RDECOM

Malcolm Baldrige National Quality Award 2007 Award Recipient

Tissue Damage Model for Estimating Terminal Performance

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Date Presented: 26 April 2016
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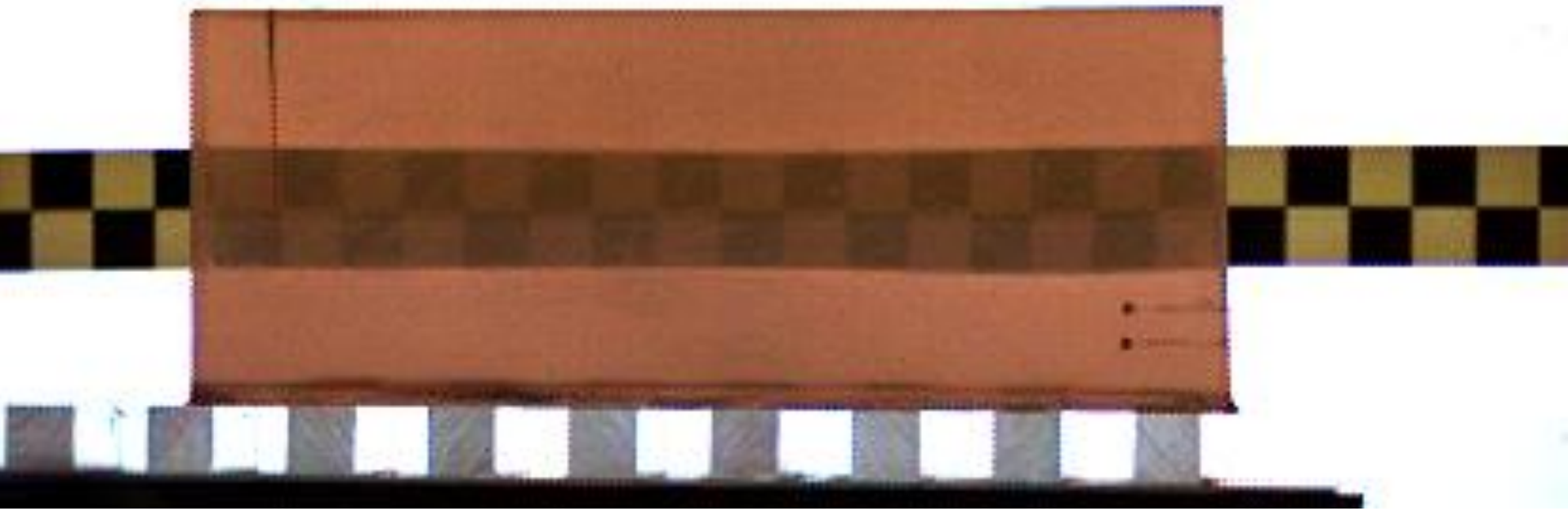
Pistol Bullet Impacting Gelatin



Briefing Outline

- Background & Objective
- Army Lethality
- What the Tissue Damage Model (TDM) is and how it works (top level)
- Comparative examples of commercial product
- TDM interactive session
- Task/Schedule
- Summary

Background

•Upcoming requirements documents have performance evaluations in terms of Probability of Incapacitation, P(i).

•Neither industry, nor most of government, has the ability to evaluate P(i) to the current ORCA/SDF standard.

•A "screening" process or "bridge" model to allow more efficient collaboration between industry/OGA and Army, has been discussed between ARDEC and ARL numerous times over the past 10 years.

• Ammunition Industry interviewed to understand how they guide their ammunition development and compared to how the Army does.

•Heavy reliance on FBI methodology by industry which evaluates **hit and damage separately,** at the technical level. These are later combined at the programmatic level.

•Both industry and FBI are in agreement that industry needs a way of evaluating its developmental product in correlation to the buyer's requirements.

•ARDEC has developed a validated model for "pistol-class" ammunition; working on rifle

Current Analysis Philosophies for small arms effectiveness evaluation

Fall into 3 categories…

1. Probabilistic
2. Ballistic Measurables
3. Individual / Anecdotal Experiences

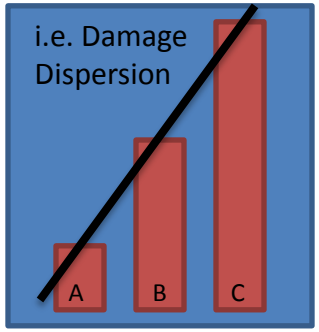
Analysis Hierarchy
What drives which level you use?

Q: At what level do you make a decision on which system (A,B or C) is best for the soldier?

A: depends on your role in the organization

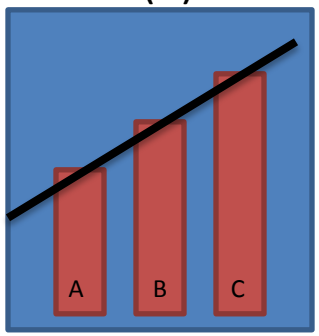
Ballistics
(measureables)

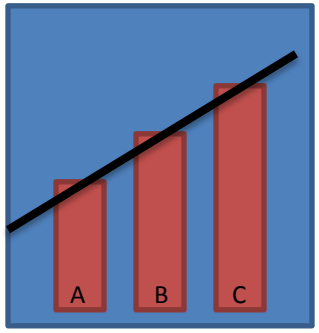
Velocity
Mass
Lethal Mech
Recoil
Flight Mech
etc…



Probabilistic Effects

P(h)

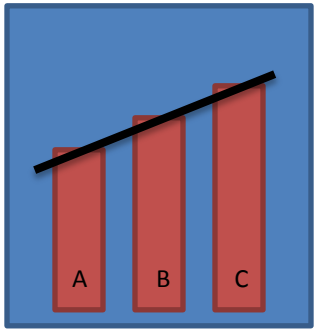




P(i/h)

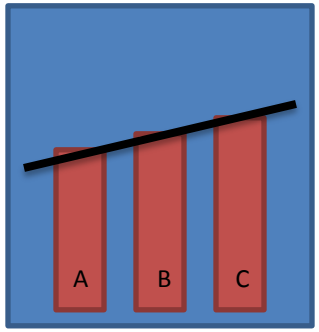
Probabilistic Target Reaction

P(i)



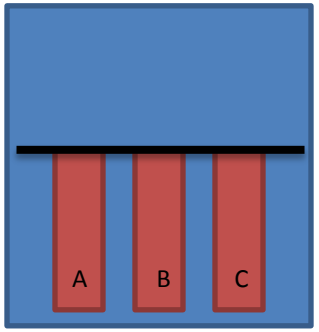
Statistical Loss exchange Ratio

Force on Force



The whole picture

War



Assume C is much more costly than A.

