Mississippi State University Center for Advanced Vehicular Systems Extension

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Mine-Resistant Ambush Protected Case Study: Navistar Defense's Plant in West Point, Mississippi

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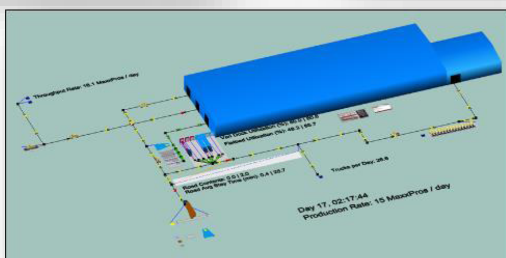

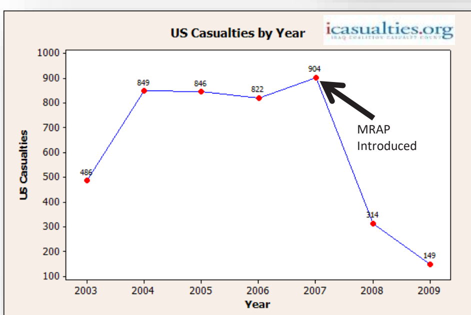

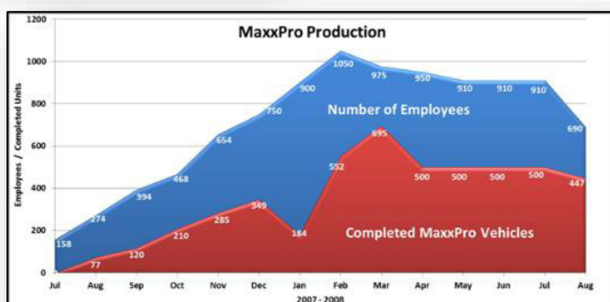

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NAVISTAR DEFENSE

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Abstract

During Operation Iraqi Freedom and Operation Enduring Freedom, the need for better protection of personnel and equipment traveling in military wheeled vehicles became critically apparent. In order to meet this need, the Department of Defense (DoD) authorized the expedited acquisition of the Mine Resistant Ambush Protected (MRAP) wheeled vehicle from multiple contractors. The acquisition program ultimately proved to be very successful in meeting mission requirements; however, the program costs were excessively high in relation to other typical, non-expedited DoD acquisition programs for a wheeled vehicle. This case study, related to the "manufacturability" of one version of the MRAP vehicle, the Navistar MaxxPro®, was initially published by the Mississippi State University Center for Advanced Vehicular Systems Extension in 2014. It thoroughly documents the history of this specific MRAP program and provides a list of lessons learned from the various experiences that occurred during program execution that may prove conducive for facilitating future DoD acquisition programs.

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Preface

This study was conducted for the Department of Defense (DoD) High Performance Computing Modernization Program (HPCMP) of the U.S. Army Engineer Research and Development Center (ERDC) under Project Number, “Developing High Performance Computing Prototype Software for Ground Vehicle Weapons Systems ERDC Contract Number W15QKN-13-9-0001.” The technical monitor was Dr. Simon R. Goerger.

The work was performed by the Center for Advance Vehicular Systems – Extension of Mississippi State University for the Institute for Systems Engineering Research, Computational Analysis Branch (ID-C), Computational Science and Engineering (CSED), U.S. Army Engineer Research and Development Center, Information Technology Laboratory (ERDC-ITL). At the time of publication, Elias Arredondo, P.E., was the Chief, Computational Analysis Branch; Dr. Jerrell R. Ballard, Jr., was the Chief, Computational Science and Engineering Division, CEERD-IE; and Dr. Simon R. Goerger was the ERDC Director of the Institute of Systems Engineering Research (ISER). The Deputy Director of ERDC-ITL was Patti S. Duett and Dr. Reed L. Mosher was the ITL Director.

COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Acronyms

BOM	Bill of Material
CARC	Chemical Agent Resistant Coating
CAVS-E	Center for Advanced Vehicular Systems Extension
COTS	Commercial Off the Shelf
DCMA	Defense Contracting Management Agency
DoD	Department of Defense
DPAS	Defense Priorities and Allocation System
EMCC	East Mississippi Community College
ERT	Emergency Response Team
FIR	Final Inspection Report
FMTV	Family of Medium Tactical Vehicles
FSR	Field Service Representative
GAP	Garland Assembly Plant (Navistar)
GTT	General Troop Transport
HMMWV	High Mobility Multi Wheeled Vehicle “Humvee”
HPU	Hours Per-Unit
IED	Improvised Explosive Device
ITAR	International Traffic in Arms Regulations
JUON	Joint Urgent Operational Need
KBR	Kellogg, Brown, and Root
M-ATV	MRAP All Terrain Vehicle
MCSC	Marine Corps Systems Command
MRAP	Mine Resistant Ambush Protected
MRP	Manufacturing Resource Planning
MSU	Mississippi State University
MV	Military Vehicle
NATO	North American Treaty Organization
OJT	On the Job Training
PPE	Personal Protective Equipment
QA	Quality Assurance
RCMP	Royal Canadian Mounted Police
RFP	Request For Proposal
SPAWAR	Space and Naval Warfare Systems Command
TACOM	(U. S. Army) Tactical Command

TSV	Tactical Support Vehicle
UA	Urgent Action
WAWF	Wide Area WorkFlow

1 Introduction

The purpose of this case study is to document the major activities, technologies, management practices, and lessons learned required to successfully launch Navistar Defense's armored vehicle plant in West Point, Mississippi. This report places particular emphasis on the launch of the MaxxPro® platform of Mine Resistant Ambush Protected (MRAP) vehicles. The approach used in this case study focuses on organizations and functions rather than particular people. This was done in order to place emphasis on the systems related issues involved in the case study.

It should be noted, the case study authors include several people who were intimately involved in the execution of the project. Since the goal of the case study is to reflect accurately the actual events, milestones, and technologies involved, multiple reviewers have been used.

2 Background

Navistar Defense, LLC. was established in 2004 as a division of Navistar Corporation for the manufacturing of armored and un-armored wheeled vehicles specifically designed for deployment in military applications. The potential customer base included:

- All branches of the U.S. Military,
- Military organizations of foreign allies (primarily the North American Treaty Organization [NATO]),
- Quasi-military organizations in the continental U.S. and Canada, (i.e., Royal Canadian Mounted Police [RCMP]),
- Non-NATO foreign governments engaged in support of U.S. Military operations in the Middle East,
- Private corporations providing contractual support to the U.S. Military worldwide.

Formerly known as International Truck and Engine Corporation, Navistar Corporation is a large manufacturer of medium, heavy, and severe duty trucks and engines. With manufacturing and distribution facilities in all 50 states and several foreign countries, Navistar Defense leveraged nearly 100 years of vehicle engineering expertise and manufacturing experience in the development of its trucks and engines.

The concept basis for military vehicle manufacture by Navistar Defense was a simple one. Navistar Defense used its standard commercial severe duty chassis with a standard Navistar heavy-duty diesel engine as the base military vehicle. Onto this chassis, Navistar Defense builds a unique armored body, capable of meeting, and exceeding the rapid mobility and personnel protection requirements of military forces operating in foreign combat theaters.

3 The Problem

The design, testing, manufacture, and delivery of military vehicles destined for combat theaters is frequently a lengthy and complex process, often requiring years of planning, engineering, prototype development, government approvals and testing. With the large numbers of U.S. military forces deployed in Middle Eastern countries, there became an urgent need for new types of armored vehicles to protect U.S. troops while accomplishing objectives in the field.

During the early period of the Middle East conflicts, most armored vehicles deployed were heavy-duty tracked vehicles such as the Bradley Fighting Vehicle and the M1 Abrams Tank. Smaller personnel carriers were limited to un-armored trucks and the High Mobility Multipurpose Wheeled Vehicle (HMMWV) (commonly known as the Humvee). The HMMWV, both armored and un-armored versions, was the most widely deployed vehicle in all combat areas. However, it offered little or no protection to the occupants from roadside bombs, Improvised Explosive Devices (IED)s, and in some instances, small arms fire. Casualties of HMMWV occupants were high and as a result, a rapid-deployment solution was formally designated by the U.S. Department of Defense (DoD) as an Urgent Action (UA) and the desired vehicle was named the MRAP.

“The MRAP program should be considered the highest priority Department of Defense acquisition program,” Secretary of Defense, Robert M. Gates (Memorandum, 2007). In response, Navistar Defense committed its entire organization to the development, manufacture, and fielding of the MaxxPro® armored tactical support vehicle.

4 After Kellogg, Brown, and Root (KBR) came MaxxPro®

Navistar's entry into manufacturing armored vehicles began in the autumn of 2005 with an order from Kellogg, Brown, and Root (KBR) for the manufacture of 600 Class 8 trucks (those used to power 40–53 foot commercial trailers) equipped with armored cabs, for deployment in support of U.S. military forces in Iraq. The total contract period for the design, testing, manufacture, and shipment of these vehicles was less than six months.

Figure 1. Plant before renovations.

Navistar Defense elected to open a manufacturing facility in West Point, Mississippi, to manufacture the KBR armored cab. The site chosen was an older heavy-manufacturing facility, previously used for the production of steam boilers (Figure 1).

Figure 2. Kellogg, Brown, and Root (KBR) cab assembly.

Extensive infrastructure renovations were required, including a completely new assembly line, paint booths, and tooling. The facility was established, equipped, and staffed in less than 60 days (Figure 2).

For the design and engineering of the armored cab, Navistar Defense partnered with Griffin Armor Incorporated, an established manufacturer of commercial armored vehicles, located in Byhalia, Mississippi.

The armored cab was a fully welded enclosure constructed of MIL-DTL-46100 high-hard armor plate. Additionally, transparent armor windshield and door glass were added and the unit was designed specifically to fit without modification onto a standard 5000 Series International (Navistar) chassis.

Figure 3. Kellogg, Brown, and Root (KBR) cabs shipping to Garland, Texas.

Navistar Defense further leveraged its Garland Assembly Plant (GAP), in Garland, Texas, to manufacture Navistar's standard commercial 5000 Series chassis on the GAP high-speed assembly line. The GAP is a medium and heavy truck manufacturing facility capable of producing 150 trucks per day. The 5000 Series chassis utilizes standardized commercial parts, a common well-established supply chain, and a standard high-speed assembly line process.

Armored truck cabs, manufactured at the West Point Assembly Plant, were shipped by truck (Figure 3) to the GAP assembly line, where they were installed fully trimmed onto the vehicle chassis in the same manner a commercial cab is installed (Figure 4).

Figure 4. Armored Kellogg, Brown, and Root (KBR) truck.

The manufacture and on-time delivery of the KBR armored cab validated the Navistar Defense plan to leverage standardized commercial processes and materials for the development of specialized military wheeled vehicles. The plan for development of the MaxxPro® MRAP was a direct successor to the KBR armored cab and followed many of the design and manufacturing techniques developed by the KBR program.

The innovations developed by Navistar during the design and manufacture of the MaxxPro® MRAP, can best be viewed in comparison with the MRAP designs of other manufacturers. While the designs and armored vehicles built by other manufacturers were mission capable and performed well in actual combat conditions, their designs were more conventional, requiring specialized manufacturing processes that were less flexible from an ongoing maintenance perspective.

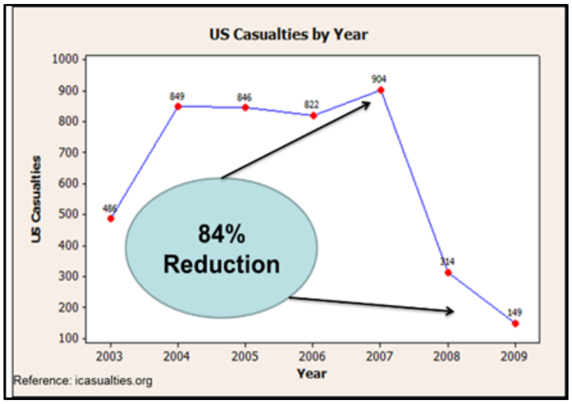
Navistar Defense chose a vehicle design that incorporated the following factors:

- Use of a standard commercial truck chassis without modification.
- Use of standard commercial parts readily available through an established supply chain.
- Use of existing commercial manufacturing facilities capable of high-speed manufacture of the base chassis.
- Design and manufacture of an armored body that used an integrated bolt and bond process that was superior in performance to welding.
- Leverage Navistar's world-wide distribution of standardized parts for immediate delivery in support of combat maintenance and repair.
- Employment of standardized, high-speed, moving assembly-line processes designed to maximize production and delivery to the customer in response to UA mandates.

