

Authenticating Lethality and Vulnerability Measurements



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The Problem

- Weapons Systems such as Abrams M1A1 Tank are Required by Law to be “Live Fire Tested” for Vulnerability.
- Cost of Destroying such a Weapon is Huge, ∴ Not Many Destroyed.
- Solution: Test via Simulation

The Problem

- Simulation via CAD Models (BRL-CAD)
- 67 Systems/Subsystems Modeled
 - Sample Space Contains 2^{67} Elements
 - Data is Binary - System Destroyed or Not
- 1000 Replications of the Experiment
- Two “Live Fires” $\not\subset$ the 1000 “Simulations”
∴ Simulations Declared not Realistic

Solution

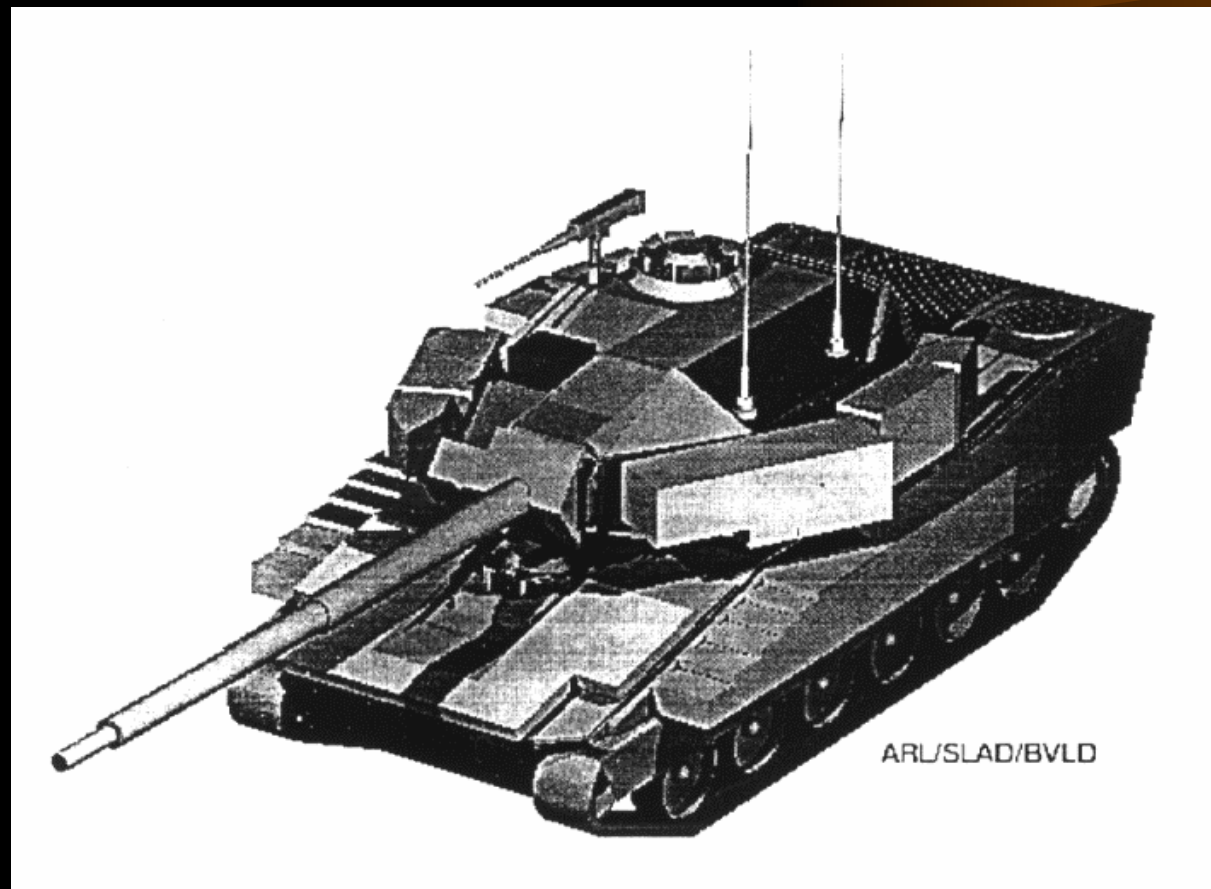


- Each Replication Creates a Binary Damage Vector of Length 67
- Show that Simulations Cluster into a Small Number of Clusters and that Live Fire Tests Fall into these Clusters
- Note: 1000 Replications Does not Begin to Fill the Sample Space

