



Mapping Mitigation Risk Consequence for Crew Needing Assistance or Rescue on the Lunar Surface

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Disclosure Information

93rd Annual Scientific Meeting



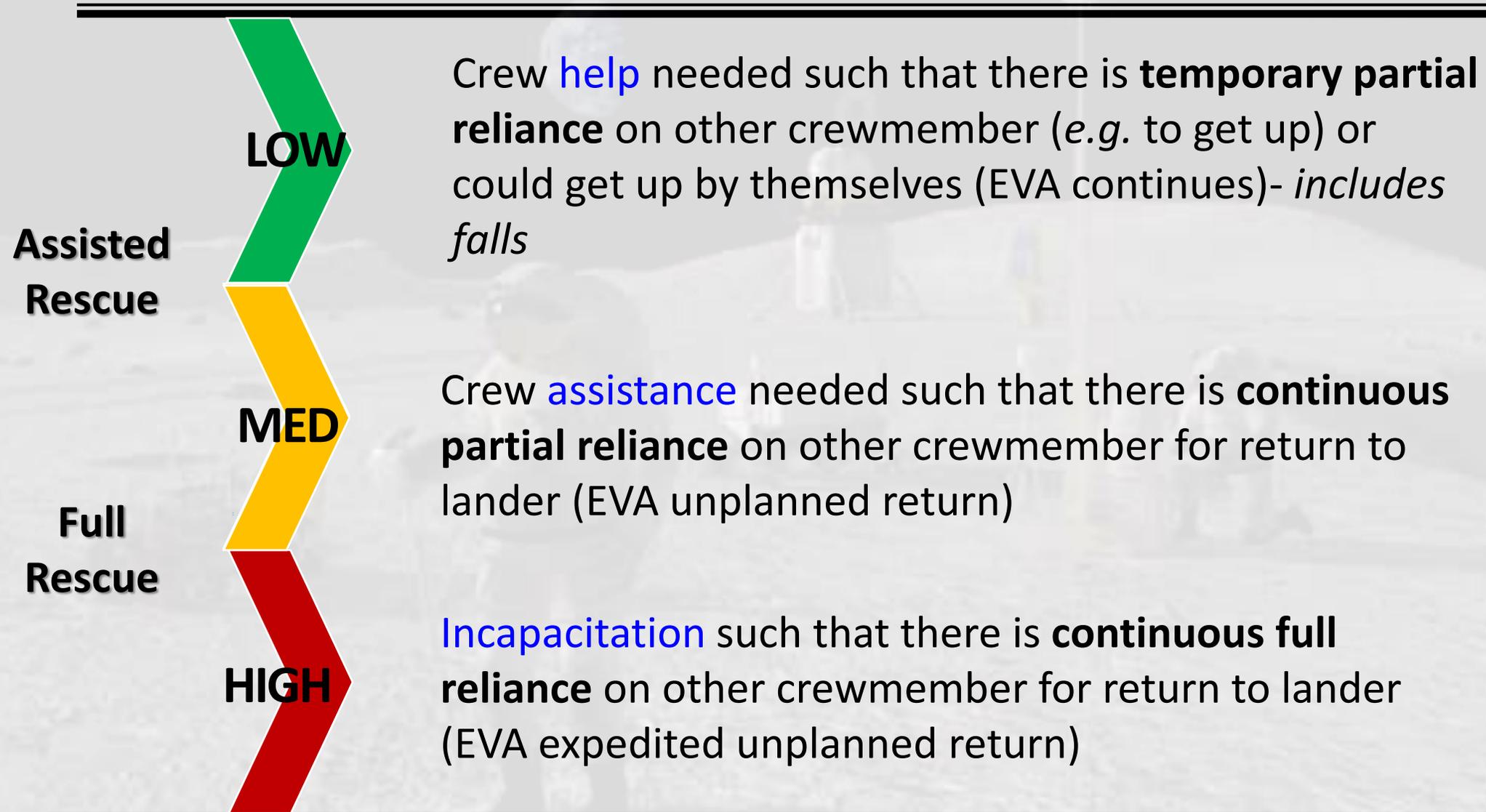
Robert Sanders, M.D.

I have no financial relationships to disclose.

I will not discuss off-label use or investigational use in my presentation.



