



SANTOSH HUMAN®

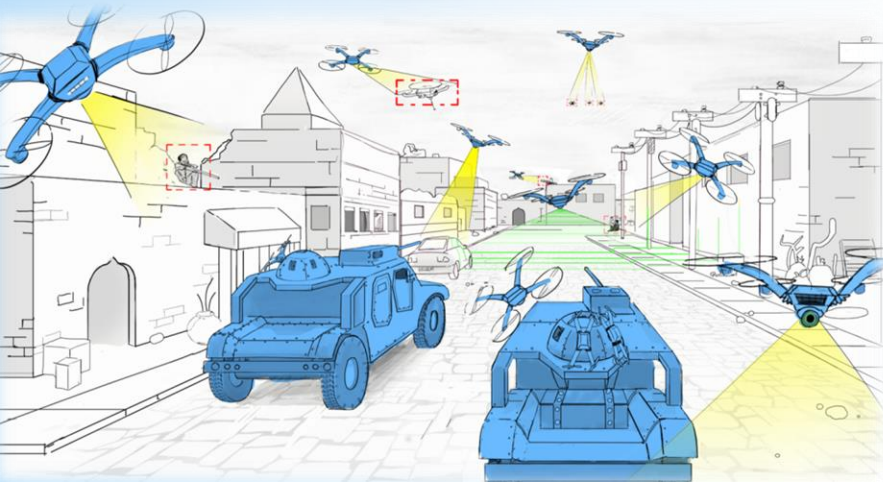
PREDICTIVE HUMAN MODELS AND THE THIRD OFFSET

OPTIMIZATION-BASED COUPLED HUMAN SYSTEMS INTEGRATION





What is it?



**“If you don’t have a
competitive advantage,
don’t compete.”**

JACK WELCH
legendary CEO







Key Points:

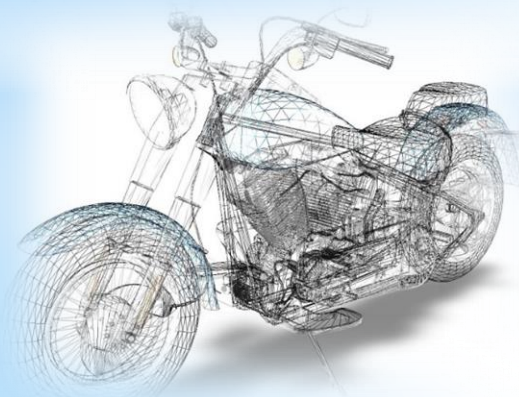
- 1) Autonomous deep learning machines and systems for intelligence
- 2) **Human**-machine collaboration for improved decision-making
- 3) Assisted-**human** operations
- 4) Advanced **manned** and unmanned combat teaming
- 5) Network-enabled semi-autonomous and autonomous weapons, hardened for EW



The New Big 5 (for the latest Army Operating concept):

- 1) Optimize **soldier and team** performance
- 2) Develop adaptive and innovative **leaders**
- 3) Ensure interoperability
- 4) Allow for scalable and tailorable joint and combined-arms formations
- 5) Leverage concepts and technologies to maintain capability overmatch



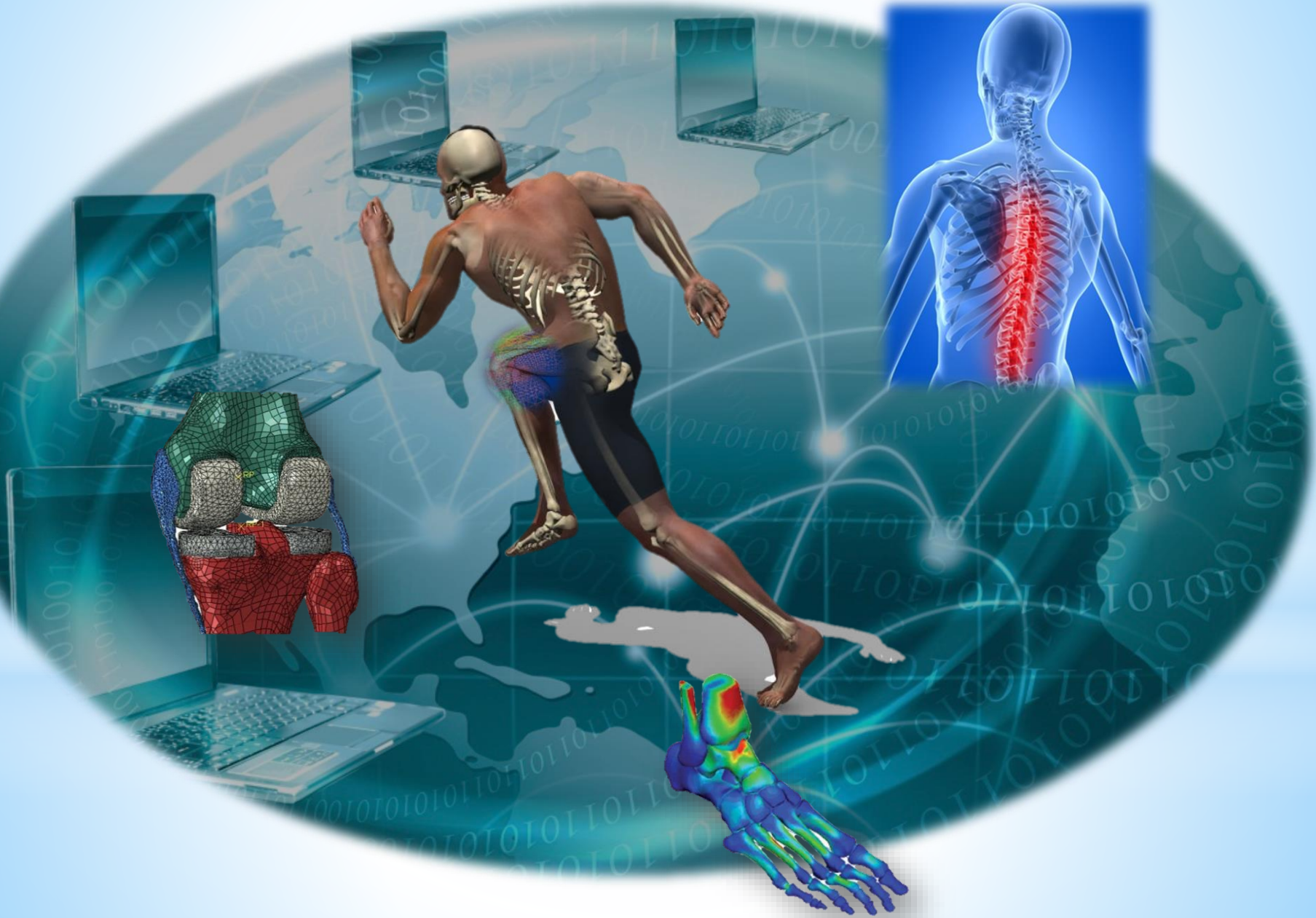


Humans interact with most products and processes...

