ASCE EARTH & SPACE 2010

Exploration and Utilization of Extraterrestrial Bodies

Symposium 3

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Risk Assessment Visualization Study for Lunar Outpost Landing Zone Surface Preparation

Space Enterprise Council Space Transportation Working Group

Lunar Surface Systems Risk Study

Risk #11

<u>Inadequate Landing Zone Surface Preparation</u>

XArc

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Architecture for New Worlds®

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Scenario 4.2.1.20 – Emplaced Surface Element Assets at ISC

Premises:

- Scenario 4.2.1.20 is the reference Outpost build-up sequence for surface preparations.
- The Risk 11 premise occurs prior to ISC since first need date for landing pad and regolith protective berm is prior to arrival of the ISC 14 day mission in FY21.

Methodology:

- Created illustrated sequencing of the Outpost buildup to ISC with pictorials of mission “snapshots” to play out the operational scenario and help visualize the sequence of risks along the way to how the prepared landing zone gets to its ready state in time for the ISC mission.
- Identified and ranked risks according to Risk Matrix Priority Scoring using CxP criteria for risk consequence scoring.
- Identified risk mitigation approaches.

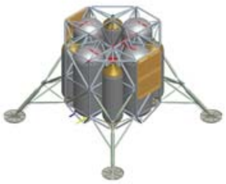
Assumptions:

- Test Flight landing zone is in vicinity of future Outpost operations.
- Altair for Mission 4 ISC is Extended Stay Sortie configuration.

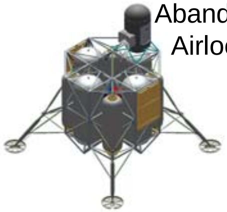
Caveats:

- Form factor of landing pad berm geometry illustrated in the pictorials of the Outpost buildup sequence scenario is for reference only and is not intended to convey a berm design solution.

Test Flight Lander

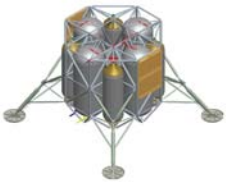


Sortie Lander



Abandoned Airlock 1

Cargo Lander



Sortie Extended Stay Lander

Abandoned Airlock 2

Sortie Mission Chassis Rover

Small Pressurized Rover 1

Small Pressurized Rover 2

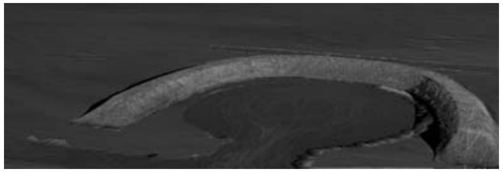
Crew Mobility Chassis w/ excavation blade

Portable Utility Pallet 1

Portable Utility Pallet 2

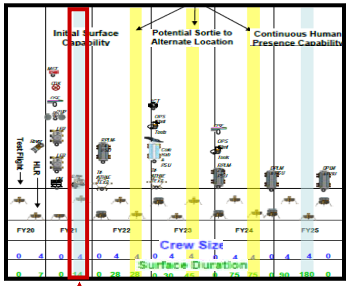
Lunar Surface Manipulator System

Chassis A + Robot Assistant



Landing/Launch Pad

Scenario 4.2.1.20



ISC Phase

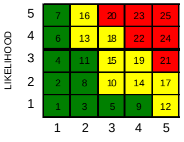
Risk Statement

Risk #11 - Inadequate Landing Zone Surface Preparation

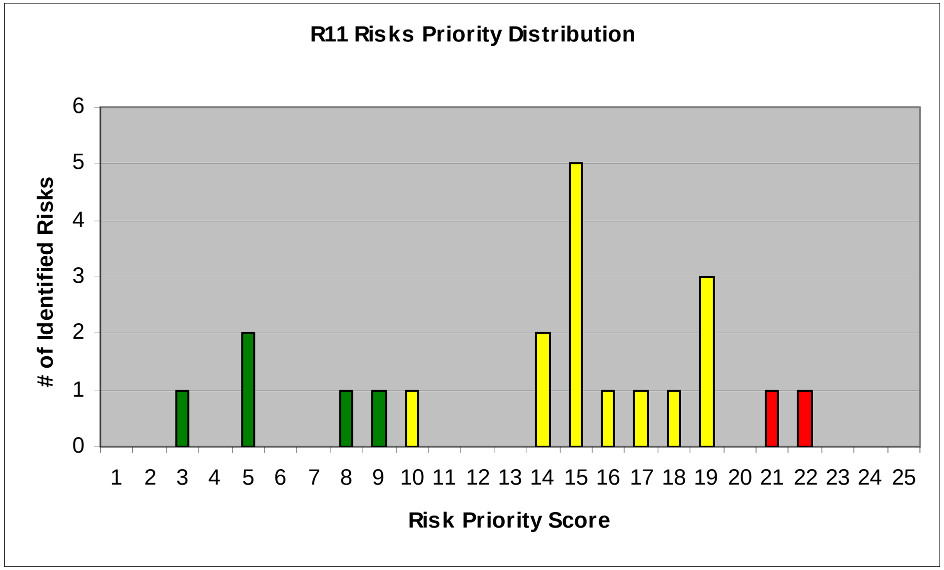
If the excavator system, CMC w/ blade or other, fails to build the desired regolith protective berm, there is a possibility the emplaced surface assets could be damaged by debris and ejecta from the arrival of the next lander or departure of the ascent module.

21 Mission Ops Risks to ISC Landing Zone Surface Preparation Identified.

- 2 Scored Priority Red
- 14 Scored Priority Yellow
- 5 Scored Priority Green



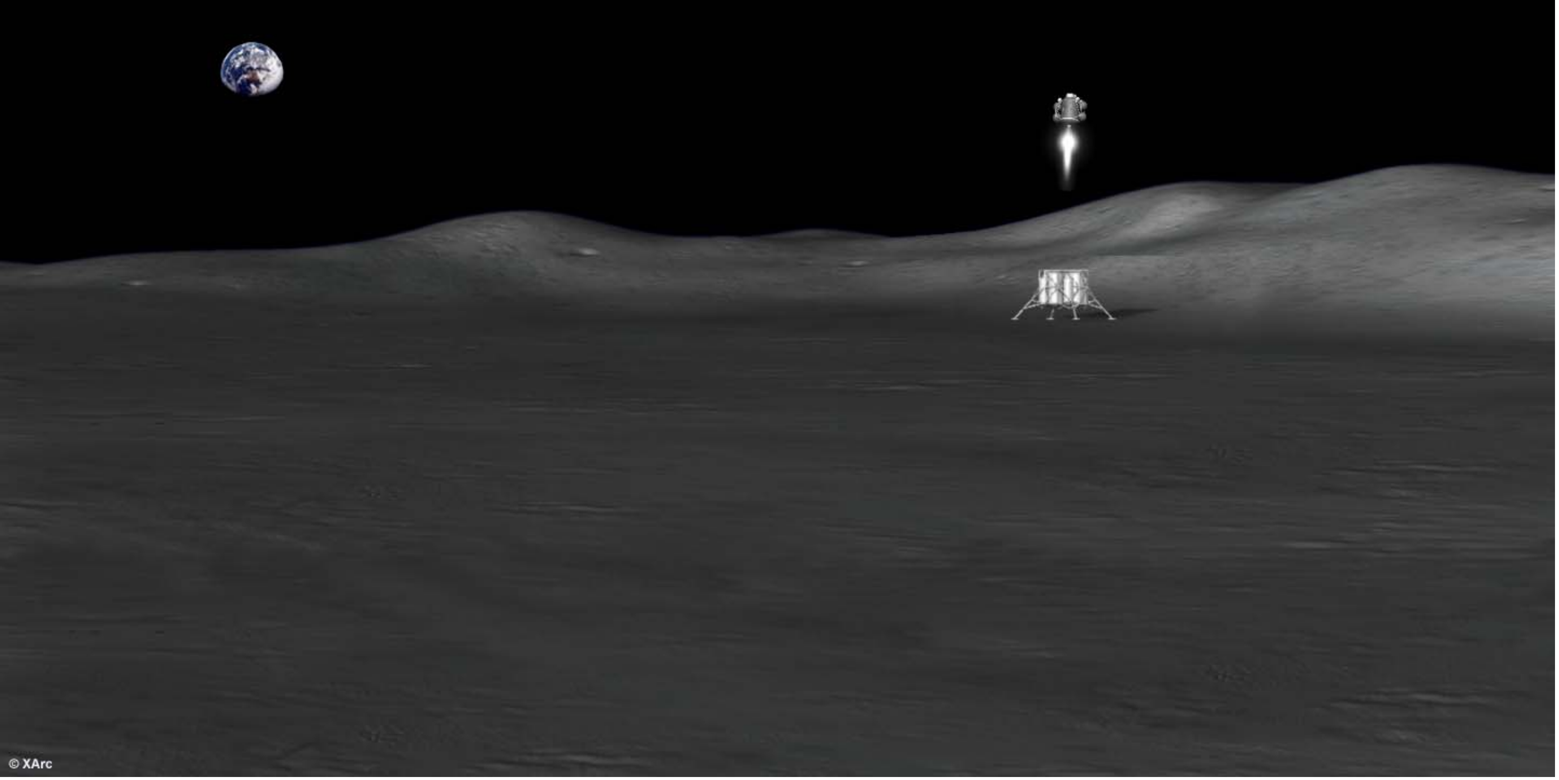
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5
	CONSEQUENCE				

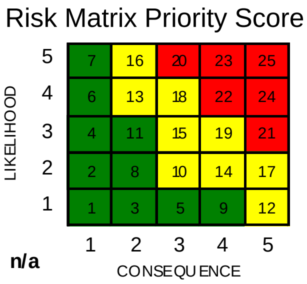


Risk #	Risk Title
R11-07	Failure to optimize landing zone separations to protect surface assets in event of powered descent abort
R11-15	Berm design form factor not optimized for sufficient protection
R11-04	Lander fuel cells fail to provide surface power for off-loading CMC excavator
R11-06	Off-loading collision or damage to excavator
R11-17	Ejecta discharge from top layer of berm
R11-13	Downtime from numerous recharging events causes scheduling inefficiency
R11-19	CMC not configured for tele-robotic pre-emplacement of navigation aids at completion of ISC landing pad

Top Five Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Description
R11-07	**Failure to optimize landing zone separations to protect surface assets in event of powered descent abort** Given there is an operational correlation between location of the Mission 3 Cargo Altair landing zone and location of the landing pad for Mission 4 ISC, there is a possibility the distance between the two landing zones will not have sufficient separation to avoid subsequent crewed landing plume ejecta debris damage to Cargo Altair cargo elements in event of protective berm failure, or CMC excavator system is not successfully deployed, or fails to construct berm.
R11-15	**Berm design form factor not optimized for sufficient protection** Given the complexity of interacting forces between the lunar environment, lunar surface features, and the Altair propulsion system causing debris and ejecta during landing and launch, there is a possibility of not achieving an optimized geometry (height, shape, mass, deflection angle) for the protective berm's form factor, causing it to be over or under designed for effective protection.
R11-04	**Lander fuel cells fail to provide surface power for off-loading CMC excavator** Given the lander fuel cells are assumed to provide power on the surface to support the offloading of the CMC prior to deploying the PUP solar array, there is a possibility the assumption is erroneous in that the lander fuel cell design has not been sized to accomplish this operation.
R11-06	**Off-loading collision or damage to excavator** Given the Uncrewed Cargo Altair is tele-robotically operated, there is a possibility offloading collision or damage to the CMC excavator system can occur.
R11-17	**Ejecta discharge from top layer of berm** Given the top layer of the regolith protective berm may be relatively uncompacted, there is a possibility the outer skin of the berm will be a source for discharging ejecta.





