PAYING FOR WEIGHT IN BLOOD:

An Analysis of Weight and Protection Level of a Combat Load During Tactical Operations

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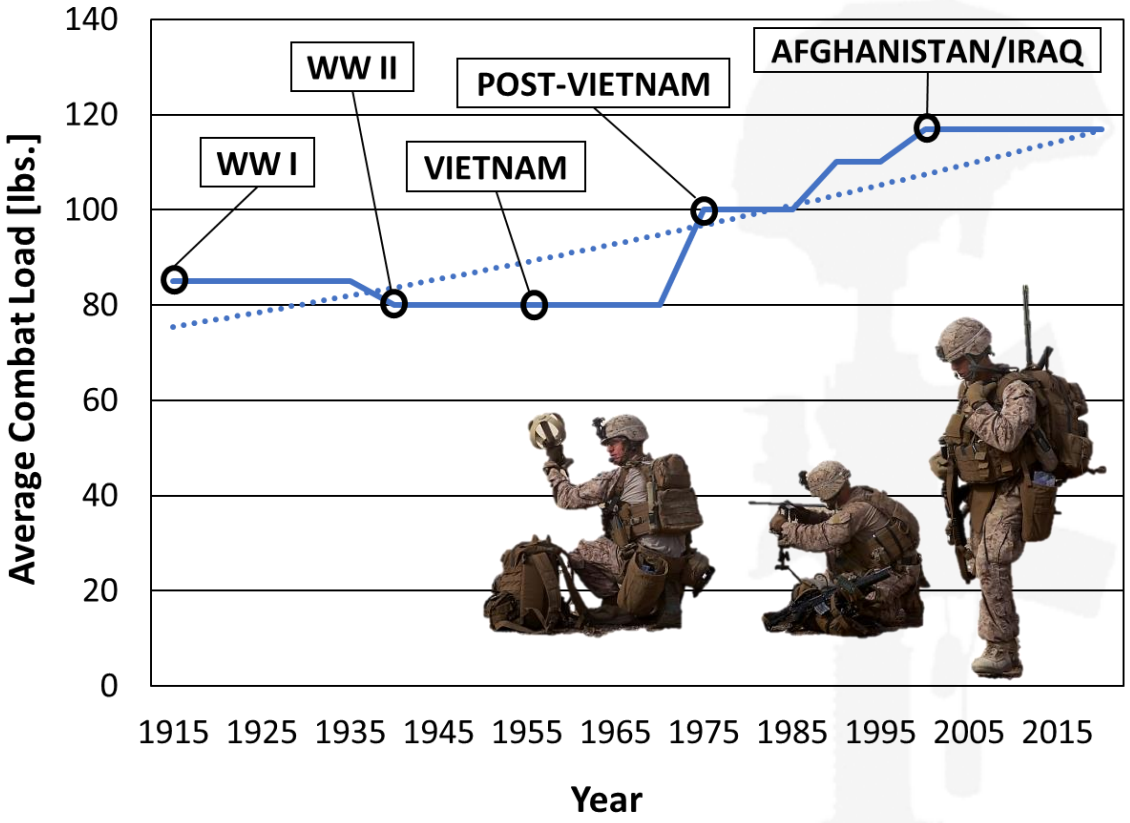
The Problem



HUMAN-SUBJECT RESEARCH

Performance decrement:

0.36 – 0.68% / lb.

THESIS OBJECTIVE

Support commanders' understanding of how external load can both enhance and diminish the effectiveness and survivability of the warfighter

THESIS QUESTIONS

- What is the effect of increasing external load on casualties and mission success?
- Is there a critical point in weight which should not be exceeded?

Bottom Line

Weight = ***Casualties***

43 lbs.

+

15 lbs.

=

One Additional Casualty

CONCLUSIONS	RECOMMENDATIONS
▪ Speed matters more against peer adversaries ▪ <u>Goal</u>: Enable Marines to be twice as hard to hit as stationary targets (results in 60% reduction in expected casualties)	▪ Fighting load weight ≤ 50 lbs. ▪ Assault load weight ≤ 75 lbs. ▪ Holistic approach to weight reduction

Thesis Scenario

SITUATION

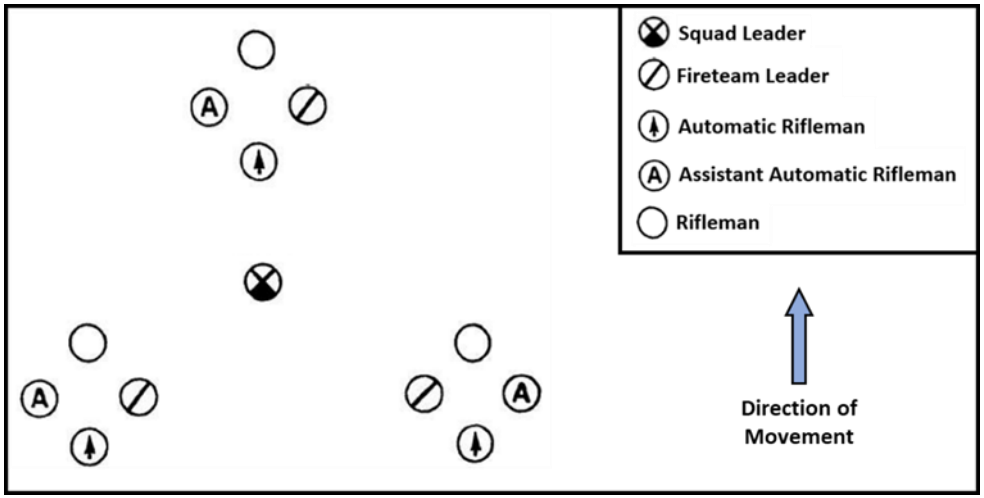
- **Fireteam-sized (4)** element of insurgents with **AK-47 assault rifles**
- Expect a **surprise attack**

MISSION

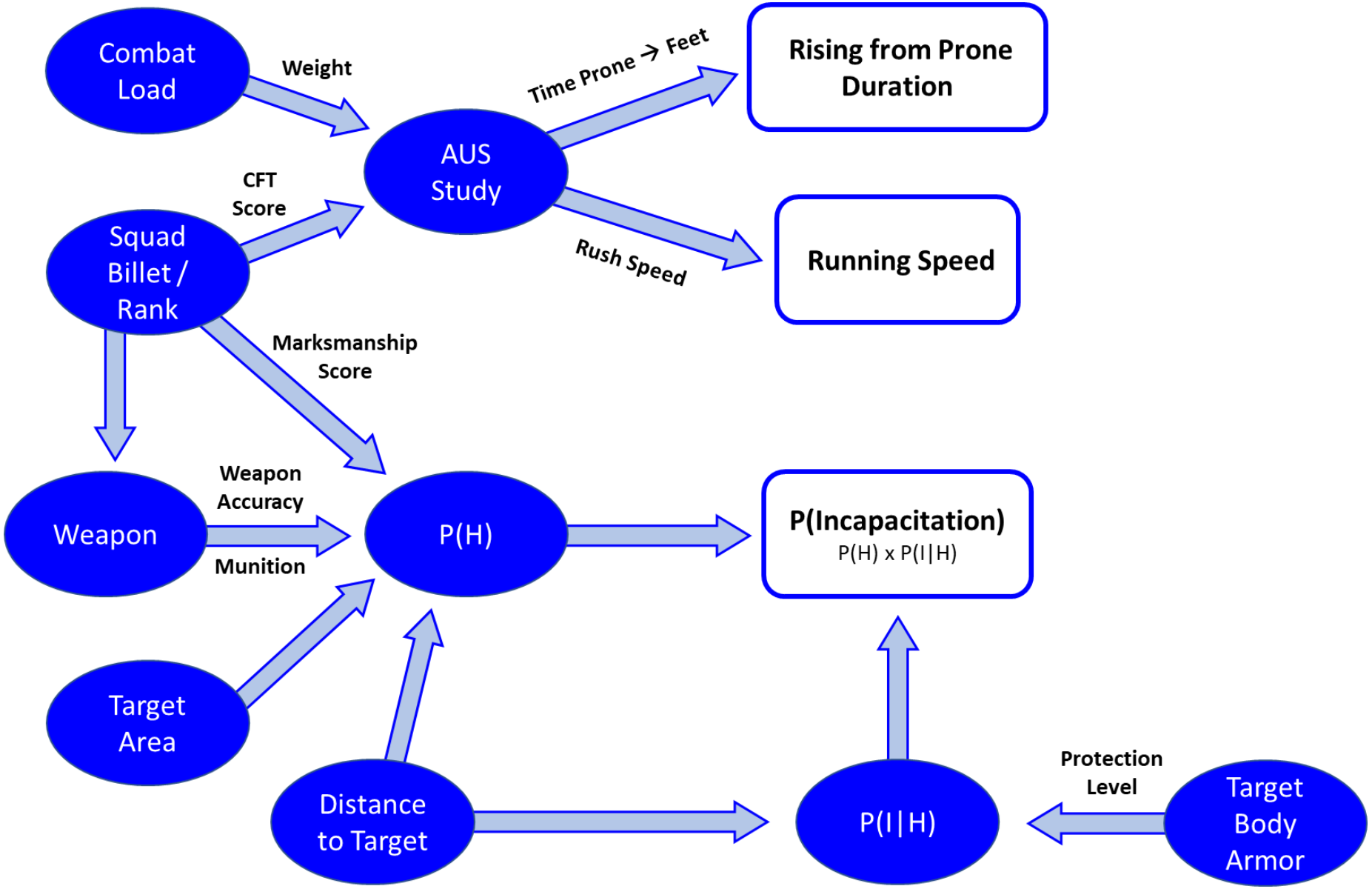
13-Marine rifle squad conducts a **dismounted patrol** in vicinity of the town in order to control the urban region and deny the enemy the ability to harm the local populace.

