# Minimum number of settlers for survival on another planet

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# MINIMUM NUMBER OF SETTLERS FOR SURVIVAL ON ANOTHER PLANET

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**Abstract**: We address the difficult problem of determining the minimum number of settlers and resources for survival on another planet. A mathematical model is proposed and its parameters are discussed. It is based on an estimation of the average annual time needed for a settler to produce all objects. The main parameters are the number of technologies that have to be mastered, the number of settlers and the sharing factor, which depends on the number of shared objects among the settlers.

**Keywords:** Survival, settlement, Moon, Mars

## 1. INTRODUCTION

There are many reasons to justify a human mission to the Moon or Mars [1,4,7]. One of the reason is the long term goal of establishing a permanent base in order to start a settlement [5,6,7]. For example, one of the motivation of the Moon Village association is to “establish relations with those who are, or plan to be active participants in the exploration, development and eventual settlement of the Moon”. The Mars Society defines itself as “the world's largest and most influential space advocacy organization dedicated to the human exploration and settlement of the planet Mars” [9]. In the last NASA designs of human missions to Mars, that long term goal is also clearly stated [2,3]. Other organizations, such as Elon Musk with Space X, set the settlement of Mars as a primary objective. However, even if intentions are clear, the projects are vague, the complexity of the enterprise is very high and the feasibility is uncertain, especially if no economical return is expected or not enough (tourism) [5]. One of the most important difficulties is typically the ability to increase the number of settlers and at the same time to provide all necessary objects for them, maintaining life support systems in acceptable conditions. Intuitively, it is generally felt that the colony can achieve autonomy when there are enough people (e.g., thousands or millions) to develop and maintain local industries, but the problem is to find a sustainable development of the colony. As long as the number of settlers is kept relatively low, such difficulties can be easily overcome, but if the number of colons rises up to several thousands and if it is required to transport thousands of tons per year to the planet, the settlement project would rapidly become too expensive and would be stopped. In this case, as it would be very difficult to transport everyone back to Earth, the settlers would have to survive on their own. But what is the feasibility of surviving on another planet without the help from earthlings? In addition, the same question would have to be addressed in case of war or cataclysm breaking down important industrial assets of the space sector, stopping the colonization process for a long period of time.

The feasibility of survival on another planet is also a fundamental problem if humans are all threaten with death due to a planetary disaster (e.g., impact with a giant asteroid or world pandemic) and the only solution is to settle another planet [1]. In case of time and payloads constraints, the number of people that could be sent to the planet (Moon or Mars) would be limited [2,3,4,8]. An important question would therefore be to determine the minimum number of people and the most appropriate organization to make the settlement feasible. This difficult question is addressed in this paper. It is possible to make assumptions and to discuss different scenarios, but what is generally lacking is a methodology to perform quantitative assessments. The objective of the paper is to show that a mathematical modeling of the problem is possible. In Section 2, a mathematical expression is proposed and the parameters are discussed. In Section 3, some assumptions are made and some results are presented showing that the feasibility of the survival can be quantitatively assessed.

## 2. MATHEMATICAL MODEL

### 2.1. Main principles

The problem can be mathematically defined in different ways. Basically, the minimum number of settlers for survival depends on their capacity to produce essential objects and consumables using local resources. Obviously, if many resources are sent to the planet, the survival could last several years even with a small number of settlers but it is expected that these resources would finally be exhausted and in the end the survival would be a failure. As a consequence, at least in first approximation, the survival (long term) does not rely on the amount of resources sent from Earth. Providing that the initial state is viable, it is assumed here that the survival depends only on two important variables:

- Available local resources. Specific resources have to be available for survival (water, oxygen, etc.) or there should exist an engineering process to produce them.
- Production capacity. For a given number of settlers, the capacity has to reach an acceptable threshold allowing survival and development of the colony.

If it is possible to find appropriate resources on the planet, the threshold depends on:

a) The number of settlers (direct impact on the needs).
b) What living conditions are acceptable.

And the production capacity depends on:

c) The selected agricultural, industrial and chemical processes for maintaining life support and producing essential consumables and objects for the settlers.
d) The working time capacity of settlers.

Intuitively, as the number of settlers grows, the needs also grow but not linearly because some objects can be shared among several settlers. For instance, a habitat or a vehicle can be shared by several persons. The working time, however, grows proportionally with the number of settlers. For that reason, it is expected that for a high enough number of persons, the survival becomes possible. Mathematically, it can be simply expressed using the following expression (1):

$$\frac{r}{s(n)} < w \tag{1}$$

Where:

r is the individual annual working time requirement to run all essential production processes.
s(n) is the sharing factor, with n the number of settlers.
w is the annual individual working time capacity

Remark: intuitively, in order to produce all the needs of the settlers, the left part of the inequality should be linearly dependent upon the number of settlers. However, as the capacity of work should also be linearly dependent upon the number of settlers, the inequality was simplified and n only remains as a parameter of the sharing factor.