Risk Matrix Priority Score

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

CONSEQUENCE

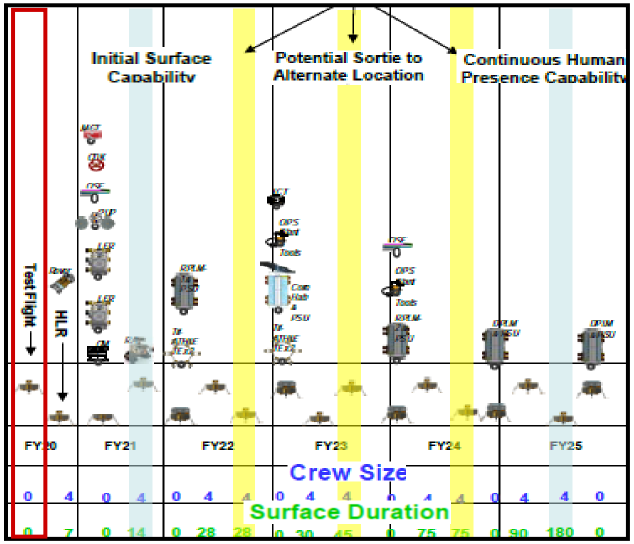
n/a

Figure 1

Mission 1 - Test Flight

Uncrewed Test Flight of Altair Lander with Ascent Module

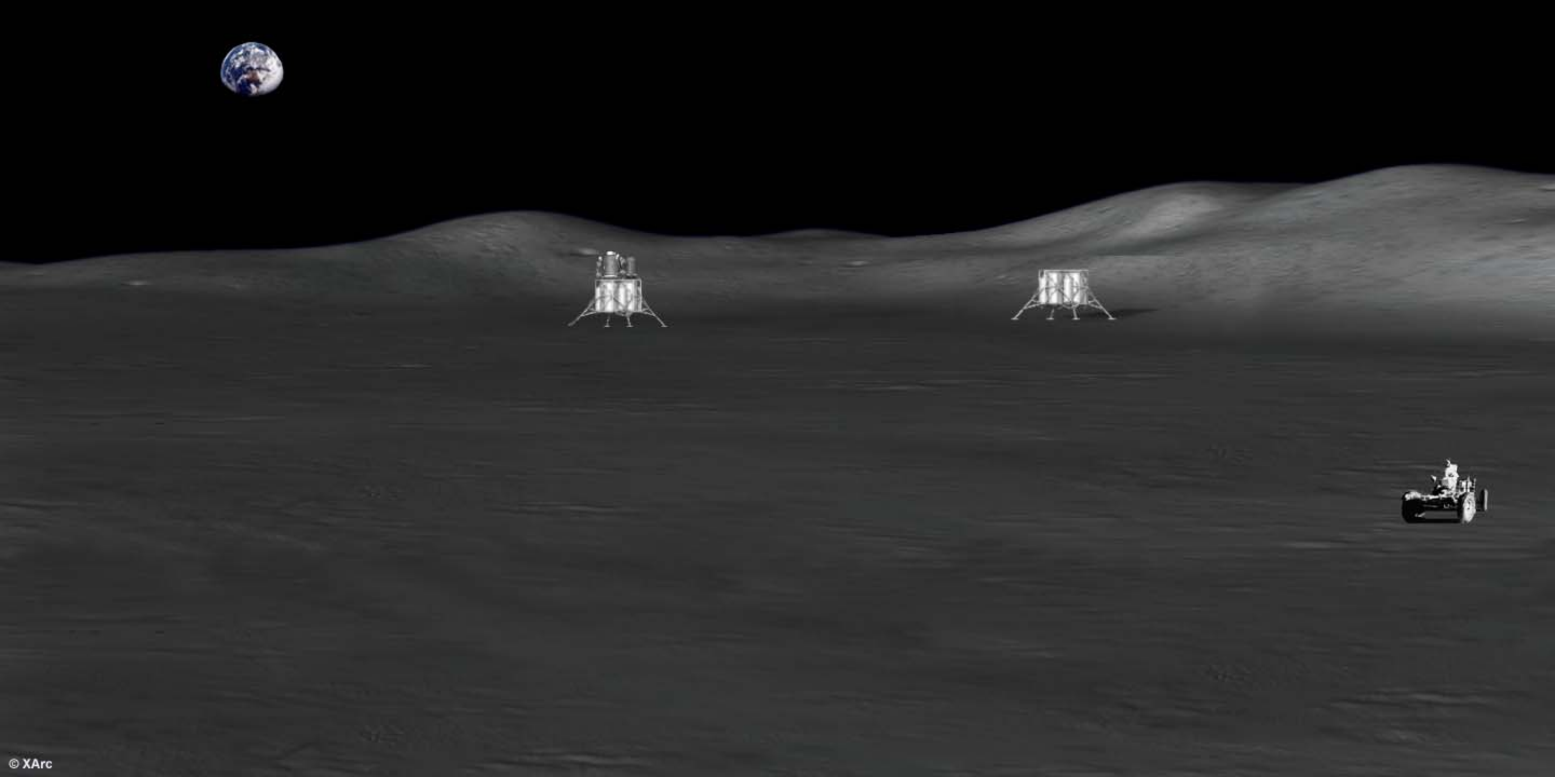
- ConOps shown is Ascent Module departure.
- Test Flight landing zone is in vicinity of future Outpost operations. Assumption is lander residual consumables may be needed for excavator system and/or other future Outpost operations.

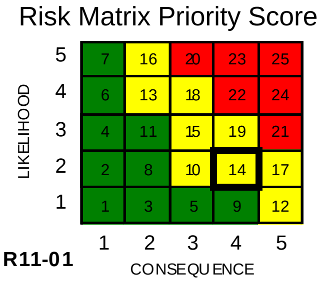


Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
	n/a - None identified for Test Flight





Risk Matrix Priority Score

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

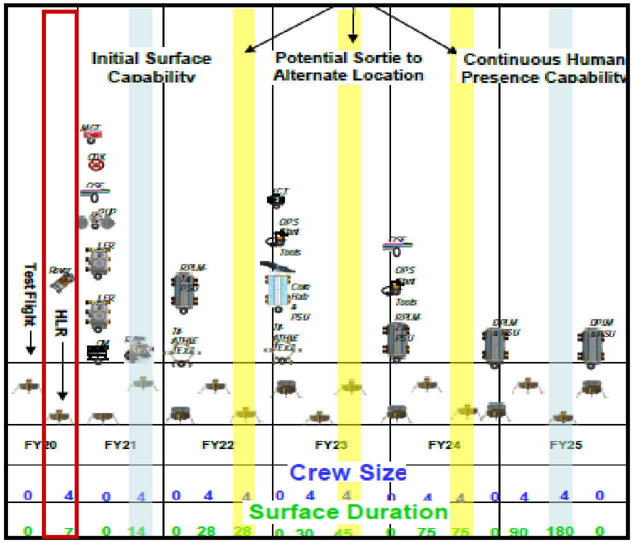
R11-01 CONSEQUENCE

Figure 2

First Human Lunar Return (HLR)

- ConOps shown is Altair Sortie configuration in proximity to Test Flight landing zone; crew conducting exploration with Sortie Mission Chassis (SMC) rover.
- Crew performs recon and emplacement of navigation aids for cargo Mission 3 landing zone.
- Crew conducts site survey verification for location of Mission 4 landing pad and regolith protective berm, (three landing pads are planned).

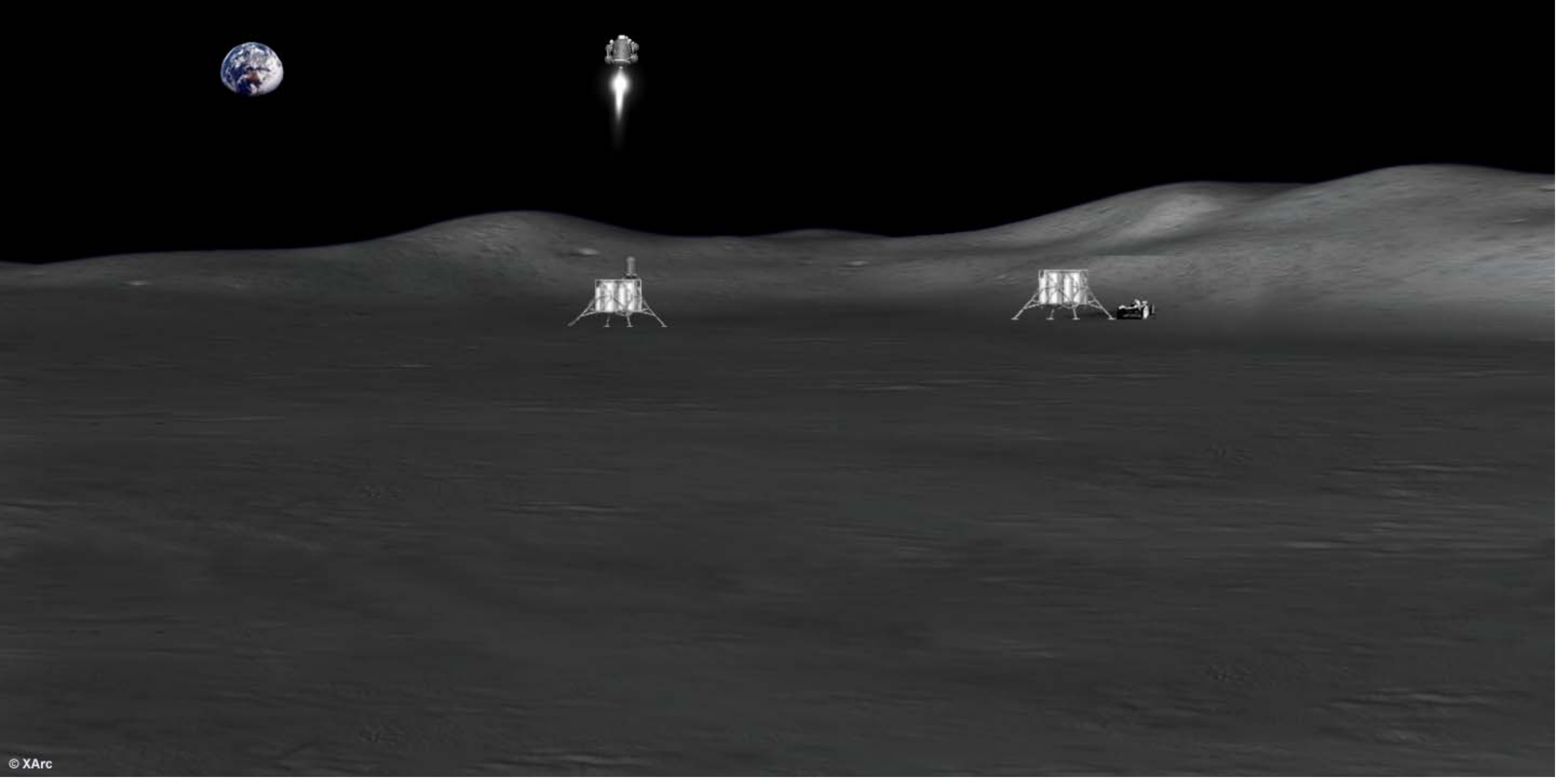
Mission 2 - Lunar Sortie Crew DRM



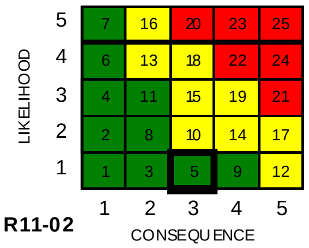
Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-01	Lack of scientific data to properly characterize lunar surface environment at selected landing and excavation sites



Risk Matrix Priority Score



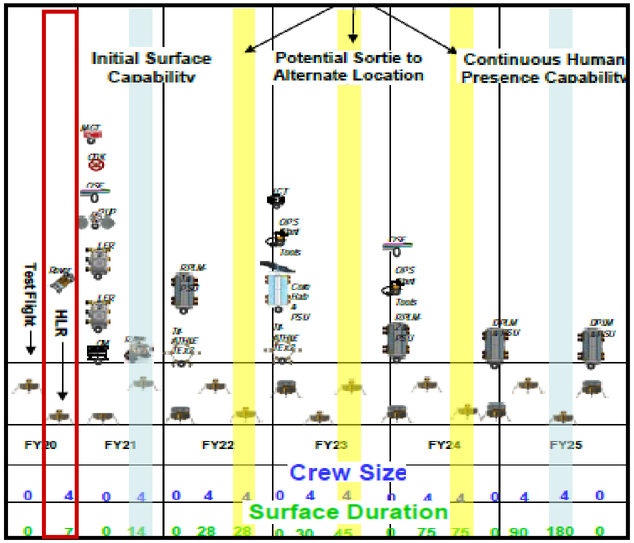
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12
R11-02	1	2	3	4	5
	CONSEQUENCE				

Figure 3

7 Day HLR Mission End

- ConOps shown is crew departure in Ascent Module.
- Airlock and SMC rover abandoned.
- SMC parked behind Test Flight Descent Module to minimize damage from plume ejecta debris.