EXECUTION

- Insert via convoy and dismount approx. **100 meters** outside the town
- Conduct patrols around the town's perimeter, then through the city in a **squad wedge formation**



USMC (Blue) Agent Inputs



Assumptions

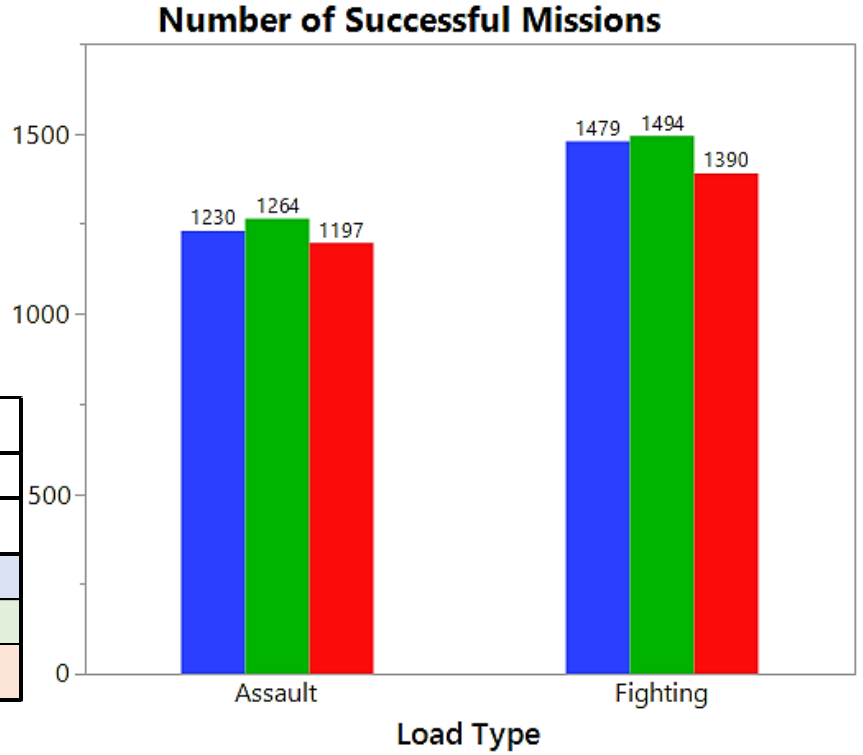
Assumption	Reasoning
Red agents have no body armor	Estimation of enemy equipment
Probability of a Red agent hitting a Blue agent is for a stationary target	Blue agents run directly towards Red with no lateral movement
Probability of a Blue agent hitting a Red agent partially obscured behind cover = Probability of hitting an agent in the prone firing position	Estimation of the amount of exposed body area of an enemy fighter firing from behind a wall or through a window
Probability of a Red agent hitting a Blue agent rising from prone = Probability of hitting an agent in the kneeling firing position	Estimation of presented target area

Results: T&R Standard Loads

Fighting Load [lbs]: II = 43, III = 62, IV = 65 **Assault Load** [lbs]: II = 58, III = 77, IV = 80

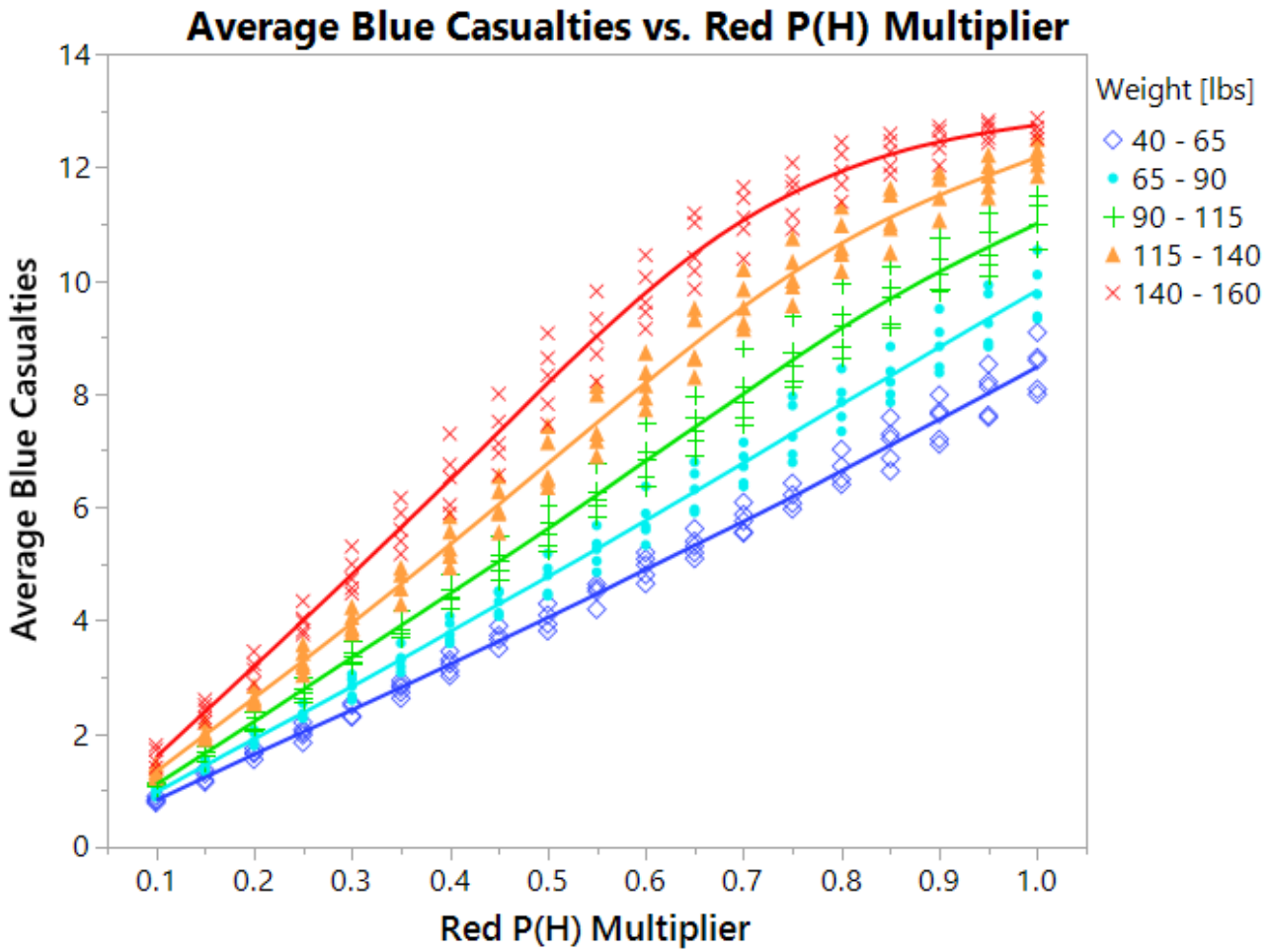
Body Armor			
	Level	*Description*	*Protection*
	II	Soft Armor Vest	9 mm
	III	II + SAPIs	7.62 mm
	IV	II + ESAPIs	0.30 cal. AP