### 2.2. Individual working time capacity estimation

The annual individual working time capacity may be determined by different ways. This parameter may vary according to the type of work, the organization of the colony, habits, etc. In modern societies, a person usually works 1600 to 2000 hours per year. However, in the context of our problem, the working time should include tidying up and cleaning the habitat (minimum), preparing the meals, and all required daily activities for a decent survival. The value of w is therefore much higher than 2000, probably in the order of 4000 hours.

### 2.3. Individual working time requirement estimation

In order to estimate the annual individual working time requirement, it is necessary to determine the list of all human activities required to sustain the lives of the astronauts. It is important to notice that some objects have a very long lifetime but nevertheless have to be recreated at one point for survival. This is for example the case of vehicles and habitats. Therefore, their production or construction has to be considered in the annual working time requirement according to an annual contribution. For survival, the principal needs are:

- Air revitalization: oxygen production, carbon dioxide removal, etc. (assuming the atmosphere of the planet is not breathable).
- Water production and recycling.
- Food production.
- Energy production.
- Habitat construction and maintenance.
- Basic medical acts.
- Raising children.

Obviously, in order to fulfil these needs, numerous chemical and industrial processes have to implemented, which in turn may require other industrial processes. For instance, for the construction of a habitat, it might be required to extract specific ores, which requires the use of tools made of iron, which in turn can be made thanks to an iron industry, from ores extraction to the production of iron tools. For survival and in order to minimize the individual annual working time, the best strategy would be to minimize the number of industries that have to be implemented to fulfil the needs. Though modern tools such as computers and robots would highly increase the productivity, the construction of such complex objects using local resources would indeed have a terrible impact on the number of industries that would have to be developed and therefore on the annual individual working time requirement. For a first approach of the problem, we propose the following list of activities:

- $a_1$: In the domain of chemistry, collecting atmospheric local resources, controlling air composition in habitable modules, producing appropriate gazes, collecting, controlling and processing water, producing chemical elements such as ethanol or methane for combustion engines and producing other useful elements such as ethylene.
- $a_2$: In the domain of biology and agronomy, agricultural activities, storing and transforming food, as well as exploiting plants for specific uses (e.g., wood for objects and specific plants for pharmaceutical products).
- $a_3$: In the domain of iron industry, extracting, collecting and processing ores, producing tools for all other industries and producing iron based elements for the construction of vehicles and buildings.
- $a_4$: In the domain of ceramics and silicon industry, extracting, collecting and processing appropriate soil, producing glass, producing photovoltaic cells for energy production.
- $a_5$: In the domain of buildings construction, collecting appropriate ores, preparing construction materials, building the habitats, greenhouses and other habitable zones. The maintenance of the habitat also has to be taken into account.
- $a_6$: Last but not least, for survival and for the development of the colony, it is important to raise children and to educate them.

r is defined by the sum of all annual individual working time for these activities (equ. 2).

$$r = \sum_{i=1}^{i=6} r(a_i) \quad (2)$$

This list is not exhaustive and different technological choices are possible. The objective is to provide an idea of the minimum list of human activities that have to be implemented in order to survive on another planet. From that list, it can be easily inferred that the value of r is probably very high and a large number of persons is required. Importantly, different values can be chosen according to the available resources on the planet. For instance, if it is not practical to use the sunlight to grow plants, artificial lighting would be required and there would be an impact on $a_1$ and perhaps also on the model itself with another industry for the production of LED. A comparison between the survival on the Moon or Mars can be made. Without going into detail, it can be anticipated that many activities would be impacted by the choice of the planet:

- Water extraction.
- Collecting carbon dioxide for chemistry.
- Plants growing, artificial lighting or not.
- Energy production.
- Collecting and processing construction materials.
- Collecting and processing ores.

Based on that list, it could be argued that survival on Mars would require simpler technologies with less impact on the value of r. However, it is not in the scope of the proposed study to provide a clear answer to that question.

### 2.4. Sharing factor

The final parameter is the sharing factor. As the number of persons grows in the colony, more and more objects are shared among them. For instance, people can live in the same habitable module, sharing the same air revitalization system, the same water processing system, the same energy production system, etc. Obviously, the scale of such systems have to be adapted to the number of persons, but scaling up has often a small impact on the required time to develop and operate the systems. For some activities, however, scaling up does not provide substantial time saving. For instance, in the agriculture domain, in first approximation, provided that the work is mostly manual, the number of plants and therefore the working time is almost linearly dependent upon the number of persons. Other systems can be shared but among a rather limited number of persons, for instance, space suits or vehicles. Considering boundary conditions, the sharing factor is a function of n that can be defined with three properties:

- For n=1, the sharing factor must be equal to 1 (no sharing possible).
- For n>1, the sharing factor must be a monotonously increasing function of n.
- For very high values of n, it is expected that the sharing factor would not increase in a significant way.