Mission 2 - Lunar Sortie Crew DRM



Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-02	Incongruities in site planning data

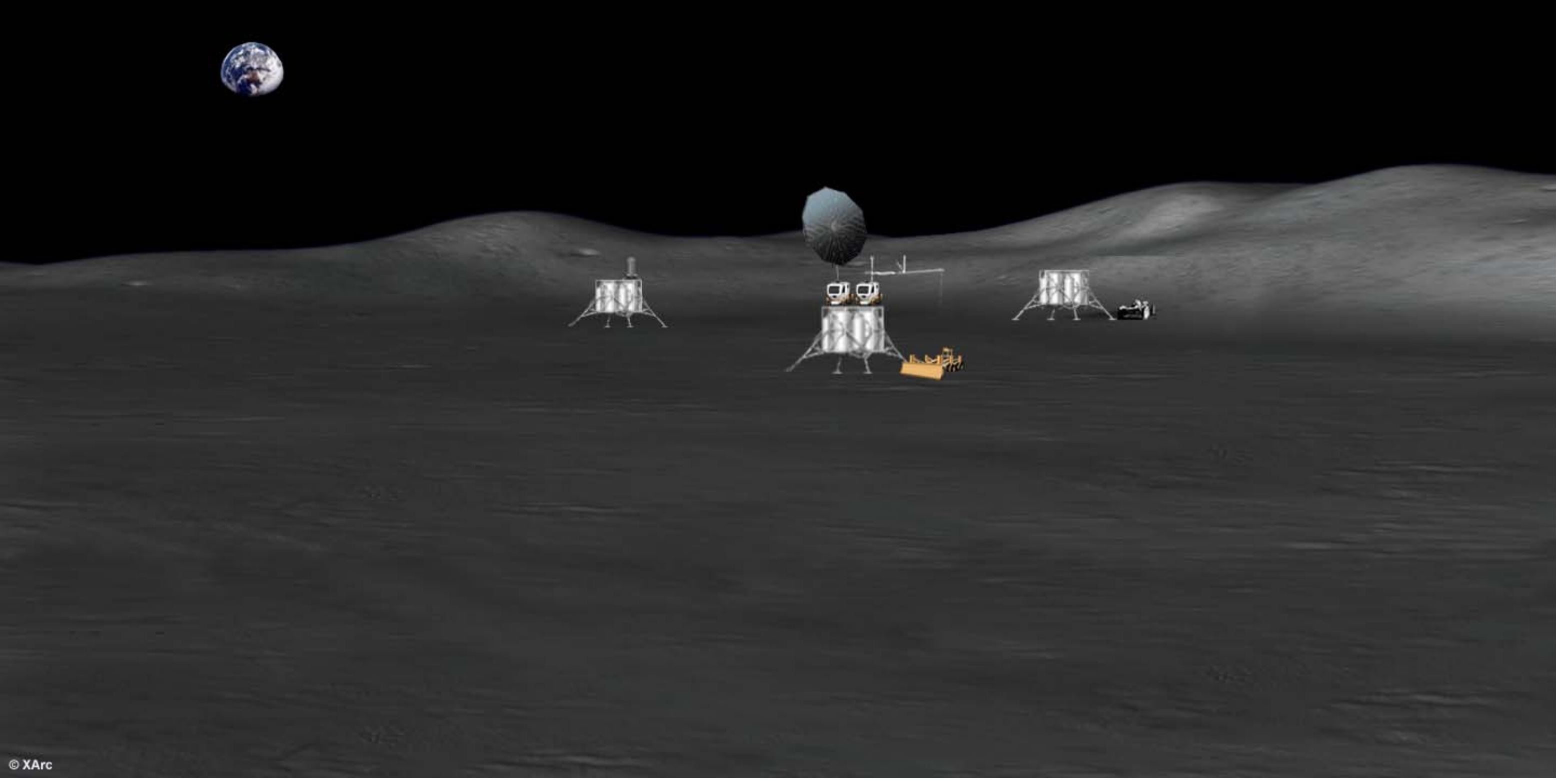
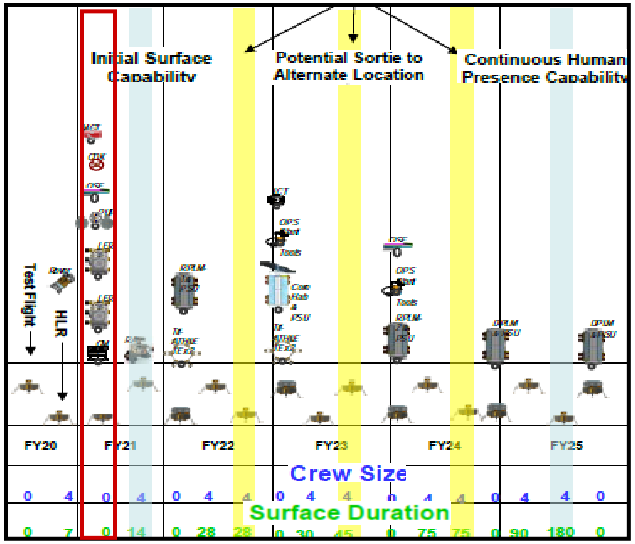


Figure 4

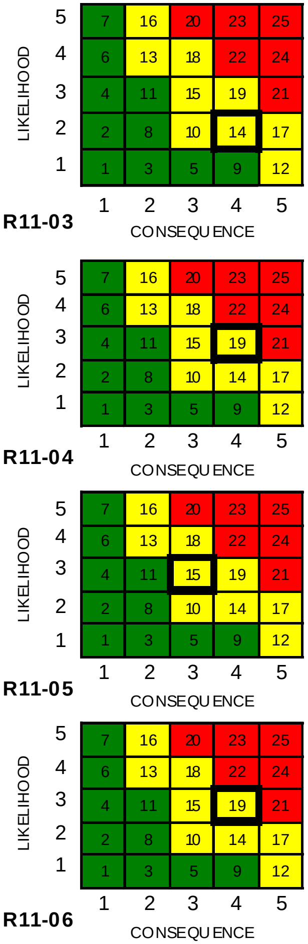
Initial Mobility Delivery

- ConOps shown is Crew Mobility Chassis (CMC) with attached excavation blade and Chassis Driving Kit (CDC) offloaded using Lunar Surface Manipulator System (LSMS).
- Deployed PUP solar array, (PUP solar array deployed after CMC is offloaded).
- CMC stationed at lander base, testing power recharge station.
- Small Pressurized Rovers (SPR) and associated PUP cargo elements are assumed crew-supervised EVA offloaded when crew arrives in Mission 4.

Mission 3 - Uncrewed Cargo Altair DRM



Scenario 4.2.1.20



Risk Matrix Priority Score

R11-03

LIKELIHOOD					
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4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	**14**	17
1	1	3	5	9	12
CONSEQUENCE	1	2	3	4	5

R11-04

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

R11-05

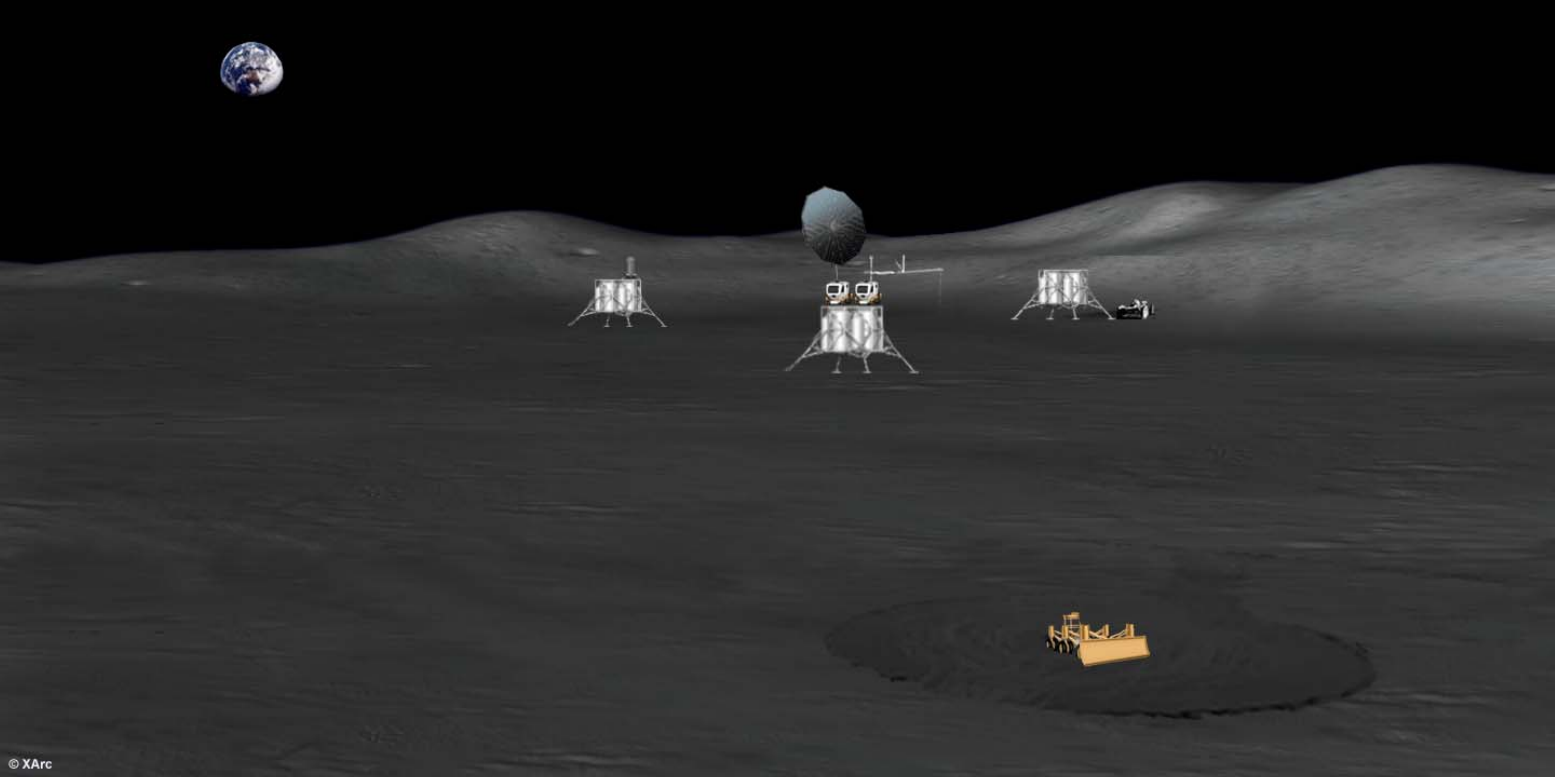
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	**15**	19	21
2	2	8	10	14	17
1	1	3	5	9	12
CONSEQUENCE	1	2	3	4	5

