final report

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Autonomous Range Management Vehicle: Proof of Concept Prototype

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Executive summary

Over the past six years, HDT and the US armed forces have invested over seven million US dollars in developing a half-ton unmanned vehicle. The purpose of this vehicle is to carry heavy loads across rugged terrain to supply infantry soldiers. The precursor system (Protector) is powered by a 24 kW turbo-diesel engine and will travel 100 kilometres on 60 litres of diesel fuel. The vehicle produces about 2 kW of electrical power for payloads. We have sold a number of these vehicles to the US Army, which have been used in nearly a dozen different field evaluations. For the Australian livestock market, we believe this vehicle needs to have higher fuel efficiency, longer range, greater mission duration, and a limited silent-run capability for operating near livestock.

This project focused on the development of a *proof-of-concept* prototype of a hybrid diesel-electric drivetrain, which would allow multi-day endurance, while also providing an electric-only silent drive mode to reduce the potential of disturbing livestock. The hybrid drive was integrated onto an unmanned vehicle and tested in off-road environments. Power requirements were measured over different terrain types while carrying varying amounts of load.

There are many operations on remote cattle and sheep stations that are difficult to perform consistently, due to labour constraints that a rugged, autonomous ground vehicle could enable and/or facilitate. To this end HDT, through MLA, formed a Steering Committee for this project with representation from six Australian companies. Some of the potential applications proposed by the Steering Committee are listed below:

- traverse pastures in a grid pattern and identify where livestock are congregating (animal monitoring),
    - the vehicle can also deploy a tethered multi-rotor unmanned aerial vehicle that can use an inexpensive thermal imager to perform accurate livestock counts, as well as locate and identify pest animals.
- gather information about soil chemistry and moisture (i.e. Water and Soil sampling),
- deliver of supplements and/or feed to the cattle,
- mustering (or mustering assistance),
- fence line integrity checking, among others…

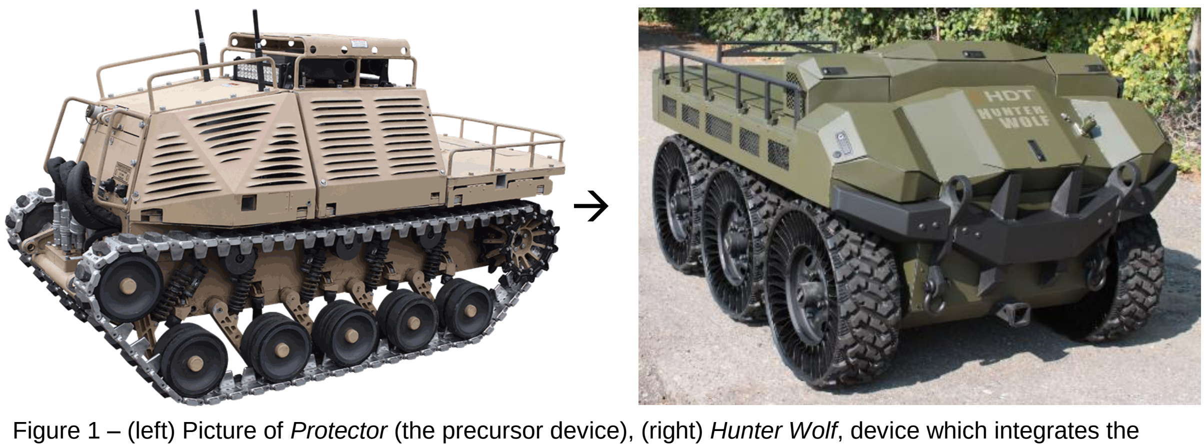

Figure 1 – (left) Picture of *Protector* (the precursor device), (right) *Hunter Wolf*, device which integrates the hybrid drive train developed as part of this project.

This project was the first step in adapting a ground vehicle to serving the needs of remote cattle and sheep stations. Given the project's successful completion (see Table 1), we recommend that follow-on efforts include the development and "experimental prototype" that will:

1) extend its range and further increase its mission duration via the addition of a larger – secondary - fuel tank,
2) incorporate an autonomous navigation controller,
3) integrate waypoint GPS navigation software and operator interface,
4) integrate video streaming and/or local recording,
5) integrate basic obstacle avoidance such as auto stop.

