U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – GROUND VEHICLE SYSTEMS CENTER

Next Generation NATO Reference Mobility Model (NG-NRMM)

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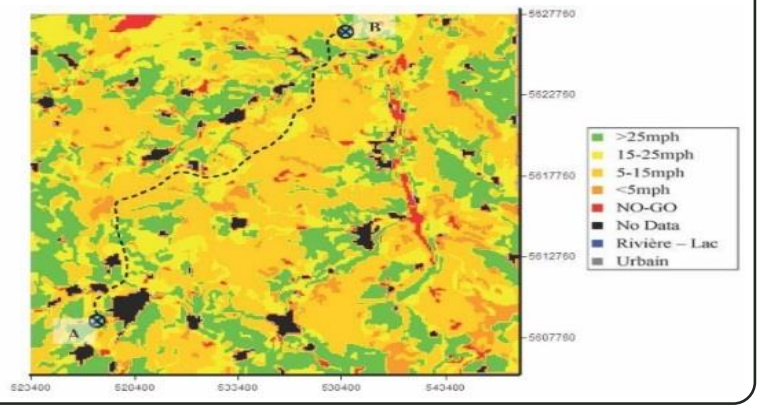
Mobility Challenges

Mobility Go/NoGo Map



MOTIVATION: OFF-ROAD GROUND MOBILITY

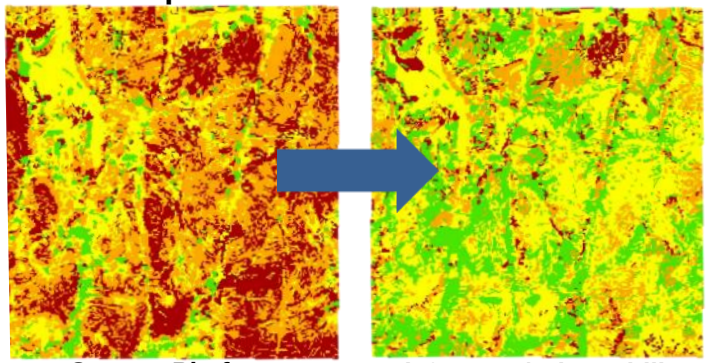
- **Army developed first mobility model in 1960s**

- **Applications**
  - Operational analysis
  - Acquisition
  - Design

- **Inputs**
  - Vehicle data
  - Terrain maps (soil, topography, vegetation, roads & obstacles)
  - Terrain properties
  - Scenario data/weather effects

Advanced Mobility Technology enables Increased terrain access at higher speeds

Representative Area of Interest

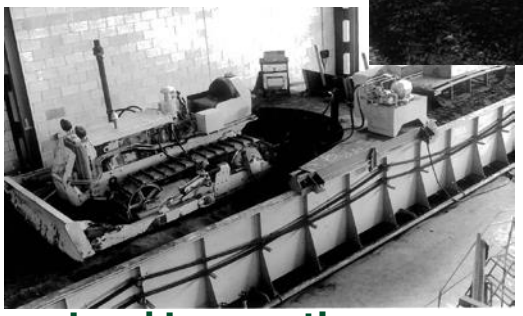


Current Platform
NOGO: 22%, V50: 10 mph
Current Bradley

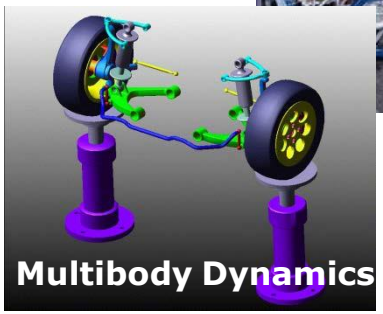
Plaftorm w/Adv Mobility
NOGO: 6%, V50: 15 mph
Bradley w/Adv Mobility

NATO Reference Mobility Model (NRMM)