Background

- The Tank is Carefully Drawn in BRL-CAD with 67 Vital Systems Modeled in Correct Geometric Location.
- A Virtual Weapon (Long Rod Penetrator) is Fired Against the CAD-Modeled Tank.
- Behind Armor Debris is Ray-Traced to Assess which Systems are Damaged.

BRL-CAD Model



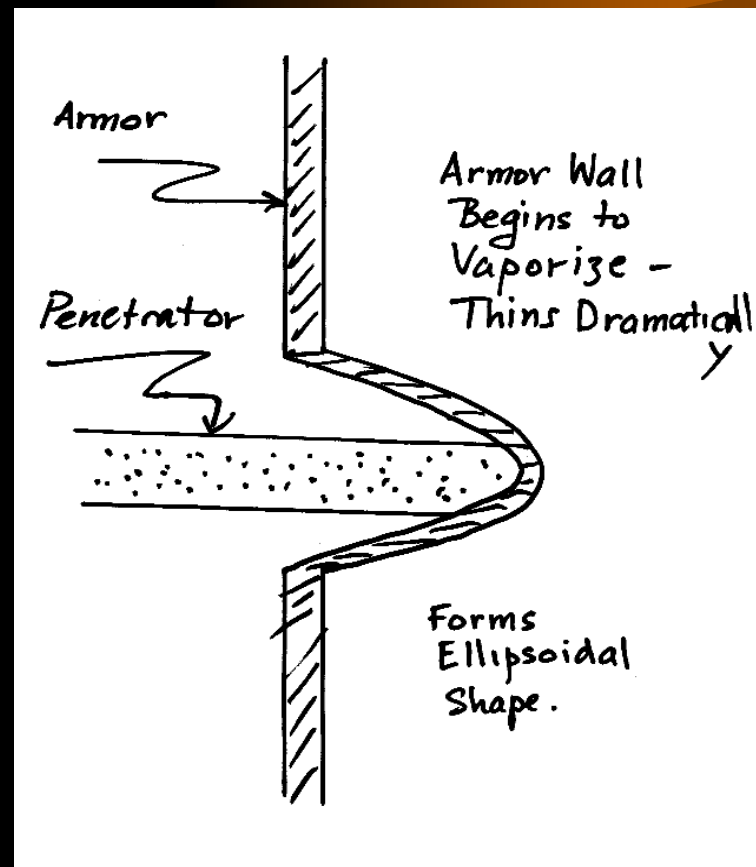
ARL/SLAD/BVLD

Long Rod Penetrators

- Anti-Armor Weapons are not usually High Explosives, but Kinetic Energy Weapons.
- A Long Rod Penetrator Might Be a Cylinder of Tungsten Three Inches in Diameter and Two Feet Long Fired at High Velocity
- Kinetic Energy Begins to Vaporize Armor and Fracture it to Behind Armor Debris

