Human Engineering and Ergonomics Risk Analysis Process, Improved Capability for Reducing Human Injury Risks

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Defense Safety Oversight Council

Acquisition and Technology Task Force

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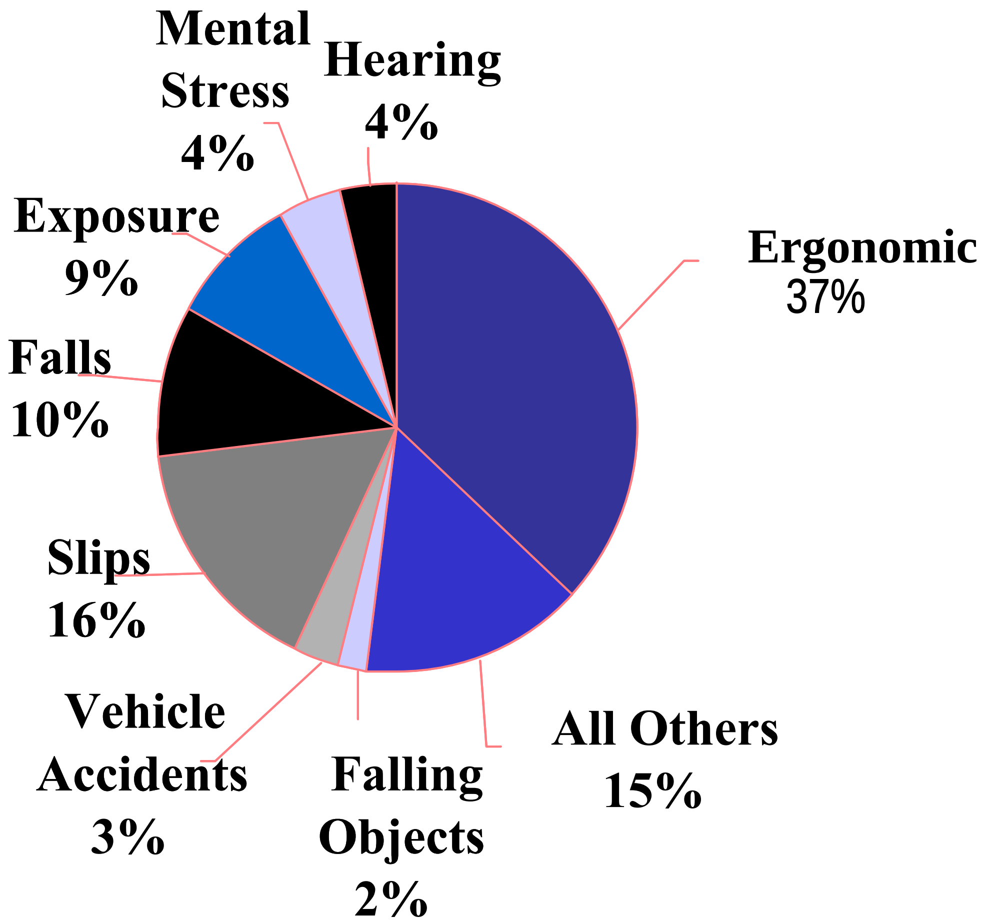
Quantifying Ergonomic/Human Systems Integration Risk and Costs to Support System Safety Analysis

Sponsor	Defense Safety Oversight Council (DSOC)	DOD –OSD Manpower and Readiness Joseph Angello
Technical sponsor	DSOC Acquisition and Technology Task Force	Liz Rodriquez-Johnson, PhD DOD AT&L coordinator
Integrating Contractor	Concurrent Technologies Corporation	Robert Gardiner Karen Freedman Nelson
Project contractor	BMT Designers and Planners	Larry Avery (project lead) Christopher Parker Alex Ruttenberg
Project contractor	Carlow International	Thomas Malone, PhD

The Problem

- Continued high incidence of human injury associated with poor design.

These figures represent only direct costs to civilian employee and do not consider indirect costs, inefficiency or lost productivity



Source: Analyzing the Navy's Safety Data by the Center for Naval Analysis, December 2001

These figures represent Navy costs, but are estimated to be representative of other Services.

The Problem (con't)

- Human engineering and safety usually don't focus upon ergonomic injuries.
- Increased life cycle costs associated with human injury
  - Estimated costs of ergonomic injury in the Navy to exceed $100M by 2009
- DoD needs a better way to reduce design-induced injuries as part of the acquisition process