Marsh Buggy



Land Locomotion



Autonomous Systems

1954 – Land Locomotion Lab established; led by Dr. Bekker

1971: AMC-71 Mobility Model

1974: AMC-74 Mobility Model

1978: NATO Reference Mobility Model

1992: NRMM II

2014: ET148, NG-NRMM

2016: RTG248 NG-NRMM

2020: NG-NRMM STANREC

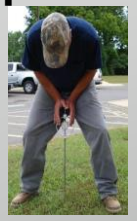
1950 1960 1970 1980 1990 2000 2010 2020

The Effort with NATO

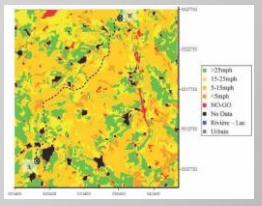
EMPIRICAL VS. PHYSICS-BASED APPROACH

NRMM (Empirical)

Vehicle Terrain Testing

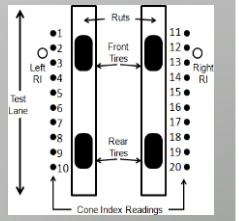


Cone Penetrometer

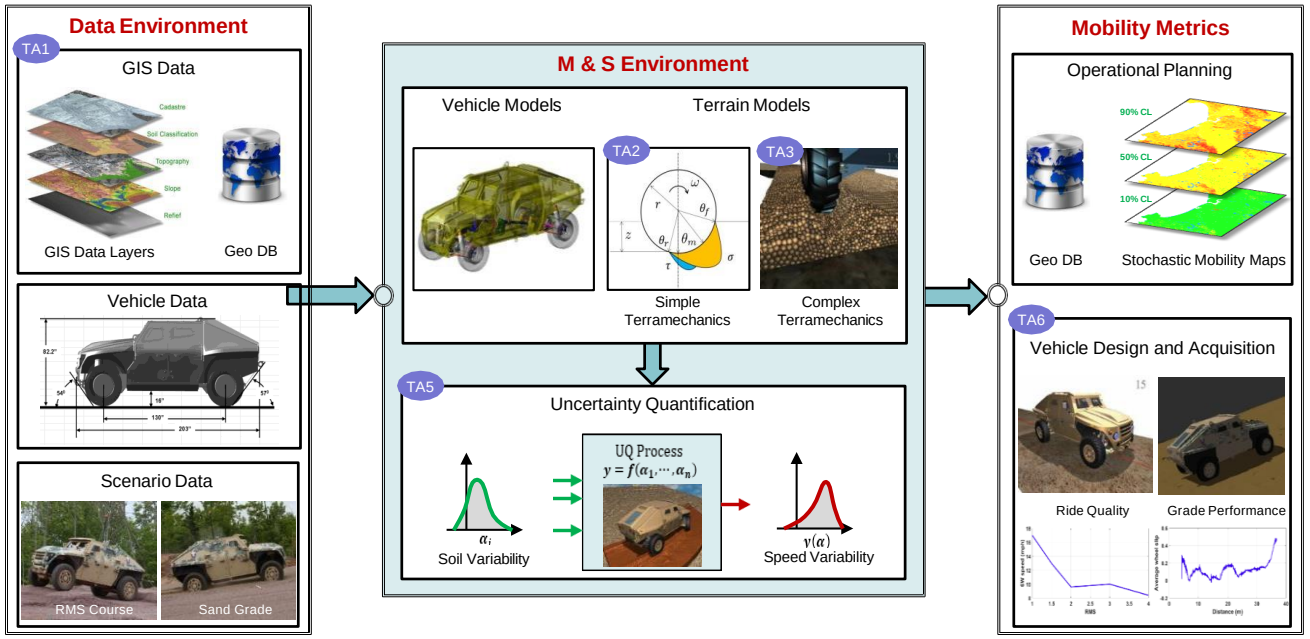


Speed-Made-Good Map

Vehicle Cone Index



NG-NRMM (Physics-based)



