Assessment of Powered Rescue Tool Capabilities with High-Strength Alloys and Composite Materials

Final Report

Prepared by:

Casey C. Grant, P.E., and Brian Merrifield

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THE FIRE PROTECTION RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION RESEARCH FOUNDATION
ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02169-7471
E-MAIL: Foundation@NFPA.org
WEB: www.nfpa.org/Foundation

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FOREWORD

Powered rescue tools are commonly used by emergency first responders to extricate trapped victims from crashed motor vehicles, and a large inventory of these tools exists throughout today's emergency response community. Recent years have seen improved auto manufacturing processes that have resulted in the proliferation of high-strength metal alloys and composite materials resistant to existing powered rescue tools.

This project identifies, collects, and assesses various informational aspects of this topic involving high-strength metal alloys and composite materials that are challenging the performance of the present generation of powered rescue tools. This includes consideration of vehicle extrication scenarios, clarification on the use of these high-strength materials, review of the existing field inventory of powered rescue tools, and recommendation to address identified knowledge gaps.

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The content, opinions and conclusions contained in this report are solely those of the author.

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PROJECT TECHNICAL PANEL

Jason Allen, Intertek Testing Services (Alternate Rep.)

David Anderson, American Iron and Steel Institute

Lew Austin, Chair of NFPA Technical Committee on Fire Department Rescue Tools

Brian Bishop, Intertek Testing Services

Samuel Boyden, State Farm Auto Technology Research (Alternate Rep.)

Ryan Depew, National Fire Protection Association

Joseph Drennan, Illinois Fire Service Institute

Tom Hollenstain, State Farm Auto Technology Research

Dan Jones, Chapel Hill Fire Dept

Ron Krupitzer, American Iron and Steel Institute (Alternate Rep.)

Ron Moore, Plano Texas

Scott Schmidt, Alliance of Automobile Manufacturers (Alternate Rep.)

Robert Strassburger, Alliance of Automobile Manufacturers

PROJECT SPONSOR

National Fire Protection Association

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EXECUTIVE SUMMARY

Emergency responders often deal with emergency situations that require extricating entrapped victims. Powered rescue tools are an important resource used by emergency first responders to cut, shear, bend, or otherwise remove fixed metal obstructions to complete their rescue mission. A common example is the extrication of a trapped individual following a motor vehicle crash.

Today a large inventory of powered rescue tools exists throughout the emergency response community. These tools are typically designed and tested according to the minimum specifications of NFPA 1936, *Standard on Powered Rescue Tools*. Improved auto manufacturing processes have resulted in the proliferation of high-strength metal alloys and composite materials that are resistant to earlier versions of powered rescue tools still in widespread use. The quest for improved energy efficiency has motivated auto manufacturers to produce lighter, stronger vehicles, and the latest available vehicle models are increasing the challenges with regard to the effectiveness of powered rescue tools.

The goal of this project is to identify and provide an assessment of current and future extrication scenarios, especially those involving motor vehicles that use high-strength metal alloys and composite materials (carbon fiber) that are resistant to the use of the current generation of powered rescue tools. The project deliverables include a review of the literature applicable to this specific topic, a summary of identified common extrication scenarios, an assessment of the use of high-strength alloys in motor vehicles, a review of the powered rescue tools field inventory, identification of the current and perceived knowledge gaps for effective tool performance, and recommendations to address perceived effectiveness gaps.

The following are the key summary observations discussed throughout this report:

<u>Extrication Scenarios and Tasks</u>

- Extrication from passenger motor vehicles are the most likely scenario confronting emergency responders involving high-strength steels and composite materials that will challenge the cutting and shearing effectiveness of powered rescue tools.
- The fire service and other emergency responders need to identify alternative methods to work around extrication emergencies when the available powered rescue tools are unable to perform their intended use.
- Standard-setting bodies need to review and update the test methods currently used for evaluating powered rescue tools that cut and shear, so that they provide a meaningful distinction that informs end users of which tools will work with which types of modern vehicles.

High-Strength Alloys and Composite Materials

- Passenger motor vehicles since the 2006 through 2008 time frame have seen a noteworthy increase in the use of high-strength steels and composite materials, which can be expected to significantly challenge the effectiveness of powered rescue tools that cut and shear.
- Future use of high-strength steels and composite materials is expected to increase in future vehicles, thus, the probability that fire departments will encounter these materials also will increase.
- Practical, credible and consistent information is needed from vehicle manufacturers on the use of materials of concern to emergency responders.
- The types of steels and other materials should be categorized to simplify the materials of interest for vehicle extrication.
- Future use of new materials should be communicated on a regular basis between vehicle designers and the emergency response community.

Field Inventory of Powered Rescue Tools

- The current inventory of powered rescue tools is assumed to be extensive and three or more decades in age, based on equipment being resold from one department to another and ultimately remaining in service.
- Concern exists that a significant portion of the existing field inventory of powered rescue tools for cutting and shearing will not be effective on passenger motor vehicles manufactured later than the 2006 through 2008 time frame.
- Clarification is needed for emergency responders on the specific attributes of powered rescue tools that are important, based on sound, credibly-established technical information (i.e., not simply spun out of the marketplace).
- Consideration should be given to implementing a comprehensive survey that will realistically identify the quantity and quality of existing equipment in the field inventory of powered rescue tools.

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1. Introduction and Background

Powered rescue tools are used by emergency first responders to extricate trapped victims. A common use of these tools involves rescuing victims from crashed motor vehicles, and a large inventory of these tools exists throughout today's emergency response community. Powered rescue tools are designed and tested according to the minimum specifications of NFPA 1936, *Standard on Powered Rescue Tools*.[1]

Improved auto manufacturing processes have resulted in the proliferation of high-strength metal alloys and composite materials that are resistant to the powered rescue tools currently in widespread use. The quest for improved energy efficiency has motivated auto manufacturers to produce lighter, stronger vehicles, and the latest available models are becoming especially problematic with regard to the effectiveness of powered rescue tools.

A specific example is the new electric vehicle Chevrolet Volt, which was cut-up at 2010 Fire-Rescue-International (IAFC Annual Meeting) in Chicago during a demonstration. The Volt was indicated as being approximately 80% high-strength metal alloys, requiring powered rescue tools with a higher level of performance.[2] Motor vehicles are among the most common applications seen by emergency responders using powered rescue tools, but other applications such as aircraft and rail transport are also seeing an increased use of high-strength metal alloys and composite materials that require greater effectiveness.

A powered rescue tool is defined as a "rescue tool that receives its power from the power unit component and generates the output forces of energy used to perform one or more of the functions of spreading, lifting, holding, crushing, pulling, or cutting."[3] There are additional tools that can be used for extrication purposes, such as air-chisels and rotating/reciprocating saws, and they are not excluded from this study. However, due to the wide range of different tools, for practicality purposes this study is focusing on hydraulic powered rescue tools.

The goal of this project is to identify and provide an assessment of current and future extrication scenarios, especially those involving motor vehicles that use high-strength metal alloys and composite materials (carbon fiber) that are resistant to the performance of the current generation of powered rescue tools. The objectives for meeting this goal are to:

a) Identify extrication scenarios faced by emergency responders requiring the use of powered rescue tools and prioritize according to the most common, with a special focus on motor vehicles
b) Clarify the trends in the use of high-strength metal alloys and composite materials in those scenarios
c) Provide a general assessment of the field inventory of powered rescue tools in use today according to age and capabilities
d) Identify perceived gaps in the effective performance of the inventory of powered rescue tools

e) Recommend a plan to address these identified gaps, such as supplemental testing methods

This project is directly applicable to the requirements addressed by NFPA 1936, *Standard on Powered Rescue Tools*. This project is also applicable to NFPA 402, *Guide for Aircraft Rescue and Fire Fighting Operations*; NFPA 610, *Guide for Emergency and Safety Operations at Motorsports Venues*; NFPA 1006, *Standard on Professional Qualification for Technical Rescuer*; and NFPA 1670, *Standard on Operations and Training for Technical Search and Rescue Incidents*.

The age of the particular rescue equipment and the items/equipment (e.g., vehicles) involved in the extrication are also important. The particular vintage directly relates to certain anticipated material properties and/or performance characteristics. For this study a retrospective time frame of 30 years has been set as being realistic and attainable with the study resources available.

Project deliverables will be a detailed report on the literature search, identified extrication scenarios, assessment of the use of high-strength alloy for the identified extrication scenarios, field inventory of powered rescue tools, effectiveness analysis, and recommendations to address perceived effectiveness gaps.

2. Overview of Emergency Responder Powered Rescue Tools

Powered rescue tools provide a critical means for emergency first responders to perform their rescue mission. This is particularly true in the rescue of trapped victims at motor vehicle crashes. In every jurisdiction a motor vehicle crash is a relatively common occurrence, and having the necessary tools to properly complete expected rescue duties is essential.

In the 1960s the proliferation of hydraulic technology found a useful application within the U.S. fire service. This technology gained popularity in the following decades and today is a common feature among typical well-equipped fire departments.[4] As the professional qualifications of the fire fighting and rescue profession evolved, so too did the equipment they were using. In the last several decades, the understanding, tools, and equipment for motor vehicle victim extrication have made this a key resource within most fire departments.[5]

Standardization and Conformity Assessment

Documents used for standardization and conformity assessment serve a key role in coordinating the design and implementation of safety equipment for emergency responders. This enables the users of powered rescue tools to obtain and use the subject equipment with expectations of credible and reliable performance characteristics. This equipment is intended to be used for life-saving tasks, and failure to function reliably could have significant adverse consequences.

As background, the general arrangement of U.S. governance has the federal government at the top, followed by State government (excluding territories), then county government, and finally local government involving cities, towns or villages. This overall approach was established in 1789 as a federal republic under a strong democratic tradition and is based on a legal system using English Common Law.[6]

The interaction between these levels of government depends of the constitutions and charters of the respective governing bodies. In the United States the Tenth Amendment of the U.S. Constitution allows the States to exercise their reserved powers which includes police powers. Consequently topics of public safety, such as EMS and other emergency responders (e.g., law enforcement and fire service), receive primary attention at the State level (based on the State's constitution) and the local level as delegated by the particular State.[7]

Private, voluntary codes and standards organizations develop model documents in the United States that have significant benefits for adopting authorities. In particular they are efficient, cost-effective, and technically competent and achieve broad consensus input that results in robust and well-founded safety requirements. The federal government recognizes these benefits and requires (through Public Law 104-113, H.R. 2196, National Technology Transfer and Advancement Act of 1996) that federal agencies use and actively participate in private voluntary codes and standards activities, rather than write their own codes and standards directly.[8]

A vast, diverse, and decentralized network of private codes and standards developers exists around the world today, and in the United States the codes and standards community maintains an inventory of almost 100,000 documents covering a wide range of topics.[9] Table 2-1 provides a summary of the codes and standards documents and developers in the United States. It includes model documents developed by private codes and standards developers and documents developed directly by the federal government.

Table 2-1: Codes and Standards Documents and Developing Organizations in the United States[10]

	Developer / Organization	# of Standards	Percent	# of Organizations	Percent
Private Sector	Codes & standards developing organizations	17,000	18	40	6
	Trade associations	16,000	17	130	19
	Scientific and professional societies	14,000	15	300	43
	Developers of informal standards	3, 000	3	150	21
	Private Total	49,000	53	620	89
Federal Govt.	Department of Defense	34,000	37	4	1
	General Services Administration	2,000	2	1	1
	Other	8,000	8	75	10
	Federal Government Total	44,000	47	80	11
	Overall Total	93,000	100	700	100

As the widespread usage of powered rescue equipment increased, the need to standardize the subject became apparent. In the NFPA codes and standards process, work first began through a subcommittee of the Technical Committee on Fire Department Equipment. In October 1992, the NFPA Standards Council organized a new committee, the Technical Committee on Fire Department Rescue Tools, which took over the responsibility for developing a new standard titled NFPA 1936, *Standard on Powered Rescue Tool Systems*.[11] The first edition was issued in 1999, with subsequent editions issued in 2005 and 2010. Later editions included a change in the title of the document to NFPA 1936, *Standard on Powered Rescue Tools*, based on its focus on individual tools rather than systems.

Standards are used to provide credible and reliable baseline information that reflects the will of society (and in this case the professionals who use this equipment) on complex technical issues (such as design and use of powered rescue tools). An additional important concept is conformity assessment. Conformity assessment activities form a vital link between standards and products, services, processes, systems, personnel qualifications, and organizations.

Conformity assessment is defined as "any activity concerned with determining directly or indirectly that relevant requirements are fulfilled."[12] The conformity infrastructure in the

United States allows consumers, buyers, sellers, regulators, and other interested parties to have confidence in the processes of providing conformity assessment, while avoiding the creation of unnecessary barriers to trade.

For powered rescue tools, concepts of conformity assessment and standards such as NFPA 1936 have a symbiotic existence. NFPA 1936 includes among its requirements reference to "listed" equipment, which translates to being acceptable to the authority having jurisdiction based on third-party review and certification, such as through a nationally recognized testing laboratory. This is marketplace driven and self-policing, based on what fire departments and others are willing to buy.

The ultimate benefit is a marketplace in which the users of powered rescue tools have acceptable confidence that the equipment they purchase will credibly and reliably perform as expected. Different specific standards (other than NFPA 1936) are typically used by the nationally recognized testing laboratories when performing their conformity assessment tests. Those standards generally contain greater detail on the types of test run on the equipment.[13]

Of particular interest are the specific requirements of NFPA 1936 that provide the baseline requirements for determining the acceptability of powered rescue tools. For example, Chapter 8 of NFPA 1936 provides the details of 25 separate test procedures. For convenience, these are summarized in Table 2-2, Summary of NFPA 1936 Testing.[14]

Table 2-2: Summary of NFPA 1936 Testing

1) Tool Operating Temperature	**9) Overload**	**18) Power Unit Pressure**
2) Spreading Force	**10) Deadman Control Device Endurance**	**19) Power Unit Pressure Relief and Automatic Limiting Device**
3) Ram Tool Spreading Force	**11) Safety Relief Device**	**20) Power Unit Dump Valve**
4) Spreader Tool Pulling Force	**12) Ram Bend**	**21) Power Unit Endurance**
5) Ram Tool Pulling Force	**13) Cutting**	**22) Directional Valve Endurance**
6) Spreading Force Sudden Power Loss	**14) Cutter Integrity**	**23) Remote Valve Block Endurance**
7) Pulling Force Sudden Power Loss	**15) Impact Resistance**	**24) Hose Reel Endurance**
8) Dynamic Endurance	**16) Noise**	**25) Hose Assembly Proof Pressure**
	17) Incline Operational	

This study has a particular focus on the powered rescue tools that cut and shear, because they are especially challenged by the new high-strength materials being used in today's motor vehicles. Thus, the sections in NFPA 1936 of key interest include Section 8.13 on "Cutting Test" and Section 8.14 on "Cutting Integrity Test".[15] Of specific interest is Table 8.13.1 of NFPA 1936, which provides the specific criteria used for cut testing and level performance rating and for comparing the effectiveness of powered rescue tools intended to cut or shear. This is shown in Figure2-1, Cut Testing and Level Performance Rating Required by NFPA 1936.[16]

The testing parameters represented by the criteria in Table 8.13.1 of NFPA 1936 are based on cutting five specific types of materials (round bar, flat bar, round pipe, square tube, and angle iron) and nine distinctly separate performance levels that account for the size and weight of the materials being cut. Those parameters provide a consistent baseline for testing, although the genesis of the criteria in this table is not clear.

