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Predictions and Possible Solutions
for the Sustainability of Mars Settlement

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Abstract:
With the end of the Cold War, political and ideological competition has decreased as a stated reason for space exploration. The possibility of establishing a settlement on Mars is being seriously evaluated by state and commercial space agencies, which includes objectives to expand human civilization and ensure the continuity of the human species. The technological challenges associated with space settlement continue to receive significant attention, but the success of space settlement will also depend on other human factors. This study presents a high-level overview of some potential issues that could arise with the development of a permanent populationand a space economyon Mars. This study highlights some of the anticipated problems of overnance, trade, production, and proliferation that will need pragmatic solutions to ensure the sustainability of a martian settlement. This paper is intended to instigate further discussion and research regarding human and economic factors that could enable or constrain future settlements on Mars.
Keywords: space exploration, mars settlement, mars economy, futures studies.

1. Introduction

Recently, space activities have been a stage for radical transformations. Globalization and advancing technology have influenced space activities which have been a strategic monopoly for certain countries ever since the dawn of space age [1], [2]. SpaceX, Deep Space Industries, Planetary Resources, and other private companies are developing their own capabilities for utilizing space resources, while state agencies like NASA, ESA, JAXA, IRSO, RFSA and CNSA have ongoing and emerging plans for Mars exploration and eventual human settlement. Perseverance is extracting the first oxygen from the Red Planet while looking for an answer to the question "was there life?" on Mars [3]. NASA's Ingenuity helicopter completed its second flight on Mars [4]. Many state institutions and private institutions have been working on a series of plans to visit Mars or asteroids, which are intended to support both financial profit and scientific transformation. It is also hoped that starting from the mid-21th century, the cost of entering an orbit will greatly decrease in accessing the near-Earth area, the Moon, Mars and beyond. SpaceX plans to use Starship for missions to the Moon as early as 2022 [5]. The company plans to fly four ships with two cargoes and two crew members in 2024 [6], [7].

Despite the discussions on the challenges brought by the radiation level on Mars, the infertile soil and low gravity; having a settlement on Mars is no longer a mere curiosity or a science fiction due to the increase in commercial interests as well as the possibility of reducing the risk of extinction on our planet.

The presence of a settlement on Mars would also enhance scientific and technologic advancement. Despite the costs and risks, such a mission would also have some ethical considerations such as providing a refuge to ensure humanity's survival in case a global catastrophe happens on Earth. Settling Mars might be a more long-term ambition than current agencies are planning, as humans are social beings and such a settlement will have biological and social challenges [8].

Nevertheless, scientists such as Carl Sagan have suggested that an extra-terrestrial settlement would be the only way to prevent the extinction of humanity [9]. The idea of building universal shelters to protect humanity from a series of global disasters has recently gained increasing attention. Such authors as Isaac Asimov, John Lesli, Martin Rees and Nick Bostrom have argued that humanity is under the threat of a series of global disasters [10]. Therefore, it is necessary to build shelters to ensure the re-establishment of civilization and the survival of humanity [11]. Accordingly, it is of utmost significance to secure a copy of our vital materials in those shelters [12]. Undoubtedly, the most important challenge for having a settlement on Mars is the high level of radiation [13]. Mars has a weak magnetic field and a thin atmosphere. As a result, the surface is not protected from radiation like it does on Earth. There are three types of radiation on Mars that we should be worried about. The first is solar winds, which consist of charged particles that are constantly coming out of stars. The second is cosmic rays and the third is solar flares. Covering the entire habitable area with about a meter of regolith might be sufficient to protect the settlers from the first and second types of radiation [14]. Addressing the radiation risks of Mars settlement remains an ongoing challenge and active area of research.

Several countries have already started to conduct robotic missions on Mars, which support immediate science goals but are part of a longer series of missions that are intended to develop a permanent settlement.

NASA launched the Perseverance explorer on 30 July 2020, which will land at the Jezero crater of Mars to collect evidence of ancient life and samples of rock and soil for possible return to Earth [15]. The United Arab Emirates became just the fifth nation to successfully send a spacecraft to Mars when its robotic probe, named Hope, began orbiting the red plant [16]. The orbiter of the Tianwen-1 Mars mission, China, successfully launched towards Mars on 23 July 2020. China's mission to Mars is to study the geological structure of Mars, surface features and climate [17]. The ESA ExoMars Trace Gas Orbiter mission launched in 2016 and detected new gas signatures on Mars. This discovery helps to unlock new secrets about Mars' atmosphere, as well as to determine whether the atmosphere of Mars contains methane, a gas associated with biological and geological activity [18]. These missions are all part of a longer program of scientific exploration on Mars by these space agencies, which all have plans to eventually send astronauts to Mars.