Physics-based modeling

- Supports 3D models
- Considers vehicle dynamics
- Enables prediction for in-design mobility systems
- Exploits advantages in simulation and computational capabilities
- Provides uncertainty-based information

Next Generation NRMM

NATO Applied Vehicle Technology Panel (70 Members, 15 Nations)

- Exploratory Team (ET-148) lasted from April 2014 - Dec. 2015
- Research Task Group (AVT-248) running from Jan. 2016 - Dec. 2018
- Research Task Group (AVT-327) running from Jan. 2018 - Dec. 2021

Goals

- Develop and demonstrate NG-NRMM - process & technologies
- Incorporate NG-NRMM as a NATO Standard
- Conduct Verification and Validation benchmarking studies
- Demonstrate technologies through CDTs

AVT Participants

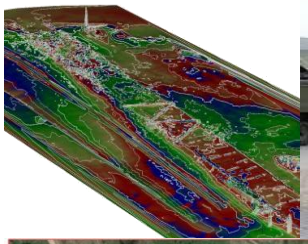
- **ET-148**: BAE, NATC, Lockeed-Martin, ESRI, NASA JPL, ESRI, DRI, ASAC, Alion, Univ Alabama Birmingham, Colorado State Univ., Mississippi State Univ., Mass Institute of Technology, U.S. Army: GVSC, ERDC, ERDC CRREL, Aberdeen Test Ctr., AMSAA, **International – 21 members/12 nations**

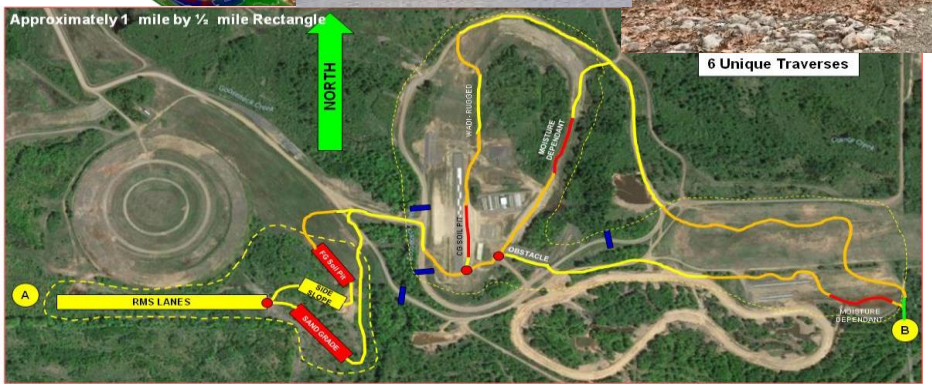
- **AVT- 248**: BAE Systems, NATC, Ricardo Defense, Lockeed-Martin, ESRI, NASA JPL, Oshkosh Truck, RAMDO, ASAC, Alion, Michigan Tech Univ., Univ Alabama Birmingham, Colorado State Univ., Univ. Illinois Chicago, Univ. Iowa, Univ. Wisconsin Madison, U.S. Army GVSC, ERDC CRREL, Aberdeen Test Ctr., AMSAA, **International – 30 members/15 nations**

- **AVT-327**: BAE Systems, Oshkosh, MTU/KRC, Michelin, RAMDO, NATC, NASA JPL, ASAC, Alion, DRI, Univ. Wisconsin Madison, Colorado State Univ., Univ. Alabama Birm, Miss State Univ., Univ. Iowa, Embry-Riddle Univ., U.S. Army: GVSC, ERDC, ERDC-CRREL, AMSAA, **International: 24 members/9 nations**

NG-NRMM AVT-308 CDT-1

MTU/KRC, Houghton, MI, USA, 25-27 September 2018





Scope

- Showcased NG-NRMM's enhanced mobility prediction capabilities and demonstrated vehicle mobility performance using hardware and in the virtual domain
- Software vendors/developers:
  - Advanced Science and Automation
  - CM Labs Simulations
  - MSC Software
  - Aarhus University
  - South African CSIR Defense