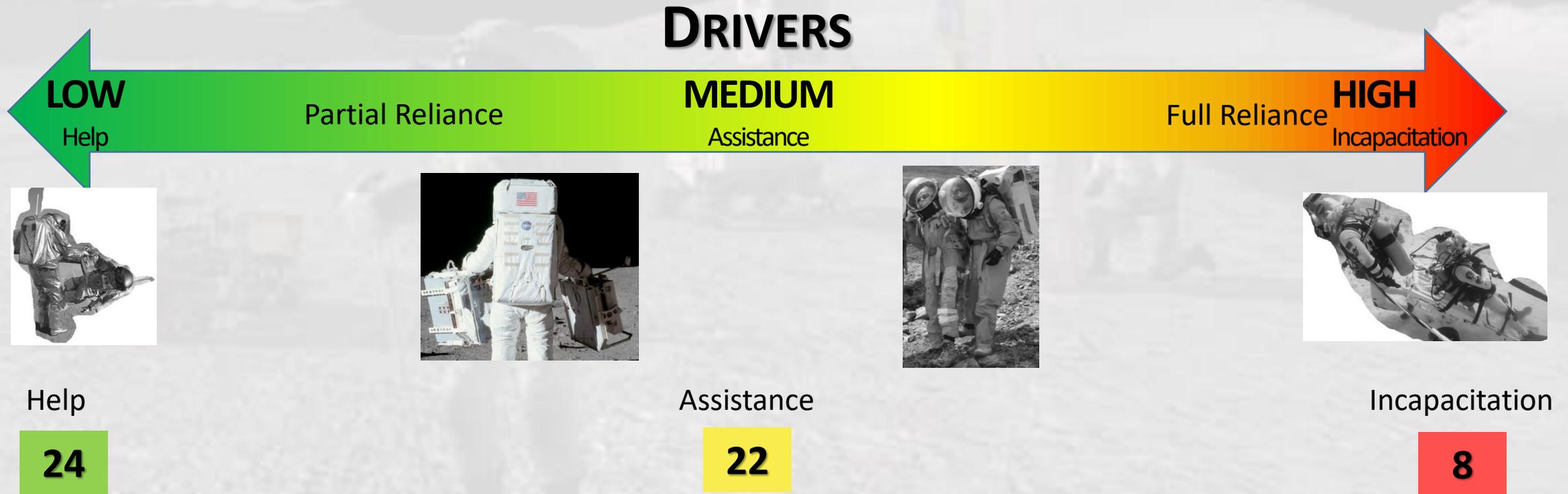
ICR/Acute Injury Scenario Definitions



Causes of Incapacitation/Acute Injury



(Total conditions = 264 → Credible causes = 157 → Drivers = 54)



Data Caveats and Assumptions



- **Suit:** Not exploration EVA suit, not suited
 - **Lunar surface:** Apollo, micro-g, terrestrial analogs
 - **Population:** US/USOS astronaut, astronaut analog, general population
 - **Fall data not quantified:** not a medical condition per se
 - **Incidence, Probability:** assumed all driver conditions are completely independent (no consideration of correlating conditions or prior EVA events)
-

Early Artemis Mission Assumptions (Probability)



- **ONLY lunar surface EVA**
- No lunar transport vehicle (LTV), pressurized rover (PR)
- Generic Human Landing System (HLS)
- Medical diagnostic and treatment resources not considered
- Max back-to-back EVAs =2
- Probabilities do not include preventions nor hazard controls (forward work)

EARLY ARTEMIS DESIGN REFERENCE MISSION (DRM)
(Used for probability calculations)

Two crew members on each EVA:

Artemis 3 EVA 1 (6 hr)

Artemis 3 EVA 2 (6 hr)

Artemis 3 EVA 3 (8 hr)

Artemis 3 EVA 4 (6 hr)

Artemis 3 EVA 5 (1 hr)

https://wiki.jsc.nasa.gov/exploration/index.php/Artemis_3

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Artemis 3 EVA 5 (1 hr)

https://wiki.jsc.nasa.gov/exploration/index.php/Artemis_3

Probabilities associated with early Artemis mission, not individual EVA



Risk by Condition: Continuous Reliance Focus

ICR/ACUTE INJURY SCENARIO (BC- best case; WC – worst case)

PROBABILITY

Very high
(1/200 < P)