Since problems are being reported in the field with the effectiveness of these cutting tools on modern passenger motor vehicles (and one of the primary motivations for this study), there are obvious questions on the need to consider updating Table 8.13.1 of NFPA 1936 and/or adding additional categories that will more realistically qualify the performance of the tools. Ultimately the purchasers and users of this equipment need a practical and credible method of evaluation. They need a test method that clarifies the performance levels with what fire fighters expect to encounter in the field in response to emergencies involving new-model passenger vehicles equipped with high-strength steels.

Material Category	A Round Bar	B Flat Bar	C Round Pipe		D Square Tube	E Angle Iron
Material	A-36 Hot-Rolled	A-36	Schedule 40 A-53 Grade B		A-500 Grade	A-36
Performance Level	Diameter (in.)	Thickness × Width (in. × in.)	Nominal size (in.)	OD × Wall Thickness (in. × in.)	Dimension × Wall Thickness (in. × in.)	Square Dimension × Thickness (in. × in.)
1	⅜	¼ × ½	⅜	0.68 × 0.09	½ × 0.06	½ × ⅛
2	½	¼ × 1	¾	1.05 × 0.11	1¾ × 0.06	1 × ⅛
3	⅝	¼ × 2	1	1.32 × 0.13	1 × 0.08	1¼ × 3/16
4	¾	¼ × 3	1¼	1.66 × 0.14	1¼ × 0.12	1½ × 3/16
5	⅞	¼ × 4	1½	1.90 × 0.15	1½ × 0.12	1½ × ¼
6	1	⅜ × 3	2	2.38 × 0.15	1¾ × 0.12	1¾ × ¼
7	1¼	⅜ × 4	2½	2.88 × 0.20	2 × 0.15	1½ × ⅜
8	1½	⅜ × 5	3	3.50 × 0.22	2½ × 0.19	2 × ⅜
9	1¾	⅜ × 6	3½	4.00 × 0.23	3 × 0.19	2½ × ⅜

For SI units 1 in. = 25.4 mm.

Figure 2-1: Cut Testing and Level Performance Rating Required by NFPA 1936
(Table 8.13.1 of NFPA 1936, *Standard on Powered Rescue Tools*)

The NFPA 1936 standard is based on providing performance-oriented criteria and attempts to avoid prescriptive requirements that could inadvertently restrict the development of improved technology and marketplace competition, without maintaining or enhancing the level of safety. An example would be the specific design of rescue tool cutting blades. NFPA 1936 provides basic information to measure their expected performance, but it does not provide detailed information about the specific materials that should be used to make the blades, how the blades should be manufactured, how they should be maintained, or when they should be replaced.[17]

Information Resources

There is a significant spectrum of information resources available to assist with addressing high-strength steels, passenger motor vehicles, victim extrication from motor vehicles, and similar aspects of this topic. It is noted that the constituent groups involved with these sub-topics are at times significantly diverse, for example, the fire service personnel handling victim extrication are typically far removed from material professionals involved with motor vehicle design.

From the perspective of motor vehicles and the materials they use, multiple organizations provide important informational resources. Because the automobile marketplace is relatively competitive and involves significantly large companies, organizations that focus on the needs of automakers are a key information resource, such as the Alliance of Automobile Manufacturers (www.autoalliance.org) and Global Automakers (www.globalautomakers.org). Likewise, organizations representing the interests of material providers provide valuable support, such as the American Iron and Steel Institute (www.steel.org) and Steel Market Development Institute (www.smdisteel.org). Of special note are organizations that blend the interests of both constituent groups, such as the Auto Steel Partnership (www.a-sp.org). Regulatory and other organizations are likewise key vehicle resources, such as the National Highway Traffic and Safety Administration (www.nhtsa.gov) and the American Automobile Association (www.aaa.com).

For the fire/rescue community, numerous organizations provide either direct or indirect support by addressing the topic of vehicle rescue and extrication. Table 2-3 provides a brief summary of selected national organizations that provide noteworthy direct support for today's fire/rescue community in the United States for vehicle extrication-related topics. In addition, most of these organizations provide a website that includes links to multiple other related organizations, some of which may be worthy of further possible consideration.

The organizations in Table 2-3 have evolved over the years to fulfill certain express needs. The organizational types are quite varied and include private non-profit membership associations, trade groups, State and federal government agencies, collective bargaining bodies, commercial enterprises, and so on.

Table 2-3: Selected Summary of Fire Service Organizations with Vehicle Extrication Interests

Fire Apparatus Manufacturers Association (FAMA) www.fama.org A non-profit trade association created in 1946 committed to enhancing the quality of the emergency service community through the manufacture and sale of safe, efficient emergency response vehicles and equipment.

Fire Department Safety Officers Association (FDSOA) www.fdsoa.org A non-profit association established in 1989 with a mission to promote safety standards and practices in the fire, rescue and emergency services community.

Fire Equipment Manufacturers and Services Association (FEMSA) www.femsa.org A trade association for the fire and emergency services industry with more than 150 organizational members.

International Association of Fire Chiefs (IAFC) www.iafc.org A membership association representing the fire service leadership, serving career and volunteer chiefs, chief fire officers, company officers, and managers of emergency service organizations throughout the international community.

International Association of Fire Fighters (IAFF) (www.iaff.org) A membership organization established in 1918 representing the interests of more than 298,000 full-time professional fire fighters and paramedics, protecting the majority of North America's population.

International Society of Fire Service Instructors (ISFSI) www.isfsi.org A membership organization that provides networking opportunities and resources for fire service instructors.

Metropolitan Fire Chiefs Association (Metro Chiefs) metrofirechiefs2009.com An association for members of IAFC and NFPA who serve as the highest-ranking fire department officers of cities or jurisdictions having a minimum staffed strength of 400 fully paid career fire fighters; functions as a membership section administered simultaneously by IAFC and NFPA.

National Fire Protection Association (NFPA) www.nfpa.org A non-profit membership association established in 1896 with about 85,000 members, dedicated to the mission of making the world safe from fire and explosions, and achieving this mission through public education, research, and consensus-based model codes and standards.

National Volunteer Fire Council (NVFC) www.nvfc.org A non-profit membership association comprising 49 state volunteer fire fighter organizations and other affiliated members, representing the interests of the volunteer fire, EMS, and rescue services.

North American Fire Training Directors (NAFTD) www.naftd.org An international organization that promotes the common interests of providing a quality fire training and educational experience for fire fighters, with membership comprising state fire training directors of each of the 50 states and all Canadian provinces and territories.

U.S. Fire Administration (USFA) www.usfa.dhs.gov An entity of the Department of Homeland Security's Federal Emergency Management Agency, with a mission to foster a solid foundation in prevention, preparedness, and response by providing national leadership to local fire and emergency services.

U.S. Federal Emergency Management Agency (FEMA) www.fema.gov An agency within the U.S. Department of Homeland Security whose initial beginnings can be traced back to the Congressional Act of 1803, and whose primary mission is to reduce the loss of life and property and to protect the United States from all hazards, including natural disasters, acts of terrorism, and other human-caused disasters.

U.S. National Fire Academy (NFA) www.usfa.dhs.gov/nfa The national fire training academy administered by the U.S. Fire Administration, to promote the professional development of the fire and emergency response community and its allied professionals and to support state and local training organizations to fulfill their obligation to the career and volunteer fire and emergency services.

In addition, noteworthy resources are available from the manufacturers handling powered rescue tools. With a backdrop of a competitive rescue tool marketplace, the manufacturers are typically well focused on maintaining and supporting their products to the benefit of the user community. Some offer significant direct and indirect support services and products of interest to the fire service user community. For example, some offer hard copy or electronic software that provides comprehensive detailed specific information on the high-strength steel found in all motor vehicles on the road today.[18]

Another approach to providing a clearer perspective on the number and diversity of organizations serving as resources for the fire service on the topic of vehicle extrication is through a tabulation of the applicable ongoing meetings held annually. Table 2-4 provides a summary of fire service-oriented membership meetings, conferences, and trade shows in North America that have at least some activities (past or present) relating to vehicle extrication. The dates for the annual meetings are for a recent typical event; the precise date will change from year to year.

Some of these meetings are regional sub-sections of larger membership organizations (e.g., the New England Division of the IAFC). Others are the primary annual membership meetings for key organizations and as such have significant attendance numbers for the particular constituents interested in the topic (e.g., FDIC in April, NFPA in June, IAFF bi-annually in August, and FRI in August). It is not unusual for these meetings to focus on specific themes, such as the fire fighter training, safety issues, or the built infrastructure.

Table 2-4: Typical North American Fire Service Meetings, Conferences and Trade Shows with Activities Relating to Vehicle Extrication

SHOW / MEETING	ANNUAL MTG DATE	FIRST MTG	CONTACT
FDSOA Apparatus Specification & Vehicle Maintenance Symposium	18-21/Jan		www.fdsoa.org Fire Department Safety Officers Association
Fire Rescue East	22-23/Jan		www.ffca.org Florida Fire Chiefs' Association
Firehouse World	15-19/Feb		www.firehouseworls.com Cygnus Business Media
Southwest CAFS Seminar	26-28/Feb		www.femsa.org Fire Equipment Manufacturers and Services Association
TEEX Annual Spring/ARFF Fire School	1-6/Mar	1988	www.teex.com Texas A & M Municipal Fire School, TX Eng. Ext Service
Fire PPE Symposium	9-11/Mar		www.fireppesymposium.com Fire Industry Equipment Research Organization
Annual EDIAFC Conference	14-16/Mar		www.ediafc.org Eastern Division International Association of Fire Chiefs
Industrial Fire World	23-27/Mar		www.fireworld.com Industrial Fire World
EMS Today Conference & Exposition	24-28/Mar		www.emstodayconference.com Journal of Emergency Medical Services
FAMA Spring Meeting	27-31/Mar		www.fama.org Fire Apparatus Manufacturers Association (& Fire and Emergency Manufacturers and Services Association

SHOW / MEETING	ANNUAL MTG DATE	FIRST MTG	CONTACT
FDIC: Fire Department Instructors Conference	20-25/Apr		www.fdic.com Pennwell Publishing
SAFC Conference	23-25/Apr		www.safc.sk.ca Saskatchewan Association of Fire Chiefs
OAFC Annual Conference and Trade Show	2-6/May	1952	www.oafc.on.ca Ontario Association of Fire Chiefs
Fire-Rescue Med Conference	2-6/May		www.iafc.org International Association of Fire Chiefs
EDIAFC Conference	14-16/May	1927	www.ediafc.org/conference IAFC Eastern Division
Lancaster County FIRE EXPO	15-17/May		www.lcfa.com Lancaster County Firemen's Association
Alberta Fire Chiefs Association Conference & Trade Show	24-25/May	1948	Alberta Fire Chiefs Association
PFANJ Convention & Affiliate Leadership Training Seminar	26-29/May		www.pfanj.org Professional Firefighters Association of New Jersey
International Hazardous Materials Response Teams Conference	27-31/May		www.iafc.org International Association of Fire Chiefs
2009 Conference & Fire Service Expo	31/May-4/Jun		www.fcabc.bc.ca Fire Chiefs Assoc. of British Columbia
MAFC 2009 Conference and Trade Show	4-6/Jun		www.mafc.ca Manitoba Association of Fire Chiefs
Quebec Association of Fire Chiefs Annual Conference	6-9/Jun		www.acsiq.qc.ca Quebec Association of Fire Chiefs
IAFF Barbera EMS Conference	7-10/Jun		www.iaff.org International Association of Fire Fighters
NFPA Conference & Expo	8-11/Jun	1896	www.nfpa.org/wsce National Fire Protection Association
Fire 2009: Fire Industry, Rescue, & EMS Expo	10-13/Jun	1906	www.nysfirechiefs.com New York State Association of Fire Chiefs
SEAFC Annual Leadership Conference	18-20/Jun	1928	Southeastern Association of Fire Chiefs
Metropolitan Fire Chiefs Conference	21-25/Jun	1965	metrofirechiefs2009.com Metropolitan Fire Chiefs Association
Health, Fitness and Safety Symposium	23-25/Jun	1988	Phoenix Fire Department
New England Fire, Rescue & EMS Conference	24-28/Jun	1922	www.newenglandfirechiefs.org New England Association of Fire Chiefs
TEEX Escuela en Español	5-10/Jul		www.teex.com Texas A & M Municipal Fire School, TX Eng. Ext Service
Missouri Valley Fire Chiefs Conference	8-10/Jul		www.mvafc.org Missouri Valley Division of IAFC
TEEX Industrial School	12-17/Jul	1963	www.teex.com Texas A & M Municipal Fire School, TX Eng. Ext Service
South Carolina Fire-Rescue Conference	13-18/Jul	1905	www.scfirefighters.org

SHOW / MEETING	ANNUAL MTG DATE	FIRST MTG	CONTACT
TEEX Municipal School Vendor Show	19/Jul		www.teex.com Texas A & M Municipal Fire School, TX Eng. Ext Service
TEEX Municipal School	19-24/Jul	1929	www.teex.com Texas A & M Municipal Fire School, TX Eng. Ext Service
Firehouse Expo	21-26/Jul		www.firehouseexpo.com Cygnus Public Safety Group
Americas' Fire and Security Expo (AFSE)	29-31/Jul	2001	www.americasfireandsecurity.com NFPA, and National Association of Hispanic Firefighters
World Police & Fire Games	31/Jul – 9/Aug	1985	www.2009wpfg.ca World Police and Fire Games Federation
IAFF Redmond Symposium	15-18/Aug	1958	www.iaff.org International Association of Fire Fighters
IAFF Membership Convention (Bi-Annual)	22-27/ Aug/2010	1918	www.iaff.org International Association of Fire Fighters
Department of Defense Fire & Emergency Services Training Conference	24-28/Aug		www.iafc.org International Association of Fire Chiefs
Fire-Rescue International	25-29/Aug		www.iafc.org International Association of Fire Chiefs
Incident Management Symposium	27-29/Aug	1991	http://phoenix.gov/fire/sympos.html Phoenix Fire Department
Fire Rescue Canada	20-23/Sep		www.cafc.ca Canadian Association of Fire Chiefs
FDSOA Annual Conference	21-25/Sep		www.fdsoa.org Fire Department Safety Officers Association
Southwestern Fire Chiefs Conference.	25-29/Sep		www.swd-iafc.org Southwestern Fire Chiefs Association
Pittsburgh Fire/Rescue & EMS Expo	2-4/Oct	1987	www.pittsburghfireexpo.com Kelly Simon Productions
FAMA Fall Meeting	8-10/Oct		www.fama.org Fire Apparatus Manufacturers Association (& Fire and Emergency Manufacturers and Services Association
Firehouse Central 2009	26-30/Oct		www.firehousecentral.com Cygnus Public Safety Group
IAFC Volunteer & Combination Officers Symposium	5-8/Nov		www.iafc.org International Association of Fire Chiefs
VCOS Symposium (for Volunteer & Comb. FDs)	5-8/Nov		www.iafc.org International Association of Fire Chiefs

3. LITERATURE REVIEW

Supporting background information is provided on this topic through a review of the published literature. The literature addresses various characteristics of importance, including motor vehicle material properties, usage, and trends of high-strength materials in motor vehicles, powered rescue tools, and methods for using those tools.