The success of Navistar's plan is evidenced by the following:

- During initial blast testing at Aberdeen Proving Grounds in Aberdeen, Maryland, the MaxxPro® outperformed all other designs in blast survival ability and speed of battle damage repair. In one instance, the chassis of a MaxxPro® was destroyed during blast testing without significant injury to the test occupants of the vehicle. The vehicle's armored body was "reset" onto a new Navistar chassis less than 24 hours after blast testing.
- Navistar Defense has completed delivery of more than 8000 MaxxPro® vehicles since 2007.

Figure 5. Impact of Mine Resistant Ambush Protected (MRAP) on casualties.



- The deployment of MaxxPro® vehicles and other MRAP vehicles to the combat theaters contributed to the more than 80% reduction in battlefield casualties between 2007 and 2009 (Figure 5).
- Navistar Defense has designed, built, and delivered more than eight major variations of the MaxxPro® MRAP vehicle, all of which were delivered on time and with no delay in the manufacturing process.
- The MaxxPro® "formula" has been successfully deployed in the design and manufacture of similar armored vehicles, including the Tactical Support Vehicle (TSV) Husky (British Ministry of Defence), the RCMP Personnel Carrier, and variations of the MaxxPro® for a variety of NATO military forces.
- The MaxxPro® MRAP has been selected as a part of the enduring fleet for the U.S. DoD and as such, has become part of the permanent inventory of wheeled vehicle combat platforms for all branches of the military.
- As part of the enduring fleet and subsequent to troop withdrawal from combat in the Middle East, the MaxxPro® has been selected for an upgrade to the most current configuration and is staged for immediate future deployment as required.
- Secretary of the Navy, Donald C. Winter (Winter 2007) remarked during a visit to the West Point plant "the MRAP program was the largest industrial buildup since World War II."
- The success of the MaxxPro® program may best be described in the words of a senior official at the U.S. Military Buying Command, speaking of one variant of the MaxxPro® vehicle. "The MaxxPro® MRAP wrecker was the Army's fastest procured Joint Urgent Operational Need (JUON) since World War II. With the first vehicle rolling off the production line just 19 days after the contract award, the

wrecker helped save the lives of two soldiers who took an IED explosion in the field only two weeks after delivery" (NAVISTAR 2016).

5 Navistar Design Process

Navistar leadership determined early in the MRAP development process that Navistar Defense could effectively use commercial-off-the-shelf (COTS) products with specialized armor design. The product was expected to meet, or exceed, the requirements of vehicles to be used in a combat environment, could be manufactured and fielded expeditiously in response to UA military requirements, and could be maintained, modified, and upgraded in the field.

The Navistar severe duty chassis was selected as the base platform for the MaxxPro® family of armored vehicles. The severe duty chassis is a design widely used by Navistar in heavy-duty commercial operations and has a history of reliability and versatility. Supporting the manufacture of the severe duty chassis was a strong base of tier 1 and tier 2 suppliers that could provide high quality parts and subassemblies in large volumes.

Of equal importance, the Navistar Truck Engineering Center, located in Fort Wayne, Indiana, provided chassis design and staff engineers with many years of vehicle manufacturing experience, capable of making design modifications to accommodate a variety of vehicle body designs and load requirements. The challenge was to select an armored body design that exceeded the requirements of the MRAP program.

The selection of an armored body that strategically used the strengths of the severe duty commercial chassis involved a worldwide search. Navistar engineers evaluated the armored body designs of a variety of private companies in the Unites States, South Africa, and Israel. An early consideration was an armored body manufactured by a South African company whose product was designed to be mounted to a Mercedes-Benz chassis.

Ultimately, Navistar selected an armored-body-on-chassis design developed by Plasan, located in Kibbutz Sasa, in northern Israel. Plasan is a privately owned company whose designs and production lines are based on a job shop concept, which is a process-designated functional formation. Of special significance, the Plasan armored body design was already under development and testing, and was specifically designed to mount to a Navistar commercial chassis.

The final design process with Plasan was accomplished with a small engineering team consisting of Plasan design engineers, engineers from Mississippi State University, Griffin Armor, and Navistar Defense. During this process, the engineering team worked in the Kibbutz Sasa, in Israel, the Navistar engineering center in Fort Wayne, Indiana, and at the West Point Assembly Plant in West Point, Mississippi.

The early production plan involved manufacturing the MRAP chassis at Navistar's GAP and shipping the drivable chassis to the West Point Assembly Plant. Steel armored body components and transparent armor were assembled into kits in Israel and other locations; specialty items were preassembled at a variety of Tier 1 suppliers; and all components were shipped to the West Point Assembly Plant for final assembly.

6 Facility and Production System Design Issues

In early 2007 the situation in Iraq was critical, with high casualty rates for U.S. soldiers. The biggest problem was IED explosions and the armored vehicles used in theater not providing the desired level of protection. The MRAP program was launched during this environment and several contractors developed competing designs; the resulting prototype vehicles were tested at Aberdeen Proving Ground. The Navistar MaxxPro® performed exceptionally well and planning for possible full scale production began before production orders were released.

The facility and production system design had to proceed without knowing critical pieces of information such as:

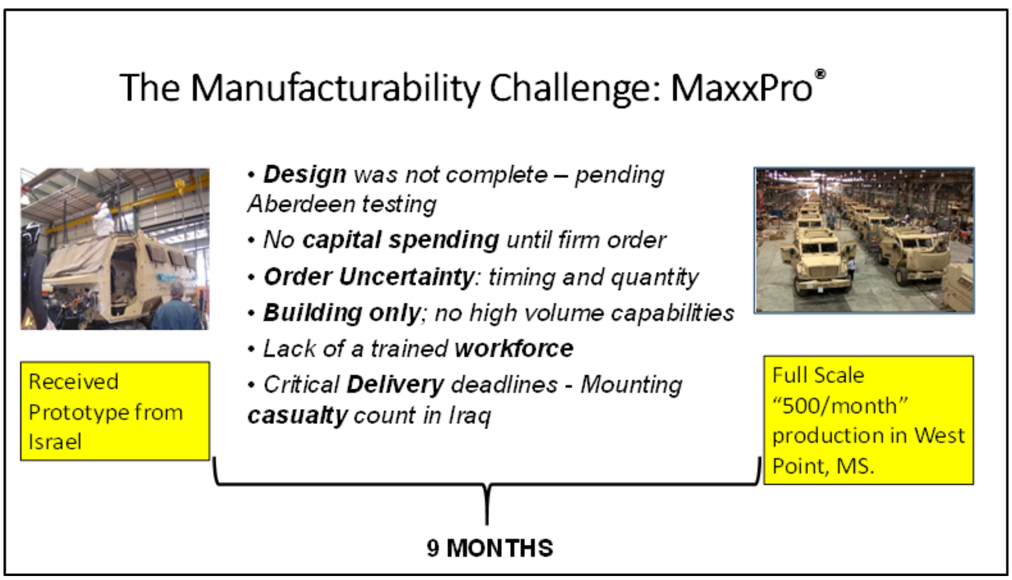
- Final vehicle design, only first generation prototypes existed.
- Capital spending was not allowed until orders were firm.
- Production order quantities for the program were not fully known.
- The targeted production rates were not known.
- The West Point facility was selected and it was thought to be sufficient, but no high volume production capability was present at the plant, only prototype capabilities existed.
- A workforce was available, but they had to be hired and trained in high volume automotive production.

Initial expectations were for an order between 200 and 1000 MRAP trucks with the indication that there would be more if early production was successful. As a result, plant master planning was accomplished across a wide range of possible production requirements. This included a plan for 250/month, 500/month, 750/month, and 900/month production. Staffing, equipment, and plant layout plans were developed in order for the plant to be successful at achieving these various production rates. One of the critical advanced planning technologies used was simulation modeling so that bottlenecks could be identified within each production scenario and the best alternative chosen.

It was determined that the 500/month production rate would be the target. As a result, detailed plans were put in motion to purchase the equipment, layout the equipment, and hire and train the workforce at an aggressive pace. Additionally, detailed planning of critical facility needs was launched. A detailed Gantt chart was developed to schedule the contactors and equipment installation. At one point in September 2007, the manufacturing and engineering team coordinated with 12 different on-site contractors during production.

Working under high levels of uncertainty (Figure 6. The manufacturing planning challenge), the manufacturing and engineering team made the initial decisions required for implementation of the production system at the West Point plant. This team, working on the prototype located at a Kibbutz in Israel, analyzed the vehicle from a manufacturability perspective. As a result, design recommendations were made, the design was modified, and detailed production plans were completed. This included workstation layout and assembly flow, and assigning component sub-assemblies within the supply chain. After this work was completed in Israel, the manufacturing plan was fully implemented and the West Point plant was in full scale production. Full scale production occurred nine months after the initial plans were completed in Israel (March 2007 through December 2007).

Figure 6. The manufacturing planning challenge.



7 Key Enablers to Production

For Navistar to produce the number of MRAP vehicles required by the DoD and ensure the quality of the products, numerous enablers were required. The most important of these enablers were:

7.1 Centralized purchasing authority

The purchase of MRAP vehicles was funded by an emergency war budget and procurement authority was centralized with the United States Marine Corps for all branches of the military. On 8 May 2007, Secretary of Defense Robert Gates stated "the acquisition of MRAPs is the Department of Defense's highest priority; so, for fiscal year 2007, $1.1 billion is earmarked for MRAP" (Erwin 2007). Brigadier General Michael Brogan was named commanding general of the Marine Corps Systems Command (MCSC) and was authorized to expedite procurement of MRAP vehicles for the Middle Eastern combat theaters. On 31 May 2007, the MCSC ordered 1200 MaxxPro®s. Subsequent contracts issued by the MCSC raised the total MaxxPro® order to more than 9000.

7.2 Local empowerment

Early in the MaxxPro® design and manufacturing process, local decision-making was encouraged so that plant personnel could quickly implement needed changes. Defense Contract Management Agency (DCMA) personnel were sent to the West Point manufacturing facility and worked cooperatively with plant personnel. A Change Control Board, consisting of both Navistar personnel and government representatives met regularly at the plant and was the final authority on process and vehicle configuration.

7.3 Defense Priorities and Allocations System (DPAS)

The Defense Priorities and Allocations System (DPAS) is a federal program designed to assure the timely availability of industrial resources to support rapid industrial response in a national emergency. The MRAP procurement program was considered a national emergency, which resulted in its being assigned a priority rating. This gave Navistar priority in purchasing raw material and manufactured parts for all of its suppliers. Using this priority procurement designation, Navistar was able to manufacture and deliver finished vehicles three months after contract

award and was able to sustain a production of more than 500 MaxxPro®
vehicles each month thereafter.

8 Workforce Development

During peak production of the MaxxPro® vehicle, the West Point Assembly Plant employed more than 1000 assembly line workers, with an additional 200 personnel in direct support roles. The majority of these workers had no previous experience in a vehicle manufacturing environment and fewer had a work history associated with an automotive assembly line process. However, Navistar Defense was able to hire, train, and effectively utilize this large workforce very quickly (i.e., largely within six months). This agile approach may serve well as a model startup for the heavy duty military vehicle industry.

8.1 Industry partnerships

From the beginning of the West Point Assembly Plant, Navistar Defense developed key partnerships with a number of manufacturing, technical, and academic organizations. The foundations of these partnerships began with the development and manufacture of the KBR armored cab in late 2005. The initial partnership was with Griffin Armor Incorporated. With their headquarters located in Byhalia, Mississippi, Griffin Armor had a history of design and manufacture of armored vehicles, primarily for commercial uses. The primary role of Griffin Armor was to provide engineering design for the KBR Cab, manage the daily operations of the West Point Assembly Plant, and be a key partner in the development of future armored vehicles for military applications.

Another key partner with Navistar Defense was the Center for Advanced Vehicular Systems Extension (CAVS-E) at Mississippi State University. CAVS-E provided strategic planning and engineering guidance for the development, layout, and manufacturing processes of the West Point Assembly Plant. As the Navistar Defense business expanded and matured, CAVS-E personnel were instrumental in product design, workforce training and development, facility improvements, tooling design, and procurement. Their work laid the foundations for future product design and innovative manufacturing techniques.

As discussed before, a key partner with Navistar Defense was Plasan. This Israeli firm is a leader in armored vehicle design. Working closely with the CAVS-E team and Navistar, Plasan was instrumental in providing a ballistic de-sign for the MRAP program, sourcing and producing armor kits for assembly in West Point, and migrating the design into the commercial material supply base.