This paper provides various predictions and possible solutions regarding some of the issues that are expected to emerge during the settlement of Mars. This paper is not intended to be an exhaustive presentation of all such issues that might occur, but instead this paper is intended to highlight some of the human challenges for developing a sustainable martian settlement. The high-level discussion presented in this paper could serve to motivate further research on specific issues or could also be used to developo a more extensive research agenda for studying Mars settlement. In general, this type of analysis of the sustainability of humans in space can also be useful for future studies, such as by informing activitites in scenario development or future projections.

2. Why Should Humans Live on Mars?

The Red Planet has always been a source of mystery and challenge for everyone. Settling Mars is a popular topic today, but it also has a controversial side [19]. People have many reasons for wanting to travel to Mars and to settle there. In one sense, curiosity and exploration has been innate to humans, and aspiration of going to another planet provide a continuation of this human desire to travel beyond the boundaries of our home [20].

If humans are to live on Mars in permanent settlements, then the use of local resources will be essential for long-term sustainability. The atmosphere of Mars is composed of 95% carbon dioxide, 3% nitrogen, 1.6% argon, small amounts of oxygen and water vapour. There is also a source of methane in Mars. A large portion of Martian surface is covered with a talc powder like material. Small hematite spheres has been found in the rock samples collected from the Meridian Plain on Mars. Since 2003, sulphur, iron, bromine and other minerals have been discovered on Mars by the high resolution stereo camera located in Mars orbit. Sojourner Rover of Pathfinder measured the elements on Mars rocks with Alfa Proton X-ray spectrometer by NASA. Several discoveries by the Mars rovers have shown that the Red Planet has many of the natural resources needed to sustain human life. Solar wind sources available on Mars might be a practical solution for generating energy. The abundance of volcanic features combined with widespread craters also suggests the possibility of various ores on Mars. Further prospecting would be needed to determine the economic potential of Mars, but sufficient evidence exists to suggest that commercial agencies may take interest in a variety of mineral resources available on Mars [21].

SpaceX founder Elon Musk has stated this his goals for settling on Mars is for the survival of mankind. In terms of survival arguments, authors such as Carl Sagan, Ray Bradbury, Stephen Hawking and Paul Davies have articulated views that overlap with some of Musk's ideas [22], [11]. Various authors have discussed reasons for traveling into space and develping a permanent settlement on Mars. Many of these views have been widely represented in popular discussions of Mars settlement, such as [23], [19]:

1. Extending the sustainability of the human species
2. Searching for extraterrestrial life
3. Find new solution to problems that can improve life on Earth
4. Transforming our civilization
5. Demonstrating economic and political leadership

So far, researchers have not only discovered evidence of trace of water in the form of ice beneath its poles, but underground lava tubes are also suspected to provide potential underground habitats to future settlers. The exploration of such sites on Mars provides scientific information about the origin and the future of Earth that can also assist with planning for eventual human settlement [24].

First, reaching other planets can increase our chances of survival by providing a refuge for withstanding global catastrophes. Secondly, the purpose of Mars settlement is not just about survival but also about the contribution to sustainable growth through using the natural resources of Mars.

The third item is about improving the life quality of those people living on earth through the development of space technology. The process of technology transfer has resulted in many useful inventions in our lives today that originated as space technology. For example, weather forecasting satellites save thousands of lives each year by providing public storm warnings. Likewise, satellite communication abilities affect every aspect of civilization. Satellite technologies have made banking and finance, navigation, international and long-distance phone calls in daily communication, satellite TV and radio completely routine [25]. Fourth, space settlement provide an opportunity for the transformation of humanity as a species by challenging explorers to venture even greater distances from home. For example, the thematic epics of the long geographical discoveries of Western civilization, such as the long ships that colonized Greenland, serve as an inspiration for spaceships being designed for sending to Mars in the near future. In fact, in a way, exploring the interplanetary ocean of space is like a repeat of such old times. The curiosity about the existence of humanity, its origins and where it came from is perhaps an evolutionary drive [26]. Fifth, the state and private agencies that develop settlements on Mears will gain recognition as economic and political leaders in the emerging space sector [27].