Body Armor Level	Blue Casualties					
	Assault Load			Fighting Load		
	Q1	Median	Q3	Q1	Median	Q3
II	8	10	13	7	9	13
III	7	10	13	7	8.5	13
IV	8	10	13	7	9	13



- ↓ Weight = ↓ Casualties
- Average difference of one casualty between fighting and assault loads
- Balance of weight and protection is best regardless of load type

Results: External Load & P(H)



- Constant P(H) Multiplier: ↓ External Load = ↓ Casualties
- External load weight matters more against better shooters

Conclusion

Battles are won by slaughter and maneuver. The greater the general, the more he contributes in maneuver, the less he demands in slaughter.

– Winston Churchill

CONCLUSIONS

- 43 lbs. + 15 lbs. = 1 additional casualty
- Optimal load = lightest load with greatest level of protection
- Heavier weight = increase in casualties
- Against peer adversaries speed matters more
- Enabling Marines to be twice as hard to hit as stationary targets reduces 13-Marine squad casualties from 8.9 to 3.5 (60% reduction in casualties)

RECOMMENDATIONS

- Fighting load weight ≤ 50 lbs.
- Assault load weight ≤ 75 lbs.
- Holistic approach to weight reduction

Grade	Avg Weight [lbs]	30% | 45% Body Weight [lbs]
E1/2	164.4	49.3 | 74.0
E3	166.9	50.1 | 75.1
E4	170.1	51.0 | 76.5
E5	173.9	52.2 | 78.3

Stakeholders

Army Material Systems Analysis Activity (AMSAA)

Headquarters Marine Corps (HQMC)

- Manpower and Reserve Affairs (M&RA)
- Plans, Policies, and Operations (PP&O)

MARCORSYSCOM

- Ground Combat Element Systems
  - Marine Expeditionary Rifle Squad (MERS)

US Army Research Laboratory (ARL)

- Soldier Lethality Cross Functional Team (CFT)
- Soldier and Squad Trade-space Analysis Framework (SSTAF)

US Army Natick Soldier RD&E Center

- Advanced Soldier and Small-unit Equipment Team (ASSET)

US Army Maneuver Center of Excellence

- Capabilities Development and Integration Directorate (CDID)
- Tactical Athlete Performance Center (TAP-C)

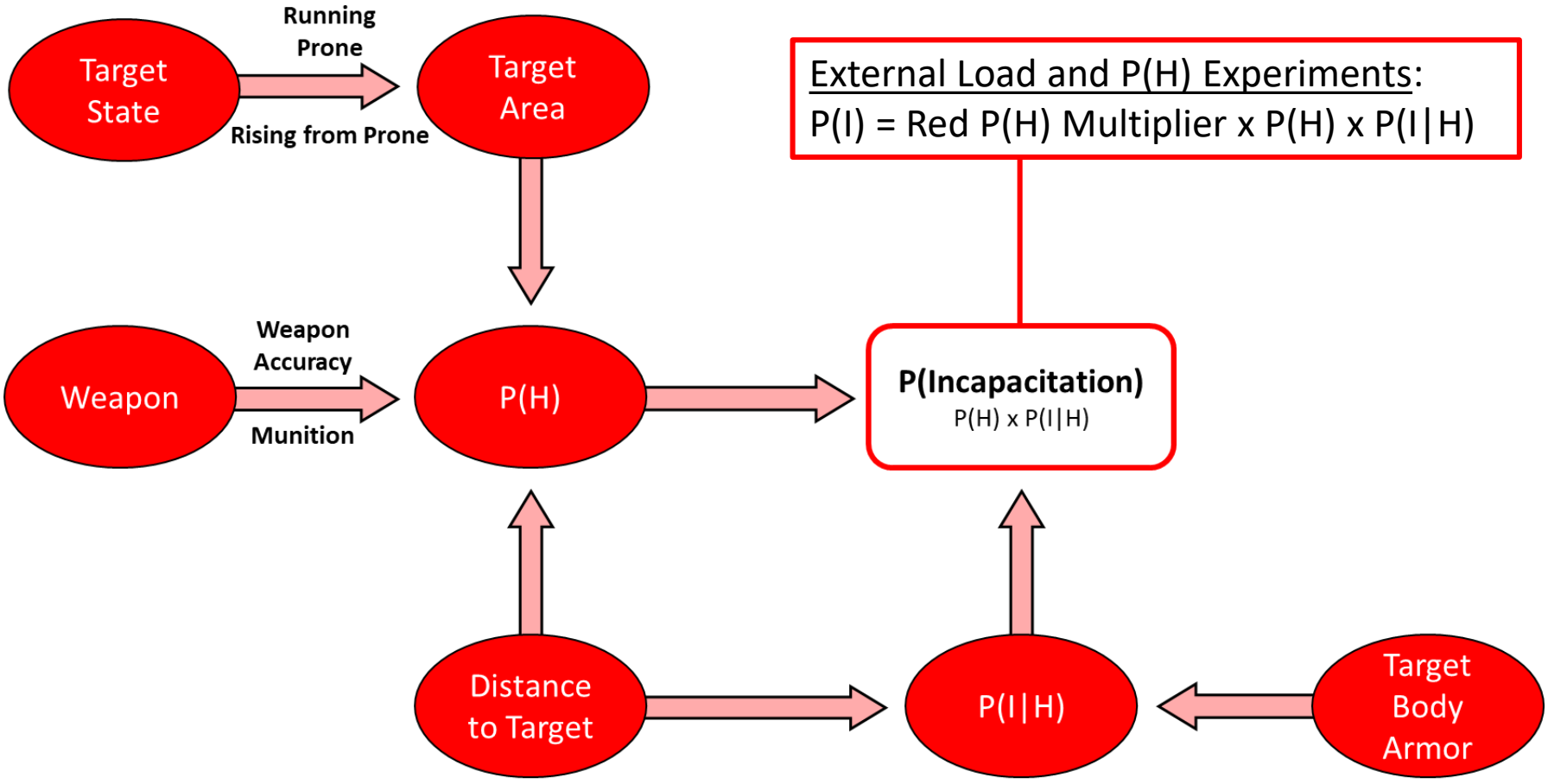
Marine Corps Warfighting Lab (MCWL)

Questions?