DSOC Ergonomics Project- seeks to integrate multiple disciplines approaches

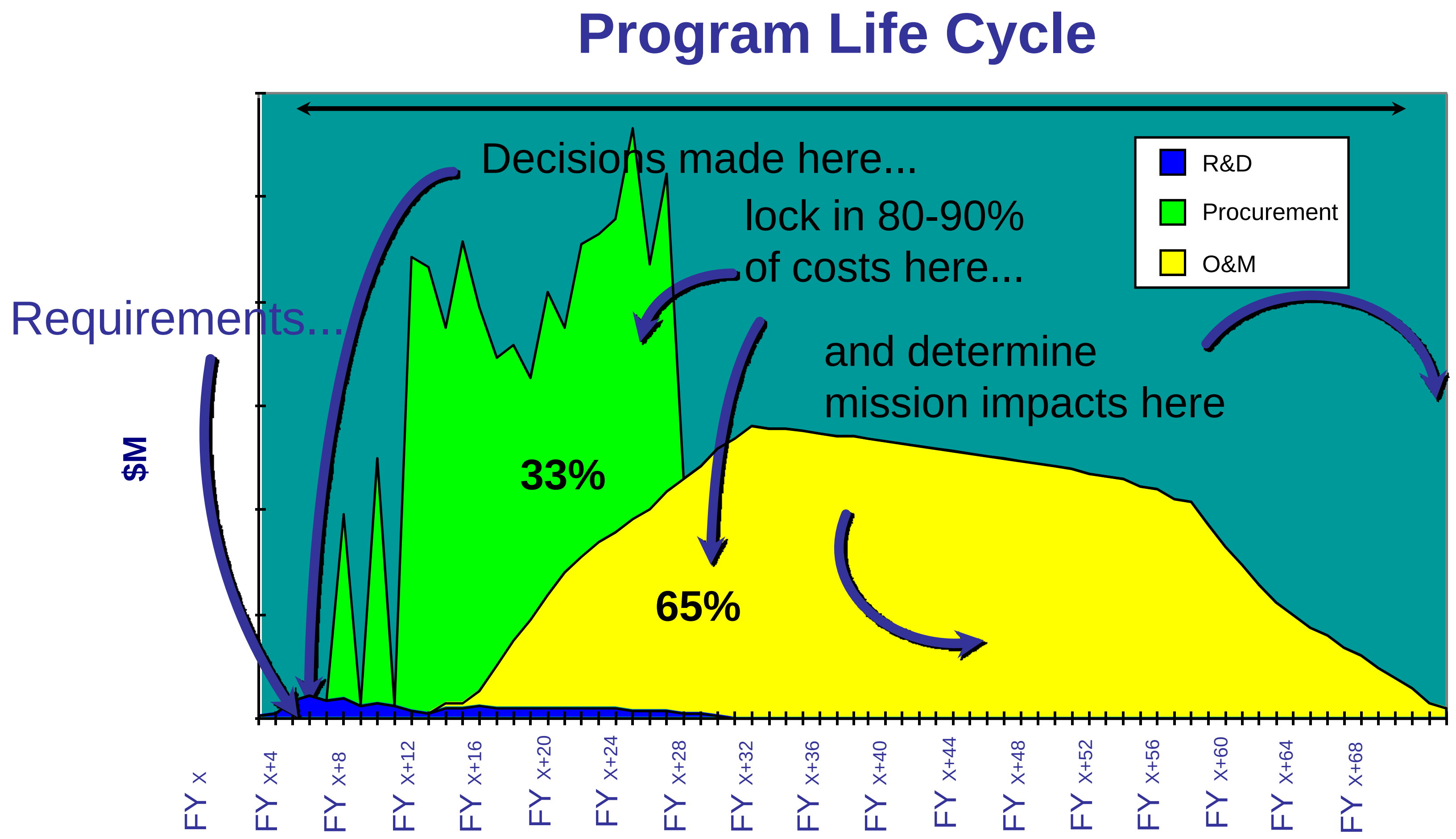
Issue depends on perspective

Is this approach consistent with systems engineering?

Project seeks to integrate systems engineering approach across multiple disciplines and show economic benefits of early design for users

- **Human systems integration**
  - **Ineffective use of manpower**
  - **Would training help?**
- **System Safety**
  - **Will they drop it?**
  - **If so, what happens?**
- **Ergonomics (and occupational safety)**
  - **Will this create a back injury?**

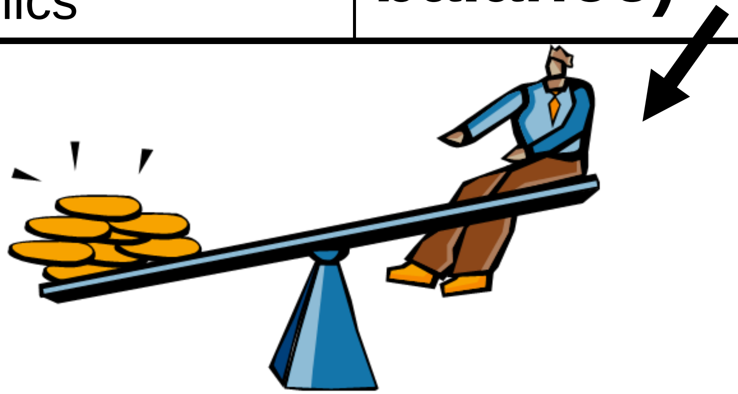
Early Integration Makes Sense, But, how do you describe the cost savings made by early investment



Early integration is the least expensive and most effective way to minimize the downstream cost, schedule, and performance impacts of any weapon system.

Trades and Balances

Immediate Drivers	Long Term Drivers
Procurement cost (investments that reduce life cycle costs are hard to support)	Life-cycle cost (previously harder to access)
Schedule (including limiting engineering analysis)	
Performance (including safety)	Maintainability
Manpower (often a KPP) Can often be reduced by human engineering/ergonomics	**Manpower (can tip the balance)**



Product needed to address the issues

- Need for better integration of the HSI domains of human engineering and safety to address design issues;
- Need for a system safety methodology focused on military system acquisition, applicable to all Services;
- Need to expand the scope of military systems safety and human engineering to better address ergonomic injuries;
- Need for a risk management approach focused on avoidance or mitigation of design-induced risks;
- Need for a risk identification process based on the HSI top down requirements analysis.
- **Need for guidelines on human interface design to reduce risk of safety hazards, mishaps, and ergonomic injury.**

Human Engineering and Ergonomics Risk Analysis Process (HEERAP)

- Project was initiated to address these issues
  - Chief Naval Operations Safety Liaison Office N09FB
  - Defense Safety Oversight Council (sponsor)

