Annex L – NG-NRMM STANDARD

Note: This Annex appears in its original format.

Standardization Recommendation (STANREC): For the Next Generation- NATO Reference Mobility Model (NG-NRMM)

CDT Meeting

KRC, Houghton MI

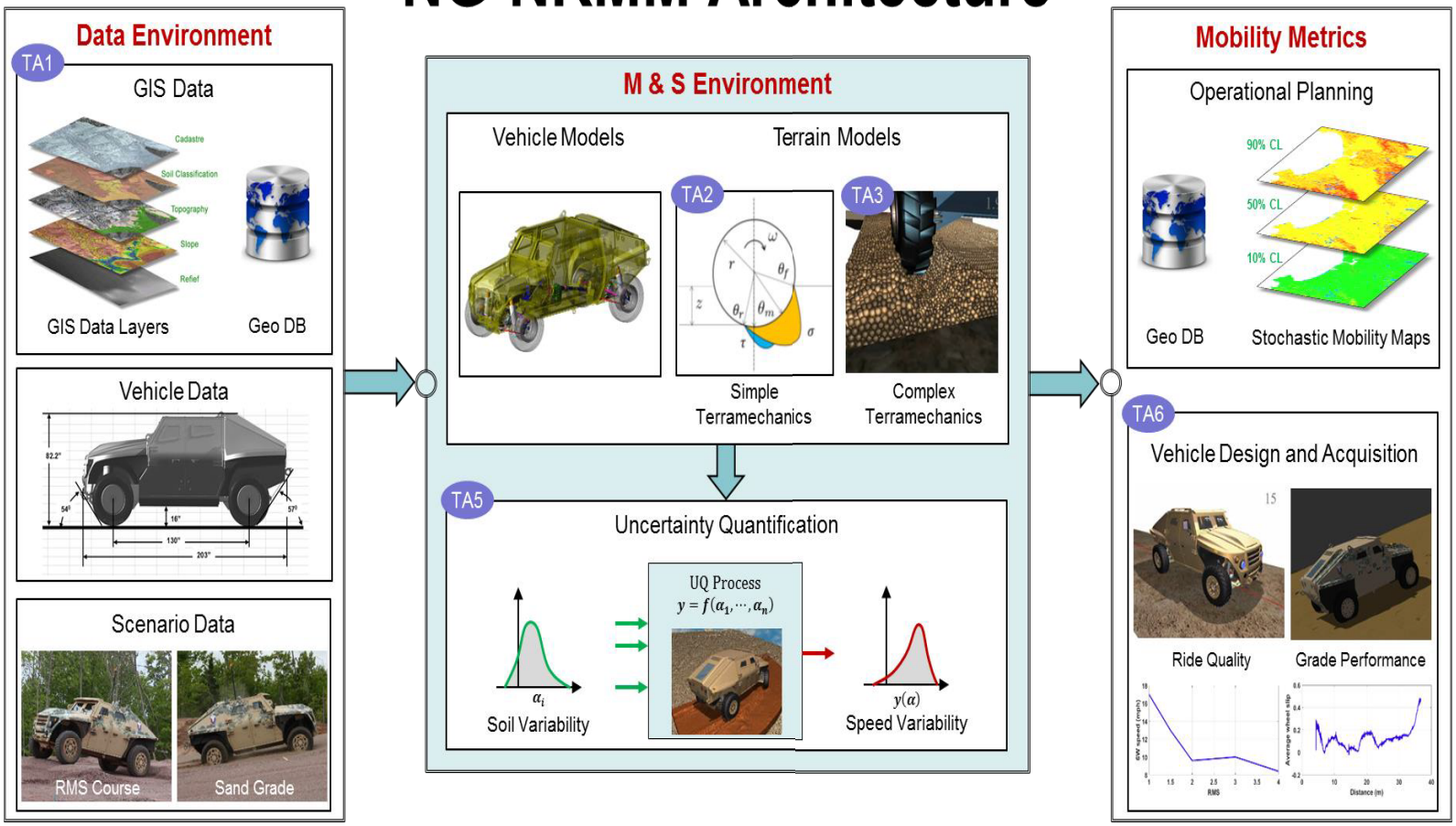
Dr. Michael McCullough
Technical Fellow
BAE Systems Inc.

September 27, 2018

Agenda

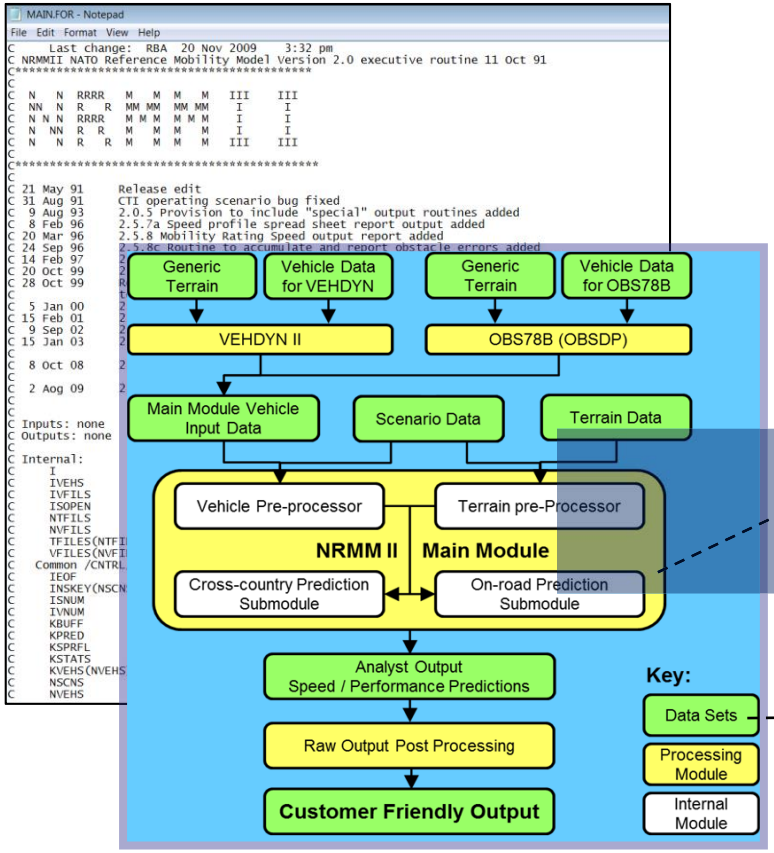
- **NG NRMM is a standard**
- **What is a NATO STANREC**
- **Objectives and Scope of Allied Modeling and Simulation Publication-06 (AMSP-06, ver 1),**
- **Current Outline:**
  - I/O
  - GIS Benchmarks
  - Terramechanics Database
  - UQ
  - VV&A
- **Enduring Support Process**
- **Conclusions**

NG-NRMM Architecture



The NG-NRMM specifications will establish a basis for VV&A of mobility M&S, guidance and benchmark data for implementation, as well as standard data schema, file formats, and mobility performance metrics (i.e., events) to support interoperability and collaboration

NG-NRMM Will Be Standards 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 & Db
  - Uncertainty Quantification
  - Autonomous Vehicles
- Legacy Terrain Files and Updated Terrain Data Format
- V&V Maturity Scale and Benchmarks
- Existing Standards (AVT, ITOPS,GIS, etc)

STANREC vs STANAG

- **STANdardization RECommendation (STANREC): non-binding document employed on a voluntary basis and does not require commitment of the Nations to implement the standards which are listed in it.**
- **STANdardization AGreement (STANAG): a policy statement is agreed by the nations to employ and implement the standards**

NG-NRMM NATO Standards

- **AMSP-06, ver 1 Standards Document: "Guidance for M&S Standards Applicable to the Development of Next Generation NATO Reference Mobility Model (NG-NRMM)", Allied Modeling and Simulation Publication-06 (AMSP-06, ver 1),**
  - *assigned by and coordinated with* NATO Modeling and Simulation Group (NMSG),
  - to be released, after NMSG review; *target date: November 2018* by AVT-248.

- **STANREC 4813, Ed 1: is a covering document that formally recommends use of AMPS-06, ver1**

- **AVT-327: Research Task Group (RTG) will establish the enduring process for development and configuration management of AMSP-06**

AMSP-06 Objectives and Scope

- **A land vehicle mobility M&S open architectural specification that:**
  - Is applicable to all land vehicle geometric scales
  - Implements GIS-based M&S methods and mobility metrics
  - Promotes Modularity, interoperability and portability
  - Is scalable M&S, embracing multiple levels of resolution: theoretically, geometrically, and numerically
  - Includes M&S verification and validation maturity scales and practical benchmarks
  - Includes standards and databases for terramechanics experimental data measurement methods that support the models

Impact and Exploitation: DOTMLPFI

The STANREC guidance codifies results of the NG-NRMM effort and establishes:

1. **An enduring artifact**
2. **A baseline as well as a development path for NATO nations mobility modelling**
    1. Methods
    2. Benchmarks
    3. Soils Database

that should be applied to physics based simulations of all operational land and amphibious mobility among the alliance.

