The Apple of Discord or The Fruit of Salvation? A Dialogue on the Practical and Legal Aspects of Safety Zones on the Lunar South Pole

Antonino Salmeri and Peter Weiss[*]

Abstract

Call it like you want but humanity will soon witness an incredible flurry of activities on the Moon. From governmental plans like the ARTEMIS Program or the International Lunar Research Station (ILRS) to several commercial missions laying the foundations for the development of a lunar economy, more and more actors are targeting our celestial neighbour for future human and robotic exploration. Buzz Aldrin once defined the Moon as a "magnificent desolation". While this was certainly the case until now, we can be relatively sure that the next individuals to walk on the lunar surface will witness a rather different scenario.

Differently from the past, these new missions will not be finished with planting a flag as they seek to establish an unprecedented network of lunar assets and infrastructures. Due to the physics of the lunar environment, the level of interdependence among actors operating on its surface will grow exponentially with the progressive increase of their number. Most likely, none of them will have the luxury of operating in the "magnificent desolation" witnessed by the Apollo 11 astronauts. In fact, it is becoming more and more apparent that lunar actors will face an unprecedented risk of potentially harmful interference. Even nominal operations such as landing and taking off hold a disruptive potential that might seriously damage or disable assets located in a wide range within the lunar surface. In recognition of this issue, the international community has recently started to debate the concrete usefulness and potential legality of area-based measures to prevent and manage the risk of potentially harmful interference among lunar operations, commonly referred to as "safety zones".

This paper discusses the practical and legal aspects of safety zones through a dynamic dialogue between an aerospace engineer and a space lawyer. Moving from the current

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situation for lunar activities, the paper discusses the risks of potentially harmful interference that might be faced by a lunar habitat operator, and consequently assesses the concrete usefulness of safety zones in neutralising them. Building upon these operational considerations, the paper considers fundamental legal aspects of safety zones including their boundary conditions, procedural aspects and substantive legal effects. Merging practical and legal considerations, the paper draws some preliminary conclusions on the potential of safety zones as a policy tool to meet the safety needs of lunar operators in accordance with international law.

Keywords: safety zones, space law, lunar exploration, international cooperation, multidisciplinary efforts

1. Introduction

A new era of lunar exploration is upon us. Through a suite of missions to the lunar surface and its vicinity, discoveries of resource deposits in the lunar regolith and ice traps at the poles, among other features, have transformed our conception of humanity's potential future on the Moon.[1] Consequently, private entities and nations worldwide with newly developed spacefaring capabilities have set their sights on returning to the Moon.[2] Differently from the past, these new missions will not be finished with planting a flag as they seek to establish an unprecedented network of lunar assets and infrastructures. The Moon is not "a step" towards Mars - it is "the step": Concepts of crewed mission to planet Mars depend on testing systems and operations in the lunar environment, and those nations that will be present on the lunar surface are the ones which will step forward towards Mars. Due to the physics of the lunar environment, the level of interdependence among actors operating on its surface will grow exponentially with the progressive increase of their number. Most likely, none of them will have the luxury of operating in the "magnificent desolation" witnessed by the Apollo 11 astronauts. In fact, it is becoming more and more apparent that lunar actors will face an unprecedented risk of potentially harmful interference. Even nominal operations such as landing and taking off hold a disruptive potential that might seriously damage or disable assets located in a wide range within the lunar surface. In recognition of this issue, the international community has recently started to debate the concrete usefulness and potential legality of area-based measures to prevent and manage the risk of potentially harmful interference among lunar operations, commonly referred to as "safety zones".

1 Anthony Colaprete, Peter Schulz et al., Detection Of Water In The Lcross Ejecta Plume, 330 (6003) Science 463-468 (2010). *See also* Ian A. Crawford, Lunar Resources, 39 Progress in Physical Geography 137-167 (2015).

2 Bryce Space, Projected Exploration Missions (2020-2030), available online (accessed August 2022).

This paper discusses the practical and legal aspects of safety zones through a dynamic dialogue between an aerospace engineer and a space lawyer. The goal of this interaction is to explore the risks of potentially harmful interference that might be faced by a lunar habitat operator, and consequently assess the concrete usefulness of safety zones in neutralising them. Building upon these operational considerations, the paper discusses fundamental legal aspects of safety zones including their boundary conditions, procedural aspects and substantive legal and geopolitical effects. Merging practical and legal considerations, the paper draws some preliminary conclusions on the potential of safety zones as a policy tool to meet the safety needs of lunar operators in accordance with international law.