Most products and processes are designed on the computer...



Integrated Digital Human Modeling



Integrated Digital Human Model



Integrated Digital Human Model

Trade Off Analysis



Integrated Digital Human Model

Automated Trade Off Analysis



Integrated Digital Human Model

Coupled Human Systems Integration



Underlying Method



FIND: JOINT ANGLES

TO OPTIMIZE: HUMAN PERFORMANCE MEASURES

SUBJECT TO:

- 1) DISTANCE BETWEEN END-EFFECTOR AND TARGET POINT
- 2) ANGLES ARE WITHIN LIMITS
- 3) COLLISION AVOIDANCE

CONTACT POINTS

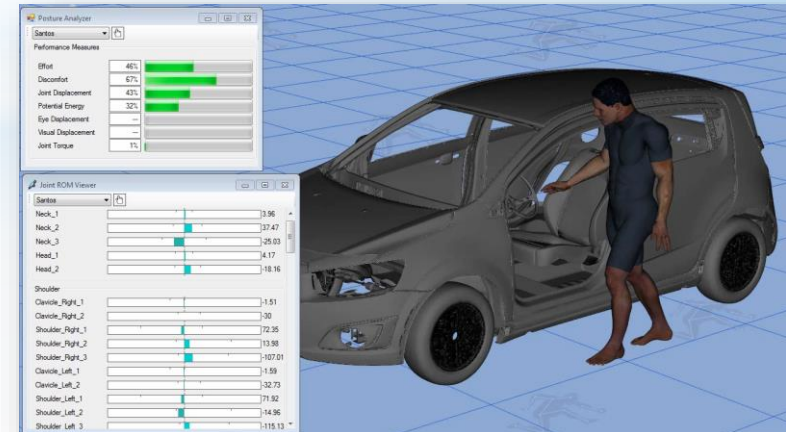
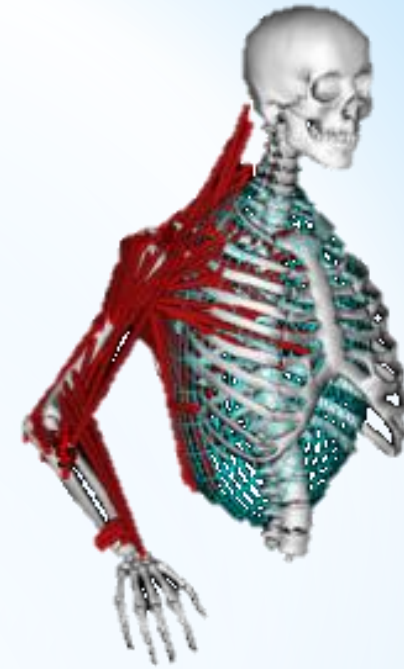
RANGE OF MOTION

$$4) \tau = \underbrace{\sum_i \mathbf{J}_i^T m_i \mathbf{g}}_{\text{gravity forces}} + \underbrace{\sum_k \mathbf{J}_k^T \mathbf{F}_k}_{\text{external load}}$$

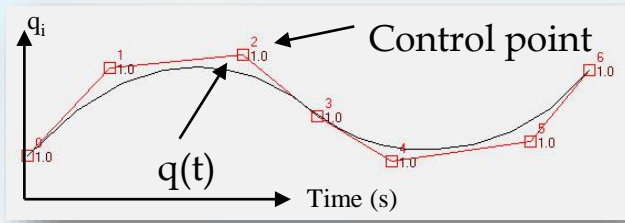
STATIC EQUILIBRIUM

5) ZERO-MOMENT POINT

STABILITY



Underlying Method



FIND: CONTROL POINTS FOR B-SPLINE CURVES (JOINT ANGLES OVER TIME)

TO OPTIMIZE: HUMAN PERFORMANCE MEASURES

SUBJECT TO:

1) DISTANCE BETWEEN END-EFFECTOR AND TARGET POINT

CONTACT POINTS

2) ANGLES ARE WITHIN LIMITS

RANGE OF MOTION

3) COLLISION AVOIDANCE

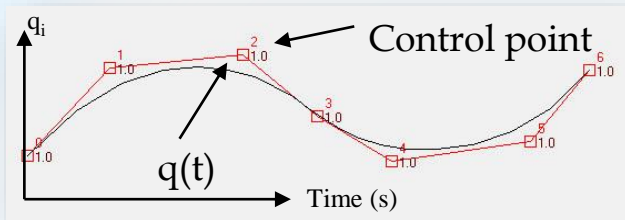
4) ZERO-MOMENT POINT

STABILITY

5)
$$\tau = \underbrace{\mathbf{M}(\mathbf{q})}_{\text{mass-inertia matrix}} \ddot{\mathbf{q}} + \underbrace{\mathbf{V}(\mathbf{q}, \dot{\mathbf{q}})}_{\text{Coriolis \& Centrifugal}} + \underbrace{\sum_i \mathbf{J}_i^T m_i \mathbf{g}}_{\text{gravity forces}} + \underbrace{\sum_k \mathbf{J}_k^T \mathbf{F}_k}_{\text{external load}}$$

EQUATIONS OF MOTION

Underlying Method



FIND: CONTROL POINTS FOR B-SPLINE CURVES (JOINT ANGLES OVER TIME)

TO OPTIMIZE: HUMAN PERFORMANCE MEASURES

SUBJECT TO:

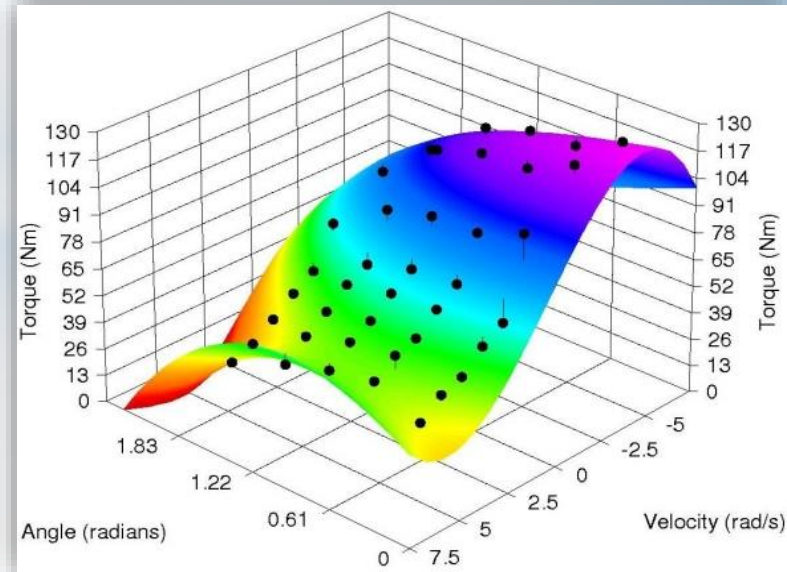
- 1) DISTANCE BETWEEN END-EFFECTOR AND TARGET POINT
- 2) ANGLES ARE WITHIN LIMITS
- 3) COLLISION AVOIDANCE
- 4) ZERO-MOMENT POINT