Research Task Group: AVT-327

- **Co-Chairs**:
  - Dr. Paramsothy Jayakumar (USA)
  - Dr. Michael Hönlinger (DEU)
  - Dr. Michael McCullough (USA)
- **Panel Mentor:** Dr. David Gorsich (USA)
- **Members:** USA, CAN, CRO, CZE, DEU, DNK, EST, GBR, ITA, NLD, POL, ROU, SVK, TUR, ZAF
- **Duration:** Jan. 2019 – Dec. 2021
- **Coordination:** NMSG
- **Related activities:** AVT-248, AVT-308 CDT

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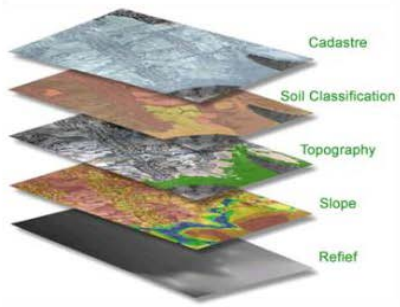
AVT248 and AVT308 have developed a detailed initial release document

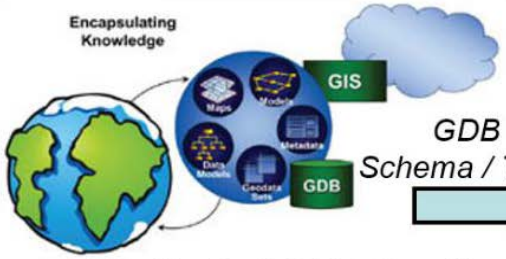
TA1: GIS Input and Output

A Potential Interoperability Approach / Workflow



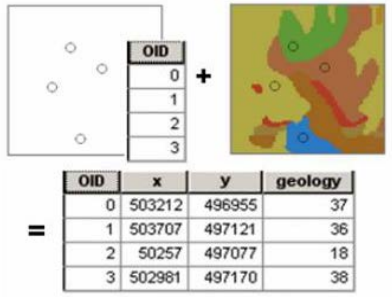
GIS Data Layers

GIS Tools / Stds



Geodatabase

GDB Schema / Tools

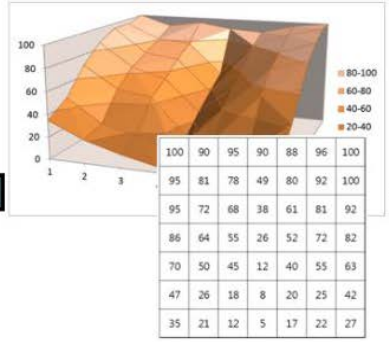


NRMM / Raster Dataset

(x, y, z, parameters 1…n)

Raster Dataset in MBD Model

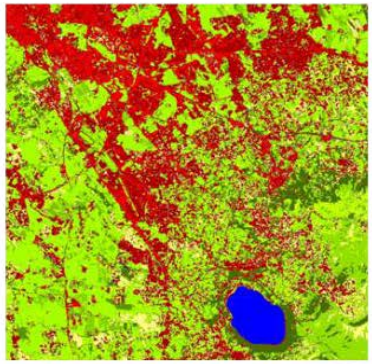
Raster Output



(x, y, z, t, parameters 1…n)

Results Raster

GIS Tools / Stds



Geodatabase / Map Product

TA1: Input Specifications

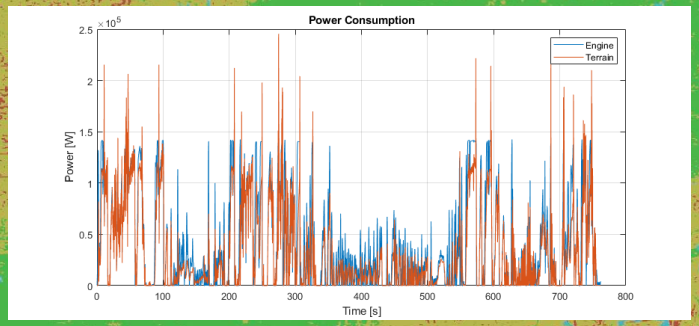
- **GIS DATA PROVIDED AS INPUT TO MOBILITY M&S**
  - Detailed list of minimal attributes for each terrain unit (NTU)
  - Feature Attribute Coding Catalog-Plus (FACC+) data m… …ma [with eventual migration to DGIWG (Digital G… Information Working Group) Featu…]
  - Legacy NRMM Code 11 …
    - The MAPTR… …at that stores geospatial d… …erent files.
      - …SCII Raster format of Terrain Units (NTUs) and their spatial
      - …PRJ file which stores the geospatial coordinate system description of the .ASC file.
      - *.TER file which stores the attribution of each NTU.

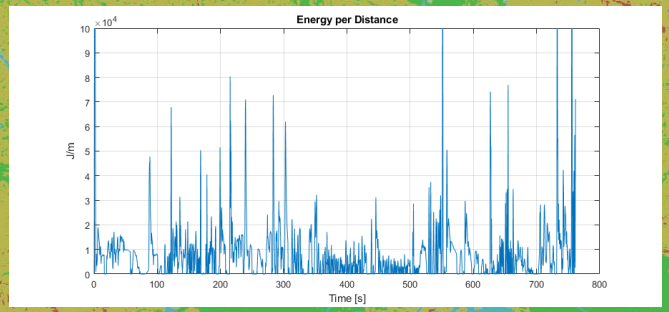
CDT has identified an additional high resolution level of Terrain Modelling that requires additional detailed Specification

- **OPTIONAL SCENARIO DATA FILES (same as terrain format)**

TA1: Output Specifications

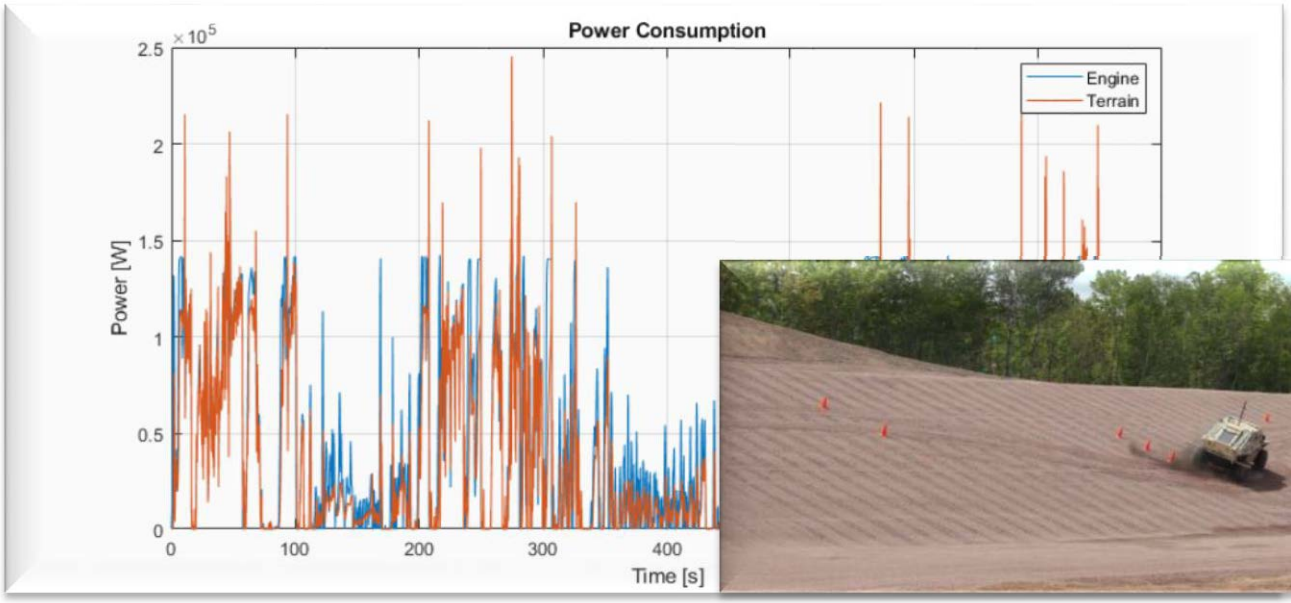
- **Mobility Metrics shall be computed and mapped to NTUs**
  - ***Go/NoGo*** and ***Speed-Made-Good and <u>Fuel Economy</u>***
    - ***Custom algorithms for aggregating multiple mobility metrics***
    - ***ReasonCodes***
    - ***A Useful Point of Reference: Legacy NRMM Operational Module***
  - **Formats**
    - GEOTIFF
    - ASCII



