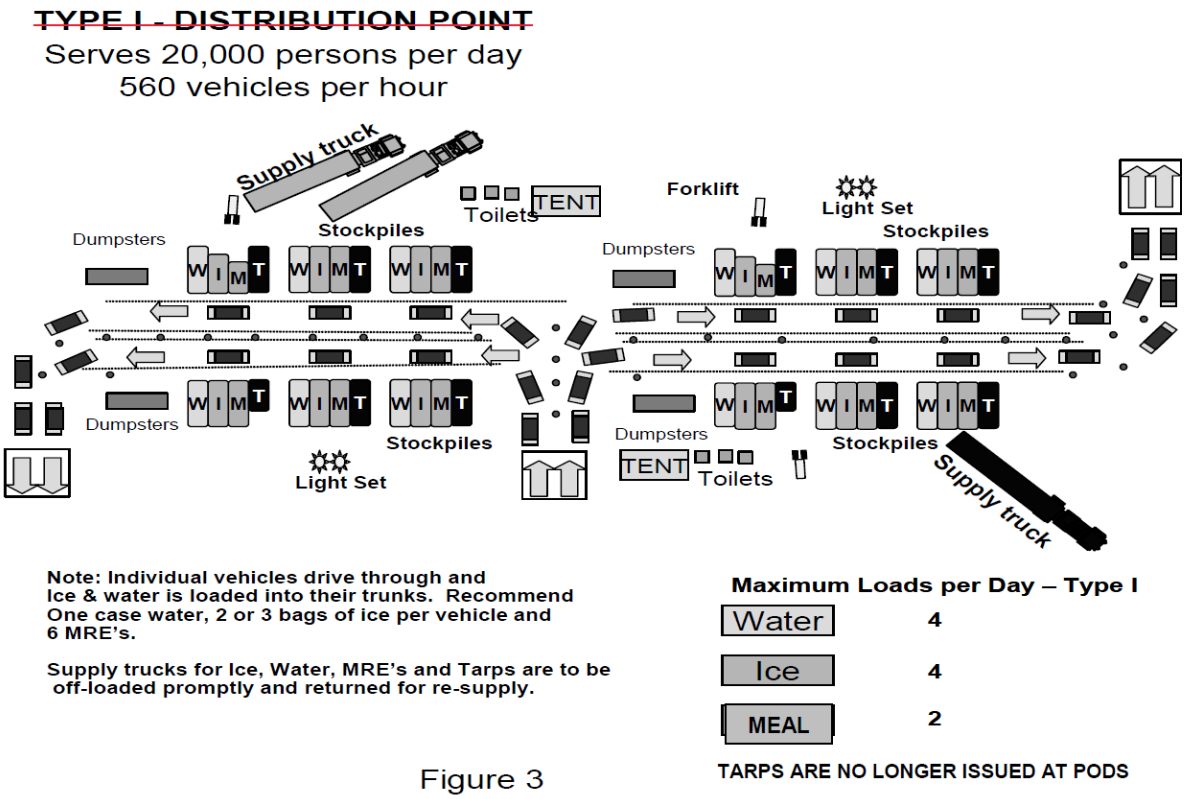


Figure 49 - Type I Distribution Point Following a Natural or Man-made Disaster (from the State of Florida Unified Logistics Plan (SERT 2015))

Table 20 - Incremental Requirements from Analysis of Unified Logistics Support Plans

No.	Requirement	Type	Description
1	Limited Personal Vehicles	Vehicle	Limited personal vehicles would be required to drive to the Type I distribution points shown in **Figure** for lifeline supplies.
2	Over the road trucks	Vehicle	Heavy duty truck commercial vehicles required for delivery of lifeline supplies to Type I Distribution Point shown in in **Figure,** grocery stores, etc.
3	Electrical Power at Distribution Points	Infra-structure	Electrical power to store ice and perishable items at distribution points (Portable generators or equiv.*).
4	Electrical Power at Warehouses	Infra-structure	Electrical power at warehouses to store perishable food items, medicine Portable generators or equiv.*).
5	Communications systems for responders	Infra-structure	Execution of all ICS based emergency response functions (**Figure)**, and the planning sequence of events shown in **Figure** will be heavily reliant on communications systems for emergency responders being up and running shortly following the attack. This involves cell towers, internet-based land-line systems, and the traditional telephone networks mentioned in **.**

8.5.3 Logistics – Logistical In-Depth Analysis (LiDA)

A more in-depth logistical analysis was performed using a process created by Austin (2017) called "Logistical in-Depth Analysis (LiDA)" to illustrate the process that would be needed to assure the proper mitigation measures are applied to the transportation sector vehicle critical infrastructure to at least be able to achieve the "y2" ideal state strategic objective shown in **Figure 43**. The process is outlined below for an example resource need relevant to an EMP attack where a significant fraction of non-MIL transportation sector vehicles could experience some level of damage requiring repair at a dealership or repair shop which is an assumption consistent with the scenario presented by Pry (2017). The LiDA form logistics analysis is driven by a resource need, and as an example, the **<u>repair of vehicles at dealership or garage</u>** was selected.

- It will be assumed these vehicles are non-MIL, non-emergency vehicles, and vehicles not required for immediate delivery of lifeline supplies to the public.
- For MIL and vehicles required for delivery of lifeline supply to the public, it will be assumed that EMP mitigation design measures have been employed.

The situation and situation scenario assumptions are noted below. The complete set of LiDA forms are presented in the **Section 13 APPENDIX.** The intent is to utilize a systematic process for logistics analysis to define the needs in support of a particular resource requested.

The Level 1 LiDA form presented in **Table 21** and the subsequent Level 2 and Level 3 forms presented in the **APPENDIX** were developed with the following situation assumptions:

1) **Situation:** Response to HEMP Attack. Multiple non-MIL vehicles require repair. 50-75% of the vehicle population experiences some failure mode per the previous discussions in **Sections 5.0 to 7.0** (assumption)
2) **EMP Deployment Scenario Assumptions:** a) 300 KM HOB; b) Optimized HEMP weapon, 100-200 Kv/m; c) Ground Zero, Omaha, NB**;** d) widespread coverage over the entire United States, parts of Canada and Mexico (see **Figure 2**)

3) **Situation scenario assumptions:** Immediately following incident, since 50-75% of vehicles within blast radius requiring repair:

- Assume dealership and repair garage diagnostic equipment have been protected from EMP.
- Until dealership or service garage performs diagnostic tests, it is unknown what parts have failed requiring repair, and if spare parts are available.
- After diagnostics are complete, ~50% of the failed vehicles (25-37% of the population) will require parts replacement with long lead times, exceeding 3-6 months. Remaining vehicles can be repaired within 6-8 weeks per normal service procedures and spare parts availability.