“[this thesis] will add value to how we approach equipping decisions and continues to emphasize that all efforts to reduce weight create a powerful return on investment.”
– LtCol Lively (Infantry Advocate, PP&O)

Backup Slides

Enemy (Red) Agent Inputs



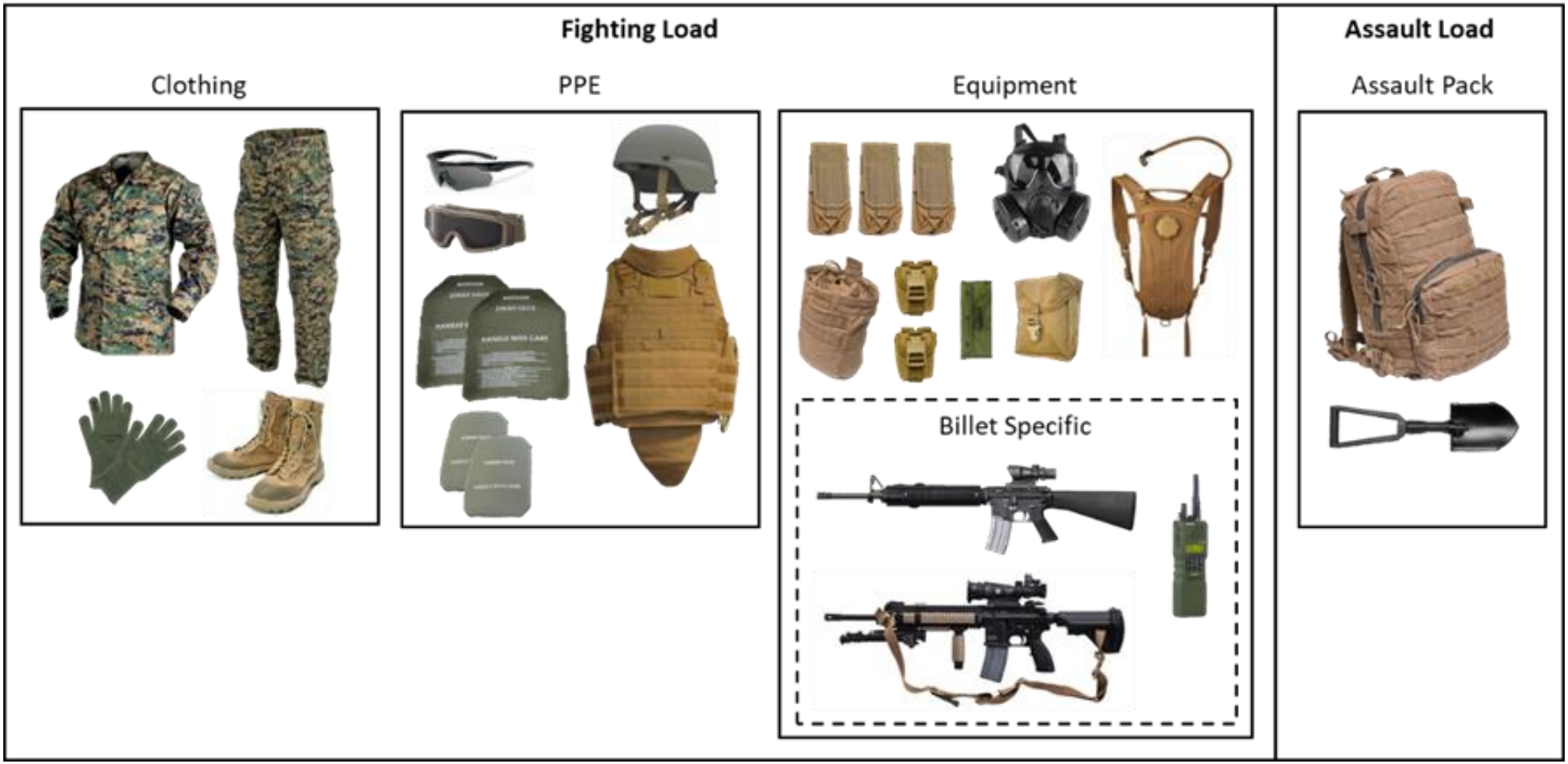
Assumptions & Limitations

Assumption	Reasoning
Blue agents never suppressed	Significant exposure
Red agents suppressed for 6 sec. when "Shot At" state is triggered	Estimation of how much time an enemy fighter would hide completely behind cover before re-engaging
Movement and visibility unaffected by terrain	Flat, desert terrain with clear visibility

MODEL LIMITATIONS

- MANA state duration Precision restricted to the nearest whole second (even with a time step of 1/10 sec)
  - Reduces accuracy of time a Blue agent takes rising from prone
- Agent state speed restricted to a single value
  - Reduces accuracy of an agent's acceleration and deceleration during the 6-meter bound after getting up from the prone position (used average speed over the course of the entire rush distance)

Blue Combat Loads



COMBAT LOAD WEIGHT RANGES

Fighting Load: [43, 65] Assault Load: [49, 80] Actual Load: [90, 159]

Blue Body Armor Levels

National Institute of Justice (NIJ) Body Armor Levels — Weight

- NIJ Level II = Soft Armor Only — 9 lbs.
- NIJ Level III = Soft Armor + (4) SAPI Plates — 28 lbs.
- NIJ Level IV = Soft Armor + (4) ESAPI Plates — 31 lbs.

Round Protection	NIJ Level II	NIJ Level III	NIJ Level IV
0.9 mm / 0.357 Magnum	X	X	X
7.62 mm (M80)		X	X
0.30 Armor Piercing (M2 AP)			X

NIJ Level II

+

NIJ Level III / IV
SAPI / ESAPI

Blue P(Incapacitation)

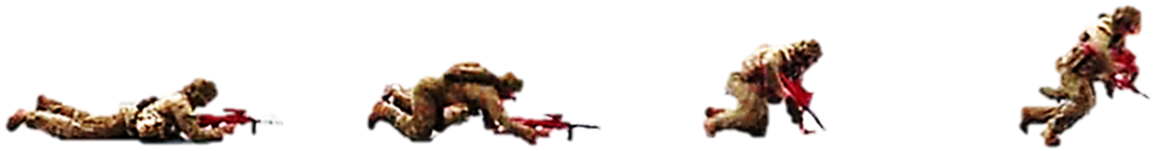
MANA P(H) = P(Incapacitation) = P(I)*

Formula: $P(H) \times P(I \mid H) = P(I)$

P(H) Factors	P(I|H) Factors
▪ Weapon ▪ Munition ▪ Target area ▪ Distance to target ▪ Marksmanship factor	▪ Body armor coverage area ▪ Body armor level ▪ Distance to target * Wounded or KIA

Grade	Billet	Weapon	Rifle	Marksmanship Factor
E1/2	Rifleman	M4	302.1	86.3%
E3	Auto Rifleman Assist Auto Rifleman	M27 M4	301.2	86.1%
E4	Fireteam Leader	M4	308.3	88.1%
E5	Squad Leader	M4	309.2	88.3%

Blue Agent States



Rising from Prone

Engaging
Red Agents

Running

Reach the Town
(End Simulation)

STATE	POSTURE	WEAPON	DURATION
Running	Running	Disabled	Speed Dependent
Engaging Red Agents	Prone	Enabled	15 sec.
Rising from Prone	"Kneeling"	Disabled	Speed Dependent

Blue Agent States

RUNNING

- AUS study found average performance reduction of 0.36% (fast group) to 0.64% (slow group) per pound of external load (1st to 16th rush)
- USMC infantry CFT scores used to designate speed groupings

	CFT		Performance
Grade	N	Average	Decrement [%/lbs]
E1/2	3110	265.1	0.5
E3	16493	276	0.5
E4	12582	286.8	0.36
E5	8909	288.7	0.36

CFT 285+: Fast group (0.36% / lbs.)

CFT 250 - 285: Average (0.5% / lbs.)

CFT 250-: Slow group (0.64% / lbs.)

FIGHTING LOAD			
NIJ Level	II	III	IV
Weight [lbs]	43	62	65
% Decrease	21.5	30.9	32.5
% Decrease	15.6	22.5	23.6
ASSAULT LOAD			
NIJ Level	II	III	IV
Weight [lbs]	58	77	80
% Decrease	28.9	38.4	39.9
% Decrease	21	27.9	29