$$\tau = \underbrace{\mathbf{M}(\mathbf{q})}_{\text{mass-inertia matrix}} \ddot{\mathbf{q}} + \underbrace{\mathbf{V}(\mathbf{q}, \dot{\mathbf{q}})}_{\text{Coriolis \& Centrifugal}} + \underbrace{\sum_i \mathbf{J}_i^T m_i \mathbf{g}}_{\text{gravity forces}} + \underbrace{\sum_k \mathbf{J}_k^T \mathbf{F}_k}_{\text{external load}}$$

6) STRENGTH LIMITS

7) ADDITIONAL MODELS

CONTACT POINTS



Human Performance

- Symmetric/ asymmetric loading
- Quantitative analysis of loading configurations
- Dynamic reaction force visualization
- Center-of-mass movement
- Dynamic torque visualization



Trade Off Analysis

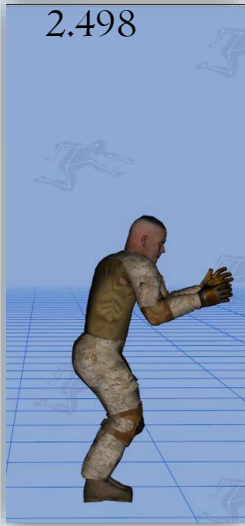


Trade Off Analysis

See cause and effect with minimal pre-recorded data

Height (m):

2.498



2.401



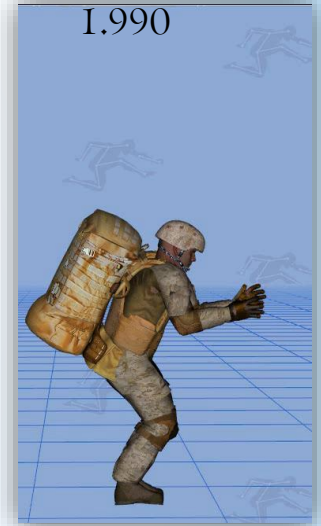
2.310



2.131



1.990



Santos
79 kg

Height (m):

2.180



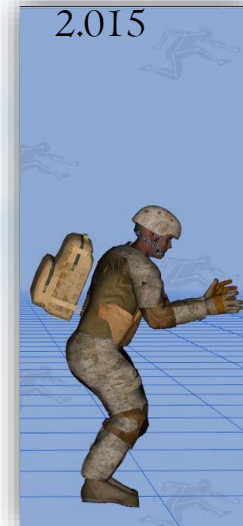
2.174



2.119



2.015



1.946



Santos
111 kg

PPE Example

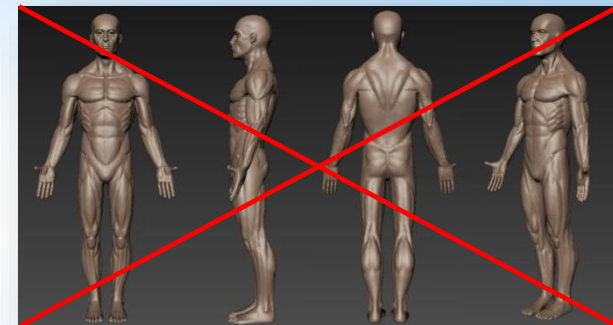


Human system integration (HSI) is insufficiently addressed when designing and analyzing body armor systems and equipment

PPE Example



The design and effectiveness of PPE, and the propensity for survivability depend critically on the task being completed, on the Warfighter anthropometry, and on the position and motion of internal viscera relative to PPE and threats. A static mannequin is insufficient!