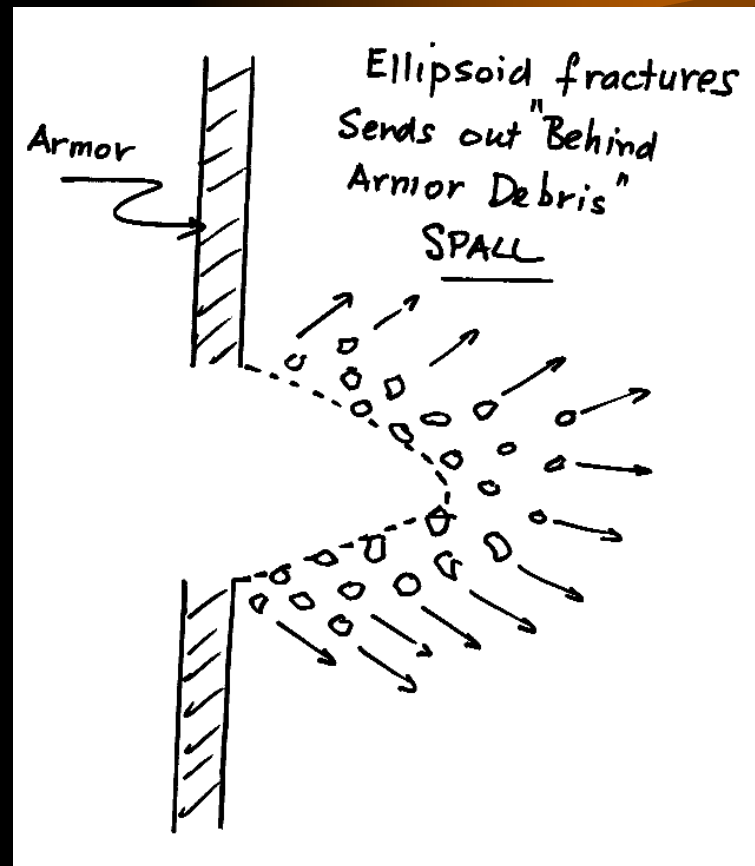
Long Rod Penetrators

- Penetrator Converts Kinetic Energy to Heat, Vaporizes Armor
- Armor Shell Becomes Thin