- Calculated speed for each rush until Reach Final Waypoint state; determined by:
  - Agent speed group (fast or average)
  - External load weight

$$speed_{16} = speed_0(1 - rate)^b$$

- Average speed of all rushes = Default state speed

Blue Agent States

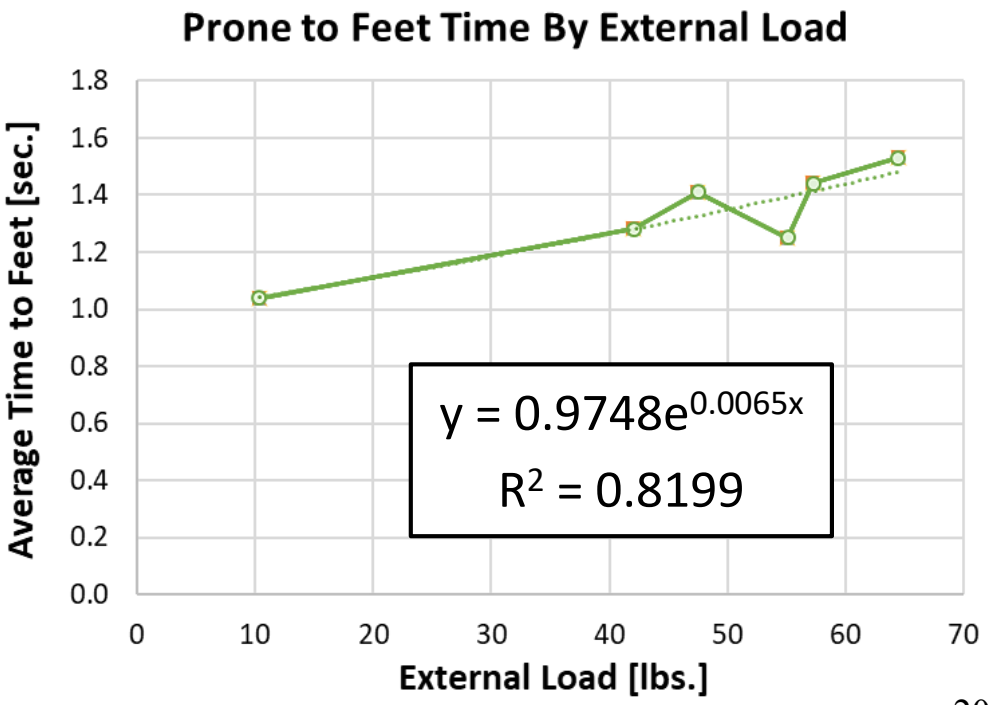
ENGAGING RED AGENTS

- State duration = 15 sec. (time for buddy to rush, get set, and begin suppression)
- Reach Final Waypoint state triggered = End of simulation

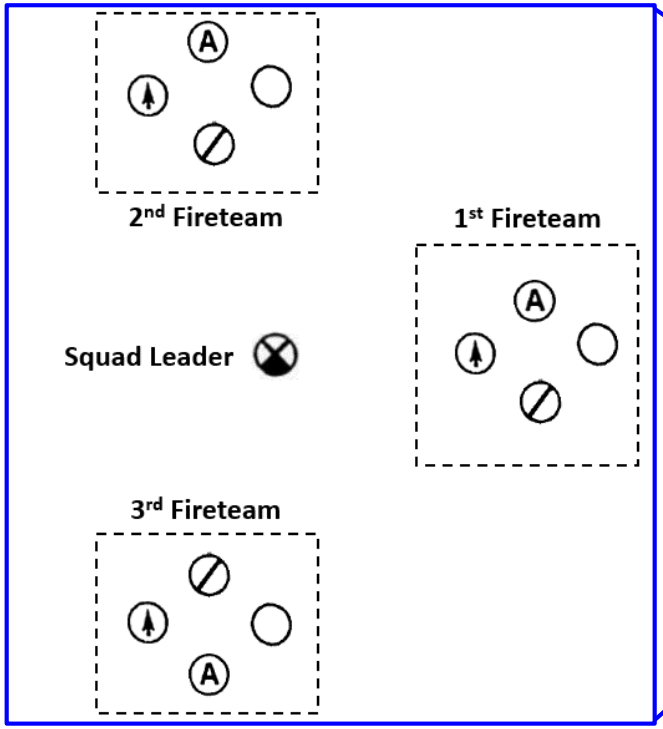
RISING FROM PRONE

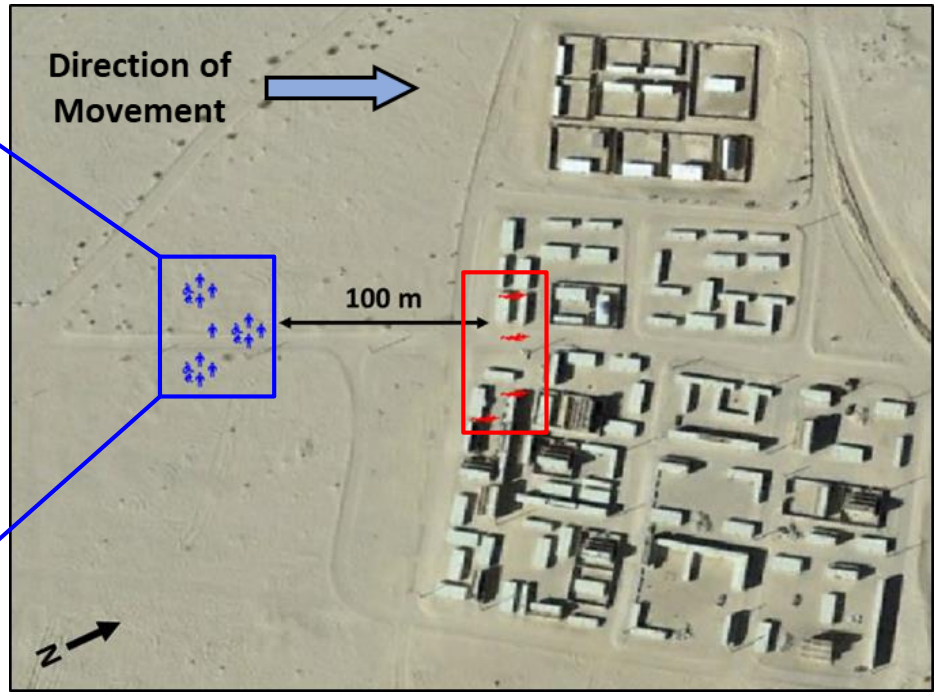
External Load [lbs.]	Average Time to Feet [sec.]
10.4	1.04
42.1	1.28
47.5	1.41
55.1	1.25
57.3	1.44
64.4	1.53

- Logistic regression (AUS study data)
- Estimate time from prone to feet based on external weight



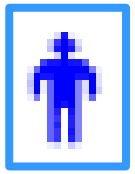
Model





	r23					
a2		r21				
	r22					
					r13	
		r4		a1		r11
					r12	
	r32					
a3		r31				
	r33					