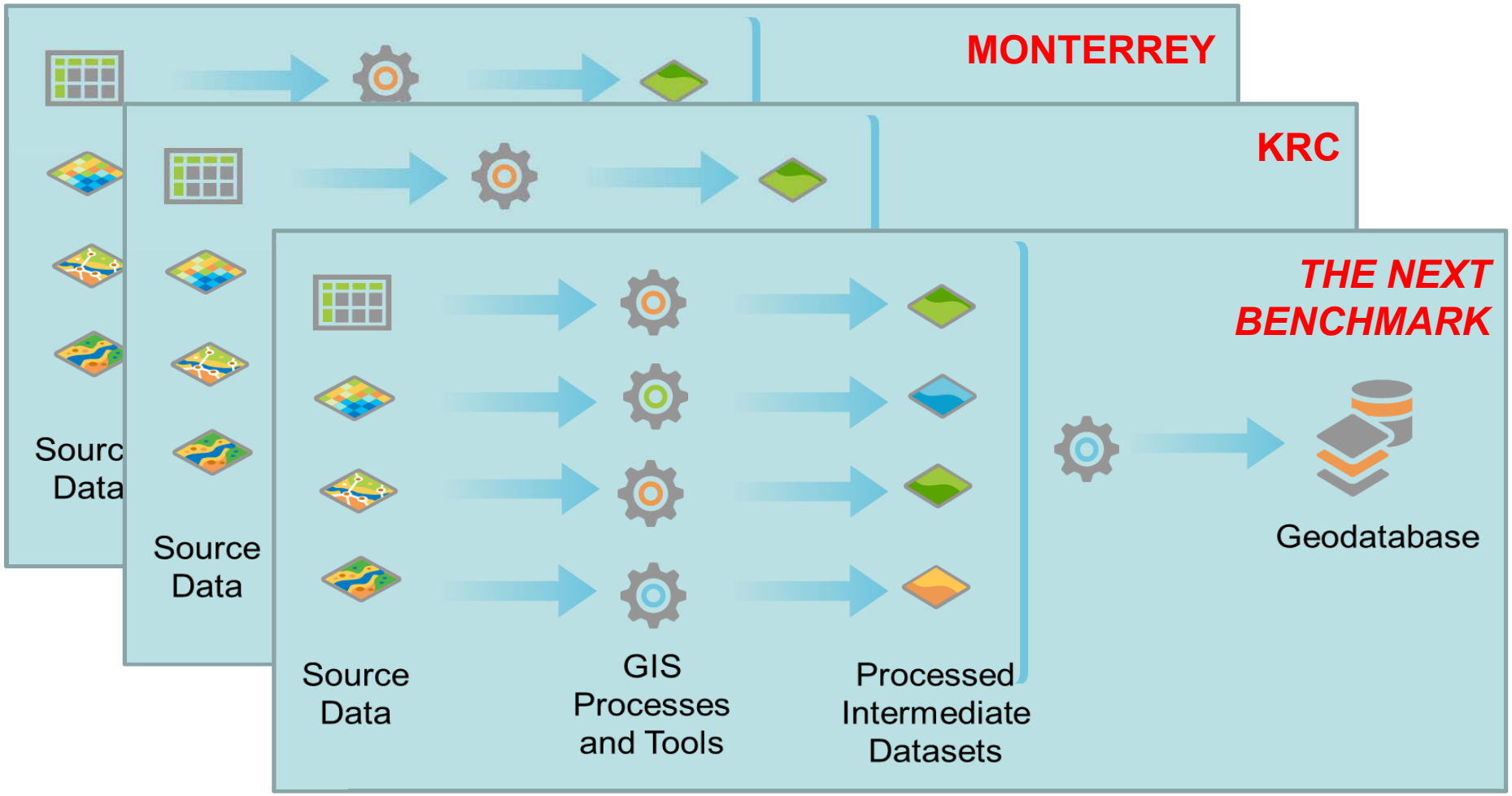


TA1: Output Specifications

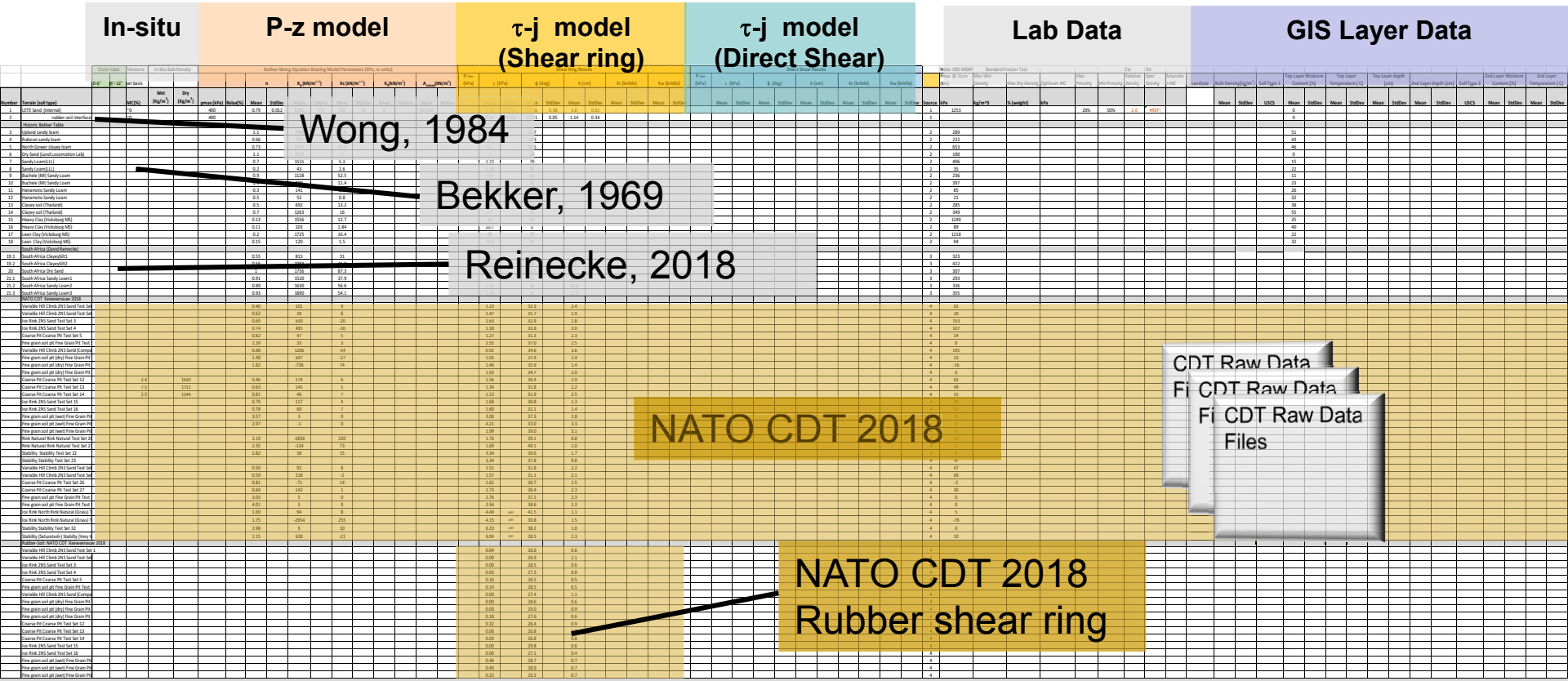
- ***<u>Fuel Economy</u> : CDT data has shown that NG-NRMM models can capture Terrain Specific Fuel Economy metrics including major influences such as turning***



Catalog of NG NRMM GIS Benchmarks

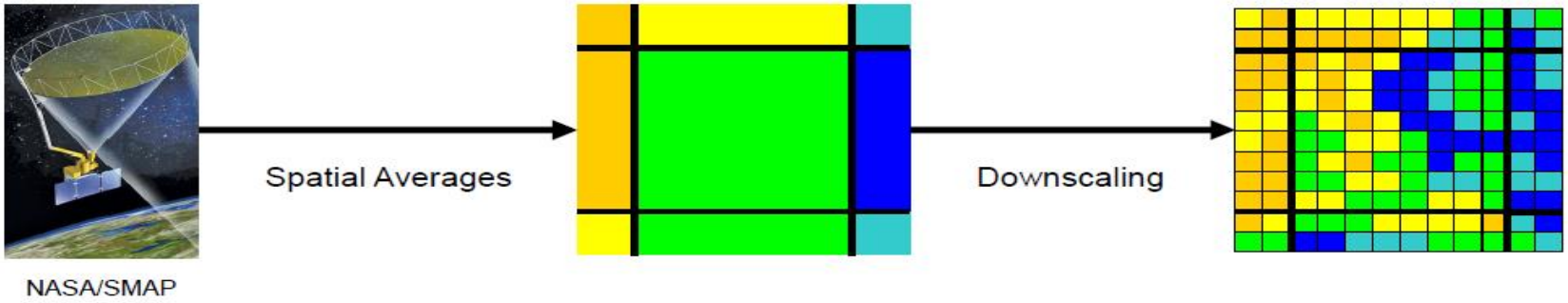


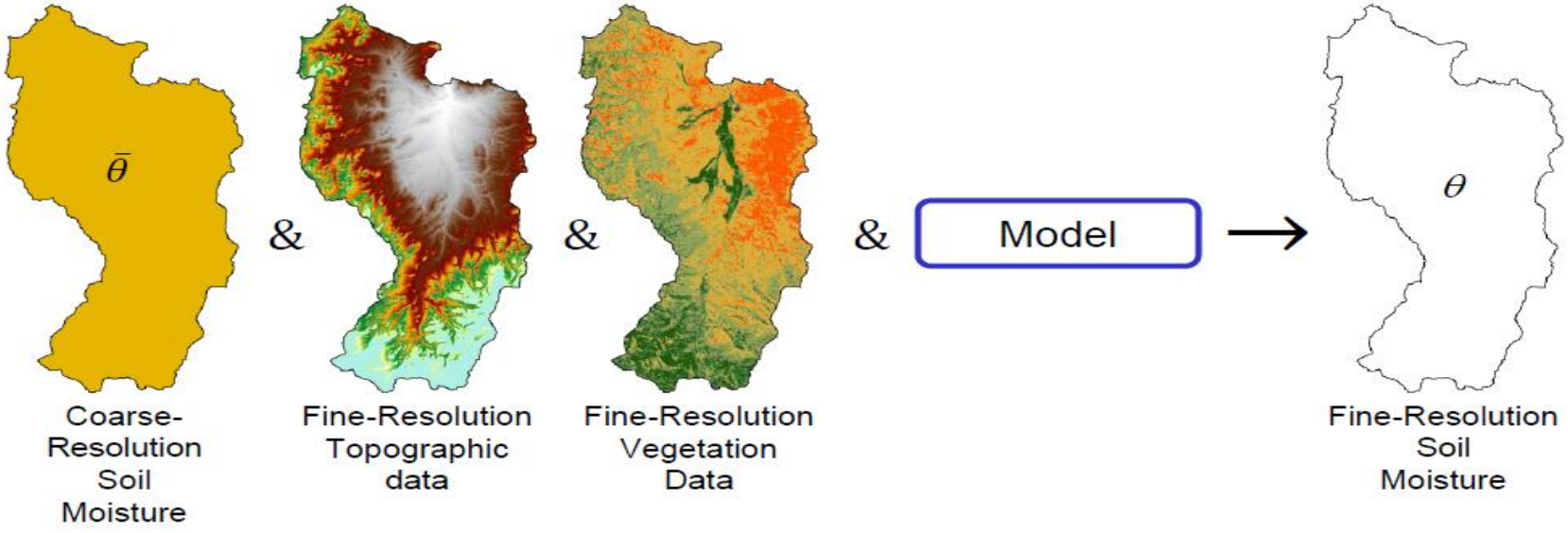
Terramechanics Database



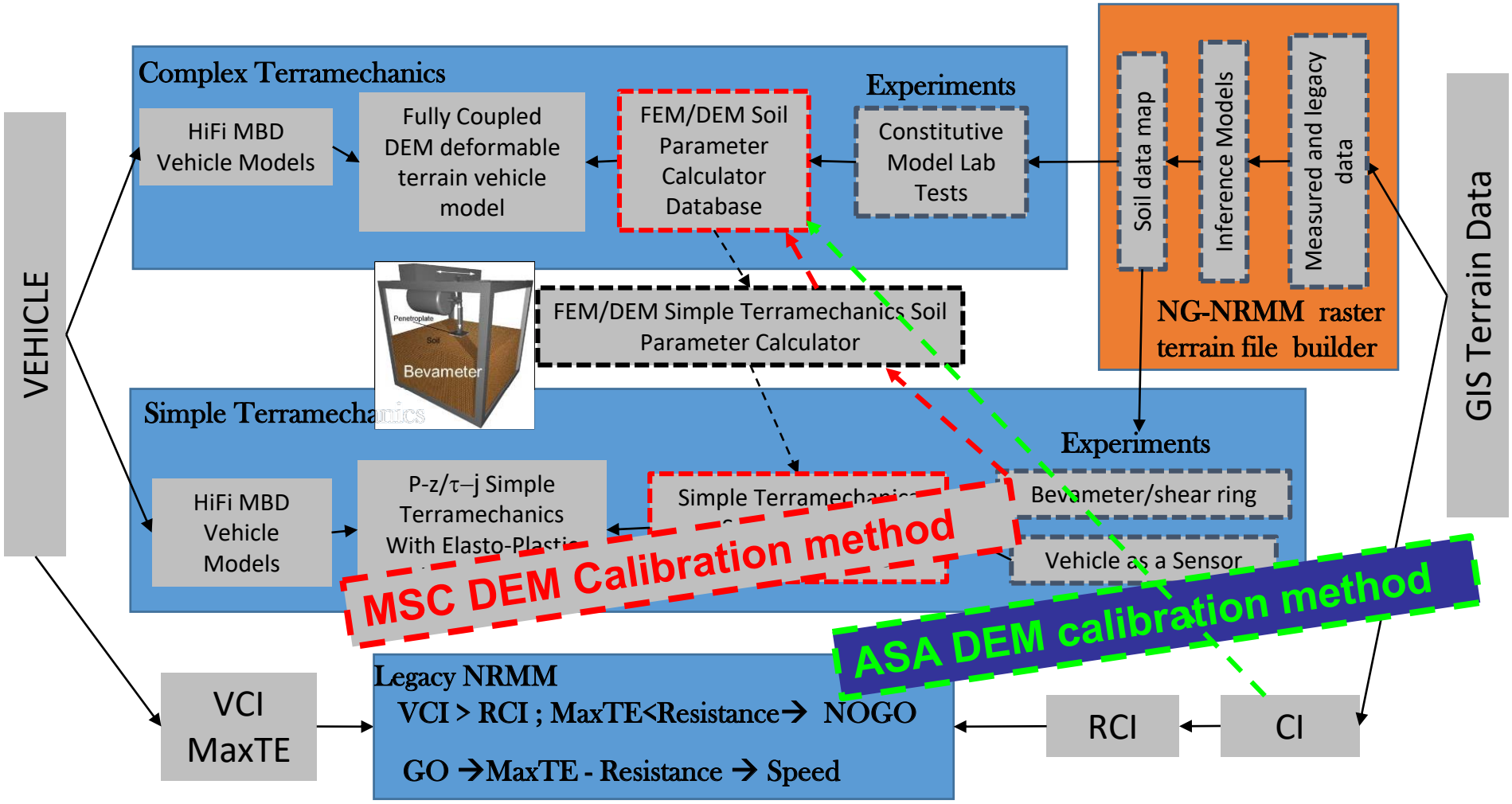
The CDT contribution to the NG-NRMM Terramechanics database will include raw data files and expand to accommodate better data fitting models, such as P-z polynomials, and will fully associate data from correlated complementary GIS, CI and CT methods