4) **Resource requested:** Repair of vehicles at dealership or service garage

Based on the LiDA form analysis for this one logistical requirement, **repair of vehicles at dealership or service garage**, the following incremental mitigation requirements presented in **Table 22** were identified as a result of the logistics analysis via the LiDA form method presented in **Table 21**, and the complete set of Level 1 to Level 3 support LiDA forms presented in the **Section 13 APPENDIX.** These requirements would be in addition to requirements presented in **Table 19** and **Table 20** from inspection of the National Response Framework (FEMA 2019)) NIMS documentation (FEMA (2017)), and the Unified Logistics Support Plans reviewed from the State of Florida (SERT 2015). If additional resource needs were analyzed by this method, additional incremental mitigation requirements would be generated to support an in-depth emergency management plan in preparation for an EMP attack.

Table 21 - Logistical In-Depth Analysis (LiDA) Level 1 Resource Request Form

Logistical Mission Requirement Request (LMRR)
Resource requested: Repair of vehicles at dealership or service garage
Level: Level 1 LiDA

Logistical factors to consider	**Method of obtaining this resource?**	**Training required to support this logistical factor?**	**Do you need another LMRR to support this logistical factor?**
1) Procurement & Cost (if known)	1.1) Vehicle owners contact tow service & repair garages via cell phone or land line	No.	Yes (cell phone, land line communications could be damaged)
	1.2) Dealerships & repair garages must address surge in repair needs from customers	Yes (Training for existing and incremental service techs)	Yes (surge in service appointments; hiring of temporary service techs)
	1.3) Service procedures- dealerships & repair shops	Yes (service procedures)	Yes (Procedures- EMP damage modes)
	1.3) Mobilize Police, Fire, EMS to respond to assist stranded vehicles	Yes	Yes (Mobilization and de-mobilization plan & training)
	1.4) Delivery of lifeline supplies to public with 50-75% damaged.	Yes	Yes (will require support from electric grid and fuel critical infrastructures)
2) Transportation to point of receipt	2.0) Tow truck w/EMP protection hardware	No.	Yes (EMP resilient emergency required)
3) Staffing & equipment REQs)	3.1) Driver of tow truck	No.	Yes (same as above)
	3.2) Personnel at dealership	Yes	Yes (address surge in service needs)
4) Storage REQs	4.0) Dealerships, repair shops- storage of vehicles	No.	Yes (Storage - waiting for repairs)
5) Distribution & Transportation REQs	5.1) Possible traffic jams, lack of access from disabled vehicles.	No	Yes (EMP resilient emergency vehicles required for response)
	5.2) Stranded motorists need transportation home.		Yes (same as above)
6) Security and Site-control	Police, Fire and EMS control chaos on streets following EMP attack.	Yes (training for EMP emergency)	Yes (same as above)
7) Safety issues	Police, Fire and EMS maintain safety in public areas following EMP attack.	Yes (training for EMP emergency)	Yes (EMP resilient emergency vehicles required for response)
8) De-Mobilization Requirements	8.1)Recovery from initial attack, immediate issues 8.2)Long-term re-build of vehicle infrastructure	Yes (training for EMP emergency)	Yes (Need mobilization and de-mobilization plan & training)
9) Other Requirements	Remove important documents from vehicle prior to being towed to dealership	No	Yes (survival kits in vehicles in the event stranded on road)
10) Transportation REQs to storage	Same as 4.0	No	Yes (see 4.0)

Table 22 - Incremental Requirements from Logistical In-Depth Analysis (LiDA)
("Repair of vehicles at Dealerships and Repair Shops" Logistical Need)

No.	Requirement	Type	LiDA Level	Description
1	Cell phone communications	Infrastructure	1	Required for stranded motorists to contact tow trucks.
2	Surge in repairs	Emergency Mgmt.	1	Surge in service appointments at dealerships & repair shops for personal/commercial vehicles.
3	Service procedures	Emergency Mgmt.	1	Procedures for likely EMP damage modes
4	Electric power for fuel stations	Infrastructure	1	Back-up power for fuel stations to pump fuel from storage tanks
5	Two truck drivers	Emergency Mgmt.	1	Personal vehicles may be damaged. Drivers need transportation to tow shops.
6	Shortage of technicians	Emergency Mgmt.	1	Shortage of technicians at dealerships and repair shops. Need to hire temp. techs.
7	Storage of vehicles	Emergency Mgmt.	1	Number of damaged vehicles exceed dealership and repair shop storage space.
8	Traffic jams	Emergency Mgmt.	1	Multiple disabled vehicles complicate retrieval by tow trucks
8	Traffic jams	Infrastructure	1	EMP resilient traffic signal hardware needed
9	Stranded motorists	Emergency Mgmt.	1	Stranded motorists with damaged vehicles need ride home
10	Response and recovery	Emergency Mgmt.	1	National preparedness drills needed for EMP attack similar to drills for natural hazards.
11	Long term recovery	Emergency Mgmt.	1	Unique issues w/long term recovery, vehicles & critical infrastructure, e.g., spare parts.
12	Vehicle survival kits	Vehicle	1	Survival kits in vehicles containing MREs and medical supplies if motorists stranded > 1day
13	Resilient cell tower hardware	Infrastructure	2	Backup batteries, generators & EMP protection hardware for cell towers
14	Internet hardware	Internet hardware	2	Internet hardware with some level of resilience to EMP
15	Cell/internet service techs	Emergency Mgmt.	2	Incremental service techs, for cellular and internet providers.
16	Spare parts – infrastructure	Emergency Mgmt.	2	Sufficient spare parts inventory for critical infrastructure, resilient to EMP
17	Defense Production Act (DPA)	Emergency Mgmt.	2	Exercise DPA to prioritize work in repair shops on damaged vehicles
18	Supply chain personnel	Emergency Mgmt.	2	OEMs will coordinate with suppliers for incremental spare parts manufacture
19	Hiring of personnel	Emergency Mgmt.	2	Incremental personnel to address surge in vehicle repairs.
20	Security for spare parts	Emergency Mgmt.	2	Spare parts for vehicle repairs could be subject to theft
21	Documentation, lessons learned	Emergency Mgmt.	2	FEMA lead in documenting lessons learned
22	EMP conversions	Infrastructure	2	Authorized dealers, EMP vehicle conversions

23	Security, EMP Conversions	Emergency Mgmt.	2	Security for authorized EMP vehicle conversion shops
24	EMP training, 1st responders	Emergency Mgmt.	2	1st responders training & preparedness drills for delivery of lifeline supplies to public
25	Emergency kits	Vehicles	2	Emergency kits, encourage use in all vehicles
26	Training, EMP conversions	Vehicles	3	EMP vehicle conversions at authorized shops will require training, certification
27	Resilient refineries	Infrastructure	3	Investments in EMP resilience measures for refineries
28	Training, EMP protection hardware	Infrastructure	3	Awareness training for EMP protection hardware for critical infrastructure