In order to start equipping the vehicle with the capabilities/functionality required to address the specific tasks needed to improve natural resource management, labour productivity, and overall value.

HDT also recommends traveling to Australia to visit with various ranchers including cattle and sheep stations in order to better understand not only the tasks that an autonomous range management vehicle could add value to but also to observe the environment/terrain and how those tasks are being performed now.

Table 1 – Results against project objectives.

Project Objective	**Protector** (precursor)		**Hunter Wolf** (Hybrid drive train)
Extend its range	100km	→	400km
Increase its mission duration	33hrs	→	65hrs
Reduce its operating expenses by lowering fuel use	32.5L/100km	→	13.9L/100km
Allow the vehicle to operate in a nearly silent mode	82db @ 10m	→	Proprietary

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1 Background

Over the past six years, HDT and the US armed forces have invested over seven million US dollars in developing a half-ton unmanned vehicle. The purpose of this vehicle is to carry heavy loads across rugged terrain to supply infantry soldiers. The current system is powered by a 24 kW turbo-diesel engine and will travel 100 kilometres on 60 litres of diesel fuel. The vehicle produces about 2 kW of electrical power for payloads. We have sold a number of these vehicles to the US Army, which have been used in nearly a dozen different field evaluations. For the Australian livestock market, we believe this vehicle needs to have higher fuel efficiency, longer range, greater mission duration, and a limited silent-run capability for operating near livestock.

1.1 Design History

1.1.1 Protector

HDT has been developing Unmanned Ground Vehicles (UGV) since 2011. HDT recognized the need within the military for a new class of robot. While small, man portable robots were available they had severe limitations in payload capacity, mission duration and terrain crossing capability. The Protector was developed to solve those deficits and allow greater effectiveness of US fighting forces (see Protector data sheet Appendix 7.1.1).

1.1.2 Wheels vs. tracks

Evolving requirements from the US Army have led to HDT investigating alternative system architectures than the Protector to better meet the need. Specifically, a faster, larger payload, longer range, and quieter platform was desired. Numerous tests were conducted and data was collected and analysed to determine the best drivetrain to meet the new requirements. Conclusions from these studies showed that a wheeled platform increased system efficiency, extending range, while also resulting in a quieter audio signature. Payload capacity and terrain mobility remained adequate when all wheel drive systems were used.

Figure 2 – Picture of MadDog, a battery only wheeled initial prototype

1.1.3 Military to Agriculture Crossover

Over the last several years HDT has developed numerous payload kits to increase functionality of the base Protector platform (see Protector data sheet Appendix 7.1.1). Of particular interest for crossover into agriculture is the development of a semi-autonomous applique kit. This kit was originally developed to allow the base Protector platform to follow a designated human leader in the exact path traversed by the leader. Additional features of the system included:

- Satellite remote operation from any global location
- Limited set of obstacle avoidance
- GPS waypoint route guidance
- Robust 4 sensor fusion to allow operation in:
    - Tall grass
    - Blackout night conditions
    - Zero visibility blowing sand/snow/rain
    - GPS denied location

1.2 Purpose and description

This project is the first step in adapting this vehicle to serving the needs of remote cattle and sheep stations. If this project is successful, follow-on developments will address the specific tasks needed to improve natural resource management, labour productivity, and overall value.

This project will focus on developing a *proof-of-concept* prototype of a hybrid diesel-electric drivetrain, which will allow multi-day endurance, while also providing an electric-only silent drive mode that will reduce the chance of disturbing livestock. The hybrid drive will be integrated onto an unmanned vehicle and tested in off-road environments. Power requirements will be measured over different terrain types while carrying varying amounts of load. The performance of this prototype will allow HDT to determine the additional range, operating time, and reduction in fuel costs. HDT will also measure the reduction in audio signature.

Eventually, this vehicle will be able to autonomously or semi-autonomously carry out tasks as recommended by a Steering Committee such as surveying the land, delivering feed and/or supplements, inspect fence lines for any damage or breaches, count livestock using a tethered multi-rotor unmanned aerial vehicle, locate pest animals, and take soil samples. For the sake of clarity, this autonomous function is not an outcome of this current project. This project will culminate in outdoor driving tests over off-road terrain at HDT's US facility.