Trade Off Analysis



Simulate Warfighter



Simulate PPE

Improve PPE

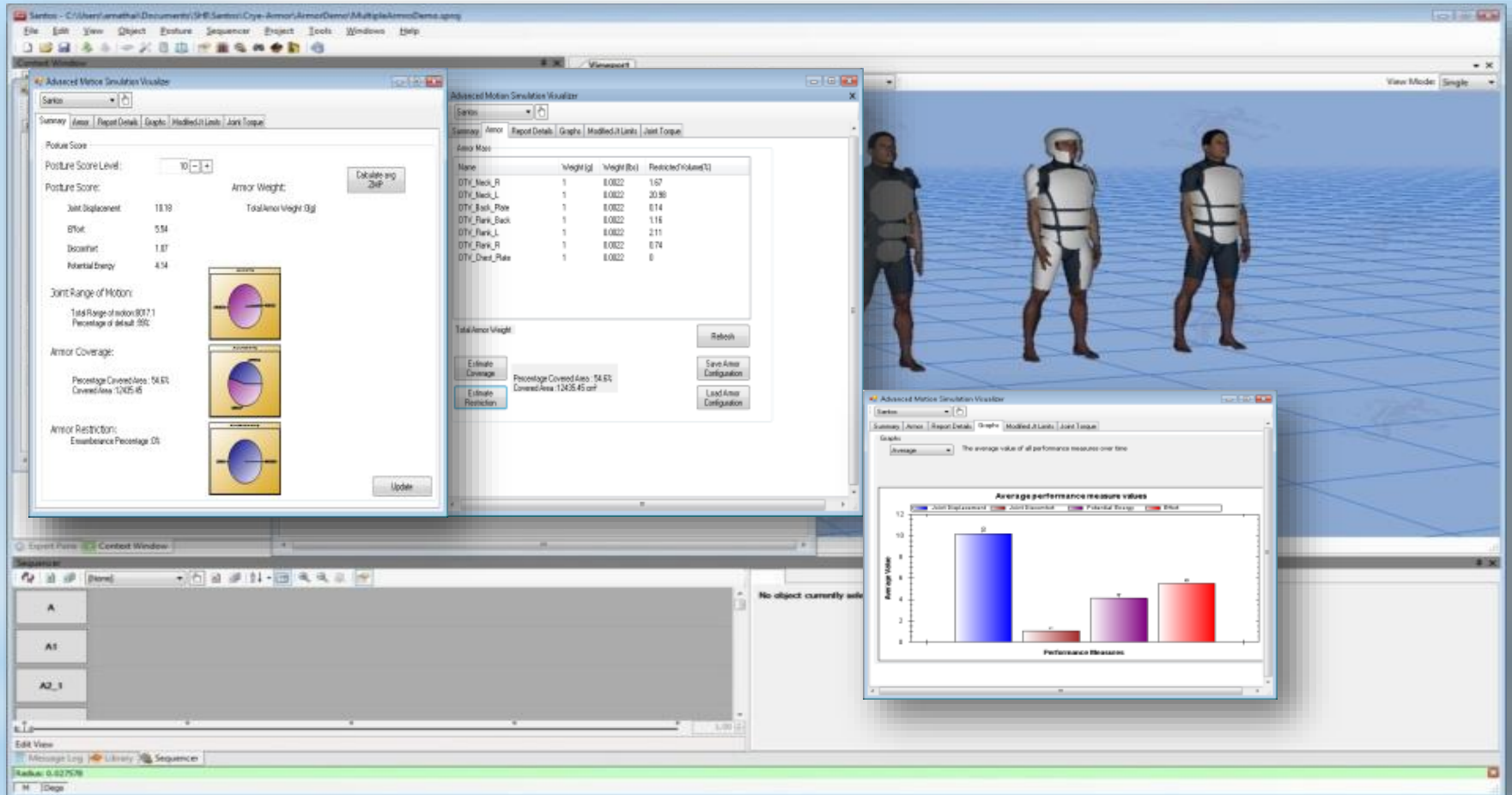


Armor Evaluation Analyzer	
Ratings	Summary Armor Report Graphs Mod
Posture :	☹️ ★★★★★
Range of Motion :	☹️ ★★★★★☆
Stability :	☹️ ★★★★★☆
Coverage :	☹️ ★★★★★☆
Restriction :	☹️ ★★★★★☆
Weight :	☹️ ★★★★★☆
Torque :	☹️ ★★★★★☆
Volume :	☹️ ★★★★★☆
Santos2	

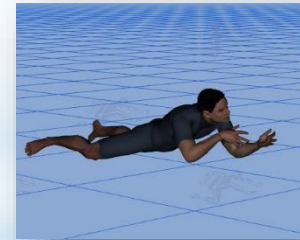
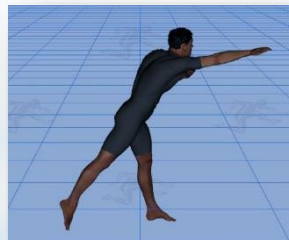
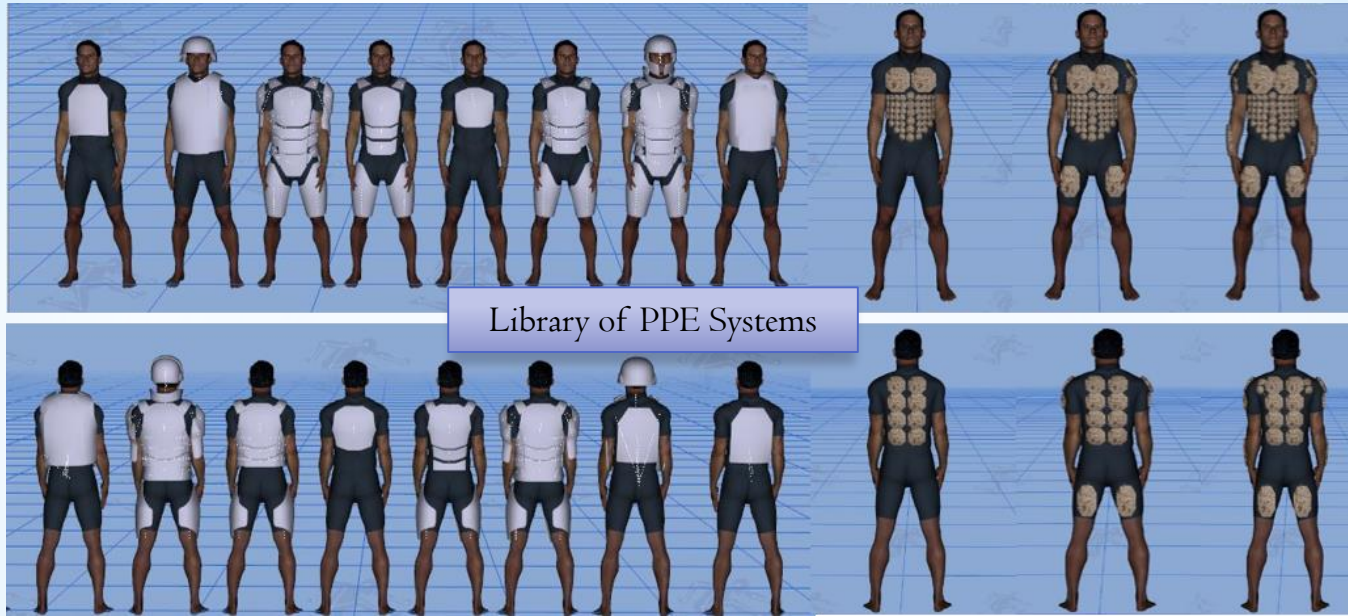
Armor Evaluation Analyzer	
Ratings	Summary Armor Report Graphs Mod
Posture :	☹️ ★★★★★
Range of Motion :	☹️ ★★★★★☆
Stability :	☹️ ★★★★★☆
Coverage :	☹️ ★★★★★☆
Restriction :	☹️ ★★★★★☆
Weight :	☹️ ★★★★★☆
Torque :	☹️ ★★★★★☆
Volume :	☹️ ★★★★★☆
Santos	

Armor Evaluation Analyzer	
Ratings	Summary Armor Report Graphs Modified Jt Limits Optimization
Posture :	☹️ ★★★★★
Range of Motion :	☹️ ★★★★★☆
Stability :	☹️ ★★★★★☆
Coverage :	☹️ ★★★★★☆
Restriction :	☹️ ★★★★★☆
Weight :	☹️ ★★★★★☆
Torque :	☹️ ★★★★★☆
Volume :	☹️ ★★★★★☆
Overall Rating :	☹️ ★★★★★☆
Santos1	
<input type="button" value="Update Scores"/>	

Trade Off Analysis PPE



Automated Trade Off Analysis



Automatically *evaluate* PPE (or other products) based on simulated tasks and specified objectives, and identify optimum systems

Automatically balance mobility, coverage, weight, etc.