- Goal was to develop methodology that would:
  - Provide process that would help identify, analyze, and mitigate risks of human injury
  - Be applicable to all DoD Services
  - Appropriate for all phases of acquisition life cycle
  - Proactive analysis of alternatives

- Development of process included:
  - Review of relevant standards and risk analysis processes
  - Review and comment by representative users: Human engineering, ergonomics, and system safety professionals

HEERAP

- Process for identifying and assessing human injury risks;
- Guidance on design solutions to mitigate the risks




HEERAP Target Users

- HSI, human engineering and human systems integration professionals
- System Safety professionals
- Ergonomics experts
- Ideally all “technical experts” involved in DoD system acquisition

Definitions- with significant overlap

<u>Ergonomics</u>

The field of of study that involves the application of knowledge about physiological, psychological and biomechanical capabilities and limits of the human body

(OPNAVINST 5100.23 NAVOSH Shore Safety Program Manual, Chapter 23 Ergonomics Programs)

<u>Human Engineering (HE)</u>

The application of knowledge about human capabilities and limitations to system(s) or equipment design and development to achieve efficient, effective, and safe system performance at minimum cost and manpower, skill, and training demands.

HEERAP Target Hazards

- Physical safety hazards associated with equipment design (e.g. acute injuries due to contact with sharp edges, excessive surface temperature).
- Occupational health hazards due to poor task design that requires repetitive and continuous performance (resulting in chronic ergonomic injuries).
- Health hazards associated with lifting and carrying excessive loads.
- Health hazards associated with reaching, placing, and maintaining the whole body, or individual limbs, in awkward positions, leading to chronic injuries.
- Safety and health hazards resulting from poor decision making, leading to acute and chronic injuries, as well as, risks to system.

HEERAP Process

The HEERAP product consists of two parts, used together, to guide risk analysis and mitigation

- Part 1 Human Engineering and Ergonomics Risk Analysis Procedure
  - systematic process supporting the analysis
  - step-by-step procedures
  - background on how HE&E fits in the acquisition process
  - provides example applications
- Part 2 Human Injury Risk Matrix
  - examples of potential risks associated with typical tasks
  - provides visualization of risk analysis
  - orients and sensitizes the user to risk issues
  - provides information to guide design risk analyses

HEERAP Process Part 1

HE&E Risk Analysis Procedure

- Addresses requirements determination in terms of 5 design objectives (or contexts):
  - Design for operability
  - Design for maintainability
  - Design for habitability
  - Design for transportability/portability
  - Design for erectability (assembly) and construction

HEERAP Process Part 1 (con't)

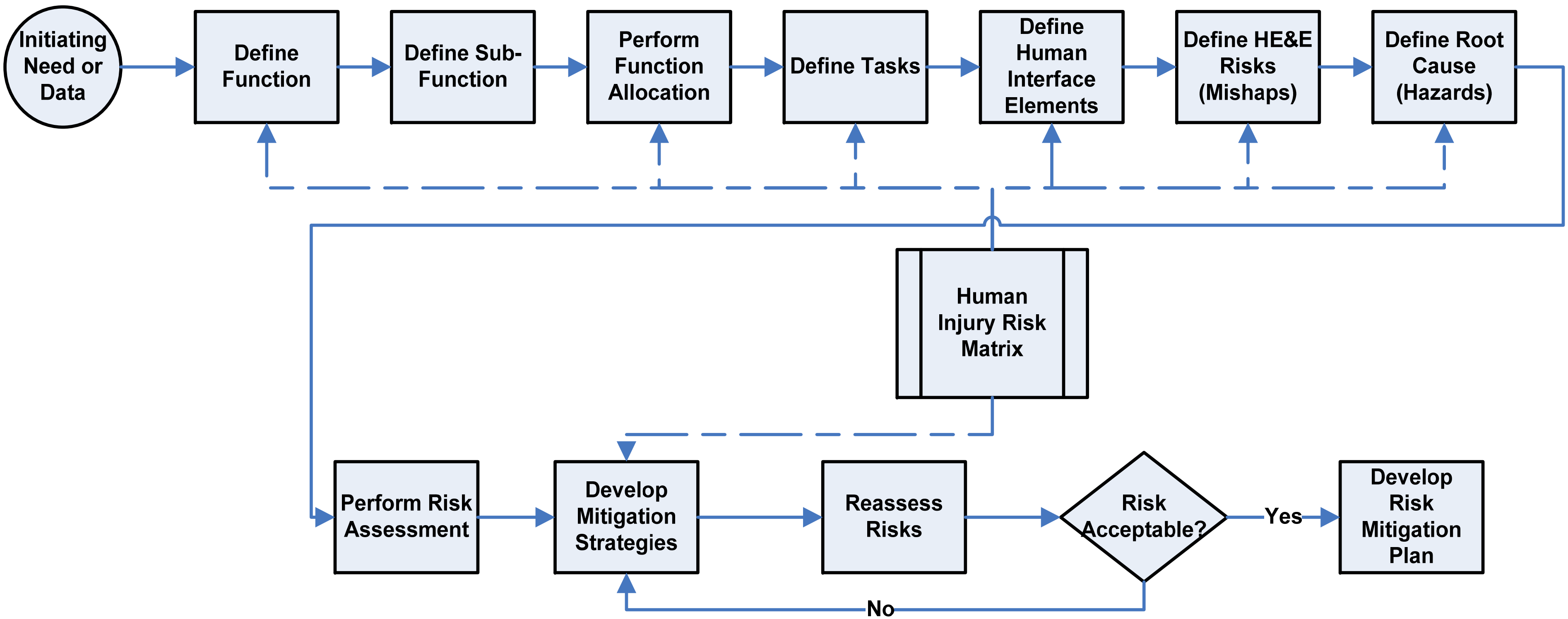
- For each design objective, adapt the HSI top down analysis process of identifying:
  - Functions (top-level functions in line with the design objective)
  - Sub-functions (second order functions)
  - Function allocation (human, automated, or human-aided)
  - Tasks and task performance requirements (third order activities)
  - Human interfaces associated with task performance
  - Standards or best practice for interface design requirements