1.3 Value proposition & benefits to the Australian meat industry

There are many operations on remote cattle and sheep stations that are difficult to perform consistently, due to labour constraints. A rugged, autonomous ground vehicle can patrol fence lines, constantly inspecting for any damage. The vehicle can also deploy a tethered multi-rotor unmanned aerial vehicle that can use an inexpensive thermal imager to perform accurate livestock counts, as well as locate and identify pest animals.

For this specific project, HDT produced a working prototype vehicle that uses a hybrid diesel-electric drivetrain. The benefit of this drivetrain is that the vehicle will be able to operate longer distances for greater time at a lower cost. An additional benefit is that the vehicle will be able to maneuver several kilometres at a time in a “silent-drive” mode, using only electric power, which will make the vehicle much less likely to frighten livestock and cause injury.

2 Project objectives

Create a *proof-of-concept* prototype that will develop a hybrid diesel/electric drivetrain to integrate with HDT's unmanned vehicle to:

1) extend its range,
2) increase its mission duration,
3) reduce its operating expenses by lowering fuel use, and
4) allow the vehicle to operate in a nearly silent, electric-only mode when it is around livestock in order to lower the risk of startling the animals and causing injury.

3 Methodology

The project is outlined by five (5) main activities/tasks, those being:

1) Product definition – customer driven design; HDT/MLA will establish an Australian producer steering group to *determine required outcomes* for the vehicle
2) Develop – design/develop prototype vehicle
3) Fabricate – build a prototype vehicle
4) Integrate & test – integrate and verify the system
5) Demonstrate – perform validation testing

3.1 Product definition

3.1.1 Producer Steering Committee

HDT believes in industry / customer driven design innovation. To this end HDT, through MLA, has used pre-project YouTube video (https://www.youtube.com/watch?v=e9jUiO9xuF8) to explain the pre-project development platform and have preliminary discussions about how the platform could be evolved from a military specification to an Australian agriculture specification.

The following Australian companies have expressed a desire to form the steering committee for this project:

1) CPC
    a. 5.6 million hectares (Queensland, N. Territory & Western Australia)
    b. 16 properties
    c. http://www.pastoral.com/en
2) AACo
    a. 7 million hectares (Queensland and Northern Territory)
    b. 17 properties
    c. https://aaco.com.au/
3) ACC
    a. 0.7 million hectares (Queensland)
    b. 54 properties
    c. http://www.accbeef.net.au/
4) Stanbroke
    a. 1.6 million hectares (Queensland)

b. 8 properties
c. http://stanbroke.com/

5) KPCA
   a. 36.7 million hectares (North Western Australia)
   b. 158 properties
   c. https://www.kpca.online/
6) Paraway Pastoral Co
   a. 4.4 million hectares (Victoria, NSW, Queensland)
   b. 30 properties
   c. http://www.parawaypastoral.com/

The following list of possible applications has been solicited by MLA:

1) Traverse pastures in a grid pattern and
   a. gather information about soil chemistry and moisture (i.e. Water and Soil sampling)
   b. identify where livestock are congregating (animal monitoring)
2) Delivery of supplements and/or feed to the cattle
3) Fitting with weed sensing cameras or gps points where we know weeds are and dropping or spraying chemical.
4) Monitoring and baiting of feral pests
5) Safety recovery vehicle ('man down return to base)
6) Mustering (or mustering assistance)
7) Hauling equipment (as a support vehicle)
8) Fence line integrity checking

On August 16, 2017 members of HDT, MLA, and four (4) Australian producers carried out the first *Steering Committee* meeting (via teleconference) and reviewed the current design parameters to ascertain fit for purpose and also continued to develop the list of potential future uses.

3.1.2 Performance Requirements

As the project goals were non-specific in the technical and performance requirements of the system, the identification and selection of ***Key Performance Parameters*** (KPP) and ***Key System Attributes*** (KSA) at the outset of the project was a priority. The envisioned use case was defined and analysed to determine the base KPP's and KSA's required to meet the end users' needs. As the technology being developed for this project will also be utilized outside the meat and livestock industry additional criterion were considered for the KPP's and KSA's. As its primary use will be with the US Army, input from that customer was gathered and included in the design.

