Implementation of Clustering Analysis in Engineered Resilient Systems Tools for Enhanced Trade Space Exploration of Military Ground Vehicles

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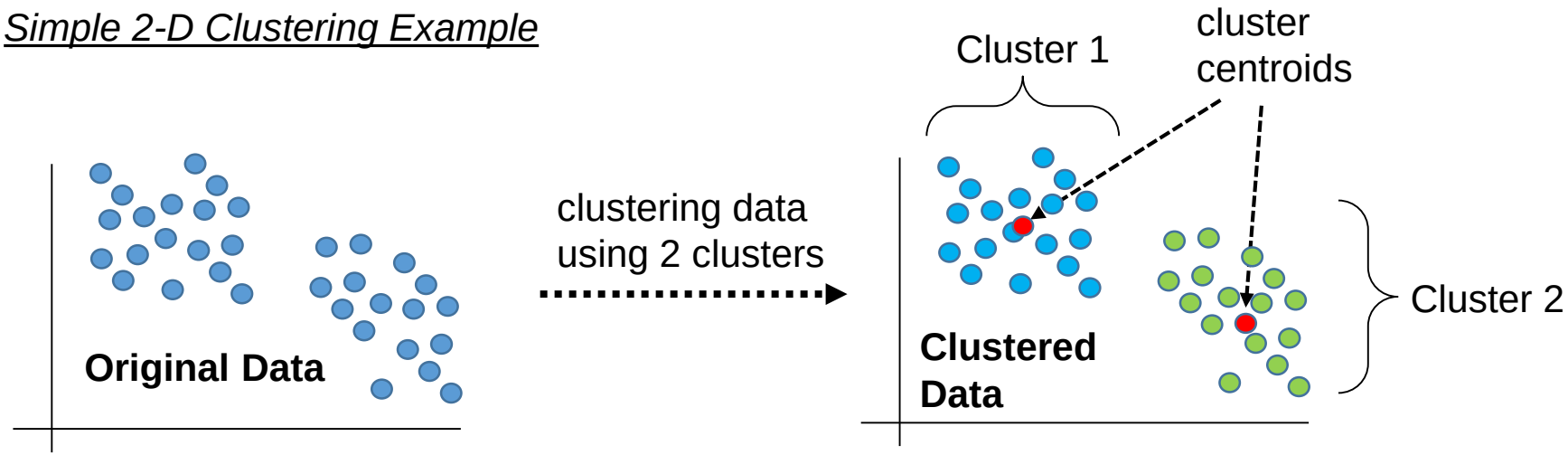
Background and Motivation

- Performing multidisciplinary design optimization of a military ground vehicle is extremely challenging
- One challenge is related to analyzing large, highly dimensional vehicle design datasets
- Analysis questions to answer regarding these datasets:
  - Do my highest-ranked designs reside in multiple regions of the trade space?
  - How many promising regions are there?
  - Does each region represent variations on a single design concept or multiple design concepts?
  - How can I best characterize the unique features of each design concept?

Clustering

- Simply put, clustering is the process of assigning data points to groups based on how closely their values are to a common group centroid
- A way to group data that is highly dimensional
- Different algorithms available
- Machine learning technique

Simple 2-D Clustering Example



Clustering for Trade Space Design Populations

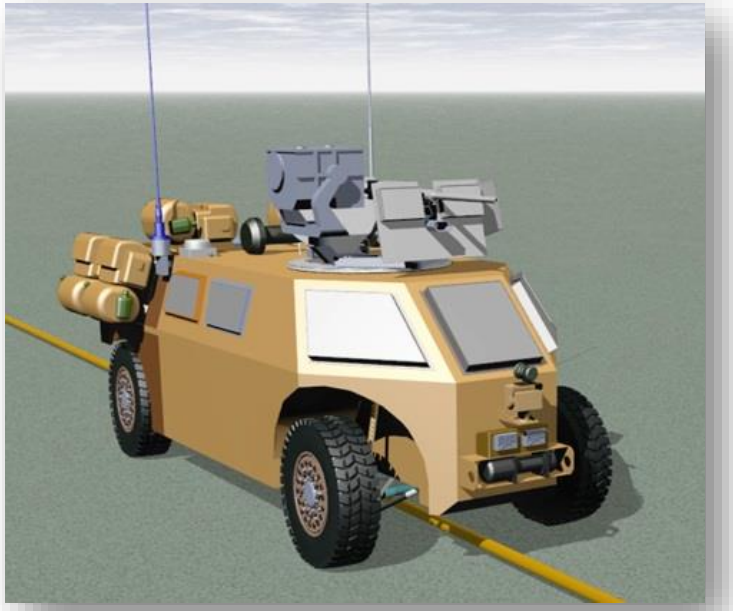
- Reduce large, highly dimensional datasets to more manageable, digestible sizes. This can make it easier to draw conclusions

- Automated way of quantifying and qualifying design differences - ***characterizing***; may help answer the question of : "How different are the top ranked vehicle designs?"

- Clusters could be used to provide promising vehicle design groups, and therefore promising characteristics, to be taken to the next stage of vehicle development

Objectives

- Learn, evaluate, and provide feedback to developers of **CREATE-GV and ERS Tools**
- Apply these tools to the **LRV notional concept vehicle** to perform **trade space exploration**
- Develop new trade space exploration methods for ground vehicles



CREATE-GV: Computational Research and Engineering Acquisition Tools and Environments – Ground Vehicles