Back Sprain/Strain bc; Blisters bc; Dehydration bc; Eye: Extraocular Foreign Body bc; Finger Pain/Sprain/Strain bc; Hand Pain/Sprain/Strain bc; Paresthesias Secondary to EVA bc; Shoulder Sprain/Strain bc; Skin Abrasion bc; Skin Laceration bc

Blisters wc; DCS Secondary to EVA bc; Heat Related Illness bc; Paresthesias Secondary to EVA wc; Skin Abrasion wc

High
(1/1000 < P ≤ 1/200)

Ankle Sprain/Strain bc; Acute Stress Response bc; Elbow Sprain/Strain bc; Hip Sprain/Strain bc; Knee Sprain/Strain bc; Neck Sprain/Strain bc; Wrist Sprain/Strain bc

Eye: Extraocular Foreign Body wc; Finger Pain/Sprain/Strain wc; Hand Pain/Sprain/Strain wc

Moderate
(1/10,000 < P ≤ 1/1000)

Finger Dislocation bc; Lower Extremity Fracture (stress) bc; Nose Bleed (not Space Adaptation) bc

Back Sprain/Strain wc

Low
(1/100,000 < P ≤ 1/10,000)

Dental: Tooth Fracture bc; Wrist Fracture bc

Dental: Avulsion (Tooth Loss) bc; Elbow Sprain/Strain wc; Herniated Disc bc; Hip Sprain/Strain wc; Knee Sprain/Strain wc; Shoulder Sprain/Strain wc; Wrist Sprain/Strain wc

Ankle Fracture wc; Ankle Sprain/Strain wc; Acute Stress Response wc; Lower Extremity Fracture (pathological/traumatic) bc

Very low
(P ≤ 1/100,000)

Acute Neurapraxia bc; Head Injury bc

Acute Neurapraxia wc; Ankle Fracture bc; Dental: Tooth Fracture wc; Elbow Dislocation bc; Lumbar Spine Fracture bc; Nose Bleed (not Space Adaptation) wc; Shoulder Dislocation bc

Head Injury wc; Herniated Disc wc; Hip/Proximal Femur Fracture bc

Risk Assessment: Mapping and Criteria



LIKELIHOOD	5	10	16	20	23	25
	4	7	13	18	22	24
	3	4	9	15	19	21
	2	2	6	11	14	17
	1	1	3	5	8	12
		1	2	3	4	5
	CONSEQUENCE					

Safety Consequence	Criteria
1	Minor injury not requiring first aid treatment, minor discomfort
2	Injury requiring first aid treatment, moderate discomfort
3	Terrestrial injury or occupational illness requiring medical treatment
4	In-flight injury or illness that requires medical intervention from a second crewmember and/or Flight Surgeon and is not treatable by first aid alone; ground personnel occupational injury or illness requiring definitive/specialty hospital/medical treatment
5	Loss of crew life (LOC) or permanent, disabling injury

Continuous Reliance 5 x 5



ICR/ACUTE INJURY CONDITIONS (BC- best case; WC – worst case)

Mapping Mitigation Risk for Crew on the Lunar Surface

LIKELIHOOD

<p>5-Very high (1/200 < P)</p> <p>4-High (1/1000 < P ≤ 1/200)</p> <p>3-Moderate (1/10,000 < P ≤ 1/1000)</p> <p>2-Low (1/100,000 < P ≤ 1/10,000)</p> <p>1-Very low (P ≤ 1/100,000)</p>	10	Heat Related Illness bc 16	DCS bc 20	Blisters wc; Paresthesias wc; Skin Abrasion wc 23	25
	7			Eye: Extraocular Foreign Body wc 22	24
	4				Back Sprain/Strain wc 21
	2			Dental: Avulsion (Tooth Loss) bc; Knee Sprain/Strain wc; Herniated Disc bc 14	Ankle Fracture wc; Ankle Sprain/Strain wc; Acute Stress Response wc ; Lower Extremity Fracture (pathological/traumatic) bc; Hip Sprain/Strain wc 17
	1			Ankle Fracture bc; Lumbar Spine Fracture bc; Dental: Tooth Fracture wc; Elbow Dislocation bc; Shoulder Dislocation bc; Nose Bleed (not Space Adaptation) wc 8	Head Injury wc ; Herniated Disc wc; Hip/Proximal Femur Fracture bc; Acute Neurapraxia wc 12
	1	2	3	4	5
				CONSEQUENCE	

Continuous Reliance 5 x 5: Catastrophic Focus



ICR/ACUTE INJURY CONDITIONS (BC- best case; WC – worst case)