HEERAP Process Part 1 (con't)

- Conduct a risk analysis
  - Define possible risks of injury for human interfaces associated with tasks
  - Define risk root causes - poor interface design, non-compliance with standards, unsafe use procedures or environments
  - Perform a risk assessment - identify red flags
  - Develop risk mitigation strategies
  - Define mitigation metrics and reassess the risk

HEERAP Process Part 1 (con't)

Part 1 Analysis Process



HEERAP Part 2 Human Injury Risk Matrix

HEERAP Part 2 – Human Injury Risk Matrix

Context: Transportability

Function	Sub-function	Allocation	Task	Interface Elements	Standards/Best Practices	Risks (Mishaps)	Risk Root Cause (Hazard)	Red Flag	Mitigation Strategy	Mitigation Metrics
Lift	NA	Human Unaided	**Grasp lifting points**	Handles, grasp areas	ASTM F1166 Section 16.5 - Design of Handles and Grasp Areas, MIL-STD 1472F Para 5.9.11.5 - Handles and Grasp Areas	Slippage of load causes back or other muscular-skeletal injury	Inadequate handles or grasp areas making it difficult balance and lift the load.	High rates of actual errors or potential errors in grasping lifting points prior to lifting where such errors can result in injuries to personnel doing the lifting. Frequent dropping and damaging of load.	Design the package so that grasp areas and handles meet the criteria in the standards and allow the user to lift the load without risk of the load slipping or shifting, placing undue stress on the back and other parts of the body.	Probability of injury due to inadequate handle design.
				Vibration, moving surface	ASTM F1166 Section 14.4 - Whole Body Vibration, MIL-STD 1472F Para 5.8.4 - Vibration, MIL-HDBK 759C 5.8.4 - Vibration	Stress on body causes back or other muscular-skeletal injury.	Design of the grasp areas and handles does not allow the user to adequately secure the load when exposed to vibration or moving surface causing physical stress and/or slippage.		Ensure that design of the grasp areas and handles are sufficient for the user to be able to grasp and firmly control the load.	
			Raise and stabilize	Weight and weight distribution	ASTM F1166 Section 16.2 - Weight Lifting, MIL-STD 1472F Para 5.9.11.3 - Weight, Applications Manual for the NIOSH Lifting Equation	Back or other muscular-skeletal injury due to improper lifting and/or twisting of body; difficult to stabilize leading to musculo-skeletal strain or physical trauma if equipment slips and falls.	Weight too heavy/improperly distributed and/or task requires twisting of body/repeated lifts leading to too much stress on the body which results in injury.	High rates of actual errors or potential errors in lifting the load where such errors can result in injuries to personnel doing the lifting.	Design load so that 1) user understands limitations, 2) load weight is low enough for one-person lift, 3) weight is distributed to allow safe lifting, 4) task is designed to minimize twisting or repetitive lifts, 4) weight is distributed to allow easy stabilization.	Probability of injury due to inadequate provisions for lifting the load.
				Vibration, moving surface	ASTM F1166 Section 14.4 - Whole Body Vibration, MIL-STD 1472F Para 5.8.4 - Vibration, MIL-HDBK 759C 5.8.4 - Vibration		Vibration and/or moving surfaces creating physical stress on human as they continually compensate for load movement.		Ensure that design of the grasp areas and handles are sufficient for the user to be able to grasp and firmly control the load.	Probability of injury due to inadequate handle design.

HEERAP Part 2 - Human Injury Risk Matrix (simplified)

Context; Transportability

Function	Allo-cation	Task	Interface	Risks	Root cause	Mitigation
Lift	Human (unaided)	Grasp lift points	Side of box	Slip, back injury, drop box	Hard to grasp	Add handles

HEERAP Risk Analysis Process

- Approach modelled after MIL-STD-882D
  - Identify risk (e.g, mishap)
  - Identify root cause (e.g., hazard)
  - Estimate severity of risk should it occur

Severity Rating	Category	Human Impact	Potential Life Cycle Cost Implications
I	Catastrophic	Death or permanent total disability	Recruitment and training of replacement, lost work time, survivor benefits
II	Critical	Permanent partially disabling injury, injuries or occupational illness that may result in hospitalization of at least 3 people.	Disability, medical, recruitment and training of replacement
III	Marginal	Temporary disabling injury or occupational illness resulting in one or more lost workdays	Disability, medical, lost work time
IV	Negligible	Minor injury or injury not resulting in a lost work day.	Medical, lost work time

HEERAP Risk Analysis Process (con't)

– Estimate likelihood of risk occurrence

Likelihood Rating	Category	Injury Occurrence
A	Extremely Likely	Likely to be experienced almost continuously when performing the task or repetitive action within the task
B	Likely	Likely to be experienced frequently when performing the task or repetitive action within the task
C	Occasional	Likely to occur sporadically when performing the task or repetitive action within the task
D	Unlikely	Unlikely, but can reasonably be expected to occur when performing the task or repetitive action within the task
E	Extremely Unlikely	Extremely unlikely but possible to occur when performing the task or repetitive action within the task