C will be the system you need, once in a while; is it worth the cost?

(depends if you're the one who needs it, or the one who rights the check)

Error bar on any one predicative value

FBI Methodology Overview

The FBI terminal performance evaluation method is a 500 point system referred to as the "Penetration Model"

Penetration Model Summary

1. Penetration depth of deepest portion of projectile
   a. They want to see 12-18" and assign point accordingly as established by medical professionals

2. Standard deviation of the penetration depth
   a. This speaks to their desire to have consistent performance. Large SD's result in significant point deductions.

3. Projectile retained weight
   a. They want to see 100% weight retained and award accordingly.

4. Projectile expansion
   a. They want to see the greatest expansion , optimized to seek maximum diameter that will achieve the 12 – 18" of penetration.

5. The number of shots that penetrated less than 12 inches
   a. This again speaks to consistency. The more shots that penetrate less than 12, the more points you lose.

ARMY Lethality
ORCA Static-Dynamic Framework (SDF)

The framework is composed of three stages: (1) Delivery, (2) Damage to Target (injury) and (3) the ability to assess the target's reduced capability to accomplish tasks (incapacitation). Each one of these stages requires an in depth understanding of the rifle and the projectile's characteristics in terms of aerodynamics and terminal effects.

Delivery

Hit a Target

Target posture/geometry
Aim point
Aim error
Yaw (fleet)
Trajectory
Velocity decay
Wind drift
Ranging error
Dispersion

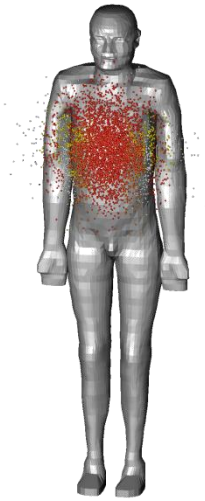
Damage to Target

Injury

Hit location
Shot line in target
Projectile behavior
Tissue response

Incapacitation

Task-based Assessment



Assess target's reduced ability to accomplish tasks, using ORCA

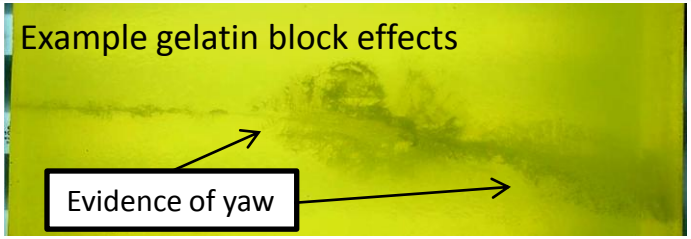
Lethal Mechanisms

Bullet Design / Lethal Mechanism

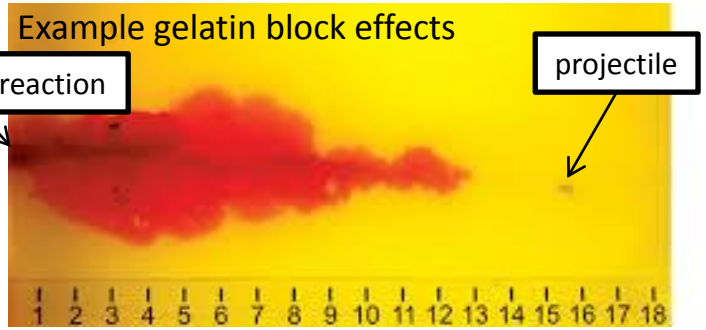
Example Gelatin impact Images

Non-Deforming FMJ (Yaw)

Low velocity

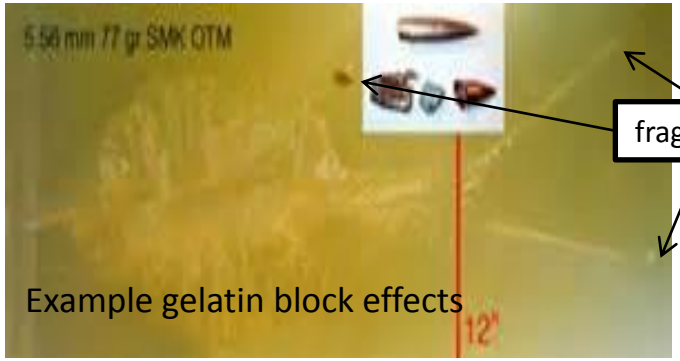


Designed Expansion (JHP/EFMJ etc…)