The first settlers on Mars might be representatives of state or private agencies that are driven by mission requirements with rigid guidelines. However, as the settler population begins to grow to include a larger staff, tourists, and others, such a rigid system is less likely to be sustained. For this reason, a new governance order would likely emerge as a permanent and self-sustaining population develops on Mars.

3. Predictions

This section raises some questions and offers some predictions on the future of Mars settlement as well as the solutions for some possible challenges. These predictions are qualitative and speculative, but they are intended to help frame the discussion about Mars settlement and promote further analysis.

3.1. Who Will Go Fırst?

In terms of ethnicity, religion, terminology, and personal characteristics; the identity of Martian settlers is unknown. Personal values, political beliefs or other "psychographic" factors with which people identify themselves can become quite significant in the process. Besides, in case the private organizations offer guidance to the Mars settlement; the culture of this organization may also play a role.

The initial small group of settlers might consist of altruistic, distinguished and technologically strong individuals [19]. By sending robots to Mars first, a field station could be built on the Martian surface. Using propulsion systems similar to Deep Space Transport, the spacecraft could transport and land supplies, habitats, equipment for in-situ resource use (ISRU) and other equipment using robotic flights [28]. If a Mars settlemet is actually able to develop to the point at which it can sustain an excess population beyond those required to manage it, then Mars may attract a wide population of tourists and other visitors. Mars could be a shelter for those feeling overwhelmed by overcrowding; or it could be an attractive place for to those who want to abandon Earth. One can even imagine extreme cases in which forced labor could occur in space settlements that lack sufficient oversight. However, such futuristic space settlements might also include a mixture of different social classes in addition to lower classes. Such a broad range of possibilities is a ripe opportunity for developing different scenarios for the emergence of a Mars population [29]. In such a distant future, if Mars were to become a self-sufficient independent planetary state, then it could even be a place where people might willingly and easily travel to, which conceivably could include monitored travel that requires an international passport or a visa, similar to international travel on Earth today.

3.2. *Who Will Lead the Development of Mars Settlements?*

Both state and commercial space agences are seeking to eventually send humans to Mars, but it is not yet clear who will suceed first. State agencies might tend to prioritize scientific missions that also support political objectives. Commercial space agencies may priotitize missions that generate profit, which may make the partnerships between the government and the industry quite complicated [30].

Several private companies, including SpaceX and Blue Origin, have announced their intention to continue developing space touring opportunities in the coming years. Such ventures may ultimately enable tourist travel to Mars. Successful or not, such efforts show increased public interest in space settlement and suggest the possibility that private companies may be the first to arrive on Mars, rather than state space agencies.

3.3. *How Will Trade be Economıcal?*

Just as nation-states on Earth need to trade so that they can financially improve themselves; so will the future planetary civilizations. While it is possible to send food or other basic necessities to settlers on Mars, an important possible export could be patents and other forms of intellectual property. The settlers on the Red Planet will need to innovate to meet their own needs. And there is no doubt that they will be capable of making several technological inventions in a space without boundaries thanks to their bright, wise, and skilled nature. For instance, they will need to grow their crops in greenhouses, which certainly requires optimization for plantation area within the greenhouses. As a result, they will have a strong incentive to resort to genetic engineering to boost crop yields. An advanced technology to recycle wasted yet valuable materials. Such inventions will also prove themselves to be significant for life on Earth and patents licensed on Earth will thus create a flow of sustainable income for the Red Planet [31]. Zubrin, favours the idea to license intellectual property for the profitability of the Mars settlement. He says that interplanetary trade will have three outlines in the future. His first suggestion for export business in interplanetary trade is helium-3, a rare isotope of considerable value that does not exist on Earth and can be used for second-generation thermonuclear fusion reactors if extracted on the Moon. Mars does not yet have a known helium-3 resource, although helium-3 deposits have been detected on the Moon. On the other hand, because of its complex geological history, Mars currently possesses a considerable amount of concentrated mineral ores with precious metal ore concentration since men have intensely scanned terrestrial ores for the last five years. The second suggestion is deuterium. Deuterium is more expensive than other elements, even with cheap power. Its current market value is 25% more valuable than silver (27 dollars per ounce) or gold (1200 dollar per ounce). Zubrin suggests that a Mars settlement could profit from selling deuterium. Zubrin also suggests asteroid mining. When the Mars settlement starts living on the Red Planet, the settlement will have a crucial role in supplying ore to the asteroid belt. Zubrin also considers Phobos and Deimos as valuable preparation spots on the way to the asteroid belt. He combines all these suggestions under a concept of "triangular trading activity" in which our planet sends high technology finished goods to Mars; Mars sends low technology finished goods to the asteroid belt and possibly food staples to the Moon, and metals are sent over the asteroids [32]. Until the moment Mars settlers transform into a self-sustaining community, they will be dependent on Earth. Hence, its financial independence will be based on technological inventions that do not exist on Earth, products that cannot be acquired on Earth, and other activities.