Mapping Mitigation Risk for Crew on the Lunar Surface

LIKELIHOOD

<p>5-Very high (1/200 < P)</p> <p>4-High (1/1000 < P ≤ 1/200)</p> <p>3-Moderate (1/10,000 < P ≤ 1/1000)</p> <p>2-Low (1/100,000 < P ≤ 1/10,000)</p> <p>1-Very low (P ≤ 1/100,000)</p>	10	Heat Related Illness bc 16	DCS bc 20	Blisters wc; Paresthesias wc; Skin Abrasion wc 23	25
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CONSEQUENCE

Ground Rules and Assumptions – Mitigation Assessment



1. Considered worst of worst case for assessment- there are no data to back these up!
2. Considered each Driver condition as independent event
3. Prevention – lowering the likelihood of ever getting to the scenario where the event occurs (Driver condition)
4. Mitigation – event has occurred; we are now trying to reduce the consequence and/or likelihood of LOC
5. Mitigation device performs as designed or capability works as planned for consequence scoring
6. Mitigation may not lead to a full or complete medical or mission resolution for a given event
7. Single fault failure captured for each mitigation
8. Transport device could provide additional stability and might be a preventative falls measure but not taking credit for it on the preventions map assessment
9. **Only assessed for Artemis III, but should be thinking towards Artemis V+**

Mitigations to Catastrophic Drivers



Catastrophic Event	Mitigations								
	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work Hardening
Back Sprain/Strain (WC)	x								
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

Acronyms	
BC	Best Case
WC	Worst Case

x box-box change

*EVA Tool design not accounted for in other columns

Mitigations to Catastrophic Drivers



Catastrophic Event \ Mitigations	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work Hardening
	Back Sprain/Strain (WC)	x							
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

Acronyms	
BC	Best Case
WC	Worst Case

x box-box change

*EVA Tool design not accounted for in other columns

Mitigation Analysis: Process Overview (box-box change)



Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

LIKELIHOOD

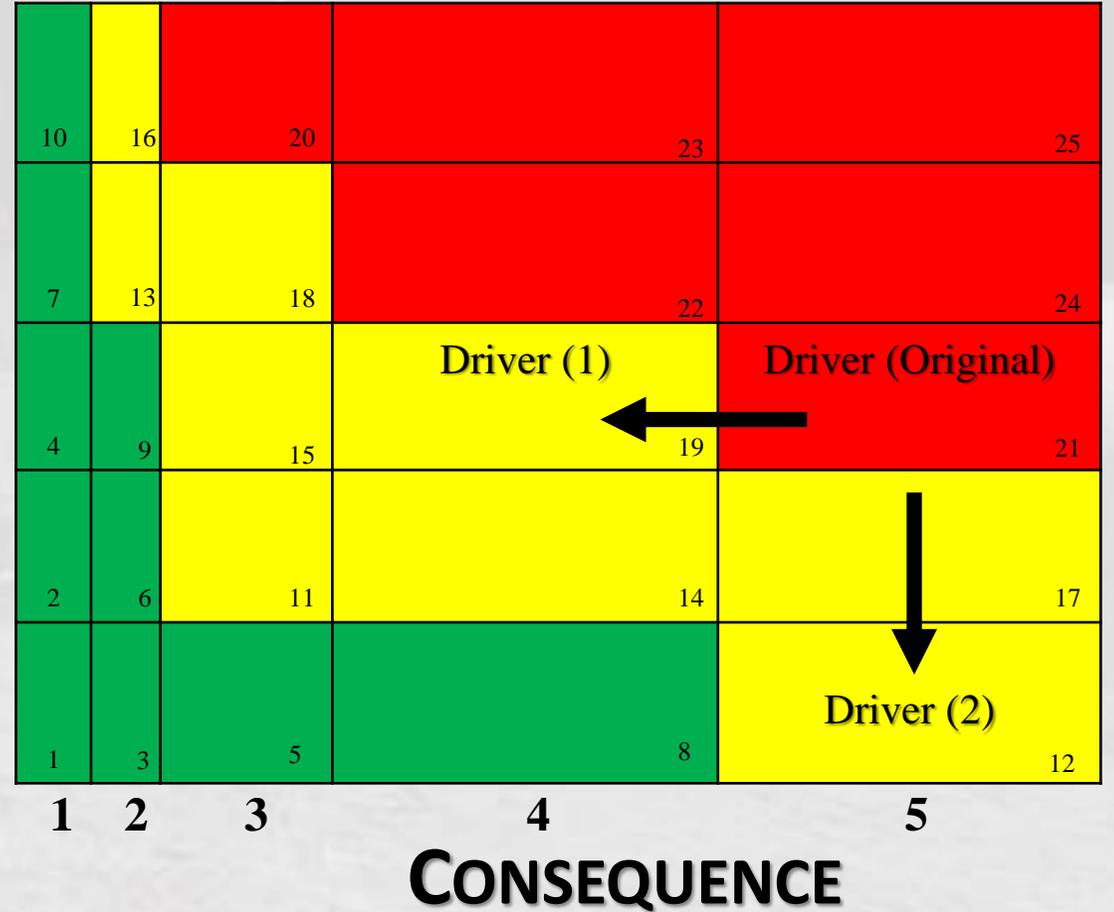
5-Very high
($1/200 < P$)