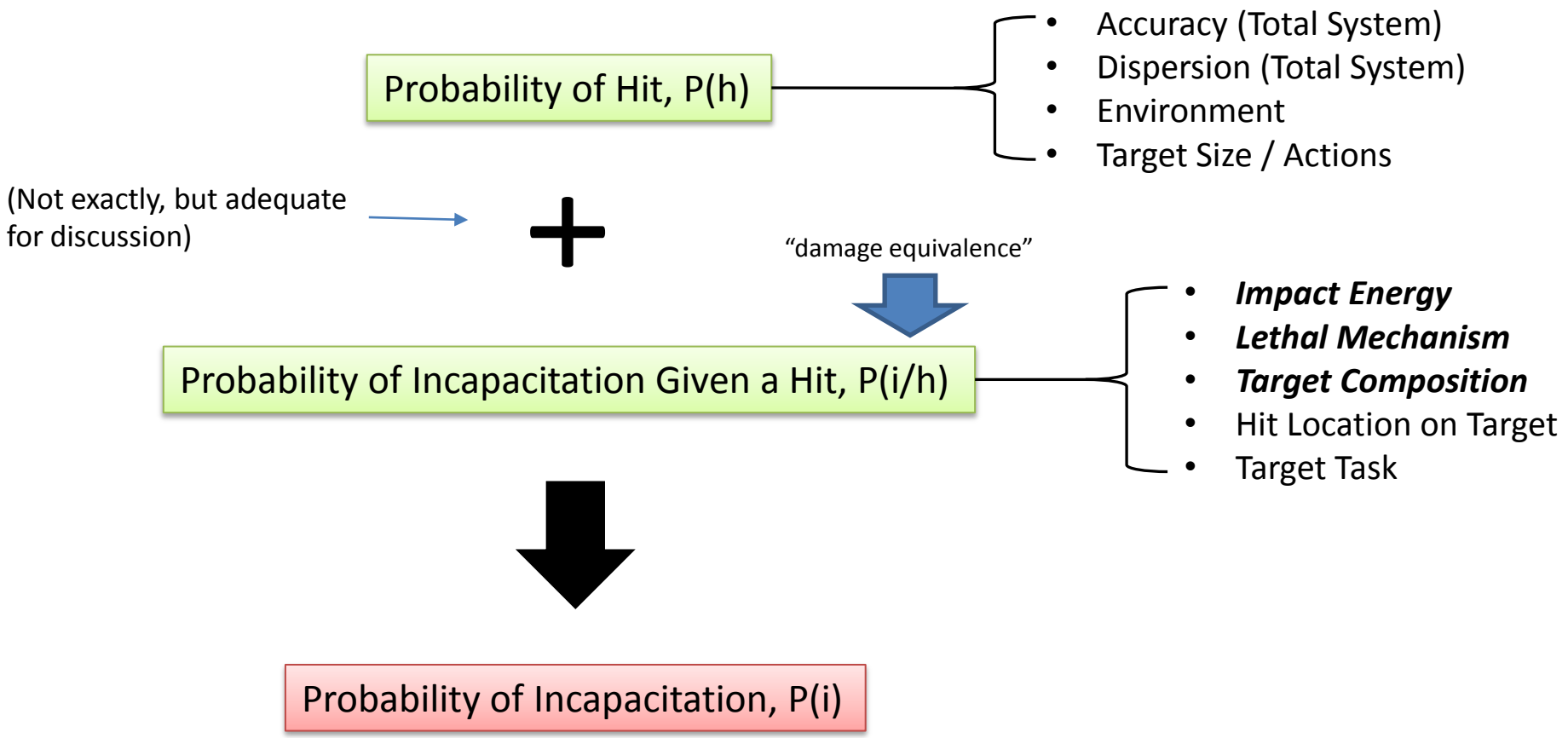


Velocity/Design Induced Fracture (Fragmenting, Frangible, etc…)

High velocity



Army Lethality, simplified

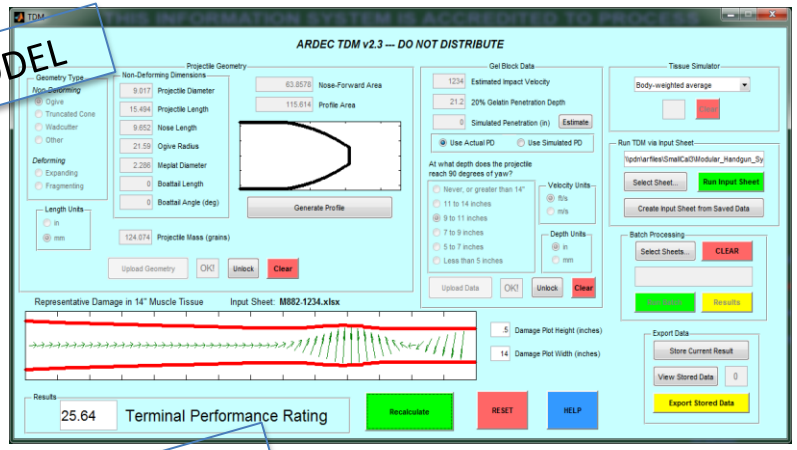


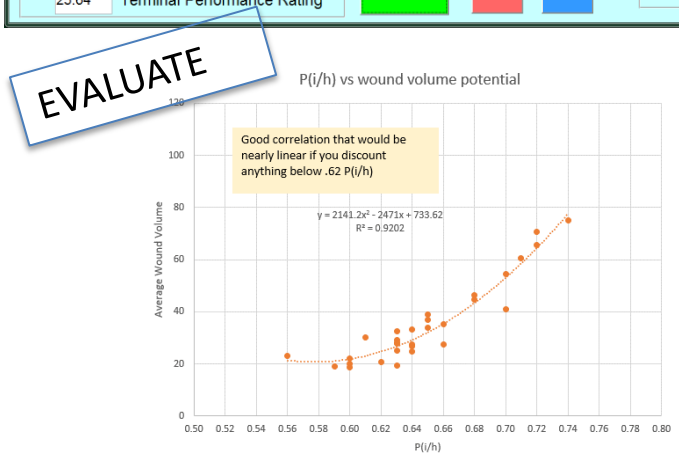
TDM Concept/Objective

ARDEC has built an analysis tool for industry that allows them to estimate the amount of average tissue damage a given munition will create when impacting a human target. U.S. Army will ensure the tool aligns with lethality requirements established by their users.

Payoff (when complete):

- Increases the number of R&D organizations and efforts working towards ***accurately*** meeting the users needs
- Save cost to the U.S. Army in terms of time investigating commercial concepts with sub-standard terminal performance
- Save cost to industry in terms of prototyping and submissions
- Strengthen technical bonds between gov't tech community, OGA and industry counterparts