8.6 Discussion – Emergency Management Plan

The analysis above was created to demonstrate how the mitigation requirements for transportation sector vehicles to support delivery of critical lifelines after an EMP attack could be analyzed. It was assumed that personal transportation sector vehicles would be damaged due to the costs involved in EMP mitigation actions applied to all non-MIL transportation sector vehicles; however, the repair systems would be enhanced to address the increased need of vehicle repairs over a short period of time. If the requirements described in **Table 19**, **Table 20**, and **Table 22** were implemented, then there's a chance to migrate to the "y2" ideal state as presented in the p-diagram in **Figure 43** yielding a response continuum resembling more of the 1st scenario with mitigation actions applied and minimum casualties presented in **Table 18**; hence, enabling the FEMA National Preparedness Goal (FEMA 2015) to be achieved.

9 SUMMARY AND CONCLUSIONS

A plan has been developed on how the resilience of transportation sector vehicles can be improved in the event of a nuclear WMD attack optimized to generate an electromagnetic pulse over a targeted area of the U.S. The fundamental factors leading to a national security threat from state actors, and to a lesser extent, terrorist organizations, were studied. The methodology for risk analysis and mitigation actions utilized engineering and emergency management disciplines to analyze the potential failure modes of modern-day transportation sector vehicle electronics sub-systems and components to an EMP threat. A comprehensive test plan for passenger cars, light trucks, and medium / heavy-duty trucks was developed to generate new and valuable data supporting an updated hazards risk analysis for modern-day transportation sector vehicles as exposed to an EMP environment characteristic of EMP weapons possessed by state actor potential adversaries. Based on a preliminary hazards risk analysis, design mitigation countermeasure proposals were developed to improve resilience to the EMP effect, the primary noise factor in this analysis. Finally, an emergency management plan was proposed that would rely on design mitigation countermeasures to be implemented on emergency vehicles and vehicles supporting delivery of lifeline supplies to the public nationwide. It is expected the proposals and analyses developed in this report can serve as the foundation for future research, test programs and mitigation proposal verification and validation test programs, all aimed at improving resilience of transportation sector vehicles to the nuclear EMP threat from potential adversaries.

The conclusions from this study are summarized as follows:

- A national security threat exists regarding potential state actor adversaries deploying nuclear weapons 30-400 Km above the earth, optimized to generate an EMP pulse, or sequence of pulses, that could be devastating to the electronics components in the electric grid, transportation sector vehicles, and electronics components supporting the remainder of critical infrastructure.

- To avoid massive casualties associated with long term disruption of critical lifeline supplies and lack of emergency services for fire, police and EMS, the foundation of the emergency management plan resides in conversion of at least emergency vehicles and vehicles supporting delivery of lifeline supplies to the public to become resilient to EMP.
- Cost estimates were developed for the test program that will be critical in generation of new data to complete the hazards risk analysis.
- Engineering reliability analysis methods helped visualize the potential failure modes for an EMP environment imposed on modern-day automotive vehicle sub-systems and components.
- Mitigation proposals were developed to attenuate the EMP pulse amplitude imposed on the vehicle wiring system via a transition voltage suppression device installed across the vehicle battery supply +/- terminals. Methods to provide a means of filtering for specific components in a manner that could be implemented in and validation tested for "as-built vehicles" aftermarket EMP vehicle conversions was also discussed.
- The emergency management plan was proposed relative to the assumption that at least emergency vehicles and vehicles supporting delivery of lifeline supplies to the public were retrofitted for EMP mitigation measures.
- Logistics plans were developed using a Logical In-Depth Analysis method to define the requirements for repair of as-built vehicles exposed to EMP after the EMP event.

10 FUTURE PATHS

The contents of this report should serve as the foundation for follow-up projects and research studies to improve resilience of transportation sector vehicles to an EMP attack, projects that reside in emergency management, national security, or engineering organizations. In the process of considering any project involved with testing, mitigation countermeasure design and development, or implementation of mitigation actions nationwide on target non-MIL transportation sector vehicles, costs will always be part of the equation in funding grant proposals and implementation. The test plan proposals were sufficiently detailed in **Section 6.0** with costs estimated at ~$0.5 M for cars and light trucks, and ~$0.75M for Medium and Heavy-duty Delivery Trucks. Although not discussed, costs for a preliminary design mitigation and validation testing programs would likely reside in a similar cost range since validation testing would be required after design actions and prototype hardware were created.

The remaining element for successful execution of the proposed emergency management plan are the estimation of costs for implementation of mitigation measures on transportation sector vehicles supporting delivery of emergency services and lifeline supplies to the public. To estimate costs for police, fire and EMS vehicles, the following projections were made.

- Police Vehicles:
  - Approximately 750,000 police officers in the US (BJS 2016).
  - Assume number of police vehicles is 50% the number of police officers, ~375,000 vehicles
  - Assume cost for EMP conversion parts based on preliminary mitigation measures investigation (**Section 7.0**), target cost ~ $500/vehicle
  - Cost of labor and oversight to install parts (assumes service procedure developed via non-recurring engineering costs), ~$500/vehicle

- Total estimated cost for EMP conversions for Police vehicles (rough order of magnitude estimate): 375,000 x ($500 + $500) = $375,000,000 = $375M

- Fire trucks and engines:
  - Total estimated pumpers and suppression vehicles in the US (Evarts and Stein, 2020): (72,100 + 80,900) = 153,000 vehicles
  - Estimated cost for conversion = (same as police cars +$1000 due to size of vehicles, complexity to perform conversions on-site, plus some protection for specialized electronics equipment) = $2000
  - Total cost for conversions = $2000 * 153,000 = $306M
- EMS Vehicles:
  - Estimated no. of vehicles = 75,000 vehicles (Mears 2011)
  - Estimated cost for conversion (Same as fire trucks due to complexity and specialized electronics equipment) = $2000
  - Total cost for conversions = $2000 * 75,000 = $150M

- Total estimated conversion cost for all emergency vehicles = $375M + $306M + $150M = $831M

The above very preliminary and cursory analysis shows that following a proper engineering program to determine the optimal EMP resilient conversion package, applying this package to emergency vehicles nationwide could be implemented at a cost ~ $1.0B. Cost for conversion estimates would be needed for over the road heavy duty trucks, medium duty trucks, electric utility bucket truck vehicles, and local delivery vehicles. As one can see from the emergency vehicle analysis, these conversion costs are minimal as comparted to the costs incurred both financial and loss of life if long term disruptions occurred in the critical infrastructure due to an EMP attack. One can also see from these estimates that they are way below what was spent in the context of major hurricane natural disasters. For example, hurricane Katrina and Superstorm Sandy were estimated to cost $170B and 74B, respectively.