2. A Much Needed Dialogue Between Space Engineers and Space Lawyers

This section frames the context for the analysis conducted in the paper through a dynamic dialogue among the two authors, an aerospace engineer and a space lawyer. Accordingly, all the considerations expressed in this section are the sole opinion of the author advancing them.

Dr. Weiss (Engineer)
If Christopher Columbus would have discovered the Americas in 1492 by being governed by rules similar to the Outer Space Treaty (OST) or the Planetary Protection Law then history books would not have been written the same. The exploration, exploitation and colonization of America would have been significantly different (with its positive and negative aspects): most of the discovered lands would most probably be still pristine from settlements and the raise to the power of Europeans nations would not have happened. The current laws that are governing (protecting) extra-terrestrial surfaces prevent industrial investments in space exploration on a large scale and keep industry at a level of suppliers for agencies. But this situation is similar to what can be witnessed for the exploitation of maritime resources, where there is a high resistance towards activities that target to harvest metals and rare earth materials in the deep see – but the alternative is to exploit such resources on land with the side effect of a severe impact on our forests; because out current society needs these resources. With the ARTEMIS Program a new chapter in human space exploration is opening. But *if* ARTEMIS shall differ from the past APOLLO Program then it is primordial to foresee (and permit!) industrial activity on the lunar surface. Elsewise this new program will be limited to "flag planting and sample collection" but certainly not going towards a "sustainable presence" on the lunar surface - it would have been like if the missions following Columbus' discovery would have not allowed to embark merchants and miners on board their ships but only biologists and geologists...

Dr. Salmeri (Lawyer)
The analogy between space (and in this case lunar) exploration and the discovery of the Americas always fascinates me. While there is no way to know for sure if history would have changed for better or for worse had the Outer Space Treaty been the relevant governance instrument for that endeavour, I would argue that the resulting society would have been more balanced and inclusive. I certainly do not think that the OST would have prevented the creation of large settlements nor the participation of the industry. Under Article I OST, space and celestial bodies shall be free for exploration *and use* by all States. The term "use" refers to both scientific and commercial endeavours, which are both equally allowed. Nothing in the OST prevents industrial investments in space activities or the development of large scale infrastructures, both in space and on celestial bodies. Under the regime set forth in the OST, the global space economy flourished as a commercial industry currently worth 370 billion dollars and projected to go over a trillion by the end of the decade. It is *not* the fault of the OST if the large majority of commercial space endeavours are not directed towards space exploration. Rather, it is a natural consequence of the difficulties in generating monetary profits with this particular kind of space activities. Sure, under Article II OST celestial bodies cannot be appropriated by either public or private entities. However, so is for orbits and frequencies - and yet the global telecom market is worth a few thousands billion dollars. Merchants and miners are thus welcome onboard humanity' ships towards the Moon. The OST does not prevent these people from getting onboard – it only forbids them from taking exclusive control of the ship and everything that comes after. As a result, miners and merchants won't dominate our journey to the Moon like they did with Columbus. I fail to understand why this would be a bad outcome though...

Dr. Weiss
Of course human and robotic space exploration should not transform solely into space *exploitation*. But the case of the Moon unfortunately shows that such large endeavours need to be motivated by strong factors. In the past it was the Cold War and the Space Race. Once these motivators disappear the interest of the government shifted and the Moon got back its "magnificent desolation" for 50 years.
Are todays crewed lunar programs driven by a similar situation? Probably. And if this is the case then this does not guarantee a future sustainable presence in outer space as many of us would like to see in the future. Therefore it is positive that also the private sector is entering this game. But the rules need to allow these actors to play a significant role in it. Call it like you want, but there is a new Space Race ongoing towards the Moon. But contrary to Apollo, it will not be finished by the "*setting up of a flag*". The