The Outer Space Treaty of 1967 gives states responsibility and jurisdiction over any non-government organizations, so the laws of the host state regarding patents and intellectual property will likely also apply to private space agencies. For example, consider a group of people living on Mars. Initially, settlers will be dependent on Earth. However, the mass of the products to be supplied from the world will be very costly as the population increases in time.

As the incentives for technological development increase, financial growth will follow. The cost of importing food from Earth to Mars will result in financially high export and import rates for many products as the cost will include transportation and labour work, and as a result it will eventually be cheaper to produce food on Mars. In this context, the Martian economy will be dependent on capital initially, and over time the settlers will attempt to capitalize their products and inventions [33].

4. Can We Develop our Own Food Production on Mars?

When the first settlements reach Mars, one of the biggest challenges will be producing a food source. It will be very costly to continually procure these food resources from Earth. Over time, this will push settlers on Mars towards a self-sufficient and sustainable agriculture [34]. So what kinds of foods can we produce on Mars? Transporting large animals into space and set up the facilities necessary to house the animals as livestock is infeasible in the short term, but smaller animal protien sources such as crickets could supplement plant-based foods [35].

In the long term, Mars settlers will contribute to the manufacturing of anything varying from food and medication to breathable air, industrial chemicals and construction materials, depending on the options for on-site production. Biological manufacturing will be of utmost importance in Mars as it will help Mars settlements transform gradually from full dependence on Earthly resources to full independence. Biotechnology is one of the most urgent needs for food production on Mars. For instance, it will take about five tons of food to feed a crew of six with a daily 3.000 calories for a 500-day surface mission. For emergencies, this will vary from eight to ten tons. Traditionally, nutrient and calorie dense foods are the preferred dietary options for astronauts to minimize the workload, which does not necessarily priotize the variety and aroma of foods. Although the first missions will transport all the food needed to survive; microbial organisms might supplement the basic food supply [36].

Insects and clean meat (cultured meat) may be produced as food on Mars. As time progresses, Mars settlers may increasingly turn to different options beyond plant-based options. In a study conducted at Lunar Palace 1 in China, they created a menu of cultivated plants and insects that feed 3 people in 105 days. In such studies, microbes have been suggested as a direct or indirect food source that could be used on Mars [37]. Plants and vegetables have been successfully grown in NASA's hydroponic greenhouses that mimic greenhouses on Earth [38]. The use of synthetic biology, which offers a new perspective on growing plants and vegetables on Mars, could also improve the potential performance of plant life on Mars [39]. Synthetic biology is 'a new field aiming to use engineering principles to reprogram living systems' [40]. An advanced synthetic biology facility could improve many of the features needed to ensure crops thrive on Mars, and developing such these next-generation products on Mars might even benefit people on Earth [34].

5. What Governance Structures Will Develop on Mars?

The Outer Space Treaty forbids any claim to sovereignty on celestial bodies. Yet space agencies are still developing plans to permanently settle Mars, while refraining from making explicit sovereign claims. Such an ambiguity suggests the need for new governence models to apply to the sharing of Mars.

Bruhns and Haqq-Misra suggest a large-scale planetary parks and land approach for Mars settlement to limit sovereignty over certain regions of Mars. According to this model, the international community will determine a planetary park system to exclude irregular trespassing or settlement within the park borders of Mars [41]. The model also suggests the establishment of an administrative Mars Secretariat. Intersettlement relationships and conflict resolution will be diplomatically managed as in line with international agreements by a commission of representatives for Mars settlements [41]. Once Mars settlements reach a certain size, then conflict and the need for conflict resolution may become inevitable.

The leaders of martian settlements may not always be able to resolve all conflicts with other settlements. Therefore, it could be beneficial to have a Mars Secretariat as a mediator, although it should be emphasized that such a Secretariat does not hold any formal power or claim sovereignty over other states.