Literature Review Methodology

To enable handling of the published literature summarized in this section, a unique identifying number has been given to each item. These numbers are assigned according to the sequence the documents have been identified, and do not indicate a priority or similar sequencing

Several mechanisms have been introduced to facilitate the handling of this literature summary. In addition to the general citation information itself, a notes-field (i.e., "notes") has been included that provides a brief description of the citation and how it relates to the subject of powered rescue tool effectiveness.

The literature can be conveniently separated into three basic categories of subject matter, as illustrated in Figure 3-1, Literature Review Subject Areas:

- "M" - Material Properties
- "V" - Vehicle Usage and Trends
- "E" - Extrication Tools and Methods

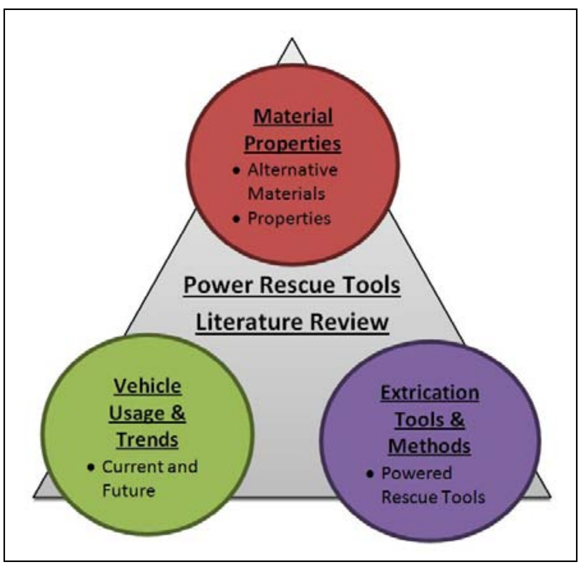

Figure 3-1: Literature Review Subject Areas

In the summary of applicable literature these basic categories are represented by the first initial of each term, that is, “M,” “V,” and “E.” For example, a particular article that is focused more toward the properties and categories of alternative materials, such as advanced high-strength steels, would be designated with “M.” Similarly, “V” designates automotive trends or specific uses within a vehicle, and “E” indicates extrication techniques or information specifically about powered rescue tools.

For literature citations that cover more than a single basic category, multiple designations are provided. When this is the case, the designations are indicated in order of most prominent. For example, “MVE” designates a citation that predominantly focuses on material properties but also addresses the vehicle trends and to a lesser extent touches on extrication techniques. While this characterization admittedly is subjective, it is offered to provide the user with helpful guidance.

As the literature for this study was collected and reviewed, each citation was also evaluated to include a rating as to whether its relationship to the focus of this study was “critical,” “major,” or “minor.” Like the aforementioned categories for subject areas, this too is admittedly subjective, but nevertheless was deemed worthy to be included to assist others with processing this information. In addition to the relationship ratings of “critical,” major,” and minor,” a fourth category is offered for “reference” documents. These ratings are summarized in Table 3-1, Literature Review Characteristics.

Table 3-1: Literature Review Characteristics

	Scope Relativity (Directly Related / Indirectly Related)	**Contribution** (Original / Repetitious)	**Applicability** (Current / Outdated)	**Content** (Shallow / Rich)
Critical	Directly addresses project scope	Original	Current and timeless	Rich in content
Major	Partially addresses project scope	Partially original	Somewhat current	Some applicable content
Minor	Indirectly addresses project scope	Repeat of earlier work	Somewhat outdated	Superficial or shallow content
Reference	Superseded by information in other articles; summarized baseline information; potentially out of date			

To further clarify the thought process in determining each relevance designation, the characteristics of “scope relativity,” “contribution,” “applicability,” and “content” were all considered and are indicated in Table 3-1. “Scope relativity” addresses if the citation is directly or indirectly related to the subject of this study, while “contribution” considers if the citation is original or repetitious of earlier work. “Applicability” seeks to clarify the age of the publication, that is, whether it is current or outdated, and "content" addresses the substance of the published materials as it relates to the subject matter of this study.

Implementation and Results

While there may be other documents indirectly related to the subject matter of this study, this literature includes more than five dozen of the top articles and references that have been identified and deemed to be appropriate for inclusion.

Of the three designated categories, the most common are "Vehicle Usage and Trends," with 29 citations and "Extrication & Tools," also with 29, followed by "Material Properties," with 15. The primary focus of this literature review is on published literature with a preference toward peer-reviewed publications. Information such as manufacturers' literature generally has not been included.

Table 3-2: Cross Summary of Literature Review Categories by Document Number

	M (Material)	V (Vehicle)	E (Extrication & Tools)
Critical	4, 8, 9, 11, 12, 35, 36, 37, 68	13, 16, 18, 19, 20, 30, 33, 37, 43, 44, 68	22, 23, 24, 26, 27, 28, 29, 36, 39, 44, 55
Major	1, 2, 3, 10	15, 17, 31, 32, 48	21, 25, 40, 41, 53, 63, 69
Minor	5, 6, 7	14, 34, 51, 52, 54, 55, 56, 57, 58, 60, 61, 64, 65	42, 45, 46, 47, 49, 50, 51, 59, 60, 61, 62, 67
Reference		38	

In recognition that the user of this information may have a preference for certain topics, Table 3-2 provides a cross summary of the literature review categories by document number, which allows a focus toward the subject matter of most interest to the user of this study. This supports the full literature summary, which is included in Table 3-3, Summary of Literature Review Documents.

Table 3-3: Summary of Literature Review Documents

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
1	*Advanced High-Strength Steels Add Strength and Ductility to Vehicle Design*	Machine Design	Geck, P.	2010 May			Article	M	Review of AHSS benefits and properties
2	*Boron in Steel: Part Two*	Key to Metals					Article	M	Chemical compound's hardening ability

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
3	*Press Hardening Process of Boron Steel Sheets*	Auto Focus Asia	Kolleck, R.				Article	M	Crash requirements for components, manufacturing methods, and optimization
4	*MVA Extrication Information – Stronger Metals on Vehicles*	RTC Rescue					Article	M	Common steel material descriptions, locations, and vehicle types
5	*Properties of Carbon Fibre for Automotive Crash Structures*	Auto CRC	Sudharsan, R.	2011 Feb.			Power Point	M	Testing carbon fibre and Aluminum
6	*Training Book - Chapter 4: Aircraft Basic Construction*	US Navy Sea Cadet Corps				Ch.4	Book	M	Describes use of carbon, boron, tungsten fibre in military aircraft
7	*Carbon Fibre*	Car Design Online						M	Carbon Fibre material overview
8	*Extrication Challenges of Advanced Steel in Vehicles – Part 1*	Firehouse Magazine	Moore, R.E.	2009 May		37-38	Article	M	"More steel" reinforcement method
9	*Extrication Challenges of Advanced Steel in Vehicles – Part 2*	Firehouse Magazine	Moore, R.E.	2009 June		47-48	Article	M	"Advanced steel" reinforcement method
10	*UltraLight Steel Auto Body (ULSAB)*	ICAR Advantage		1998 July/ Aug.	XI/4	1-4	Article	M	Full Frame Unibody that is lighter but stronger
11	*Implementations of Current & Advanced Materials and Technologies for the FMVSS 216 NPRM*		Magna Steyr	2006 Dec.			Power Point	M	Comparative research of future auto materials, technologies, and techniques
12	*Implementations of Current & Advanced Materials and Technologies for the FMVSS 216 NPRM*		Magna Steyr	2006 Dec.			Report	M	Detailed comparison of future auto materials, technologies, and techniques
13	*Evolution of Advanced High Strength Steels in Automotive Applications*	General Motors Company	Hall, J.N.	2011 May			Power Point	V	In depth details on current auto trends and materials
14	*India: Maruti to Increase use of High Strength Steel*		Auto-motive World .com	2010 Sept.			Article	V	Suzuki announcing majority of their cars will use HSS by 2012
15	*European Vehicles Exceed Standard for US Car Roofs*	The Center for Auto Safety/The Detroit News	Plungis, J. and Vlasic, B.				Article	V	Compares dolly roll over testing and drop tests to the standard roof crush test required

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
16	*Ultra-High-Strength Steels*		Ford's Media Team	2010 April			Article	V	Ways Ford is enhancing vehicle safety and improving fuel efficiency
17	*Will it Blend? Ford Fiesta Ultra- High-Strength Boron Steel puts YouTube Blender to Test*		Ford's Media Team				Article	V	Use of boron in Ford Fiesta and boron details
18	*Tough Cars Tougher on Rescue Workers*	MSNBC.com	Associated Press	2008 March			Article	V	Overview of the issue regarding "golden hour" delays, costly upgrades, and the new material in newer cars
19	*Vehicles with Boron and UHSS*	Boron Extrication .com	Smith, M.	2011 Jan.			Web Site	V	Independent website with research and list of all the cars with boron and UHSS.
20	*FMVSS 216 NPRM – DOT's 571.216 Roof Crush Resistance Requirements*	National Highway Traffic Safety Administration		2008 Oct.			Code	V	Department of Transportation requirements for roof crush resistance
21	*RTA Persons Trapped – Vehicle Accident Rescue*		L. M. Watson				Article	E	In-depth extrication guide with spec sheets on numerous older recue tools
22	*Cutting Performance Defined: Debunking the Myths Surrounding Rescue Tool Cutting Forces*		Hurst Jaws of Life				Bro-chure	E	Explains cutting capability of rescue tools and theoretical vs. actual cutting force
23	*Emergency Response Guides*	Boron Extrication .com	Smith, M.				Web Site	E	Independent collection of emergency response guides
24	*Extrication Challenges of Advanced Steel in Vehicles – Part 5*	Firehouse Magazine	Moore, R.E.	2009 Sept.		43-46	Article	E	New rescue techniques to avoid AHSS sections
25	*Hurst Jaws of Life Tools*	Jaws of Life				284-311	Bro-chure	E	Compliant regulations and rescue tool specs.
26	*Rescue Tool Blades are Not Created Equally*	Fire Apparatus Magazine	Haddon, C.	2010			Article	E	Blade design and considerations
27	*Extrication Challenges of Advanced Steel in Vehicles – Part 3*	Firehouse Magazine	Moore, R.E.	2009 July		47-51	Article	E	Evaluation of common types of rescue tools against AHSS boron
28	*Extrication Challenges of Advanced Steel in Vehicles – Part 4*	Firehouse Magazine	Moore, R.E.	2009 Aug.		33-34	Article	E	Evaluation of power cutter extrication tools

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
29	*NFPA 1936, Standard on Powered Rescue Tools*	NFPA Codes and Standards	NFPA	2010	14		Code	E	NFPA code for definitions, product design, performance, and testing requirements
30	*Review of Technical Literature and Trends Related to Automobile Mass-Reduction Technology*		Lutsey, N.	2010, May			Report	V	Summary of trends and use of advanced material to reduce mass in new automobiles
31	*Ford Does it Again with Top Picks from the Insurance Institute for Highway Safety*	Town and Country Ford.com		2010, Aug.			Article	V	Ford Fiesta's use of HSS to earn Top Safety Pick from IIHS
32	*High-Strength Steels Advance in Cars*	Design News	Smock, D.	2007, Marc h			Article	V	Examples of HSS in Roadster, Sebring, and Civic
33	*The Trends of Steel Products in the European Automotive Industry*		Jeanneau, M. and Pichant, P.	2000, Sept.			Report	V	Automotive trends in European market caused by regulations and customer requirements
34	*FutureSteelVehicle Steel Technology Assessment and Design Methodology*	World Auto Steel	Future Auto Steel	2010, June			Interim Report	V	Automotive concept design criteria; mostly for Tables 1-2, 1-3, Figures 1-1, 1-2
35	*Advanced High-Strength Steels a Collision Repair Perspective*	I-Car Advantage Online		2006, June			Article	M	Compares and categorizes most common steel types
36	*Boron Steel in Vehicles: Implications of HSLA/UHSS and Boron Steels for Rescuers*	ResQmed	Watson, L.	2008, Aug.			Article	M, E	Detailed review of responding to a vehicle extrication involving boron and the issues faced
37	*Working with Boron Steel*	I-CAR Advantage Online		2004, May			Article	M, V	Properties of boron and how to work with it along with mentioning pre-2007 cars using boron
38	*Moditech Crash Recovery System*		Moditech	2006			Soft-ware	V	Hurst's computer program for fire fighters to know where the vital components such as air bag canisters and AHSS are located
39	*Holmatro's Vehicle Extrication Techniques*		Holmatro				Book	V, E	Vehicle extrication manual to identify key components on cars

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
40	*NFPA 1670 – Chapter 8*		NFPA	2010			Code	E	Technical search and rescue document on vehicle extrication
41	*NFPA 402 – Chapter 9*		NFPA	2010			Code	E	Aircraft forcible entry rescue tools and evacuation methods.
42	*NFPA Aircraft Familiarization Charts Manual*		NFPA	1996			Manual	E	Does not directly apply, but is a rescue manual used in ARFF response and an example of quick reference guide for fire rescue
43	*Application of High-Strength Steels (AHSS) in Modern North American Vehicles*	American Iron and Steel Institute	Anderson, D. and Potter, C.	2008, Oct.			Power Point	V	Presentation covering requirement and material trends within automotives
44	*The VSDS Proposal: Providing Critical Data To Rescue Personnel*	Firehouse Magazine	Moore, R.E.	1999 July	24/7		Article	E, V	Proposal for approach similar to MSDS, but instead for Vehicle Safety Data Sheet
45	*Electrical Systems: Part 1*	Firehouse Magazine	Moore, R.E.	2000 May	25/5	31-32	Article	E	Part 1 of 2 on electrical shutdown and vehicle battery locations
46	*Electrical Systems: Part 2*	Firehouse Magazine	Moore, R.E.	2000 June	25/6	25-26	Article	E	Part 2 of 2 on electrical shutdown and vehicle battery locations
47	*The Thoughtful Rescuer*	Fire-Rescue Magazine	Kidd, J. S.	2001 June	19/6	20-21	Article	E	Review of strike zone and other extrication concepts
48	*Hybrid Vehicles: Part 1 - What Are Hybrid Vehicles? How Do They Work?*	Firehouse Magazine	Moore, R.E.	2001 July	26/7	112	Article	V	Part 1 of 3 providing a review of current and anticipated hybrid-fueled vehicles
49	*Hybrid Vehicles: Part 2 – Emergency Procedures*	Firehouse Magazine	Moore, R.E.	2001 Aug	26/8	35-36	Article	E	Part 2 of 3 describing the emergency procedures that should be used for a hybrid vehicle fire
50	*Hybrid Vehicles: Part 3 - Rescue Operations*	Firehouse Magazine	Moore, R.E.	2001 Sept	26/9	35-36	Article	E	Part 3 of 3 focusing on extrication and rescue from a hybrid vehicle