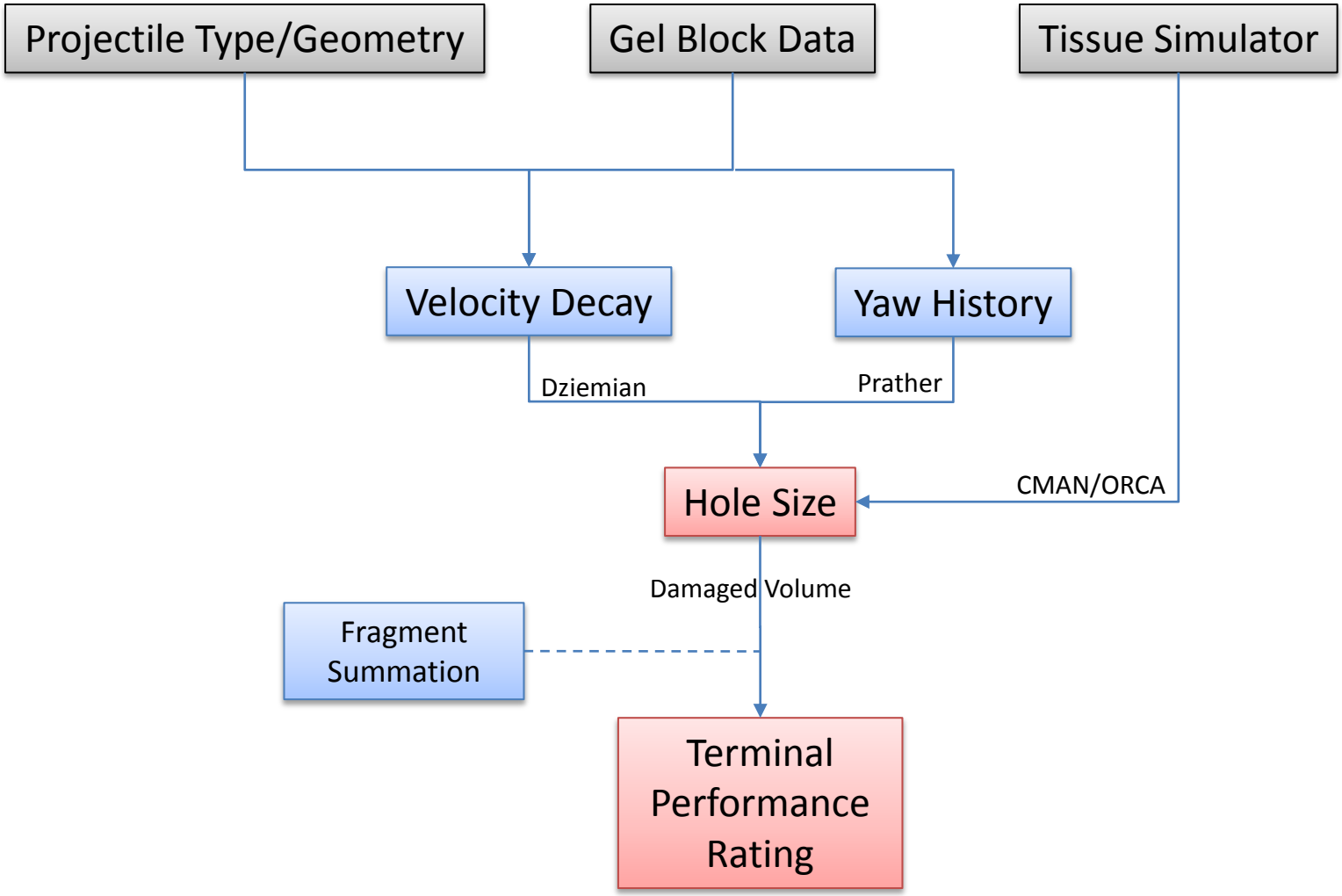


Recent Events (2nd QTR FY16):

- Evaluated first gen concept
- Began technical code development for version 2
- Gather OGA/SME feedback and working into model

TDM Architecture

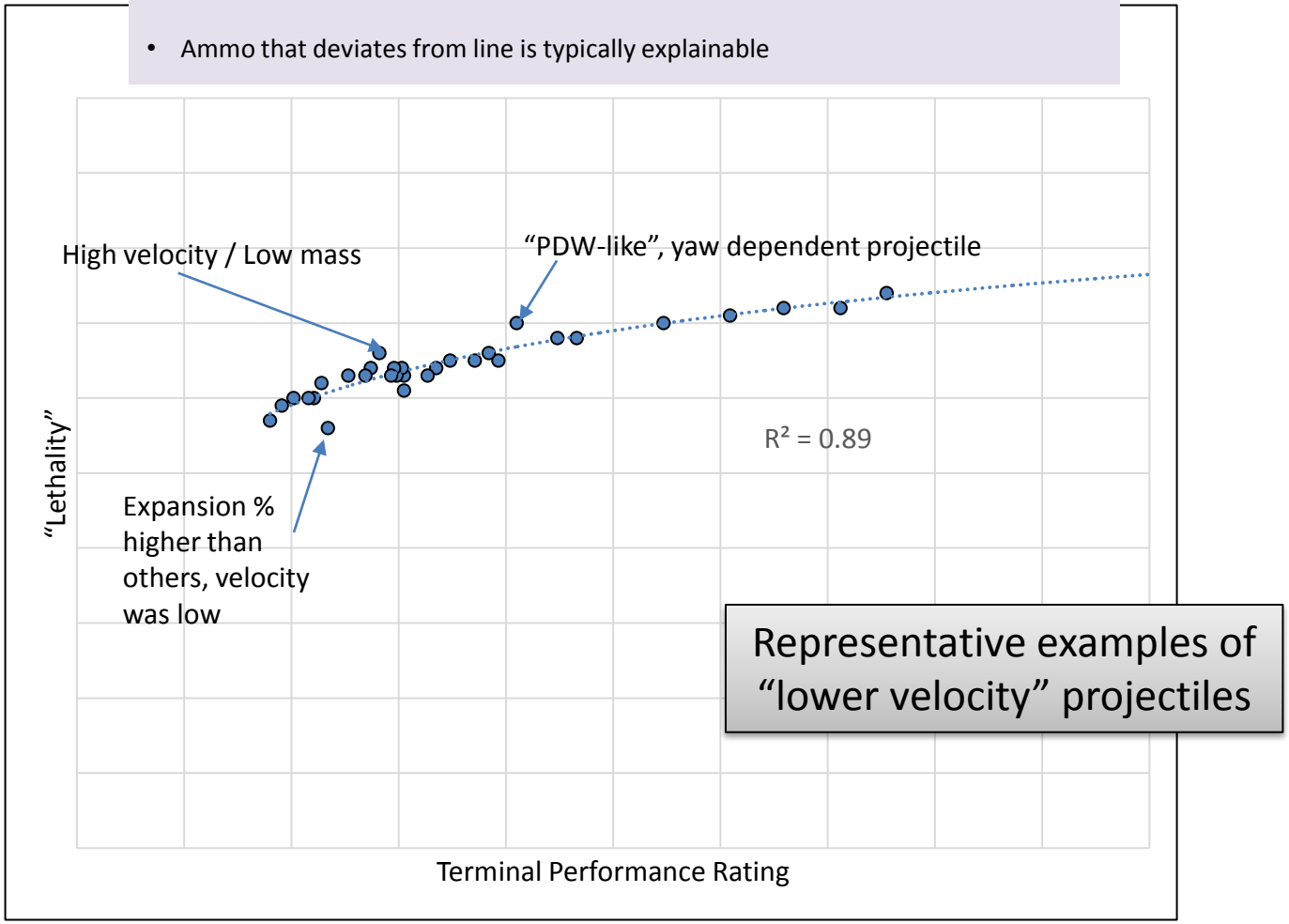
How the Tissue Damage model (TDM) works…