- NRMM consistently over predicts S-M-G for all segments. Average value of over prediction is 75%
- NG-NRMM over and under predicts S-M-G. Average value of over / under predictions 6.2%

Impact and Exploitation: DOTMLPFI

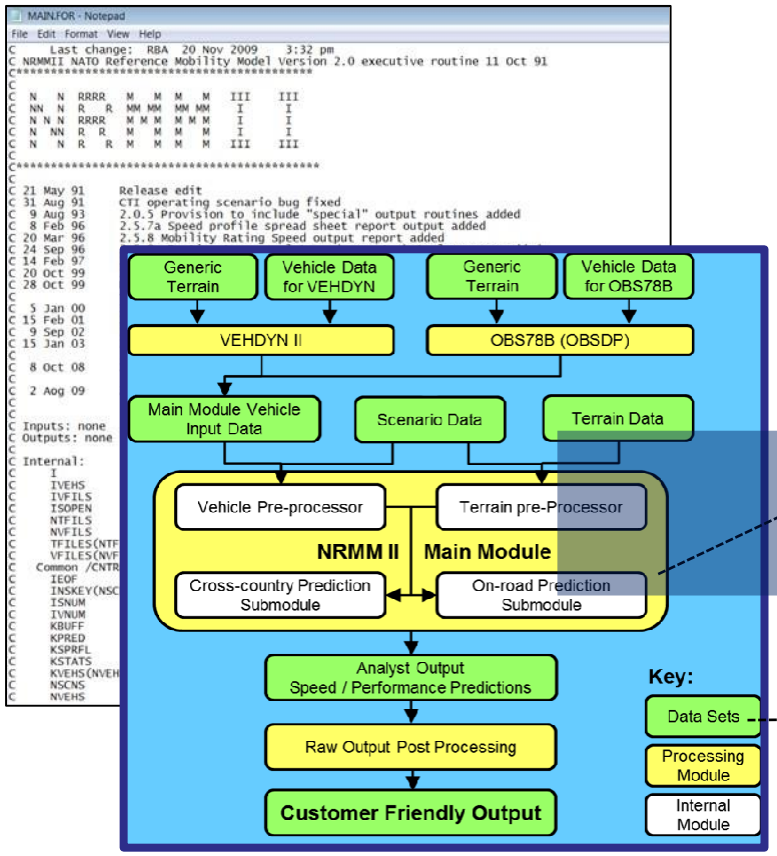
- The CDT demonstrated accurate and verifiable M&S solutions to ground vehicle mobility
- The results of the CDT energized the terramechanics community to further development and refinement of mobility solution predictions

CDT-1 Takeaways

- **Confirmation that NG-NRMM is Capable of Performing Mobility Simulation**
- **A complete set of vehicle data, terrains/courses, benchmarking/validation data, instrumentation/test plans, photos, and videos available at**
  ftp://ng-nrmm:thread$panel@nrmm.mtukrc.org

Test Name	Terrain
1 Straight Line Acceleration and Braking (TOP 2-2-602)	Pavement
2 Wall to Wall Turn Circle Radius	Pavement
3 Steady State Cornering (30 m radius) (SAE J2181)	Pavement
4 NATO Double Lane Change (AVTP 03-160 W)	Pavement, Gravel
5 Max. Side Slope with Sinusoidal Steer & Obstacle Avoidance	Hard-Packed Crushed Mine Rock
6 Maximum Longitudinal Grade	Pavement, Coarse Grain Sand
7 Vertical Step: 12", 18", 24"	Concrete
8 V-Ditch	Concrete
9 Half-Round Obstacle: 4", 8", 10", 12"	Pavement
10 Symmetric Random Roads: 1", 1.5", 2", 3", 4" RMS	Hard-Packed Crushed Mine Rock
11 Asymmetric Random Roads: 1", 1.5", 2" RMS	Hard-Packed Crushed Mine Rock
12 Soft-Soil Mobility: Drawbar Pull	Course Grain Sand Fine Grain Organic/ Silty Sand: Dry & Wet
13 Mobility Traverse	Composite of Natural Terrain & Engineered Courses