GIS Inference Models For Moisture





Database Development for Terramechanics



Detailed List of ST Database Parameters

- p_{max} applicable max pressure range
- R_{elax} 2-second normal stress relaxation of bevameter platen at p_{max} (%)
- MC applicable moisture content (dry weight basis)
- K_{USCS} soil type
- g_s specific gravity of solids
- G_s maximum dry (or wet) density (must specify) [also known as max bulk density]
- D_r relative density of natural in-situ sample [or natural bulk density]
- c surface layer cohesion
- f surface layer internal friction angle
- k surface layer shear strength modulus
- n bearing strength exponent
- k_f bearing strength frictional co
- k_c bearing strength coh
- K_0 bearing elastic reload

- A_u bearing elastic progres
- k_{f2} 2nd layer fri
- k
- strength
- strength exponent
- ng elastic reload stiffness
- A_{u2} bearing elastic progressive stiffening
- p_{max2} applicable max pressure range
- CI (0-15cm)
- CI (15-30cm)

CDT demonstrated need to specify and study effects of depth of in-situ density measurement

Bevameter Implements for CDT

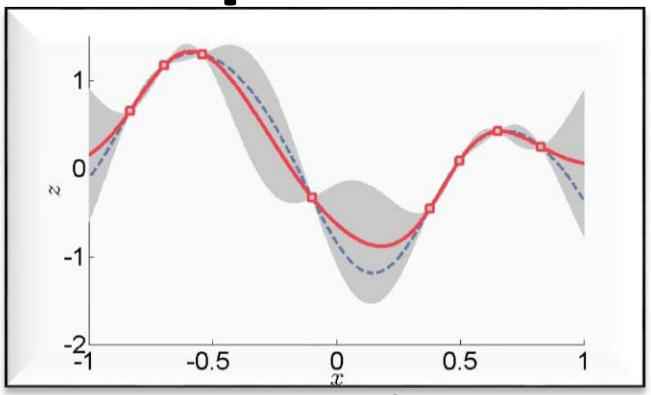
Related Data Tabulated in ST Database

- ST Snow model parameters (Wong, 1984)
- ST Muskeg model parameters (Wong, 1984)
- Notional model of ST model parameters vs soil type
- Notional model of generic soil strength vs soil type and MC
- USDA SSURGO Web Soil Survey Bulk Density and MC vs Soil Type
- Geotechdata.info, Soil void ratio, http://geotechdata.info/parameter/soil-void-ratio.html (as of November 16, 2013).
- Mulhearn study on cone index vs soil type and moisture

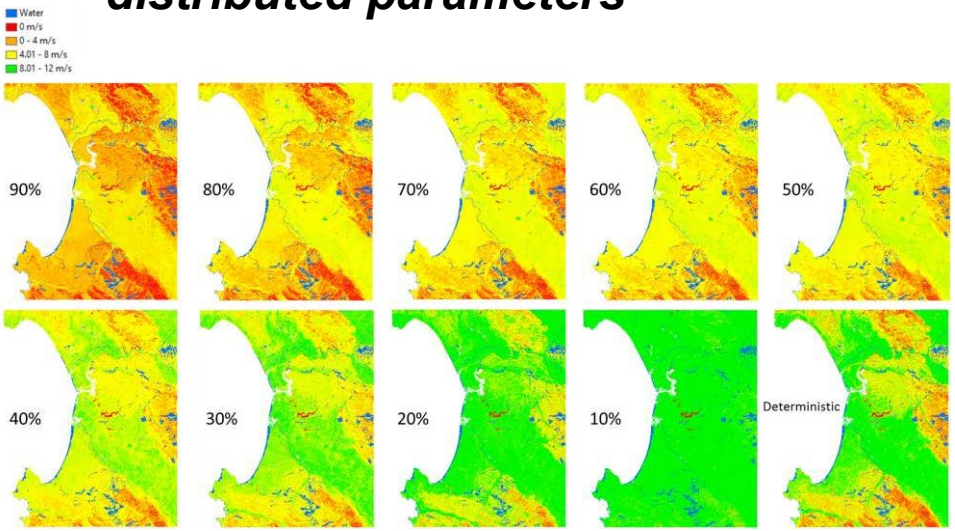
Uncertainty Quantification Specification

Two steps are recommended for generating reliability based mobility maps:

- Step 1. Process for interpolation and/or extrapolation of geostatistical data such as terrain elevation, feature occurrence and feature parameters as well as physical properties
- Step 2. Process for Propagation of geostatistical data uncertainty through mobility models for Generation of **Reliability-Based Mobility Map.**



Advanced Kriging for geo-statistically distributed parameters



Verification and Validation (V&V)

- **Based on formal US DoD V&V and Accreditation Standards (5000.61)**
- **Maturity Scale Tailored to Ground Vehicle Mobility M&S**
- **Benchmark Vehicle Data sets: Tracked, Wheeled, CDT**
- **Benchmark Mobility Event List :**
  - Addressing Gaps in current mobility metrics for ground military vehicles
    - Land Capability Group/Land Engagement linkage
  - Highlighting
    - Well validated 3D on-road vehicle performance metrics
    - Development/V&V of Soft soil (Terramechanics) mobility M&S
  - Template for future expansion

Benchmark Mobility Events

- **Steering Performance**, including wa
  cornering per SAE J266 [4] and SAE J2181 [5], and double lan
  guideline.
- **Side Slope Stability** with TOP 2-2-610
  unpaved surfaces.
- **Straight Line Acceleration** bas
  as a general guideline, including paved and unpaved.
- **Ride Quality** outlined by TOP 1-1-014 [9]
- **Obstacle Crossing,** based on TOP 2-2-
  positive and negative trapezoids.
- **Off-road trafficability** including sir
  with TOP 2-2-604 [11] as a general guideline and motior
- **Closed loop traverse** including speed made good ar
  03-10 [12].

MSC SOFTW
NEXT GENERATI
BENCHMARK S

RECURDYN

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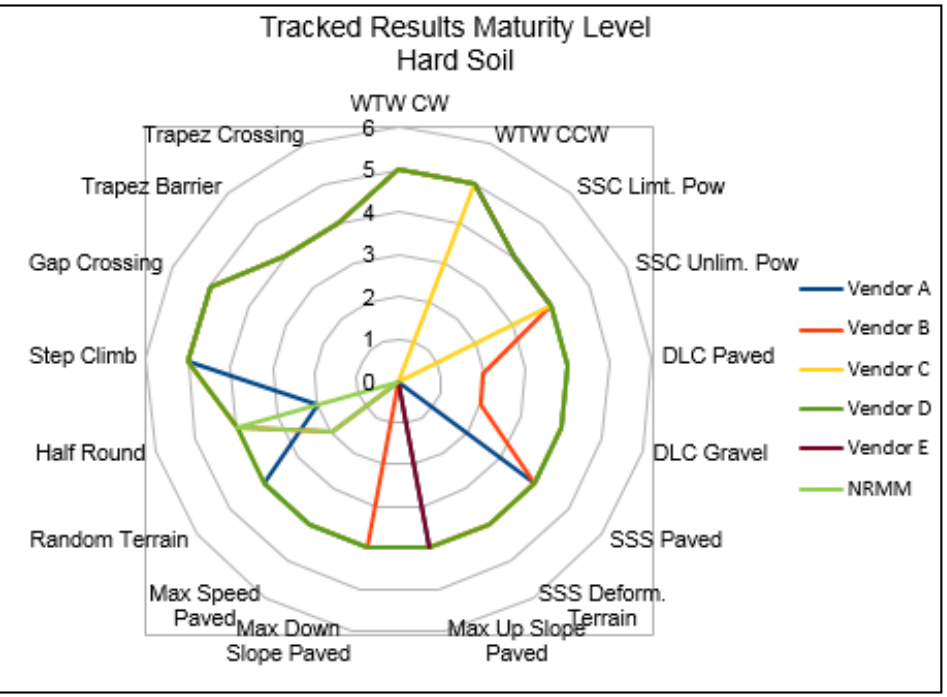
Technical Report TR–2016–08