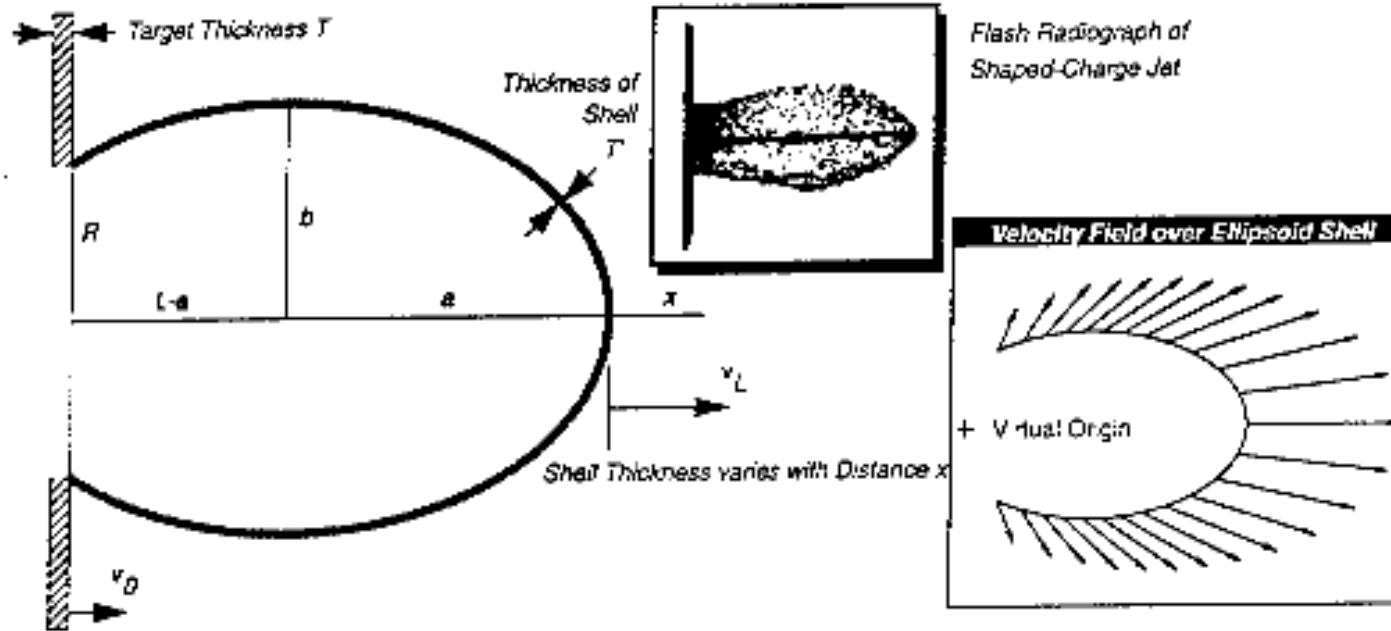


Long Rod Penetrators

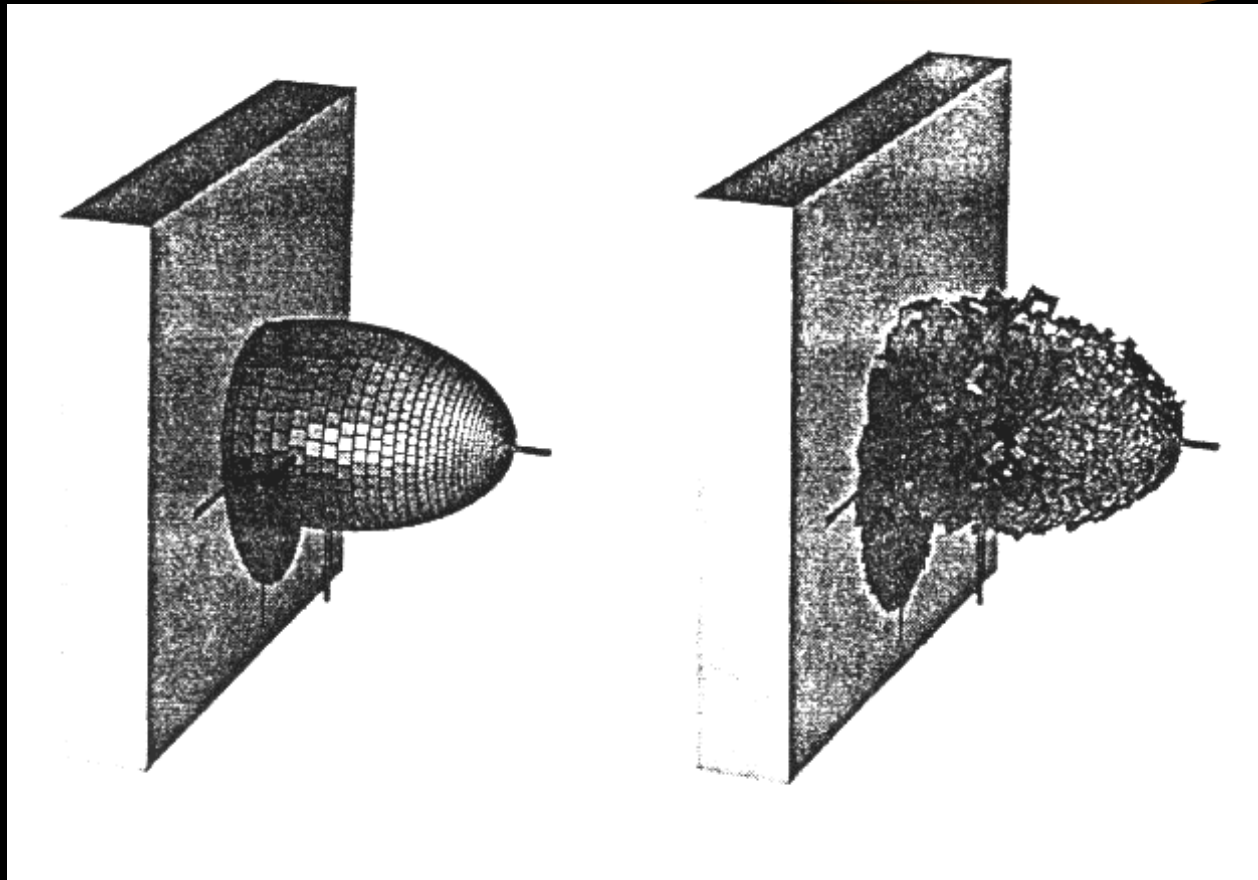
- As Armor Thins to an Ellipsoid, it Fractures into a Cloud of Small Metal Particles
- This is Called Spall
- Damage is Done by the Spall, not the Weapon!