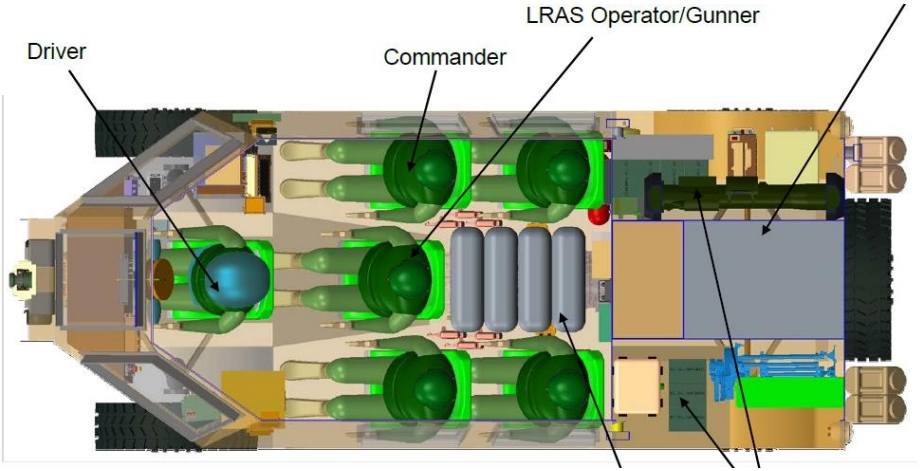
ERS: Engineered Resilient Systems

LRV: Light Reconnaissance Vehicle

LRV – A Notional Concept for a New-Start Vehicle

Notional concept was initially developed based on these requirements:

- Crew of 6
- Power for 96-hour mission
- Silent watch, silent move
- Advanced reconnaissance & surveillance equipment package
- CH-47 internal transport and sling-load transport



Trade Space Exploration Process

Reviewed initial concept & requirements

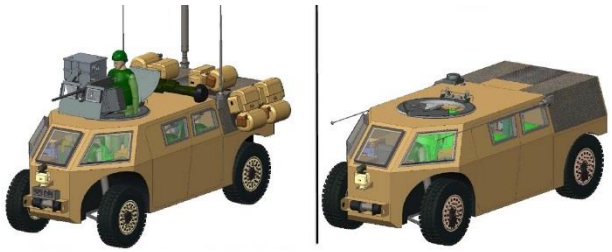
Performed analysis to build trade space

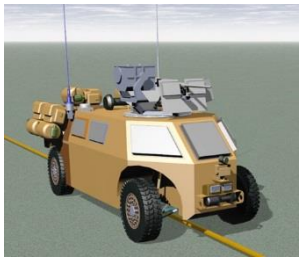
Revisited concept & varied requirements

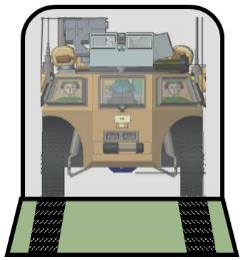
Performed analysis to expand trade space

Generated new design set = new concept

Iterative Concept-Analysis Loop







ENGINEERED RESILIENT SYSTEMS

Trade Space Exploration Process

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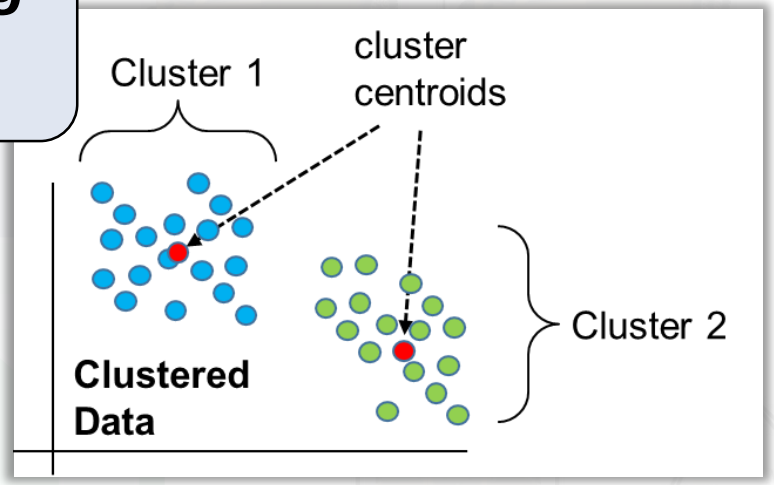
Clustering Analysis



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Trade Space Construction in ERS TradeBuilder

CREATE-GV	
1	On-Road Speed
2	Off-Road Speed
3	Max Sandy Grade
4	Off-Road No-Go %
5	Soft-soil mobility

ERS TradeBuilder	
1	Surveillance
2	Crew
3	Stability
4	Silhouette
5	Power density
6	Survivability
7	Transportability
8	Lethality