3.1.2.1 KPP's and KSA's

The information presented in **Error! Reference source not found.** below represents the KPP & KSA's selected by HDT as design goals for the development of the system. These parameters are primarily driven by the military program the system is intended to serve. Some of these lines are not relevant to crossover into agricultural markets while some of them will serve this secondary use case quite well. Take note that the requirements bound only the lower ends of performance and actual system performance may greatly surpass these marks. In particular, range of 60 miles is considered to be under the absolute worst case condition of carrying a full 1,000 lb (454kg payload, exporting maximum power, driving in worst terrain and only using internal fuel storage (no range extending tanks). Actual range under average cases will be much greater.

Once the KPP's and KSA's were selected and defined, specific derived requirements for the system, and its sub components, were identified.

3.1.2.2 System Level Design and Key Component Identification

Research into current hybrid drive systems and analysis of their pros and cons was used to select the appropriate system architecture to meet the KPP's and KSA's. System operating states were identified and defined and the flow of energy between the system sub components was diagrammed for all states. The key sub components were identified from the system architecture block diagram.

3.1.2.3 Trade Study

With the key sub components identified from the system architecture block diagram research into available components in the commercial trade space was conducted. Specifications for components was collected and analysed to grade the components against each other to select samples appropriate for this project. The cost, availability, performance, size, mass, environmental rating (IPxx) and interfaces of each component was considered.

The three key system component for the hybrid drivetrain were determined to be the engine/gen-set, the battery bank, and the drive motors. Refer to Appendix 7.2 to see the data gathered to weigh the competitive markets for those systems. All factors considered, the following selections were made. The gen-set will be procured from Polar Power, a 30kw output system utilizing a Doosan D18 engine. The battery bank was constructed from lithium ion modules.

System performance calculations were done during and after component selection to validate that the KPP's would be achieved. Of particular interest to this project were calculations on system range under various conditions. The proposed internal fuel tank will allow the system to reach a mission range of 60 miles (96.5 km) minimum under worse case conditions, i.e. fully loaded with 1,000 lbs (454 kg) and in unfavourable terrain conditions. **In favourable conditions, lightly loaded and on mild terrain, average range was calculated to be >250 miles (400 km) with best cases ranges passing the 300 mile (480 km) mark.**

3.2 Develop

3.2.1 Mechanical Design

The requirements and models of the components that resulted from the product definition phase were collected and integrated into a complete system conceptual design. Some of these component models were able to be provided by the manufacturers while others needed to be created using data sheets and 2d drawings. The mechanical interfaces were identified as well as the recommended mounting orientations and mechanical requirements to incorporate into a system.

Additional considerations for air and liquid cooling of some of the components was also considered.

Solidworks was used as the software package to develop the system design. As components were down selected based on trade studies, 3D models were generated to insert into the top level system model for system integration. Additional space claim models were also generated for components that have not yet been down selected, and space allocated for those models so a chassis could be designed and built around the components and space claims. We conducted several Finite Element Analyses (FEA) on the system and chassis using estimated loads, component weights, and environmental load cases based on previous field tests to determine if the chassis and system was sufficiently robust. A cooling analysis has also been underway to determine the necessary amount of heat the system would generate under varying conditions, and a sufficient radiator cooling system designed to meet these conditions.

3.2.2 Electrical Design

All of the systems required electrical components were taken from the system block diagram (**Error! Reference source not found.**) and information about their electrical interfaces were collected. A system schematic was created detailing the connectors, wire conductors, routing lengths and bundling information. Calculations on wire sizing for the correct current handling capability of the high power conductors was performed to identify the correct wire gauges.

The system control architecture layed the foundation for the high level electrical wire interconnects between the various subsystems. Our system integrates a main vehicle controller that serves as the master controller, with overriding control over various subsystems. Each subsystem was broken down into separate wiring diagram pages and details were broken out down to the connectors and wire bundles. The wiring document breaks down the various power buses and grounding locations. Our system will have an isolated high voltage DC bus, while the lower voltage buses will share a common ground. Safety was key in the development and fuses, circuit breakers, relays and contactors were integrated to provide various levels of electrical shock protection.

The user will have access to electrical interfaces through two (2) NATO connectors for 28VDC offload power and 120VAC through a standard NEMA 5-15R. Safety E-STOPs will also be made accessible both on the vehicle itself and on the wireless controller. Additionally, a ignition key switch which will serve as an ON switch will be provided on the vehicle. External system indiciators will also be provided to inform the user of battery state of charge, communication integrity to the wireless controller, and system faults.