Behind Armor Debris



Behind Armor Debris

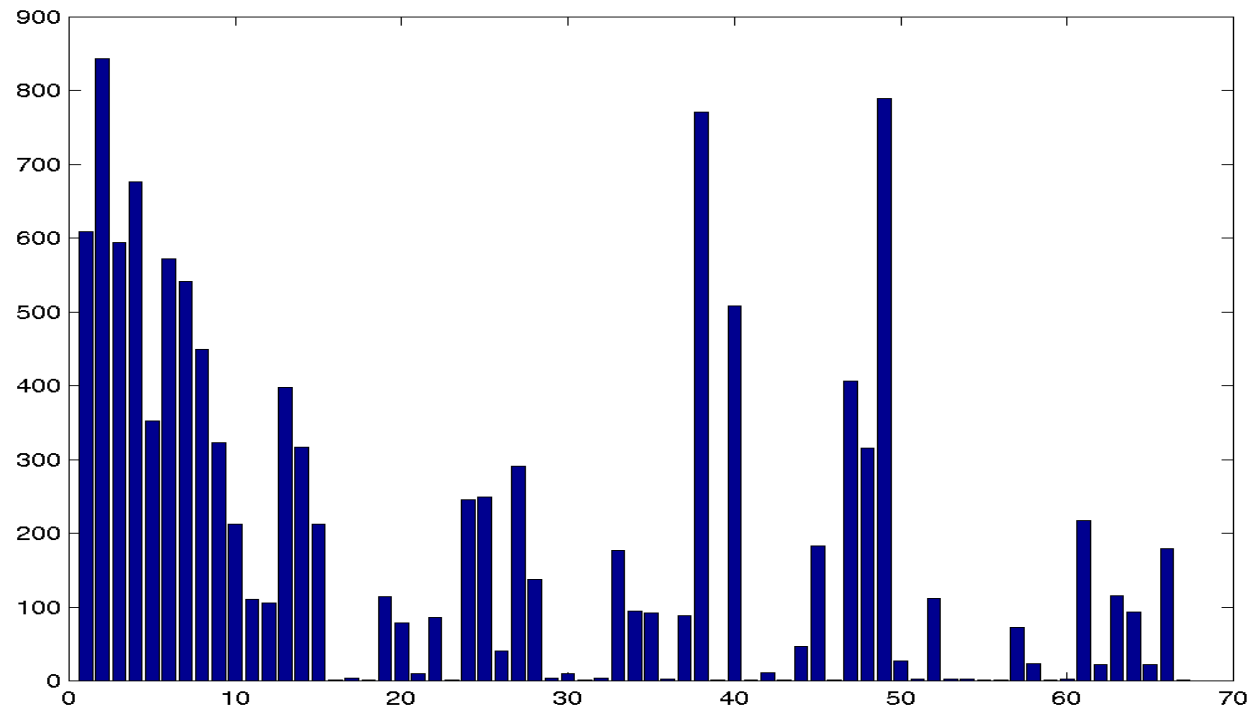


Clustering



- How Many Systems Get Damaged How Often
 - Form Counts For Each System Across All Cases
- Some Systems Usually Get Damaged
- Many Rarely Get Damaged