Automated Trade Off Analysis

Armor Evaluation Analyzer
Santos

Summary | Ratings | Armor | Report | Graphs | Modified Jt. Limits | Optimization | Settings

Performance: 0.000
Minimum Performance (%): 25.00

Restriction: 0.000
Maximum Restriction (%): 25.00

Range Of Motion: 0.000
Minimum ROM (%): 25.00

Weight: 1.000
Maximum Weight (kg): 15.00

Balance: 0.000
Minimum Balance (%): 25.00

Coverage: 0.000
Minimum Coverage (%): 25.00

Accept All Modified Joint Limits

Dynamic Optimization: [Dropdown]
Scale Chicklets | Update Texture

Heart
 Liver

Optimize

Minimize Weight

Armor Evaluation Analyzer
Santos

Summary | Ratings | Armor | Report | Graphs | Modified Jt. Limits | Optimization | Settings

Performance: 0.000
Minimum Performance (%): 25.00

Restriction: 0.000
Maximum Restriction (%): 25.00

Range Of Motion: 0.000
Minimum ROM (%): 25.00

Weight: 0.000
Maximum Weight (kg): 15.00

Balance: 0.000
Minimum Balance (%): 25.00

Coverage: 1.000
Minimum Coverage (%): 25.00

Accept All Modified Joint Limits

Dynamic Optimization: [Dropdown]
Scale Chicklets | Update Texture

Heart
 Liver

Optimize

Maximize Coverage

Armor Evaluation Analyzer
Santos

Summary | Ratings | Armor | Report | Graphs | Modified Jt. Limits | Optimization | Settings

Performance: 0.000
Minimum Performance (%): 25.00

Restriction: 0.000
Maximum Restriction (%): 25.00

Range Of Motion: 0.000
Minimum ROM (%): 25.00

Weight: 1.000
Maximum Weight (kg): 15.00

Balance: 0.000
Minimum Balance (%): 25.00

Torque: 0.000
Maximum Torque (%): 25.00

Coverage: 1.000
Minimum Coverage (%): 25.00

Bulk: 0.000
Maximum Bulk (%): 25.00

Accept All Modified Joint Limits

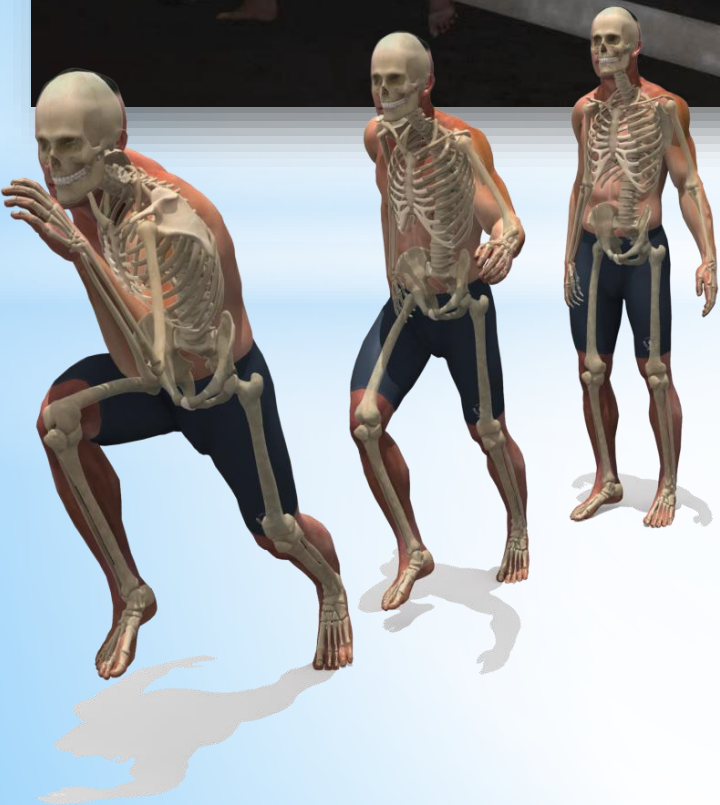
Dynamic Optimization: [Dropdown]
Scale Chicklets | Update Texture

Heart
 Liver

Optimize

Maximize Coverage &
Minimize Weight

Coupled Human Systems Integration





Hit Detection

Santos

Hit Detection Results Lambert-Jonas

Blast Device: Marker [Blast]

Number of Collisions: 500

Display: Amor Body Missed [Check All] [Uncheck All]

Organs: Heart Lungs Liver Large Intestine Kidneys Trachea Stomach Small Intestine

Results (% of fragments):

Total Body Hits:	<input type="text"/>	Total Amor Hits:	<input type="text"/>
Total Vital Organs Hit:	<input type="text"/>	Total Avatar Miss:	<input type="text"/>



Hit Detection

Santos

Hit Detection Results Lambert-Jonas

Blast Device: Marker [Blast]

Number of Collisions: 400

Display: Amor Body Missed [Check All] [Uncheck All]

Organs: Heart Lungs Liver Large Intestine Kidneys Trachea Stomach Small Intestine

Results (% of fragments):

Total Body Hits:	<input type="text"/>	Total Amor Hits:	<input type="text"/>
Total Vital Organs Hit:	<input type="text"/>	Total Avatar Miss:	<input type="text"/>

Coupled Human Systems Integration

➤ FIND

- Design Variables: z_n, θ_n, e_n

➤ TO MAXIMIZE

- $Val = f(\theta_i, z_i) = \sum_{i=0}^n (CoverageValue(Hit\ detection\ (z_i, \theta_i)))$

➤ WHERE

- $Hit\ detection\ (z_i, \theta_i) = u_i, v_i$
- $CoverageValue(u_i, v_i) = Regression(u_i, v_i)$

➤ SUCH THAT

- $0 \leq z_i \leq l_i$
- $0 \leq \theta_i \leq 2\pi$
- $(z_i - z_j)^2 + (\theta_i - \theta_j)^2 > r$
- $0 \leq e_i \leq 1$
- $\sum_{i=0}^n e_i * w_i \leq Max\ Weight$

Find

- Location and existence of armor components

To Optimize

- User defined set of objective functions (i.e. Weight, coverage, survivability)

Subject to

- User defined constraints (e.g. less than 10kg)
- Location bounds

Parameters

z_i : The height of the origin location of the ray

θ_i : The lateral location of the origin location of the ray

n : The number of component

u_i : 2D mapping of body location

v_i : 2D mapping of body location

l_i : The height of sphere around Santos

r : The radius of an armor component

e_i : The existence variable of component i

w_i : The weight of component i



ALLOW MORE
MATERIAL

Coupled Human Systems Integration

➤ FIND

- Design Variables: z_n, θ_n, e_n

➤ TO MAXIMIZE

➤ WHERE

- Hit detection $(z_i, \theta_i) = u_i, v_i$
- CoverageValue $(u_i, v_i) = \text{Regression}(u_i, v_i)$

➤ SUCH THAT

- $0 \leq z_i \leq l_i$
- $0 \leq \theta_i \leq 2\pi$
- $(z_i - z_j)^2 + (\theta_i - \theta_j)^2 > r$
- $0 \leq e_i \leq 1$
- $\sum_{i=0}^n e_i * w_i \leq \text{Max Weight}$