goal is to establish a sustainable presence on the lunar surface and to prepare capacities to go further, towards planet Mars. The Moon is the obligatory steppingstone for destinations further out in the solar system, and the lunar surface will allow those nations involved to shape this future. But there is also another significant difference of current space programs and Apollo: the closest distance between two Apollo sites is 181 kilometres (Apollo 12 to 14). But today, all current missions target the Lunar South Pole with a geographic extend of Larger Paris, roughly 30 km x 30 km. In this area are concentrated many of the valuable resources that can support crewed missions on the lunar surface. Permanently Shadowed Regions (PSR) offer the potential to mine water ice which will also be used to electrolyte hydrogen to store power. Very close to the PSR are located Peaks of Eternal Light (PEL), zones of high illumination, which offer almost constant sunlight during the lunar day-night cycle. PEL will play an important role in powering facilities on the surface and support equipment with power even during lunar nights. Both features combined can only be found on the poles, and nations that want to have a "sustainable seat" on the Moon (and further human space exploration) will need to "fight" for these precious spots. Drawing back to the analogy with Christopher Columbus: the situation is as if all the settlements of the European Powers would had to concentrate on the Island of the Bahamas!

The setting up of the ARTEMIS Accords[3] is therefore a step in the right direction. Clear regulations are required to deconflict activities on this small lunar region. "Safety Zones", as they are defined in Section 11, will allow to avoid conflicts and accidents at least amongst the nations that agreed to adhere to these Accords. The definition of the area, volume and temporal extend of these zones will be a major, practical challenge: the way I see it, one safety zone could deprive other nations from strategic sites such as safe landing sites (which are also spare on the mountainous South Pole) or the beforementioned PEL and PSR. These in particular have a very limited spatial extension[4]: the sites that offer high illumination throughout the lunar day-night cycle are located on the crater rims, sometimes with a size of some hundred square metres only. There might be a race towards these strategic locations and the ARTEMIS Accords offer a possibility to regulate such activity while also opening the possibility for civil use of the resources. Such peaceful regulation is a positive motivator to all nations involved in human spaceflight to secure their strategic locations on the lunar surface now.

3 The Artemis Accords, Principles for cooperation and civil exploration and use of the Moon, Mars, comets, and asteroids for peaceful purposes (2020), available online (accessed August 2022).

4 Martin Elvis, Tony Milligan and Alanna Krolikowski, The Peaks of Eternal Light: a Near-term property issue on the Moon (2016), Space Policy, 38 DOI: 10.1016/j.spacepol.2016.05.011.

Dr. Salmeri
I fully agree that challenging endeavours require strong drivers. And sure, power, prestige and money traditionally have been the primary ones fuelling humans in their desire to explore the unknown. Nonetheless, the negative externalities produced by those drivers have also created significant damage that we simply cannot afford to create on the Moon. As you rightly point out, the current centre of interest for lunar activities is a small area in its south pole. By the end of this decade several actors plan to reach and begin operations in this area, each with their own preferences and goals pursue. However, the nature of international space law actually forbids these actors to *fight* for any of their desired spots. According to Articles I and II OST, none of them can exclude the others from accessing or utilising any part of the Moon, as the latter *is not subject to national appropriation by any means,* and *there shall be free access to all areas thereby*. Contrary to the example of the Americas, who gets to the Moon first does not get to exclude the others from its use.
The question therefore is how to make sure that different actors can *coexist* on the Moon in a safe, peaceful, rational and sustainable manner. And I agree with you the Artemis Accords are a great step in finding a workable solution to this complex task. And not by chance the Accords are *principles for cooperation,* **not competition**, in the peaceful exploration and use of the Moon and other celestial bodies. All its sections propose tools to unite actors, not divide them – and safety zones are no exception to that. As we will see in the next part, safety zones are meant to help different operators located in the same area to coordinate their activities so that all of them can be conducted in a safe manner. You will tell me that this will be hard – and I will reply that this goal will serve to organize and measure the best of our (intellectual) energies and (diplomatic) skills, because this challenge is one that we are willing to accept, one we are unwilling to postpone, and one that we intend to win.

3. The Lunar Scenario and How Safety Zones May Fit In

The dawn of the new era in space exploration was heralded by US and Chinese initiatives to return human astronauts to the lunar surface. The US ARTEMIS Program emerged from previous programs in 2017 under the Trump legislation. The International Lunar Research Station was unveiled by the Chinese Space Agency CNSA and ROSCOSMOS during the Global Lunar Exploration Conference in Saint Petersburg 2021. China recorded already several milestones in robotic surface exploration with the CHANG'E Program and the YUTU rovers on the surface.
Current plans target the lunar South Pole due to its expected occurrence of features necessary for human space exploration into deep space. The poles of the Moon host sites that bear water ice which can support future life support systems, energy storage (fuel cell) and propellant (hydrogen). Next to these