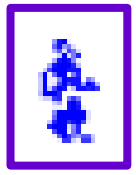
USMC Agents



Rifleman

A/Auto Rifleman

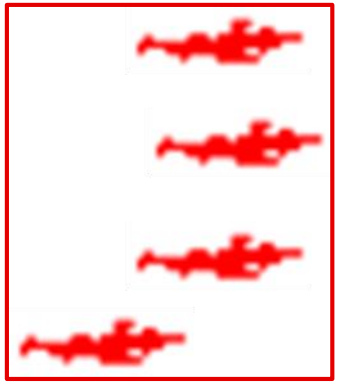
Fireteam Leader



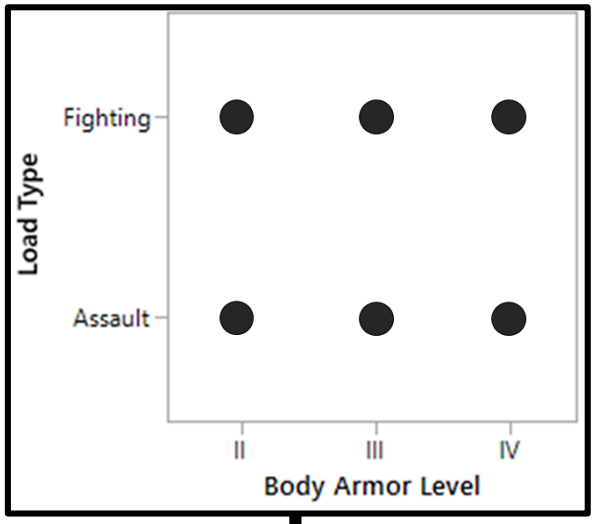
Squad Leader

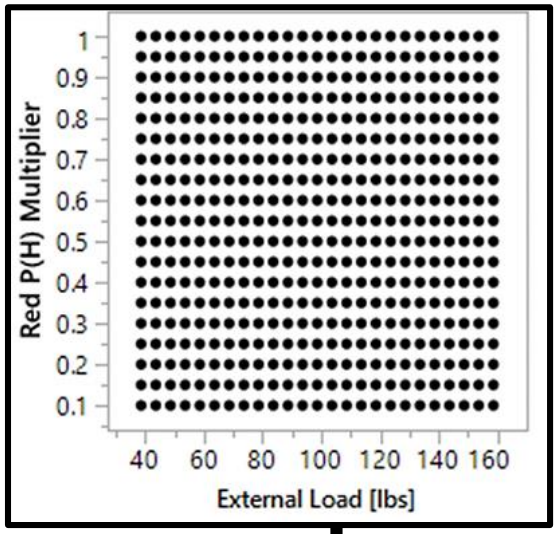
Automatic Rifleman

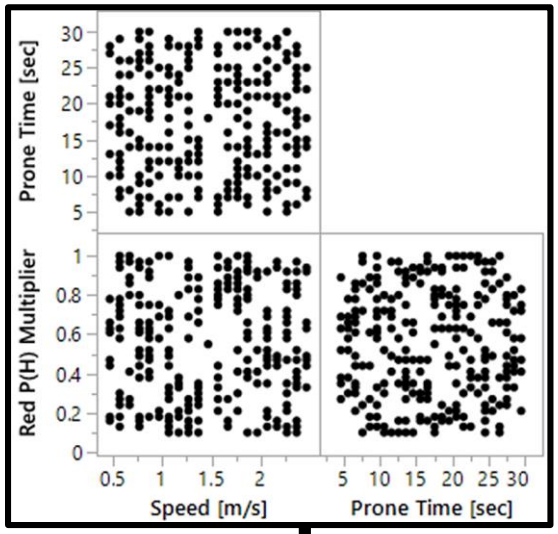
Enemy Agents



DOE







Experiment 1: Standard Load Analysis

- Load Type (2-level): Fighting, Assault
- Body Armor Level (3-level): II, III, IV

Experiment 1.1: P(H) Multiplier [0.1, 1.0]

Experiment 2: External Load & P(H) Analysis

- External Load [lbs] (25-level): [40, 160] by 5
- P(H) Multiplier (19-level): [0.1, 1.0] by 0.05
- Body Armor Level = III (constant)

Experiment 3: Sensitivity Analysis

- Speed [m/s]: [0.5, 2.5]
- Prone Time [sec]: [5, 30]
- P(H) Multiplier: [0.1, 1.0]

Results: T&R Standard Loads

	Blue Casualties					
	Assault			Fighting		
Body Armor Level	25th Q	Median	75th Q	25th Q	Median	75th Q
II	8	10	13	7	9	13
III	7	10	13	7	8.5	13
IV	8	10	13	7	9	13

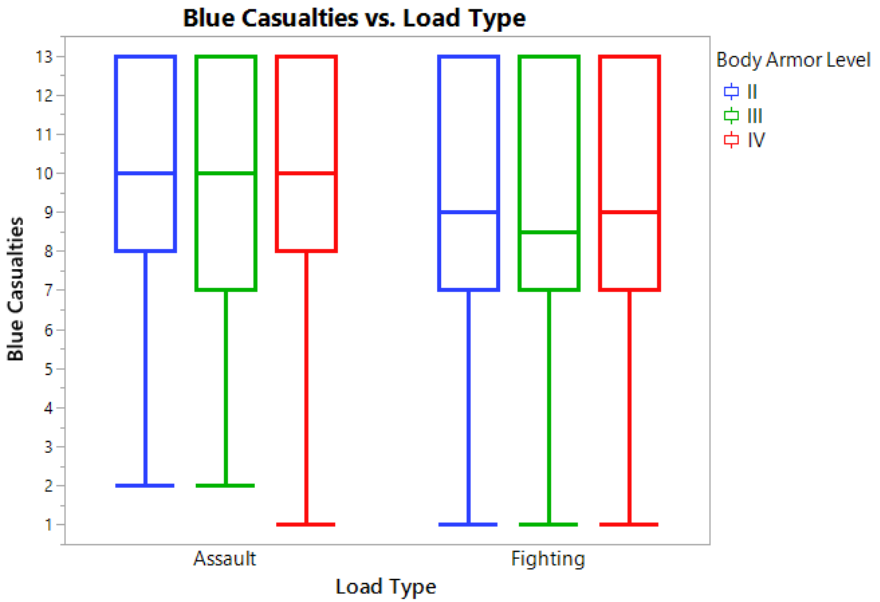
- ↓ Weight = ↓ Casualties
- Average difference of one casualty between fighting and assault loads

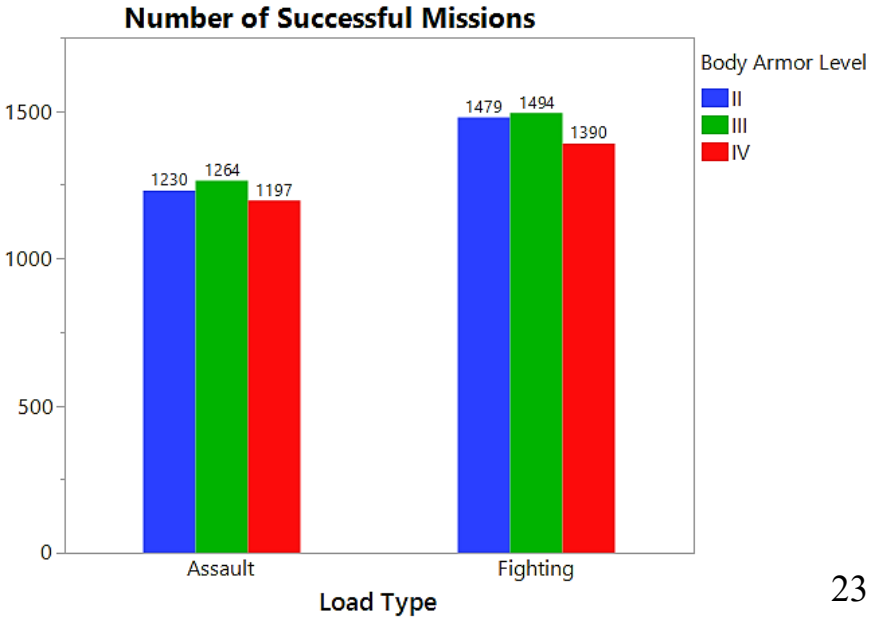
	Assault Load		Fighting Load	
Body Armor Level	P(Success)	SE	P(Success)	SE
II	0.615	0.0109	0.740	0.0098
III	0.632	0.0108	0.747	0.0097
IV	0.599	0.0110	0.695	0.0103