NG-NRMM Phase I Benchmarking:
Chrono Tracked Vehicle Simulation Results Summary

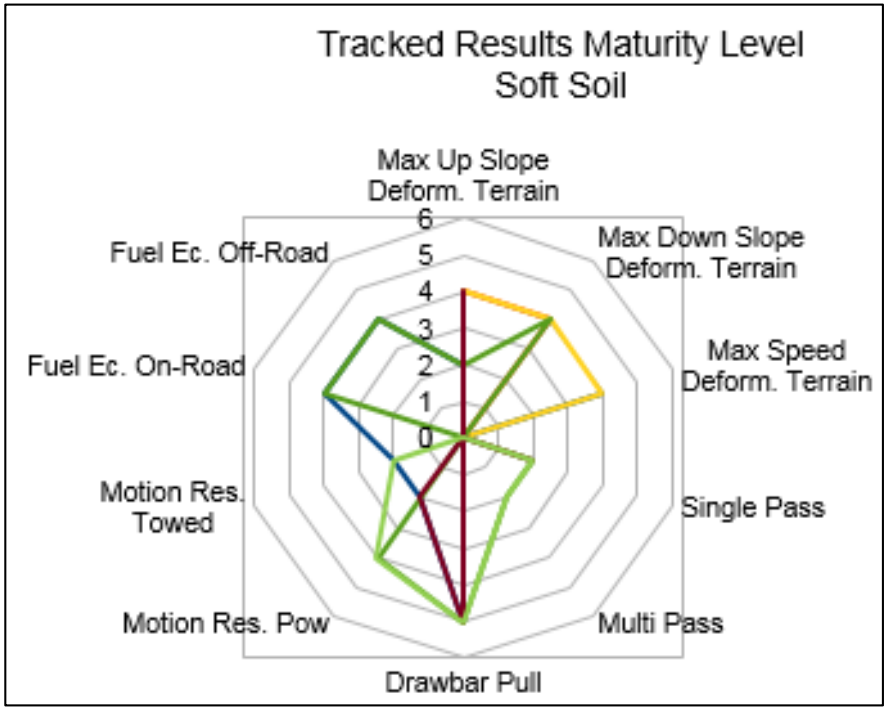
Radu Serban, Michael Taylor, Daniel Melanz, Dan Negrut

Simulation Based Engineering Lab
University of Wisconsin – Madison

NG-NRMM Benchmark Rating



Tracked Vehicle Benchmark Results on Hard Soil



Tracked Vehicle Benchmark Results on Soft Soil

NG-NRMM M&S Capability Maturity Levels

1	**DEMONSTRATION:** *Demonstration of a correct implementation of a theoretically and conceptually consistent model.*
2	**PARAMETER SENSITIVITY DEMONSTRATION:** *Verification that performance change with a change in system parameter such as GVW or terrain deformability is consistent with theory and physics principles.*
3	**INDEPENDENT USER VERIFICATION:** *Independent user demonstration and correlation to vendor results*
4	**CROSS CODE VERIFICATION:** *Cross verification with another accepted mobility simulation code*
5	**CALIBRATION:** *Calibration to a real vehicle test data set*
6	**VALIDATION:** *Blind correlation to a real vehicle test data set*
7	**PARAMETER VARIATION VALIDATION:** *Blind correlation to a real vehicle test data set with a change in system parameter(s).*

AMSP-06 Change Process

Mirroring process from AMSP-01 [3]:

a. Any member of the NG-NRMM modeling and simulation standards subgroup (NG-NRMM MS3) (subcommittee formation is currently being proposed), as well as Task Group chairpersons or NG-NRMM development group (currently AVT-248, evolving to AVT327) members, or NMSG may propose standards for inclusion in, or removal from, this AMSP-06 document based on the scope of NG- in sections 2-4. Proposals will be submitted in the form of a complete Submissions shall be sent to NMSG via a

b. The video teleconference, be included. If the 75% thresho ays) shall be observed, follow ot be included. Abstentions do n

c. All er calendar weeks.

d. All sta reviewed at least once every three years, and the NG-NRMM MS3 membership shall vote for continued inclusion or modification using the voting procedures described in 'b' above

e. The process in steps 'a' to 'd' occurs on a continuing basis.

f. The AMSP-06 shall be reviewed in a period not to exceed two years and any changes made submitted to the NMSG for approval. Upon the NMSG approval, the document shall be posted to the NMSG web site and submitted to NATO Standardization Office (NSO) for promulgation.

g. Any other comments or proposals regarding AMSP-06 may be addressed via the points of contact or directly to the secretary of NG-NRMM MS3

- *There is a change process*
- *Provided by AMPS-01*
- *Promotion to a STANAG is covered by a different broader NATO standard process*

AMSP-06 Change Log: Issues TBD

Reviewer	Number	Paragraph	Comment	Proposed Change
McCullough	TA1-1	2.1, 2.2	If there are GIS processing tools specific to NG-NRMM process, we should list and describe them	Add a section desc[illegible]-NRMM custom GIS tools
McCullough	TA1-2		The MAPTBL format cont[illegible]	[illegible]iscuss the necessity of the legacy [illegible]inimize the file size
McCullough				[illegible]tabase with CDT data
McCullough	T			[illegible]ex Terramechanics unique
McCullough	TA		[illegible]chanics	Consolidate benchmark suggestions into a Complex Terramechanics benchmark Attachment
McCullough	TA6	Attach 5	Populate with tracked vehicle and soil input data	Populate with vehicle and soil input data
McCullough	TA7-2	all	CDT will have numerous lessons learned to be incorporated across all sections	Incorporate all CDT lessons learned
Balling	TA1-3	2.1.2	Input data format for local terrain geometry standards need to be discussed and codified	TBD based on discussion: TIN, quads, etc
McCullough	TA7-2	2.3.iii	Nuke densometer depth of sensor for in-situ	Suggest 30cm, open discussion
McCullough	TA7-2	2.3.1.5.e.i	shear ring normal loads	Operational level of Pmax not necessary;update per final conclusions
McCullough	TA7-2	2.3.1.5	As part of calibration procedure Bevameters should be tested for repeatability in lab with known homogeneous soils	Add intial paragraph to this effect, with appropriate details on volume of sample, depth, etc based on platen sizes.

- *The change process has a formal tracking tool*
- *AVT327 will begin with this list*
- *CDT issues are being appended as they are noted*

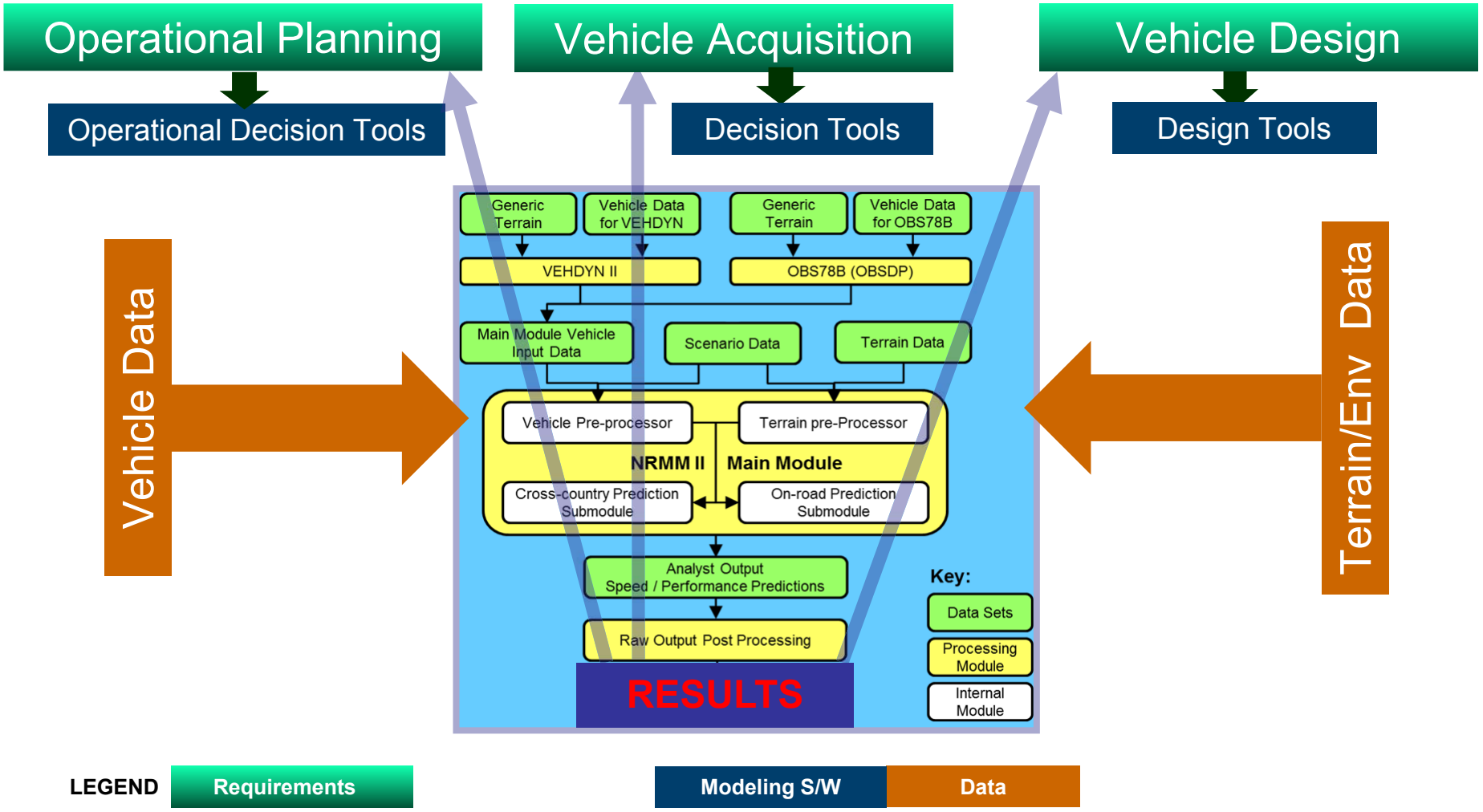
NG NRMM STANREC Conclusions

- **AMSP-06 is an enduring artifact and development path for NATO nations mobility modelling methods, benchmarks and source databases that should be applied to physics based simulations of all operational land and amphibious mobility among the alliance.**
- **The initial release will occur in November 2018**
- **A new RTG, AVT327 will manage initial support**
- **An enduring forum and change process should be established for codifying future changes to NG-NRMM standards**