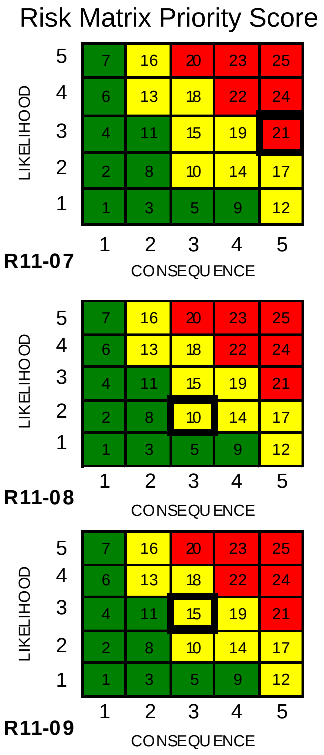
R11-06

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

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-03	Comm link failure for tele-robotic ops
R11-04	Lander fuel cells fail to provide surface power for off-loading CMC excavator
R11-05	Final landing orientation precludes proper orientation of Solar panel array
R11-06	Off-loading collision or damage to excavator


© XArc


Risk Matrix Priority Score

R11-07

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

CONSEQUENCE

R11-08

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

CONSEQUENCE

R11-09

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

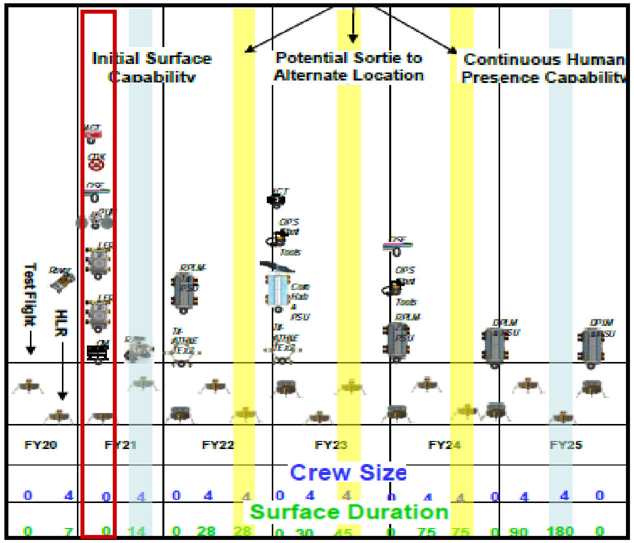
CONSEQUENCE

Figure 5

Mission 3 Ops Landing Pad Excavation Phase Begins

- ConOps shown is CMC tele-robotically preparing landing zone for next mission.

Mission 3 - Outpost Remote Operations DRM



Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-07	Failure to optimize landing zone separations to protect surface assets in event of Altair powered descent abort
R11-08	Dust ejecta from excavation or solar wind plasma interaction near the lunar surface contaminating solar array
R11-09	Failure to optimize landing zone separation to minimize traverse distance to Altair CMC recharge station

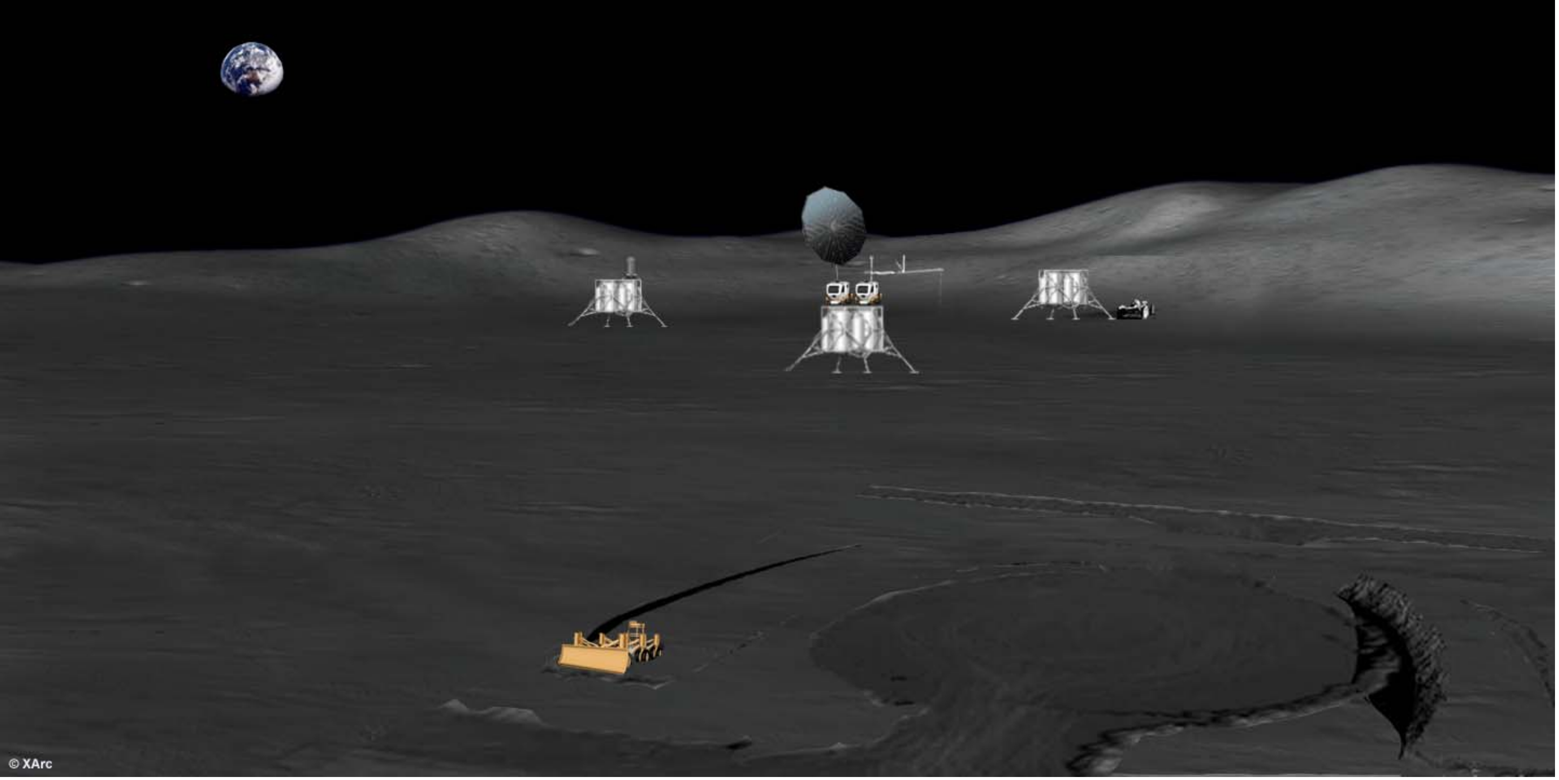
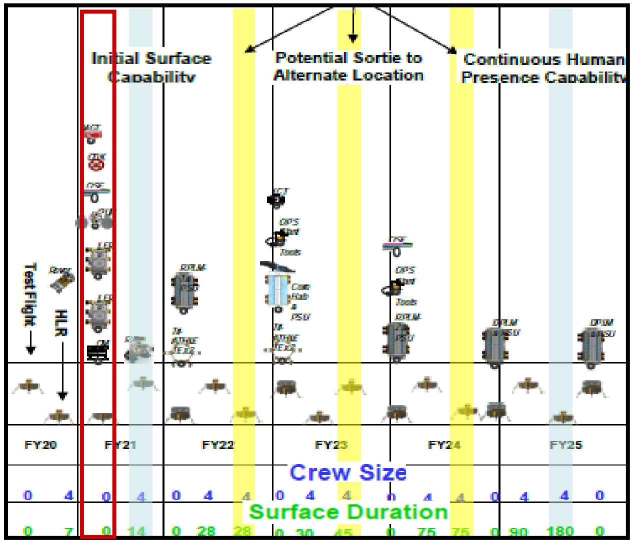


Figure 6

Mission 3 Ops Berm Excavation

- ConOps shown is CMC tele-robotically constructing protective regolith berm around landing zone.

Mission 3 - Outpost Remote Operations DRM

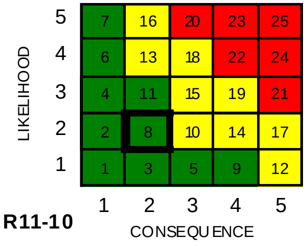


Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-10	Loss of video surveillance from lander vantage point compromises situational awareness for tele-operations
R11-11	Human error due to improperly designed HCI / GUI for tele-operator
R11-12	CMC excavator system reliability
R11-13	Downtime from numerous recharging events causes scheduling inefficiency

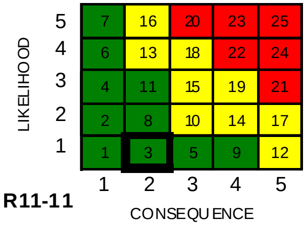
Risk Matrix Priority Score



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

CONSEQUENCE

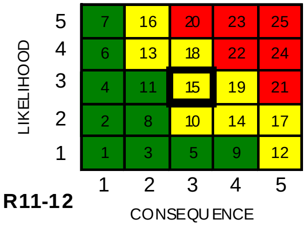
R11-10



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

CONSEQUENCE

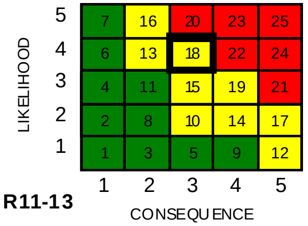
R11-11



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

CONSEQUENCE

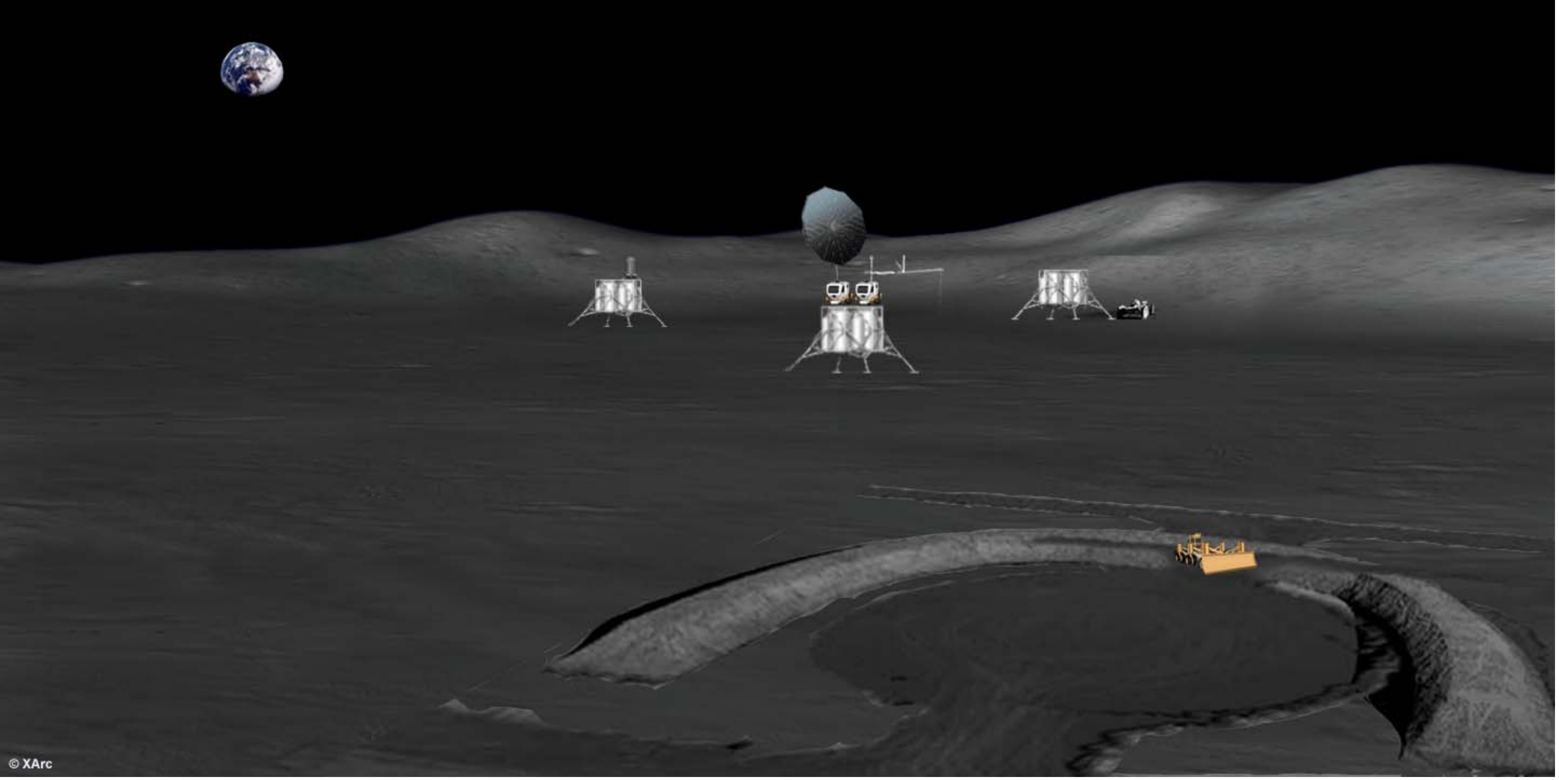
R11-12



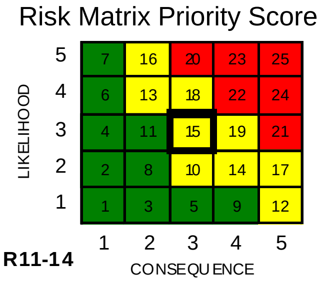
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	**18**	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