- Balance of weight and protection is best

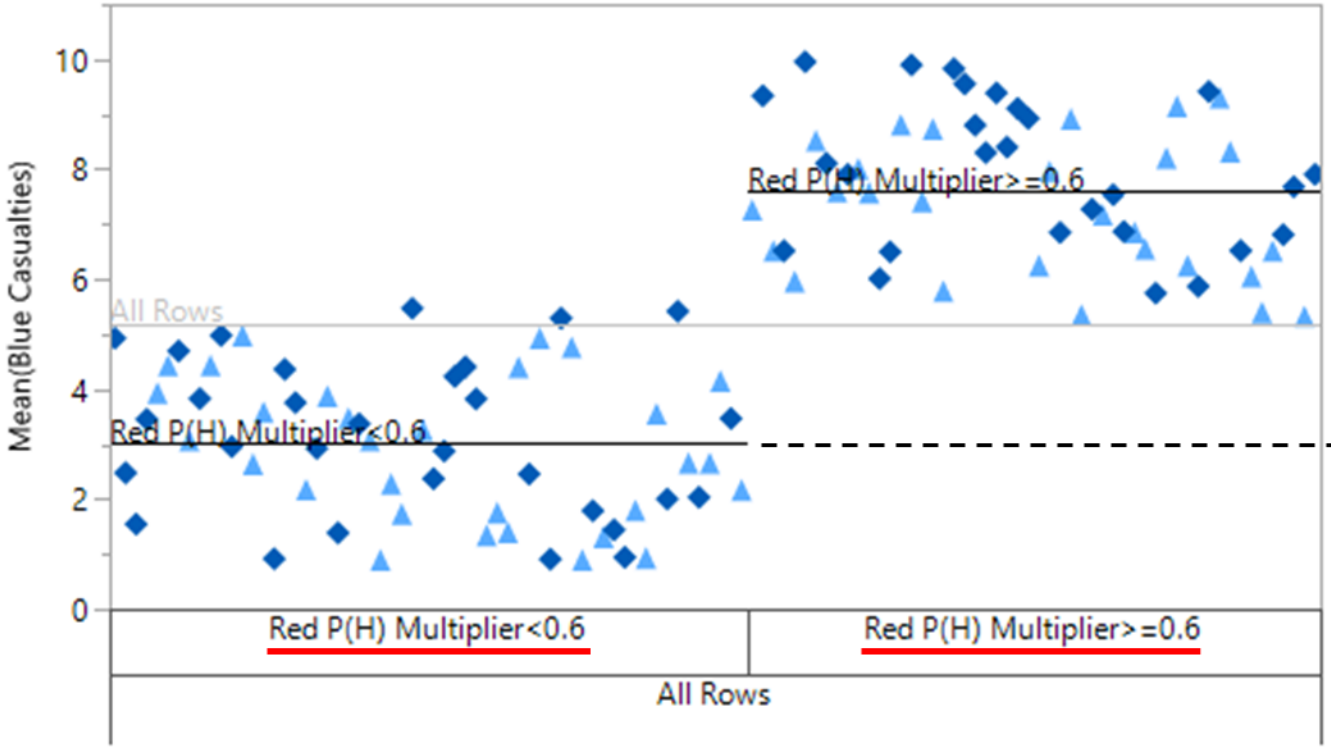
$$SE = \sqrt{\frac{p(1-p)}{n}}$$

	Fisher's Exact Test P-Value		
Load Type	**II and III**	**II and IV**	**III and IV**
Assault Load	0.2815	0.3003	0.03195
Fighting Load	0.6124	0.001996	0.0002802





Results: T&R Standard Loads



Mean = 7.6 Casualties

Difference = 4.6 Casualties

Mean = 3 Casualties

RSquare	RMSE	N	Number of Splits	AICc
0.747	1.3347132	114	1	395.564

All Rows		
Count	114	Difference
Mean	5.1852368	4.59023
Std Dev	2.6639586	

Red P(H) Multiplier<0.6	
Count	60
Mean	3.0109167
Std Dev	1.3593838

Red P(H) Multiplier>=0.6	
Count	54
Mean	7.6011481
Std Dev	1.3321767

Load Type
- Assault
- Fighting

Results: External Load & P(H)

External Load Analysis

- ↑ External Load = ↑ Exposure Time = ↑ P(H) Effect
- ↓ External Load = ↓ Casualties (constant P(H) Multiplier)

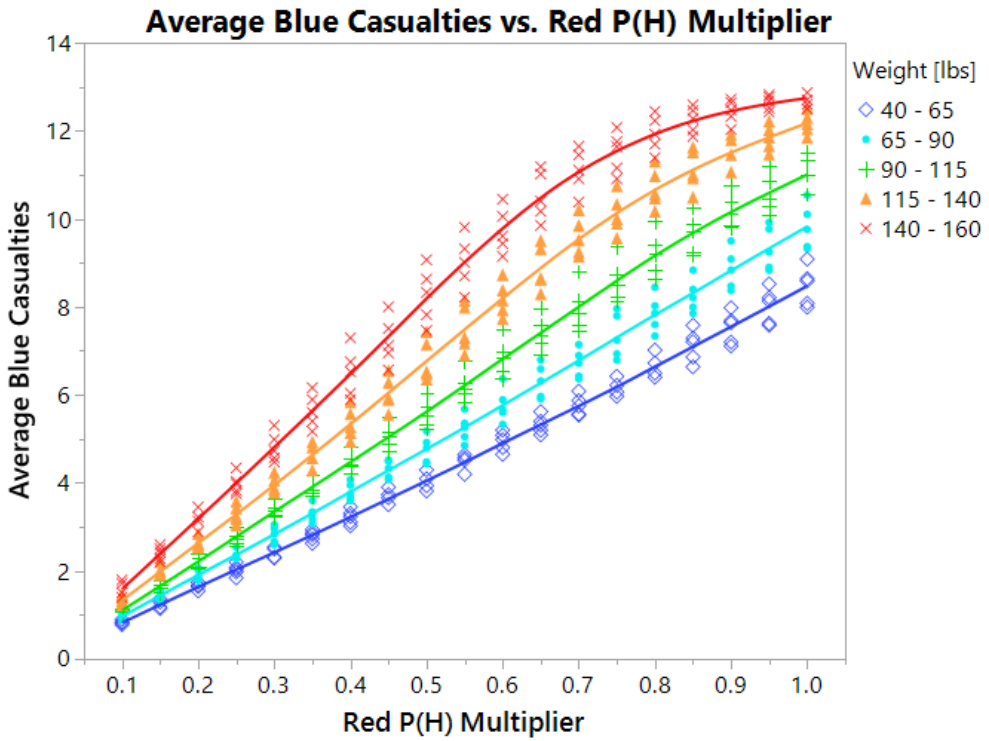
RSquare	RMSE	N	Number of Splits	AICc
0.625	2.0725423	475	1	2046.38

All Rows		Difference
Count	475	
Mean	6.3197516	5.36246
Std Dev	3.3894981	

Red P(H) Multiplier<0.55	
Count	225
Mean	3.4974044
Std Dev	1.8034055

Red P(H) Multiplier>=0.55	
Count	250
Mean	8.859864
Std Dev	2.2952905

P_{still}: Red P(H) Multiplier = 1



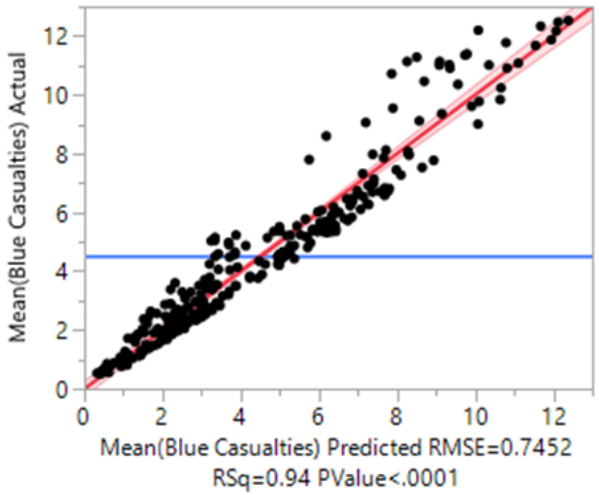
P(H) Analysis

$$P_{move} < 0.55P_{still} \rightarrow P_{still} > 1.8P_{move}$$

- If P(H) moving target is at least twice as hard as P(H) stationary target, then average USMC casualties drops by ~ 5

Results: Sensitivity Analysis

Actual by Predicted Plot



Summary of Fit

RSquare	0.93654
RSquare Adj	0.93519
Root Mean Square Error	0.745204
Mean of Response	4.537696
Observations (or Sum Wgts)	289

Effect Summary

Source	PValue
Red P(H) Multiplier	0.00000
Speed [m/s]	0.00000
Speed [m/s]*Red P(H) Multiplier	0.00000
Prone Time [sec]	0.51924
Speed [m/s]*Prone Time [sec]	0.72079
Prone Time [sec]*Red P(H) Multiplier	0.79375

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.0710669	0.179614	22.67	<.0001*
Speed [m/s]	-2.631976	0.072814	-36.15	<.0001*
Prone Time [sec]	-0.003758	0.005823	-0.65	0.5192
Red P(H) Multiplier	8.1668792	0.161516	50.56	<.0001*
(Speed [m/s]-1.50623)*Prone Time [sec]-17.5017)	0.0037006	0.010344	0.36	0.7208
(Speed [m/s]-1.50623)*(Red P(H) Multiplier-0.55031)	-4.559432	0.274267	-16.62	<.0001*
(Prone Time [sec]-17.5017*(Red P(H) Multiplier-0.55031)	-0.006271	0.023963	-0.26	0.7938