To summarize estimated costs for testing, development of EMP mitigation measures and costs for strategic conversion of vehicles to support the emergency management proposed plan, a preliminary financials summary **Table 23** was created to place the EMP conversions for transportation sector vehicles into perspective relative to other disaster response expenditures. The costs can be used for budgetary numbers for the initial risk analysis test program, the subsequent mitigation design and development programs, and finally the widespread implementation of the mitigation measures to support an emergency management infrastructure that is at least able to support delivery of emergency services and lifeline supplies to the public.

Table 23 - Path Forward Cost Estimates

Description	**Estimated Cost**	**Comment**
Non-Recurring Engineering Costs:		
Initial Test Program & Risk Analysis	$1.25 M	**Section 6.0**
Mitigation Investigation & Validation Tests	$2.25 M (Prelim. Est.)*	Address issues from test program with mitigation actions. Tests repeated for validation of mitigation actions.
Service procedure and validation testing for vehicles supporting emergency services and delivery of lifeline supplies	$2.25 M (Prelim. Est.)*	Assumes service procedure developed, EMP mitigation hardware validation tested on target vehicle.
Subtotal (non-recurring costs):	$5.75 M	
Recurring Engineering Costs:		
Police vehicle EMP conversions	$375 M	See comments above
Fire truck & engine conversions	$305 M	See comments above
EMS Vehicles	$150 M	See comments above
Utility bucket trucks for electric power and communications	$250 M (Preliminary Estimate)*	Estimate, need more data, trucks are 25% gas, 75% diesel. Similar conversions as for heavy duty and medium duty delivery trucks.
Over the road delivery trucks, medium duty delivery trucks to support delivery of lifeline supplies	$1,080 M (Prelim. Est.)*	Estimate. Assume same cost as all emergency vehicles and utility trucks combined.
Subtotal (recurring costs for initial implementation):	$2,160 M	
Preliminary Grand Total Cost Estimate >	$2.17 B	Note: Budgetary estimate <<< cost of recent large-scale natural disasters such as Hurricane Katrina or Hurricane Sandy, costing ~$170B and $74 B, respectively (GAO 2020)

*Preliminary cost estimates prior to having more accurate budgetary numbers
** Note: “M” == million (10^6); “B”== billion (10^9)

11 FINAL COMMENT

In light of the summary and conclusions of this report, and the preliminary cost estimates presented in the prior Future Paths section, a path to the future can be envisioned to create a more robust emergency management plan with a cost effective solution to retrofit transportation sector vehicles to become resilient to EMP supporting the initial emergency response and recovery efforts. Such actions will greatly assist and mitigate situations leading to long term casualties and hardships that could be incurred from an EMP attack.

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13 APPENDIX – LOGISTICAL IN-DEPTH ANALYSIS

A more in-depth logistical analysis was performed using a process created at by Austin (2019) called "Logistical in-Depth Analysis (LiDA)". The process is outlined below for a given resource need. The resource need is the "repair of vehicles at dealership or garage" damaged due to the EMP attack. We will assume these are non-MIL, non-emergency vehicles, and vehicles not required for immediate delivery of lifeline supplies to the public, but nevertheless, damaged due to the attack and require repairs. The situation and situation scenario assumptions are noted below. The subsequent LIDA forms address the resource requested at a high level, Level 1, and then drill down to lower level needs as show in the Level 2 and Level 3 LiDA forms. The intent is to utilize a systematic process for logistics analysis to define the needs in support of a particular resource requested.

For the set of LiDA forms presented in this Appendix, the following represents the situation assumptions and the requested resource.

Situation: Response to HEMP Attack. Multiple non-MIL vehicles require repair. 50-75% of vehicle population (assumption)

EMP Deployment Scenario Assumptions: a) 300 KM HOB; b) Optimized HEMP weapon, 100-200 Kv/m; c) Ground Zero, Omaha, NB**;** d) widespread coverage over the entire United States, parts of Canada and Mexico (see **Figure 2**)

Situation scenario assumptions: Immediately following incident, 50-75% of vehicles withing blast radius require repair. Until dealership or service garage performs diagnostic tests, it is unknown what parts have failed requiring repair, and if spare parts are available. It will be assumed that after diagnostics are complete, ~50% of the failed vehicles (25-37% of the population) will require parts replacement with long lead times, exceeding 3-6 months. Remaining vehicles can be repaired within 6-8 weeks per normal service procedures and spare parts availability.

Resource requested: Repair of vehicles at dealership or service garage

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Resource requested: Repair of vehicles at dealership or service garage

Level: Level 1 LiDA

Logistical factors to consider	Method of obtaining this resource?	Training required to support this logistical factor?	Do you need another LMMR to support this logistical factor?
1) Procurement & Cost (if known)	1.1) Vehicle owners contact tow service & repair garages via cell phone or land line	No.	Yes (cell phone, land line communications could be damaged)
	1.2) Dealerships & repair garages must address surge in repair needs from customers	Yes (Training for existing and incremental service techs)	Yes (surge in service appointments; hiring of temporary service techs)
	1.3) Service procedures- dealerships & repair shops	Yes (service procedures)	Yes (Procedures- EMP damage modes)
	1.3) Mobilize Police, Fire, EMS to respond to assist stranded vehicles	Yes	Yes (Mobilization and de-mobilization plan & training)
	1.4) Delivery of lifeline supplies to public with 50-75% damaged.	Yes	Yes (will require support from electric grid and fuel critical infrastructures)
2) Transportation to point of receipt	2.0) Tow truck w/EMP protection hardware	No.	Yes (EMP resilient emergency REQd)
3) Staffing & equipment REQs)	3.1) Driver of tow truck	No.	Yes (same as above)
	3.2) Personnel at dealership	Yes	Yes (address surge in service needs)
4) Storage REQs	4.0) Dealerships, repair shops- storage of vehicles	No.	Yes (Storage - waiting for repairs)
5) Distribution & Transportation REQs	5.1) Possible traffic jams, lack of access from disabled vehicles.	No	Yes (EMP resilient emergency vehicles required for response)
	5.2) Stranded motorists need transportation home.		Yes (same as above)
6) Security and Site-control	Police, Fire and EMS control chaos on streets following EMP attack.	Yes (training for EMP emergency)	Yes (same as above)
7) Safety issues	Police, Fire and EMS maintain safety in public areas following EMP attack.	Yes (training for EMP emergency)	Yes (EMP resilient emergency vehicles required for response)
8) De-Mobilization Requirements	8.1)Recovery from initial attack, immediate issues 8.2)Long-term re-build of vehicle infrastructure	Yes (training for EMP emergency)	Yes (Need mobilization and de-mobilization plan & training)
9) Other Requirements	Remove important documents from vehicle prior to being towed to dealership	No	Yes (survival kits in vehicles in the event stranded on road)
10) Trans REQs to storage	Same as 4.0	No	Yes (see 4.0)

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LEVEL 2

LIDA Forms

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Cell phone/land line communications	**Level:** 2
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L1, 1.1

Situation scenario assumptions: Assume major electric grid failure. Multiple cell towers damaged requiring repair (failures in battery/generator backup systems; towers interconnected with the local and long-haul telecommunications networks, vulnerable to EMP. Key elements of internet provider hardware and users IT equipment damaged. (Baker and Volant 2018).