3.2.3 Software Design

The datasheets of the control components selected were reviewed and the communication protocol and message structure for each component was collected. A communication document was compiled capturing all the required commands to control the various components. A software flow chart was developed that described the user input and system set points that would initiate state changes of the control system. The states of the system were defined.

The vehicle will operate in a various modes as illustrated in the state diagram . During normal operation the unit will be in the standby, stealth, or hybrid states. In standby the unit is parked and provides offload power to payload and power to accessories, etc. While in standby the on-board generator can be started to charge batteries but only under strict user control.

When not parked (i.e. in standby) the vehicle can move in either the stealth or hybrid mode. In stealth mode the vehicle and payloads operate solely from onboard battery power and the generator will never start. In hybrid mode the vehicle still operates from battery power but the generator will automatically start to recharge batteries once a minimum state of charge threshold is reached. The vehicle will be powered from both generator and batteries (as needed) during recharging and the generator will remain on until the batteries are fully charged or until the user commands it to stop. While in hybrid mode a user may at any time initiate battery charging by turning on the generator to top off batteries.

The vehicle will offer a number of features to enhance its safety and operation. An emergency stop (E-Stop) button will be provided to enable immediate disabling of the systemThe system will also provide user controlled lighting in the front and back as well as offloaded 28VDC power and USB convenience charging ports.

3.2.3.1 Software Flow Chart and Communication Protocols

Software development resulted in a preliminary design based on using a real time operating system supported by the vehicle controller. Software functionality was divided in separate units (i.e. tasks) that will operate with apparent concurrency in the system controller. These tasks and their relationships were documented in a data flow diagram . Each task will execute based on an assigned priority such that critically important functions take precedence over others. For instance, controlling vehicle movement via motor control will be more important that fetching data from the generator.

Communication protocols were dictated by the components selected for use in the system. Components that do not offer a data interface will provide feedback to the controller as discrete digital inputs or analog signal inputs. The controller will also provide control using discrete digital outputs.

3.3 Fabricate

3.3.1 Procurement

All components specified in device’s BOM(Bill of Materials).

3.3.2 Fabrication

Mechanical structures and required bracketry were fabricated to mount all components. Specifically, the vehicle chassis, sponsons, and sheetmetal skin were fabricated and fitted. Additional bracketry for the mounting of components were cut, bent, welded and fitted.

Wiring harnesses between the electronics components were fabricated or constructed from modified COTS provided harnesses.

3.3.3 Software

Base software code was written and individual components have been bench tested. The software is ready for full system integration testing.

3.3.4 Assembly

Fabricated pieces, purchased off-the-shelf (OTS) mechanical components, and custom electrical harnesses were assembled into a full system.

Figure 3 – Picures of the device during fabrication.

3.4 Integrate

The assembled hybrid drive system and its sub components were integrated with the software and debugged within the full prototype vehicle.

Wiring was debugged through a process of point to point continuity checks cross referencing shematics. Visual inspection of all connections combined with torque checks where applicable for interfaces was performed. As interconnects were verified as being correct they were marked with paint pens as a way to track quality control.

Software systems feature sets were integrated incrementally and tested for interaction with previously implemented features. All integration testing was carried out with the system elevated on blocks for safety. Proper response of the battery driven system was implemented first then the additional application of the automated hybrid recharging of the battery was implemented.

Figure 4 – Pictures of the device during integration.

3.4.1 Testing

Testing of the full system across a range of terrains and load cases was performed. Telemetry data was collected for analysis.

Full rolling system prototype was rigorously tested in suitable comparative environments and at wide range to loads and duty cycles. Several test sites were located to test the system for audio signature, fuel efficiency, load carrying capability, off-road performance, thermal management, and transportability.

Figure 5 – Pictures of the device during internal testing.

3.5 Demonstrate

On September 14, 2017 HDT hosted MLA representatives Nick Sangster and Rob Williams at our Fredericksburg, VA facility. The visit included a live demonstration of the proof of concept vehicle showing its different hybrid operating states as well as the general capabilities of the vehicle.