8.2 Labor pool

The West Point Assembly Plant is located in an area of central Mississippi known locally as the Golden Triangle and is composed of West Point, Starkville, and Columbus. The area historically supports a strong industrial base, and is largely non-union. The area is home to several community colleges and major universities, including East Mississippi Community College (EMCC), and Mississippi State University. Navistar Defense successfully used many of these factors in developing a work force at the West Point Assembly Plant. At the start of the KBR Armored Cab program, Navistar employed a variety of skills, including welders, painters, assembly line workers, electricians, material handlers, and a variety of office personnel. After the KBR program was completed, Navistar retained all supervisors and a number of key workers, collectively named the "Core 88." This Core 88 preserved all of the skill sets developed during the KBR program as Navistar Defense transitioned into the MRAP program.

Subsequent to the startup of the West Point Assembly Plant's KBR program, a large meat packing plant in West Point closed, resulting in the loss of approximately 1800 jobs. Coincidently, this plants closing coincided with the ramp-up of the Navistar Defense West Point Assembly Plant for the MaxxPro® program. Therefore, many of those unemployed workers from the meat packing plant were immediately available. Most of the unemployed workers had many years of experience in the workplace. Although their skill sets were different from those needed in a vehicle manufacturing plant, the workers did possess certain basic skills that proved a good foundation for the Navistar Defense requirements. For many of the workers, the transition in job skills was smooth due to an accelerated training schedule described in the next section.

8.3 Skill set development

Navistar Defense worked closely with the CAVS-E staff and EMCC staff to develop a training program for the West Point plant. This included 40 hours of training for each employee and involved both classroom training and on-the-job training. Specific job skills, such as welding, utilized a training partnership with EMCC. Through its affiliation within a larger consortium of local community colleges, EMCC provided instructors for all the employees including the following:

- MRAP program overview.
- Detailed description of the MaxxPro® vehicle.
- Plant layout and tour.
- Brief introduction to lean manufacturing.
- Hands-on training with torque tools using practice boards at the Training Center.
- Using the team leaders, detailed training on actual assigned workstations using work instructions.

CAVS-E engineering developed, implemented and refined formal work processes, assembly line layouts, specific tooling applications, written work instructions, and other lean manufacturing applications.

The final component in the development of skill sets at the West Point plant was the use of experienced manufacturing and product engineering personnel from a variety of locations. Engineering staff from the Navistar Truck Engineering Center in Fort Wayne, Indiana, Plasan located in Israel, CAVS-E engineering staff, and Griffin Armor engineers and management personnel, provided temporary full-time support for ongoing production. This core of professionals provided the expertise, guidance, and expertise in assembly line processes required to train an inexperienced workforce within a short period.

An intangible factor that played a role in workforce training and production quality at the West Point plant was worker awareness that American lives were saved when production quality was high. The workers at the West Point plant quickly realized that defects in workmanship or delays in production could have deadly consequences for the young men and women those vehicles were designed to protect. As a result, employee morale was extremely high, acceptable quality levels were achieved (i.e., approximately 99% first pass of final vehicle inspection) and absenteeism and turnover were very low.

Another important training task was to develop Field Service Representatives (FSR)s which were Navistar contractors. The initial commitment was to provide an FSR for every ten MRAP vehicles. This was a six to eight week program training over 300 FSRs. The content of the training included a thorough knowledge of the automotive systems (engine, transmission, door operation, pumps and cylinders). This training was developed and taught by Navistar master technicians and mechanics. EMCC eventually provided an off-campus training center to facilitate this effort.

9 Supply Chain

A key ingredient in Navistar Defense's success with MaxxPro® production was the supply chain. With more than 4000 individual parts for the chassis and an additional 3000 parts for the armored body, the timely and accurate procurement of vehicle components was essential. With a large bill of material (BOM) associated with the vehicles, it was critical to source and purchase the necessary parts, and receive them at the manufacturing location when needed. Due to the compressed timeframe, the major supply chain strategy was to leverage existing Navistar supply chain relationships. Where there were gaps in the existing supply chain (e.g., armor), new suppliers were qualified as quickly as possible. Qualification involved sending quality management and acquisition staff to visit suppliers and develop the relationship from both a business and quality perspective. Dimensional inspection activities were performed by the vendor and not the plant. These parts were primarily supplied directly to the line at the West Point plant.

Navistar's commercial truck manufacturing experience, and the decision to predominantly utilize COTS parts, were key concepts in the Navistar plan for MaxxPro®. Since MaxxPro® utilized two Navistar manufacturing plants, parts procurement took two separate, but parallel, paths (i.e., West Point and GAP).

The majority of supplied parts were single sourced, this was due to both time and resource limitations. Also, strategic relationships and unique vendor capabilities played a role in these decisions (e.g., due to press brake tonnage requirements and dimensional tolerances of the V-Hull, very few suppliers were capable of providing this critical component). Parts and components were primarily sourced domestically, though some items were obtained from non-domestic suppliers (e.g., an Israeli vendor initially supplied the armored body).

9.1 Garland Assembly Plant (GAP)

The production of the base MaxxPro® chassis at the GAP followed established material acquisition processes already in place for commercial trucks. Utilizing a manufacturing resource planning, (MRP) software system referred to as BAAN (Akashmavle 2011), the Navistar Engineering Center released parts designs into the MRP system as standard components. These engineering releases were grouped into "feature codes" which assured a high standardization of parts across the fleet and simplified procurement with suppliers. At the GAP, truck builds were scheduled or "line set" well in advance of the actual build dates. These line set dates were programmed into the BAAN MRP system, which generated the required purchase orders for the required parts from established suppliers. Parts were received on a just-in-time basis and distributed to the assembly line in line-set order for individual truck builds.

9.2 West Point assembly plant

The production of the MaxxPro® armored body at the West Point plant utilized a similar, but separate, material acquisition process. Utilizing an MRP software system called Expandable, the armored body BOM was loaded into an expandable, at the part number level, and purchase orders were generated to Tier 1 suppliers based on the planned build schedule of the assembly plant. Parts were primarily received on a just-in-time basis and distributed to the assembly line as needed.

9.2.1 Tier 1 supplier quality

Navistar Defense maintained a rigorous parts quality assurance program, both within the assembly plants and on-site with Tier 1 suppliers. Quality assurance inspectors worked directly with suppliers at their manufacturing locations to ensure product quality on a continuing basis. Parts received by Navistar were inspected for quality once the parts arrived at the manufacturing plant and prior to distribution of the part to the assembly line. These inspections minimized assembly line stoppages and/or slowdowns due to material issues. Parts quality is a high priority of the U.S. Government, whose representatives worked closely with Navistar quality personnel in the inspection and approval of supplier parts and manufacturing processes.

9.2.2 DX-Procurement authority

As a primary contractor for the DoD MRAP program, Navistar Defense, and its Tier 1 suppliers were authorized to apply a DX Rating to all orders for parts and raw materials used for the MRAP. Under DPAS, the DX rating gives priority purchase authority for the acquisition of items required to support a wartime effort during a national emergency. While the DX rating does not require lower pricing, it does require Tier 1 and Tier 2 suppliers to expedite orders for parts and raw material in a priority manner ahead of all other orders for the same or similar material. The DX rating was of critical importance to Navistar Defense in meeting the contract delivery dates for MaxxPro® vehicles established by the MCSC.

9.2.3 Supply chain flexibility

The quality of the Tier 1 suppliers selected by Navistar Defense for the MaxxPro® program was evidenced by the flexibility and adaptability of the various suppliers to the changing configurations and variants of the MaxxPro® vehicle. To date, there have been eight major reconfigurations of the MaxxPro®, with the most significant being the change from a solid-axle suspension to an independent suspension. This change was made without major delay in the full production line and did not affect finished vehicle delivery dates. During MRAP® production, hundreds of configuration changes and upgrades were made, with most being implemented online and with no delay in production.

The supply chain provided great support for the MaxxPro® program. It provided readily available spare parts, field upgrade and repair kits, and configuration modification parts and kits. The spare part programs were essential to the support of fielded vehicles, especially when deployed thousands of miles away.

There are current programs underway that reset and refurbish Maxx-Pro® vehicles returned to the U.S. to become part of the U.S. Army's Enduring Fleet. The supply chain continues to respond efficiently, thereby ensuring quality support to the MaxxPro® program.

9.2.4 Supply chain management

While the supply chain for the MaxxPro® chassis has remained virtually unchanged, the location for building the chassis has changed. Initially the chassis was made at a Navistar facility in Garland, Texas. However, with the closing of that facility, Navistar relocated chassis production to its plant in Springfield, Ohio which has the capacity to support higher production volumes (e.g., 500/month). In addition, the West Point Assembly Plant also has chassis-build capability, but only for low production volumes. The supply chain for the armored body components has evolved since inception of the MRAP program. Initially, most armored components of the MaxxPro® were fabricated and pre-assembled into subsystems by Plasan and other Tier 1 suppliers. These subassemblies were shipped to the West Point plant for final assembly onto the chassis.

As the MRAP program gathered momentum and the demand for finished vehicles increased, Plasan and other small suppliers could not meet the delivery schedules for component kits in the timeframe specified. In addition, the cost of shipping heavy armored components from Israel and other countries was a large expense. In response, Navistar was able to source all armored components and most of the transparent armor components with suppliers in the United States. This change served to help retain U.S. jobs, provide support for U.S. businesses and industry, and lowered Navistar's costs.

As the skill sets developed at the West Point facility, the need for outside procurement of many subassemblies gave way to onsite subassembly of component parts and final assembly at the West Point facility. Currently, more than 90% of all MaxxPro® parts and subassemblies are fabricated in the United States.

9.2.5 Electronic payment system

A key enabler of the high production rate and quick response to engineering changes was the DoD electronic payment system Wide Area Workflow (WAWF). The WAWF application is a secure web-based system that enables electronic submission of invoices, government inspection, and acceptance documents in order to enable a paperless acquisition process. This system enabled Navistar to be paid quickly when the trucks were accepted by DCMA, and subsequently, gave Navistar the cash flow needed to pay employees and purchase needed materials and components.

10 Development of the West Point Assembly Plant

10.1 Establishment of the Brownfield site

The West Point Assembly Plant is located on 80 acres in the West Point, Mississippi, North Industrial Park. The principal buildings were constructed in the mid–1950s and formerly occupied by a heavy steam boiler manufacturer. The manufacturing facilities were expanded and modernized in the mid–1990s and the original 200,000 square foot assembly building, housing Bays 1, 2, 3, and 4, were used only for storage.

In autumn 2005, Navistar Defense was awarded the KBR armored cab contract which required the temporary stand-up of a new Brownfield site, separate from Navistar's existing commercial manufacturing facilities. The boiler manufacturing facility was available and was chosen by Navistar in partnership with Griffin Armor Inc. The original intent was to utilize only two bays in the old boiler manufacturing building for the KBR project. Since the KBR contract was for a specific single order of armored cabs, the expectation was that the boiler manufacturing site would be utilized by Navistar for only a few months. "In and out in less than six months" was the accepted plan of action.

Figure 7. Brownfield site clean-up.

The development of the Brownfield site required significant efforts to meet operational requirements in less than a two month period (Figure 7). In addition to extensive site and interior building cleanup, many pieces of heavy machinery had to be disconnected and relocated to other locations. Extensive repair to electrical systems, plumbing, HVAC, natural gas and compressed air systems, and physical facilities were required after machinery removal (Figure 8). Additionally, the administrative office area required restoration and the collection/disposal of hazardous waste material left by the previous occupants had to be completed.

Figure 8. Bay 1, machinery removal.

For the cleanup and restoration effort, Navistar contracted a local firm with several years of experience in factory cleanup and maintenance. Working 12 to 14 hours a day, seven days a week, the Brownfield cleanup work was completed in 31 days.

Simultaneous to the site and building cleanup, the CAVS-E engineering staff prepared plans for the assembly line setup, developing specifications for the required tooling and equipment to accomplish the cab build processes. Since the KBR cab was to be fabricated and assembled at the West Point plant, a variety of processes and associated equipment were needed. Since the plan was to use a moving cab trim assembly line, workstation layout and specific work instructions were required to be an integral part of the master manufacturing plan.

Figure 9. Kellogg, Brown, and Root (KBR) paint booth.

Working with the armored cab design engineers and shop floor supervisors, the CAVS-E engineers developed, and executed, a master layout plan that included the following major workstations:

- Parts fit-up and tack weld.
- Intermediate weld.
- Final weld.
- Sand Blast.
- Paint.
- Cab Trim and Assembly.
- Electrical test and inspection.
- Packaging and shipping.