PSR are located peaks and crater rims that offer a high degree of solar illumination throughout the lunar day-night cycle. Any facility that is to be installed on the surface needs be able to survive the lunar nights in order to become a sustainable asset. The lunar poles also offer access to the Far Side of our celestial neighbour; sites there offer a quite unique environment, shielded from Earth's activity (e.g. radio waves). On the other hand the poles differ from most of the previous human landing sites. The area is mountainous (highlands) and safe landing sites are sparse and need to be selected carefully. Radio communication with Earth is not possible on all locations, much of the surface around the pole is shielded and therefore requires a communication relay in orbit. Future lunar activities will be established around a limited set of landing sites. In order to establish a sustainable presence on the Moon it is necessary to use similar equipment and assets on multiple missions. Thus, it is likely that a network of infrastructure assets for lunar logistics will be established by the first players on the Moon to support human and robotic exploration, as well as commercial activities. Like building blocks that support each other, they need to be able to interact; and therefore need to be in close proximity.

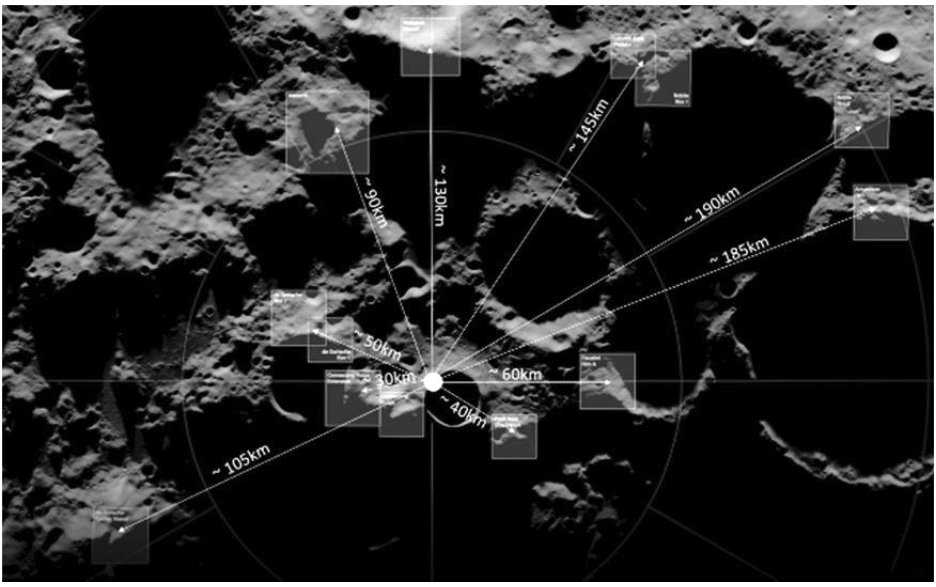

Figure 1: Distances of the NASA ARTEMIS Candidate sites with projected distance to the South Pole [adapted from [5]].

5 NASA 2022. NASA Identifies Candidate Regions for Landing Next Americans on the Moon, NASA Release 22-089, retrieved from https://www.nasa.gov/press-release/nasa-identifies-candidate-regions-for-landing-next-americans-on-moon.

In August 2022, NASA published a set of locations as candidate sites for the landing of ARTEMIS III. Figure 1 shows the sites in close proximity around the South Pole with an indication of the distances to the Pole as reference. Activity on the lunar pole could be comparable to activity on Earth's South Pole, Antarctica, where several nations share in peaceful cooperation the territory. Figure 2 illustrates the difference in size of both regions (lunar South Pole and Antarctica).

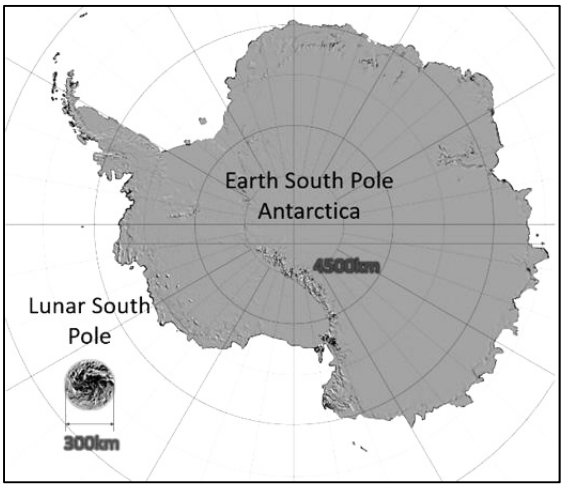

Figure 2: Comparison in size between the lunar South Pole region of interest for ARTEMIS and Antarctica[6]

A highly organized setup will be required to manage the lunar South Pole territory in a similar successful manner as Antarctica, to enable cooperation and prevent potentially harmful interference.