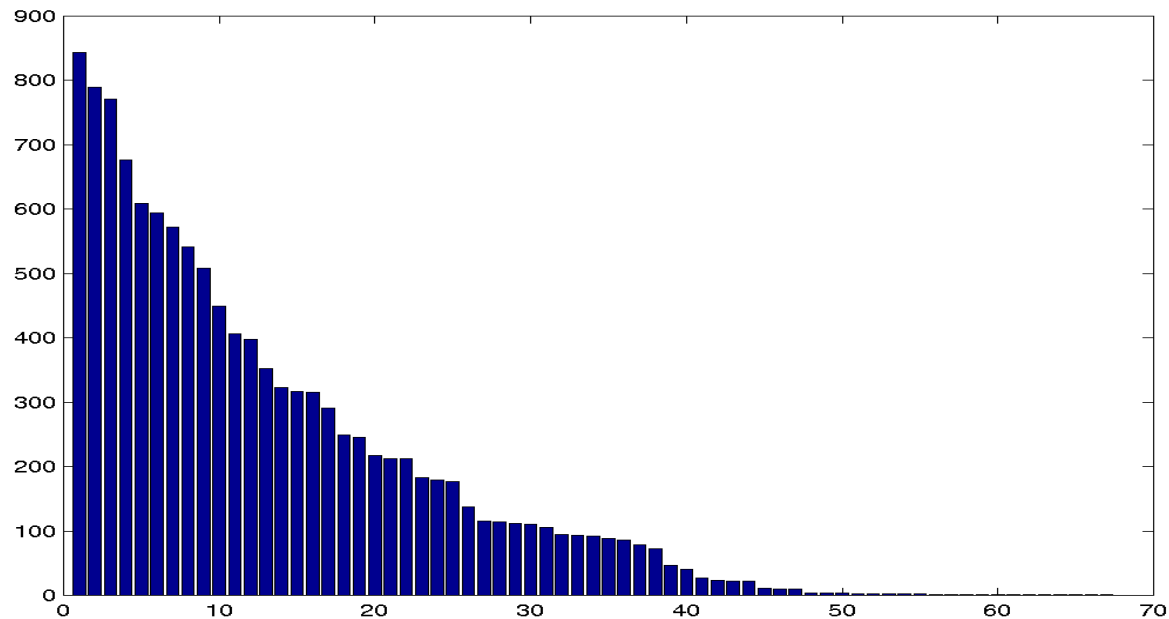
Frequency of Damaged Systems



Frequency of Damaged Systems

- Sort Systems in Order of Most Frequently Damaged to Least Frequently Damaged
- Systems Least Frequently Damaged Do Not Contribute to Clustering We Can Discard Them and Reduce Dimension from 67 to about 46

Frequency of Damaged Systems Sorted



Damaged Systems in Order of Frequency of Damage

Most Commonly Damaged Systems

2	loader - whole body (843)
49	sincgars radio (789)
38	cable 1w306 adp to srs (771)
4	loaders thorax (676)
1	commander - whole body (609)
3	loaders head (594)
6	loaders pelvis (572)
7	loaders arms (541)
40	cable 1w316 adp to srs (508)
8	loaders legs (449)
47	citv sensor citvs (407)
13	commanders arms (398)
5	loaders abdomen (353)
9	commanders head (323)
14	commanders legs (317)

Least Commonly Damaged Systems

54	hydraulic check valve (2)
53	position-navigation unit (2)
36	cable 1w622-8 ubc b-3 to rsm5 (2)
67	fifth torsion bar left (1)
59	hyd line-tdm to ammo door actu (1)
56	hyd line-filter manifold to hd (1)
55	filter manifold (1)
46	citv electronics unit citveu (1)
43	radio interface unit (1)
41	cable 2w114-pn unit to rsm3 (1)
39	cable 1w312 intercom amplifier (1)
31	cable 1w607-8 dbc b-1t to riu (1)
23	cable 1w210-9 tpu to tr (1)
18	cable 1w113-8 gcdp to rsm4 (1)
16	cable 1w100-8 mb2 to rsm5(1)