- Running speed and Red P(H) Multiplier matter most
- Prone time not significant

Future Research

MANA Model

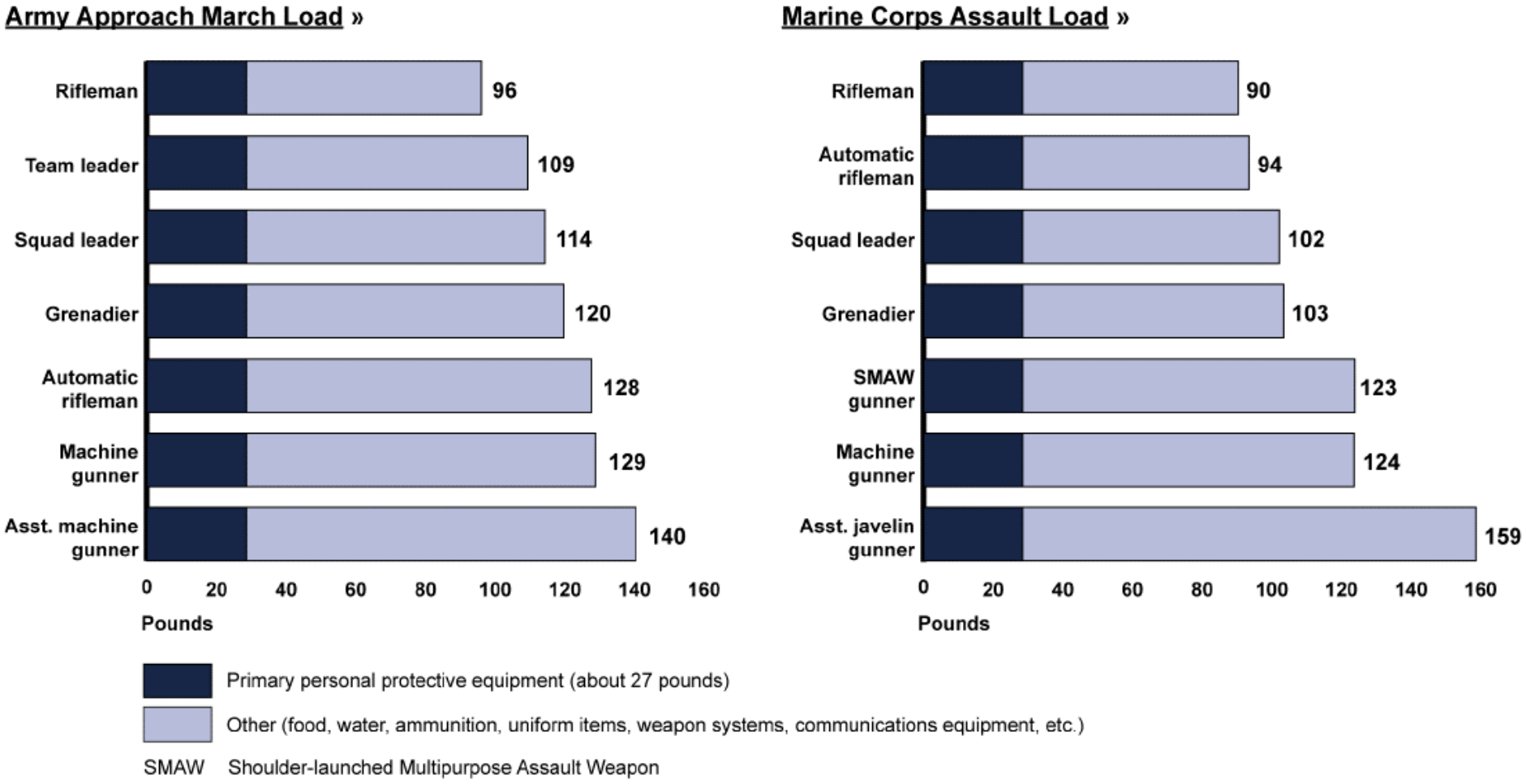
- Vary: (1) squad travel distance, (2) number of enemy fighters, and (3) terrain type
- Incorporate the effect of weight-induced fatigue on marksmanship
- Modify to simulate live fire testing done in the summer of 2018 conducted by The Marine Expeditionary Rifle Squad Team (MARCORSYSCOM)
  - P(H) moving targets at various speeds (100-300 meters)

Repeat experiments with a high-resolution simulation model (e.g. COMBAT XXI)

Conduct field experiments to compare with the simulation results

Explore weight's effect on medical readiness and separation/retirement rates

GAO Load Report



Source: GAO analysis of Army and Marine Corps data. | GAO-17-431

Standard Fighting Load

Fighting Load			
Clothing Worn & Packed	Weight [lbs.]	Quantity	Total Weight [lbs.]
MCCU, Blouse and Trouser	2.97	1	2.97
Uniform, Utility, Belt	0.3	1	0.3
Ballistic Eye Pro	0.31	1	0.31
M50 Mask w/ carrier	3	1	3
Gloves	0.3	1	0.3
T-Shirt, Green	0.18	1	0.18
Undershorts	0.25	1	0.25
MC Combat Boots w/ laces	3.12	1	3.12
Socks	0.16	1	0.16
Watch, Wrist	0.1	1	0.1
Card, ID	0.03	1	0.03
Tags, ID	0.1	1	0.1
Helmet w/ cover, band, and NVG base plate	3.5	1	3.5
Plate Carrier w/ soft armor	9	1	9
SAPI Plates (front, back, and 2x side)	19	1	19
Pouches (1-dump, 3-magazine, 2 grenade)	2	1/3/2	2
IFAK - A1 First Aid Kit	2.1	1	2.1
AN/PVS-14 w/Elbow/Rhino Mount	1	1	1
Hydration System, CamelBak (Full)	6.91	1	6.91
Total Fighting Load Weight (not including weapon, SL-3, and MOS-specific equipment)			**54.33**

Standard Assault Load

Assault Load			
Clothing Worn & Packed	Weight [lbs.]	Quantity	Total Weight [lbs.]
MCCU, Blouse and Trouser	2.97	1	2.97
Uniform, Utility, Belt	0.3	1	0.3
Ballistic Eye Pro	0.31	1	0.31
M50 Mask w/ carrier	3	1	3
Gloves	0.3	1	0.3
T-Shirt, Green	0.18	1	0.18
Undershorts	0.25	1	0.25
MC Combat Boots w/ laces	3.12	1	3.12
Socks	0.16	1	0.16
Watch, Wrist	0.1	1	0.1
Card, ID	0.03	1	0.03
Tags, ID	0.1	1	0.1
Helmet w/ cover, band, and NVG base plate	3.5	1	3.5
Plate Carrier w/ soft armor	9	1	9
SAPI Plates (front, back, and 2x side)	19	1	19
Pouches (1-dump, 3-magazine, 2 grenade)	2	1/3/2	2
IFAK - A1 First Aid Kit	2.1	1	2.1
AN/PVS-14 w/Elbow/Rhino Mount	1	1	1
Hydration System, CamelBak (Full)	6.91	1	6.91
Assault Pack	5.51	1	5.51
MRE	1.3	3	3.9
Parka and Trouser, APEC	3.6	1	3.6
Tool, Entrenching w/ Case	2.7	1	2.7
Total Assault Load Weight (not including weapon, SL-3, and MOS-specific equipment)			**70.04**

Past Recommended Loads

Recommendation by Source (in lbs)		
Year	Recommending Body	Fighting Load (lbs)
Late 1800s	German William Frederick Studies	48
1920s	Hygiene Advisory Committee of the British Army	40-45
1930s	British Aldershot Committee	35
1950	U.S. Colonel SLA Marshall	40
1990	U.S. Army FM 21-18	48
2001	U.S. Army Science Board Summer Study	50
2003	USMC Combat Load Report	50.7
2007	U.S. Naval Research Advisory Committee	50

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Photos

- Google images
- http://archive.defense.gov/photoessays/PhotoEssaySS.aspx?ID=5148