Directions: See Level 1 LiDA

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	1.1) Cell towers require repair. Time frame - days, weeks.	Yes	Yes – Mitigation (cell towers w/back-up batteries and generators resilient to EMP)
	1.2) Internet provider hardware and users IT equipment require repair.	Yes	Yes – Mitigation (Internet provider hardware & IT equipment resilient to EMP)
2) Transportation to point of receipt	Utility vehicles need to reach reaching towers for repairs	No.	Yes – Mitigation (EMP resilient utility vehicles for cell service and internet providers)
3) Staffing/ equipment requirements	Cell service & internet provider service technicians	Yes	Yes - Transportation to/from work; training, repairs from EMP damage.
4) Storage REQs	Storage of spare parts for equipment vulnerable to EMP	Yes	Yes (likely requires legislation)
5) Distribution & Transportation REQs	Transport of spare parts damaged by EMP nationwide	No	Yes (Requires EMP resilient over the road & box delivery trucks.
6) Security and Site-control	n.a.	No	No
7) Safety issues	n.a.	No	No
8) De-Mobilization REQs	Documentation of failure modes. Updated risk analysis.	Yes (FEMA guidance)	Yes- Methodology, hazards risk analysis, EMP vulnerable equipment
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	Storage of EMP vulnerable spare parts	No	Yes (storage plan)

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Address surge in service appointments for vehicle repairs			**Level:** 2.1
EMP Deployment Scenario Assumptions: See Level 1 LiDA			**Ref Level:** L1, 1.2, 3.2
Situation scenario assumptions: Significant fraction of the vehicle population requiring repairs. Assuming repairs are sufficiently complex in nature, will require dealership diagnostic tools. Dealership repairs must be prioritized to support rebuild of the critical infrastructure for emergency vehicles, utility vehicles, delivery vehicles for lifeline supplies, and personal transportation vehicles. Exercising Defense Authorization Act likely.			
Directions: See Level 1 LiDA			
Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	1.1) Execute Defense Authorization Act (DAA) to prioritize how dealerships will complete repairs to damaged vehicles	Yes	No – DAA Bill, passed by congress, signed by the President. Local jurisdictions provide oversight to dealerships. Training for dealership management required for DAA
	1.2) Supply chain personnel, coordinate spare parts procurement, supplier production ramp-up	YES	YES – Coordination w/component suppliers and production ramp-up will likely be a major issue.
2) Transportation to point of receipt	n.a.	No	n.a.
3) Staffing/ equipment requirements	Hiring of additional personnel to address surge. Qualified temporary technicians from other repair shops, the military. Extended 24/7 work hours until surge needs reside	Yes	Yes – Training will be required for temporary technicians
4) Storage REQs	Additional storage, spare parts required for vehicle repairs	no	No
5) Distribution & Transportation REQs	Transport of spare parts to dealerships to address surge	No	No. Utilize existing dist. system once delivery vehicles repaired
6) Security and Site-control	Security for spare parts. Could be subject to theft	Yes	No – Just training for parts depts. for security measures.
7) Safety issues	n.a.	No	No
8) De-Mobilization REQs	Documentation lessons learned for future disasters	Yes (FEMA guidance)	Yes- FEMA lead documentation of lessons learned
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	Storage of EMP vulnerable spare parts	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Repair procedures for dealerships & repair garages.			**Level:** 2.0
EMP Deployment Scenario Assumptions: See Level 1 LiDA			**Ref Level:** L1.0, 1.3
Situation scenario assumptions: Repair procedures for dealerships & repair garages. What can be expected from a vehicle damaged by an EMP attack.			
Directions: See Level 1 LiDA			
Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	Create generic and if required, specific service bay prepare procedures for vehicles damaged by EMP attack (FEMA contract outside contractor SME)	No	No. New document (does not exist)
2) Transportation to point of receipt	Deliver as service bulletin via same system used now for service bulletin updates	No	No
3) Staffing/ equipment requirements	SME contract personnel hired by FEMA to create procedures	No	No
4) Storage REQs	None	No	No
5) Distribution & Transportation REQs	None	No	No
6) Security and Site-control	None	No	No
7) Safety issues	None	No	No
8) De-Mobilization REQs	None	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Delivery of lifeline supplies to public with significant fraction of transportation sector vehicles damaged, plus damage to electric grid, fuel supply critical infrastructure.	**Level:** 2.1
EMP Deployment Scenario Assumptions: See Level 1 LiDA Form	**Ref Level:** L1.0, 1.4

Situation scenario assumptions: To avoid disruption of food supply deliveries to food distribution centers and grocery stores, heavy duty over the road and medium/light duty delivery trucks must incorporate EMP resilient design features. Otherwise, food supplies could run out in 15 days (Baker and Volandt 2018)

Directions: See Level 1 LiDA Form

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	1.1) Over the road heavy duty trucks w/EMP resilience hardware; or repairs < 5 days**	No.	Yes (EMP resilient hardware incorporated into over-the-road heavy duty trucks)
	1.2) Medium/light duty delivery trucks w/EMP resilience hardware or repairs <10 days	No	Yes (EMP resilient hardware incorporated into medium/light duty commercial delivery trucks)
	1.3) Transportation fuel refining facilities protected, EMP resilient design features	No	Yes (Plan for EMP resilient fuel refining facilities – contain SCADAS)
	1.4) Fuel stations w/backup generators, EMP hardware		YES (plan for EMP resilient fuel stations)
2) Transportation to point of receipt	Delivery of food items to warehouses & grocery stores	No	No. Existing supply chain network as long as vehicles are functional
3) Staffing/ equipment requirements	Develop and implement cost effective EMP conversions	No	No
4) Storage REQs	May want to consider larger inventories in food depots vs. Just In time concept.	No	No
5) Distribution & Transportation REQs	Delivery of food items to warehouses and from warehouse to grocery stores	No	No. Existing supply chain network as long as vehicles are functional
6) Security and Site-control	Emergency personnel (Police) guard food supply warehouse.	No	No. Existing police emergency personnel if vehicles functional
7) Safety issues	Monitor safety of public and food providers	No	No. Existing Fire/EMS emergency personnel if vehicles functional
8) De-Mobilization REQs	Demobilize once emergency is completed.	No	No
9) Other logistical REQs	None	No	No
10)Trans. REQs-storage	None	No	No