NG-NRMM is a Standard Not a Specific Computer Code



Next Generation NATO Reference Mobility Modeling Standards

GIS Based Input and Output

Mobility Metrics:

Speed Made Good
GO/NOGO
Fuel Economy

Terramechanics Models
Uncertainty Quantification
Autonomous Vehicles

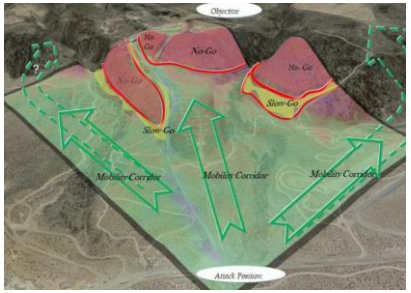
Legacy Terrain Files and Updated Terrain Data Format

V&V Maturity Scale and Benchmarks

Existing Standards (AVT, ITOPS,GIS, etc)

NG-NRMM CDT-2

Test Center for Vehicle Mobility (WTD41), Trier, DEU, 17-19 May 2022



Scope

- Showcase the enhanced mobility prediction capabilities of the NG-NRMM
- Test Vehicles
  - Marder A3 IFV (Tracked)
  - Boxer 8x8 Multirole Vehicle
  - M29 Weasel (Tracked)
  - Milrem THeMIS (Tracked Hybrid Modular Infantry System, remote controlled UGV)

Topics to be covered:

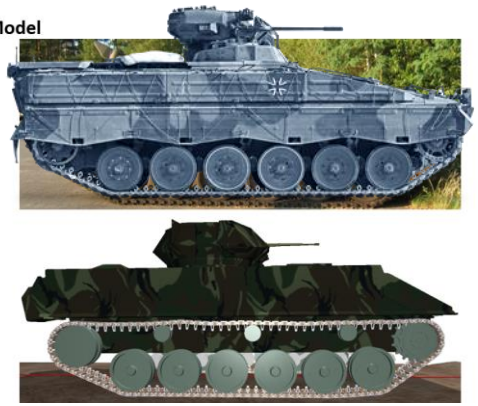
- M&S Tools and new applications to support Military Planners, Acquisition and Vehicle design
- Terramechanics, soil measuring and M&S methods
- Demonstrate vehicle mobility performance using tracked and autonomous vehicles on real test terrain as well as in virtual domain

Impact and Exploitation: **DOTML**PFI

- CDT results / STANREC will have an influence across NATO in the further development of NG-NRMM applications
- Wider NATO use in operational planning, and implementation in driver mobility assistance systems
- NG-NRMM / CDT results will be used in future multinational development programs

Expected Results

- The CDT results will solidify the NG-NRMM and STANREC activities and will be used by NATO autonomous workgroup(s)
- Demonstrate the extended usage of NG-NRMM for mobility prediction of tracked vehicles (MARDER) and of autonomous vehicle systems (THeMIS from MILREM Robotics)
- Motivate NATO nations' further development of NG-NRMM application functions and refinement of mobility solution predictions
- Energize stakeholders to make Allies aware of capabilities of new methodology