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
51	*Now Showing in Your District: Hybrid Vehicles!*	Size Up	Wimer, D.R.	2004 Fall		58-59	Article	E, V	Basic steps to take for handling hybrids
52	*Alternate-Fueled Vehicles*	Firehouse	Blatus, R.J. and Richardson, T.J	2005 Mar		88	Article	V	Addresses hybrid and alternative-fuel vehicle fire hazards
53	*Pry, Pry Again*	Fire Chief	Hoffman, T.	2005 May	49/5	72-77	Article	E	Addresses extrication from hybrid vehicles involving multiple airbags and extensive restraint systems
54	*A Guide to New Rides*	Fire Rescue Magazine	Uttley, M.	2006 Mar	24/3	72-78	Article	V	Glimpse of new technology that could affect vehicle rescue from the 2006 North Amer. Int'l Auto Show
55	*Gasoline-Electric Hybrid Vehicles*	Firehouse	Moore, R.E.	2006 Nov	31/11	43-44	Article	E	Hands-on training exercise on hybrid vehicles in accordance with NFPA 1670
56	*Hybrid Vehicles: What's All The Buzz About?*	Fire Engineering	Dalrymple, D.	2006 Nov	159/11	24-29	Article	V	Review of current and future hybrid vehicle designs and identifiers for rescuers
57	*Hybrid Vehicles*	Firehouse	Moore, R.E.	2006 Dec	31/12	39-40	Article	V	Review of rescue from two hybrid pickups
58	Hybrid Vehicle Update – Part 1 Color-Coding High Voltage Cables & Connectors	Firehouse	Moore, R.E.	2007 July	32/7	43-45	Article	V	Part 1 on color-coding of hybrid vehicle high-voltage cables & connectors
59	*Compound Factors*	Fire Chief	Emery, J.D.	2007 Aug	51/8	92-95	Article	E	Focus on extrication and electrocution hazard of hybrid vehicles
60	*Hybrid Hints And Hazards*	Fire Fighting in Canada	Methner, P.	2007 Nov	51/7	36-40	Article	V, E	Review of size-up, cutting power, and extrication methods for hybrid vehicles
61	*Hybrid School Buses: Response Considerations*	Fire Engineering	Hollins, L.T.	2008 Jan	161/1	107-108	Article	V, E	Case study review of a hybrid school bus
62	*Hybrid Vehicle Rescue: Replacing Fear with Knowledge*	Carolina Fire Rescue EMS Journal	Shaw, R.	2008 Winter	22/3	44-71	Article	E	Review of basics for emergency responders
63	*Best Practices for Today's Extrication*	Size Up	Dalrymple, D.	2009	3	33-35	Article	E	Review of technology and operational facets of vehicle extrication
64	*Rescue and Alternative Vehicle Power*	Fire Engineering	Dalrymple, D.	2009 Apr	162/4	151-152	Article	V	Review of rescue concerns with alternative-fueled vehicles, including electric hybrids

	Title	Publication	Author(s)	Year	Vol/ Issue	Pg(s)	Format	Cate-gory	Comment
65	*Hybrid Vehicles: Separating Fact From Fiction*	Fire Engineering	Emery, J.D.	2009 July	162/7	73-82	Article	V	Review of hybrid vehicles through 2011
66	*Ultra- High Strength Steels in 2009 Model Year GM Vehicles*	Electric Vehicle Safety Training					Report	V	Quick reference sheet listing the zones in which GM used UHSS in 2009
67	*Evaluation and Analysis for Motor Vehicle Rescue*	USFA NFA Executive Fire Officer (EFO) Paper	Dillingham, D.D.	2004 Oct			Report	E	Evaluation and analysis for motor vehicle rescue in a small department
68	*Future Steel Vehicle: Overview Report*	Steel Market Development Institute		2011 May			Report	V, M	Strategic plan for future use of new steels by the auto industry
69	*New Technologies in Vehicle Extrication*	FEMA / US Fire Admin, National Fire Academy		1994 Sept	FA-152		Report	M, V, E	Comprehensive review of vehicle extrication technology

4. Extrication Scenarios and Tasks

Today advanced high-strength steels and composite materials are often used in applications where high strength is required, but low weight is preferred. Yet only in the last several years has the fire service taken notice of the more widespread use of these materials, which are challenging the effectiveness of their rescue tools.

The use of advanced high-strength steels and composite materials is not new. For motor vehicles, however, the extended use of these materials has been limited and it has not been until the last several years that they have seen more widespread mainstream use. For certain specialty applications, such as aircraft, locomotive trains, racing vehicles, or collapsed buildings, emergency responders already understood that conventional rescue tools could be challenged to their performance limits, and special equipment would sometimes be required. The ability for rescuers to be prepared to handle any incident no matter the material is vital to ensuring the quick rescue of anyone who is trapped.

Motor vehicles are arguably the most common rescue and extrication scenario in which emergency responders might encounter high strength steels and composite materials. Certainly these materials are encountered during other emergency events, such as rail or aviation incidents, but motor vehicle crashes occur more frequently. Thus, motor vehicle events are the primary focus on this study.

Within the automotive industry, the driving force pushing the use of advanced high-strength steels and composite materials has been twofold. First, advancements in industry safety standards such as through the National Highway Traffic Safety Administration (NHTSA) have heightened vehicular structural requirements. Second, and just as influential, the competitive automobile marketplace has had a growing emphasis on high fuel efficiency based on consumer demand. Nearly every large manufacturer has stated its intentions to utilize greater percentages of advanced high-strength steels and composite materials into future designs.

All motor vehicles on the road today have multiple potential hazards that may confront emergency responders. Some of those hazards are independent of the type of propulsion system used, such as compressed gas or the explosive cartridges used for air bags. In contrast, the type of propulsion system can have a direct effect on certain features that affect vehicle extrication, such as high-strength structural supports for the primary battery in an electric vehicle. The general hazards typically found in today's traditional motor vehicle are shown in Figure 4-1, Hazardous Materials Normally Found in Conventional-Motor Vehicles.

An emergency incident involving a motor vehicle is not an uncommon occurrence for the fire service. It would not be unusual for a fire department to respond to a motor vehicle crash or fire during any given day. This is based on the large number of motor vehicles, of all types, that exist today on public roadways in the United States.

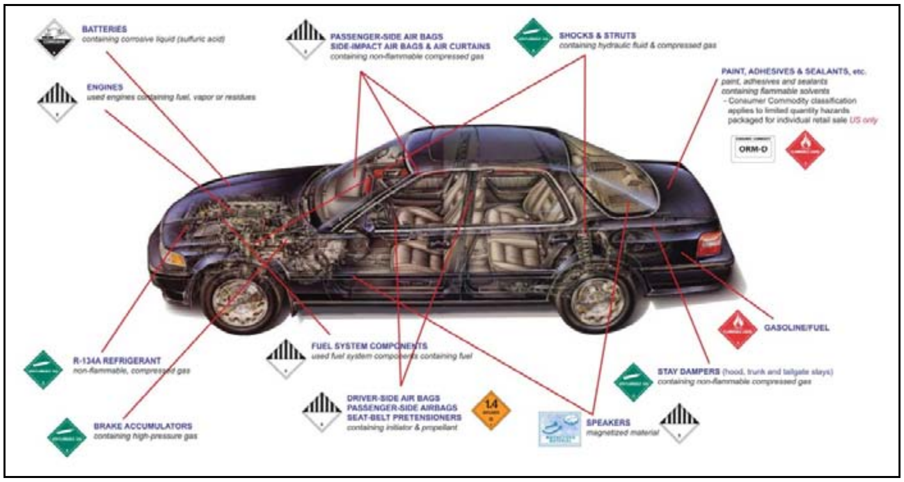

Figure 4-1: Hazardous Materials Normally Found in Conventional-Motor Vehicles[19]
(Diagram courtesy of Pipeline and Hazardous Materials Safety Administration)

The primary emergency scenarios that could be expected by the fire service responding to a motor vehicle emergency event are illustrated in Figure 4-2, Key Emergency Scenarios for Motor Vehicles. This figure considers four basic possibilities: (1) Extrication/Rescue; (2) Fire; (3) Water Submersion; and (4) Other Scenarios.

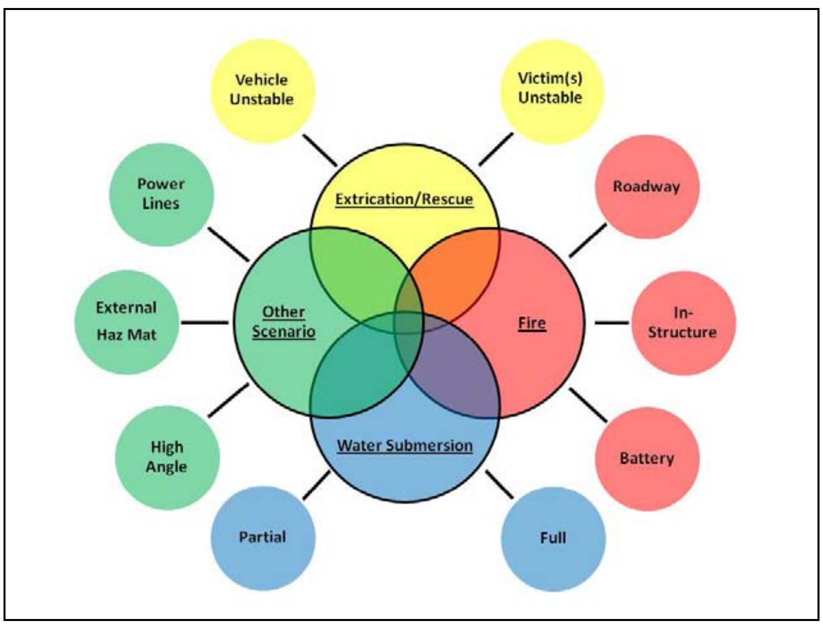

Figure 4-2: Key Emergency Scenarios for Motor Vehicles

The most probable emergency event involving motor vehicles is a motor vehicle accident (MVA). An MVA could involve a collision with another vehicle, multiple vehicles, a stationary object (e.g., telephone pole), or any combination of these. Often an MVA includes victims with injuries requiring prompt medical attention. In some situations the victims may be trapped and require extrication. The four basic ways a motor vehicle can be involved in a collision are: (1)

Head-On, or Frontal; (2) Rear-End; (3) Side Impact, or "T-Bone"; and (4) Rollover. A motor vehicle emergency often involves more than one of these collision scenarios.[20]

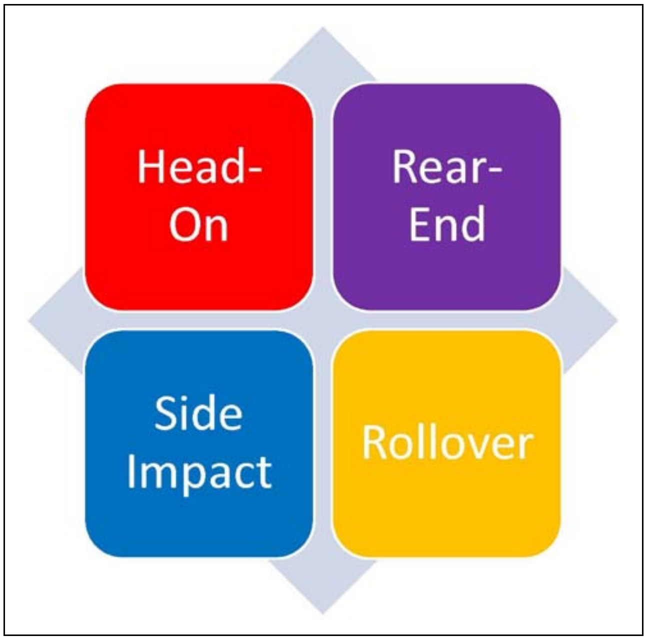

Figure 4-3: Types of Motor Vehicle Collisions

Extrication of trapped victims from a damaged motor vehicle is among the most significantly challenging tasks faced by fire fighters during an emergency event involving a motor vehicle. Often the victims are in immediate need of medical treatment and rapid intervention is essential. Meanwhile, the risks of the situation may be further complicated with a cadre of additional challenges such as vehicle fire, downed power lines, or an external hazardous materials exposure.

Preparation and training for vehicle extrication are paramount to achieving an efficient operation that takes reasonable precautions for emergency responders and victims alike. While every event involving extrication and rescue is unique, certain approaches used by the fire service provide clear direction to emergency personnel on how to handle the event.

Successfully performing a rescue involving vehicle extrication is a complex task that requires a well-coordinated team approach. An example of one team-oriented methodology is based on coordinating resources into four teams: stabilization team, power-down team, extrication team, and the decontamination team.[21] Each of these resource units has specific duties and responsibilities, and they interact and support each other using defined brother-sister relationships. This concept is illustrated in Figure 4-4, Example of Approach to Extrication & Rescue.

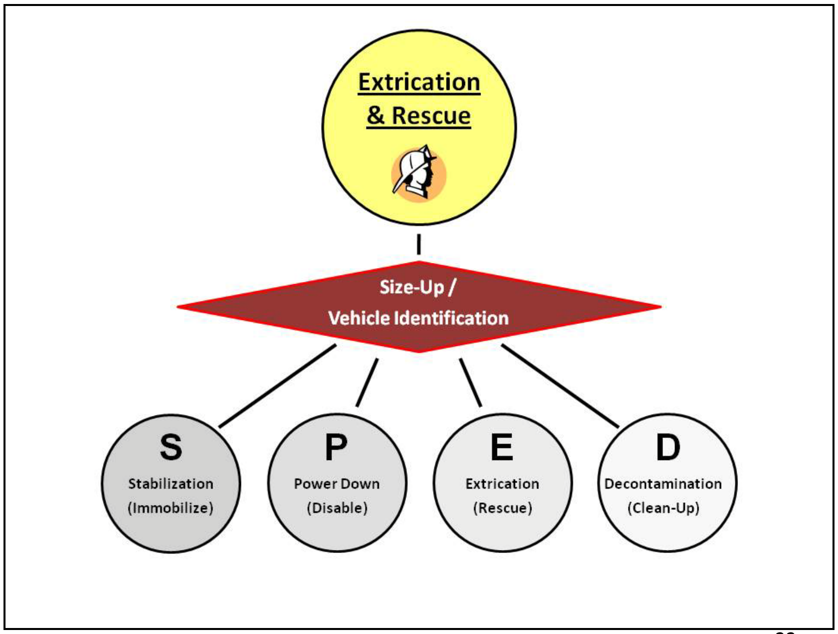

Figure 4-4: Example of Approach to Extrication & Rescue[22]

The primary elements included in the procedures for handling extrication and rescue of victims from any motor vehicle will vary. However, the basic elements are included in Figure 4-5, Summary of Basic Elements of Vehicle Rescue from NFPA 1670, as taken from Chapter 8 of NFPA 1670, *Standard on Operations and Training for Technical Search and Rescue Incidents*.[23] As part of their hazard identification pre-planning and risk assessment, it is intended that emergency responders identify the types of vehicles and machinery within their response area.