HEERAP Risk Analysis Process (con't)

– Assign a human injury risk value

		Severity Levels (S)			
		I CATASTROPHIC	II CRITICAL	III MARGINAL	IV NEGLIGIBLE
Likelihood of Occurrence	A - Extremely Likely	1 (High)	3 (High)	7 (Serious)	13 (Medium)
	B - Likely	2 (High)	5 (High)	9 (Serious)	16 (Medium)
	C - Occasional	4 (High)	6 (Serious)	11 (Serious)	18 (Low)
	D - Unlikely	8 (Serious)	10 (Serious)	14 (Medium)	19 (Low)
	E - Extremely Unlikely	12 (Serious)	15 (Medium)	17 (Medium)	20 (Low)

– Risk acceptance authority

Human Injury Risk Value	Category	Human Injury Risk Waiver Authority (Acceptance Level)
1-5	High	Component Acquisition Executive (CAE)
6-9	Serious	Program Executive Officer (PEO)
10-17	Medium	Program Manager
18-20	Low	As Directed

HEERAP Risk Analysis Process (con’t)

– Develop Risk Mitigation Strategies
  - Eliminate risk root causes through design/redesign
  - Incorporate safety devices
  - Provide warnings
  - Provide procedures and training

HEERAP Risk Analysis Process (con't)

Example HEERAP from hypothetical system

Human Engineering and Ergonomics Risk Analysis										
System	XYZ Vehicle									
Initiating Need/Data	Reported injuries									
General Task Description	Changing tire on large construction vehicle. User must jack up, disconnect, remove, and replace the tire. Tire weighs approximately 100 pounds and requires a minimum of 2 soldiers to safely remove, more if maintenance crews include female soldiers, though task is sometimes performed by one person.									
Task Environment Conditions:	Indoors, outdoors, all weather conditions, day or night with artificial lighting									
								Risk Analysis		
Function	**Sub-function**	**Allocation**	**Task**	**Interface Elements**	**Injury Risk**	**Root Cause**	**Likelihood**	**Severity**	**Analysis**	**Mitigation Strategy**
Prepare for Tire Removal	Access Tools	Human Unaided	Locate and Unstow Jack, other tools, and manuals	Connectors, etc.	Contusions, abrasions, or other trauma due to falling tools	Location of tools requires user to crawl under chassis, leading to possibility of uncontrolled dropping if opened incorrectly	C - Occasional	III - Marginal	11 - Serious	1) Design storage so that it can not be opened to allow tools to fall 2) Provide warnings of risk and procedures for minimizing risk of dropping tools

HEERAP Risk Analysis Process (con't)

Example: Evaluated a **<u>hypothetical</u>** process to illustrate potential impact of reducing injury risk

Process Evaluated: Changing a 100 pound truck tire

Legacy Process: Truck is elevated off the floor with a standard lift or jack. Safe tire removal and replacement requires three people to lift and mount the wheel and tire (2 to lift, 1 to remove lug nuts). Sometimes task is done by less people.

Risks/Inefficiencies Noted: Risk of back injury during manual manipulation of the tire. Coordination by three people during a noisy operation (use of pneumatic tool) increases the difficulty and chance of a slip. Lifting from ground level also decreases mechanical efficiency and increases risk of injury.

Possible Alternative: Device holding and raising the tire during mounting/ dismounting operations. Allows one person to perform this task. Lowers apparent injury risk.

HEERAP Risk Analysis Process (con't)

Hypothetical Costs Impacts: Modeling of hypothetical costs savings and risk reduction. Shows savings associated with common process improvement

Potential HSI impacts (include safety, human engineering and inefficiency costs)	**Significant manpower costs 3200 man/hours -year 1.6 man years $50K/man-year = with potential injury risks ($800K/yr)**
Potential Corrective Actions	**Tire lift allows one person to do task previously done by 3 people (40-60% time savings)** **<u>$400 K/ year saving for $64K non-recurrent investment</u>)** **$2K tool x 32 locations)**

HEERAP Way Ahead

- Perform a more detailed user evaluation.

- Develop a data companion for the HEERAP
  - Consolidate the relevant human injury and ergonomics data
  - Describe common HE&E design issues, guidance and criteria for “good” HE&E design,
  - Provide case studies and exemplars of design.

- Enhance the delivery from hard copy to new enabled process.
  - Automated process tool
  - A web-enabled application
  - DVD with illustrations.

- Integrate cost trade-off models.
  - Current version of the HEERAP focuses primarily on the identification and analysis of human injury risks
  - Mentions but does not incorporate cost factors into the analysis process. Integrating cost information would strengthen the process.

- Develop example ergonomic specification language.
  - A “guide” that has sample language to help to people involved in acquisition and would be a strong accompaniment to the HEERAP.
  - OPNAVINST 5100.24B System Safety Program has some model language

HEERAP Project Status

- DSOC project complete – deliverables received
- Information to be posted on relevant human systems integration and ergonomics websites
- Outreach via presentations and articles
- May submit a follow-on DSOC project
- Engaging varied users to apply the tool and supporting information

HEERAP

Points of contact

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  Carlow International Incorporated
  (703) 444-4666
  Tbmalone@carlow.com

Available at Navy Safety Center website: www.safetycenter.navy.mil/acquisition (refer to section on human systems integration and ergonomics)

Back-ups

The HEERAP product consists of two parts, used together, to guide risk analysis and mitigation

- Part 1 Human Engineering and Ergonomics Risk Analysis Procedure
  - systematic process supporting the analysis
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  - background on how HE&E fits in the acquisition process
  - provides example applications

- Part 2 Human Injury Risk Matrix
  - examples of potential risks associated with typical tasks
  - provides visualization of risk analysis
  - orients and sensitizes the user to risk issues
  - provides information to guide design risk analyses (including standards).