4-High
($1/1000 < P \leq 1/200$)

3-Moderate
($1/10,000 < P \leq 1/1000$)

2-Low
($1/100,000 < P \leq 1/10,000$)

1-Very low
($P \leq 1/100,000$)



Mitigation Analysis: Process Overview (box-box change)



Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

Crew Mission Assurance Risk (Risk 1):
 3x4: provided safe crew return,
 protected affected crew

LIKELIHOOD

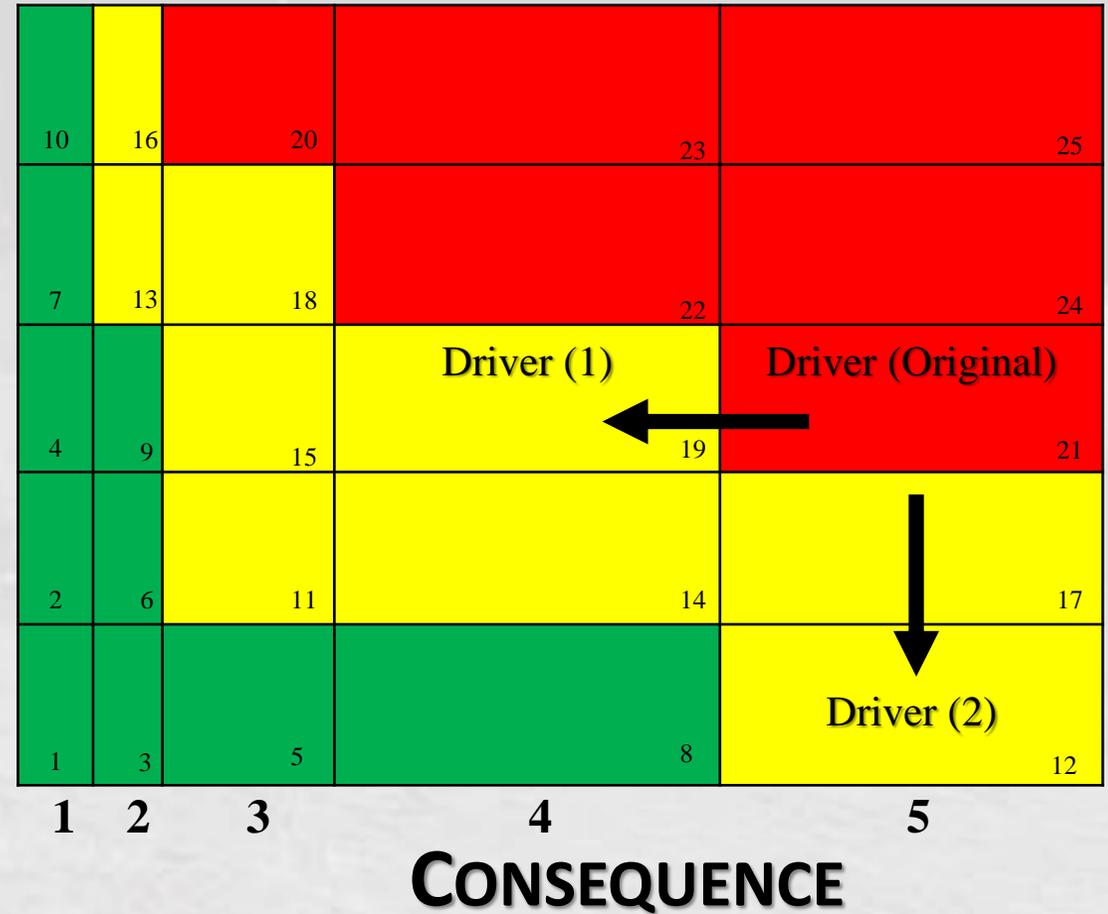
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4-High
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3-Moderate
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2-Low
 ($1/100,000 < P \leq 1/10,000$)