Each of the workshops consisted of multiple workstations, each requiring individual work instructions and specialized tooling, fixtures, equipment, and processes. While some workshop layouts and equipment were industry standard, such as the paint and cure workstation, (Figure 9) most workstations required specially designed fixtures and tooling. CAVS-E engineering, working with shop floor personnel and fabrication contractors, designed and supervised the build of dozens of weld fixtures, welded component handling devices, specially designed transfer dollies, forklift adapters, and other specialty tooling.

Figure 10. Kellogg, Brown, and Root (KBR) final line.

In addition, CAVS-E engineering designed and supervised the construction of a *cab trim and assembly moving* assembly line that proved to be an effective and innovative approach to KBR Cab production. The final assembly line (Figure 10), was located inside Bay 1 and was fully equipped with electrical, compressed air, and high-intensity lighting for cab interior trim and assembly.

Each workstation on the assembly line installed a specific feature of the armored cab interior. The armored cab moved along the assembly line while workers remained stationary at their workstations and performed the same procedures on each article. The assembly line process increased worker efficiency and product quality while simultaneously producing a consistent flow of production among all workstations.

10.2 Site development for the MaxxPro®

While a significant portion of the Brownfield site development was accomplished in preparation for the KBR armored cab production, more site development was required for the MRAP production. Most of the facility upgrades and improvements were carried forward into the facility development for MaxxPro® and other vehicle production models. As a result, the facility design was flexible and robust, key aspects of resiliency.

Figure 11. Navistar West Point before MaxxPro®.

Major upgrades to Navistar's West Point plant began in June 2007, immediately after the initial order for 1500 MaxxPro® vehicles was received from the MCSC.

The MaxxPro® program required major changes to the site configuration as originally developed in the mid-1950s. The site layout shown in the aerial photograph, Figure 11, shows the original configuration as used by Navistar during the KBR program.

As configured, Navistar primarily used the main assembly building, a small detached office building, and an employee parking lot. A ten acre forested area along the west side of the property served as a buffer between the industrial site and an adjoining residential area.

Figure 12. West Point Plant during MaxxPro® build.

The aerial photograph, Figure 12, shows some of the significant modifications that were made to the site. As labeled, these additions are described in sections 10.2.1–10.2.7.

10.2.1 Vehicle staging area

A portion of the ten acre buffer zone on the west side of the site was cleared of trees and a six acre vehicle parking and staging area was developed (Figure 13). A forested buffer zone was retained, separating the plant area from the adjoining residential zones. This buffer provided effective mitigation of industrial noises and dust associated with the manufacturing operations and also retained residential zone aesthetics.

Figure 13. Staging area.

With MaxxPro® vehicles weighing in excess of 50,000 pounds, the staging area required specialty subsoil and surface preparation. A local engineering firm provided successful civil engineering design and construction oversight for the project, which was completed in 60 days. In addition to the six acre staging area, the project also included the construction of a new roadway connection from the interior of the plant to 6th Street on the west side of the property. This access road was used exclusively for egress and ingress of MaxxPro® vehicles during off-site road tests.

10.2.2 Chassis-prep building

As previously noted, the MaxxPro® chassis was manufactured at the Navistar GAP and shipped to the West Point facility for installation of the armored body. These chassis were transported from GAP to West Point in a three-chassis piggy-back configuration (Figure 15). This method of transportation minimized costs, but required un-decking upon arrival at the West Point facility.

The Chassis-Prep building facilitated the quick and safe un-decking of arriving chassis (Figure 14). The 12,000 square foot building featured four parallel 120 ft. drive-through bays equipped with a high-bay, 10 ton overhead cranes, and 16 ft. electric overhead doors. During peak production periods, this facility had the capacity to un-deck more than 50 chassis per day.

Figure 14. Chassis prep building.

Figure 15. Decked chassis.

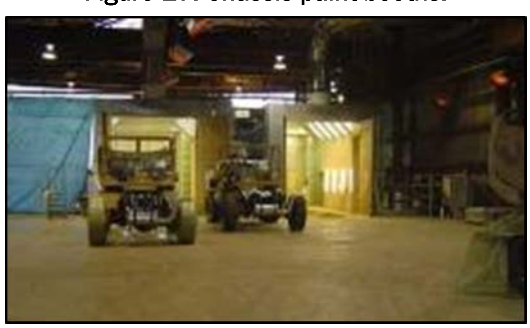
10.2.3 Test and Tune building

The MRAP program required special inspection and ownership transfer procedures that were unique to the UA vehicles and the critical need to deploy these vehicles as quickly as possible. To maximize the inspection and ownership transfer process, Navistar Defense constructed a separate test and tune building to house these activities at the West Point plant (Figure 16).

Figure 16. Test and tune building.

The building was constructed with 16 high-bay workstations, each with 16 ft. overhead doors with drive-through access to the six acre staging area for MaxxPro® trucks. In this building, finished vehicles were presented to the government inspectors representing the DCMA for final inspection and acceptance. The DCMA inspectors worked on-site with Navistar mechanics and technicians subjecting each vehicle to a technical inspection in accordance with the detailed Final Inspection Report (FIR). The FIR included an inspection and sign-off for every major mechanical, electrical, and hydraulic subsystem and a rigorous inspection of the armor components. In a final test, DCMA inspectors and certified MaxxPro® operators took each vehicle on an 18 mile road test evaluating all MRAP systems. After the road test, the vehicle returned to the test and tune building, where the DCMA inspectors issued final approval and the electronic transfer of ownership from Navistar to the U.S. Government. Accepted vehicles were immediately staged for outbound shipment.

Figure 17. Chassis paint booths.



10.2.4 Chassis paint facility

All MRAP vehicles required the application of Chemical Agent Resistant Coating (CARC) paint to all surfaces except tires, hoses, glass, and engine components. CARC paint differs in a number of ways from conventional automotive paint, and dedicated equipment and special procedures are required for application. The GAP was not able to incorporate CARC paint into the MaxxPro® chassis assembly process. Therefore, each chassis shipped to West Point had only standard automotive primer applied. As a result, the facility development for West Point required the installation of facilities and equipment for application of CARC paint to each chassis (Figure 17). To accommodate the chassis paint operation, the east ends of Bays 1 and 2 were extended and enclosed to house chassis paint booths, curing ovens, air compressor equipment, and CARC paint mixing and storage areas (Figure 18).

Figure 18. Chassis Chemical Agent Resistant Coating (CARC) paint.

CAVS-E engineers, working closely with equipment suppliers and local contractors, developed plans and specifications for tooling and equipment specially modified to facilitate the CARC paint application. Simultaneous to the facility modifications and equipment acquisitions, CAVS-E engineers developed detailed processes and work instructions designed to produce a CARC paint workflow that supported production line requirements.

Each chassis paint booth was a fully enclosed, filtered, downdraft design, and each booth included an in-ground pit to accommodate CARC painting of the underside of the chassis. Operators working in the paint booths wore full-protection paint suits and helmets with self-contained air supplies.

10.2.5 Truck docks

Concurrent to the development of other phases of the site, Navistar Defense constructed a below-ground level truck loading and unloading dock on the west end of Bay 1 (Figure 19). The production of MaxxPro®

required high volumes of raw material and parts receipt, processing, and warehousing to occur quickly and efficiently. Because of the 50 trucks per day production schedule, the just-in-time receipt of all material was closely monitored. The truck docks at the West Point plant were designed to allow for the simultaneous unloading of four van-type trucks and two flat-bed trucks. This was consistent with the objective of incorporating resiliency in the facility design. The docks were constructed in such a manner as to allow forklifts to drive directly into van trailers to unload palletized material and parts. Automatic levelers installed on the docks assured proper height alignment for a variety of trailers being used.

Figure 19. Truck docks under construction (left) and completed (right).

The dock area was equipped with an automatic below-ground water collection and pumping system that kept the dock area free of water. Safety lights, alarms, automatic controls, and other equipment were installed to make the dock area a state-of-the-art operation.

Figure 20. Main gate security house.

10.2.6 Security upgrades

Major upgrades to the plant site were required to meet government requirements as a military defense facility. The MaxxPro® is covered under International Traffic in Arms Regulations (ITAR), administered by the U.S. Department of State Directorate of Defense Trade Controls. Among other requirements, ITAR regulations require that access be limited to U.S. citizens. The entire West Point Assembly Plant site was required to be secured, with controlled access points and around-the-clock security (Figure 20). Security upgrades included over two miles of 6 ft. high security fencing, black-out curtains on certain fenced areas, badge controlled employee turnstiles, security guard houses at all entrances, electronic gates, badge controlled door entry to all buildings, security cameras, roving security patrols, and electronic on-site location devices on all operational MaxxPro® vehicles.

Figure 21. Administrative headquarters.

10.2.1 Administrative workplace upgrades

Extensive upgrades were made to several buildings that house non-production personnel. The four main buildings requiring upgrade were the administrative headquarters building, the human resources and security building, the Engineering and Materials Management Building, and the DCMA headquarters building (Figures 21 and 22).

Figure 22. Defense Contract Management Agency (DCMA) office building.

As most of these buildings had been unused by the former occupants for a number of years, extensive upgrades were required to electrical systems, HVAC systems, plumbing and restrooms, flooring, ceilings, walls, lighting, and communications systems.

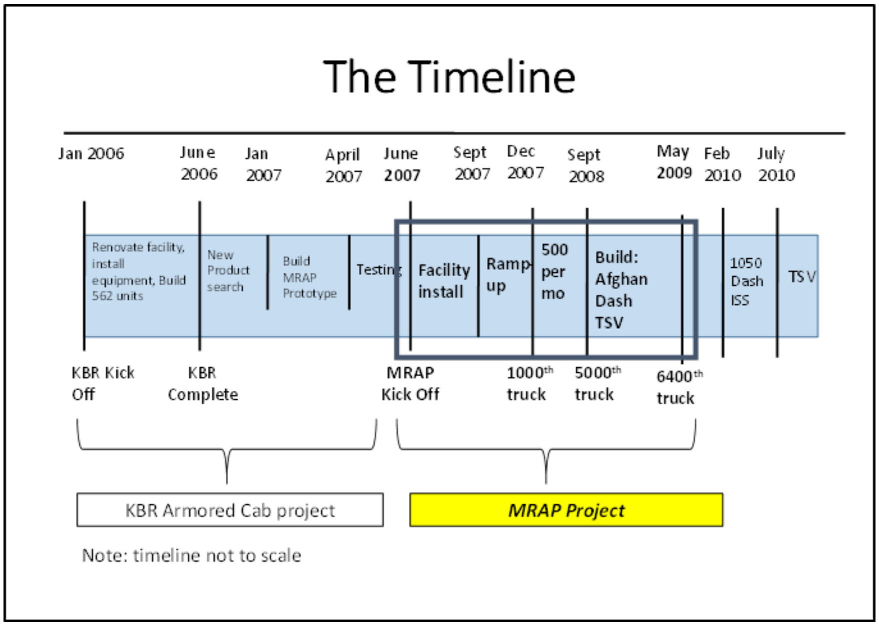
A modern plant-wide telephone system was installed combining internal and external communications minimizing operating costs by reducing external communication lines. Stand-alone computer servers that were firewalled from outside connections preserved proprietary. Selected systems were linked to the West Point Facility directly from Navistar networks.

Figure 23. Main conference room.

Considerable investment was made in on-site conference and classroom facilities (Figure 23). Each of these areas was equipped with state-of-the-art presentation and communications equipment, including audio/video conferencing equipment, and on-site and off-site wireless computer network connections. Throughout the MRAP program, these working conference centers were important tools in managing daily communications, both internally within Navistar and with outside agencies such as DCMA and other government agencies. These tools were critical for response to the often fluid and urgent requirements of the MRAP program, and were important factors in the reduction of travel and training costs, minimizing production delays, resolving problems, and expediting scarce material and vehicle components.

In combination, all of the aforementioned West Point facility upgrades contributed to the enhancement of Navistar's capability to meet the aggressive timeline for KBR and MRAP production as shown in Figure 24. Ultimately, Navistar did accomplish that contractual objective.

Figure 24. Timeline for KBR and MRAP implementations.