Notes: ** within 15 days with major disruption of electric grid, major impact on transportation sector vehicles, grocery distribution centers would be empty (Baker and Volandt 2018)

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: EMP Resilient emergency vehicles required for response	**Level:** 2.2
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L1, 2.0, 3.1

Situation scenario assumptions: Without design measures applied to emergency vehicles, critical infrastructure can remain paralyzed for months following the EMP attack. Legislation needed to require all emergency vehicles to be resilient to EMP. Classes of emergency vehicles are Police, Tow service, Fire, EMS. Since Fire and EMS vehicles spend majority of time inside buildings waiting to be deployed, may utilize building/facility EMP protection vs. vehicle.

Directions: See Level 1 LiDA

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	Utilize technology developed per the Test Plan, Section 6.0, and the Risk Analysis and Mitigation Section 7.0.	Yes	Yes – Training and procedures for conversion of existing vehicles for incorporation of EMP mitigation design actions.
2) Transportation to point of receipt	n.a.	No	n.a.
3) Staffing/ equipment requirements	Authorized dealer concept for conversions with EMP resilience hardware	Yes	Yes – Training for authorized dealers for EMP conversions
4) Storage REQs	Manufacture and storage of EMP conversion hardware	No	No
5) Distribution & Transportation REQs	Delivery of conversion hardware to authorized dealers	No	No
6) Security and Site-control	Security measures similar to obtaining a cell phone or internet service contract	Yes	No – training as part of becoming an authorized dealership for EMP conversions.
7) Safety issues	n.a.	No	No
8) De-Mobilization REQs	Documentation lessons learned for during incident if EMP attack occurs	Yes (FEMA guidance)	No – Documenting effectiveness of EMP resilience hardware.
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	See 4.0	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Storage of customer vehicles at dealership and service garages to address surge for repairs	**Level:** 2.3
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L1, 4.0

Situation scenario assumptions: Without design measures applied to emergency vehicles, critical infrastructure can remain paralyzed for months following the EMP attack. Legislation needed to require all emergency vehicles to be resilient to EMP. Classes of emergency vehicles are Police, Tow service, Fire, EMS. Since Fire and EMS vehicles spend majority of time inside buildings waiting to be deployed, may utilize building/facility EMP protection vs. vehicle.

Directions: See Level 1 LiDA

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	Rent parking space close to dealership (shopping center parking lots, etc.)	No	No
2) Transportation to point of receipt	Direct tow trucks to deliver vehicles to temporary parking lot	No	No
3) Staffing/ equipment requirements	Need personnel at temporary parking lot to receive vehicles from tow service.	No	No
4) Storage REQs	Temporary parking lot – rent space	No	No
5) Distribution & Transportation REQs	Receive vehicle, keys, customer info. Provide receipt of delivery to tow service.	No	No
6) Security and Site-control	Security service to protect vehicles in temp. parking lot.	No	No
7) Safety issues	n.a.	No	No
8) De-Mobilization REQs	Eliminate temporary parking lot when surge needs reside	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	See 4.0	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Emergency vehicles w/EMP resilient design features able to respond to emergency needs following EMP attack	**Level:** 2.4
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L1, 6.0, 7.0

Situation scenario assumptions: It is assumed emergency vehicles will be converted to designs resilient to EMP to respond to needs that arise due to massive damage to personal and commercial transportation sector. Classes of emergency vehicles are Police, Tow service, Fire, EMS. Fire and EMS utilize building/facility EMP protection vs. vehicle design changes. Without resilient emergency vehicles, critical infrastructure will likely be paralyzed for months following an EMP attack.

Directions: See Level 1 LiDA

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	Emergency vehicles deployed: a) assist stranded drivers w/tow service & transporta-tion home; b) maintain law and order; c) temporary delivery of lifeline supplies to public	Yes	Yes – Training and procedures on how to respond to an EMP attack similar to training provided for radiological attack
2) Transportation to point of receipt	n.a.	No	n.a.
3) Staffing/ equipment requirements	Existing police, fire, EMS and tow service personnel	Yes	Yes – same as 1.0
4) Storage REQs	n.a.	No	No
5) Distribution & Transportation REQs 6) Security and Site-control	5.1) 911 dispatchers triage deployment of emergency vehicles (stranded motorists)	Yes	Yes – same as 1.0
	5.2) 911 dispatchers triage emergency vehicles (delivery of lifeline supplies)	Yes	Yes – same as 1.0
7) Safety issues	Emergency vehicles address security and site control needs as required	Yes	Yes – same as 1.0
8) De-Mobilization REQs	Emergency vehicles address safety issues as required	Yes	Yes – same as 1.0
9) Other logistical REQs	State of emergency continues until critical infrastructure fully restored to normal	Yes	Yes – same as 1.0
10) Transportation REQs to storage	None	No	No
2) Transportation to point of receipt	No	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Emergency vehicles Vehicle & Personnel Mobilization & Demobilization Plan Following EMP Attack	**Level:** 2.5
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L1, 1.3, 8.0

Situation scenario assumptions: Following EMP attack, emergency vehicles and personnel must be mobilized with special instructions on what to expect once they respond to the numerous 911 calls. It is assumed emergency vehicles will be converted to designs resilient to EMP. Emergency personnel will be mobilized in emergency situation until critical infrastructure is restored to normal, could be months after attack. National emergency will be declared.