1-Very low
 ($P \leq 1/100,000$)



Mitigation Analysis: Process Overview (box-box change)



Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

Crew Mission Assurance Risk (Risk 1):
3x4: provided safe crew return, protected affected crew

Crew Safety Risk (Risk 2):
1x5: capability mitigation- didn't remove all potential for permanent disabling injury

LIKELIHOOD

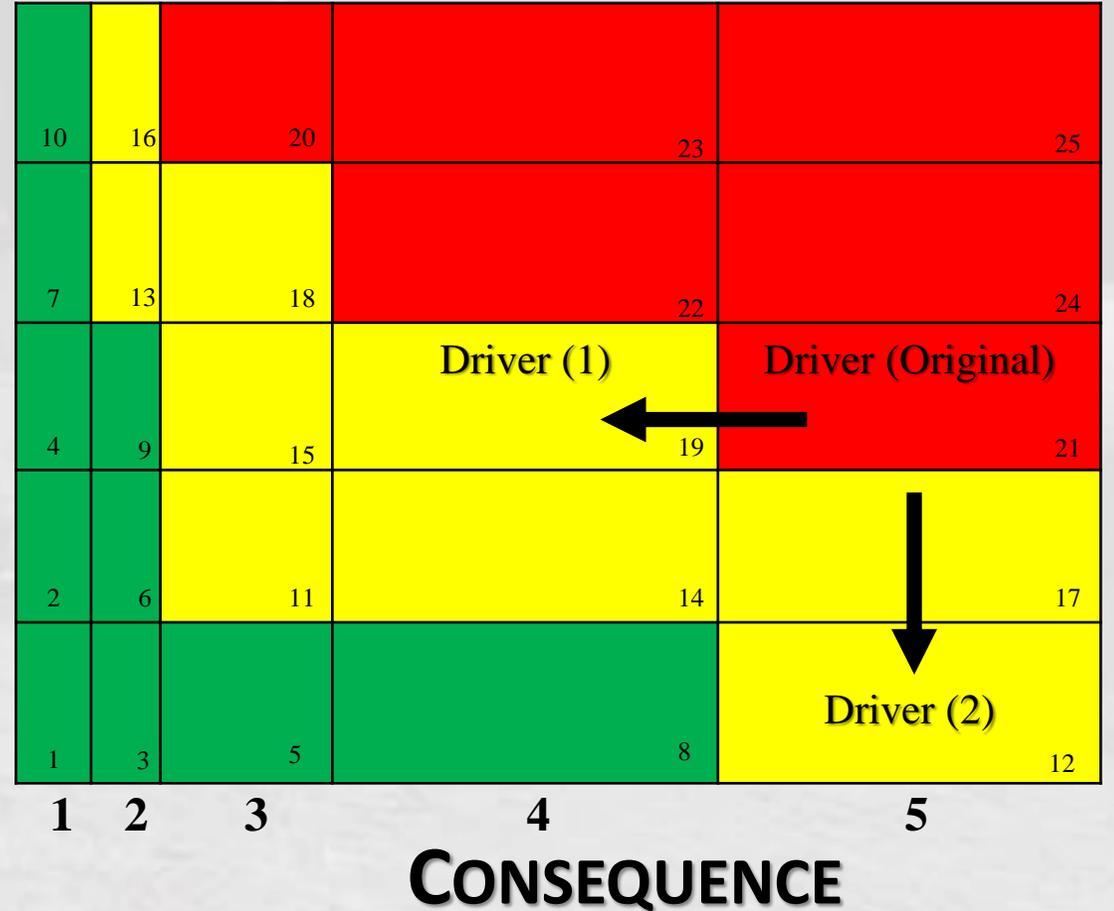
5-Very high
($1/200 < P$)

4-High
($1/1000 < P \leq 1/200$)