10.3 Development of the MaxxPro® assembly line

10.3.1 Assembly line design

This was another key enabler for this project. Typically military vehicles are produced using a stall-build production system due to the relatively low volume and high flexibility of requirements. A stall-build production approach involves a unique location for each vehicle to be assembled, requiring all of the parts and operators to flow to the vehicle-station. This involves very long cycle times (e.g., days), very careful staging, and sequencing of incoming materials and operators. The stall-build approach often works well for very low volume, high variety products (e.g., 30–40 per month), but it is very inefficient at higher production levels (e.g., 500 per month). Since relatively high volume production was expected, due to the pressing need of getting vehicles quickly to the field, the stall-build concept was eliminated and an assembly line concept was chosen by the Navistar production team. An assembly line, or flow line approach involves moving the vehicle to prearranged stations with materials, tooling, and operators focused on specific tasks at specific locations. This provided several advantages including scalability to higher production rates, shorter learning curves for employees, and the more effective use of less skilled workers. This key component enabled the plant to produce

500 MRAP's per month while other MRAP manufacturers were producing on the order of 50–100 per month.

While the KBR Cab was fully fabricated and welded during the assembly process, the MaxxPro® was designed to be a bolt and bond process. All welded components of the MaxxPro® were sub-assembled at Tier 1 suppliers and shipped to the West Point site ready to be bolted and bonded onto the MaxxPro® chassis. Not only were the assembly processes different, they were also more standardized; the tooling and assembly line equipment was designed, and installed, to support a high-speed assembly process. Navistar used an assembly line layout designed by CAVS-E engineering to include task-specific tooling, overhead crane systems, in-floor conveyor systems, and custom designed subassembly areas. Three distinct assembly lines and several subassembly lines were set up in Bays 1, 2, and 3 of the main assembly building.

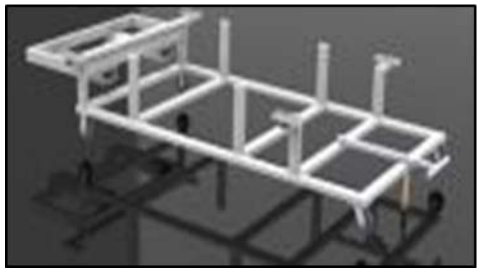
10.3.2 Bay 1 assembly line

Each of the three primary assembly line bays measured 675 ft. in length and 75 ft. in width, with a ceiling height in excess of 50 ft. Each bay was divided by two "cross-towns," roughly 200 ft. from either end. These enabled vehicular traffic to cross perpendicular to the work flow, from bay to bay. Bay 1 was a multipurpose space, with the western one-third of the bay used for the shipping and receiving of parts. The eastern two-thirds of bay 1 was used during peak MRAP production as a chassis preparation area. Incoming chassis from the GAP were inspected and MRAP components installed prior to being inducted into the main line for final vehicle assembly. During subsequent build programs, Bay 1 was the primary assembly line for assembly of the U.S. Army Tactical Command (TACOM) non-armored troop carrier vehicles and other products produced at the West Point facility simultaneous to the MaxxPro® production.

Figure 25. Roof subassembly.

Bay 1 was completely reconfigured from the old KBR armored cab layout and was fully equipped during the early MaxxPro® ramp-up. Major installations included light-rail overhead crane systems, a single-line in-floor conveyor system, high-intensity lighting, multiple-voltage electrical outlets, and high-speed internet connections.

Figure 26. Roof cart.



Bay 1 also housed several subassembly areas for major components, the most important of which was the MaxxPro® roof subassembly (Figure 25). The area located between Bays 1 and 2 were used for special rolling roof carts (Figure 26). Designed by CAVS-E engineers and fabricated locally, roof subassemblies were completed while inverted on the carts, maximizing worker efficiency and significantly reduced assembly time. Once completed, the roof subassemblies were moved into Bay 2 while still on the rolling cart where they were incorporated into the main assembly line process of the vehicle.

10.3.3 Bay 2 assembly line

The Bay 2 assembly line was considered by Navistar Defense as the most important series of processing and assembly stations in the West Point Assembly Plant. Bay 2 was designed to house two parallel assembly lines with nine workstations each and was the location of the majority of armored components installed on the vehicle chassis. The entire line was fully equipped with electrical, compressed air, natural gas, lighting, communications, and other heavy manufacturing support services.

Figure 27. Bay 2, west.

The western third of Bay 2 was equipped with two overhead gantry crane systems, each with hook heights in excess of 25 ft., each capable of lifting up to four tons (Figure 27). The area contained six subassembly areas and six main-line assembly workstations and was where the MaxxPro® assembly process started. The MaxxPro® chassis, which were previously CARC painted and prepped, were placed in the Bay 2 assembly line. CAVS-E engineers, working closely with Navistar engineers and operations staff, used a combination of existing and new equipment completed the construction of this area in 4 weeks.

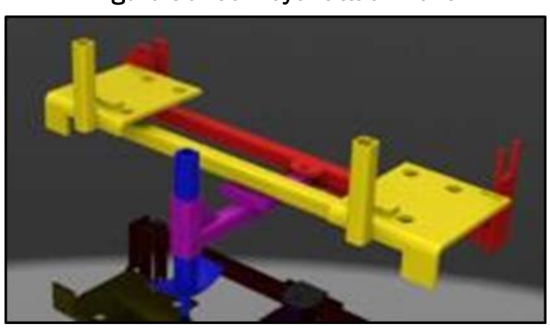
Figure 28. Bay 2 assembly line.

The Bay 2 assembly area between the east and west cross-towns, was designed using parallel assembly lines, each equipped with an in-floor conveyor system capable of moving 15 fully-armored MaxxPro® trucks simultaneously (Figure 28). The overhead crane system on this section of the assembly line consisted of ten, 5 ton bridges and hoists on a runway spanning the entire length of the assembly line. Any two adjacent bridges were “ganged” or coupled together with an adjoining bridge, increasing the lift capacity to 10 tons. Since all bridges ran on a continuous rail system, a total of four bridges were used for a total combined lifting capacity of 20 tons. This unique overhead crane system was designed by CAVS-E engineers that worked closely with a leading crane system supplier. The entire system was erected by the crane supplier immediately prior to the start of the MaxxPro® production.

Figure 29. Bay 2 main line.

Bay 2 (Figure 29) was equipped with two parallel in-floor conveyor systems for moving in-process vehicles down the assembly line. Vehicles were connected to the conveyor chain using an attachment that was further connected to the steering mechanism of each truck (Figure 30). These attachments were designed and manufactured by a local welding and fabrication contractor and were unique to each variant of the MaxxPro® family of vehicles. The conveyor was not continuous; it was automatically indexed to the next work station based on the targeted *takt* time (i.e., targeted production cycle time).

Figure 30. Conveyor attachment.



Bay 2 also housed a major subassembly area for MaxxPro® armored doors. Both driver and passenger doors were heavily armored. Each door weighed in excess of 500 pounds when fully assembled with complex operating and safety mechanisms. Known as the *door line*, the subassembly process was a smaller moving assembly line where door subcomponents were hung on a rotating overhead structure that moved the assembly from workstation to workstation (Figure 31).

Figure 31. Door assembly line.

Workers remained in stationary positions and performed the repetitive work on each truck, aided by lift-assist equipment installed above the door line. This innovative assembly method was designed by an on-staff Navistar operations engineer and was produced and installed by a local welding and fabrication contractor. Over time, the door line became increasingly efficient, and as a secondary function was able to assemble and package door kits used as spare parts for field repairs. While a significant portion of facility upgrades were completed prior to the start of MaxxPro® production, some construction was still underway when production began under the UA mandate. Several MaxxPro® production crews built trucks during the day, and construction crews sawed concrete and installed the in-floor conveyor system at night. The professionalism of the production, engineering, and construction teams became a key element in resolving conflicts and competition for common workspaces. By November 2007, all systems had been installed in Bay 2 and the production process was increasing in efficiency.

10.3.4 Bay 3 assembly line

Bay 3 was the final trim assembly line for the MaxxPro® vehicles and was of similar configuration to Bay 2, with several important differences. Bay 3 was the same length and width as Bay 2, except Bay 2 lines ran west to east and Bay 3 assembly lines ran east to west. Bay 3 utilized two parallel in-floor conveyor systems identical to Bay 2, but the overhead crane system in Bay 3 was a light-rail crane system similar to Bay 1. Most components added to the final assembly of the vehicle on the Bay 3 lines weighed less than 1000 pounds, so heavy duty cranes were not required.

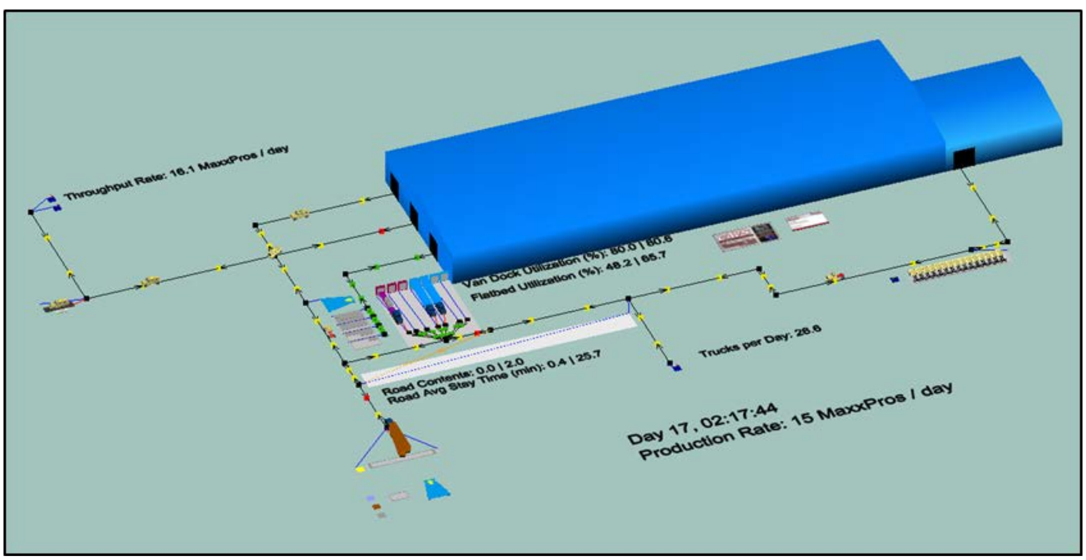
Bay 3 workstations performed installations of transparent armor, seats and other internal body components, HVAC equipment and ductwork, communications and lighting wiring, and associated equipment and components. Bay 3 workstations also included areas for fluid fill, electrical tests, ABS testing, and front-end wheel alignment.

The west end of the Bay 3 assembly line was a dedicated area for the final inspection, a final coat of CARC paint, and stencil activities which were performed in one of two enclosed, drive-through, down-draft paint booths and attached drive-through stencil booths. After the CARC paint, each vehicle's unique registration number and other important assignations were stenciled on the vehicle. After stenciling, the vehicle was taken on an 18 mile road test, where all systems were checked under operational conditions. After the road test and repair of any deficiencies noted, each vehicle was ready for presentation to DCMA for final inspection and acceptance.

11 Simulation - Analysis Tool for Facility Design; MRAP Traffic Flow and Dock Analysis

During the development of the facility, an advanced engineering tool for simulation, modeling, and analysis was used to analyze the external traffic of the facility (Figure 32). The goal was to evaluate the required number of dock door and flatbed truck areas to achieve varying levels of demand. An initial simulation model was rapidly developed (i.e., within 2 weeks) for the operations of the facility including: chassis un-decking, raw material delivery, delivery truck, chassis painting, and production vehicle movement through the yard and road tests. In addition to identifying the required number of dock doors and flatbed areas, the simulation also identified issues with paint booth capacity, road test, and manning at the receiving department for various production levels (i.e., 15, 30, 45, and 55 vehicles per day). The plant did not initially know the required production rate, therefore the model was used to perform sensitivity analysis. This enabled the production team to identify constraints at different production levels between the minimum and maximum rates.

Figure 32. Plant simulation model.



The simulation was also able to analyze congestion associated with raw material delivery. The facility had a requirement that delivery trucks could not be queued up on any public street. Analysis was able to show how the congestion would manifest and whether there would be issues as demand increased.

Specifically the model provided the following metrics:

- MaxxPro® throughput rate,
- Delivery truck throughput rate,
- Van dock utilization (average, max),
- Flatbed dock utilization (average, max),
- Truck waiting time (average, max),
- Number of trucks waiting (average, max).