THANK YOU

Backup

Current NRMM is a Set of FORTRAN Computer Codes and Standard Data Files



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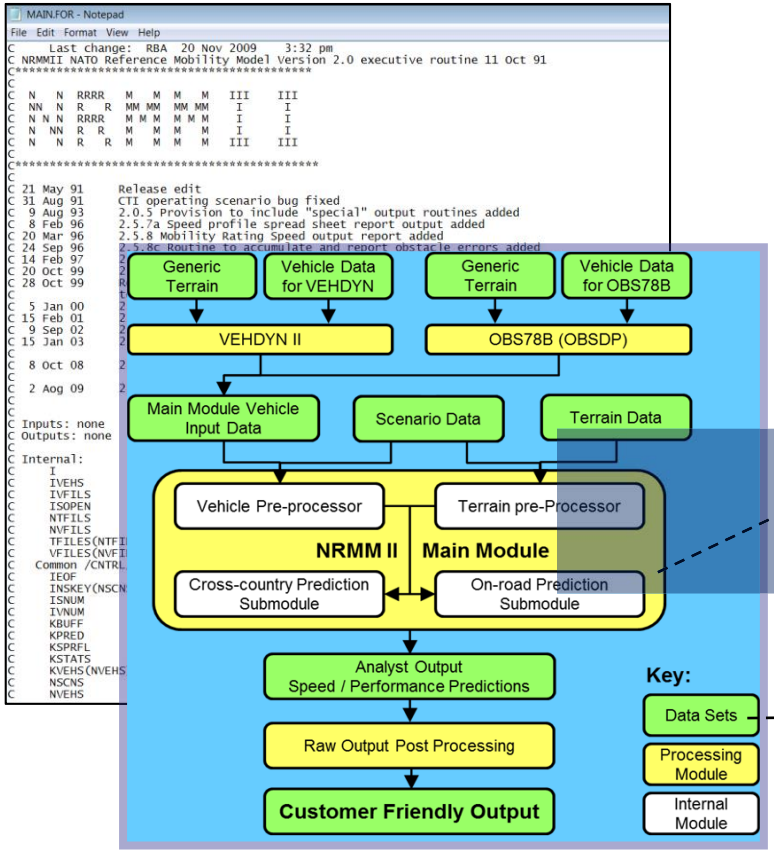

Next Generation NATO Reference Mobility Modeling Standards

- GIS Based Input and Output
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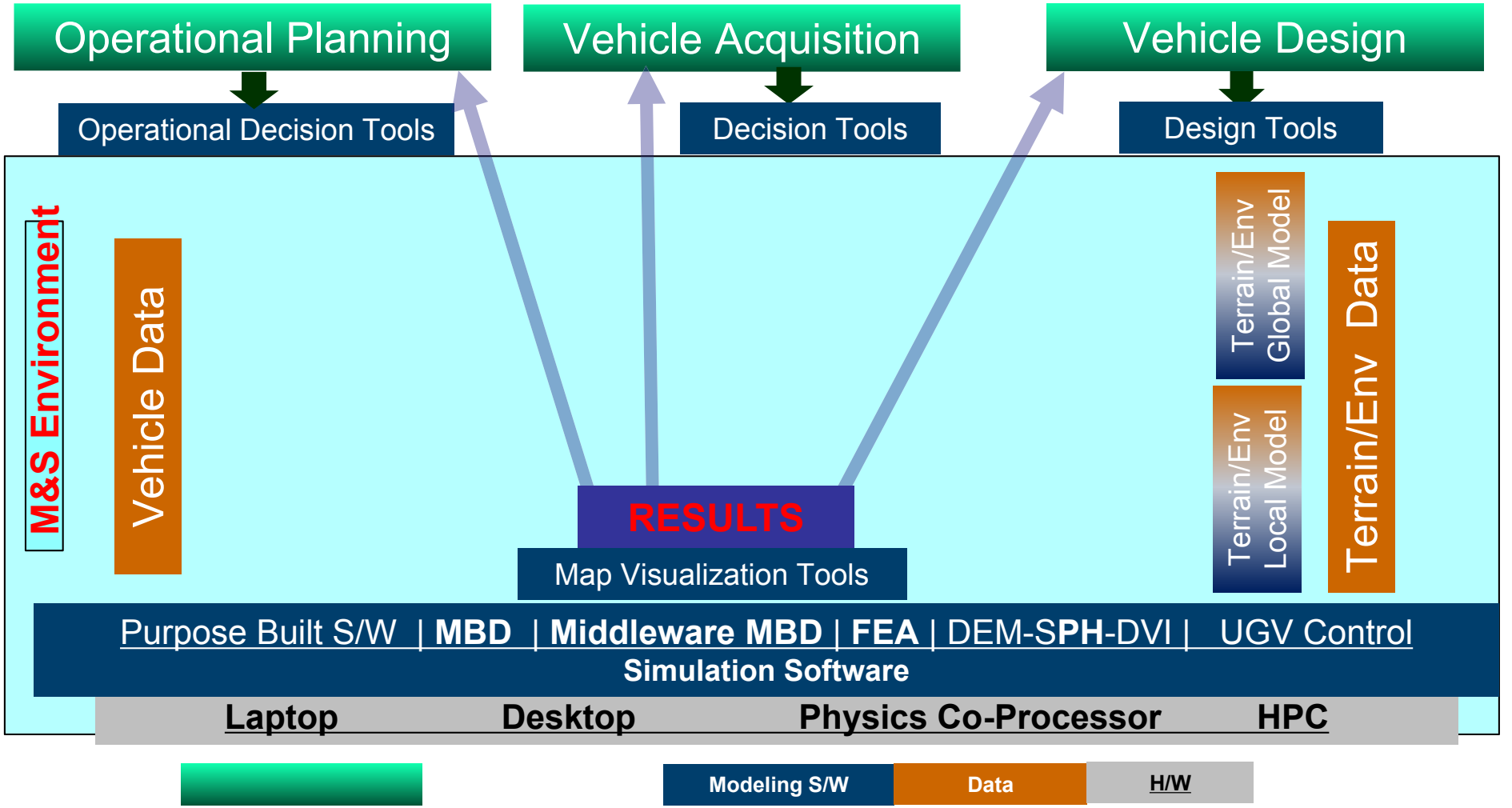
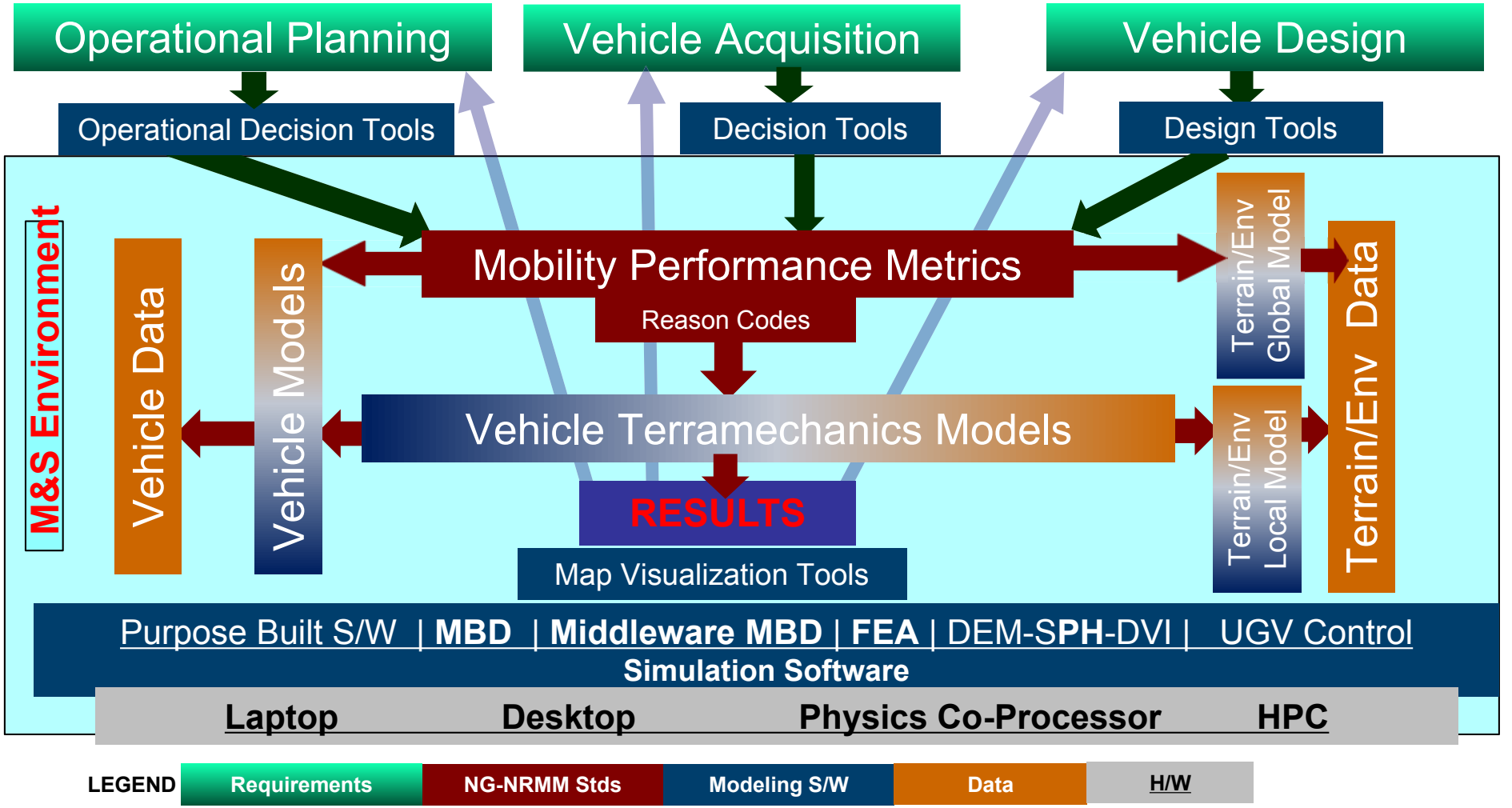
  - Reason Codes
- Terramechanics Models & Db
  - Uncertainty Quantification
  - Autonomous Vehicles
- Legacy Terrain Files and Updated Terrain Data Format
- V&V Maturity Scale and Benchmarks
- Existing Standards (AVT, ITOPS,GIS, etc)