Performance Metrics imported from result files

Performance Metrics evaluated in ERS TradeBuilder

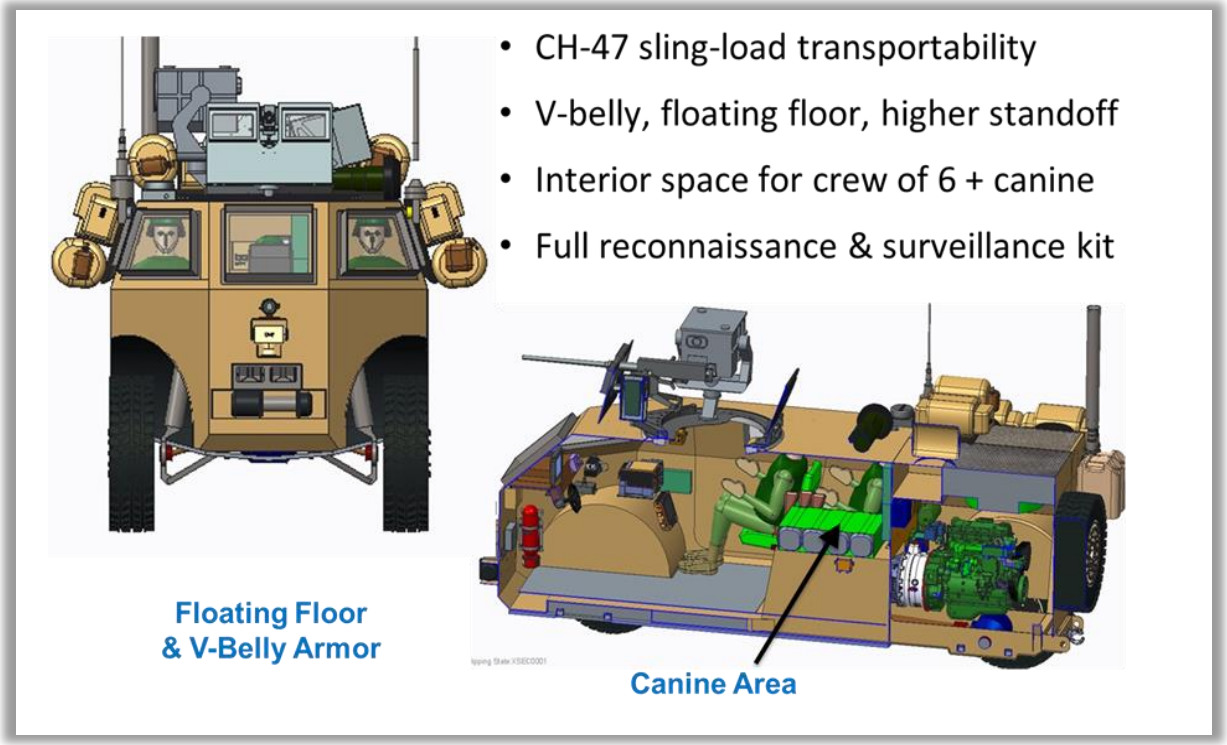
Design Variables

#	H	L	W	…											
1	H_1	L_1	W_1												
2	H_2	L_2	W_2												
3	H_3	L_3	W_3												
4	H_4	L_4	W_4												

Designs

Trade Space Vehicle Design Characterization

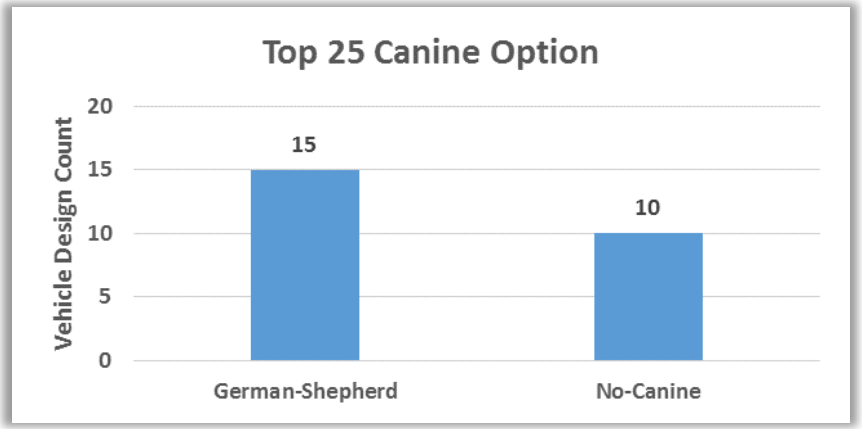
- Common features from highest-ranked designs:

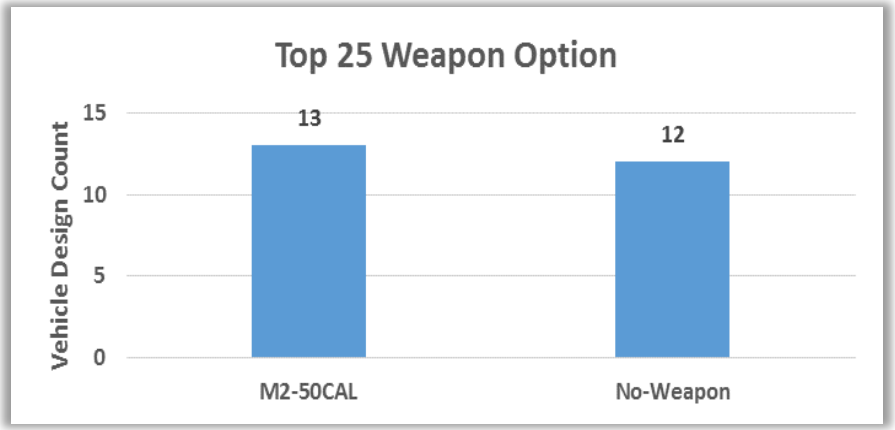


These are general features typically seen in the top 25 ranked vehicles, **though not all of the top 25 designs had the same features**

Trade Space Vehicle Design Characterization

- Two areas where differences are seen in the top 25 designs :



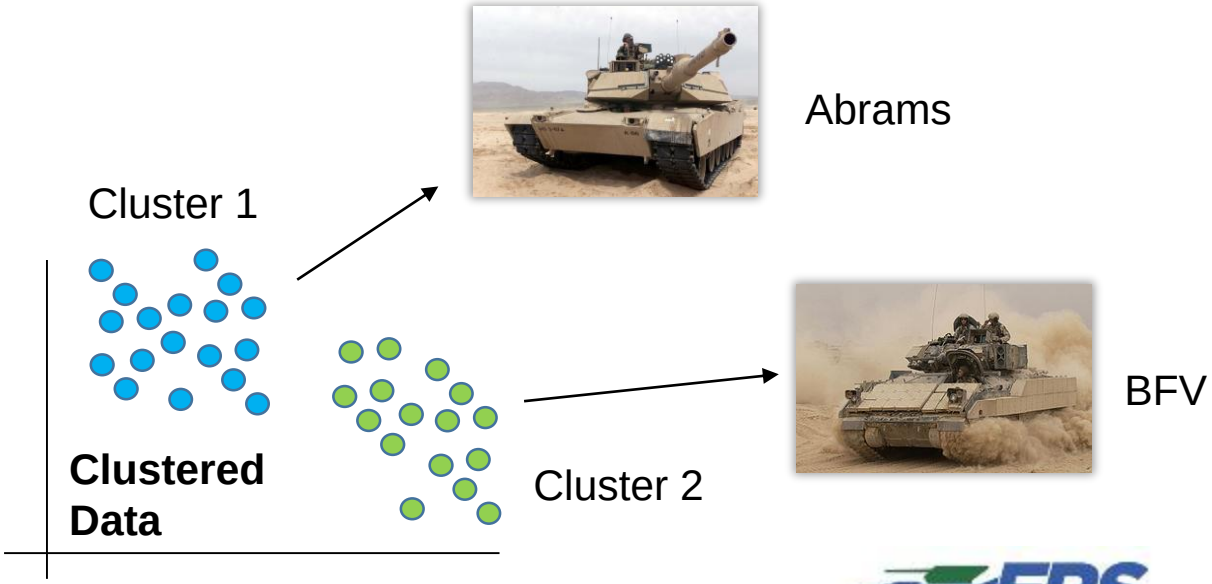


- Characterizing the top ranking designs as a whole may not lead to as useful conclusions regarding which features a single vehicle design should have
- We could be **unintentionally characterizing multiple vehicle designs, multiple variants**, *a potential outcome when performing multi-objective design optimization*