3-Moderate
($1/10,000 < P \leq 1/1000$)

2-Low
($1/100,000 < P \leq 1/10,000$)

1-Very low
($P \leq 1/100,000$)



Mitigation Analysis: Process Overview (in box change)



Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

Crew Mission Assurance Risk (Risk 1):
 1x4: provided safe crew return, protected affected crew

Crew Safety Risk (Risk 2):
 1x5: capability mitigation- didn't remove potential for permanent disabling injury but decreased the severity

LIKELIHOOD

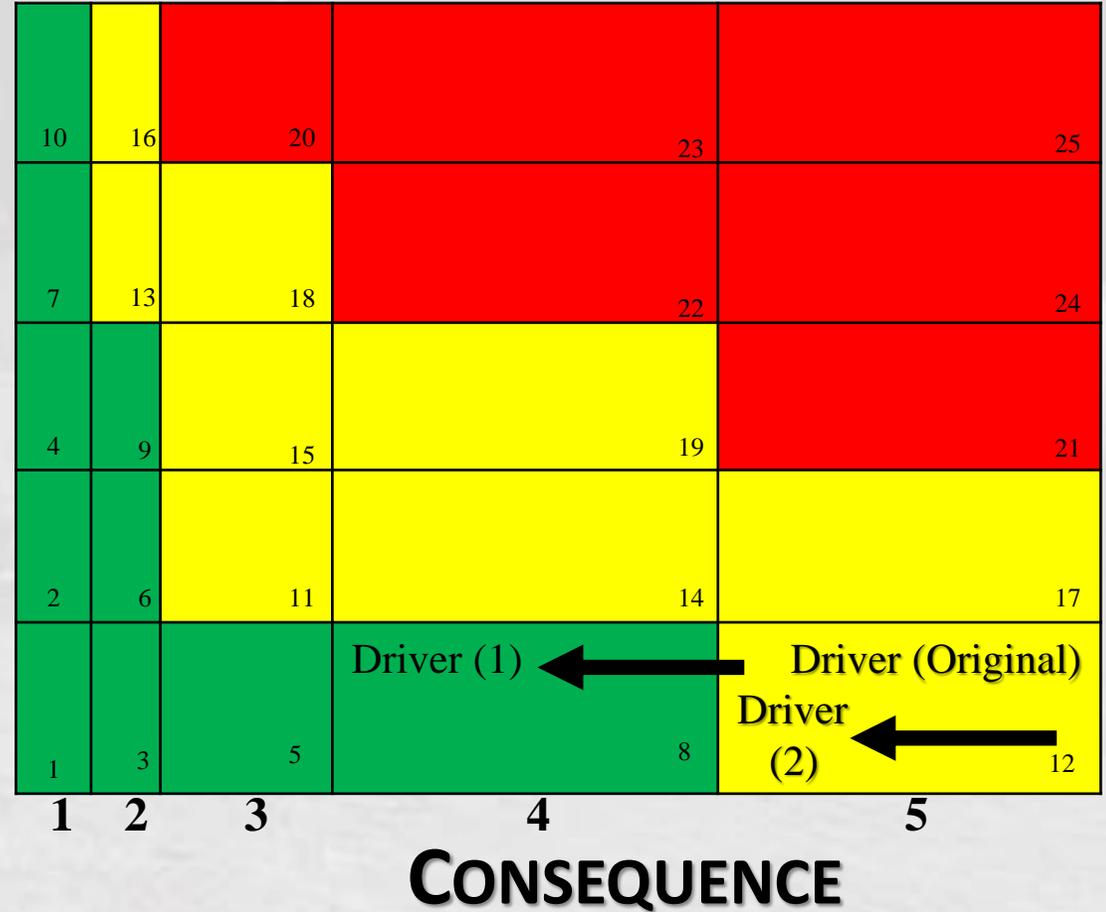
5-Very high
($1/200 < P$)

4-High
($1/1000 < P \leq 1/200$)

3-Moderate
($1/10,000 < P \leq 1/1000$)

2-Low
($1/100,000 < P \leq 1/10,000$)

1-Very low
($P \leq 1/100,000$)



Mitigation: Wheeled Transport Device



Capability: wheeled transport

- Mitigation (consequence)
 - Decrease return timing
 - Decrease progression of injury (protection)
 - Decrease rescuer exertion during return to lander