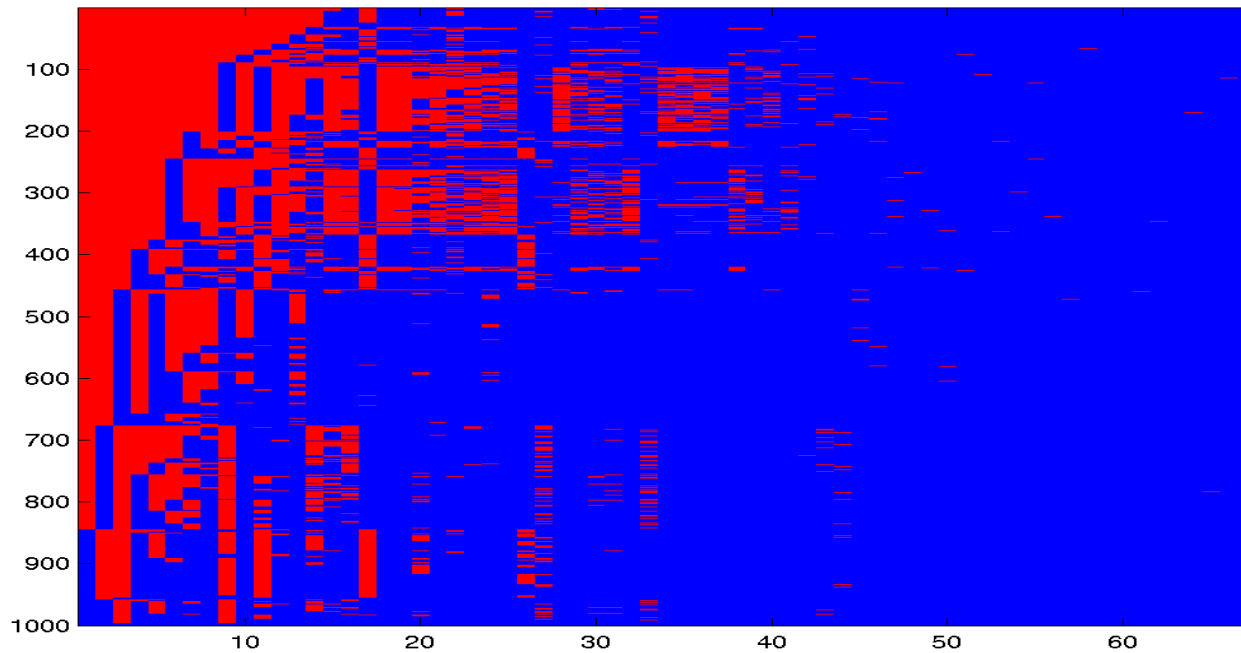
Moral of the Story

- Don't Take a Job as Ammunition Loader
 - Gets killed with probability .843
- Don't Take a Job as Tank Commander
 - Gets killed with probability .609
- Don't Take a Job as Cable Repair Guy
 - Is basically unemployed, killed by boredom
- With Probability .006, There is No Damage

Clustering by Color Histogram

- A Color Histogram plots cases (sample size) by variables (dimension).
- Red = “1”, Blue=“0”
- Original, Wegman (1990)
- Renamed “Data Image” by West and Minnotte (1998)