Parameters

z_i : The height of the origin location of the ray

θ_i : The lateral location of the origin location of the ray

n : The number of component

u_i : 2D mapping of body location

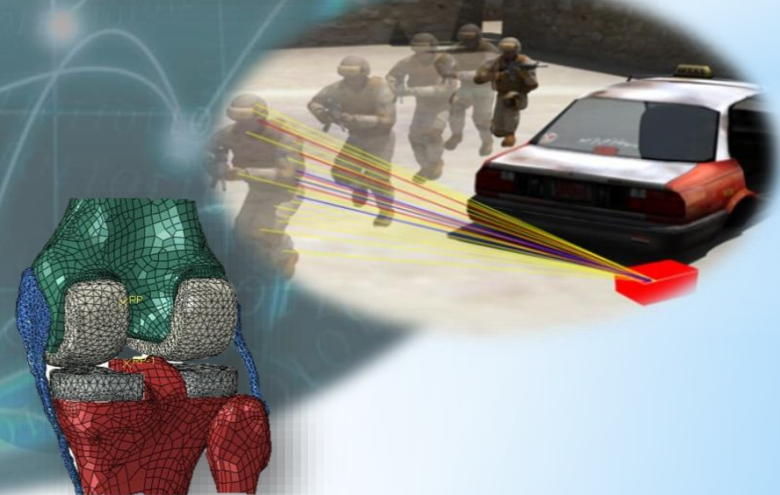
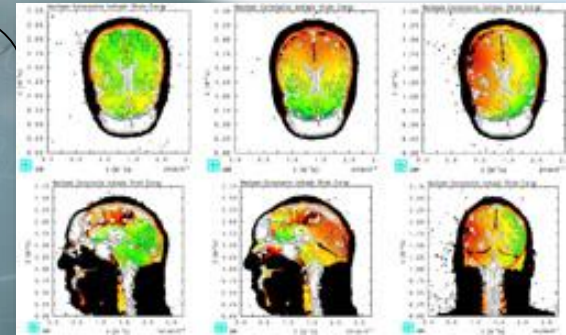
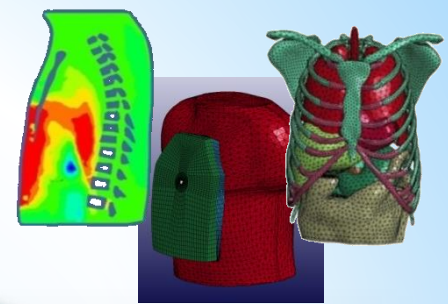
v_i : 2D mapping of body location

l_i : The height of sphere around Santos

r : The radius of an armor component

e_i : The existence variable of component i

w_i : The weight of component i



Coupled Human Systems Integration

Simulate Human System Integration



Simulate Vehicle Dynamics



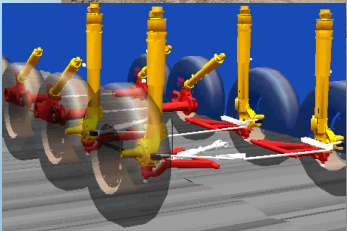
Simulate the Blast



High Fidelity Injury Models

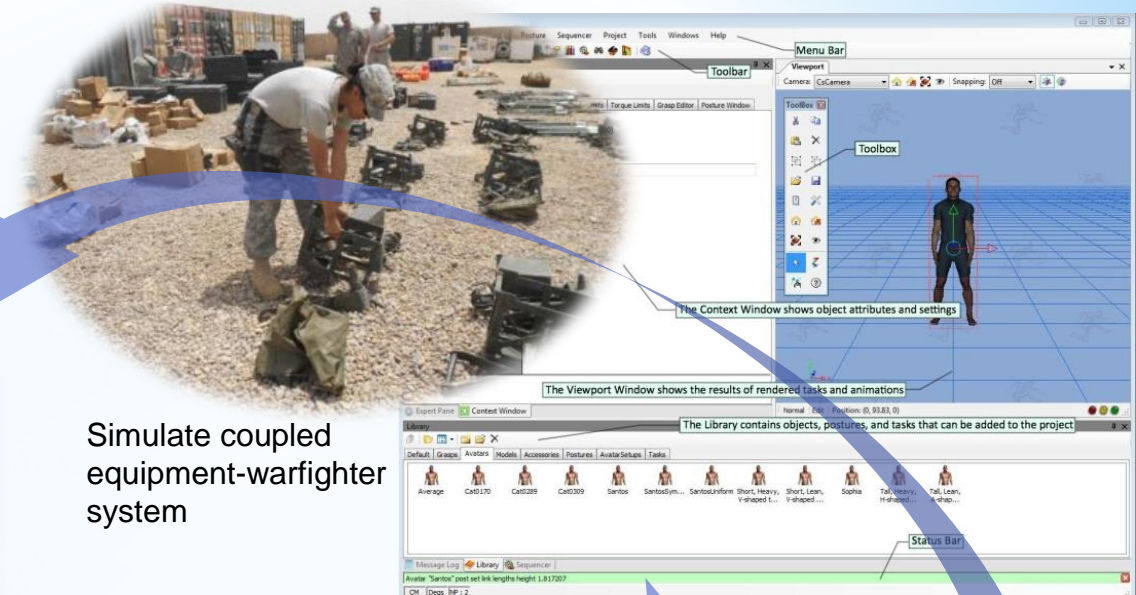


Use human reactions and propensity for injury to automatically impose optimal design changes that reduce injury