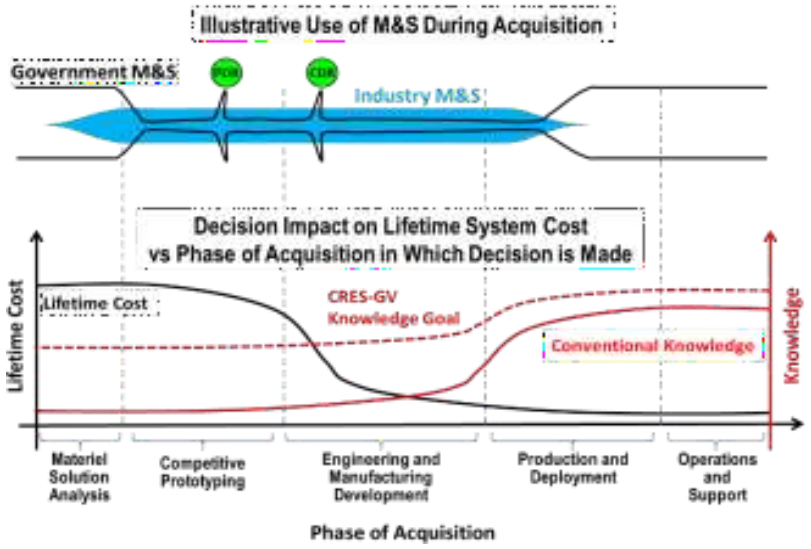


CREATE-GV Program Direction

Computational Research and Engineering Acquisition Tools and Environments

Enduring Key Program Goals:

- Enable greater and earlier physics informed performance assessments for analysis of trades in ground vehicle system development
- Enable a new ground vehicle acquisition paradigm by making sound performance data available for use in tradespace analysis
- Achieve via software tools tailored for HPCMP major shared HPC resources with unlimited government use and distribution rights



Mobility and Dynamics

- Vehicle Dynamics Performance Analysis
- Ride & Shock Quality
- Lateral Stability
- Soft Soil Performance

Vehicle Performance for Trade Space

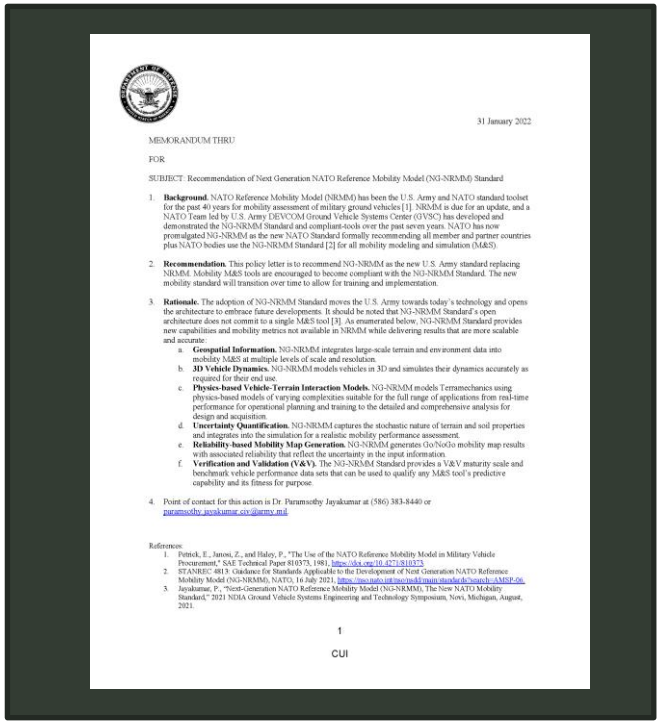
CREATE-GV Components

The CREATE-GV program is developing high-fidelity, physics-based software tools

- **Mercury:** (Flagship product) – Physics-based co-simulation tool for simulating proving-ground performance tests used as acquisition requirements
- **Mobility Analysis Tool (MAT):** Computational tool for predicting mission-level mobility performance metrics used as requirements
- **Ground Vehicle Interface (GVI):** Portal-accessible user interface providing a simplified, intuitive process to launch HPC simulations using Mercury and MAT and produce performance data required for robust tradespace analysis

Army Policy Letter

- **Efforts are also currently underway to have the NG-NRMM methodology approved as a U.S. Army standard**
- **This policy letter is to recommend NG-NRMM as the new U.S. Army standard replacing NRMM**
- **Mobility M&S tools are encouraged to become compliant with the NG-NRMM Standard**
- **The new mobility standard will transition over time to allow for training and implementation**