Also, the model provided senior management with the following recommendations:

- 15 and 30 vehicles per day:
    - Build 3 van docks
    - Build 2 flatbed docks
    - Increase number of road test teams to at least 3 per shift.
- 45 vehicles per day:
    - Build 4 van docks
    - Build 2 flatbed docks
    - Add 1 paint booth
    - Add 1 cure oven
    - Increase number of road test teams to at least 4 per shift.
- 55 vehicles per day:
    - Build 4 van docks
    - Build 2 flatbed docks
    - Add 2 paint booths
    - Add 2 cure ovens
    - Increase number of road test teams to at least 5 per shift.
    - Increase number of repair teams to at least 5 per shift.
- The actual targeted production rate that the plant had to achieve was 500/month (or 30 per day), so senior management decisions regarding the number of paint booths and number of docks were based on the above simulation results.

The preceding example is one of several simulations that were developed in support of the plant. On several occasions simulations were developed in support of DoD proposals including large proposal efforts like M-ATV

(MRAP – All Terrain Vehicle) and the FMTV (Family of Medium Tactical Vehicles).

12 Design for Manufacturability

12.1 The Navistar defense business plan

The creation of Navistar Defense, LLC in 2005 as a division of Navistar, Inc. was a decision by the Board of Directors to enter the military market for wheeled vehicles. The decision was based in part on nearly a century of experience in the design, manufacture, and marketing of light, medium, and heavy duty trucks, school buses, and farming equipment produced under the International brand name. The successful business model that Navistar developed carried over as the fundamental cornerstone for the manufacture of military vehicles. Some of the more important elements of the business model were:

- Centralized management.
- Market-tested engineering design.
- A centralized, well-developed supply base.
- Commonality of parts across fleet models.
- High speed manufacturing processes.
- High quality standards.

The Navistar team, tasked with the responsibility of developing the manufacturing plan, performed a cursory examination of other MRAP type vehicles. The team discovered that the current state of the manufacturing plan had the following inherent limitations:

- Unique design for a narrowly defined military missions.
- Unique parts and exotic materials.
- Minor or no use of commercially available components.
- Unique assembly processes.
- Little or no local control of in-process changes or design modifications due to configuration control requirements.
- Use of specialty tooling and equipment.
- Long lead-time for design, parts manufacture, and finished product delivery.

The Navistar Defense proposal business plan was developed to assist the DoD to address these perceived limitations. In addition, the plan applied the lessons Navistar learned in the manufacture of commercial trucks to the production of specialized wheeled vehicles for military applications.

These fundamental concepts formed the basis of the proposal and the resulting business plan:

- Engineering design that retained the commercial truck design concept of independent chassis and body, as opposed to a monolithic design.
- Maximum utilization of COTS parts and material.
- Maximum application of a bolt and bond manufacturing process.
- Modular component design and assembly to expedite field modifications and repair procedures in combat theater environments.
- Maximum use of the base commercial chassis design and drive train components to accommodate future vehicle variants that would be needed to meet evolving combat conditions (e.g., wrecker, ambulances).
- Leverage the established Navistar supply base and Navistar proprietary MRP systems for production materials and after-market spare parts.
- Leverage existing Navistar commercial manufacturing plants for chassis production with minimal assembly line modification or special tooling requirements.
- Retain Navistar Defense change control authority (with DoD concurrence).

12.2 Impact of bolt and bond design on manufacturability

Early in the project, Navistar was looking for various partners to be part of their MRAP proposal. This included companies in South Africa and Israel. As a result of this search, Plasan in Israel which had extensive experience in developing blast resistant products, was selected to provide the ballistic package (i.e., armored body) for the proposed Navistar MRAP. This relationship resulted in Navistar providing the automotive expertise and Plasan providing the ballistics expertise.

Plasan's prototype, being developed during the proposal process, used a bolt and bond method for joining, rather than relying upon the traditional welding method. There was extensive testing, at the request of DoD, to ensure that the bolt and bond joining method performed at least as well as welding.

As a result of successful test results, this joining method proved to be one of the major contributors to efficiently achieving production volumes without reduction in functionality. The bolt and bond method was determined to be superior to welding for the following reasons:

- Assembly process for bolt and bond is far less complex and produces a more consistent cycle time.
- Much quicker to implement a bolt and bond workstation and related equipment (torque equipment and adhesive applicators as opposed to welding machines, welding wire and gasses, dust collection, and extra safety gear needed by operator).
- Bolt and Bond can have more people working simultaneously within a relatively small work zone, this is much more limited with welding.
- Less sensitive joining method, bolt and bond does not produce metal distortion due to heat.
- Component testing showed that the bolt and bond union was comparable to the strength of welded joints.
- Welding is deemed a special process in that its use changes base material properties. As a result, welding requires extensive control of input parameters (e.g., preheat, temperatures, current settings) and additional testing and qualification to verify quality (destructive tests, and non-destructive tests). None of this special treatment or testing is needed for the bolt and bond joining method.
- Implementation of welding workstations would have taken much longer to accomplish.
- Bolt and Bond provides for more environmentally friendly working conditions in the plant versus welding. (i.e., welding produces toxic fumes and more hazardous materials).
- Safety is generally higher for the operator for bolt and bond than for welding due to the elimination of weld splatter and burns on the skin and eyes. Also, no additional personal protective equipment (PPE) is required for bolt and bond beyond normal safety glasses, while welding requires extensive PPE.
- Less training is required for the workforce to master bolt and bond, as opposed to extensive need for finding and developing certified welders.
- Maintainability in the field is facilitated by the relative ease and convenience (i.e., no special tooling and fixtures) of replacement of bolt and bond components as opposed to welding.

12.3 Implementing the plan

The contract to build the KBR armored cab provided the opportunity for Navistar Defense to implement the new business plan on a limited basis and with minimal risk. While the KBR cab did not provide an opportunity to develop the bolt and bond process to the extent that it later exploited for the MRAP program, all other elements of the business plan were fully implemented. Partnering with Griffin Armor Inc., the design of the KBR armored cab was engineered to be installed onto a standard 5000 Series International chassis, and to be installed from an overhead assembly line conveyor as a single component on-line at Navistar's GAP.

Standard COTS parts were used for the base chassis and for the fabricated armored cab to include standard International cab trim, seats, and driver's control module components at the West Point Assembly Plant, and the 5000 Series chassis, built at GAP. With only the armored cab shell and the installed transparent armor (windshield and door glass) as specialty items, the finished product used almost all COTS material, standard Navistar MRP systems, and an established supply base for both production material and after-market spare parts.

An important lesson learned from the KBR cab program was the critical importance of maintaining Navistar change control authority. Standard commercial vehicle platforms (and some military vehicle platforms) often take years to plan, design, prototype, test, and release for production. In the case of the KBR armored cab, and later the MRAP vehicles, the normal, deliberate, and calculated design and development process was disregarded by the urgency to design, build, and deliver vehicles destined for an active combat theater in a matter of weeks and months, not years. Navistar established a single-point engineering change control process that mitigated unnecessary modifications during production. The benefits of managing design changes proved to be numerous, including product standardization, mitigation of parts obsolescence, reduction of production delays and work stoppages, and standardization of repairs and maintenance.

When Navistar Defense committed to the MRAP program, it did so with its basic business plan firmly in mind, and was fresh from the lessons learned during KBR armored cab production. Navistar's decision to select the MaxxPro® armored body was largely based on the Plasan design and plan for the body to be mounted onto a standard commercial 7000 Series

International severe duty chassis. To ensure that the Plasan armored components would leverage the COTS components and the established supply base, engineers from Navistar Defense, Griffin Armor, CAVS-E, and Navistar (Truck) worked directly with Plasan engineers to develop and test the final configuration. The proof of the validity of the Navistar Defense plan came on 31 August 2007 when Navistar delivered the first 77 completed MaxxPro® vehicles, just 92 days after contract award, and subsequently delivered the 1000th only 4 months later.

13 Development of the Workforce

13.1 Job descriptions

The skill sets required for the manufacture of the MaxxPro® vehicle were separated into five main divisions, trim and assembly, test and tune mechanic, quality assurance (QA), electrical technician, and blast and paint. Each division employed workers with specific aptitudes, training, and experience.

13.1.1 Trim and assembly

This labor division comprised a significant part of the direct labor during the build of armored vehicles at the West Point Assembly Plant. Utilizing the Navistar bolt and bond process, most parts were shipped to the manufacturing floor from Tier 1 suppliers ready for sub-assembly or final assembly. Other parts and sub-assemblies were fabricated on sub-assembly lines at the assembly plant and fully incorporated into the vehicle by trim and assembly personnel. Personnel assigned to this category of labor were located at static work stations along the moving assembly lines and performed repetitive tasks as work-in-progress moved along the assembly line. This category of labor was responsible for sub-assembly and final assembly of components. Typical tasks would be bolting armored panels into place; installing vehicle components such as seats, lights, etc.; installation and fitting of non-armored parts such as tool boxes; and other similar tasks. Typically labor in this category was skilled labor, requiring proficiency in the use of overhead cranes and other heavy-duty equipment; use of a wide variety of hand tools and power tools; and performing in-station quality checks. Other typical tasks included detailed trim and subassembly work for items such as doors, roof headliners, and transparent armor installation.

13.1.2 Test and tune mechanics

This division of labor included personnel with a variety of job skills, including mechanical, electrical, engine and chassis repair. These personnel were typically some of the most skilled labor in the assembly process and were responsible for working closely with DCMA inspectors during preparation of the FIR which is the basis for acceptance of vehicles by the customer. This category includes QA inspectors, engine mechanics, highly-skilled assembly workers, electricians, and drivers. These personnel inspect and test all automotive systems, all lighting, and all installed tools and components. This category of labor also performed detailed repair/replacement, troubleshooting, and electronic programming of Navistar diesel engines, drive train components and other related testing, repair, and assembly.

13.1.3 Quality Assurance (QA)

This division of labor included on-line personnel who performed quality inspections during the manufacturing process in support of the overall Quality Assurance Plan (QAP). Technicians in this labor category preformed initial technical inspections; verified incoming product quality; confirmed that manufacturing processes were followed (in-process audits); inspected and verified that work was performed on-line pursuant to applicable work instructions; assisted the Quality Manager with issue resolution; supported the Visual Factory, status boards, task cards, and other 5S activities; and worked to eliminate waste and continuously improve the quality of the production process and its outputs. This position was also primarily responsible for conducting and documenting the FIR and for direct inter-face with DCMA in the final acceptance process.

13.1.4 Electrical technicians

This division of labor comprised highly skilled electrical technicians who performed a variety of work on vehicle electrical systems in multiple workstations along the assembly line. Typical tasks for this category of labor would be assembly and installation of wiring harnesses, connection and testing of non-engine electrical components installed in vehicles; testing, troubleshooting, and repair of vehicle electrical systems; recovery component electrical systems and related tasks. Personnel assigned as electrician technicians were also responsible for installing, maintaining, and programming of various computer chips and related devices that were essential to the operation of engines, transmissions, and other drive-line components. High computer skill levels were required as well as unsupervised installation and operation of various computer and electrical automotive components of the vehicle.

13.1.5 Blast and paint

This division included skilled personnel and is further subdivided into two main sub-categories:

13.1.5.1 Blast and prep

Personnel assigned to blast and prep were skilled workers who utilize specialized equipment and recoverable media to grit blast metal sub-components prior to treatment and final paint. These personnel were skilled in the use of sand blast equipment, overhead cranes, and other production line equipment. These personnel were required to follow safety requirements and maintain high quality control standards.

13.1.5.2 Paint

Personnel assigned to paint were highly skilled workers in the application of automotive and CARC paint to finished vehicles. In general, this category was further divided into the following sub-categories: paint prep, chassis paint, final paint, and marking and stencil. In paint prep, technicians masked surfaces such as tires and performed other similar tasks to prepare vehicles for automotive and/or CARC paint. Chassis paint personnel were skilled painters who applied primer and final coat automotive and/or CARC paint to the base vehicle chassis prior to the chassis entering the assembly line for body installation. Final paint and stencil was the process for a finished vehicle. Both chassis paint and final paint personnel were skilled in the use of paint guns, paint booth operation, mixing of paint components, direct application of paint, and follow-on paint finishing.

13.2 On the job training

Navistar Defense provided extensive on-the-job training (OJT) for all assembly line workers, regardless of prior training or experience. New employees received extensive classroom training immediately upon employment in such areas as safety, environmental hazards, workplace rules and regulations, lean manufacturing techniques and goals, general housekeeping, operation of equipment, and basis assembly line tasks. The classroom training was integrated with part-time work on the assembly line under close supervision. Typically, OJT required six to eight weeks for the average worker.

During the initial eight month ramp up for the MaxxPro® build, typically 20 to 25 new workers were employed each week and enrolled in the OJT program. At peak production in February 2009, over 1000 workers had been employed and trained.