I) General Requirements. Comply with General Requirements (Chapter 4) of NFPA 1670, which includes consideration for:
- **a)** Training;
- **b)** Documentation;
- **c)** Standard operating procedures;
- **d)** Hazard identification and risk assessment;
- **e)** Incident response planning;
- **f)** Equipment; and
- **g)** Safety.

II) Awareness Level. For rescue emergencies involving vehicles and similar machinery; requires compliance with Chapter 4 of NFPA 472, *Standard for Professional Competence of Responders to Hazardous Materials Incidents*. Procedures for "Awareness Level" shall include:
- **a)** Recognize need for a vehicle and machinery search and rescue;
- **b)** Identify resources necessary to conduct operations;
- **c)** Initiate the emergency response system for incident;
- **d)** Initiate site control and scene management;
- **e)** Recognize general hazards associated with incident, including the following;
  - **i)** Utilities, such as:
    - Electrical services (primary and secondary);

- Gas, propane, fuel oil, or other alternative energy sources;
- Water;
- Sanitary systems;
- Communications; and
- Secondary service systems (e.g. compressed, medical, or industrial gases).

ii) Hazardous materials;
iii) Personal hazards;
iv) Movement of vehicle(s) and machinery;
v) Release of high-pressure vehicle systems; and
vi) Other hazards.

f) Initiate traffic control.

III) Operations Level. For rescue emergencies involving vehicles and similar machinery; requires compliance with "Awareness Level" and with Chapter 5 of NFPA 472, *Standard for Professional Competence of Responders to Hazardous Materials Incidents*. Also requires organizational member capability for recognizing hazards, using equipment, and implementing techniques necessary to operate safely and effectively at incidents involving persons injured or entrapped in a vehicle or machinery. Procedures for "Operations Level" shall include:

a) Size-up incident, with initial and continuous evaluation of:
i) Scope and magnitude of the incident;
ii) Risk/benefit analysis (body recovery versus rescue);
iii) Number and size of vehicles or machines affected;
iv) Integrity and stability of vehicles or machines affected;
v) Number of known or potential victims;
vi) Access to the scene;
vii) Other hazards such as disrupted or exposed utilities, standing or flowing water, mechanical hazards, hazardous materials, electrical hazards, and explosives;
viii) Exposure to traffic;
ix) Environmental factors; and
x) Available versus necessary resources

b) Identify probable victim locations and survivability;

c) Make the search and rescue area safe, including the stabilization and isolation (e.g., lockout/tagout) of all vehicles and machinery involved, with consideration for actions such as:
i) Establishing operational zones (i.e., hot, warm, cold) and site security;
ii) Utilizing specific techniques and tools (including cribbing, chocks, and wedges) to stabilize the vehicle;
iii) Utilizing specific techniques and tools (i.e., lockout and tagout) to isolate the involved equipment;
iv) Making the search and rescue area (i.e., hot zone) safe for entry;
v) Safely undertaking disentanglement and extrication operations using hand tools;
vi) Ventilating the search and rescue area and monitoring its atmosphere when necessary
vii) Supporting unbroken utilities;
viii) Providing protective equipment for victims, if possible, when necessary;
ix) Prohibiting entry into an unsafe vehicle or machinery search and rescue area; and
x) Preventing the touching or operating of equipment or machinery involved until its safety has been established.

d) Identify, contain, and stop fuel release;
e) Protect victims during extrication or disentanglement;
f) Package victims prior to extrication or disentanglement;
g) Access victims trapped in a vehicle or machinery;
h) Perform extrication and disentanglement operations involving packaging, treating, and removing victims trapped in vehicles or machinery through the use of hand and power tools, with training and on-scene consideration of:
    i) Types of passenger restraint systems;
    ii) Frame and construction features of vehicles;
    iii) Types of suspension systems in vehicles;
    iv) Types and classification of impacts;
    v) Categories of mechanical injury;
    vi) Various stabilization techniques;
    vii) Center of gravity and its relationship to rollover;
    viii) Use of cribbing and chocks;
    ix) Building a crib box;
    x) Types and examples of levers for mechanical advantage;
    xi) Proper and effective use of hand tools including hammer, pry bar, hacksaw, glass punch, Halligan, knife or belt cutter, cable cutter, and come-along;
    xii) Disentanglement through primary access points;
    xiii) Victim packaging prior to removal from a vehicle or machine;
    xiv) Protection of the victim during extrication or disentanglement operations; and
    xv) Proper and effective use of power tools including hydraulic, pneumatic, and electrical spreading, cutting, lifting, and ram-type tools.
i) Mitigate and manage general and specific hazards (e.g., fires and explosions) associated with vehicle and machinery search and rescue incidents;
j) Procure and utilize the resources necessary to conduct vehicle and machinery search and rescue operations; and
k) Maintain control of traffic at the scene of vehicle and machinery search and rescue incidents.

IV) Technician Level. For rescue emergencies involving vehicles and similar machinery; requires compliance with “Awareness Level” and “Operations Level”. Procedures for “Technician Level” shall include:

a) Evaluate existing and potential conditions at incident;
b) Perform extrication and disentanglement operations involving packaging, treating, and removing injured or trapped victims, with training and on-scene consideration of:
    i) Frame and construction features of heavy, large vehicles and machinery;
    ii) Use and components of a search and rescue chain assembly;
    iii) Pneumatic high-, medium-, and low-pressure lifting bags;
    iv) Use, care, and maintenance of wire rope and its associated equipment;
    v) Large and heavy object weight estimation;
    vi) Steps necessary to lift or move large objects;
    vii) Use of cribbing and chocks with large and heavy objects;
    viii) Use of commercial heavy wreckers and recovery services to assist at incidents involving large transportation vehicles;
    ix) Use, care, and maintenance of both manual and power winches;
    x) Types and examples of lifting devices that use mechanical advantage principles;

- **xi)** Proper and effective use of power tools, including hydraulic, pneumatic, and electrical spreading, cutting, lifting, and ram-type tools;
- **xii)** Disentanglement through both primary and secondary access points using available power tools;
- **xiii)** Protection of the victim during extrication or disentanglement operation;
- **xiv)** Lockout/tagout of machinery; and
- **xv)** Identification and use of various sling configurations.

c) Handle advanced stabilization of unusual vehicle and machinery search and rescue situations (e.g. extrication or disentanglement operations at incidents involving small or large non-upright vehicles, using techniques and equipment such as chains, cables, jack devices, and cribbing/shoring); and

d) Use all specialized search and rescue equipment immediately available and in use by the emergency response organization, including:

- **i)** Powered rescue tools (e.g., hydraulic cutters/ spreaders/rams, air bags, other power tools, and hand tools); and
- **ii)** Training necessary to remove, cut, and move components required for extrication.

Figure 4-5: Summary of Basic Elements of Vehicle Rescue from NFPA 1670[24]

5. High-Strength Alloys and Composite Materials

Throughout the automobile industry, the growing trend over the last decade has been the use of high-strength steels (HSS) and advanced high-strength steels (AHSS) in new-vehicle designs. Indications are that this trend will continue, since the use of these materials is in all new passenger vehicle makes and models in response to new safety standards and marketplace incentives for fuel efficiency. This trend applies to all passenger vehicles and is not limited to new alternative-fuel vehicles such as those using propane, natural gas, electric, and hybrid propulsion.

The benefits of new materials such as HSS and AHSS are numerous. The increased vehicle strength helps manufacturers adhere to ever increasing safety testing requirements to increase crash worthiness. Lowering the vehicle weight increases fuel efficiency, which is a significant feature for the vehicle consumer. Lighter vehicles also collectively decrease unwanted gas emissions such as CO into the atmosphere. Strong national interest exists to reduce dependency on foreign energy supplies beyond direct governmental control.

Background and General Principles

Material choices for a vehicle design are inherently dependent on multiple factors to achieve desired performance requirements. Examples of such factors are strength (for safety), workability (for manufacturing), durability (for corrosion resistance), and weight (for fuel efficiency). In a competitive automobile marketplace, these and other factors have significant influence on the ultimate choice of materials. Further, certain external influences such as increasingly stringent vehicle safety standards can be the motivating reason for industry-wide change.

Several different types of steels are available today, and they are often referred to in the literature and elsewhere by their representative acronyms. A spectrum of SAE standards address these various types of steel and provide detailed requirements for their manufacture.[25] For convenience, the most common steels found in today's motor vehicles are summarized in Table 5-1, Summary of Types of Steels Found in Modern Motor Vehicles.[26] The steel types are sorted into three groups. First are the terms used for general categorization, followed by the sub-types that are considered conventional HSS and then the sub-types for AHSS.

In the automobile market, the trend has clearly been the increased use of HSS and composite materials. Further, indications are that this trend will continue based on improvements in manufacturing technology for HSS and other materials, which is making these materials more available and affordable.

Comparison data are available for the use of basic materials in the average passenger motor vehicle in the North American marketplace, over a time period of roughly three decades.[27] This information is shown graphically in Figure 5-1, Average Percent Content of Motor Vehicle Materials in 1975, which is followed by Figure 5-2, Average Percent Content of Motor Vehicle Materials in 2007.[28]

Table 5-1: Summary of Types of Steels Found in Modern Motor Vehicles[29]

Acronym	Name of Steel Type	Classification
AHSS	Advanced High-Strength Steel	General Category
DR	Dent Resistant Steel	General Category
HSLA	High-Strength Low Alloy Steel	General Category
HSS	High-Strength Steel	General Category
MILD	Mild Steel	General Category
UHSS	Ultra High-Strength Steel	General Category
BH	Bake Hardenable Steel	Conventional HSS
CMn	Carbon-Manganese Steel	Conventional HSS
IF	Interstitial-Free Steel	Conventional HSS
IF-HS	Interstitial-Free High-Strength Steel	Conventional HSS
IS	Isotropic Steel	Conventional HSS
CP	Complex Phase Steel	AHSS
DP	Dual Phase Steel	AHSS
DP-CP	Dual Phase – Complex Phase Steel	AHSS
FB	Ferritic-Bainitic Steel	AHSS
HF	Hot Formed Steel	AHSS
MART	Martensitic-Phase Steel	AHSS
MS	Martensitic Steel	AHSS
PFHT	Post-Forming Heat-Treatable Steel	AHSS
SF	Stretch Flangeable Steel	AHSS
TRIP	Transformation-Induced Plasticity Steel	AHSS
TWIP	Twinning-Induced Plasticity Steel	AHSS

The pie charts in Figure 5-1 and Figure 5-2 demonstrate the increase of AHSS in motor vehicles. For example, a typical vehicle in 1975 consisted of nearly 56% mild steel and approximately 4% medium steel and HSS. By comparison, the typical vehicle in 2007 contained just over 43% mild steel and almost 12% HSS.[30]

In addition to the shift from mild steels to HSS, collectively there has been a decrease in the use of steels compared to other materials, most notably aluminum and plastics. Collectively the use of steel has dropped from approximately 60% in 1975 to 55% in 2007. However, for emergency responders dealing with extrication, steel is the key component for the vehicles structural framework and the primary material of interest. Further, in just two years from 2007 to 2009, it is estimated that the overall use of AHSS has increased as much as 5% in the average passenger vehicle, based on the increased use of these materials for vehicle body components, closures, bumpers, wheels, suspensions, and subframes.[33]

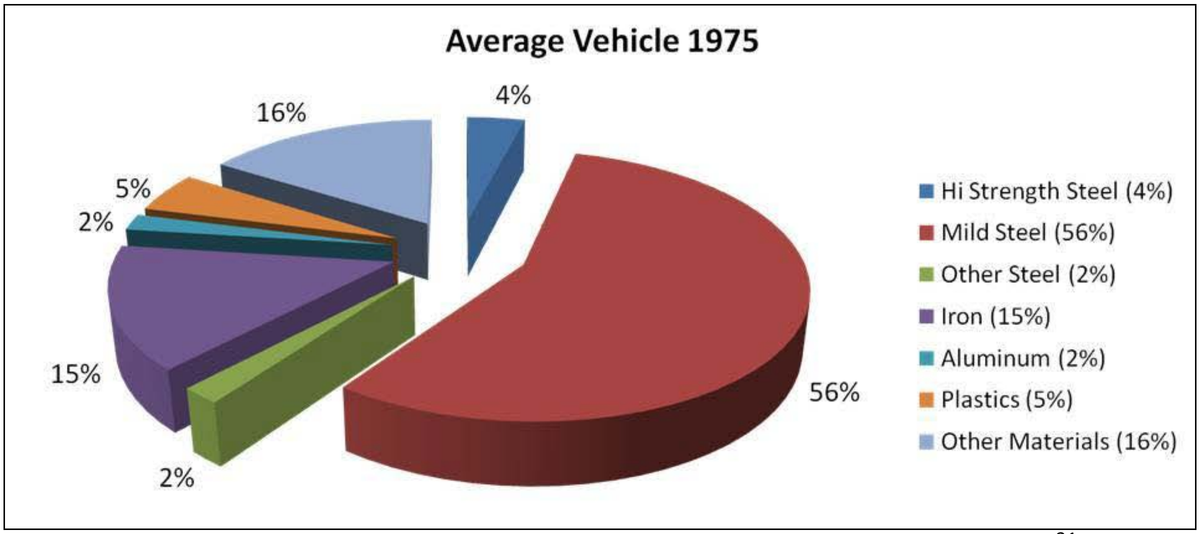

Figure 5-1: Average Percent Content of Motor Vehicle Materials in 1975[31]