HEERAP

Part 1 HEE Risk Analysis Procedure

1. Address requirements determination in terms of 5 design objectives (or contexts):
   - Design for operability
   - Design for maintainability
   - Design for habitability
   - Design for transportability/portability
   - Design for erectability/assembly
2. For each design objective, adapt the HSI top down analysis process of identifying:
   - Functions (top-level functions in line with the design objective)
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   - Tasks and task performance requirements (third order activities)
   - Human interfaces associated with task performance
   - Standards or best practice for interface design requirements

System	Aircraft XYZ	Person completing form	J Jones	Phone Email	JJones @navy.mil	Date	5-12-07
Context (stage in use) Indicate by letter O=operations **<u>M= Maintenance</u>** T=transport H= Habilitability C= construction	Function of Concern (operation)	Risk Factor (stressor)	Potential Consequence (of overexposure)	Population affected (numbers involved as key job component)	Severity of injury	Probability	Risk Range
Example							
Initial assessment using legacy equipment and process							
Aircraft parts maint (airframe support)	Grinding/polishing parts for XYZ using electric hand sanders	Repetitive motion, hand-arm vibration	Reynaud's disease, carpel tunnel syndrome	200 in maintenance depots	II III IV	0.001 0.01 0.1	4 to 16 (11 most plausible)
Reassessment after process re-design (use of abrasive blast cabinet) (complete only if appropriate)							
Aircraft parts maint (airframe support)	Grinding/polishing parts for XYZ using glove box	Repetitive motion, hand-arm vibration	Reynaud's disease, carpel tunnel syndrome	100 in maintenance depots	III IV	0.0001 0.001	14 to 18 (18 most plausible)
Comparison	Process change	Minimal injury risk	Stated disease risk virtually eliminate	100 reduced due to process improvement	Serious to medium risk initially, reduced to low risk		PM acceptance required initially, no

HEERAP

Final HEERAP development step - collect user feedback

- User feedback on the methodology was collected on
  - **How well it supported user expected need.**
  - **Perceived overall usefulness.**
  - **Ease of use.**
  - **Potential improvements.**
- A draft of the HEERAP, with instructions, was provided to a sample of representative users who volunteered to review it and provide feedback.

  These volunteers included the following:

  - **13 individuals representing the Navy in both a civil service and contractor capacity.**
  - **4 individuals representing the Army in a civil service capacity.**
  - **1 individual representing an academic perspective.**

Integration of approaches needed

Human Systems Integration/ Manpower analysis

- Manpower evaluation
- Life cycle cost evaluation
- Risk reduction through designs minimizing cognitive errors
- Well connected with acquisition
- Often omits physical safety issues
- Often omits maintenance