“Lethality” vs. Average Wound Volume

Why we are using it…

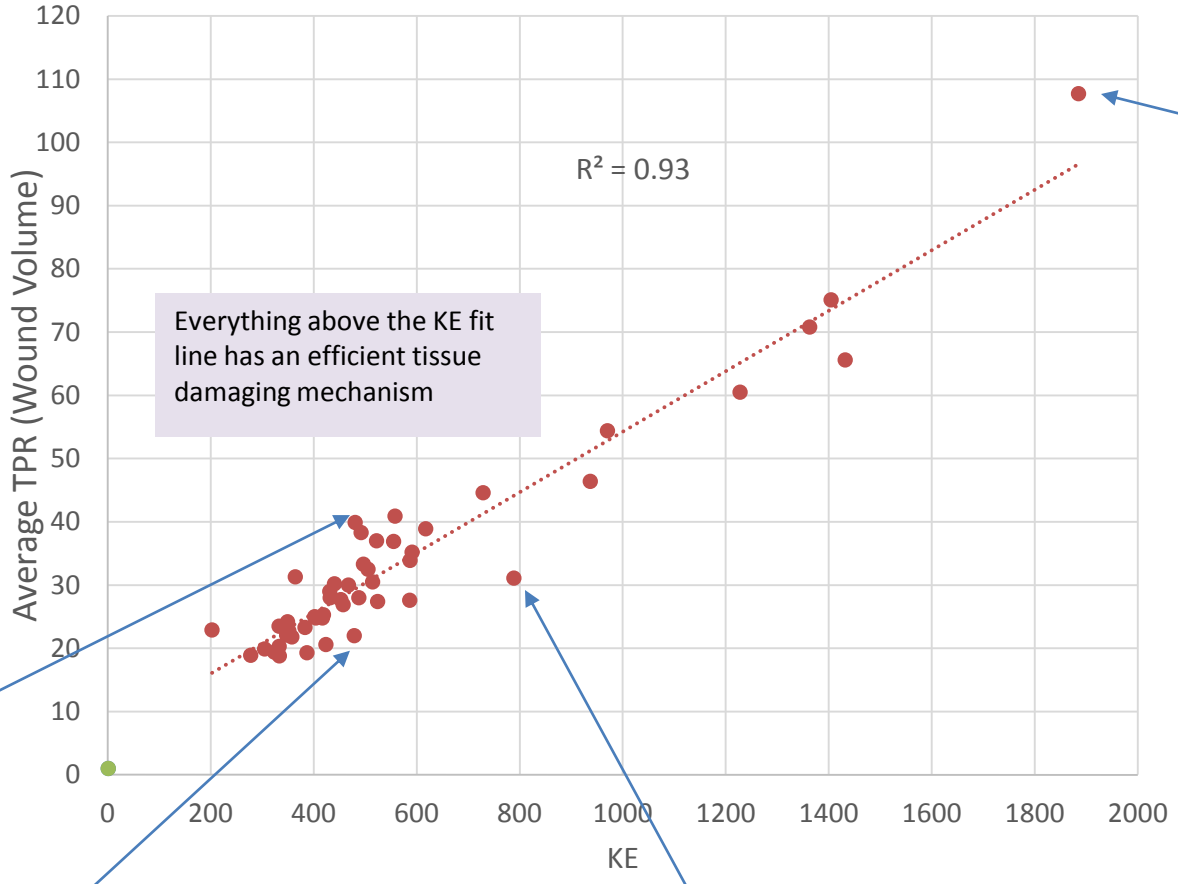
- Correlates well to “Lethality” values divorced from hit probability
- Ammo that deviates from line is typically explainable