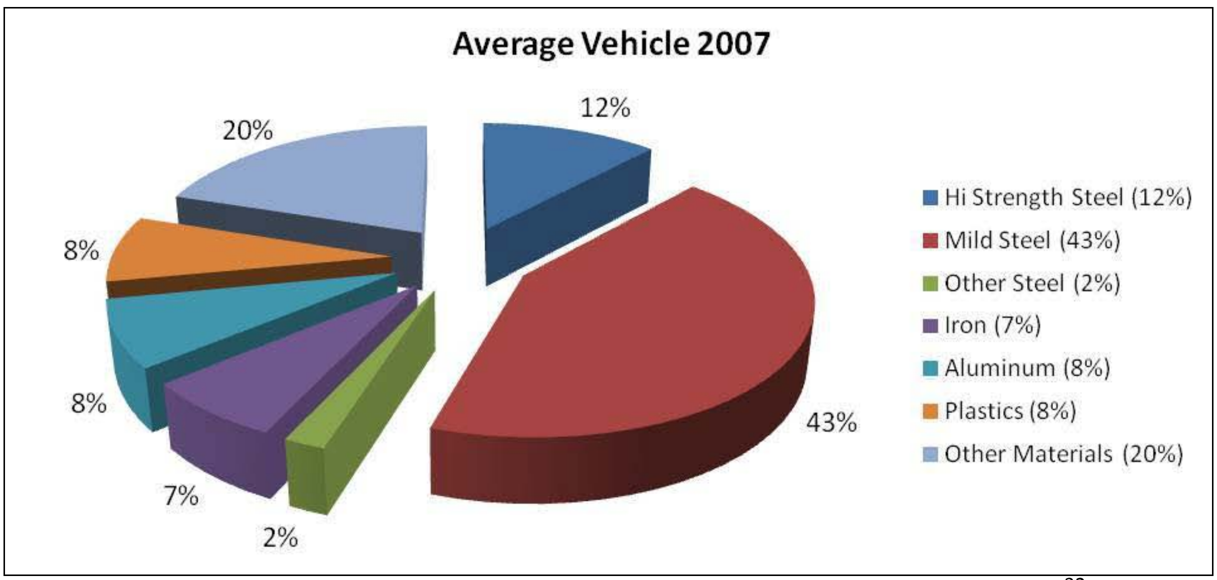

Figure 5-2: Average Percent Content of Motor Vehicle Materials in 2007[32]

The trend is for the increased use of HSS in future vehicle models, and the likelihood of emergency responders seeing these materials at typical motor vehicle crashes is increasing. The "FutureSteelVehicle" (FSV) program is an initiative through the Steel Market Development Institute, which is promoting the use of steel body designs with structures that reduce mass by more than 35 percent but comply with all applicable crash and durability requirements. Figure 5-3 illustrates the types of steels that are offered in one particular package of the new FSV program and that can be expected to be seen in more and more new vehicles.[34]

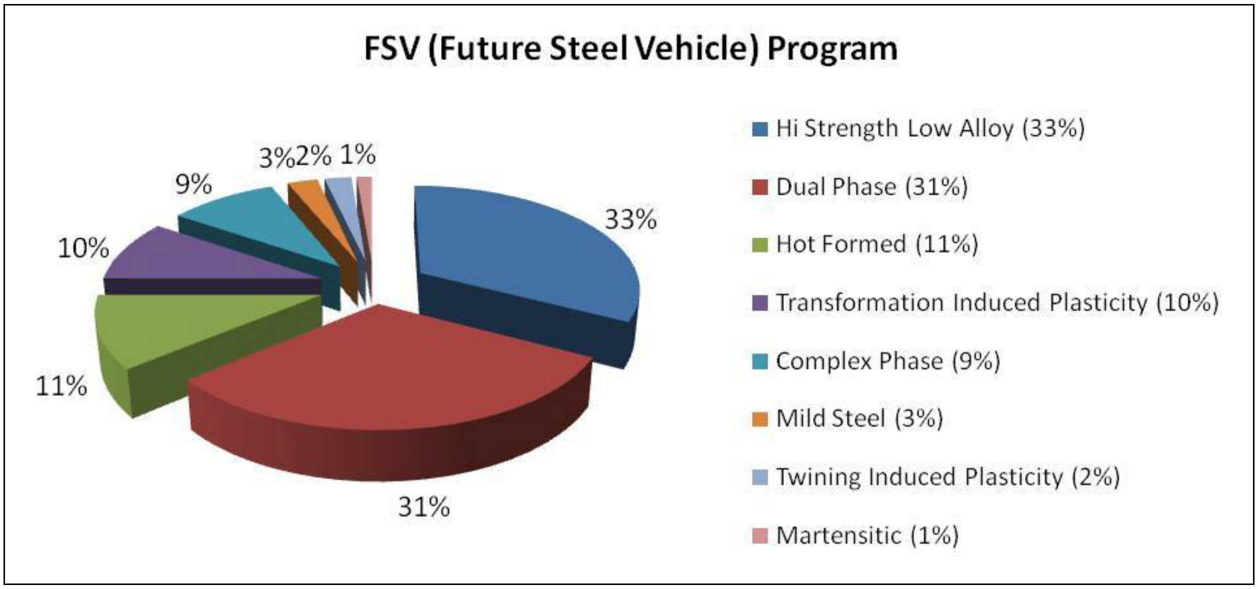

Figure 5-3: Types of Steels in "FutureSteelVehicles" (FSV) Program

The prominent use of materials like HSS in vehicles is not altogether new. For specialty applications (race cars for instance), a significant portion of the vehicle utilizes these materials. Emergency responders who work at motorsport venues are already familiar with the need for extrication tools adequate for their application.[35]

Likewise, some manufacturers are already using these materials for mainstream motor vehicles. One example is Volvo, which is credited as one of the first manufacturers to incorporate HSS and AHSS into their mainstream commercial vehicles. It is estimated that by 2020 close to a third of all vehicles on the roadway will be using appreciable amounts of HSS and composite materials.[36]

The variations in steel properties are what continue to make it the most used material in automobile design. There are many variables to consider and balance when choosing which material would be best for a design, including strength, workability, durability, weight, and cost effectiveness. These properties often offset each other. For example, depending on the circumstance, while a particular material may be the strongest (e.g. martensitic-phase steel), it may not be the most cost-effective solution.

Use of Materials in Motor Vehicles

There is a multitude of ways to categorize steel properties and characteristics. The myriad of different names and classifications are often confusing, with similar names describing the same materials and individual auto manufacturers using different names to describe the same strength category of a particular steel.

For example, a common term often used by emergency responders to refer to AHSS is “boron” or “boron steels.” Boron is the fifth element in the periodic table of elements and has properties that are borderline metal-nonmetal.[37] With steel blends, boron is used as a strengthener. Steels that include boron are generally very high strength, and are sometimes referred to as “boron-carbide” or “boron-steels.”

The overall landscape of the types of steels used in motor vehicles can generally be separated into four basic categories. These groupings recognize the steels’ increasing tensile strength, which ranges from low to high as follows:[38]

- mild steels (MILD);
- high-strength steels (HSS);
- high-strength low-alloy steels (HSLA); and
- ultra high-strength steels (UHSS), or advanced high-strength steels (AHSS).

The four categories of steel have seen traditional use in certain areas and components of modern vehicles. Figure 5-4 illustrates of the use of these materials in a typical modern passenger automobile. In general, the key components that are of interest to emergency responders during extrication scenarios have been increasing in strength.

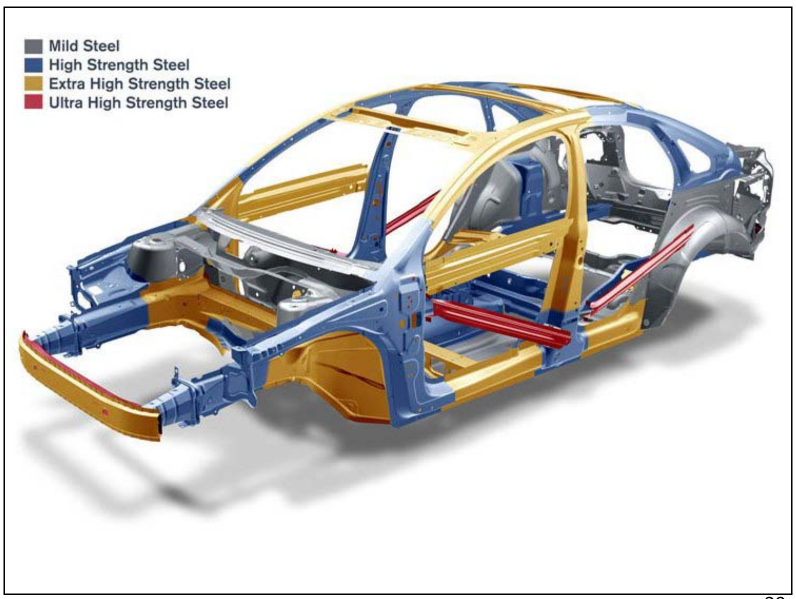

Figure 5-4: Typical Use of Steels in Passenger Automobiles[39]
(used with permission)

The use of mild or low-strength steels has typically been for vehicle section areas such as rocker panels, floor pans, and fenders. Conventional high-strength steels are usually used in hoods, door skins, and quarter panels and are made from slightly stronger metals.[40]

High-strength low-alloy steel is typically the material of choice for the pillar posts, side members, front and upper rails, and the shock tower supports. Ultra high-strength steels, the strongest types of steel, are generally used in side-impact door beams and reinforcement bars.

Some common types of UHSS are boron, martensitic, and some transformation induced plasticity (TRIP) and dual-phase (DP) steels. These UHSS metals are also considered to be advanced high-strength steels.[41]

What is the future of new steel materials in motor vehicles? An initiative currently underway, the Steel Market Development Institute's "FutureSteelVehicle," or FSV, symbolizes the increasing display of enhancements. The FSV program features steel body designs with structures that reduce mass by more than 35 percent and total life cycle emissions by nearly 70 percent when compared to a benchmark vehicle, all while meeting a broad list of global crash and durability requirements.[42]

The FSV program is the most recent addition to the global steel industry's series of light-weight initiatives offering steel solutions to automakers around the world. FSV follows the "Ultra-Light Steel Auto Body" program (1998), the "Ultra-Light Steel Auto Closures" program (2000), the "Ultra-Light Steel Auto Suspension" program (2000), and the "ULSAB-Advanced Vehicle Concepts" program (2001).[43]

Automobile design metallurgists compare and contrast these steels based on different physical characteristics. One common approach to comparing the differences in the types of steel is to graph the materials tensile strength (MPa) versus total elongation (%). Figure 5-5 visually compares the material properties for the types of steel commonly used in motor vehicles.[44] Design professionals use this type of chart as a key comparison tool to address structural materials for motor vehicles.

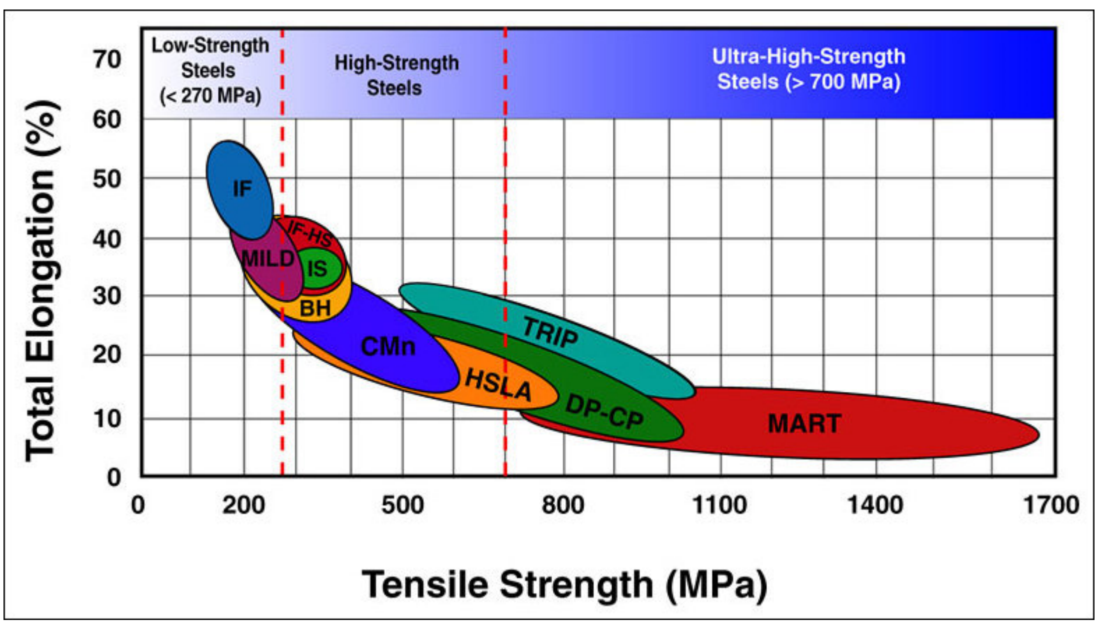

Figure 5-5: Comparison of Material Properties for Types of Steel Used in Motor Vehicles[46]
(used with permission)

For any particular type of steel, the interrelationship of the various material properties is noteworthy. For example, a characteristic of UHSS is that as the tensile strength of the material increases, the ductility decreases, making it less bendable and workable. Yet compared to other types of steel, the characteristic of spring back (based on higher yield strength) is better in UHSS than in mainstream sheet steels."[45]

Figure 5-5 is a widely referenced graphic depiction that illustrates the critical properties of the steels of interest in this study. However, it offers more information than necessary for emergency responders. For that reason, a simplified version of the same information is offered in Figure 5-6, Tensile Strength for Types of Steels Used in Motor Vehicles. The simplified figure does not include the physical property of total elongation, which is not necessary for this discussion. The types of materials addressed in Figure 5-5 and Figure 5-6 are:

- IF: Interstitial-Free Steel
- MILD: Mild Steel
- IF-HS: Interstitial-Free High-Strength Steel
- IS: Isotropic Steel
- BH: Bake Hardenable Steel
- CMn: Carbon-Manganese Steel
- HSLA: High-Strength Low Alloy Steel
- DP-CP: Dual Phase – Complex Phase Steel
- TRIP: Transformation-Induced Plasticity Steel
- MART: Martensitic-Phase Steel