CONSEQUENCE

R11-13



Risk Matrix Priority Score



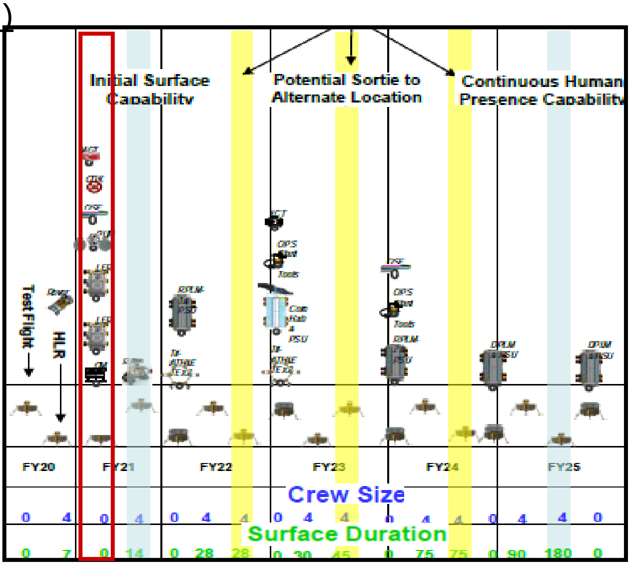
LIKELIHOOD	1	2	3	4	5
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12

R11-14 CONSEQUENCE

Figure 7 **Mission 3 - Outpost Remote Operations DRM**

Mission 3 Ops Berm Excavation (cont.)

- ConOps shown is CMC tele-robotically nearing completion of protective regolith berm around landing zone.



Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-14	Top layer material of regolith source field in proximity to landing zone may be depleted before completion of berm

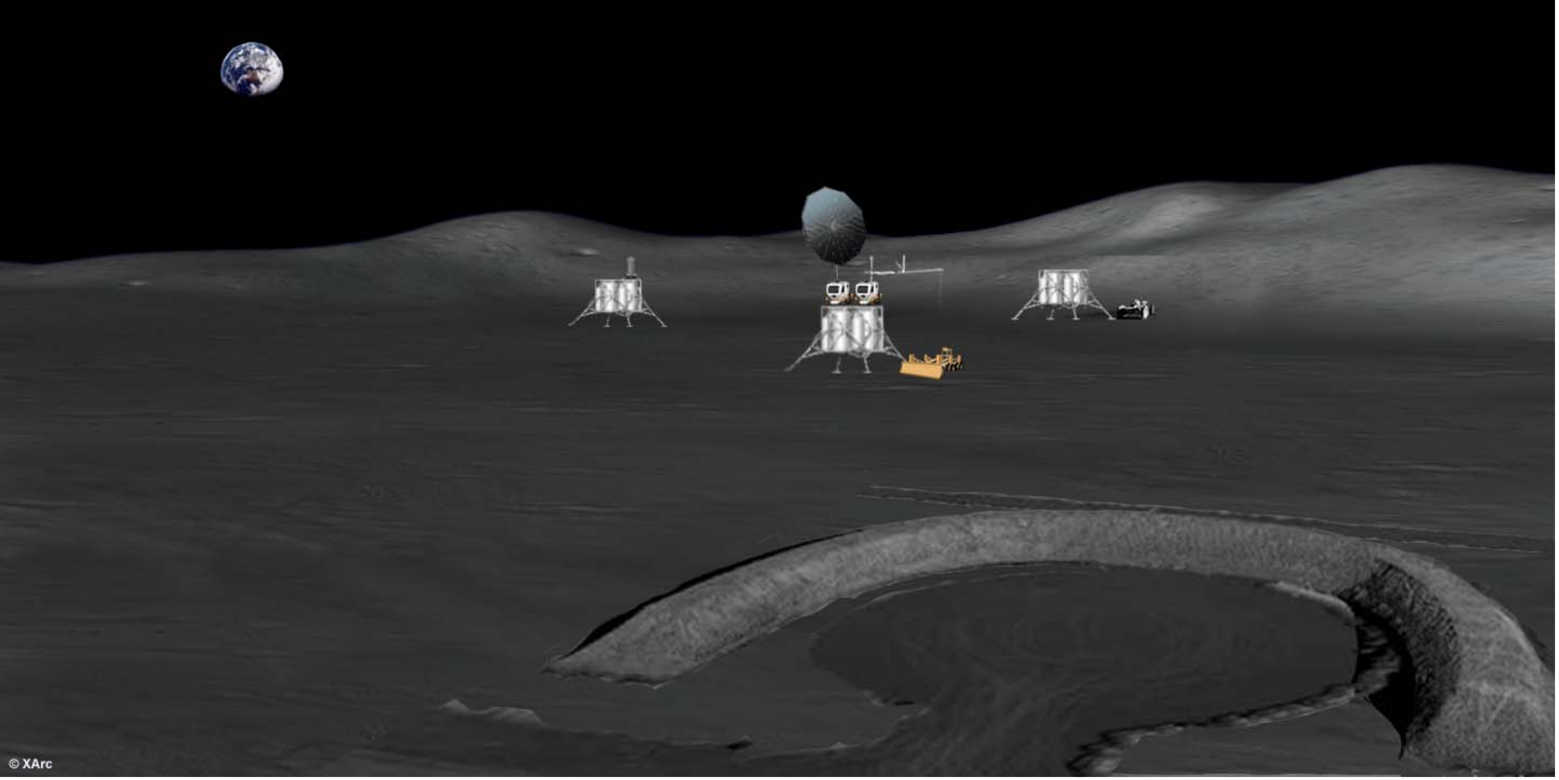
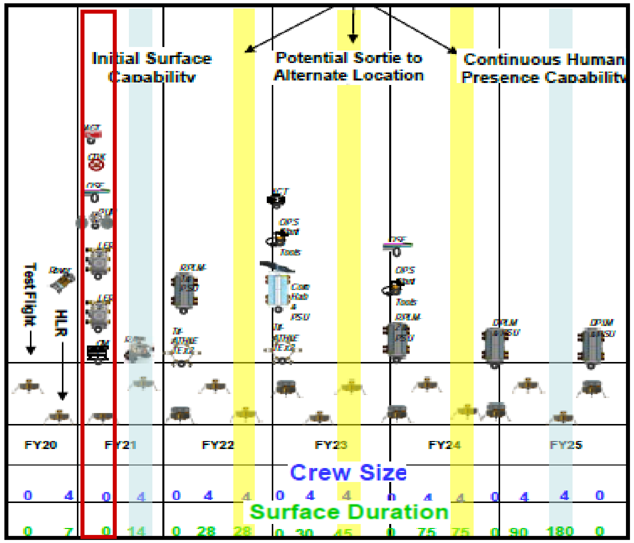


Figure 8

Mission 3 Ops, Landing Pad Excavation Complete

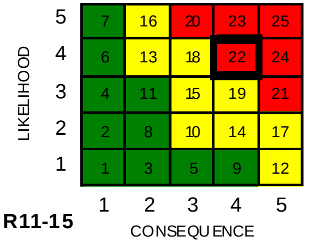
- ConOps shown is completed landing pad prepared to receive next mission.
- CMC parked at lander base power recharge station.

Mission 3 - Outpost Remote Operations DRM



Scenario 4.2.1.20

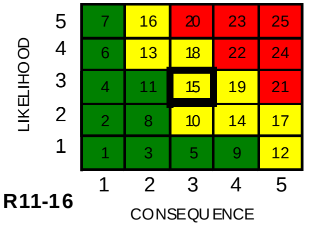
Risk Matrix Priority Score



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

CONSEQUENCE

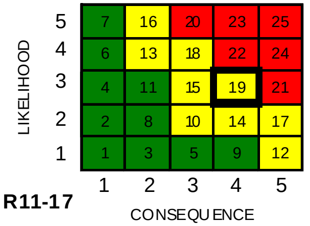
R11-15



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

CONSEQUENCE

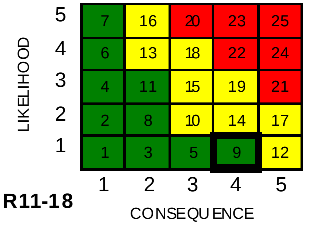
R11-16



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

CONSEQUENCE

R11-17



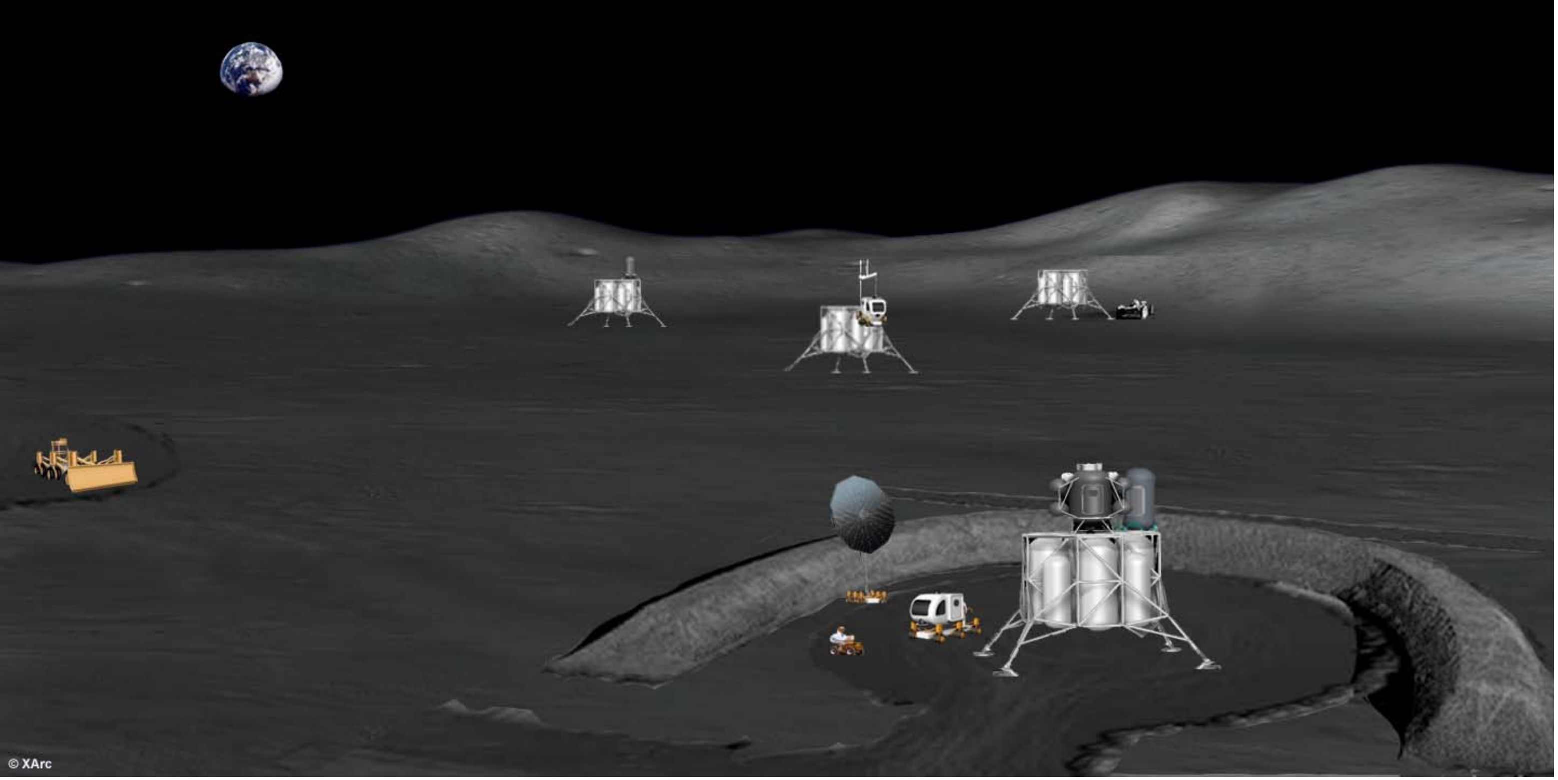
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	**9**	12
	1	2	3	4	5