Since their first appearance in Section 11 of the ARTEMIS Accords, safety zones rapidly became one of the hottest topics within the discussion related to space resource and lunar activities. On the one hand, operators look at safety zones as a reassuring tool to protect their right to operate without harmful interference. Likewise, investors see safety zones as a critical safeguard enabling successful completion of the missions they are funding. On the other hand, States and stakeholders which are not directly involved in space resource and/or lunar activities fear that the real intent behind safety zones could be the *de facto* establishment of a first-come-first-served regime. As is often the case, the truth lies in the middle. To be sure, safety zones can

6 National Snow and Ice Data Centre, High-resolution mosaic of Antarctica, retrieved on 29/08/2022 from https://earthobservatory.nasa.gov/images/6087/high-resolution-mosaic-of-antarctica

either be used to uphold legitimate expectations for safe operations or abused to circumvent free access and benefit sharing. The important element to clarify in this regard is that safety zones do not exist under international space law (yet?). As such, we have the opportunity to structure them in a way that meets the needs of operators in compliance with international space law.[7] A decisive factor in this regard will be the interpretation of the principle of due regard under Article IX OST.

A systemic reading of this provision suggests that paying due regard to the corresponding interests of others will require a certain degree of self-restraint in the planning and conduct of space resource and lunar activities. This directly impacts the way safety zones can (and should) be designed to be compatible with international space law. The main boundary condition affecting the design of safety zones is the right of free access to all areas of celestial bodies established by Article I OST. Because of this right, safety zones can **never** be structured as keep-out zones.[8] However, they can be designed to trigger the obligation to conduct "appropriate international consultations" under Article IX OST for all those entering the designated area. It is crucial to note that this obligation to consult exists autonomously under Article IX OST and thus *is not a consequence of the safety zone*. What a safety zone does is determining the insurgence of the conditions foreseen by Article IX OST. Pursuant to this provision, a State is obliged to undertake appropriate international consultations *if it has reasons to believe* that its activity may cause potentially harmful interference with the activities of others. Declaring, through the establishment of a safety zone, that a certain space activity is being conducted in a given area at a given time, can be sufficient to provide others with reasons to believe that further activities can cause potentially harmful interference. As a result, any State planning or conducting activities in the area would be obliged to undertake appropriate international consultations. And since Article IX OST requires consultations to be undertaken *before* proceeding with the activity, the establishment of a safety zone would meet the need of operators to be shielded from potentially harmful interference.

It is important to note that the mechanism described above **does not translate into a priority right.** This is because Article IX OST does not technically prohibit the conduct of the "potentially interfering" activity, but rather delays it until "appropriate international consultations" have been conducted. So long as these have been undertaken in good faith, proceeding

7 For a thorough review of the meaning and implications of safety zones under the Artemis Accords *see* Gabriel Swiney & Amanda Fernandez, Lunar Landing & Operations Policy Analysis, Nasa Office For Technology, Policy & Strategy (2022).

8 *Id.* at 30.

with the activity would not be against Article IX OST. While this corollary is not ideal from the perspective of the actors that may suffer interference, this mechanism incentivizes States to find a mutually acceptable solution that would be difficult to achieve if the actor coming first would enjoy absolute priority. Furthermore, designed in this way, safety zones could help determining the apportion of fault-based liability in case of damages. For example, if an actor enters a safety zone without consulting the State the has declared it, and then an accident occurs, this actor could be *presumably* considered at fault for it. This is because to willingly disregard the existence of a safety zone might be tantamount to being reckless. An example from the other end of the spectrum could be envisaged when an actor would *fail to establish* a safety zone in an area interested by hazardous or particularly invasive operations. If an accident would happen in this area, a *prima facie* attribution of fault would point to the State which did know about the existing risks and willingly hid them from the others. Read in these terms, safety zones can also help implement existing obligations of responsible behaviours for safe and sustainable operations.