Trade Space Vehicle Design Characterization

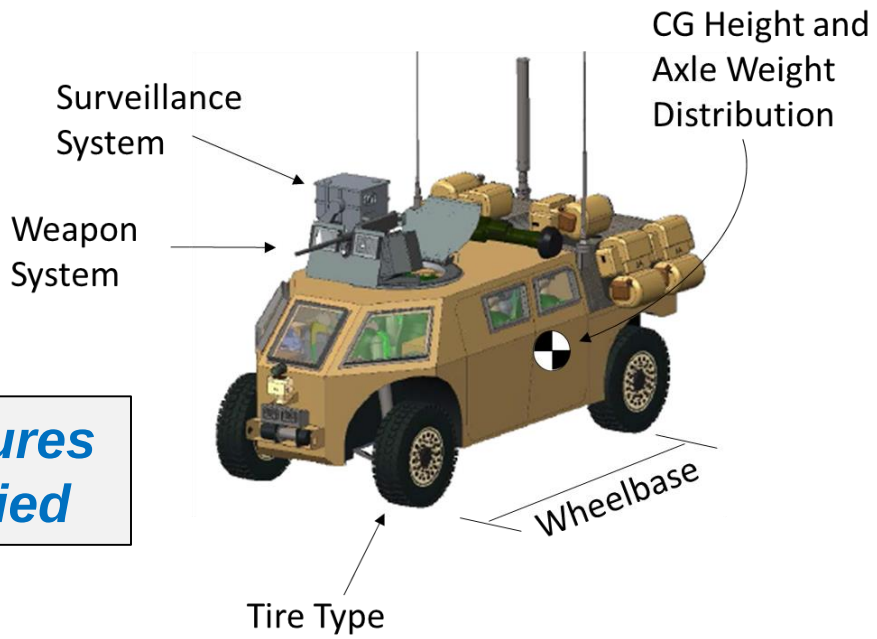
- Early in the concept development phase, the trade space is large, with a design space that could be spanning regions consisting of two or more completely different vehicle designs
- … and this is not apparent
- We want to understand if potential regions exist early on in the analysis process to understand what unique concepts we may have

Potential example outcome of early concept, highly dimensional, multi-object design optimization



Clustering Analysis - Setup

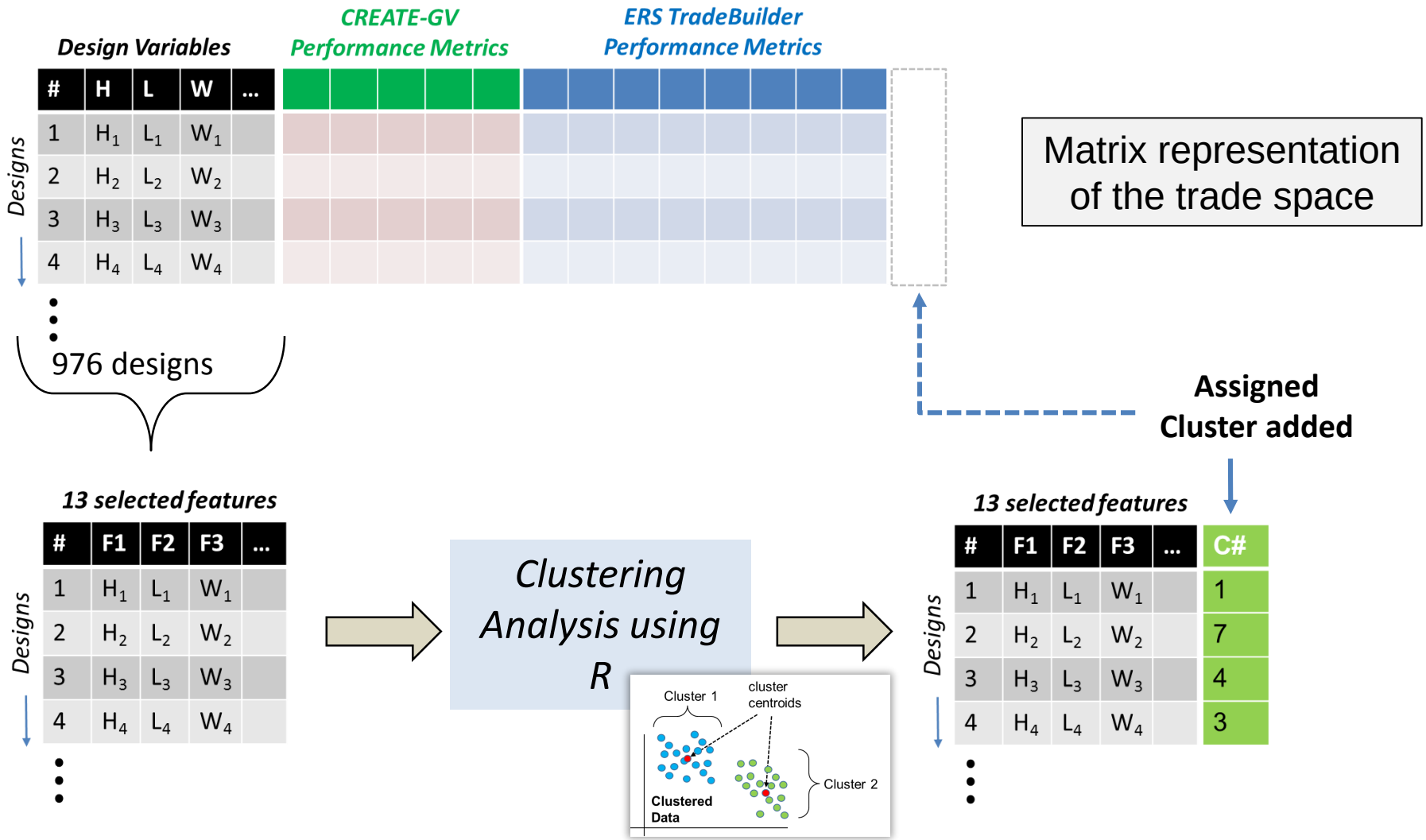
- **K-means clustering** algorithm used within R ("Hartigan-Wong" version)
- **Chose to generate 10 clusters** based on the "within sum of squares (WSS)" count selection method
- Design variables and characteristics chosen for features:



13 features specified

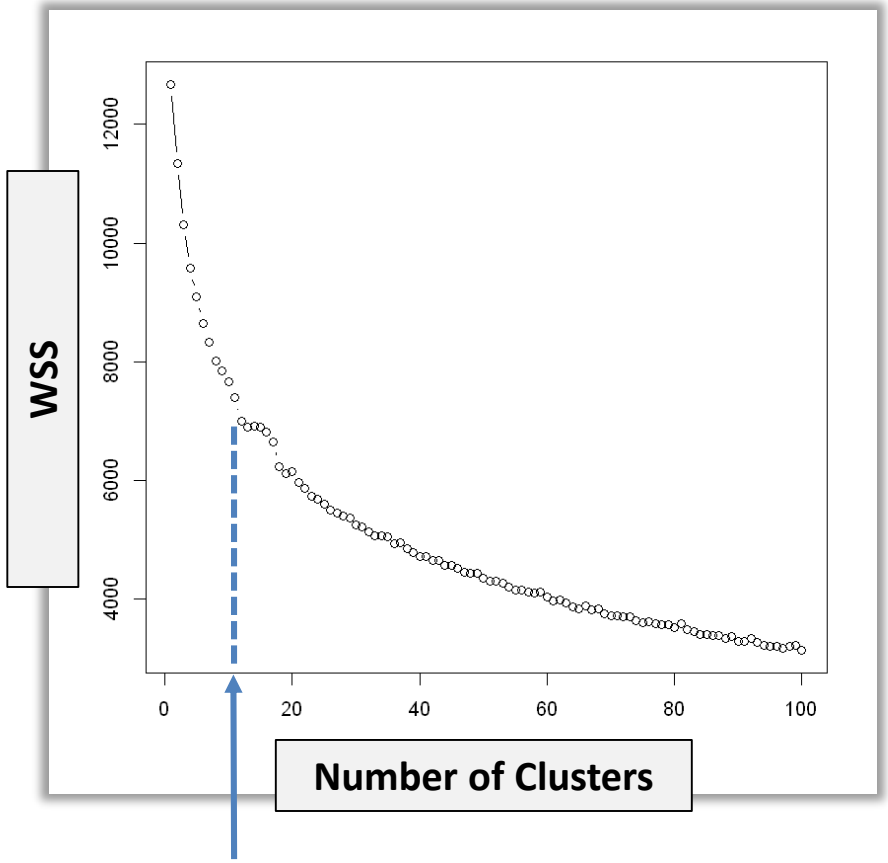
- Suspension characteristics (damping ratio and ride frequency) for the front and rear axles
- Canine
- Crew size
- Armor weight

Clustering Analysis - Setup



Clustering Analysis – Selecting Cluster Count

- Within Sum of Squares cluster count selection method (WSS)