Representative examples of “lower velocity” projectiles

Kinetic Energy vs. Wound Volume

That Energy Thing…



Everything above the KE fit line has an efficient tissue damaging mechanism

12 gauge 00 buck

Efficient Lethal Mechanism

Inefficient Lethal Mechanism

Poor expansion, no yaw

Calibrated with "lower velocity" projectiles

TDM Usage Example

Tissue Damage Estimation Tool

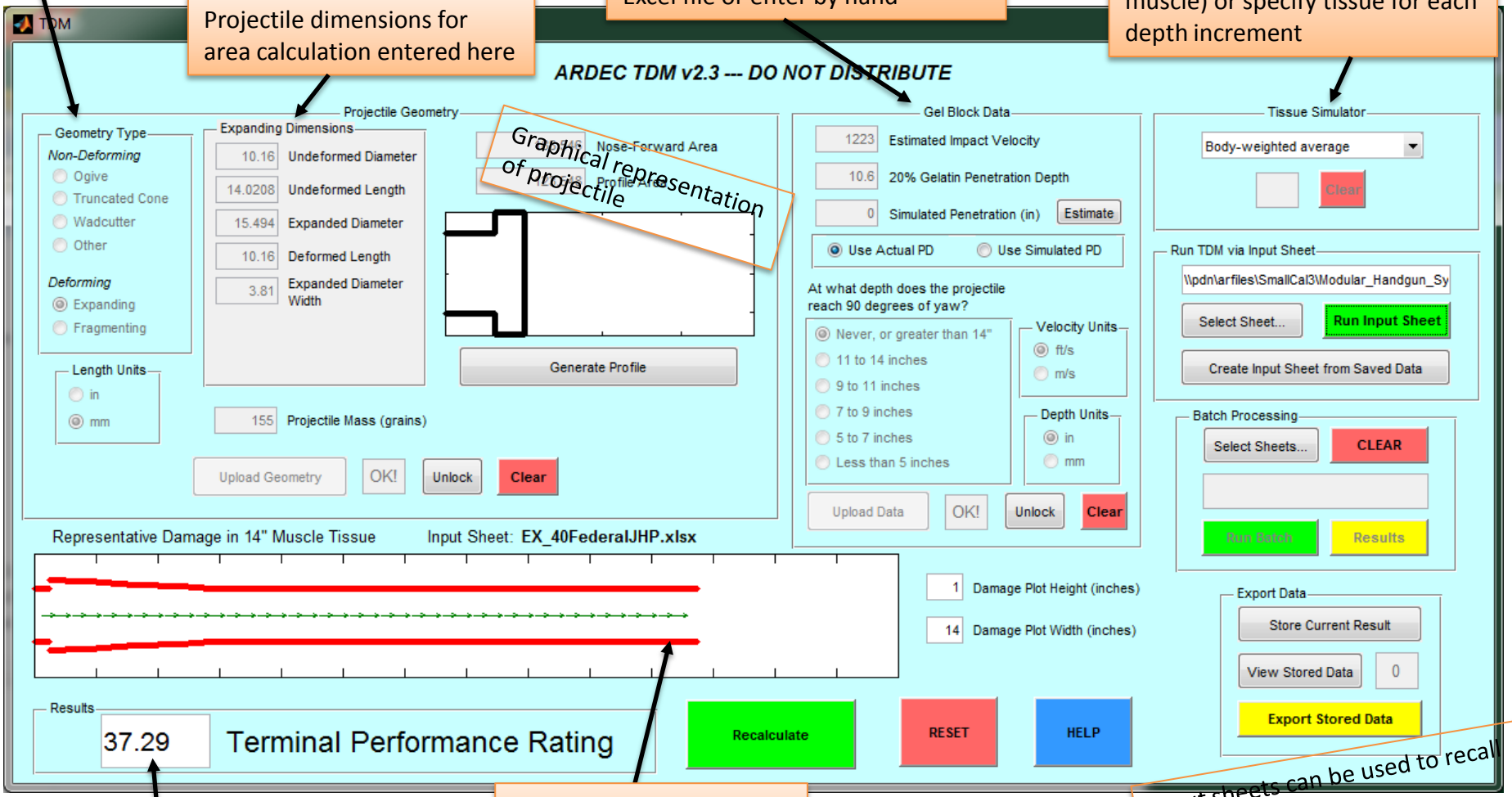
Example: .40 cal JHP

Projectile geometry (nose shape or expanding/fragmenting)

Projectile dimensions for area calculation entered here

Projectile trajectory - depth, velocity, yaw history - import from Excel file or enter by hand

Tissue definition - preset (e.g., all muscle) or specify tissue for each depth increment



Wound volume output

Red line: Wound diameter
Green arrows: Yaw angle

Input sheets can be used to recall previous models

Today's Case Study

5 commonly used commercial cartridges chosen solely to evaluate the range of the models capability

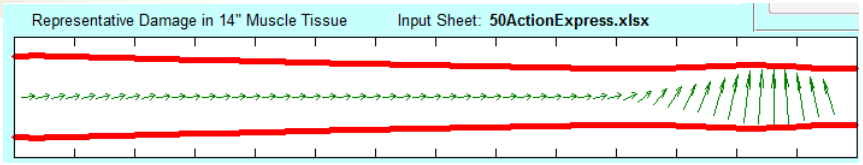
1. .50 AE, FMJ, 325 grains, 1305 ft/sec, TPR = 60.5
2. .40 cal S&W, JHP, 180 grains, 1110 ft/sec, TPR = 47.4
3. .45 ACP+P, FMJ, 185 grains, 1130 ft/sec, TPR = 30.1
4. .45 ACP, FMJ, 230 grains, 890 ft/sec, TPR = 27.0
5. 9mm Parabellum, FMJ, 124 grains, 1140 ft/sec, TPR = 20.6
6. .22LR, FMJ, 40 grains, 1200 ft/sec, TPR = 8.6