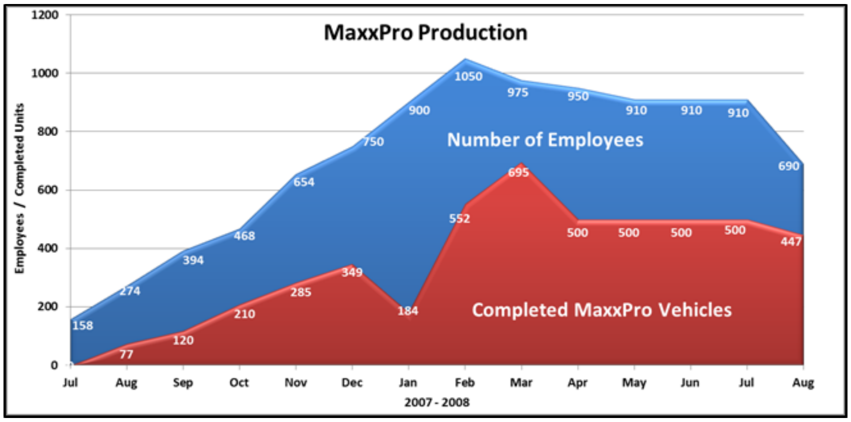
13.3 Manufacturing metrics

Production of the first 77 MaxxPro® vehicles began in July 2007. The base chassis was manufactured at Navistar's GAP and shipped to the body manufacturing plant in West Point, Mississippi. As shown in Figure 33, the West Point plant began with a labor force of 158 workers, most of which were experienced assembly personnel from the KBR Armored Cab program. By August 2007, the labor force had increased to 274 as new workers were employed and trained in a variety of job skills directly related to the MaxxPro® assembly process.

As shown in Figure 34, peak production during this period was 695 vehicles per month, or 32 completed vehicles per day. Peak employment reached 1050 in February 2008, supporting two shifts. In the following months, employment leveled out at 910 assembly line workers as the assembly line processes became more efficient.

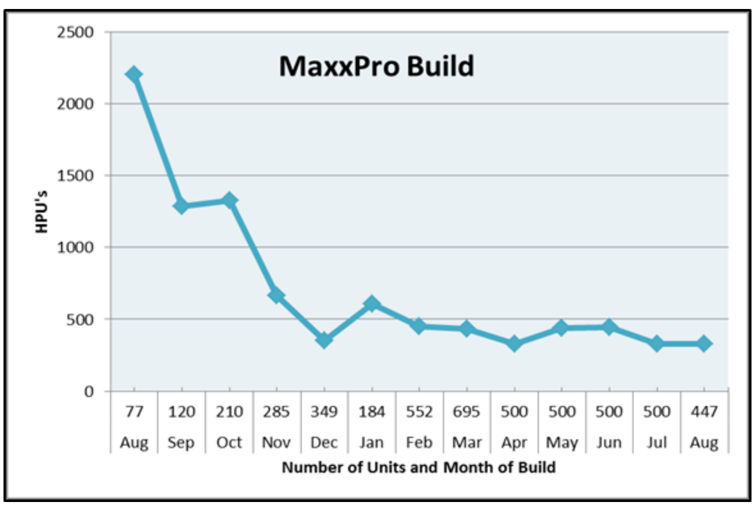
As MaxxPro® production ramped up in late 2007 into 2008, a significant material constraint in the supply chain was experienced which limited production. Specifically, Plasan, supplier of the armor kits could not deliver the increased Navistar material quantities within the necessary timeframe. As a result, in January 2008, only 184 MaxxPro® vehicles were produced and delivered. However, the Navistar team reacted immediately to develop and qualified new suppliers for the kits and quickly recovered from the January setback by delivering 552 units in February and 695 units in March to get back on schedule. Production then leveled out at 500 units per month, which was the contract commitment as shown in Figure 34.

Figure 33. West Point production and employee levels.



Hours per Unit, or HPUs, is a measure of the man-hours required to build a MaxxPro® vehicle. The chart (Figure 33) shows the average per-unit man-hours required each month during the initial build period, compared with the total number of vehicles built. Figure 34 demonstrates the increased efficiencies developed by the West Point Assembly Plant workforce over the span of the 13–months of the initial build. These efficiency metrics were achieved while simultaneously experiencing production delays due to material shortages, design changes, and workforce training and turn over.

Figure 34. Plant productivity (hours/units).



Production records indicate the first completed MaxxPro® vehicle required a total of 2,357 man-hours (HPUs). The learning curve is fairly steep, demonstrating the effectiveness of the training process and the quality of the workforce. The final vehicle in the initial build, vehicle number 4919, required only 281.4 HPUs. The average labor effort of 485.1

HPUs for the entire build period was achieved in February, 2008 at vehicle number 1500.

13.4 Plug and play electronics

Navistar MaxxPro® vehicles were shipped to a Space and Naval Warfare Systems Command (SPAWAR) facility for the design, simulation, testing and integration of C4ISR (Command, Control, Communications, Computers Surveillance and Intelligence) equipment on the vehicles. It soon became evident by program management that the plant could out produce SPAWAR and this integration effort resulted in bottle-necking the process.

A quick analysis of the process determined that SPAWAR was performing work that could be performed more efficiently in the plant, which would better protect any secret or sensitive equipment information. The optimum placement of radios and antenna mounts on the vehicles was SPAWAR designed and tested by using the first vehicles presented to them as live test subjects. Additionally, SPAWAR integrated this equipment into its production line, which required disassembly of vehicle components in order to run power cables, wiring harnesses and add antenna mounts.

The decision to integrate essential components into the truck at the West Point Assembly Plant before shipping to SPAWAR was made early in the program. This required a coordinated effort by Navistar engineering, purchasing, supply chain, and manufacturing management to procure components and integrate them into the production line as rapidly as possible. Since units were beginning to accumulate at SPAWAR while awaiting integration, Navistar decided to delay shipping finished units from the plant until the new components could be added to the production line at West Point. To facilitate this effort, the CAVS E team designed a temporary production process so that units arrived at SPAWAR in a plug and play C4ISR configuration.

The temporary line disruption had the benefit of piloting component part insertion into the assembly line work stations/work instructions for all new trucks being built. The benefit of this was immediate and beneficial to the program and its ultimate users. The processing time for the MaxxPro® at SPAWAR reduced from 40 to 8 man hours and the overall lead-time to ship trucks to Iraq was reduced by several weeks. As a result, the temporary line became permanent, so that these installations continued throughout the production period.

13.5 Production surge

During the early planning for MaxxPro® production, Navistar Defense recognized the potential need for a rapid acceleration, or a surge in production on a temporary basis. A number of factors could have possibly generated a surge requirement, including material shortages, U.S. Government directives, acts of God, or changes in project scope. Manufacturing engineers and program managers planned for such an eventuality in the following ways.

13.5.1 Work shift design

The standard work schedule for the West Point Assembly plant was two 10-hour work shifts per day, four days a week. This shift schedule was selected because it allowed for surge capacity. The plant was idle four hours each day Monday through Thursday, and all day and night on Friday, Saturday, and Sunday. This provided opportunities for flexible overtime schedules and planned maintenance during the week. Third and fourth shifts, or "surge shifts" were designed for Friday, Saturday, and Sunday. Each of the surge shifts was a 12-hour shift, providing a total of 72 additional hours of potential surge production each week. During the production period, the plant used all these shift arrangements.

13.5.2 Facility design

The facility layout, assembly line equipment, and supporting infrastructure were designed to support a multiple-shift operations.

13.5.3 Materials expediting

The availability of material to support a surge build was planned from program outset. Using a third-party logistics partner, production material was available with lead times as short as one week.

As a result of a combination of factors, the West Point production of completed MaxxPro® vehicles dropped below the planned build quantity in December 2007. The surge plan was therefore activated in January and February 2008. The manufacturing plant labor force surged to 1050 workers in February (in order to staff the surge shift). The surge shift utilized a single 12-hour weekend shift (Friday, Saturday, and Sunday), and resulted in a peak MaxxPro® production of 695 vehicles in one month. Once the surge requirement was met, the plant returned to a normal 2-shift, 4-day work week.

14 MaxxPro® Production 2009 to Present

The first MRAP vehicles built at the West Point Assembly Plant, designated as Category I MaxxPro® Vehicles, were solid-axle configurations using Navistar's Series 7000 severe duty commercial chassis. As the MRAP program continued to grow and mature, later variants would employ specialized features, including independent suspension, enhanced armor designs, ambulance variants, and MRAP Recovery Vehicles. The initial builds were important however, as they were all virtually identical and enabled Navistar to validate the design and the assembly line building process.

When the initial manufacture of 4919 of the Category I variant was completed in August 2008, additional variants were already designed and ready for production at West Point. Other variants were built in varying quantities, based on periodic orders from the U.S. Marine Corps Buying Command. These variants included:

- Category II MaxxPro® Vehicles – The Category II vehicles were essentially the same as the Category I, but with a longer chassis frame rail and a longer armored body. Designed primarily as a troop transport in hostile combat situations, it has three transparent armor windows on each side. The Category II MaxxPro® can carry up to 10 soldiers. Only 16 units of this variant were built.
- MaxxPro® Plus – In June 2008, Navistar began production at the West Point facility of new version called MaxxPro® Plus. The MaxxPro® Plus had enhanced suspension, dual rear wheels, a larger more powerful engine, and increased payload. This variant also had the capability for the field installation of an Explosive Formed Projectile kit. Production volume of this model was 2243.
- MaxxPro® Dash – On 4 September 2008 Navistar Defense received orders for production of the MaxxPro® Dash. The MaxxPro® Dash is a lighter, smaller, and more mobile variant of the MaxxPro® MRAP family. The Dash maintains the survivability system used on all MaxxPro® MRAP variants while offering a smaller turning radius and higher torque-to-weight ratio. Optimized for Afghanistan operations, the MaxxPro® Dash can accommodate additional armor. Production of this variant began in October 2008, with 822 completed vehicles delivered by February 2009. The total production volume was 1222.

- MaxxPro® Ambulance – Two versions of the MaxxPro® Ambulance were manufactured at the West Point facility from 2009 through 2012. The first variant utilized the MaxxPro® Category 1 platform. An improved version with special Casualty Evacuation (CASEVAC) was built utilizing the MaxxPro® Dash platform. The production volume of the two versions was approximately 1000. A third ambulance version is currently planned for production in early 2015, utilizing a new platform known as the Long Wheelbase Rolling Chassis (LWBRC).

- MaxxPro® Dash DXM - The MaxxPro® Dash DXM is a lighter, smaller and more mobile variant of the MaxxPro® MRAP family. With its Hendrickson independent suspension, the Dash DXM provides a solution for extreme theaters like Afghanistan because of its greater maneuverability, tight 54-foot turn radius and increased payload. The suspension is also easily installed, allowing a quick retrofit of units in the field. Production of the Dash DXM began in 2010 and continued through 2011. Production volume was 1050.

- MaxxPro® Recovery Vehicle - Based on Navistar's commercial International® WorkStar® platform, the MaxxPro® Recovery Vehicle (MRV) is designed specifically to provide MRAP-level protection for crews running damaged vehicle recovery missions. The MRV vehicle allows two - to three-man crews to retrieve damaged or mission-disabled vehicles and carry out other support missions. The new MaxxPro® utility variant provides its crew with the same ballistics; IED protection and mine used on all MaxxPro® MRAP vehicles currently in Iraq and Afghanistan. Production Volume was 390.

Each of the MaxxPro® variants described above was built at the West Point Assembly Plant using the same facilities, equipment, workflow, and high-level processes developed by the CAVS-E and Navistar engineering staff at the beginning of the MaxxPro® program. While each individual variant requires some specialized fixtures and tooling, the cost and design effort has been minimal. Equally important, these same facilities, tooling, and processes have been employed in the manufacture of other armored and non-armored vehicles that are not part of the MaxxPro® family of armored vehicles. This is an example of a resilient production system made possible because of initial product design, production layout, and equipment selection.

15 Other Vehicle Production

Simultaneously with the manufacture of the MaxxPro® family of vehicles, varieties of other armored and non-armored military vehicles were built by Navistar Defense at the West Point Assembly Plant. These vehicles used the same facilities, assembly line equipment, tooling, and in many instances the same manufacturing processes, that were developed for the MaxxPro® production. Equally significant, the manufacture of these non-MaxxPro® vehicles used the same basic design elements that were successfully employed for the MaxxPro® production.

- Base vehicle platform - standard commercial truck chassis.
- Maximum use of standard commercial parts.
- An armored body design that used an integrated bolt and bond process.
- Leverage of Navistar's world-wide distribution of standardized parts.
- Employment of standardized, high-speed, moving assembly-line processes.