CONSEQUENCE

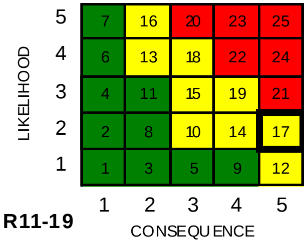
R11-18

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
🟥 R11-15	Berm design form factor not optimized for sufficient protection
🟨 R11-16	Berm over-design causing requirements creep for excavator system design
🟨 R11-17	Ejecta discharge from top layer of berm
🟩 R11-18	Unforeseen consequences if blast ejecta debris forms a medium reflecting pressure energy off berm design



Risk Matrix Priority Score



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

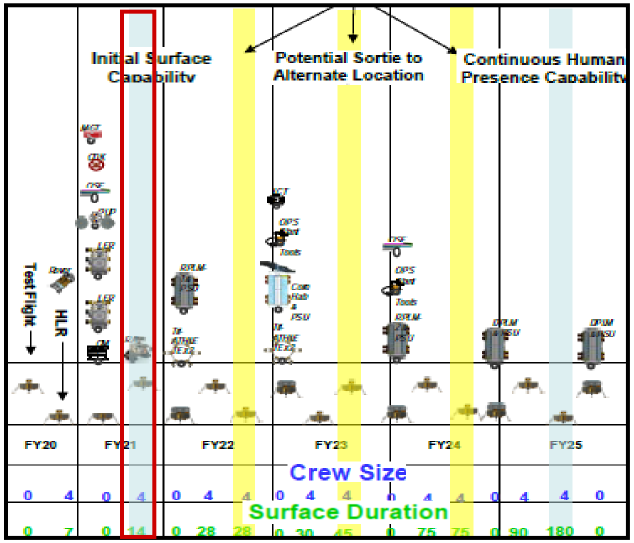
R11-19

Figure 9

Mission 4 - Visiting Lunar Outpost Expedition DRM

Initial Surface Capability (ISC)

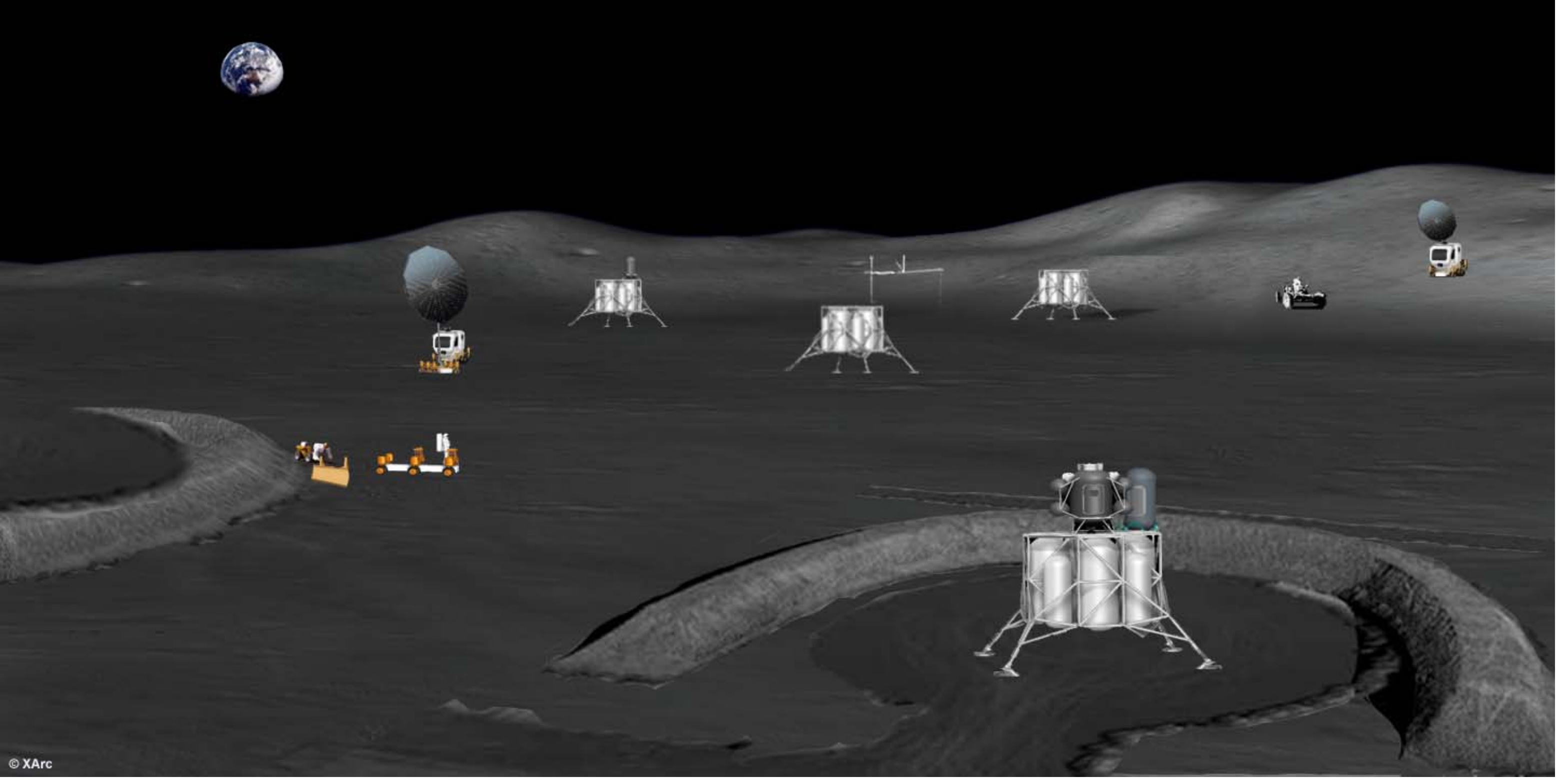
- ConOps shown is successful landing of Altair at landing pad.
- Altair is in Lunar Sortie Crew configuration, and relies on Lunar Surface Systems resources to extend surface stay to 14 days.
- PUP 1 moved to landing pad by SPR 1; LSMS offloads remaining SPR 2/PUP2.
- Chassis A with Robotic Assistant (RA) is delivered.
- CMC initiating excavation of 2nd landing pad.



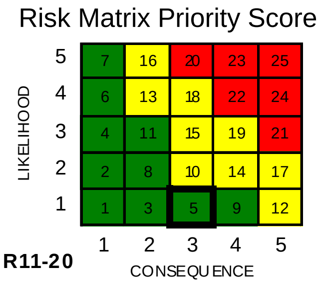
Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-19	CMC not configured to pre-emplace navigation/beacon aids at completion of landing site (or for construction phase)



© XArc



Risk Matrix Priority Score

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

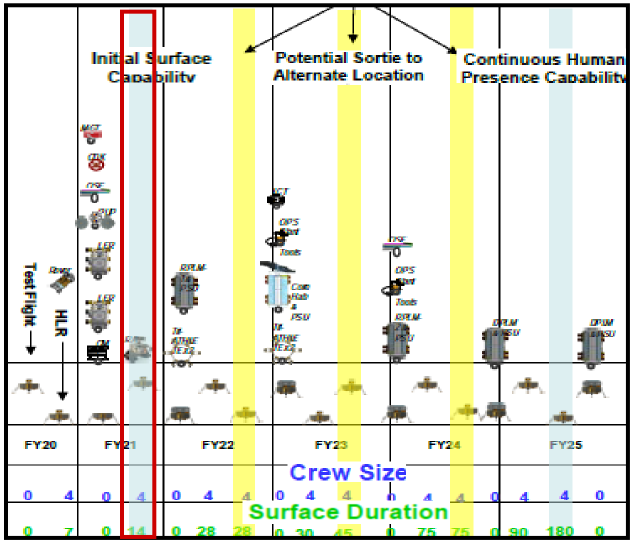
CONSEQUENCE

R11-20

Figure 10 **Mission 4 - Visiting Lunar Outpost Expedition DRM**

ISC Operations

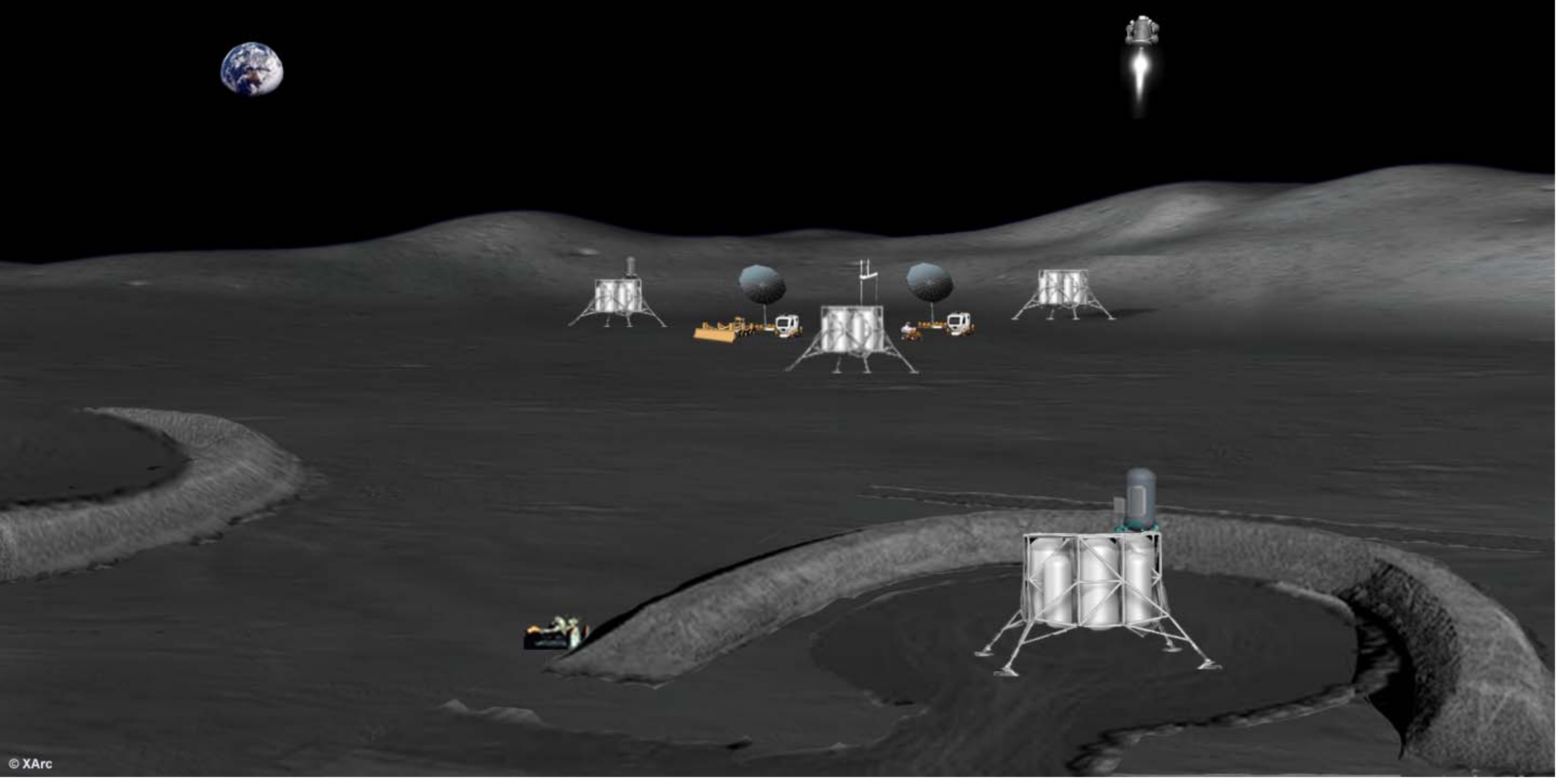
- ConOps shown is Crew member performing CMC excavator maintenance check, assisted by RA.
- SMC Rover is revived and powered after 1 year dormancy period.
- SPRs performing exploration and science activities.