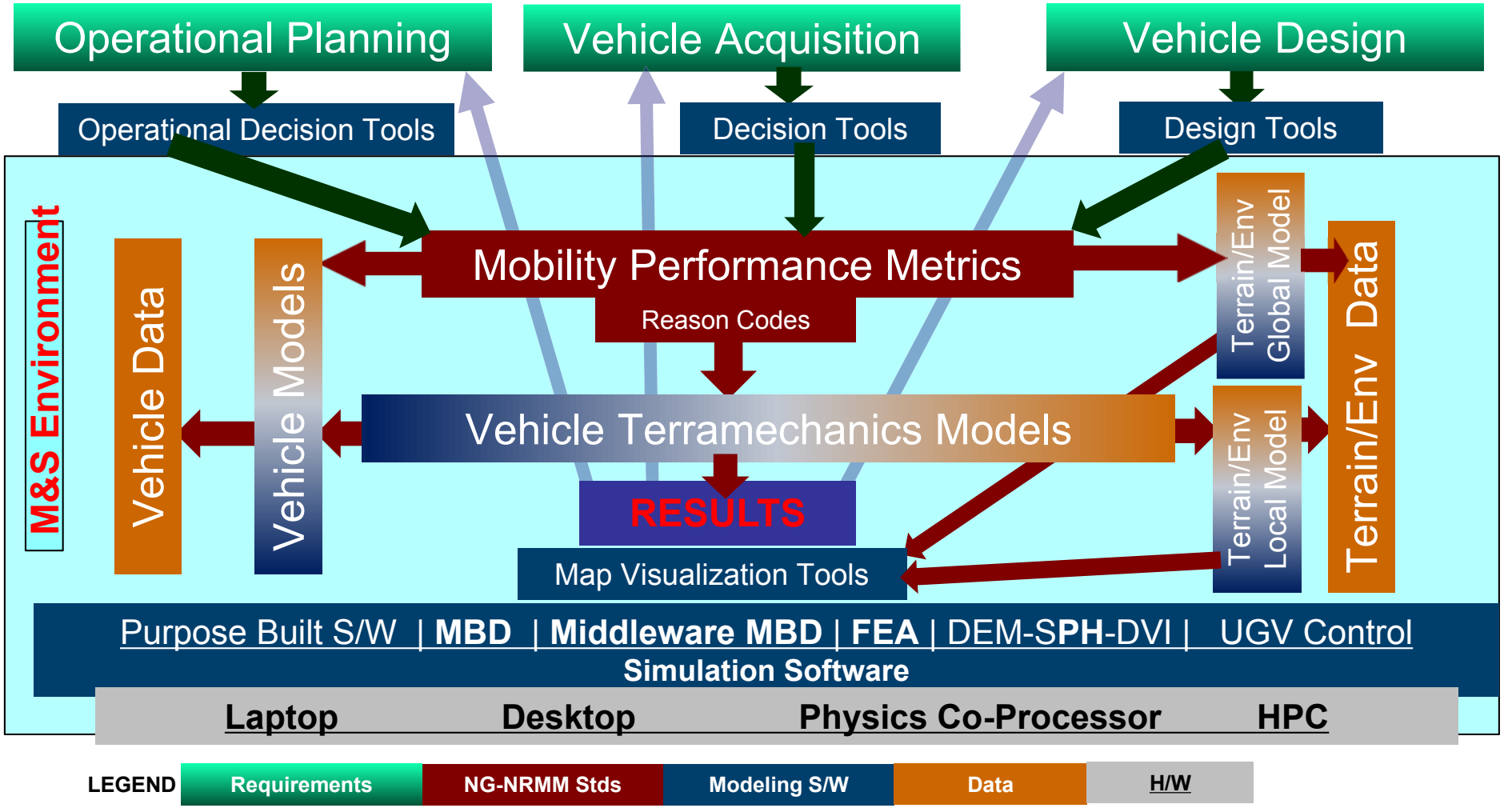
NG-NRMM Is Software Agnostic



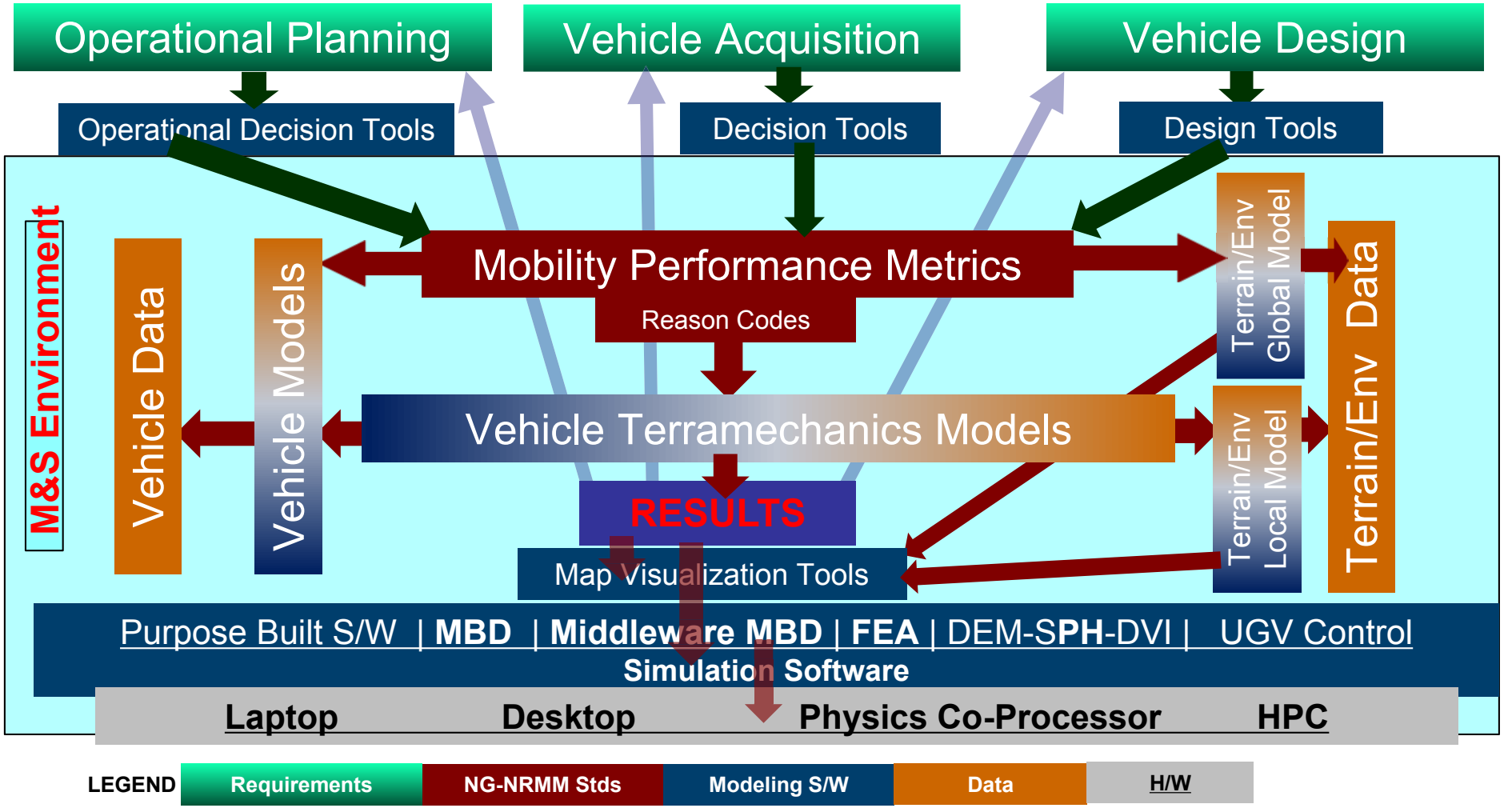
NG-NRMM Standards Establish a Modular Open Architecture Wherein Each Application Drives Its Own Requirements



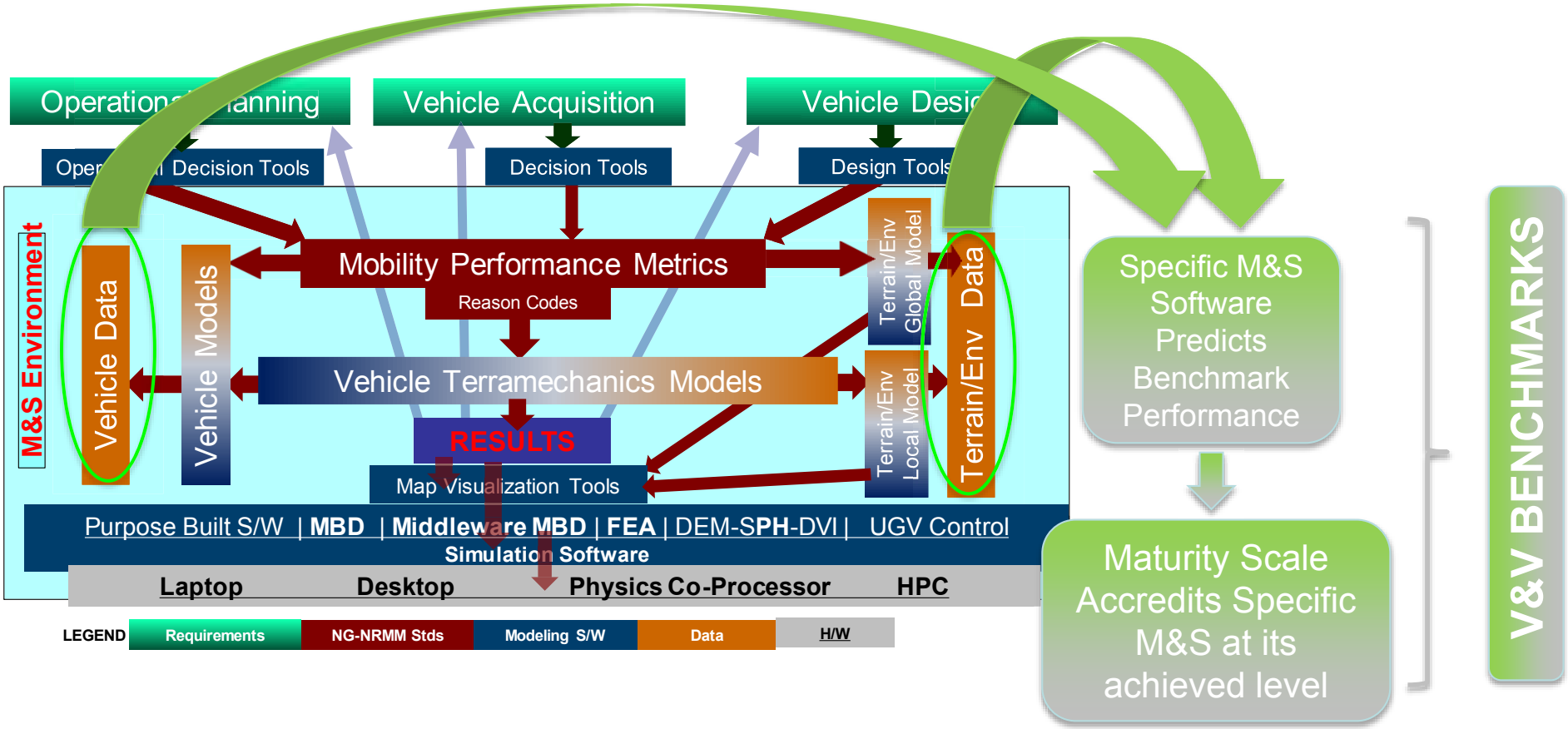
NG-NRMM Standards Assure GIS Interoperability