Beginning in 2009 and continuing through 2013, four types of military vehicles were manufactured at the West Point Assembly Plant.

15.1 Tactical Support Vehicle (TSV) Husky

The Husky is a medium-armored high-mobility TSV designed specifically for the British Army. The vehicle is based on Navistar's International MXT (medium duty) four-wheel drive chassis with an armored body designed by Plasan. The Husky employed the same bolt and bond manufacturing process as the MaxxPro® vehicles and was built on the same assembly lines. Initial production consisted of 232 vehicles in two configurations, Command Vehicle and Utility Vehicle. The Utility Vehicle is equipped with a flat bed, while the command variant has an enclosed cab at the rear. Both variants have medium-duty armor, run-flat tires, strong drivetrain components, independent suspension, and is powered a MaxxForce® 6.0D I6 diesel engine. The Husky is designed with a low profile for transport by C-130 cargo aircraft. In September 2010, the British Ministry of Defence placed an additional order for 89 of these vehicles. Delivery was completed in early 2011.

15.2 Series 7000- Military Vehicle (MV) General Troop Transport (GTT)

The International® 7000-MV General Troop Transport (GTT) is designed for off-road missions as a hauler of heavy-duty material or converted to heavily armored personnel carrier. Based on Navistar's versatile commercial platform, these trucks offer high commonality among variants and are easily adapted to suit the mission. The 7000-MV GTT offers a 5 ton off-road capacity and a weapon station that can handle a 50 caliber weapon. The GTT has removable seating to transport up to 20 soldiers or cargo. More than 8,000 of these unarmored vehicles were built at the West Point Assembly plant from 2008 through 2011 and deployed in combat theaters in the Middle East in support of U.S. forces and NATO allies.

15.3 Series 7000-Military Vehicle (MV) Tanker

The Series 7000-MV Tanker is a variant of the GTT and is used by the military for transport of fuel and water. Navistar Defense manufactured both fuel and water variants at its West Point Assembly Plant from 2009 through 2011. Many of these trucks were deployed with U.S. forces and NATO allies to combat theaters in the Middle East. As with the GTT variant, the 7000-MV Tanker offers a 5 ton off-road capacity and a weapon station that can handle a 50 caliber weapon. On-board pumping equipment allows for off-loading of liquid cargo. The 7000-MV Tanker was manufactured only in the non-armored configuration, however an armored cab version is available and existing non-armored vehicles can be factory retrofitted.

15.4 Royal Canadian Mounted Police (RCMP) Tactical Armored Vehicle

The RCMP Tactical Armored vehicle is another variant based on Navistar's International MXT (medium duty) four-wheel drive chassis. The armored body was jointly designed by Navistar Defense and RCMP engineers and built at the West Point Assembly Plant. The RCMP is a medium armored response vehicle used by the RCMP's Emergency Response Team (ERT) for tactical deployment with action/reaction capability. The vehicle features gun ports, sentry hatches, a protected observation station, elevated ladder platform system, fire detection/suppression system, front bumper winch, first aid equipment, infrared night lighting.

15.5 General Troop Transport (GTT) Armored Cab

The versatility and adaptability of the Navistar manufacturing model was demonstrated in 2012 with the manufacture of the GTT armored cab vehicle. Originally manufactured and sold to the U.S. military as the Navistar® International® 7000-MV GTT (unarmored), these vehicles were returned to the West Point Assembly Plant for re-manufacture as armored vehicles. Working with Griffin Armor, Navistar's longtime partner, the armored cab was fabricated in the Griffin facility in Byhalia, Mississippi, and shipped to the West Point facility for final assembly. At the West Point plant, the unarmored cab was removed from the 7000-MV GTT vehicles on the West Point assembly line, and the new armored cab installed. The design and manufacture of the armored cab allowed installation without modification of the original unarmored GTT vehicle chassis. A total of 208 of these armored vehicles were produced on-line at the West Point facility with no modifications to the facility or additional tooling. The experienced labor force required only 119 hours per unit to assemble the cab to remove the old unarmored cab and install the new armored cab.

16 Manufacturing Operations Going Forward

The withdrawal of U.S forces from combat in the Middle East has directly impacted the demand for new armored military vehicles and has shifted the focus of the military buying command. A significant portion of the armored vehicles deployed over the past five years will be returned, reset, and become part of the Enduring Fleet. While the size and scope of the Enduring Fleet is still an evolving military decision, the inclusion of MaxxPro® Dash DXM is a certainty. Other MaxxPro® variants, including the MaxxPro® MRV and the LWBRC Ambulance are also scheduled for inclusion.

16.1 MaxxPro® reset program

On 28 August 2014, the U.S. Army Tactical Command (TACOM) awarded a $38.4 million contract to Navistar Defense for the reset of 785 MaxxPro® vehicles currently located in the U.S. and abroad. The reset work includes the replacement of mandatory parts and labor for maintenance repairs and upgrades to bring the vehicles to a Code-A standard. The work will be performed at Navistar's West Point Assembly Plant, with an estimated completion date of 30 June 2016. Navistar will utilize the same facility, layout, tooling, and manufacturing processes developed for the MaxxPro® production. An important factor in DoD's selection of the MaxxPro® for the Reset Program was the bolt and bond design, rather than welding (used by the other MRAP contractors). A welded design due to the difficulty of disassembly is much harder to upgrade than the bolt and bond approach. This illustrates another aspect of the resiliency of the MaxxPro's design.

16.2 New MaxxPro® production

The Navistar Defense MaxxPro® has been selected by a number of NATO allies for use during 2015. These vehicles will be produced at the West Point facility along with the ongoing MaxxPro® Reset program. In addition to the assembly of the armored body, the base vehicle chassis will also be manufactured at the West Point plant. This change in process is the result of a maturing manufacturing operation at the West Point facility. These new vehicles will incorporate all of the upgrades and ballistic improvements made to the MaxxPro® platform over its lifetime.

17 Lessons Learned

There are seven important lessons learned from the initial MaxxPro® production outlined in this chapter. The lessons categorized into production system, manufacturability, contractor and DoD relationships, facilities, workforce characteristics, extending the enterprise, and supply chain.

17.1 Production system

Military vehicles are typically produced using a stall-build production system, rather than an assembly line. This case study showed that military vehicles could be produced in relatively high volumes using flow methods which better provide for flexibility and scalability.

17.2 Manufacturability

The contractor went from prototype in Israel to full scale production implementation in West Point, Mississippi, in nine months. This was enabled by use of a manufacturable design coupled with experienced manufacturing engineering capability (from both academia and industry) that consulted early in the project.

One of the key components of the manufacturable design was the use of an off the shelf chassis with a custom armored body. Since chassis production is typically the constraint in producing military vehicles, the use of this commercially available chassis alleviated this constraint and was a major contributing factor to achieving the high production volumes.

The vehicle design requirement of a bolt and bond joining process rather than relying upon welding. This resulted in the plant employing a broader, more readily available workforce without having to rely upon specialty skills (e.g., certified welders).

Particularly at the beginning of the program, it was extremely important to have design engineers from both Navistar and Plasan co-located at the West Point Plant with manufacturing engineers, quality engineers, and supply chain personnel. This was necessary for the timely resolution of unexpected issues encountered, typical in many production start-up.

17.3 Relationship between contractor and DoD

Locally empowered change control authority, primarily between DoD and Navistar personnel, allowed timely resolution of issues. Weekly change control meetings were hosted and managed by Navistar at the plant, where issues were presented and discussed. As a result, change requests were promptly resolved by Navistar and DoD. It is important to note that no major warranty/recall issues came up during the MRAP production build period.

The use of the electronic payment system enabled an efficient paperless acquisition of incoming raw materials (and other required resources). This resulted in improved working capital position, sharing risks, and timely payment of suppliers.

17.4 Facility

It was critical to have local tooling design and fabrication capabilities to support changing demands for the finished product during production. For example, a local fabrication shop was instrumental in enabling the plant to quickly design and builds special tooling, rework incoming parts as needed, and make facility changes.

The production system (facility, equipment, production lines, etc.) was designed so the plant was capable of handling a surge, or temporary increase in production during critical times. The plant was designed to handle a 50% surge, this resulted from using additional space available at the facility (i.e., outfitting an additional production line). As a result of the supply chain shortage (previously discussed) the West Point plant achieved a 40% surge in production to overcome the problem (i.e., beginning in January 2008 and peaking in March 2008).

Production flexibility is a major attribute to the launch of a successful military automotive plant. In this case, the facility layout and work processes were flexible and adaptable to multiple vehicle variants (i.e., eight different MRAPs) and configurations (e.g., type of suspensions).

17.5 Workforce

Operating under these conditions was essential to have a flexible and motivated workforce. In this case, the West Point workforce was motivated and exhibited a great degree of pride in their jobs and the vehicles being produced; this in turn, generated self-discipline and enhanced workmanship. Navistar management frequently invited top DoD officials to celebrate major milestones (e.g., 1000^{th} truck, launch of a new model, etc.) and every employee was invited to these celebrations. Therefore, each employee knew the importance of their job in relation to the project and to national defense.

It was essential to keep a core group of workers, thus capturing the trade knowledge for future efforts (e.g., training new workers). Therefore an intentional training plan was implemented in order to accomplish the production ramp-up. This was particularly needed given the production volume fluctuations experienced by the West Point plant.

17.6 Extended enterprise

The use of advanced engineering tools, such as simulation modeling and analysis, provided timely and beneficial information for management such as capital expenditure and operational decisions (e.g., traffic flow, paint booths, process flow) were made for the facility. Also these simulations and visualizations developed by MSU CAVS Extension, illustrated Navistar capabilities to the DoD and other stakeholders during the proposal stage.

The development of the West Point plant benefitted by relying upon rapidly formed external partnerships involving academia, industry, and government (e.g., MSU CAVS Extension, EMCC, contractors, other Navistar units, and various DoD agencies). These entities working together formed a virtual and flexible enterprise.

17.7 Supply chain

Numerous Requests for Proposals (RFPs) with short response times caused much effort and cost to be spent on proposal development. This often made even intermediate term planning (i.e., beyond three to four months) more difficult. This added substantial costs to the plant, facility, and the supply chain.

The initial supply chain included bringing in a key component from overseas (i.e., armored body troop carrier module from Israel). Over time as production requirements ramped up, this source of supply was re-shored to a domestic supply source. This illustrates the critical need to have sourcing options that enable the supply chain to meet delivery requirements.

Open lines of communication and a commitment to continuous improvement is needed to make the overall supply chain operate in a resilient manner. In this case, close coordination was needed between the production plant and SPAWAR. The addition of power cables, wiring harnesses, and antenna mounts at the plant provided an efficient "plug and play" solution for final integration at SPAWAR. Substantial benefits in MRAP throughput were obtained. As a result, the final outfitting at SPAWAR went from 40 hours to 8 hours (80% reduction in processing time) and the lead-time to ship trucks to Iraq was reduced by several weeks.

18 Conclusions

The entry of Navistar Defense into armored military vehicle manufacturing has been documented in this case study. This study has centered primarily on the launch and production of the MaxxPro® vehicle at the West Point, Mississippi plant. Particular emphasis has focused on facility changes, manufacturability attributes, manufacturing processes, and workforce development. This case study is certainly not exhaustive and several other topics should be explored in order to more fully understand contributing factors to this successful effort. Some of these additional topics include the challenge of managing multiple contractors, development of a vehicle design platform that ultimately supported multiple MRAP variants, and field service issues like reparability and maintainability.

There were many challenges that had to be met including speed to market, increased protection of vehicle occupants, and reliability of vehicle operation. This was accomplished by using outside ballistic design experts (Plasan) for increased occupant protection and speed to market by using a bolt and bond process, assembly line, and a COTS chassis. Overall, effectiveness was also positively influenced by the efforts of an extended enterprise including participation from industry, government, and academia (i.e., MSU CAVS Extension, Navistar, Griffin, EMCC, DoD and DCMA). A supply chain of critical items, originally located in Israel, was re-shored to U.S. providers due to capacity requirements. This was especially beneficial for improving transportation costs and reducing the lead-time. The surrounding community had an immediate source of available workers and a suitable existing plant site, allowing for a resilient production system supporting the production of nine different models of MRAP vehicles.

The Navistar West Point plant provides us with a rich case study the rapid deployment of a resilient product-process designed armored vehicle. As a result, the vehicle produced by this effort, MaxxPro®, played an important role in supporting and protecting our U.S. and coalition partner combat troops.

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