4 Results

4.1 Test Data

Utilizing controlled test sites and procedures HDT was able to obtain the the following performance characteristics of the *proof-of-concept* system:

- Rated payload capacity = 453.5kg (1000lbs)
- Slope accend/decend, forward/reverse, with max payload = 60%
- Lateral slope with max payload = 30%

- Water fording depth = 60cm (24in)
- Max speed = 30kph
- Gap Crossing with max payload = 76cm open gap (30in)
- Tow speed = 80kph (50mph)
- Fuel consumption, max payload, improved road, 10.5kph
- Fuel consumption, max payload, unimproved road, 6kph
- Fuel consumption, max payload, off-road dense forest, 2.8kph

4.2 Video

The links below are to videos demonstrating the functionality of the prototype vehicle. Shown in the video are the off-road terrain capabilities. All validation tests were done with the full payload, 450kg, on the payload deck.

All links go to the same video, just different resolutions.

- http://www.stratbot.com/video/Hunter_WOLF_Fort_Benning_1080p.m4v
- http://www.stratbot.com/video/Hunter_WOLF_Fort_Benning_720p.mp4
- http://www.stratbot.com/video/Hunter_WOLF_Fort_Benning_640x360.mp4

5 Discussion

All the project objectives were achieved, see the table below.

Project Objective	Protector (precursor)		Hunter Wolf (Hybrid drive train)	Comments
Extend its range	100km	→	400km	Flat road
Increase its mission duration	33hrs	→	65hrs	@ 5kph
Reduce its operating expenses by lowering fuel use	32.5L/100km	→	13.4L/100km	Flat road. Proof of concept can offload power without burning fuel → hybrid
Allow the vehicle to operate in a nearly silent mode	82db @ 10m	→	Proprietary	Protector had to run engine continuously

6 Conclusions/recommendations

HDT believes it has successfully completed the development of a proof-of-concept prototype vehicle, demonstrated its feasibility, and achieved its objectives. Given that, and the feedback and interest of the Steering Committee HDT recommends that the project continue on to the creation of an "experimental" prototype that will:

6) extend its range and further increase its mission duration via the addition of a larger – secondary - fuel tank,
7) incorporate an autonomous navigation controller,
8) integrate waypoint GPS navigation software and operator interface,
9) integrate video streaming and/or local recording,

10) integrate basic obstacle avoidance such as auto stop.

HDT also recommends traveling to Australia to visit with various ranchers including cattle and sheep stations in order to better understand not only the tasks that an autonomous range management vehicle could add value to but also to observe the environment/terrain and how those tasks are being performed now. HDT's Directors would also take advantage of that opportunity to meet with members of the ARM-V steering committee meeting, as available.

7 Appendix

7.1 Data Sheets

7.1.1 Protector

HDT PROTECTOR

Squad Multipurpose Equipment Transport (SMET)

HDT's Protector is a rugged load-carrier for dismounted infantry. Closely matching the mobility of infantry, the Protector can traverse narrow trails, steep slopes, and dense jungles. Using only internal fuel, the vehicle has a 100 km (60 mile) range and 72 hour endurance. The new series electric hybrid version adds a "silent drive" capability.

Since 2012, the Protector has proven itself in more than a dozen evaluations with the US Army, Marine Corps, and SOCOM. The Army Test and Evaluation Command has awarded numerous Safety Releases for military units to operate the system.

The Protector's ruggedness and simplicity make it very affordable. The system's modular architecture and full compliance with the Army's interoperability protocols makes the vehicle easy to upgrade, using a wide variety of missions kits, and also keeps life cycle costs low.

KEY FEATURES

- Rugged design, developed by HDT specifically for these demanding conditions. Meets MIL-STDs.
- Carries up to 450 kg (1,000 pounds) 100 km (60 miles) using internal JP-8 or diesel.
- 72 hours of operations without resupply.
- Exports kilowatts of power, while on the move or while halted to supply a small base camp.
- Modular architecture, open interfaces, and full compliance with the Inter-Operability Protocol (IOP).
- New series electric hybrid powertrain provides a "silent drive" capability.
- Demonstrated mission kits include:
  - Remote weapon station firing M240B, M134, and M2
  - Flail and mine roller for dismounted route clearance (won JIEDDO Dismounted Route Clearance Competition)
  - Lightweight Expeditionary Bridge, spans 36 feet, deploys in 25 minutes
  - Backhoe/Loader, digs two-man fighting position in 30 minutes, fills double-stacked Hesco in an hour.
  - Follow-Me kit, works in GPS-denied environments
  - Dual stretcher mounts for CASEVAC