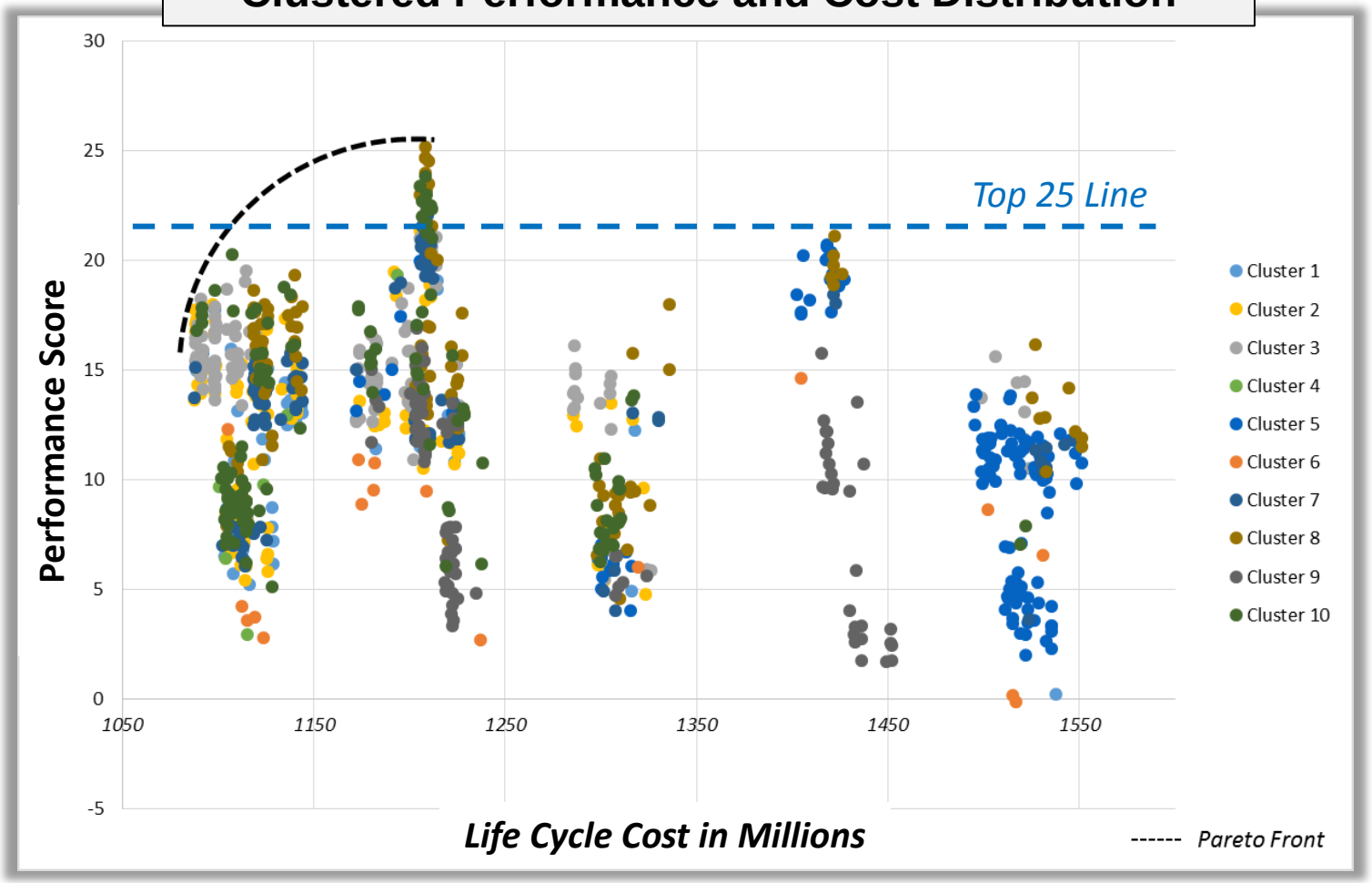


… at 976 clusters, the sum of squares value would equal 0

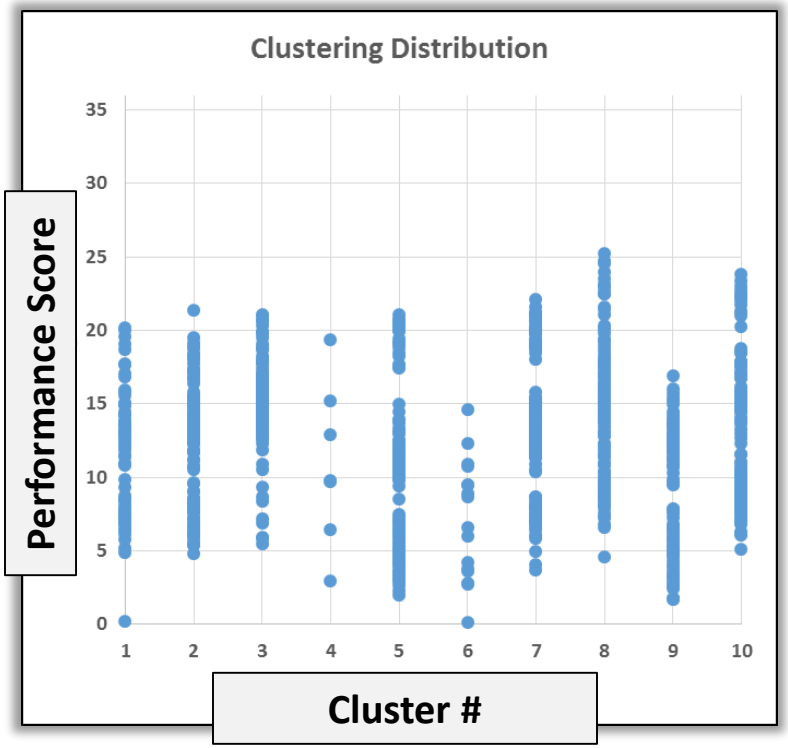
10 Clusters

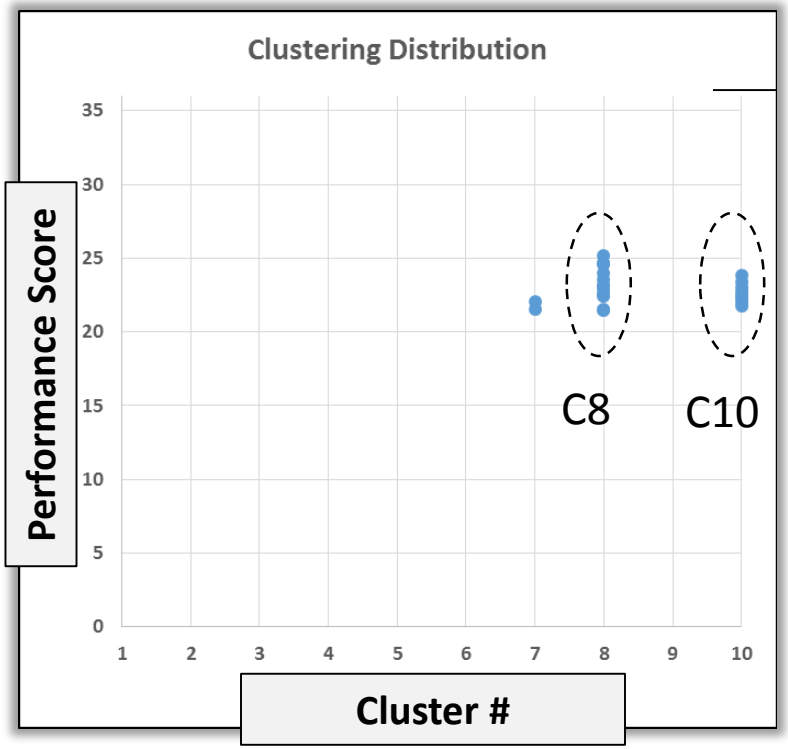
Clustering Analysis – Results

Clustered Performance and Cost Distribution



Clustering Analysis – Characterization





36: Highest Possible Score

Plot shows clustering results using 10 specified clusters for the 976 vehicles designs investigated

Showing 3 clusters in the top 25:

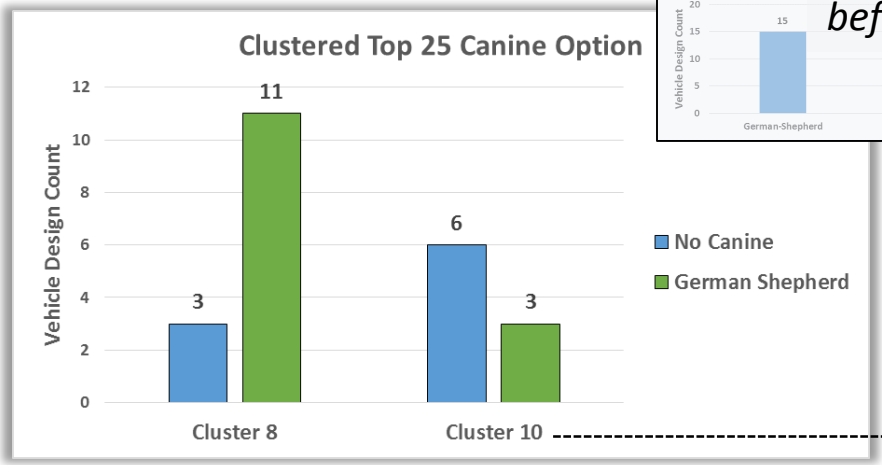
Cluster 7 (C7) : 2 designs

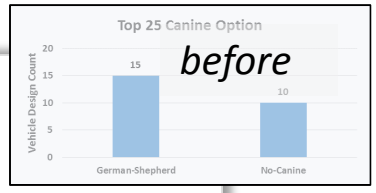
Cluster 8 (C8) : 14 designs

Cluster 10 (C10) : 9 designs

Clustering Characterization Comparison

- *Looking at the same two features as before…*



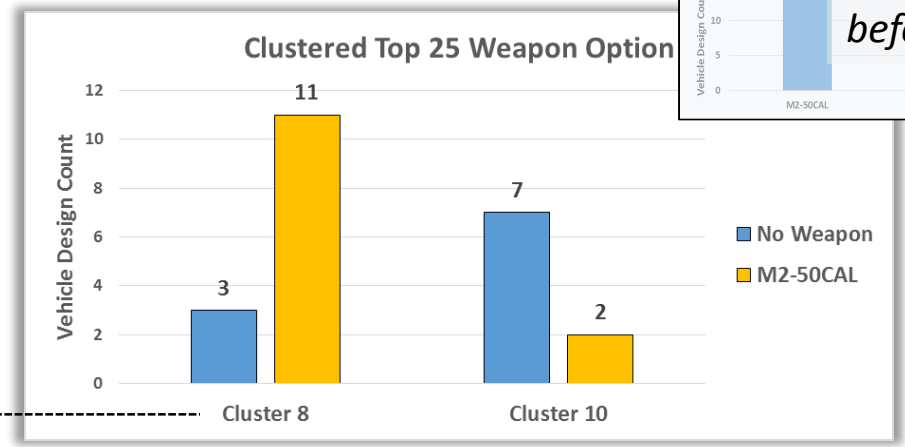


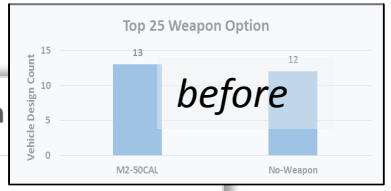
Cluster 10 Designs:

Mostly <u>do not</u> include a weapon or canine

Cluster 8 Designs:

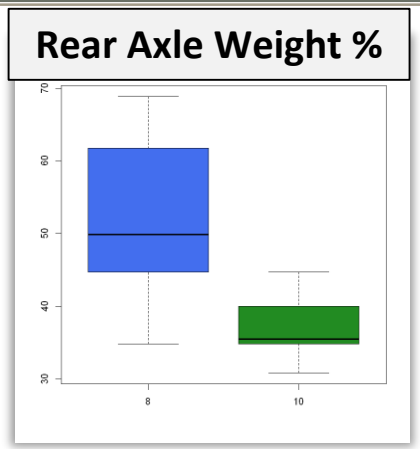
Mostly include weapon and canine

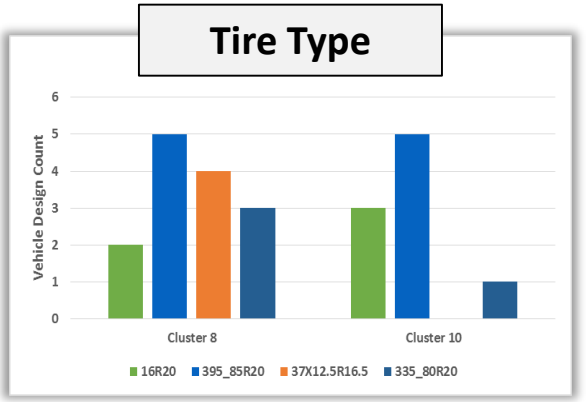


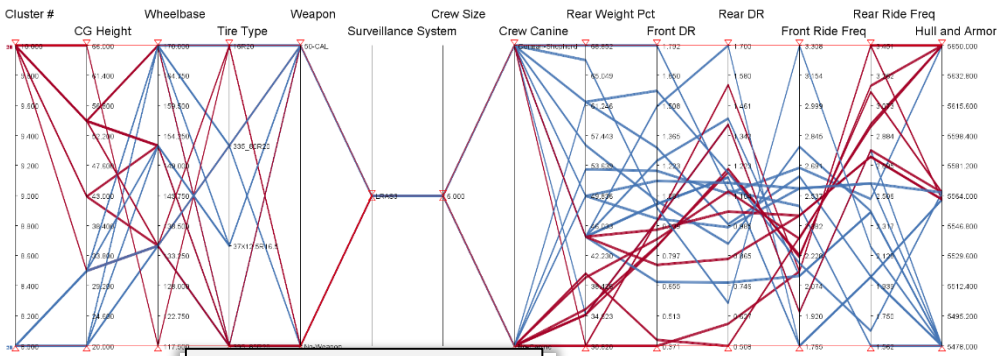


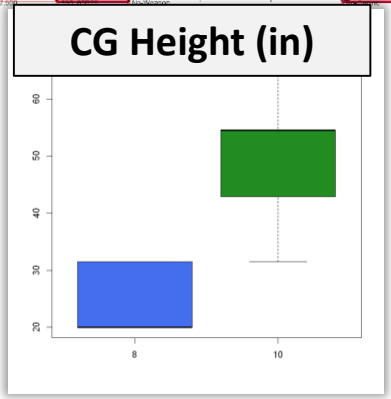
Clustering Characterization - Features

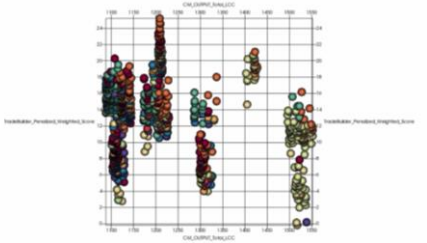
- Various visualizations used to distinguish the differences between the top 25 designs within **clusters 8** and **10** concerning their *design variables and characteristics*