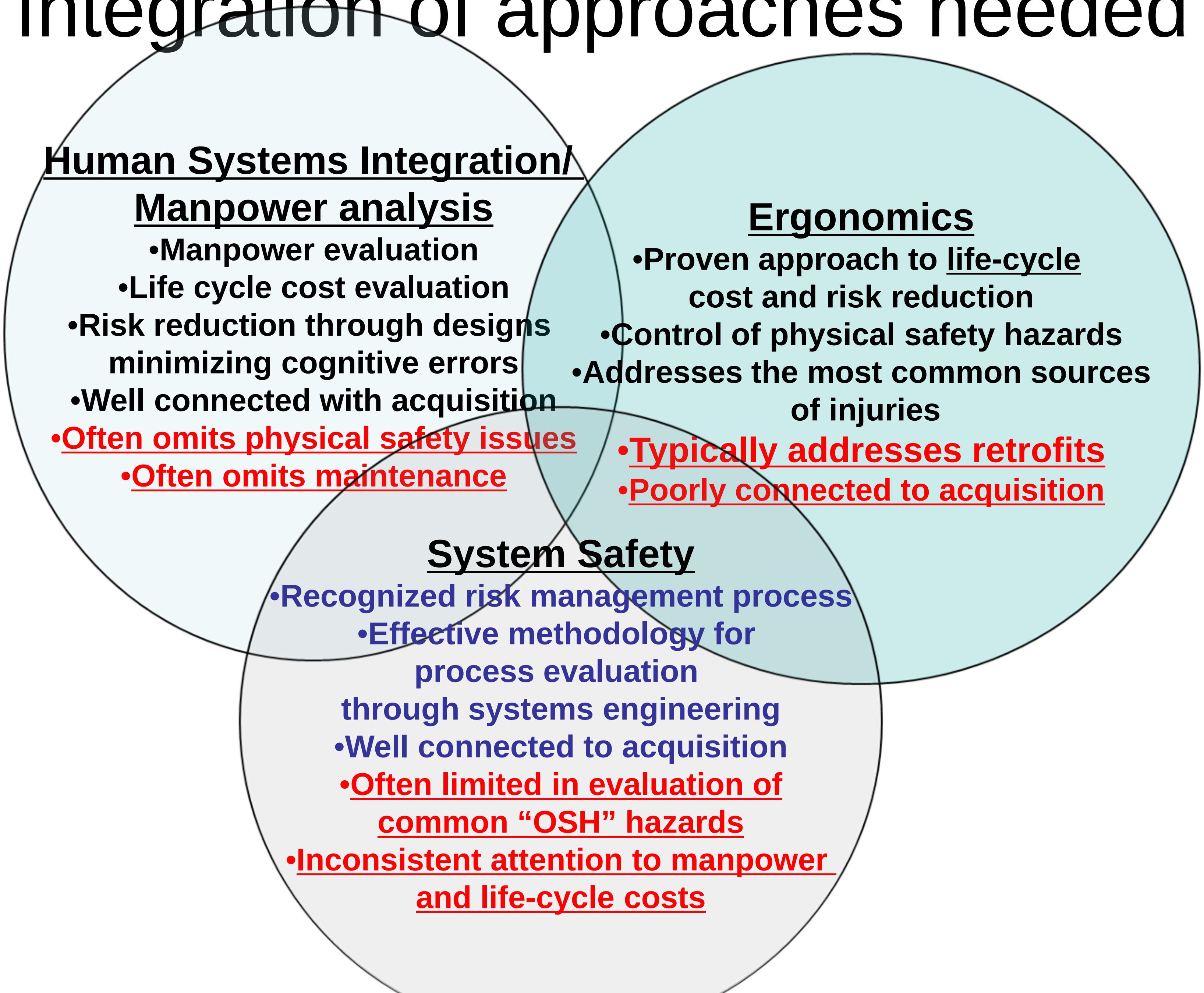
Ergonomics

- Proven approach to life-cycle cost and risk reduction
- Control of physical safety hazards
- Addresses the most common sources of injuries
- Typically addresses retrofits
- Poorly connected to acquisition

System Safety

- Recognized risk management process
- Effective methodology for process evaluation through systems engineering
- Well connected to acquisition
- Often limited in evaluation of common “OSH” hazards
- Inconsistent attention to manpower and life-cycle costs

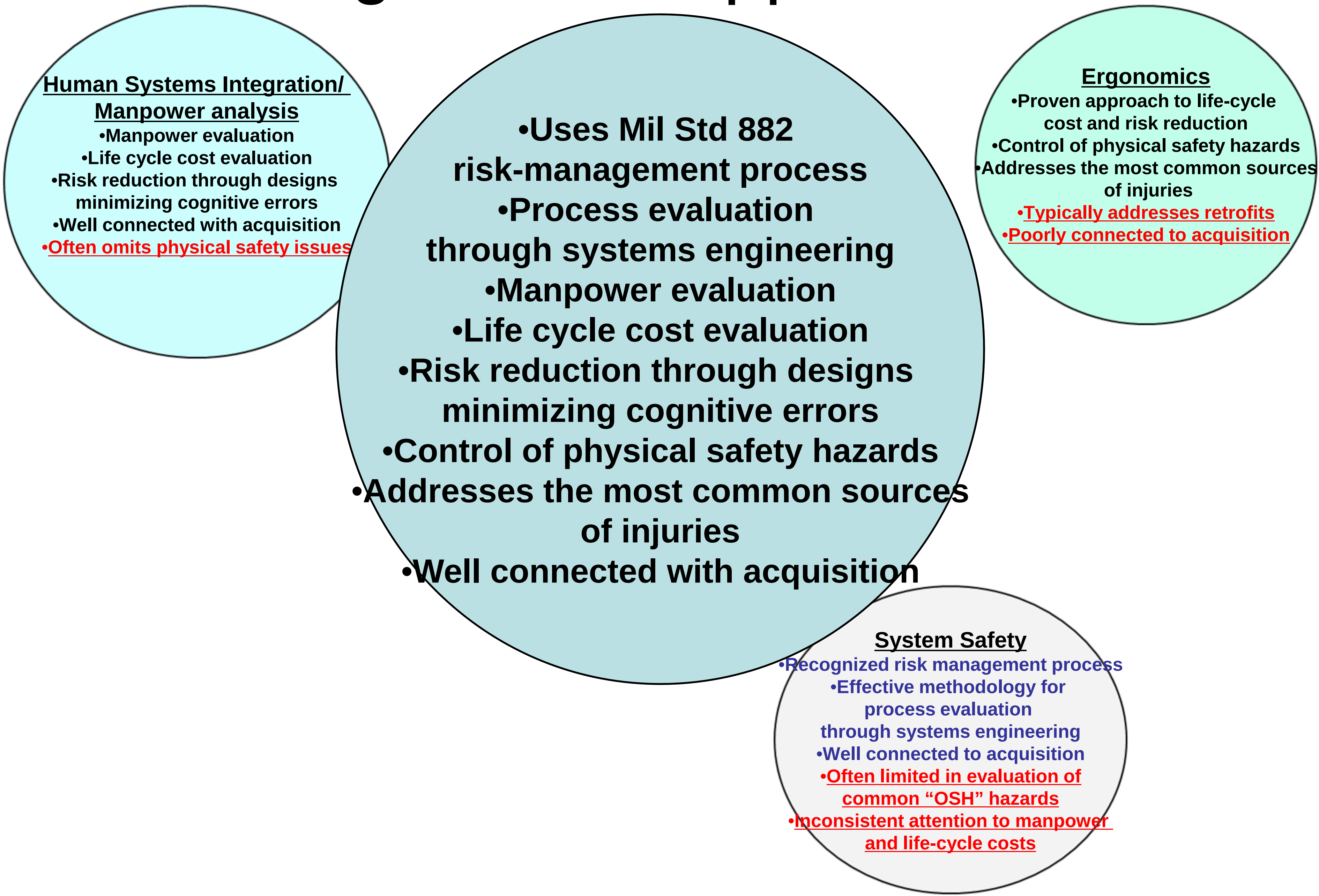
Integration of approaches needed



HEERAP Way Ahead

- Perform a more detailed user evaluation.
- Develop a data companion for the HEERAP which would consolidate the relevant human injury and ergonomics data to describe common HE&E design issues, guidance and criteria for “good” HE&E design, and provide case studies and exemplars of design.
- Enhance the delivery. The current version is hard copy. Usability and utility significantly improved by enhancing how the information is delivered to the user. This could include an automated process tool, a web-enabled application, or a DVD with illustrations.
- Integrate cost trade-off models. The current version of the HEERAP focuses primarily on the identification and analysis of human injury risks and only mentions but does not incorporate cost factors into the analysis process. Integrating cost information would strengthen the process.
- Develop example ergonomic specification language. Providing a “guide” that has sample language would be a major help to people involved in acquisition and would be a strong accompaniment to the HEERAP.