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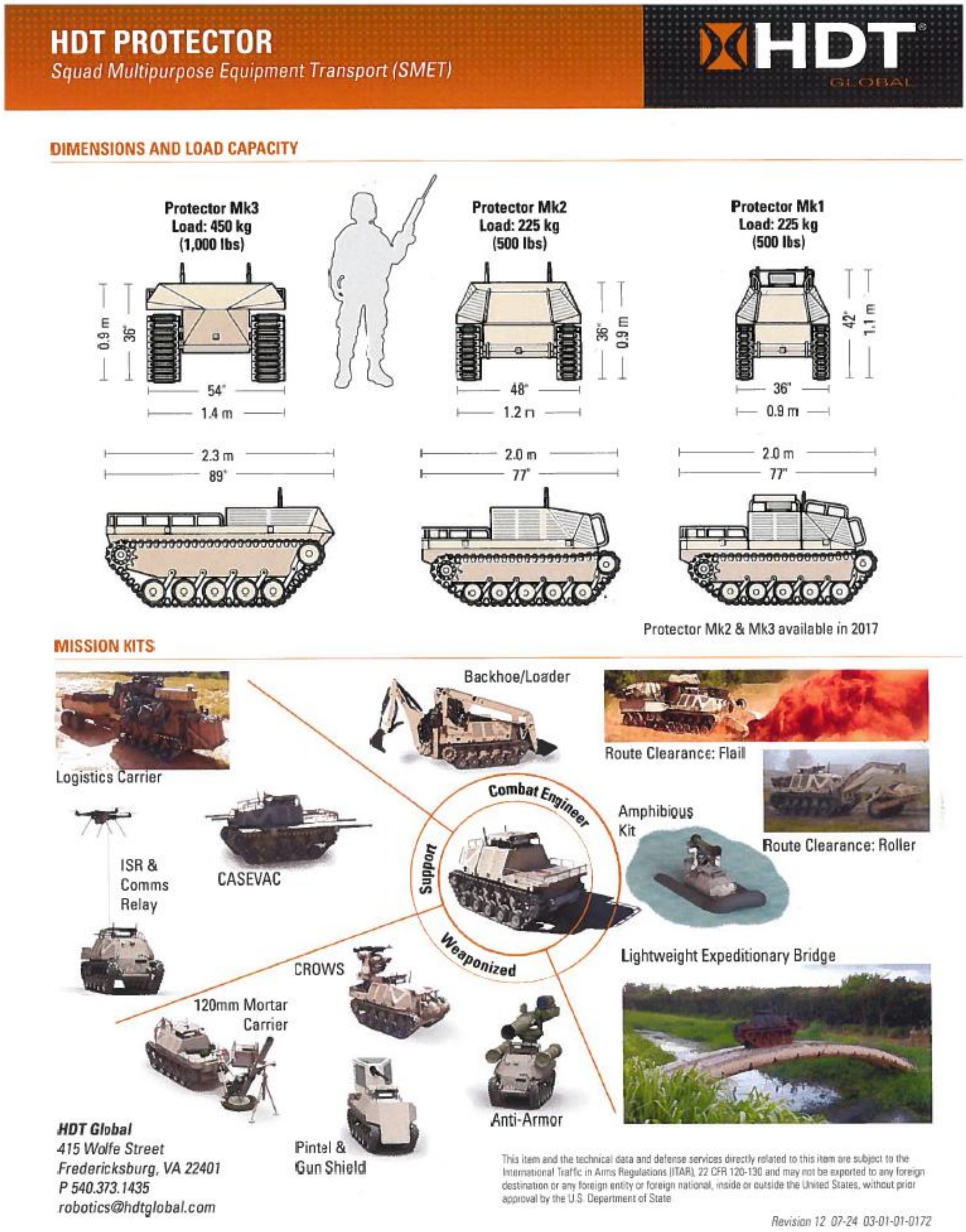

7.2 Component Tradestudy

7.2.1 Engines

7.2.2 Batteries

7.2.3 Motors