Directions: See Level 1 LiDA

Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	Emergency vehicles deployed per emergency declaration from local state governors followed by Presidential declaration (Stafford Act)	Yes	Yes – Training and preparedness drills for EMP emergency response, includes mobilization, and demobilization.
2) Transportation to point of receipt	Emergency vehicles deployed to points of receipt successfully because they employed EMP resilient design features	No	n.a.
3) Staffing/ equipment requirements	Existing police, fire, EMS and tow service personnel	Yes	Yes – same as 1.0
4) Storage REQs	n.a.	No	No
5) Distribution & Transportation REQs	Once EMP emergency procedures mobilized, emergency vehicles and personnel able to respond per 911 call center requests.	Yes	Yes – same as 1.0
6) Security and Site-control	Emergency vehicles mobilized to address security and site control needs	Yes	Yes – same as 1.0
7) Safety issues	Emergency vehicles mobilized to address safety issues	Yes	Yes – same as 1.0
8) De-Mobilization REQs	State of emergency continues until critical infrastructure fully restored to normal	Yes	Yes – same as 1.0
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	No	No	No

 30 July 2017

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 2 LiDA

Resource required: Vehicle Survival Kits	**Level:** 2.6
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L1, 9.0
Situation scenario assumptions: Motorists could be stranded on the road following an EMP attack, in need of food, water, first aid supplies. Nobody likes to prepare survival kits unless you have a boy scout or girl scout in the house. Suggest automotive OEMs offer kits as accessories at time of purchase of vehicles. Also, non-government organizations (NGOs) offer sale of kits during community events for fund raisers.	
Directions: See Level 1 LiDA	

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	Survival kit for transportation sector vehicles, food/water for 1 day/4 people, flashlight, first aid supplies.	No	No. > Should be <$50/kit. > Make it stylish to have a kit. > Need to establish need due to threat of attack (like the Cold War)
2) Transportation to point of receipt	Offered by Automotive OEMs at time of vehicle purchase. Offered by local NGOs, boy scouts, girl scouts, etc. as fund raisers, and annual event like the girl scout cookie season.	No	No
3) Staffing/ equipment requirements	Staffing to design kits, develop marketing plan.	No	No
4) Storage REQs	Any food items need to be non-perishable, 2-4 yr. shelf life.	No	No
5) Distribution & Transportation REQs	Distribute at time of vehicle purchase (OEM version). Distribute at annual community events (NGO versions).	Yes (FEMA supplied guidelines for kits)	No
6) Security and Site-control	n.a.	No	No
7) Safety issues	Food items, safe, non-perishable.	No	No
8) De-Mobilization REQs	Replace food items per shelf life requirements	Yes	No – same comment as 1.0
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	No	No	No

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LEVEL 3

LIDA Forms

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Coordination w/component suppliers and production ramp-up will likely be a major issue.			**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA			**Ref Level:** L2.0, 1.2
Situation scenario assumptions: Motorists could be stranded on the road following an EMP attack, in need of food, water, first aid supplies. Nobody likes to prepare survival kits unless you have a boy scout or girl scout in the house. Suggest automotive OEMs offer kits as accessories at time of purchase of vehicles. Also, NGOs offer sale of kits during community events for fund raisers.			
Directions: See Level 1 LiDA			
Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	Engage Defense Authorization Act (DAA) for known Tier 1 suppliers of parts.	No	No
	Issue grant funding for suppliers to engage 24/7 to address parts shortages		
	Issue grant funding for Tier 2 suppliers who can assist Tier 1's with production ramp-up		
2) Transportation to point of receipt	Provide financial incentives for expedited delivery of parts to dealerships and repair garages	No	No
3) Staffing/ equipment requirements	Grant funding for parts suppliers to hire additional temporary supply chain personnel	No	No
4) Storage Requirements	Buffer storage warehouses w/centralized support (FEMA) to assure fair distribution of parts to areas affected by EMP	No	No
5) Distribution & Transportation Requirements	Same as 2.0.	No	No
6) Security and Site-control	Security for parts & personnel in storage areas & during transportation.	No	No
7) Safety issues	Normal safety precautions	No	No
8) De-Mobilization Requirements	Continue DAA efforts until parts shortage issues resolved.	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	No	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Over the road heavy duty trucks and Medium/Light Duty Trucks w/EMP resilience hardware; or repairs < 5 days	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA Form	**Ref Level:** L2.1, 1.1, 1.2
Situation scenario assumptions: Without EMP vehicle conversions, or repairs completed within 5 days (very unlikely), food supplies at food distribution centers could run out in 15 days (Baker and Volandt 2018)	
Directions: See Level 1 LiDA Form	

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	1.1) Identify optimum design solution for EMP conversion based on test results	No.	No. Assume testing was completed for heavy duty over the road trucks (diesel engines) where failure modes were identified
	1.2) Implement design solutions for manufacturing.		No. Find way to mandate installation on heavy duty trucks.
2) Transportation to point of receipt	Delivery of EMP conversion hardware to dealerships and repair shops	Yes	No. Use existing supply chain.
3) Staffing/ equipment requirements	Train technicians to install EMP conversions	Yes	No. Installation and validation procedure needed.
4) Storage REQs	Manufacturers of EMP conversion hardware responsible for storing inventory.	No	No
5) Distribution & Transportation REQs	Delivery via normal supply chain if functional	No	No.
6) Security and Site-control	Security and site control for EMP conversion parts	YES (SIT training)	No.
7) Safety issues	Safety measures as required	No	No.
8) De-Mobilization REQs	Legislation or agreements among manufacturers to install EMP conversion hardware on all vehicles.	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

 30 July 2017

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Transportation fuel refining facilities protected, EMP resilient design features	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA Form	**Ref Level:** L2.1, 1.3
Situation scenario assumptions: Transportation fuel refineries are vulnerable. Requires electrical power, many microprocessor based SCADA systems for process control. Facilities need to become resilient to EMP to avoid major disruptions in transportation sector critical infrastructure (Harris and Volandt 2018).	
Directions: See Level 1 LiDA Form	

Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	1.1) IEC TS 61000-5-10 (2017) technical specifications applied to fuel refineries 1.2) Also backup power generation at refineries in event of electric grid attack	No.	No. Need legislation from government or inter-company working agreements
2) Transportation to point of receipt	Resilient refineries able to continue fuel deliveries to service stations.	Yes	No. Existing supply chain.
3) Staffing/ equipment requirements	Awareness training for EMP hardware	Yes	No. Awareness training
4) Storage REQs	Store EMP protection hardware at suppliers, some backups at refineries.	No	No
5) Distribution & Transportation REQs	Delivery via normal supply chain if functional	No	No.
6) Security and Site-control	Security and site control for EMP conversion parts	YES (SIT training)	No.
7) Safety issues	Safety measures as required	No	No.
8) De-Mobilization REQs	Demobilize once refineries install EMP hardware	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Fuel stations w/backup generators, EMP protection hardware	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA Form	**Ref Level:** L2.1, 1.4
Situation scenario assumptions: Fuel stations are vulnerable to an EMP attack due to failure of the electric grid, and damage to microprocessor based fuel pumping equipment. Low cost EMP resilient features for fuel stations are required.	
Directions: See Level 1 LiDA Form	

Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	1.1) Back-up generators for power in event of grid failure 1.2) EMP resilient facilities per IEC TS 61000-5-10 (2017) standards	No.	No. Implement 1.1 & 1.2
2) Transportation to point of receipt	Delivery and installation of back up generators and EMP protection hardware	Yes	No.
3) Staffing/ equipment requirements	Coordinate with fuel supply corporations	Yes	No. Awareness training
4) Storage REQs	None	No	No
5) Distribution & Transportation REQs	Same as 2.0	No	No.
6) Security and Site-control	Security and site control for backup generators & EMP conversion parts (security cameras)	YES	No.
7) Safety issues	Safety measures as required	No	No.
8) De-Mobilization REQs	Demobilize once backup generators & EMP hardware installed.	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Training will be required for temporary technicians in dealerships and repair garages to address surge	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L2.1, 3.0
Situation scenario assumptions: Dealerships and repair garages overwhelmed with number of vehicles that require repairs. Need to ramp-up technician support staffs to address the huge back-logs avoiding months-years to restore critical infrastructure.	
Directions: See Level 1 LiDA	

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	Engage Defense Authorization Act (DAA) for technician training programs	No	No
	Reach out to all talented personnel who can assist.	No	No
	Government provide financial incentives to hire temporary incremental personnel	No	No
2) Transportation to point of receipt	Technicians sent to hard hit areas may require hotel accommodations	No	No
3) Staffing/ equipment requirements	Incremental technicians will need proper tools	No	No
4) Storage Requirements	Pool of trained incremental technicians can move to locations with greatest needs.	No	No
5) Distribution & Transportation Requirements	Technicians need working personal vehicles.	No	No
6) Security and Site-control	Security needed for repair facilities working 24/7 to address repair needs.	No	No
7) Safety issues	Must address any safety issues.	No	No
8) De-Mobilization Requirements	Continue DAA until technician shortage issues resolved.	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	No	No	No

 30 July 2017

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: FEMA lead documentation of lessons learned	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L2.1, 8.0
Situation scenario assumptions: Nobody is better in documenting emergency procedures than FEMA. Need to document EMP emergency response plan as well as capture lessons learned for updates if event occurs.	
Directions: See Level 1 LiDA	

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	Engage FEMA to create EMP emergency response documentation	No	No
	Engage FEMA to capture lessons learned in preparedness drills	No	No
	Engage FEMA to capture lessons learned in the event of an attack	No	No
2) Transportation to point of receipt	FEMA to coordinate preparedness drills at likely EMP deployment sites.	No	No
	FEMA to travel to deployment sites In event of attack to assist in response and recovery, and to capture lessons learned.	No	No
3) Staffing/ equipment requirements	FEMA staffing as required.	No	No
4) Storage Requirements	None	No	No
5) Distribution & Transportation Requirements	Same as 2.0	No	No
6) Security and Site-control	Security provided to personnel at deployment sites.	No	No
7) Safety issues	Safety issues to be addressed at deployment sites.	No	No
8) De-Mobilization Requirements	Process continued until emergency declaration complete	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Training for authorized dealers for EMP conversions			**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA			**Ref Level:** L2.2, 3.0
Situation scenario assumptions: Training required for authorized dealers to install EMP conversion kits.			
Directions: See Level 1 LiDA			
Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	FEMA or other government agency create sub-contract to certify conversion ships installing EMP hardware in existing production vehicles	No	No. Prioritize all emergency vehicles to be protected.
2) Transportation to point of receipt	Provide on-site and online training	No	No
3) Staffing/ equipment requirements	Provide staffing to conduct training. Engage help of subject matter experts (FEMA does not have these skillsets- must sub-contract)	No	No
4) Storage Requirements	None	No	No
5) Distribution & Transportation Requirements	Same as 2.0	No	No
6) Security and Site-control	Protect training material to prevent unauthorized personal to create EMP conversions.	No	No
7) Safety issues	Address safety issues as required. If testing needed at EMP levels, safety for exposure to high voltage levels.	No	No
8) De-Mobilization Requirements	Process continued until emergency declaration complete	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Training and procedures on how to respond to an EMP attack similar to training provided for radiological attack	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L2.2, 3.0
Situation scenario assumptions: Training required on how to respond to EMP attack and associated aftermath if significant damage incurred on the infrastructure.	
Directions: See Level 1 LiDA	

Logistical factors to consider	**Method of obtaining this resource?**	**Training required?**	**Do you need another LMMR to support this logistical factor?**
1)Procurement & Cost (if known)	FEMA or other government agency create training class similar to what was created for radiological emergencies	No	No.
2) Transportation to point of receipt	Provide on-site and online training	No	No
3) Staffing/ equipment requirements	Provide staffing to conduct training. Engage help of subject matter experts (FEMA does not have these skillsets- must sub-contract)	No	No
4) Storage Requirements	None	No	No
5) Distribution & Transportation Requirements	Same as 2.0	No	No
6) Security and Site-control	Protect training material to prevent unauthorized personal to create EMP conversions.	No	No
7) Safety issues	Address safety issues as required. If testing needed at EMP levels, safety for exposure to high voltage levels.	No	No
8) De-Mobilization Requirements	Process continued until emergency declaration complete	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

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Logistical in-Depth Analysis (LiDA)

Logistical Mission Requirement Request

Level: Level 3 LiDA

Resource required: Training and preparedness drills for EMP emergency response, includes mobilization, and demobilization.	**Level:** 3
EMP Deployment Scenario Assumptions: See Level 1 LiDA	**Ref Level:** L2.5, 1.0, 3.0, 5.0, 6.0, 7.0, 8.0
Situation scenario assumptions: Nobody is better in documenting emergency procedures than FEMA. Need to document EMP emergency response plan as well as capture lessons learned for updates if event occurs.	
Directions: See Level 1 LiDA	

Logistical factors to consider	Method of obtaining this resource?	Training required?	Do you need another LMMR to support this logistical factor?
1)Procurement & Cost (if known)	1.1) Create training documentation, includes situation description, scope, end-goals (FEMA)	No	No. New document (does not exist)
	1.2) Preparedness exercises and awareness programs for: a) The military b) Police, Fire, EMS c) Dealerships and major repair service providers d) Automotive OEMS, major parts suppliers e) The public, local jurisdictions f) Officials, local jurisdictions g) News media	No	No. New documentation & program (does not exist)
2) Transportation to point of receipt	FEMA to coordinate awareness and preparedness drills	No	No
3) Staffing/ equipment requirements	FEMA staffing as required. Commitment on behalf of organizations in 1.1 to participate in training	No	No
4) Storage REQs	None	No	No
5) Distribution & Transportation REQs	None	No	No
6) Security and Site-control	Part of preparedness drills	No	No
7) Safety issues	Part of preparedness drills	No	No
8) De-Mobilization REQs	Part of preparedness training	No	No
9) Other logistical REQs	None	No	No
10) Transportation REQs to storage	None	No	No

 30 July 2017

End of All

LIDA Forms

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Improved Resilience in Transportation Sector to an EMP Attack (Final Submission-v3)-11-04-2020c

Final Audit Report 2020-11-17

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