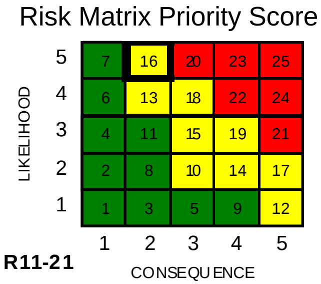


Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-20	Provisioning for CMC excavator system spares, maintenance and refurbishment not sufficiently accommodated





Risk Matrix Priority Score

LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12
R11-21	1	2	3	4	5

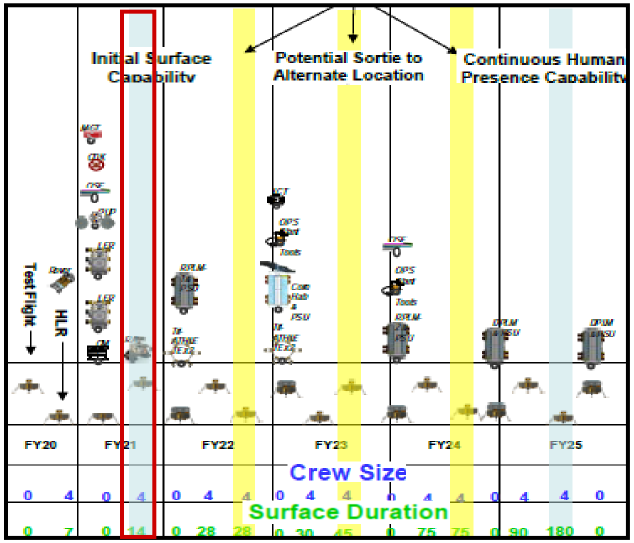
CONSEQUENCE

Mission 4 - Visiting Lunar Outpost Expedition

Figure 11

14 Day ISC Mission End

- ConOps shown is crew departure in Ascent Module.
- 2nd Airlock abandoned.
- Outpost surface assets placed in Safe Mode quiescent state prior to departure.
- SMC Rover parked behind protective berm (serves as crew's transportation to launch pad from SPR's parked location).
- CMC excavator positioned at new power recharge station, (resumes tele-robotic excavation of 2nd landing pad after Crew departure).



Scenario 4.2.1.20

Mission Ops Risks to ISC Landing Zone Surface Preparation

Risk #	Risk Title
R11-21	Ambiguous ConOps for the three planned landing pads versus the remaining 9 Altair landings to CHPC

Summary of Main Mitigation Themes

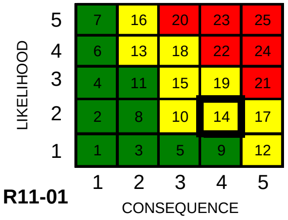
MAIN MITIGATION THEMES CAPTURED IN RISK DESCRIPTIONS AND MITIGATION APPROACHES WORKSHEETS

- Utilize SMD's International Lunar Network (ILN) of surface science stations to characterize environment of Outpost specific landing /launch sites.
- Validate data through use of extensive simulation and phenomenological modeling of lunar surface at excavation and construction sites.
- Include civil engineering and planetary geology disciplines as core crew expertise for Mission 2 sortie scouting and surveying mission.
- Deploy an integrated lunar sensor network to enhance the spatial-orientation capabilities of teleoperators and astronauts on the lunar surface.
- Ensure Altair design requirements align with LSS operational scenarios; to extent practical, align schedule of Altair and LSS design reviews.
- Design mechanical articulation of solar array orientation in Mission 3 for any positioning contingency of Cargo Altair landing.
- Extensive use of discrete modeling and event simulation tools for understanding processes and procedures, and design impacts to:
  * power generation and supply;
  * characterizing optimized landing zone separations;
  * regolith simulation of plume ejecta models;
  * berm or landing/launch zone design alternatives;
  * teleoperated excavator system designs.
- Utilization abandoned Mission 2 Sortie Mission Chassis (SMC) redeployed as a transportation carrier for:
  * a self-transporting battery system to shuttle itself to and from the charging station to the excavator while the excavator continues to work;
  * shuttling crew from parked SPR's or habitation modules to landing/launch site.
- Deploy a Lunar Dust Instrument (LDI) mission, i.e., Langmuir Probe to characterize lunar dusty plasma environment on and near the lunar surface.
- Design teleoperator control center with human-systems integration principals for workstation design.
- Use/develop software tools for modeling and analyzing workstation interfaces, crew station design and overall workflow environment
- Incorporate lessons learned from Soviet era Lunokhod teleoperator control station experience.
- Ensure CMC tool kit for Mission 3 Altair Cargo manifest includes capability for CMC to reconfigure itself for emplacement of navigation/beacon aids.
- Ensure spares provisioning and spares ConOps for CMC excavation activity is sufficiently accommodated.
- Develop CMC spares ConOps for Mission 3 telerobotic remote Outpost operations.
- Develop complete ConOps for optimized usage of landing/launch zones through CHPC to characterize potential design opportunities or shortfalls.

R-11 Risk Descriptions and Mitigation Approaches

RISK DESCRIPTION | **SCORE** | **TOP 5** | **MITIGATION APPROACHES**

<u>R11-01</u> Given lunar environment characterization is required to conduct design studies for landing on and moving over the lunar surface, and given that certain scientific data may not be available, there is a possibility of failure to completely characterize the lunar surface at selected landing sites for such environmental characteristics as surface geological environment, regolith properties, dust, regolith electrical and photoelectric properties, optical properties, thermal environment, radiation environment, surface plasma environment, and ejecta environment, which may impact safe operations and design solutions for the protective berm construction



LIKELIHOOD					
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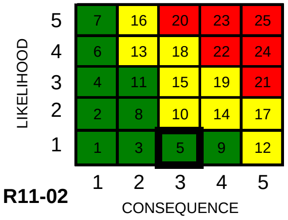
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	**14**	17
1	1	3	5	9	12
	1	2	3	4	5

R11-01 CONSEQUENCE

Ensure lunar robotic precursor science missions (including international missions) have appropriate instrument suite of sensors for characterizing Lunar Outpost's specific locations for habitation, landing and launch sites; LSS coordination with SMD on International Lunar Network (ILN) for surface stations science network.

<u>R11-02</u> Given HLR SMC rover excursions will explore and perform on-site verification of remote survey data, as well as demarcate selected landing zones and excavation sites, there is a possibility that discovery of "real-time" mission data does not coincide with remotely obtained planning data or does not match pre-mission simulations, causing significant changes to future site plans, e.g., pre-determined excavation sites not viable, or vehicle-terrain interactions grossly mis-match simulations, causing incongruities in excavator system design, etc.



LIKELIHOOD					
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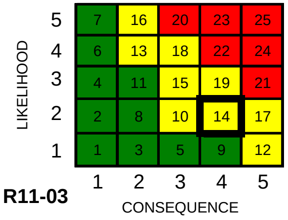
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	**5**	9	12
	1	2	3	4	5

R11-02 CONSEQUENCE

Validate data through extensive simulations; Crew expertise to include civil engineering and planetary geology disciplines (site surveying as core activity for 7 day scouting mission); deploy integrated lunar sensor network to enhance the spatial-orientation capabilities of astronauts on the lunar surface.

<u>R11-03</u> Given the Mission 3 Initial Mobility Delivery is tele-robotically operated, there is a possibility that a communications link failure will jeopardize the mission, preventing construction of the landing pad and protective berm.



LIKELIHOOD					
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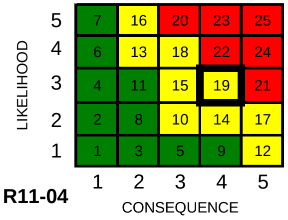
2	2	8	10	**14**	17
1	1	3	5	9	12
	1	2	3	4	5

R11-03 CONSEQUENCE

Dependent on Space Communications and Navigation Architecture (SCaN) for routing, redundancy, and link protocols.

<u>R11-04</u> Given the lander fuel cells are assumed to provide power on the surface to support the offloading of the CMC prior to deploying the PUP solar array, there is a possibility the assumption is erroneous in that the lander fuel cell design has not been sized to accomplish this operation.



LIKELIHOOD					
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4	6	13	18	22	24
3	4	11	15	**19**	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

R11-04 CONSEQUENCE

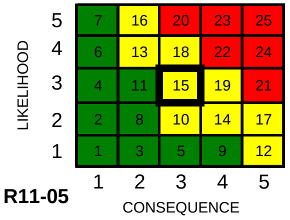
3

Coordination with Altair Project Office; ensure Altair design requirements aligned with LSS operational scenarios; to extent practical, align schedule of Altair and LSS design reviews.

R-11 Risk Descriptions and Mitigation Approaches, cont.

RISK DESCRIPTION | **SCORE** | **TOP 5** | **MITIGATION APPROACHES**

R11-05 Given the Uncrewed Cargo Altair will utilize a deployed solar array from one of the PUP cargo elements for providing power resources for Outpost Remote Operations, there is a possibility the final landing orientation of the Cargo Altair will preclude the solar panel articulating arm to maximize the exposure of the solar panel to the sun.



LIKELIHOOD					
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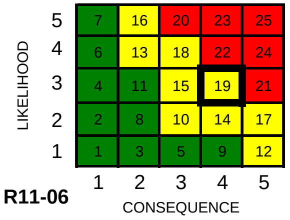
3	4	11	**15**	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

CONSEQUENCE

R11-05

Dependent on Altair navigation and beacon aids for landing; employ astronaut/pilot spatial disorientation countermeasures during landing; design mechanical articulation of solar array for all orientation contingencies, and model extensively in Lunar Surface Operations Simulator for design impacts to power generation.

R11-06 Given the Uncrewed Cargo Altair is tele-robotically operated, there is a possibility offloading collision or damage to the CMC excavator system can occur.



LIKELIHOOD					
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4	6	13	18	22	24
3	4	11	15	**19**	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

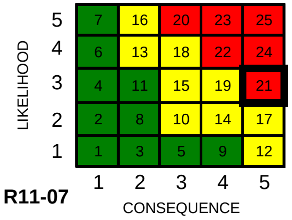
CONSEQUENCE

R11-06

4

Refer to risk mitigation approaches identified in Risk 4 "Damage During Unloading Operations"

R11-07 Given there is an operational correlation between location of the Mission 3 Cargo Altair landing zone and location of the landing pad for Mission 4 ISC, there is a possibility the distance between the two landing zones will not have sufficient separation to avoid subsequent crewed landing plume ejecta debris damage to Cargo Altair cargo elements in event of protective berm failure, or CMC excavator system is not successfully deployed, or fails to construct berm.



LIKELIHOOD					
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4	6	13	18	22	24
3	4	11	15	19	**21**
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

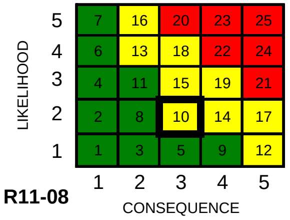
CONSEQUENCE

R11-07

1

Extensive use of simulations and modeling to characterize optimized landing zone separations; regolith simulation of plume ejecta models; berm or landing/launch zone design alternatives.