Driver (wc)	LxC old	L	C	LxC new	Decrease injury progression	Moves risk from LOC	Permanent disabling injury still possible
Back sp/st	21	3	4	19	Possible	Yes	Yes
Acute Stress	17	2	4	14	No	Yes	No
Ankle sp/st	17	2	4	14	Possible	Yes	No
LE Fx	17	2	4	14	Possible	Yes	Yes
Ankle Fx	17	2	5	17	Possible	Yes	Yes
Hip sp/st	17	2	4	14	Possible	Yes	No
Head Injury	12	1	5	12	Possible	Shift	Yes
Hip/pr fm Fx	12	1	5	12	Possible	Yes	Yes
Hern. disc	12	1	5	12	Possible	Shift	Yes
Acute neur.	12	1	4	8	Possible	Yes	Yes

Crew Safety Risk after mitigation:
1x5: Transport, injury progression

Mitigation: Walking Assist Devices



Capability: dual purposed tools, push-cart, staff

- Mitigation (consequence)
 - Decrease return timing
 - Decrease progression of injury (protection)
 - Provide rescuer stability during assisted walkback

Crew Safety Risk after mitigation:

1x5: Device, injury progression, may be insufficient; *2x5

Driver (wc)	LxC old	L	C	LxC new	Decrease injury progression	Moves risk from LOC	Permanent disabling injury still possible
Back sp/st*	21	3	5	21	No	Shift	Yes
Acute Stress	17	2	5	17	No	No	n/a
Ankle sp/st	17	2	4	14	Possible	Yes	No
LE Fx	17	2	4	14	Possible	Yes	No
Ankle Fx	17	2	5	17	Possible	Yes	Yes
Hip sp/st	17	2	4	14	Possible	Yes	No
Head Injury	12	1	5	12	No	No	n/a
Hip/pr fm Fx	12	1	5	12	No	Shift	Yes
Hern. disc	12	1	5	12	No	Shift	Yes
Acute neur.	12	1	4	8	Possible	Yes	Yes

Mitigation: Crew Assistance Only



Capability: self or rescuer

- Mitigation (consequence)
 - Decrease return timing
 - Decrease progression of injury (protection)
 - Provide rescuer stability during assisted walk back

Crew Safety Risk after mitigation:
1x5: Rescuer, injury progression, may be insufficient; *2x5

Driver (wc)	LxC old	L	C	LxC new	Decrease injury progression	Moves risk from LOC	Permanent disabling injury still possible
Back sp/st*	21	3	5	21	No	Shift	Yes
Acute Stress	17	2	5	17	No	No	n/a
Ankle sp/st	17	2	4	14	Possible	Yes	No
LE Fx	17	2	4	14	Possible	Yes	No
Ankle Fx	17	2	5	17	Possible	Yes	Yes
Hip sp/st	17	2	4	14	Possible	Yes	No
Head Injury	12	1	5	12	No	No	n/a
Hip/pr fm Fx	12	1	5	12	No	Shift	Yes
Hern. disc	12	1	5	12	No	Shift	Yes
Acute neur.	12	1	4	8	Possible	Yes	Yes

Summary/Next Step Recommendations



Mitigations Catastrophic Event	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work Hardening
	Back Sprain/Strain (WC)	x							
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

*EVA Tool design not accounted for in other columns

- Feasibility testing/proof of concept:
 - Self rescue
 - Rescuer assist
- Feasibility assessment:
 - Dual purpose tools for walking assistance/fall recovery with and without rescuer assist
 - Continued evaluation of human-powered transport system
- Assess how LXC risk changes for Artemis V+

Recommendations: A Look at Prevention



Preventions/ Mitigations	Catastrophic Event	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work hardening
		Back Sprain/Strain (WC)	x							
Acute Stress Response (WC)	x									
Ankle Sprain/Strain (WC)	x	x	x							
Lower Extremity Fracture (BC)	x	x	x							
Ankle Fracture (WC)										
Hip Sprain/Strain (WC)	x	x	x							
Head Injury (WC)										
Hip/Proximal Femur Fracture (BC)										
Herniated Disc (WC)										
Acute Neurapraxia (WC)	x	x	x							

Acronyms	
BC	Best Case
PB	Prebreathe
Tx	Treatment
WC	Worst Case

- Potential Change in Likelihood
- Potential Change in Consequence
- x** box-box change

*EVA Tool design not accounted for in other columns



Thank you!

Questions?