31 January 2022

MEMORANDUM THRU

FOR

SUBJECT: Recommendation of Next Generation NATO Reference Mobility Model (NG-NRMM) Standard

1. **Background.** NATO Reference Mobility Model (NRMM) has been the U.S. Army and NATO standard toolset for the past 40 years for mobility assessment of military ground vehicles [1]. NRMM is due for an update, and a NATO Team led by U.S. Army DEVCOM Ground Vehicle Systems Center (GVSC) has developed and demonstrated the NG-NRMM Standard and compliant-tools over the past seven years. NATO has now promulgated NG-NRMM as the new NATO Standard formally recommending all member and partner countries plus NATO bodies use the NG-NRMM Standard [2] for all mobility modeling and simulation (M&S).

2. **Recommendation.** This policy letter is to recommend NG-NRMM as the new U.S. Army standard replacing NRMM. Mobility M&S tools are encouraged to become compliant with the NG-NRMM Standard. The new mobility standard will transition over time to allow for training and implementation.

3. **Rationale.** The adoption of NG-NRMM Standard moves the U.S. Army towards today's technology and opens the architecture to embrace future developments. It should be noted that NG-NRMM Standard's open architecture does not commit to a single M&S tool [3]. As enumerated below, NG-NRMM Standard provides new capabilities and mobility metrics not available in NRMM while delivering results that are more scalable and accurate:
   a. **Geospatial Information.** NG-NRMM integrates large-scale terrain and environment data into mobility M&S at multiple levels of scale and resolution.
   b. **3D Vehicle Dynamics.** NG-NRMM models vehicles in 3D and simulates their dynamics accurately as required for their end use.
   c. **Physics-based Vehicle-Terrain Interaction Models.** NG-NRMM models Terramechanics using physics-based models of varying complexities suitable for the full range of applications from real-time performance for operational planning and training to the detailed and comprehensive analysis for design and acquisition.
   d. **Uncertainty Quantification.** NG-NRMM captures the stochastic nature of terrain and soil properties and integrates into the simulation for a realistic mobility performance assessment.
   e. **Reliability-based Mobility Map Generation.** NG-NRMM generates Go/No/Go mobility map results with associated reliability that reflect the uncertainty in the input information.
   f. **Verification and Validation (V&V).** The NG-NRMM Standard provides a V&V maturity scale and benchmark vehicle performance data sets that can be used to qualify any M&S tool's predictive capability and its fitness for purpose.

4. Point of contact for this action is Dr. Paramsothy Jayakumar at (586) 383-8440 or paramsothy.jayakumar.civ@army.mil

References:
1. Pytrick, E., Janosi, Z., and Haley, P., "The Use of the NATO Reference Mobility Model in Military Vehicle Procurement," SAE Technical Paper 810373, 1981, https://doi.org/10.4271/810373
2. STANREC 4813: Guidance for Standards Applicable to the Development of Next Generation NATO Reference Mobility Model (NG-NRMM), NATO, 16 July 2021, https://nso.nato.int/nso/nsdd/main/standards?search=AMSP-06
3. Jayakumar, P., "Next-Generation NATO Reference Mobility Model (NG-NRMM), The New NATO Mobility Standard," 2021 NDIA Ground Vehicle Systems Engineering and Technology Symposium, Novi, Michigan, August, 2021.

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Looking Forward

- **The U.S. Army is developing a tool that will be compliant with NG-NRMM standards and benchmarks called Mercury**
- **Commercial vendors have compliant software and are improving them**
- **NATO evaluating methods and approaches used to assess the mobility performance and reliability of autonomous ground systems and to establish a mobility assessment framework that would be specifically designed for assessing autonomous mobility**
- **Autonomy investments in DARPA RACER, VIPR, and ERDC/ARL/GVSC programs**
- **Near-term solution will be based on Bekker-Wong physics-based models rather than empirical assessment and far-term solution will be more advanced Discrete Element Method (DEM) models and Finite Element Models (FEM) requiring HPC**