Integration of approaches



How can early definition of safety and health requirements reduce life cycle costs and risk?

- Initial analysis-what manpower intensive tasks and safety-health risks drive later costs?
  - Movement of equipment and supplies
  - Management of chemical materials (and related safety, health and environmental measures
  - Excessive maintenance demands
  - Environmental conditions that reduce efficiency, comfort and safety

Movement of materials

- Movement of materials should be considered as an aspect of process management. Labor intensive activities may be identified for improved support systems and equipment

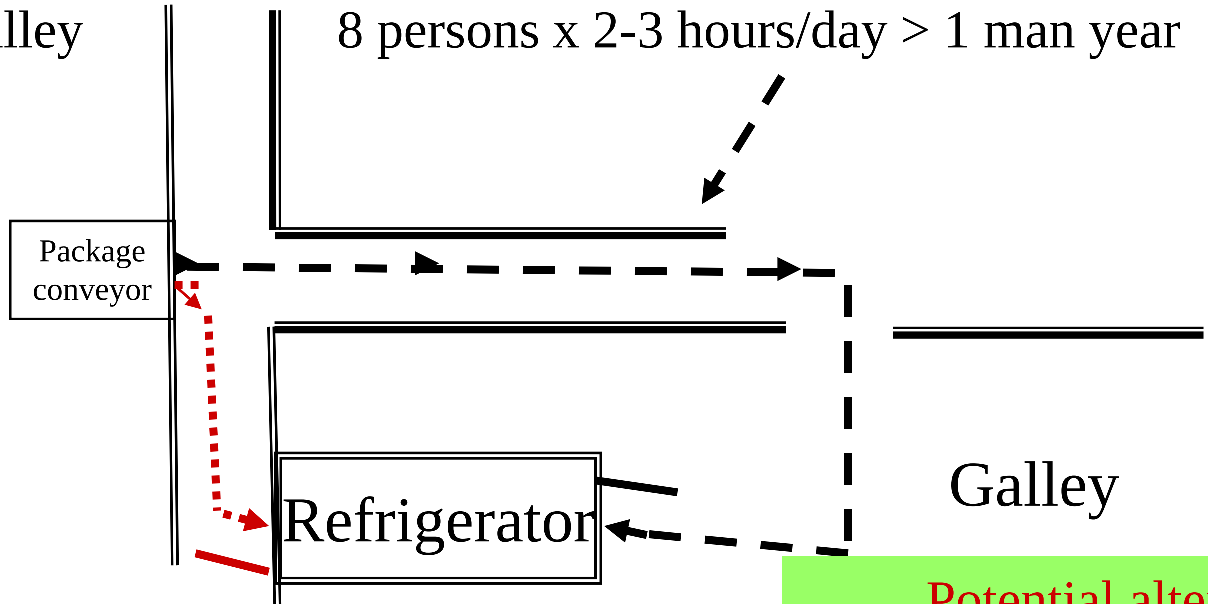
Pier side conveyer helps transport supplies and cargo.

Ordnance loading is a key area for consideration of HFE/Ergonomics during acquisition planning

Issue type: Material Handling
Space arrangements and traffic flow

Present route from freezer (below decks) to thaw refrigerator (in galley)
8 person manual chain from package conveyor through passageway via galley

8 persons x 2-3 hours/day > 1 man year



Potential alternative # 1 for newer ships –

Refrigerator with two doors

(Could save ½ man year)

Ron Casto Port Engineer LHD-7

Potential alternative # 2
Refrigerator and freezer aligned one deck above the other

Package conveyer inside freezer

(Could save even more manpower)

Don Goddard US Army CHPPM

- Example: Excessive Load Carriage
  - Heavy Army Field Infantry Load

Excessive Extrinsic Load

- Load Carriage - Head Supported Mass

Position	Ave FL[1]	Ave EAML[3]	EAML %BW
Rifleman	63 lb	127.3	71%
M240B Ammo Bearer	69 lb	144 lb	80%

[1]FL = Fighting Load
[3]EAML = Emergency Approach March Load

Soldiers Expected to Carry Heavy Equipment Load

Example provided by Don Goddard, US Army Center for Health Promotion and Preventive Medicine

Eagle Equipment
Your automotive shop equipment specialists
800 336 2776
http://www.eagleequip.com

Heavy Duty Truck Tire Changer - TC-770-T

TC-770T

Price: $5799.00

Four jaw rotating chuck with two speeds
Control unit on movable stand
Pressure regulated hydraulic motor
Quick change mount demount arm
Handles most wheels for trucks, tractors and earthmovers

Specifications

Max. Wheel Diameter 47"
Max. Wheel Width 51"
Rim Diameter 14" - 26"
Working Pressure 8-10 bar
Power Supply 220v

http://www.eagleequip.com/Merchant2/merchant.mvc?Screen=PPRINT&Product_Code=TC-770T