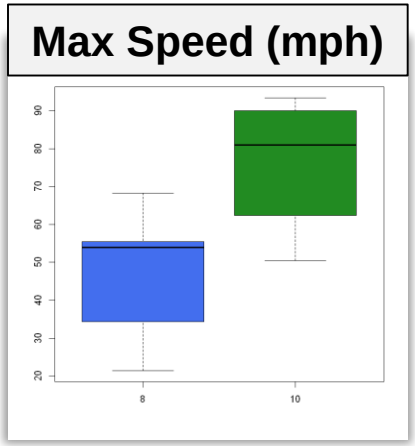
Clustering Characterization - Features

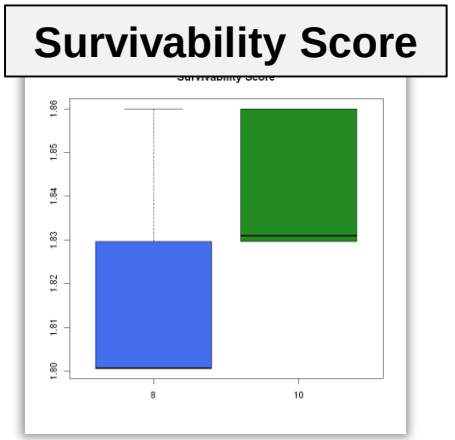
Feature	Cluster 8	Cluster 10
Weapon	Most designs include the M2-50 Cal	Most designs don't include a weapon
Canine	Most designs include a German Shepherd	Most designs don't include a canine
CG Height	Low	High
Wheelbase Length	Longer	Medium
Weight Distribution	More centered to rear heavy designs	More front heavy designs
Front Axle Ride Characteristics	Stiff, Mostly Overdamped	Less Stiff, Underdamped
Rear Axle Ride Characteristics	Stiff, Mostly Overdamped	Very Stiff, Mostly Overdamped

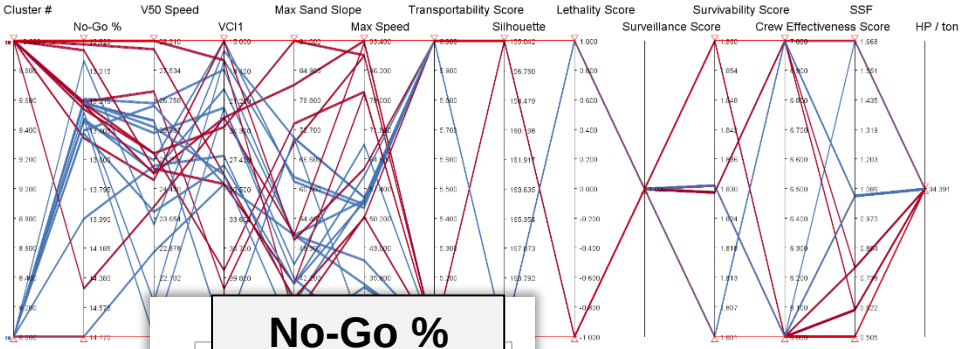
These clustered designs were **similar regarding the Tires, Hull and Armor Weight, Crew Size, and Surveillance System** features

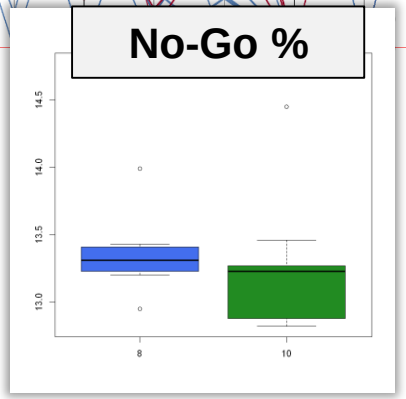
Clustering Characterization - Performance

- Various visualizations used to distinguish the differences between the top 25 designs within **clusters 8** and **10** concerning their *performance*









Clustering Characterization - Performance

Performance	Cluster 8	Cluster 10
Crew Effectiveness	Highest score	Meets requirements
Max Speed	Lower to moderate	Moderate to high
Max Sand Slope	Medium	Medium to high
SSF	High	Medium to low
Visibility (Silhouette)	Larger profile	Smaller profile
Lethality	Higher	Lower

These clustered designs were **similar regarding the Surveillance, No-Go %, VCI1, V50 Speed, HP / ton, Survivability, and Transportability** performance metrics

Clustered Characterization - Conclusions

- Highlighted two main clusters in the top 25 ranked vehicle designs and analyzed their features and performance
- Instead of describing one LRV design, now describing two LRV design variations in the top 25 – two designs that have some distinct differences, but with similar overall performance scores

Cluster 8

Well-rounded design concerning all of the areas of performance considered

Two potential variants

Cluster 10

Fast, mobile design, with smaller profile

Conclusions

New trade space exploration process *which utilized a* ***clustering technique*** *highlighted* ***two main vehicle variants*** *out of a set of top performing vehicle designs*

- Clustering is a promising trade space analysis process addition to help improve and further automate trade space characterization
- Can help answer important questions about a trade space
- And lead to improved optimal design extraction from trade spaces, and overall improved concept design development
- More to look into : clustering technique tuning and feature selection

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