As a result of these technical and legal arguments, the definition of a safety zone for lunar surface operations will depend on various factors. The prime objective would be to deconflict operations on the lunar surface (by avoiding accidents and incidents). The design will depend on the nature of the asset, the allowable risk (e.g. a human rated system does not allow a high risk versus potentially a science instrument), the danger represented by the system (e.g. a landing system that can crash on a facility would imply a higher risk of danger than a static habitat located on the surface) and the variability in a transient timeframe (e.g. a human surface rover to be used only during a specific timeframe and then dismissed). The following table proposes a first elaboration of such an approach by taking into account some predominant assets in future lunar surface operations. As a result, protection zones around those assets can be defined by these criteria. For example, a human landing system will require an extended safety zone aimed at avoiding that other landing systems crash onto the existing lander. However, it might be limited in its duration, since the safety zone can be revoked as soon as the system has departed. A permanent surface habitat might require a slightly smaller safety zone, but it may very well need it for a much longer period of time. A lunar vehicle may require an even smaller zone, but it would change its boundaries more frequently. Finally, science instruments may further require a pristine area in order to perform their job (e.g. a radio telescope on the far side or instruments for soil analysis in uncontaminated areas).

Table 1: Assets in lunar surface operations

Asset	Allowable risk[9]	Danger (to other assets)[10]	Static or dynamic[11]	Variability in time[12]
Human Lander	Low	High	Dynamic 3D	Yes
Robotic Lander	Medium	High	Dynamic 3D	Yes
Crewed surface vehicle	Low	Medium	Dynamic 2D	Yes
Robotic surface vehicle	Medium	Medium	Dynamic 2D	Yes
Science instruments	High	Low	Static	Yes
Habitat or shelter	Low	Low	Static	No
Power plant or charging station	Medium	High	Static	No
ISRU Plant	Medium	High	Static	Yes
Power lines	Low - Medium	Medium	Static	No
Communication systems	Medium	Low	Static	No
Navigation beacons	Medium	Low	Static	No
Landing Pad	Medium	Low	Static	No
Surface tracks (roads)	Medium	Low	Static	No
Mining system	High	High	Dynamic 3D	Yes

9 Based on the impact of their failure or loss on human lives, facilities or investments.
10 Based on the risk that the asset becomes a danger to other assets.
11 Dynamic in two dimensions 2D (e.g. a surface roving vehicle) versus 3 dimensions (a flying vehicle).
12 Does the assets characteristics change in a timeframe (e.g. instrument not used anymore).

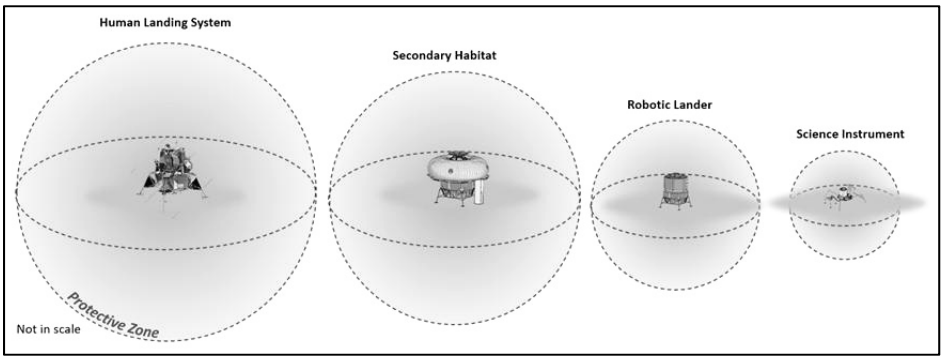

Figure 3: Illustration (not in scale) of safety zones around assets in functions of their allowable risk and danger to other assets.

Guidance, navigation and control (GNC) systems will also have a major impact on the dimensions of the safety zone. The targeted landing site for the Apollo 11 extended for 4km x 11km, whereas for ARTEMIS it will be around 15km x 15km. A differentiation also has to be made here between the *target site* (which is the area where a vehicle should land in function of its GNC capabilities) and the actual *landing site* (which is the perimeter around the landed vehicle).
Finally, a safety zone would not only need to take into account the asset itself, but also any asset that might critically interfere with it, as illustrated in Figure 5. The nature of the conducted operations will in fact impact the modalities for crossing a safety zone: e.g. a rocket landing close to existing surface facilities will require more coordination efforts than a small rover transiting nearby.