TPR = Terminal Performance Rating

Comparative Model Output: Muscle/Gelatin

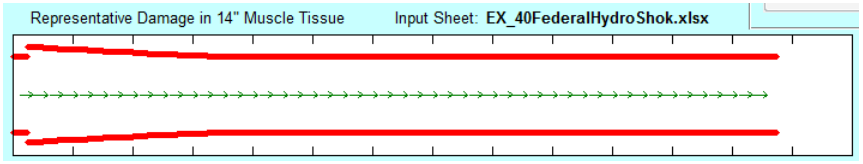
Terminal Performance Ratings

.50 AE



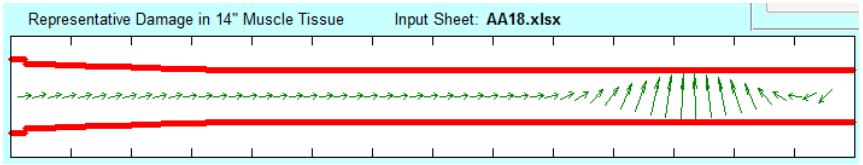
TPR = 60.5

.40 S&W JHP



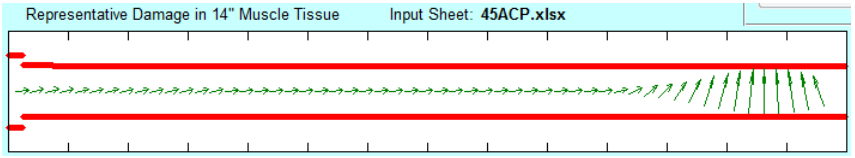
TPR = 47.4

.45 ACP +P



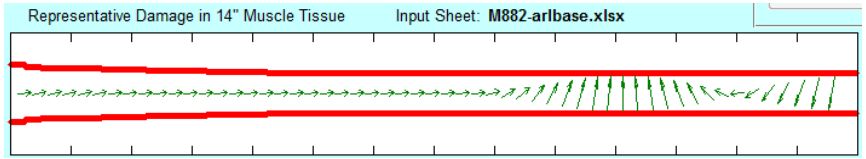
TPR = 30.1

.45 ACP



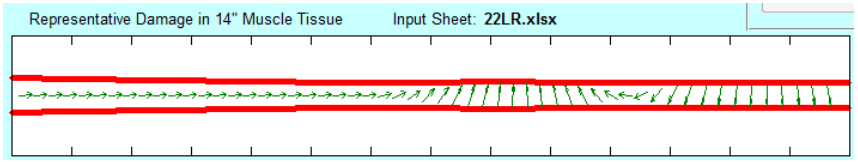
TPR = 27.0

9mm Para



TPR = 20.6

.22 LR

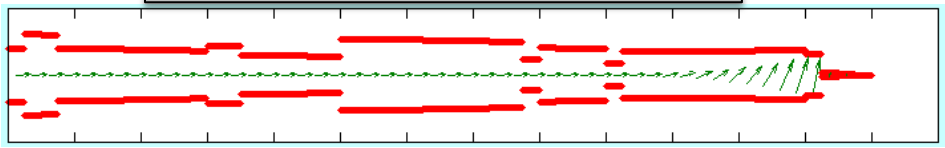
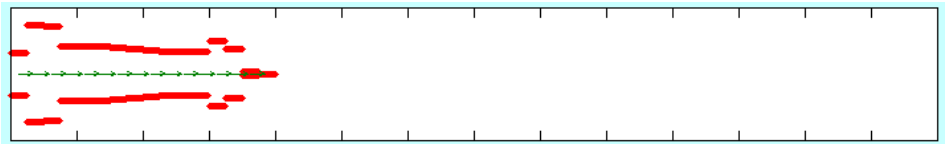
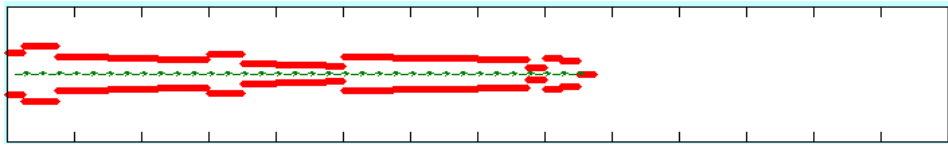
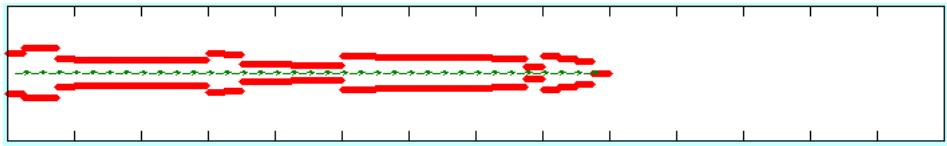
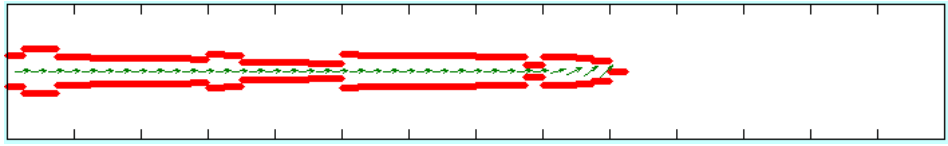
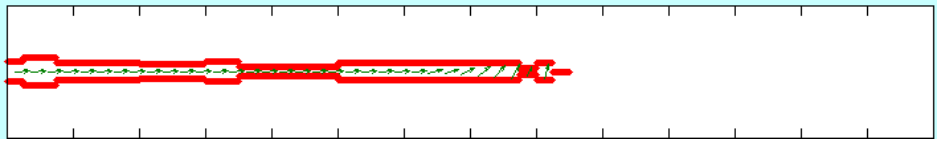


TPR = 8.6

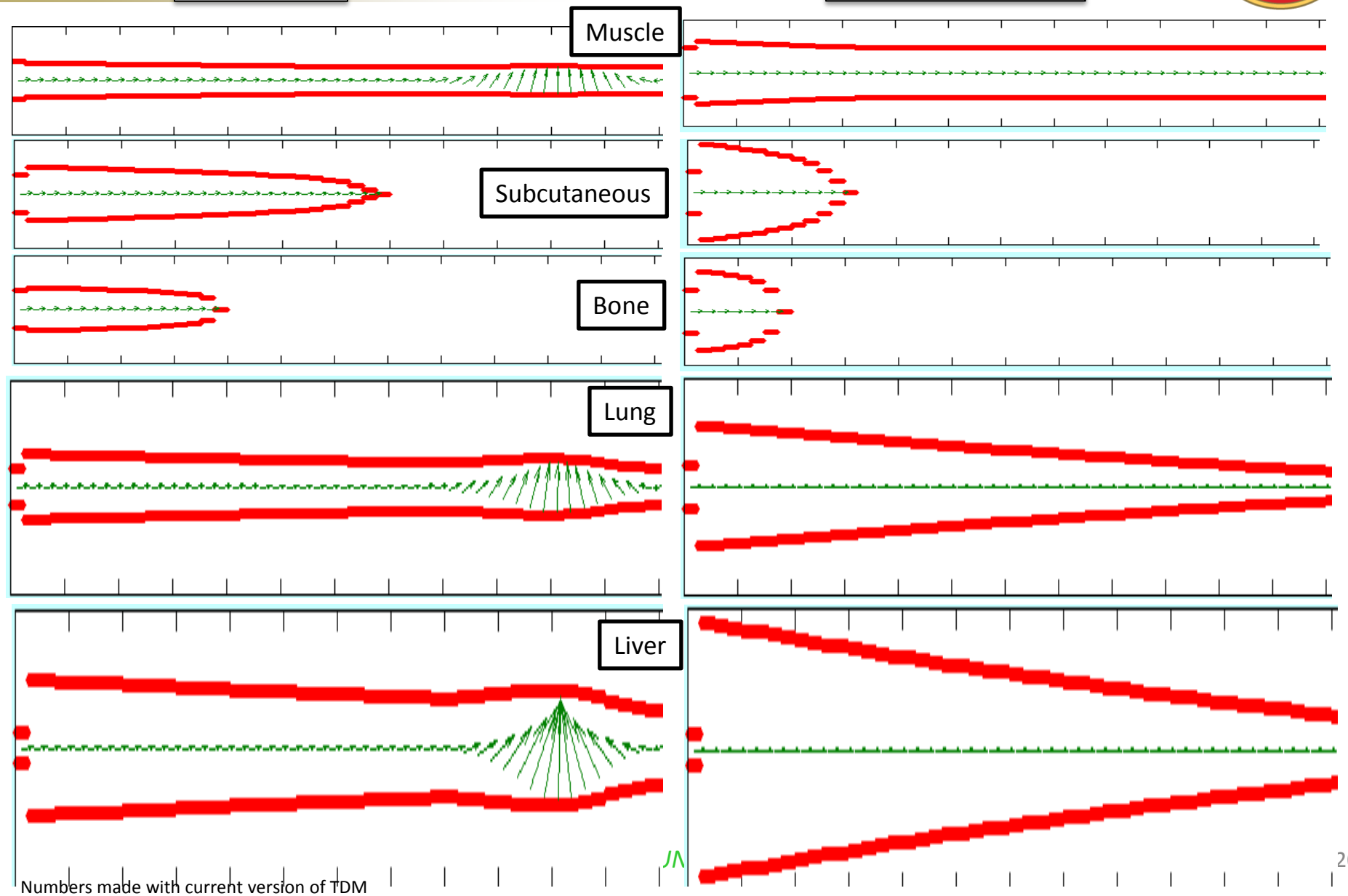
Data generated with current version of TDM