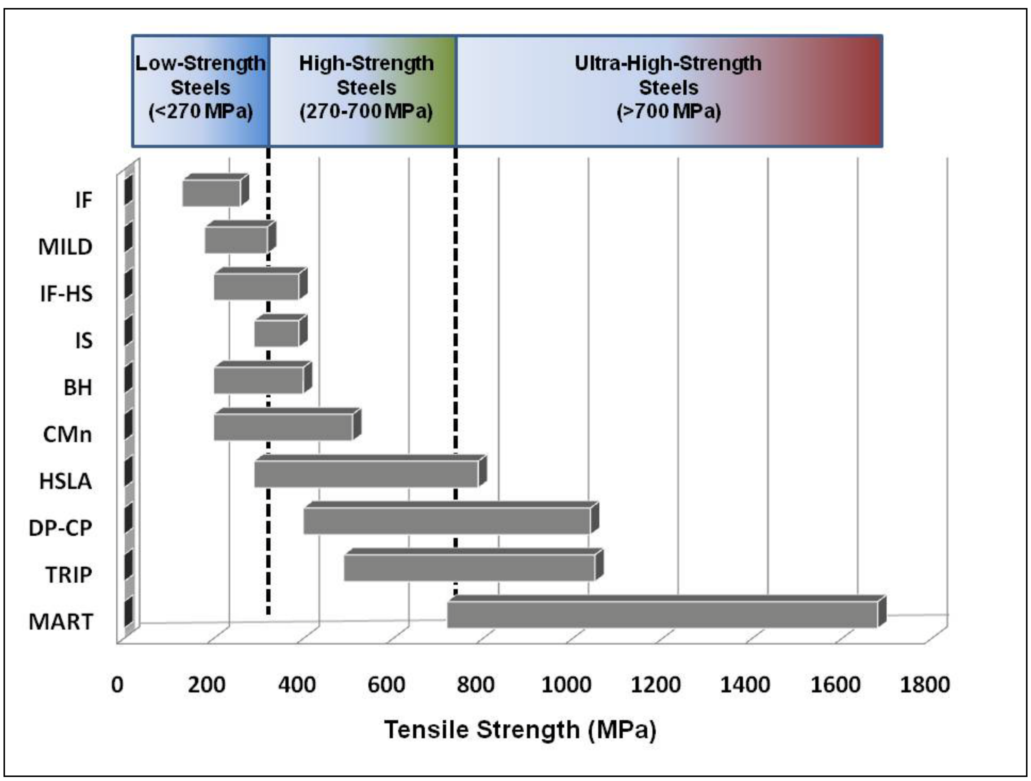

Figure 5-6: Tensile Strength for Types of Steels Used in Motor Vehicles

Certain materials other than steel are also growing in usage within the auto industry, including, for example, aluminum, plastics, and composite materials. Much of this increased usage has to do with the low weight of those materials, although they do have other desirable qualities, such as formability and cost to manufacture. While these alternative materials are increasing, plastic and aluminum account for only about 16% of the average 2007 car's total composition, compared with steel, which comprised roughly 55% of the total composition.[47]

For structural materials, aluminum is commonly found in space frame structures, exterior body panels, and structural components as energy absorbers. This is more common in higher-priced, lower-volume vehicles. Typically, using aluminum instead of conventional steel will result in a large decrease in weight, but it is not as economical for most high-volume mass produced vehicles and can be as much as four times the cost. In a similar fashion, composites such as carbon fiber-reinforced polymer (CFRP) can offer the same tensile strengths of conventional steel for just 25% of the weight, but estimated material costs can be as much as 30 times the price.[48]

The use of plastics in vehicles has nearly doubled in use in recent years due to new manufacturing methods that have decreased cost and increased versatility. For emergency responders, these materials generally support safer vehicles (based on increased safety standards), although they may require different tactics for handling during a particular emergency (i.e., plastics during a fire). The relative cost of manufacturing with a certain material is a prime factor in the magnitude of that material's usage. The relative costs of certain widely used materials found in today's motor vehicles are summarized in Table 5-2, Approximate Relative Cost of Motor Vehicle Materials.[49]

Table 5-2: Approximate Relative Cost of Motor Vehicle Materials[50]

Material Type	Approximate Relative Cost (baseline of Cold Rolled Carbon)
Hot Rolled Carbon	0.80
Cold Rolled Carbon	**1.00**
Bake Hardenable	1.10
Hot Dipped Galvanized	1.12
HSLA	1.15
Aluminized	1.21
Electrogalvanized	1.35
Dual Phase	1.40
Martensitic	1.50
Ferritic Stainless Type 409	2.60
Martensitic Stainless Type 410	2.80
Aluminum Sheet Type 5052	4.80
Austenitic Stainless Type 304	5.70
PH Stainless I7-4	9.00
CFRP	30.00

Use with Extrication Scenarios and Tasks

The increased use of HSS and AHSS in today's vehicles has resulted in safer overall vehicles, though it has in parallel resulted in the need for different methods and approaches by those servicing the vehicles, rescue and repair professionals alike. The increased strength of these materials is utilized in the new methods for crash safety where the front and rear sections of a car are meant to crumple when impacted to lessen the shock aspect of the crash, whereas the passenger compartment must be more resistant to impact to reduce risk to the occupant.

The design of today's automobiles focuses on safety of occupants during a crash. As a result, the passengers of a motor vehicle involved in a crash today are more likely to be protected due to the structural integrity of the vehicle. Conversely, because of this added protection, if a crash victim needs to be extricated, the challenges for emergency responders are magnified. The "golden hour," so-called because of its criticality in getting a crash victim stabilized with full medical attention, will further test the skills and resources of emergency responders.

The higher tensile strengths of today's materials used in portions of the motor vehicle where rescue tools are likely to cut or shear are requiring greater force to be effective. In some cases, conventional powered rescue tools that work effectively on older vehicles are not effective in late-model vehicles. Emergency response personnel can be deceived by their training activities, which use older vehicles obtained from the local salvage yard, not newer models that typically appear on the roadway today.

For rescuers, the main issue arises when they cannot quickly and efficiently extract an occupant due to their conventional tools, for example, being unable to cut through the materials used around the passenger compartment. Oftentimes during a crash, the doors become unusable, and either the doors or the roof must be removed with powered rescue tools. While AHSS had been used for quite some time in other areas of vehicles such as underneath the car, today it is being used for vehicle components that are more likely to be within the extrication cut zones, such as the A-post, the B-post, and roof sections of the vehicle.

Composite materials are also creating special challenges.[51] Multiple layers of different materials that have superior strength characteristics are used in hollow core or layered-sheet designs to minimize weight. Use of a shearing-type tool tends to collapse hollow-core arrangements of composite materials, creating a solid mass of high-strength materials that can exceed the performance ability of the particular tool. It is speculated that, in some cases, certain composite materials forced together under extremely high pressure, for example, during the shearing or cutting process, chemically change phase into materials with superior properties.

More specifically, with older vehicles the properties of mild steels would cause the sections of steel to bend and crumple together, and the mild steel could be considered a large solid section of steel forced together under extremely high pressure, i.e., during the shearing or cutting process variant only by the thickness of material. In newer vehicles with composite materials, the scenario changes slightly in that the steels do not crush together to be cut like the mild steels. AHSSs have such a high tensile strength that they behave differently during extreme conditions such as being cut after being crumpled.

6. FIELD INVENTORY OF POWERED RESCUE TOOLS

Within the fire service today, it is common practice that when a department purchases new equipment, their older equipment is often resold to other departments that need upgraded equipment but do not have the funds to purchase new equipment. This cycling of equipment means that equipment used in the field, if taken care of properly can be as old as 30 years or more.[52]

While older equipment can still be used on mild steels in older vehicles or on the weak points of new vehicles, it can be significantly challenged to cut or shear most HSS and AHSS. Manufacturers of powered rescue tool are aware of these challenges and are keeping pace with the latest available equipment, but it will take time for new tools to infiltrate throughout the existing field inventory of powered rescue tools. For example, emphasized attention is being given to performance details such as the forces created by the blade thickness and design, so as to maximize the tool's overall efficiency and effectiveness.[53]

Tool Types and Capabilities

A wide range of different types of recue tools are available for today's emergency responders. The number of different tools is significant (i.e., in the hundreds). These tools are often grouped for convenience, and one approach is according to the methods or sources used to power the device. An overview of the different tools is provided in Figure 6-1, Families of Rescue Tools.[54]

The different tools logically separate into three basic groups according to primary power sources. First are the powered rescue tools that use pressurized fluid (including pressurized gas/compressed air) supported by an external pressure pump via hose lines, with the most common liquid fluids being hydraulic or mineral oil. Second is the wide range of tools that have a self-contained motorized power source, such as a gasoline engine, compressed gas, or an electric motor. Finally, there are numerous tools that are directly powered by human energy, such as hand tools and tools directly mounted on vehicles, like a winch.

The tools of greatest interest for situations of extrication involving HSS and composite materials are those involved with cutting and shearing. Powered rescue tools that perform pushing, pulling or spreading functions generally remain effective according to their original performance intentions, despite the higher-strength materials. The same is not true for tools that cut or shear-- in some cases, they are simply unable to perform their intended tasks.

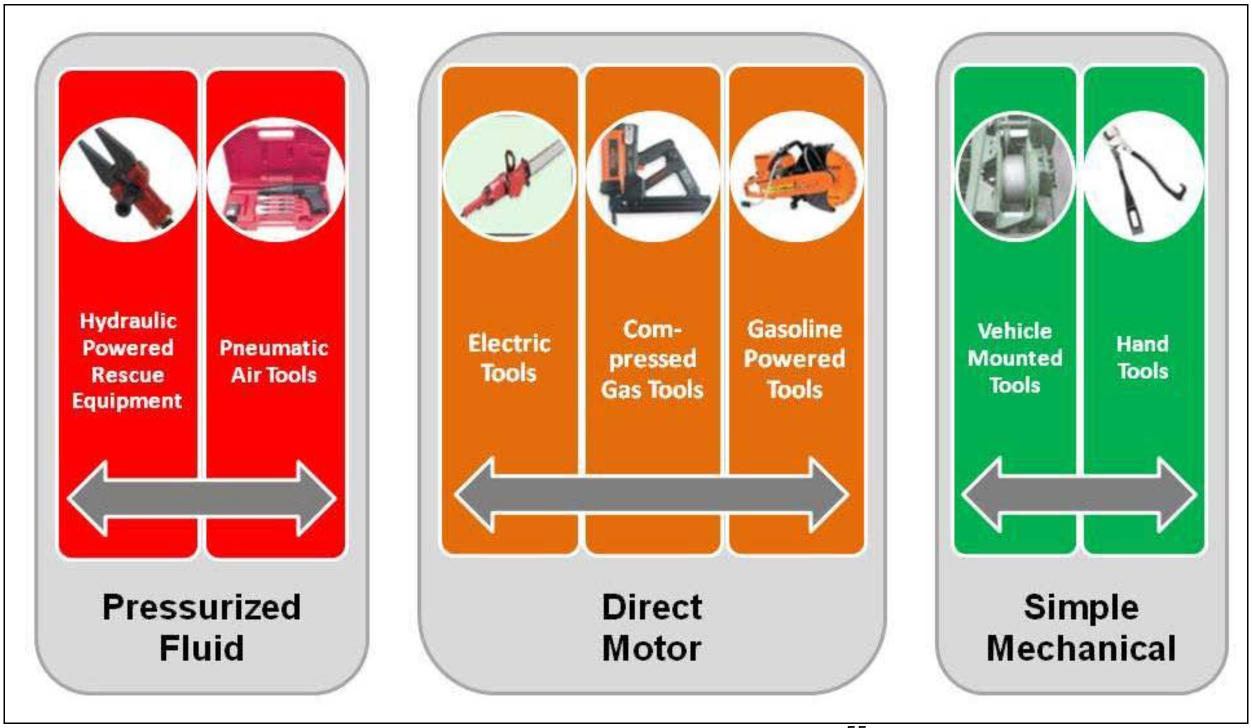

Figure 6-1: Families of Rescue Tools[55]

To realistically narrow the scope of this study, and because there are so many different tools in each family of tools, this study will focus on the tools that perform cutting and shearing functions. The types of tools that are the focus of this study are illustrated in Figure 6-2, Types of Rescue Tools of Interest.

Of primary interest are the powered cutters in the hydraulic powered rescue tool family. They are the key focus since they are the most powerful of readily-available mainstream cutting and shearing tools. Also of interest are air chisels in the pneumatic air tool family, powered reciprocating/rotating saws (e.g., motorized circular saws), and hand saws. However, even though these other tools are not excluded from the scope of this review, the primary focus is on the powered cutters within the family of hydraulic powered rescue tools.

As a general rule, powered cutters purchased before 2008 can be expected to be severely challenged by the HSS and composite materials in today's motor vehicles.[56] Several variables will understandably influence this basic guideline, such as the particular tool design and type of steel being cut. Looking at the other tools in today's emergency responder arsenal, air chisels and powered reciprocating saws are typically challenged by high-strength steels due to the lack of durability of their bits and blades. Powered rotating saws are able to cut steel that is high strength, but their dependability for extrications is normally considered impractical based on the shower of sparks they create.[57]

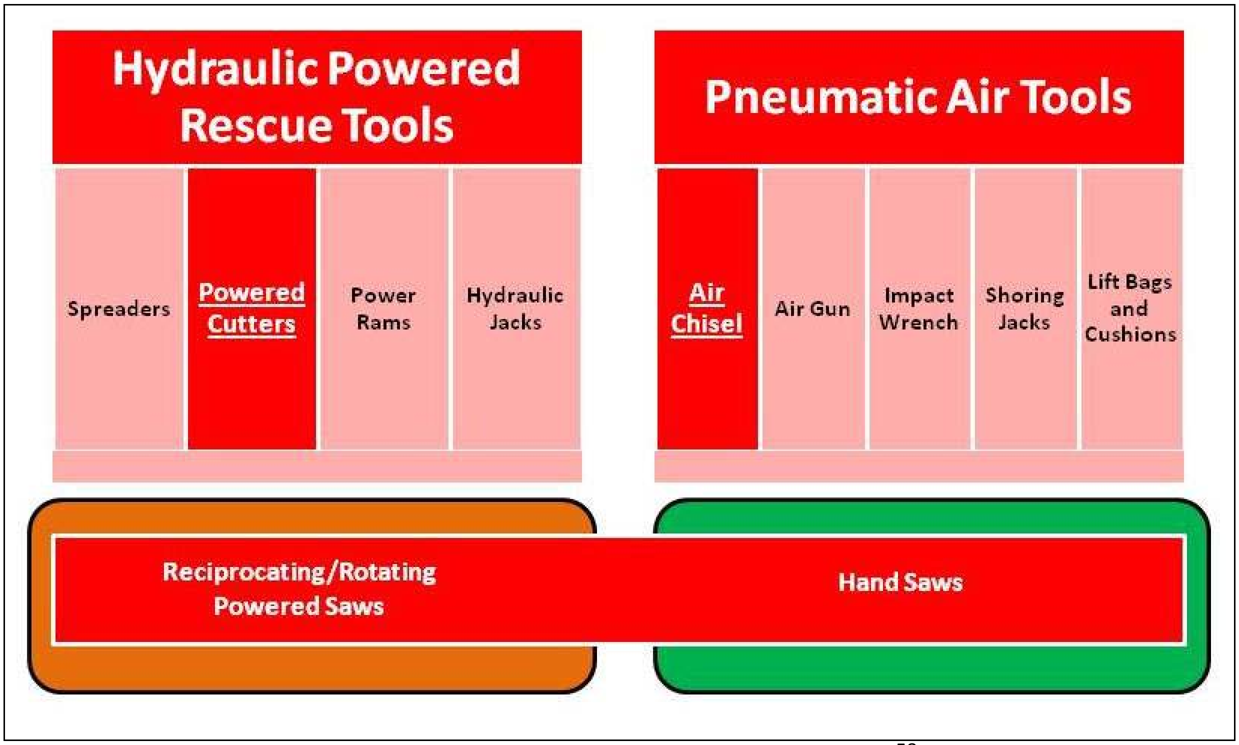

Figure 6-2: Types of Rescue Tools of Interest[58]

For powered rescue tools there are a number of characteristics that further define this equipment. One approach is to classify this equipment based on the following four main categories:

- High-Pressure Hydraulics (10,500 psi),
- Low-Pressure Hydraulics (5,000 psi),
- Electric Powered, and
- Hand-Pump Operated.