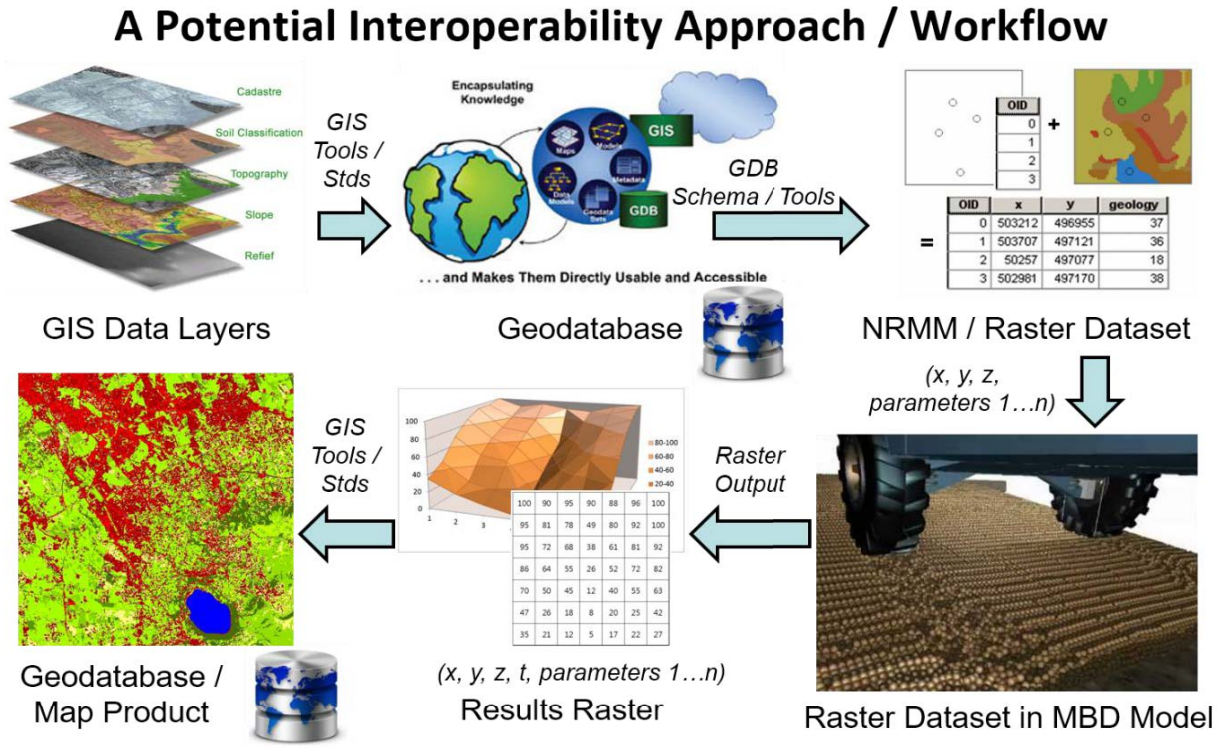
Each Application Drives Its Own Computational Model Level of Complexity

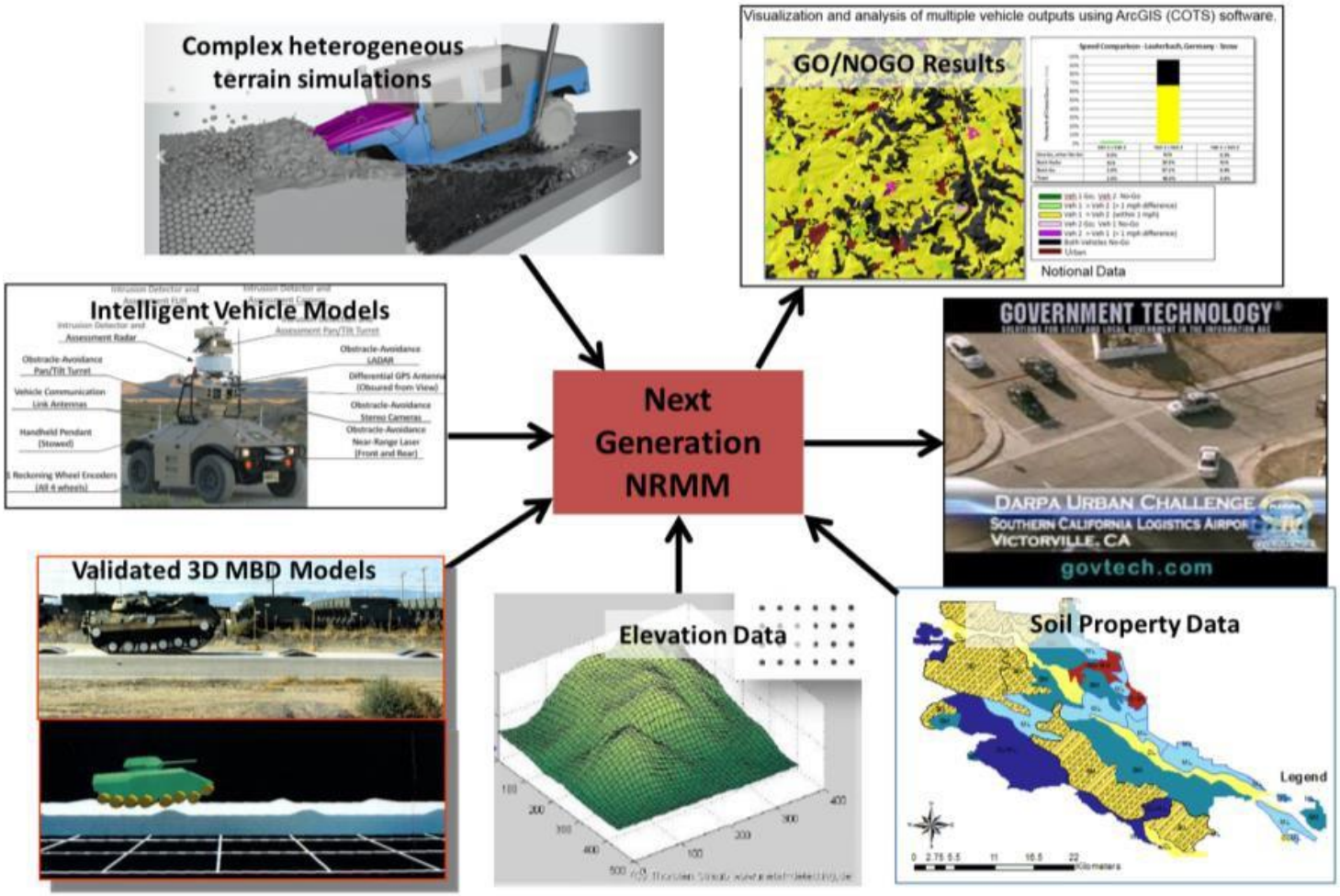


Verification and Validation Benchmarks Qualify Specific M&S Tools To Their Achieved Maturity Level

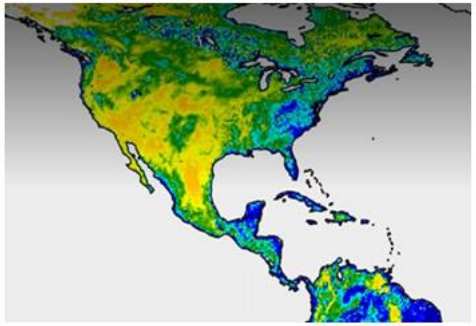


Flowchart from TA1 as reference

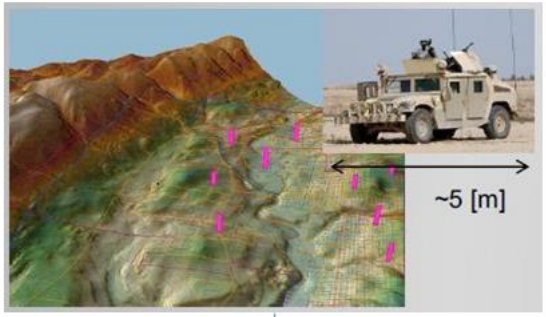



Complex heterogeneous terrain simulations
Visualization and analysis of multiple vehicle outputs using ArcGIS (COTS) software.
GO/NOGO Results
Notional Data
Intelligent Vehicle Models
Next Generation NRMM
GOVERNMENT TECHNOLOGY
DARPA URBAN CHALLENGE
SOUTHERN CALIFORNIA LOGISTICS AIRPORT
VICTORVILLE, CA
govtech.com
Validated 3D MBD Models
Elevation Data
Soil Property Data
Legend

Soil Moisture Map

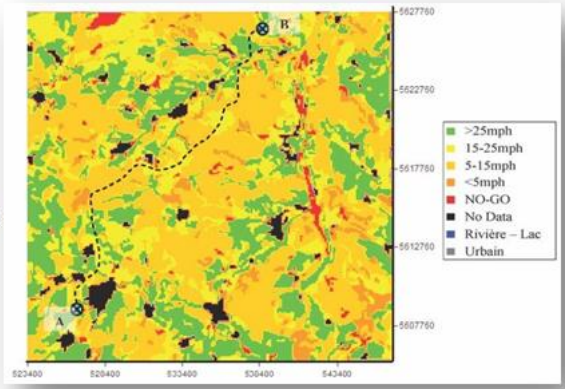


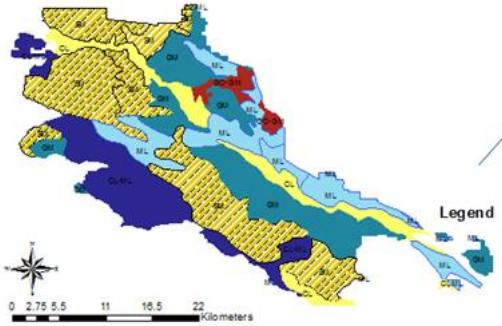
Terrain Elevation Map



Physics-Based M&S

Mobility Go/NoGo Map





Soil Type