Coupled Human Systems Integration

Inform the squad



Simulate coupled equipment-warfighter system

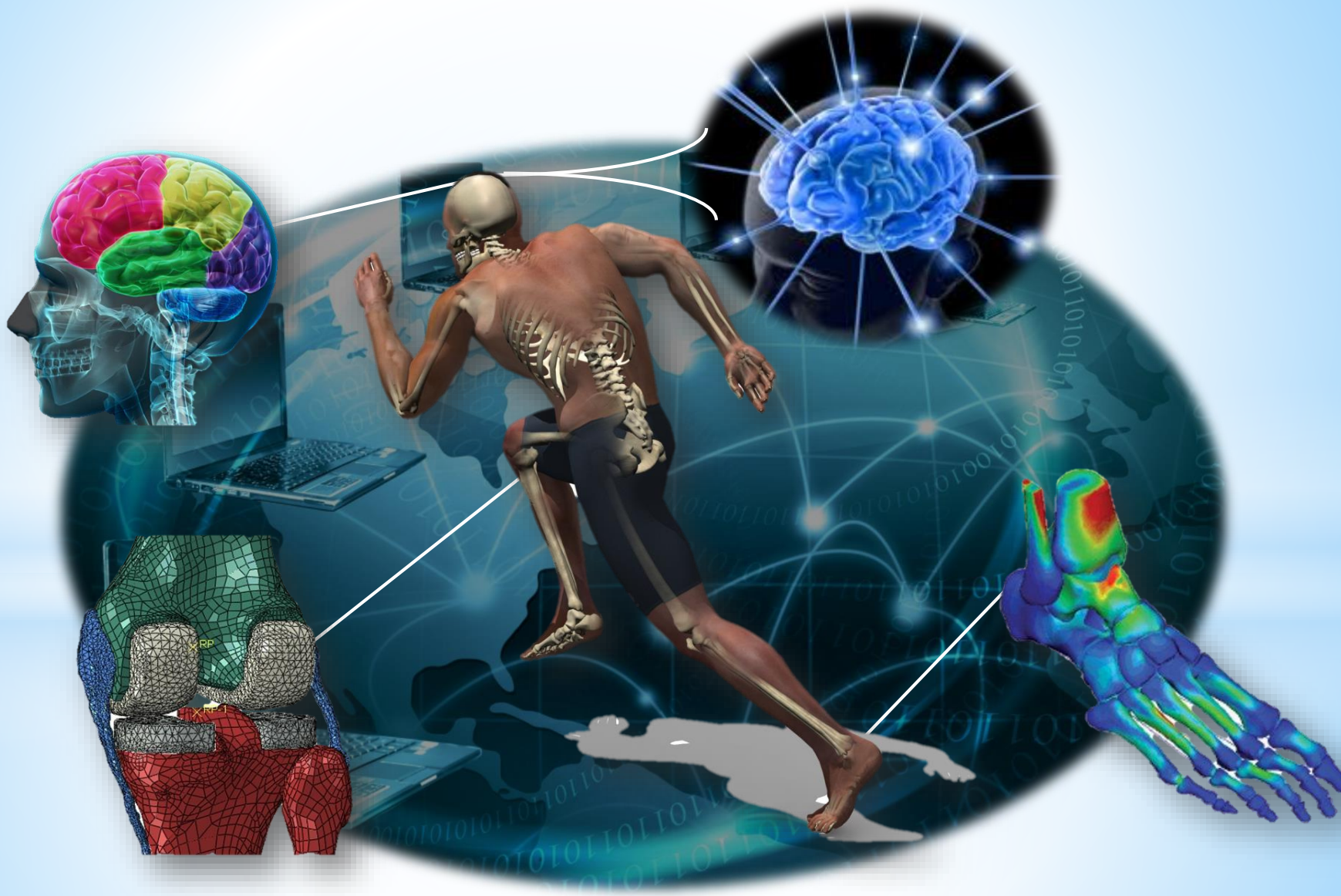
Mission Optimization
Automatically Evaluate & Optimize
Squad Performance
(load balancing)



Distribute equipment to squad and to individuals



Simulate physiological performance



PREDICTIVE HUMAN MODELS AND THE THIRD OFFSET

OPTIMIZATION-BASED COUPLED HUMAN SYSTEMS INTEGRATION





SANTOSH HUMAN®

Motivation

Squad leaders lack adequate information, and there are no means for analytic support for situational assessment or dissemination of recently acquired knowledge. There is no method in place for capturing unique experiential field-knowledge, and the training process for squad leaders has not been formalized.

There needs to be a *better organization and deployment of squad leader training tools*, and that new tools be developed to prepare leaders for the more complex in-theater experience.

There is a *lack of a systems or protocols to retain unique experiential field knowledge* that would be valuable to other squad leaders.

There is a need for investment in S&T research to *enhance decision-making with tools such as smartphone applications* for situational assessment and course-of-action evaluation, as well as training simulators that can be adapted on the fly, to suite various in-theater situations.



Lighten the Load

Mission
Equipment

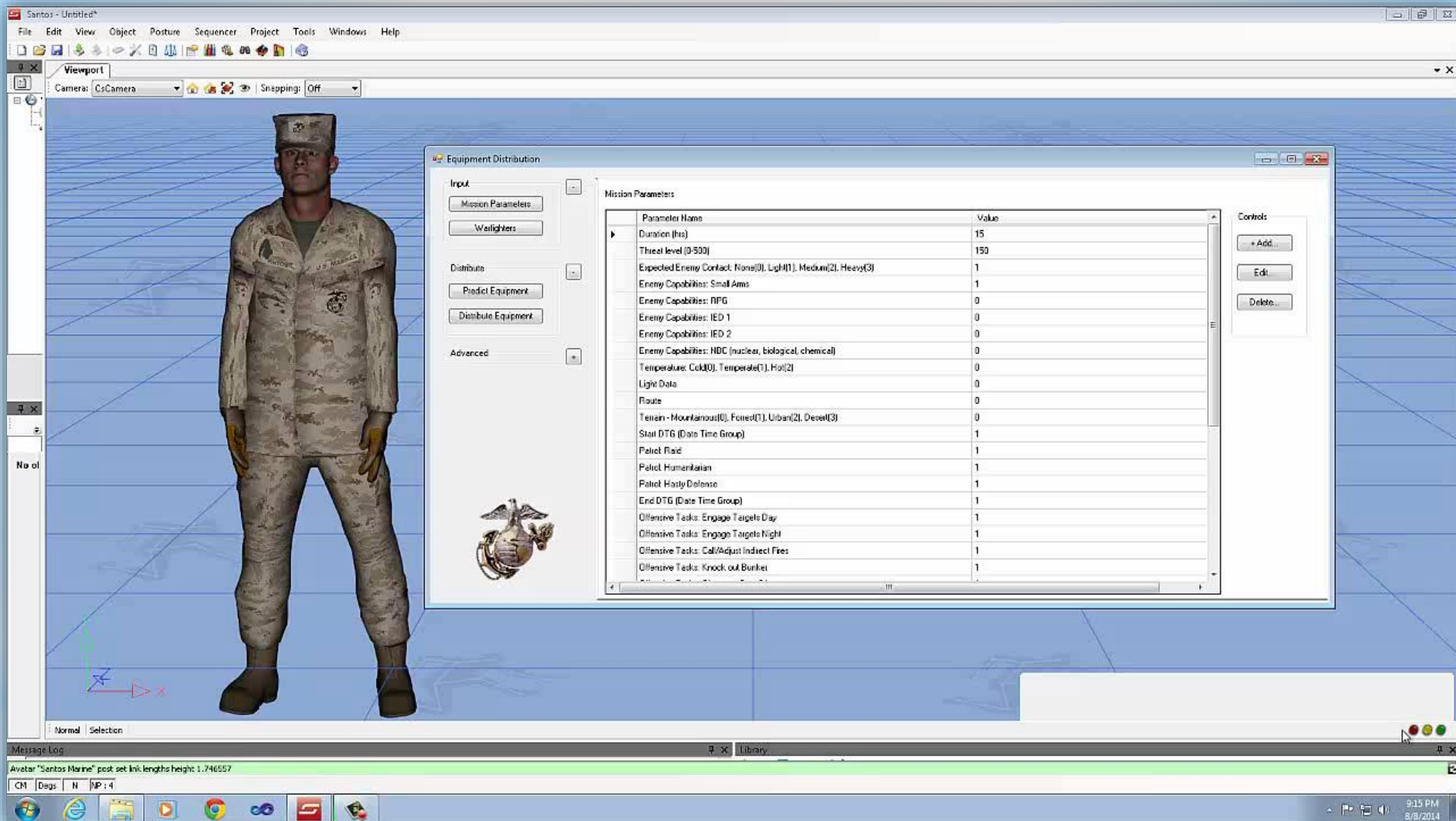
An expert system that learns...