Each category draws the initial pressure from a different source, but each has benefits as well. The high-pressure and low-pressure tools require a hydraulic pump to pressurize the system and continuously flow fluid through the system to push the piston. While this often creates continuous higher forces as a result, applications in which accessibility is an issue may view the pump as a large bulky item to carry over long distances or in tight spaces.

A newer option on the market, electric tools offer mobility without being attached to a hydraulic hose. While electric tools have certain positive characteristics such as portability, they also have limitations, such as a limited energy source for the internal pump. Many manufacturers have taken this into account by using multi-use batteries, which can be replaced when they run low. Another common solution is the ability to directly connect to an available electrical outlet to have a continuous flow of energy.

The last type, handpump-operated tools, require more work from the operator to manually create the pressures required for the cutter. The benefit is that they are very mobile and do not require any external input to perform their functions.

Each category offers its own unique advantages and disadvantage. Normally emergency response units are equipped with multiple types of tools to provide a full set of options to ensure a well-rounded response capability.

For powered rescue tools that perform cutting and shearing functions, various design details influence the effectiveness and efficiency of the particular tool. For example, a key feature for any powered rescue cutting tool is the blade design. Details such as the blades thickness, shape, and construction material can significantly influence the overall performance of the tool. The design details of the cutting blades are at a level of focus below that provided in national standards such as NFPA 1936, *Standard on Powered Rescue Tools*.[59]

Further, the blades are required to be of materials that are harder and stronger than the toughest materials to which they are applied. Boron steel, for example, is extremely hard, to the point where it must be fractured rather than cut, which means the blades in the rescue tools must be harder but less brittle in order to fracture through the boron. While the blade material is important, the blade's shape and design are often just as important to ensure that the material is drawn into the pivot point of the blades where the forces will always be at their maximum.

Collection Methods and Available Data

For an emergency responder's consumer perspective, powered rescue tools are often compared using three main categories: performance, reliability, and compatibility.[60] Performance is a key consideration and will vary greatly among tools, based on factors such as unit weight, blade design, power type, pressure created, and functionability of the tool for the intended application. The performance aspect, while it can be interpreted in part using manufacturer's specifications for the equipment, is best evaluated through actual live product demonstrations.

The second category is the reliability not only of the tool itself but of the resources that support the tool, such as the manufacturer and vendors of the tool. Considerations include the warranty programs, service support, repair resources, and so on. Compatibility is a feature that addresses user functional characteristics, such as the ability to use the tool with the department's other tools and methods.

The information collected on currently available rescue tools is included in Table 6-1, Summary of Powered Rescue Tools for Cutting and Shearing. This table lists currently available cutting and shearing tools based on available manufacturers' information. Although the focus in Table

6-1 is on hydraulic powered equipment, other applicable cutting and shearing tools (e.g., hand tools) are not necessarily excluded.

Ideally, a general assessment of powered rescue tools would include estimates of how many tools exist in the current field inventory used by fire departments. It would be valuable information to know the numbers of tools based on their year of manufacture that are still in use. However, this requires a well-designed survey or similar approach, which is beyond the scope of resources available to this particular study.

Table 6-1: Summary of Powered Rescue Tools for Cutting and Shearing

Manf.	Series	Model	Max Cutting Force (lbs)	Max Cutter Opening (in)	NFPA 1936 Rating				
					A	B	C	D	E
Hurst Jaws of Life	5000 psi Cutters	JL-500	N/A	7.3	N/A	N/A	N/A	N/A	N/A
		MOC-Ultra	195,126	5.2	N/A	N/A	N/A	N/A	N/A
		JL-MOC	156,236	11.06	7	7	7	7	8
		JL-MOC II	152,870	7	7	9	6	7	8
		X-Tractor II	72,000	6	6	7	6	7	7
		X-Tractor S	94,000	9	6	7	6	7	7
	High Pressure (10,500psi) Cutters	S 700	N/A	7.28	8	9	8	9	9
		S 511	N/A	5.9	8	8	7	8	9
		S 510	169,000	7.2	8	9	7	8	9
		S 530	166,000	11.1	8	7	7	8	9
		S 330	114,500	8.9	7	7	7	8	8
		S 311	95,000	6	7	8	6	7	7
		S 120	41,140	2.04	4	3	2	3	3
		LS 330 FI	114,500	9	N/A	N/A	N/A	N/A	N/A
	5,000psi Combo Units	ML-16S II	60,000	9	N/A	N/A	N/A	N/A	N/A
		LKE 55	56,100	N/A	5	5	5	7	7
		X-Tractor C	81,381	10.5	N/A	N/A	N/A	N/A	N/A
		MOC Combi	120,272	12.23	N/A	N/A	N/A	N/A	N/A
	High Pressure (10,000psi) Combo Units	SC 550	120,300	16.9	7	9	7	9	9
		SC 350	85,430	N/A	6	7	7	7	7
		LKS 31	45,800	N/A	N/A	N/A	N/A	N/A	N/A
		LKE 55	56,100	N/A	5	5	5	7	7
		LKS 35 FI	94,000	N/A	N/A	N/A	N/A	N/A	N/A
	eDraulic Cutters	S 700E	N/A	7.1	N/A	N/A	N/A	N/A	N/A
		S 311E	N/A	6	N/A	N/A	N/A	N/A	N/A
TNT	5,500 psi Cutters	BFC-295 -LP	295,000	7.62	7	8	8	8	8
		SLC-28-LP	156,000	7.62	7	8	6	7	6
		SLC-24-LP	118,800	5	6	5	6	7	6
	High Pressure (10,500psi) Cutters	BFC-320	320,000	7.75	8	8	9	9	9
		SLC-29	269,000	7.62	7	8	7	8	8
		SLC-28	156,000	7.62	7	8	6	7	6
		SLC-27	118,800	7.62	6	5	6	7	6
		SLC-24	118,800	5	6	5	6	7	6
		CSC-40	35,000	1.5	N/A	N/A	N/A	N/A	N/A

Manf.	Series	Model	Max Cutting Force (lbs)	Max Cutter Opening (in)	NFPA 1936 Rating A	B	C	D	E
	5,500psi Combo Units	SLCC-20-LP	118,800	N/A	6	5	7	7	6
		SLCC-30-LP	118,800	N/A	6	5	7	7	6
	High Pressure (10,500psi) Combo Units	SLCC-20	118,800	N/A	6	5	7	7	6
		SLCC-30	118,800		6	5	7	7	6
Genesis Rescue Systems	Cutters (10,500psi)	C-270 T-Rex	157,000	11	7	8	7	8	9
		C-236 Cutter	236,250	8	8	9	8	9	9
		C-231Liberty	231,000	6.5	8	9	7	9	9
		All 9	369,000	7.1	9	9	9	9	9
		C-180Raptor	90,000	7	7	7	7	8	9
		C-165Patriot	144,000	6.4	8	6	6	7	9
		C-160 T-Rex	110,000	6.5	7	7	6	9	9
		C-130 Eagle	90,000	5.13	7	6	6	8	9
		C-50 Mini	31,000	1.8	4	3	2	4	3
		C-30 Mini	31,000	1.5	-	-	-	-	-
		Mass Transit	69,300	4.7	4	3	5	6	6
	Combo Tools (10,500psi)	16c Brute	112,000	16.7	7	9	7	9	9
		14c Vario	102,600	14.2	6	8	6	8	8
		13c Vario	58,000	13.2	6	7	6	8	7
	Electric Powered Cutters (10,000psi)	F-C180 Rapt	90,000	7	6	7	7	8	9
		F-C130	90,000	5.13	6	6	6	8	9
		F-13C Freed	58,000	13.2	6	7	6	8	7
Amkus Rescue Systems	High Pressure (10,500psi) Cutters	AMK-21A	110,000	5.2	7	4	5	6	8
		AMK-21	72,000	6	6	5	5	6	6
		AMK-22	200,807	5	7	6	7	7	8
		AMK-25	60,000	4.1	N/A	N/A	N/A	N/A	N/A
		AMK-25E	60,000	7	N/A	N/A	N/A	N/A	N/A
		AMK-25S	60,000	6.2	N/A	N/A	N/A	N/A	N/A
		AMK-25P	60,000	2.2	N/A	N/A	N/A	N/A	N/A
		Mini Max	15,000	1.56	N/A	N/A	N/A	N/A	N/A
	High Pressure (10,000psi) Combo Units	AMK-C15	57,000	7	N/A	N/A	N/A	N/A	N/A
		AMK-25C	57,000	7	N/A	N/A	N/A	N/A	N/A
Holmatro	High Pressure (10,500psi) Cutters	4055 NCT	228,855	8.6	8	7	7	8	8
		4050NCT	208,000	7.125	8	7	7	8	9
		4035NCT	57,320	5.66	6	2	6	5	6
		4035	67,600	9.375	6	7	6	7	6
		4031	67,600	12	6	7	5	7	5
		4020	63,400	5.25	6	3	5	6	5
		3010	56,920	5.75	N/A	N/A	N/A	N/A	N/A

Manf.	Series	Model	Max Cutting Force (lbs)	Max Cutter Opening (in)	NFPA 1936 Rating A	NFPA 1936 Rating B	NFPA 1936 Rating C	NFPA 1936 Rating D	NFPA 1936 Rating E
		CU4007Mini	49,458	2.1875	N/A	N/A	N/A	N/A	N/A
		3005 Mini	29,225	1.5	N/A	N/A	N/A	N/A	N/A
		SMC4006	43,500	1	N/A	N/A	N/A	N/A	N/A
	High Pressure (10,000psi) Combo Units	4150	67, 600	14.25	6	7	5	7	5
		3120	49,000	10.5	N/A	N/A	N/A	N/A	N/A
	Electric Powered (10,500psi)	BCT4120	49,000	10.5	N/A	N/A	N/A	N/A	N/A
		BCU 4010	56,920	N/A	N/A	N/A	N/A	N/A	N/A
	Hand Operated Tools	HMC8UMini	N/A	1.5	N/A	N/A	N/A	N/A	N/A
		HCU 3010	56,900	5.75	N/A	N/A	N/A	N/A	N/A
		HCT 3120	49,000	10.5	N/A	N/A	N/A	N/A	N/A
Weber-Hydraulic	High Pressure (10,500psi) Cutters	C-50 Mini	31,000						
			240,000						
		C-270 T-Rex	157,000						
		Mass Transit	69,300						
			65,000						
		C-160 T-Rex	110,000						
		C-165Patriot	144,000						
		All 9	369,000						
		C-236 Cutter	236,250						
	High Pressure (10,500psi) Combo Units	14c Vario	102,600						
		16c Brute	112,000						
	Hand Operated Tools		65,000						
ResQ Tec Zumro	5000 psi Cutters	G2 Cutter	76,409	7.0625	N/A	N/A	N/A	N/A	N/A
		G4 Cutter	109,669	7.5	N/A	N/A	N/A	N/A	N/A
	High Pressure (10,500psi) Cutters	G6 Cutter	285,600	8.3465	N/A	N/A	N/A	N/A	N/A
		G6s Cutter	285,600	11.1417	N/A	N/A	N/A	N/A	N/A
		G6W Cutter	246,400	7.9	N/A	N/A	N/A	N/A	N/A
	5,000psi Combo Units	FX2	76,409	7.6875	N/A	N/A	N/A	N/A	N/A
		FX4	109,669	12.625	N/A	N/A	N/A	N/A	N/A
		FX6	315,000	11.81	8	8	7	8	8
		Q1	41,440	2.36	N/A	N/A	N/A	N/A	N/A

7. Summary Observations

The landscape is changing for the fire service use of powered rescue tools. For motor vehicle extrication, the growing trend in recent years has been the use of advanced high-strength steels and composite materials. There are indications that this trend will continue.

The use of these materials is appearing in all new passenger vehicle makes and models due to new safety standards and marketplace incentives for fuel efficiency. This applies to all of today's passenger vehicles and is not a trend limited to new alternative-fueled vehicles such as those using propane, natural gas, electric, and hybrid propulsion.

Up until about 2006 through 2008, powered rescue tools could, in most cases, effectively accomplish their cutting or shearing tasks for vehicle extrication tasks. Since that time, the HSS and composite materials now being used in passenger motor vehicles are more than doubling the amount of cutting force required. The powered rescue tools available today are evolving to meet the significant challenges of the latest materials, but older existing tools that make up the bulk of the existing field inventory are understandably limited with these new materials.[61]

It is beyond the resources available to this study to compile an actual inventory of the powered rescue tools in question. However, this would be ideal information for the emergency response community. In 1994 the USFA funded a study of new technologies in vehicle extrication, including a limited survey of fire department use of powered rescue tools.[62] Although this information is now dated and thus of limited value, it provides an excellent model for designing a new survey as part of a follow-up study by others. This would provide useful information for how much of the existing field inventory of powered rescue tools will or will not be effective for modern passenger motor vehicles.

The following are the key summary observations that have been discussed throughout this report:

<u>Extrication Scenarios and Tasks</u>

- Extrication from passenger motor vehicles are the most likely scenario confronting emergency responders involving high-strength steels and composite materials that will challenge the cutting and shearing effectiveness of powered rescue tools.
- The fire service and other emergency responders need to identify alternative methods to work around extrication emergencies when the available powered rescue tools are unable to perform their intended use.
- Standard-setting bodies need to review and update the test methods currently used for evaluating powered rescue tools that cut and shear, so that they provide a meaningful distinction that informs end users of which tools will work with which types of modern vehicles.

High-Strength Alloys and Composite Materials

- Passenger motor vehicles since the 2006 through 2008 time frame have seen a noteworthy increase in the use of high-strength steels and composite materials, which can be expected to significantly challenge the effectiveness of powered rescue tools that cut and shear.
- Future use of high-strength steels and composite materials is expected to increase in future vehicles, thus, the probability that fire departments will encounter these materials also will increase.
- Practical, credible and consistent information is needed from vehicle manufacturers on the use of materials of concern to emergency responders.
- The types of steels and other materials should be categorized to simplify the materials of interest for vehicle extrication.
- Future use of new materials should be communicated on a regular basis between vehicle designers and the emergency response community.

Field Inventory of Powered Rescue Tools

- The current inventory of powered rescue tools is assumed to be extensive and three or more decades in age, based on equipment being resold from one department to another and ultimately remaining in service.
- Concern exists that a significant portion of the existing field inventory of powered rescue tools for cutting and shearing will not be effective on passenger motor vehicles manufactured later than the 2006 through 2008 time frame.
- Clarification is needed for emergency responders on the specific attributes of powered rescue tools that are important, based on sound, credibly-established technical information (i.e., not simply spun out of the marketplace).
- Consideration should be given to implementing a comprehensive survey that will realistically identify the quantity and quality of existing equipment in the field inventory of powered rescue tools.

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