All of this to say that *one safety zone does not fit all.*

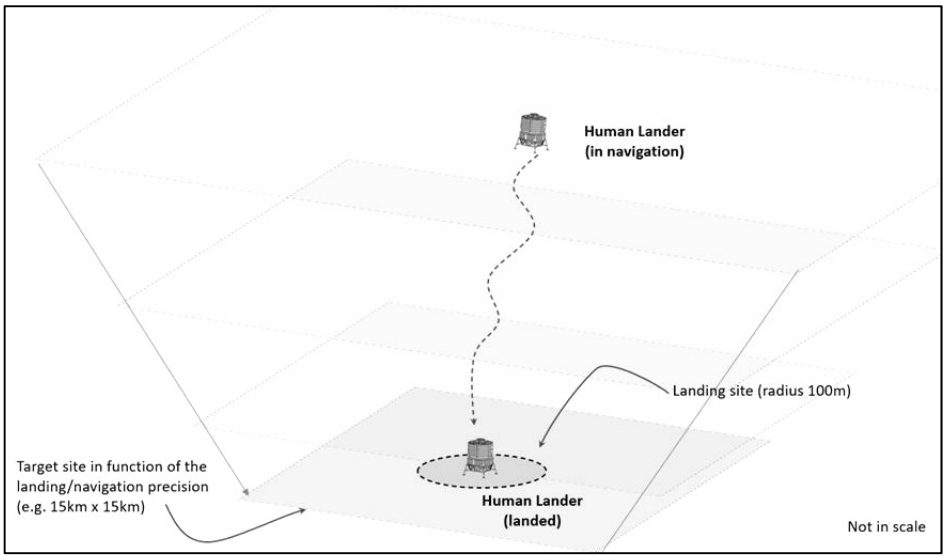

Figure 4: The Target site is the area where the vehicle could possibly land.

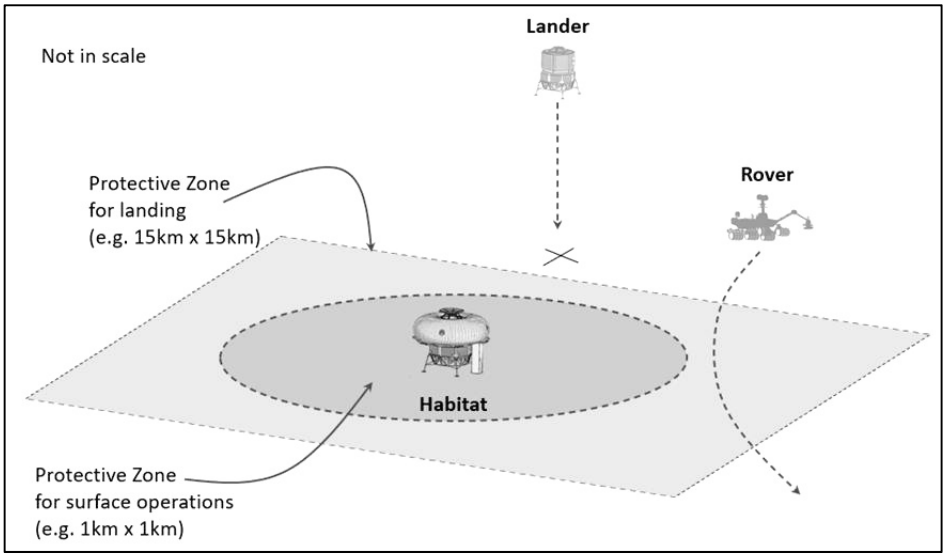

Figure 5: The extend of the protection zone might vary in function of the activity.

4. Conclusion

This paper discussed key technical and legal considerations associated with the concept of safety zones. In order to focus the discussion, the paper considered in particular the potential functioning of safety zones in the Lunar South Pole, as proposed by the Accords to deconflict surface operations. While the concrete features of each safety zone can only be evaluated on a case-by-case, the space community needs to quickly develop an overarching framework of foundational rules and procedures enabling more practical assessments. These rules will be necessary to allow various actors to operate and settle on the surface in a peaceful and sustainable manner. Hopefully, the considerations discussed in this paper can provide a useful starting point for a much needed debate on the functions and features of safety zones. The challenge of these considerations is to find boundary conditions that can align all actors under a common understanding. Because on a small body like the Moon, anything less than a globally shared approach has very little chances of being successful.