- Since** a lead leader adds new information as needed:
Which pieces of equipment which pieces of mission
- Mission parameters
 - **To optimize** characteristics
 - **Equipment** load being carried by a Warfighter
 - Dependencies

Subject to:
Mission-equipment dependencies'



Lighten the Load Equipment Distribution



Squad leaders lack adequate information, and there are no means for analytic support for situational assessment or dissemination of recently acquired knowledge. There is no method in place for capturing unique experiential field-knowledge, and the training process for squad leaders has not been formalized.

Lighten the Load

Equipment Distribution

Tools that provide a secure server-based method for aggregating squad knowledge and training new leaders

The screenshot shows a web browser window with the address bar containing `oorah.apphb.com`, which is circled in red. The page title is "VSR Lighten the Load". The main content area features a camouflage background with the Marine Corps emblem on the left and the "VIRTUAL SOLDIER RESEARCH" logo on the right. The central text reads "Equipment Distribution Training Aid". Below this, the interface is organized into three sections: "Input" with "Mission Parameters" and "Warfighters"; "Distribute" with "Predict Equipment" and "Distribute Equipment"; and "Advanced" with "Equipment Library" and "Advanced Decision Engine". Each menu item includes a right-pointing arrow.

Lighten the Load

Integration with Human Performance

...and that link with full human performance evaluation

The screenshot displays a software interface for human performance evaluation. The interface is divided into several sections:

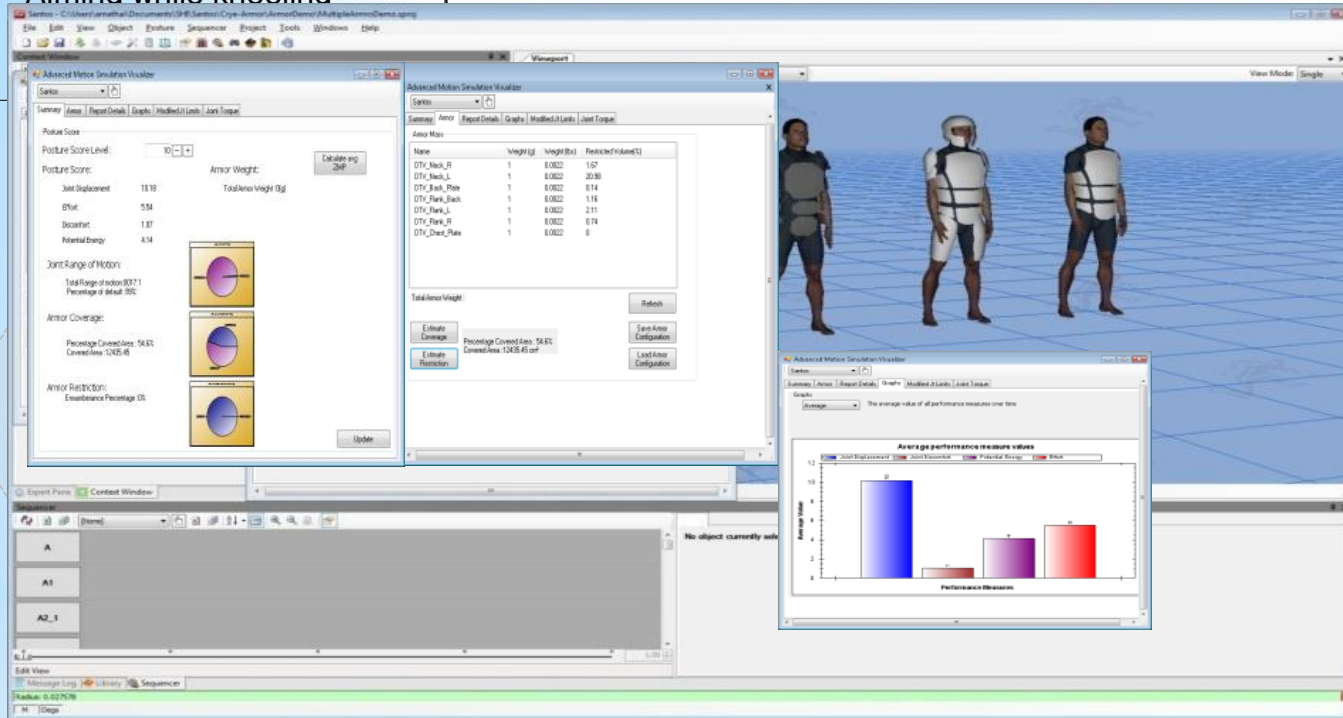
- Top Bar:** Contains a logo on the left and two buttons: "Reset Scene" and "Change Units".
- Left Sidebar:** Features icons and labels for "View", "Fitness", "Terrains", "Slope", "Speed", and "Output".
- Inputs Panel:** A central panel with the title "Inputs" containing the following parameters:
 - Fitness First Class
 - Terrain Blacktop
 - Blacktop
 - Slope 0°
 - Flat
 - Speed 0 m/s
 - Standing
 - Gear Load 4.46 kg
- Physiology and Thermal Panels:** Two vertical panels on the right side of the inputs panel, labeled "Physiology" and "Thermal".
- 3D Model:** A 3D rendering of a soldier in a desert environment, wearing a camouflage uniform and a helmet.
- Control Bar:** Located below the inputs panel, it includes a refresh icon, a play button, a stop button, a "1x" speed indicator, and a progress bar.
- Speed Selection Bar:** A horizontal bar at the bottom showing six different walking/running postures with their corresponding speeds:
 - Standing: 0.0 m/s
 - Slow: 0.5 m/s
 - Slow-Moderate: 0.9 m/s
 - Moderate: 1.389 m/s
 - Moderate-Fast: 1.7 m/s
 - Fast: 2.1 m/s

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Biomechanical Effects of PPE Analysis

Armor-evaluation Tasks

- Arm raises
- Sitting
- Aiming while standing
- Aiming while kneeling



Evaluate the ability to perform tasks, based on a suite of metrics

Evaluation Metrics

- Performance
- Mobility
- Balance
- Coverage
- Restrictive Volume
- Weight
- Torque
- Bulk