R11-08 Given there is an operational correlation between location of the Mission 3 Cargo Altair landing zone and location of the landing pad for Mission 4 ISC, there is a possibility the distance between the two landing zones will not have sufficient separation to minimize contamination of the Portable Utility Pallet (PUP) solar power array from dust ejecta or dusty plasma electric potential of approximately 6 month berm construction activity, (interaction of lunar dust and solar wind plasma near the lunar surface at ~ 6 - 10 meters high), thereby jeopardizing surface systems power recharge capability.



LIKELIHOOD					
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4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	**10**	14	17
1	1	3	5	9	12
	1	2	3	4	5

CONSEQUENCE

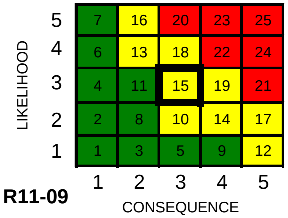
R11-08

Deploy Lunar Dust Instrument (LDI) mission, i.e., Langmuir Probe at approximately 10 meter height, as part of International Lunar Network (ILN) of surface science stations or on Altair Test Flight mission to characterize lunar dusty plasma environment on and near the lunar surface.

R-11 Risk Descriptions and Mitigation Approaches, cont.

RISK DESCRIPTION | **SCORE** | **TOP 5** | **MITIGATION APPROACHES**

R11-09 Given there is an operational correlation between location of the Mission 3 Cargo Altair landing zone and location of the landing pad for Mission 4 ISC, there is a risk the distance between the two landing zones will not minimize their separation to optimize the CMC excavator system traverse distance between Cargo Altair power recharge station and landing pad construction site.



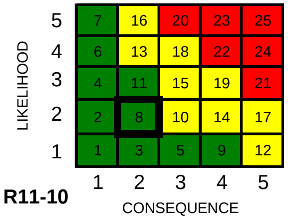
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	**15**	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

CONSEQUENCE

R11-09

Derive construction and excavation operations requirements through development of regolith excavation simulation tools; consider redeploying SMC left behind from Mission 2 as a carrier for a self-transporting battery sysem which can shuttle itself to and from the charger while the excavator continues to work.

R11-10 Given the CMC excavator system's reliance on tele-robotic control, assumed to include High Definition line-of-sight video surveillance from the Cargo Altair landing zone vantage point, there is a possibility the remote tele-operator may loose orientation / situational awareness if the HD camera goes down.



LIKELIHOOD					
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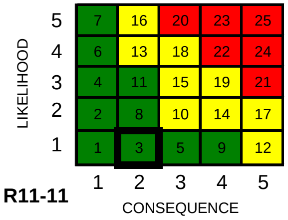
4	6	13	18	22	24
3	4	11	15	19	21
2	2	**8**	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

CONSEQUENCE

R11-10

Use integrated lunar sensor network to enhance spatial-orientation capabilities of teleoperators; integrate sensor information with computational models to provide teleoperators with self-localization and path-generation capabilities, e.g., relative positioning, generation of return paths in reverse directions, path memorization, etc.

R11-11 Given the CMC excavator system's reliance on tele-robotic control, there is a possibility that human error from the tele-robotic operator could occur due to an improperly designed Human Computer Interface / Graphical User Interface.



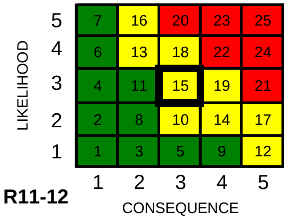
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	**3**	5	9	12
	1	2	3	4	5

CONSEQUENCE

R11-11

Design teleoperator control center with human-systems integration principals for workstation design; use/develop s/w tools for modeling and analyzing workstation interfaces, crew station design and overall workflow environment; incorporate lessons learned from Soviet Lunokhod teleoperator control station experience.

R11-12 Given the heavy excavation operations required of the CMC excavator system and reliance on tele-robotic control, there is a possibility that lack of an optimized excavator system design integrated with a specific berm design and construction methodology may diminish excavator system reliability.



LIKELIHOOD					
5	7	16	20	23	25
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3	4	11	**15**	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5

CONSEQUENCE

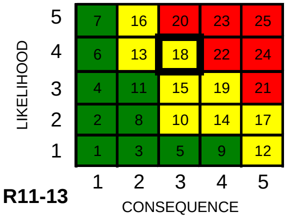
R11-12

Derive construction and excavation operations requirements with development of regolith excavation simulation tools for modeling various teleoperated excavator system designs against various berm designs, using parameters of driving speed, payload ratios, excavation resistance forces, power supply, etc.

R-11 Risk Descriptions and Mitigation Approaches, cont.

RISK DESCRIPTION | **SCORE** | **TOP 5** | **MITIGATION APPROACHES**

R11-13 Given the heavy excavation operations required of a single CMC excavator system in Scenario 4.2.1.20, and that there are likely to be high system consumable resource constraints, (e.g., power recharge time vs. power storage capacity), there is a possibility that construction scheduling inefficiency will pose a threat to completion of the berm due to downtime caused by duration and number of recharge events required in a single work period for the CMC excavator system.



LIKELIHOOD					
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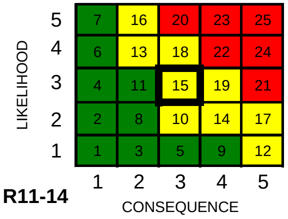
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5
			CONSEQUENCE		

R11-13

Derive construction and excavation operations requirements through development of regolith excavation simulation tools; consider redeploying SMC left behind from Mission 2 as a carrier for a self-transporting battery sysem which can shuttle itself to and from the charger while the excavator continues to work.

R11-14 Given the preliminary estimated quantity of regolith required to construct a protective berm, (Astrobotics estimate of as much as 1.2 million kg of regolith), there is a possibility the top layer material source field in proximity to the landing zone may be depleted before completion of the berm, requiring additional traversing distance for the excavator system to haul regolith back to the berm site from another source field and/or deeper digging into the regolith which will impact CMC excavator system power storage/usage requirements and excavation timeline.



LIKELIHOOD					
5	7	16	20	23	25
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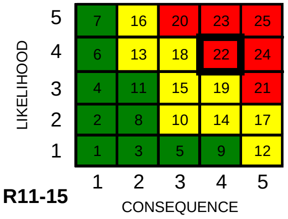
1	1	3	5	9	12
	1	2	3	4	5
			CONSEQUENCE		

R11-14

Characterize excavation site for determining distribution of regolith source field and derive operational design requirements for CMC excavator through simulation of contingency traverse paths of CMC for "offsite" material source fields.

R11-15 Given the complexity of interacting forces between the lunar environment, lunar surface features, and the Altair propulsion system causing debris and ejecta during landing and launch, there is a possibility of not achieving an optimized geometry (height, shape, mass, deflection angle) for the protective berm's form factor, causing it to be over or under designed for effective protection.



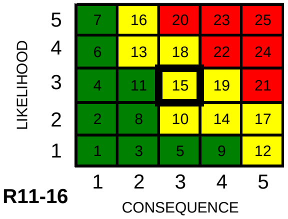
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	**22**	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	9	12
	1	2	3	4	5
			CONSEQUENCE		

R11-15

2

Evaluate other innovative design solutions for form factor other than berm design against rigid set of criteria.

R11-16 Given an over designed berm will place heavier and unnecessary requirements on the excavator system design for moving material and constructing the berm, there is a possibility interfacing systems such as the power generation, power storage, and recharge station design requirements may be over specified.



LIKELIHOOD					
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3	4	11	**15**	19	21
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1	1	3	5	9	12
	1	2	3	4	5
			CONSEQUENCE		

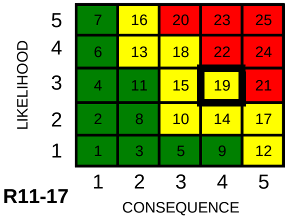
R11-16

Derive construction and excavation operations requirements through development of regolith excavation simulation tools for modeling various teleoperated excavator system designs with parameters of driving speed, payload ratios, excavation resistance forces, power supply, etc.

R-11 Risk Descriptions and Mitigation Approaches, cont.

RISK DESCRIPTION | **SCORE** | **TOP 5** | **MITIGATION APPROACHES**

R11-17 Given the top layer of the regolith protective berm may be relatively uncompacted, there is a possibility the outer skin of the berm will be a source for discharging ejecta.



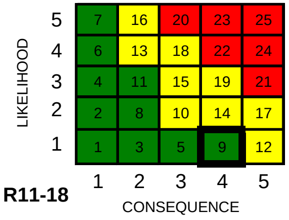
LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	**19**	21
2	2	8	10	14	17
1	1	3	5	9	12
R11-17	1	2	3	4	5

CONSEQUENCE

5

Evaluate alternative berm construction methods, compaction techniques, geotextiles, etc.

R11-18 Acoustical energy for berm design criteria is believed to be non-existent in the lunar vacuum environment. QUESTION: Can the debris cloud momentarily form a medium in which the berm design reflects or redirects acoustical and pressure energy from ignition blast back to the Altair at the launch pad at the beginning of the flight or while descending along the flight path?

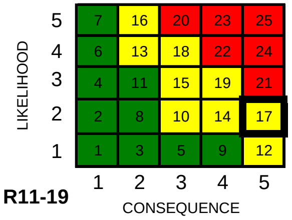


LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	5	**9**	12
R11-18	1	2	3	4	5

CONSEQUENCE

Perform phenomenological modeling of interacting forces.

R11-19 Given the completed launch pad and berm are tele-robotically constructed, and given the CMC is only configured for excavation duty, there is a possibility emplacement of navigation aids for delineating the berm during construction and for landing at the pad will not be possible prior to arrival of the Mission 4 Altair flight.

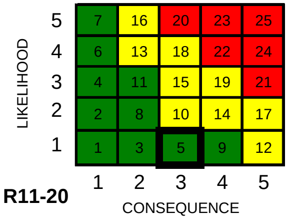


LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	**17**
1	1	3	5	9	12
R11-19	1	2	3	4	5

CONSEQUENCE

Ensure CMC tool kit and Mission 3 Altair Cargo manifest includes capability for CMC to reconfigure itself for robotic emplacement of navigation aids and beacons for construction phase and upon completion of built berm/landing site.

R11-20 Given CMC excavator system may need to excavate as much as 1.2 million kg of regolith (Astrobotics estimate), there is a possibility spares and provisioning for CMC excavator system maintenance and refurbishment may not be sufficiently accommodated in Mission 3 or Mission 4 Altair manifests.



LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	11	15	19	21
2	2	8	10	14	17
1	1	3	**5**	9	12
R11-20	1	2	3	4	5

CONSEQUENCE

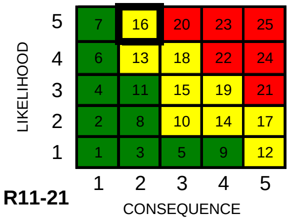
Ensure spares provisioning and spares ConOps for CMC excavation activity is sufficiently accommodated; develop CMC spares ConOps for Mission 3 telerobotic remote Outpost operations, e.g., CMC tool kit and Mission 3 Altair Cargo manifest includes capability for CMC to reconfigure itself for spares changeout task.

R-11 Risk Descriptions and Mitigation Approaches, cont.

RISK DESCRIPTION

R11-21 Given the initial landing/launch pad is completed by ISC, and given Scenario 4.2.1.20 calls for a total of 3 landing pads, there is a possibility post-ISC site construction for the landing pads #2 and #3 will be incongruous with the ConOps for the remaining 9 Altair landings planned for achieving Continuous Human Presence Capability (CHPC) by FY2025.

SCORE



LIKELIHOOD

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

CONSEQUENCE

R11-21

TOP 5

MITIGATION APPROACHES

Develop complete ConOps for optimized usage of landing/launch zones through CHPC to characterize potential design opportunities or shortfalls.