2 Discrete Shot lines

Simulated by current version of TDM

Frontal shot through center chest	Side shot through Shoulders
.50 AE	
.40 Cal JHP	
.45 ACP+P	
.45 ACP	
9mm Para	
.22 LR	

Single-tissue targets



Numbers made with current version of TDM

Comparative Model Output

COLOR BANDS TO BE DICTATED BY ORG USING WEAPONS

Data generated with 2015 version of TDM

	1					2																		
TPR	107.7	75.5	71.2	65.9	60.9	54.7	48.5	46.6	44.8	44.7	42.2	41.0	39.9	39.3	38.4	38.2	37.3	37.1	36.0	34.9	34.8	33.5	32.9	32.7	31.9
Grains	484	185	240	240	325	135	180	158	147	125	180	85	103	230	185	155	180	115	180	158	135	115	230	125	158
ft/sec	1325	1850	1600	1640	1305	1800	1110	1635	1495	1372	955	1720	1450	1100	1200	1223	1050	1475	1040	1500	1400	1395	822	1350	998
KE	1885	1405	1363	1432	1228	970	492	937	729	522	364	558	480	617	591	514	440	555	432	789	587	496	345	505	349
PF	641	342	384	394	424	243	200	258	220	172	172	146	149	253	222	190	189	170	187	237	189	160	189	169	158
LM	shot	FMJ	FMJ	FMJ	FMJ	FMJ	JHP	FMJ	FMJ	JHP	JHP	JHP	shot	FMJ	FMJ	JHP	JHP	FMJ	JHP	JHP	FMJ	FMJ	JHP	FMJ	JHP

		3							4								5							6	
31.1	30.5	30.5	30.3	29.8	29.8	29.3	28.8	28.2	27.4	27.3	26.9	26.2	25.8	25.3	23.9	23.4	22.8	22.6	22.1	21.6	21.2	20.2	19.1	18.0	8.6	TPR
165	165	185	185	200	147	115	185	124	124	230	165	147	124	147	124	95	180	124	230	170	124	116	93	95	40	Grains
980	1130	1090	1130	1010	1010	1300	1080	1460	1289	890	1028	996	1234	1110	1180	980	1030	1140	825	940	1100	1088	1160	1050	1200	ft/sec
352	467	488	524	453	333	431	479	586	457	404	387	323	419	402	383	202	424	357	347	333	333	305	278	232	128	KE
162	186	202	209	202	148	150	200	181	160	205	170	146	153	163	146	93	185	141	190	160	136	126	108	100	48	PF
JHP	FMJ	FMJ	FMJ	FMJ	JHP	FMJ	JHP	FMJ	FMJ	FMJ	EFMJ	JHP	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	FMJ	LM

Displayed bands of performance were determined by…

- Error budget calculations to determine the precision of the model
- Comparison to historical P(i) precision (.3 pts)
- Comparison to products used by OGA and deemed “effective”

Interactive Trial

Run audience-fed examples

(AT RDECOM BOOTH)

Tasks / Schedule

	2nd QTR FY16	3rd QTR FY16	4th QTR FY16	1st QTR FY17	2nd QTR FY17	3rd QTR FY17	4th QTR FY17
Yaw History							
Hole size validation							
Low velocity hole size							
High velocity hole size							
Fragmentation vs Expansion (validation)							
Rifle velocity spectrum calibration & validation							
Higher velocity impact							
Fragmentation							
Packaging							
Software Language & Interface Design							
Security & Distribution							

Summary

- Objective: Create a model that allows industry to estimate terminal performance in a manner that separates hit from damage, while maintaining adequate correlation to Army requirements
- Current Tissue Damage Model (TDM) version is validated for “lower velocity” projectiles only.
- Version two is intended to work in all mass/velocity/Lethal mechanism regions.
- JSSAP funding the creation of version 2.
- 1 year effort lead by ARDEC and supported by ARL to end 4th QTR 2016 to finalize TDM model
- Seeking release to industry by 3rd QTR 2017
- Hit probability, among other system characteristics, need to be evaluated in any selection process. This model is for terminal performance, ONLY. The author suggests a quality requirement document contain *damage*, *hit* and *probabilistic metrics,* tied together.
- **Seeking participants to assist in validation and comparison to other standards**