Many other such possibilities exist for governing Mars; however, until a state structure is built on Mars, it is strongly possible that Mars will be run by global actors [29]. Elon Musk thinks that the Mars will have not a representative democracy but a direct democracy; so that means people will directly vote on the problems. He said that laws are made with 60% of the votes and laws are abolished with more than 40% of the votes. Direct democracy would create conditions where it's slightly harder to put laws into effect than to abolish them and where laws do not automatically just last forever [42].

Technocracy is a system in which the decision makers are technical experts. The administrative roles are taken over by the scientists, engineers and technologists with the knowledge, experience, and talent [43]. Such countries as South Korea, Singapour, Malaysia, Vietnam, India, and Thailand are the countries which practice the basic elements of technocracy really well. Their basic philosophy is "minimum government, maximum governance" [29].

Meritocracy is also suggested for Mars settlements. Meritocracy is a system in which the merits, skills, effort, and competence are considered as measurements for seniority and promotions. The term merit also includes talents, education, and experience. Meritocracy can be considered as an ideal justice principle as it ignores ethnicity, origin, and gender. A combination of competence and effort is basically the key point in meritocracy focusing on the occupational achievement [44]. Singapore is the best example country for applying meritocracy principles as the qualified people are assigned to the management positions, which could be a contributor toward Singapore's financial success as a dominant ideology within the country.

This list of suggested models is necessarily incomplete and intened to be illustrative of the types of models that are relevant to Mars. Regardless of the model, it is imporatnt that such models maintain the political freedom of Mars settlers. In other words, governance should avoid any tendency toward tyranny or the infringement of civil liberties.

6. How to Proliferate on Mars

It is questionable whether it will be possible to proliferate on Mars. However, it will also be mandatory to sustain the population on Mars. Until Mars is a self-sustaining settlement, there will be a need for migration from Earth to maintain a stable population [45].

The space environment is already physically challenging for manned flight. Ionising radiation, tissue damage, cancer risk, acute radiation syndrome, and central nervous system damage are some problems [46]. Ionising radiation will cause "either directly or indirectly an atom to lose an electron or a breakdown in the nucleus" and this is significant potential risk for space travellers. This ionising radiation can directly damage cellular structures or break down water molecules, both of which may lead to abnormal cellular function, DNA mutation and even cellular death [46]. The space environment has severe impacts on muscles, bones, blood flow and immune system and thus understanding how to treat them is of utmost importance for space missions. Genetically compared to humans, mice are easy to work with and can help us understand how the human body may operate under these circumstances [47].

Russian Bion-M 1biosatellite hosted male mice in space for 30 days. The project's objective was to understand cellular and molecular mechanisms of mice when exposed to long-term microgravity [48]. In a study conducted by Italian Space Agency, mice were exposed to 91 days of microgravity [49]. Which affected their reproduction system and fertility. In another study carried out by Japanese researchers, 12 male mice were kept for 12 days in the International Space Station. While some were exposed to microgravity, the others were exposed to artificial gravity. Upon their arrival on Earth, female mice which had never been to space were fertilized with male sperm and the babies turned out to be healthy. The fact that their parents' were exposed to radiation had no negative impact on the babies and the male genital organs did not get damaged [50]. In a study trying to find the impact of space radiation on male genitals; mice sperm were preserved in the International Space Station for 9 months. Researchers found that they have a greater amount of fractal DNA than the ones on Earth, and when they fertilized a female mouse with this sperm, the space sperm managed to create healthy embryos, healthy and fertile babies [51].

Therefore, as the studies suggest, it can be said that proliferation seems possible for space environment or in a extraterrestrial settlement. However, when it comes to human proliferation, age is a significant factor that needs to be considered. As we age, DNA damage becomes increasingly widespread on our cells. As the eggs age, our body loses its skills to fix the damaged DNAs of the sperm.

Proliferation in space may pose some risks. However, it is possible that these challenges can be overcome with the help of technological advancements as it will take decades for humanity to start a settlement on Mars. Although it will be challenging to see an embryo growing in a womb during a long space flight; it can still be possible if we manage to develop an artificial womb to do the job so that both the mother and the baby will be safe.

7. Conclusion

This study focuseds on a high-level discussion of some of issues in maintaining the sustainability of Mars settlements. Thinking broadly and critically about Mars settlement is necessary today, well in advance before any space agencies begin sending the first human explorers to Mars. New studies also need to be conducted to understand possible on-site resource use and cost. Such further studies will allow for more quantitative predictions and scenario building. A new governence structure seems likely when contemplating a distant future of an independent Mars settlement, and such models should continue to consider both technological and sociological factors that may enable or limit their success.

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