In first approximation, a family of candidate functions can be used (equ. 3):

$$s(n) = n^{\alpha} \quad \text{(with } \alpha \text{ in the range [0;1])} \qquad (3)$$

## 3. RESULTS

In order to illustrate the method, some assumptions are made and some results are presented. Using equ. (3), the minimum value of n satisfying the condition in (1) can be calculated. It is given by equ. (4).

$$n = \left(\frac{r}{w}\right)^{1/\propto} \qquad (4)$$

A major difficulty is to determine the value of r. We propose to examine two scenarios with very different values to assess the impact on n. One is pessimistic and the other is optimistic.

Pessimist scenario (see Fig.1):

$w = 4000$ hours

$s(n) = n^{0.5}$

r in the range $[2 \times 10^5; 4 \times 10^5]$ hours

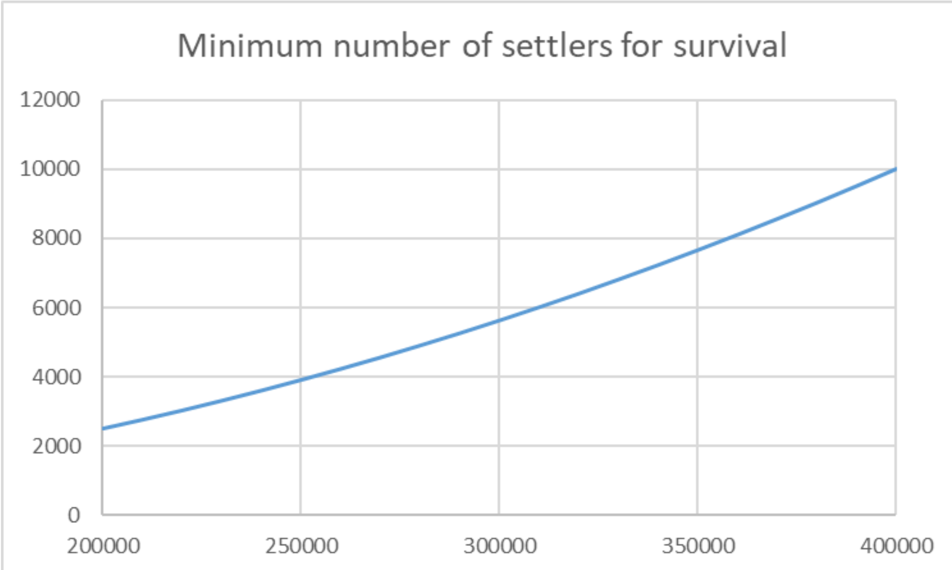


**Fig. 1. Minimum number of settlers for survival, n=f(r), pessimist scenario.**

Optimist scenario (see Fig.2):

w= 4000 hours

$s(n) = n^{0.55}$

r in the range $[10^5;2x10^5]$ hours

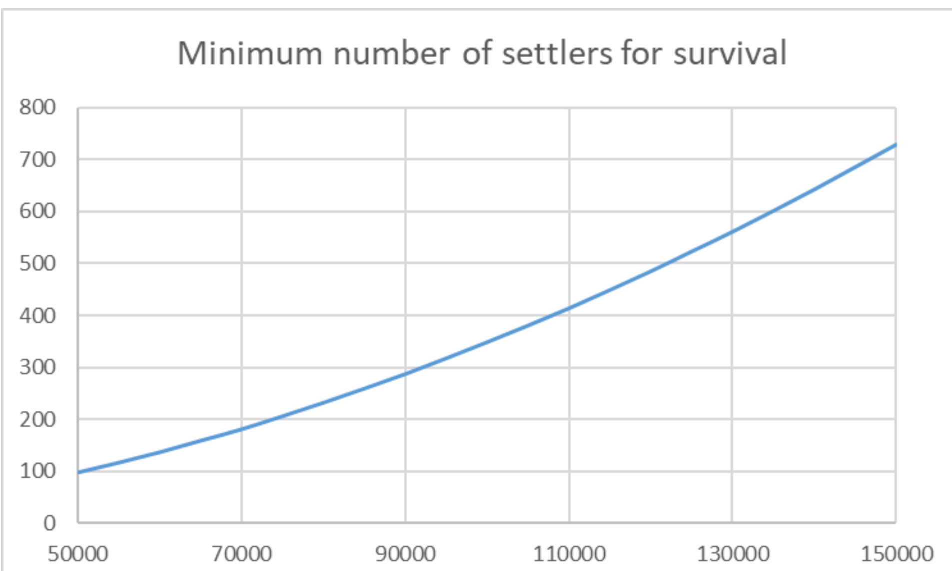


**Fig. 2. Minimum number of settlers for survival, n=f(r), optimist scenario.**

## 4. CONCLUSION

A simple method with very few parameters has been proposed to determine the minimum number of settlers for survival on another planet. It is based on the comparison between the required working time to fulfill all the needs for survival and the working time capacity of the settlers. In the examples provided to illustrate the method, the minimum number can be as high as 10,000 in the pessimist scenario and as low as 100 with optimistic assumptions. That number is also dependent upon available resources on the planet. With the proposed method, it is possible to make a comparison between the survival on the Moon or Mars. A detailed analysis of the required processes has to be carried out to determine an accurate value of the minimum number of settlers for each case.

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