Color Histogram

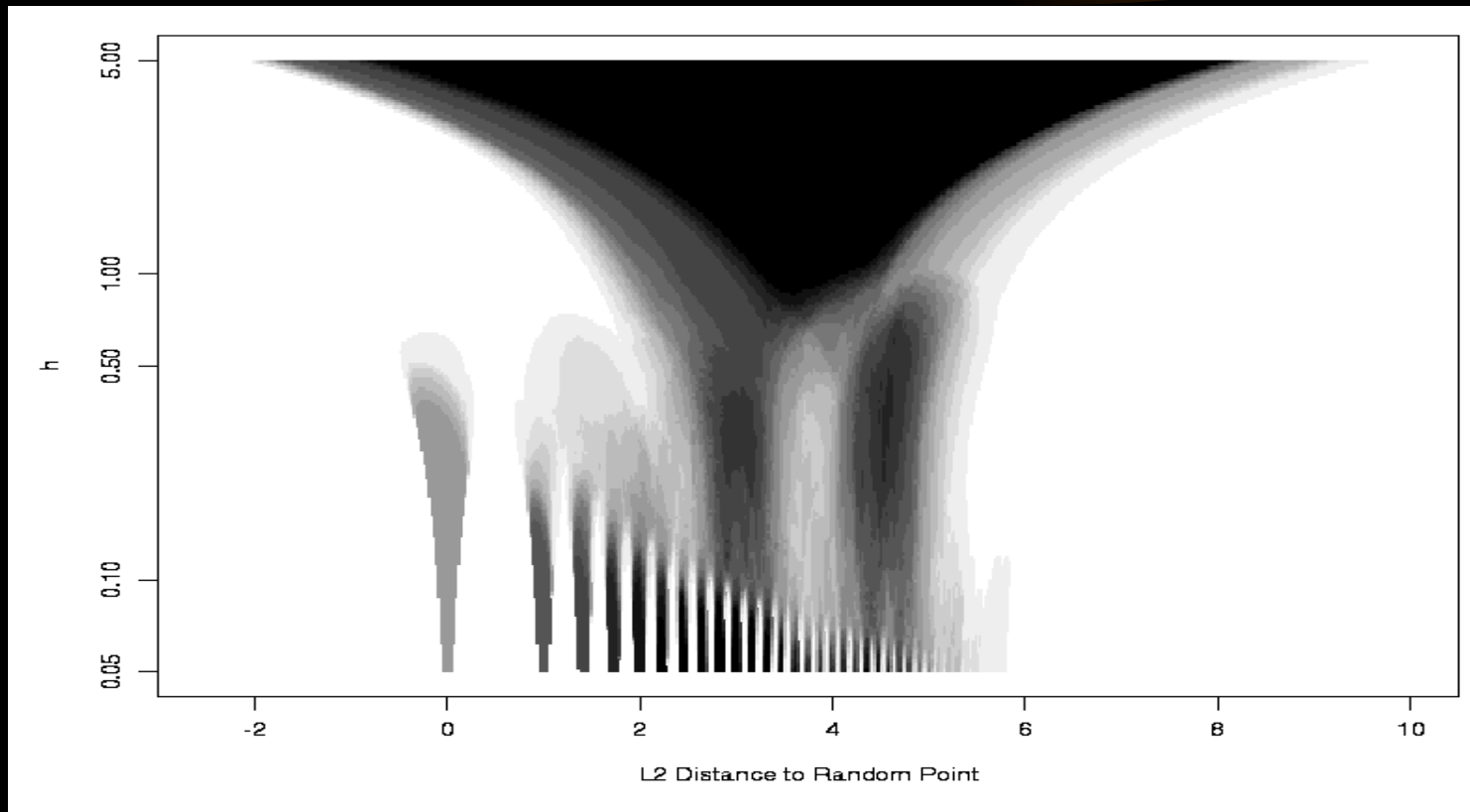


Distance Based Clustering



- Look at pairwise distances between cases
 - 499,500 such distances
 - Now one-dimensional
- Note: L_1 -distance = L_2 -distance = binary distance
- Distance clustering indicates higher-dimensional clustering
- Mode Forest: Minnotte, Marchette, Wegman (1997)

Mode Forest Diagram of Distance Data



Conclusions

- Two Major Damage Mechanisms, One Minor Mechanism ... Each Major has Two Subclusters
- Live fire tests fall into the clusters
- ∴ Simulation Approximates Live Fire and Simulation Methodology Justified.

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