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An Investigation on The Economic Feasibility of Space Elevator

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ABSTRACT

Although Space Elevator is a relatively new subject in the field of science concepts, it can now be considered as a science fiction. Space elevator was introduced as a concept in 1895 by Russian physicist Konstantin Tsiolkovsky. The space elevator has a great potential to be one of the appealing engineering projects ever designed. Nowadays, transporting the cargo to the space is both expensive, very complex and it also takes a long time. Construction of such a space elevator will enable humankind to make space travel and cargo transportation easier, cheaper. In this context, we mainly study how to extract the economic feasibility of this futuristic wonder of the giant mega structure for preliminary examination.

In this study, a qualitative research method has been used in the scope of the relevant sources in the literature. The space elevator can significantly reduce costs in sending cargo to space and provide easier access to space. It may be beneficial in terms of space tourism in the following years. It can even be a stepping-stone for asteroid mining.

The space elevator is under construction and can be an example and guide in removing economic feasibility or in future . The purpose of this article is to focus on the definition of space elevator and its construction, and also to argue on the reasons why the project is essential. Thereafter, we will discuss and analyze the effects of the space transportation mainly in the economics perspective.

Keywords: Space Elevator, The Cost Of Space Elevator, The Design Of Space Elevator.

Uzay Asansörünün Ekonomik Fizibilitesi Üzerine Bir Araştırma

ÖZET

Uzay Asansörü, bilimde nispeten yeni bir konu olup genel olarak bir bilim kurgu konusu olarak algılanmaktadır. Uzay asansörü kavram olarak 1895 yılında Rus fizikçi Konstantin Tsiolkovsky tarafından ortaya atılmıştır. Uzay asansörünün hayata geçirilmesi durumunda mühendislik ve bilimde önde gelen projelerden biri daha gerçekleşmiş olacaktır. Günümüzde kargoyu uzay boşluğuna ulaştırmak hem pahalı hem de çok karmaşık ve uzun bir süreçten oluşmaktadır. Dünyada veya Ay'da bir uzay asansörünün kurulması, uzay yolculuğunu ve kargo taşımacılığını daha kolay, ucuz ve sürdürülebilir bir hale getirebilir. Bu bağlamda bu çalışmanın amacı bu fütüristik harikası olan dev mega yapının ön incelemesi için ekonomik fizibilitesini çıkartmaktır.

Bu çalışmada uzay asansörü ile ilgili mevcut literatür taranarak ilgili kaynaklar kapsamında nitel bir yaklaşım kullanılmıştır. Uzay asansörü uzaya kargo göndermede, maliyetleri ciddi bir biçimde azaltıp, uzay'a daha kolay erişim sağlayabilir. İleriki yıllarda uzay turizmi açısında fayda sağlayabilir. Hatta asteroit madenciliği için bile bir atlama taşı olabilir.

Uzay asansörünün yapım aşamasında olduğu ve ekonomik fizilbilitesini çıkarmak ya da ileriki çalışmalarda örnek ve yol gösterici olabilir. Bu makalenin sonucunda uzay asansörünün tanımı, nasıl inşa edileceği ve neden uzay asansörüne ihtiyaç olunduğu üzerinde durulacaktır. Daha sonra, yükün uzay'a nasıl daha kolay ve ekonomik olarak taşınması gerektiği üzerine çeşitli kaynaklardan bir bilgi derlemesiyle açıklanmaya çalışılacaktır.

Anahtar Kelimeler: Uzay Asansörü, Uzay Asansörü Maliyeti, Uzay Asansörü Tasarımı.

1. INTRODUCTION

Even though it used to be considered totally as be considered as an element of science fiction, space elevator is one of the most assertive and grandiose engineering projects nowadays (Isaacs et al, 1966: Pearson, 1975: Clarke, 1979). In Bible, the story on the Tower of Babel makes a reference to a superior civilization in Mesopotamia who wished to build a tower tall enough to reach the stars. Space elevator has been a new enterprise to revive the dream of the Tower of Babel with new equipment and tools of technology (Yazıcı, 2019).

In addition to the expectation that a space elevator getting into the orbit will lower the costs considerably, it is also expected to revolutionize the way we access to outer Earth, the Moon, Mars and beyond. The concept of space elevator has great importance in future development in the late 21st century since it offers a great potential of transportation into the space just as highways, railways, energy lines and pipelines which have made life more accessible here on Earth. Space elevators can make any space-based effort more practical and feasible. They can simply make it easier to carry out studies on the colonization of the Red Planet, asteroid mining. They can also be used to generate solar energy, and shadows out of solar light. Moreover, they can even lower the costs for space tourism.

Today, traditional chemical rockets are the only method used to access space. This method is extremely inefficient because a large amount of energy is consumed during flight to overcome the depth of gravitational potential energy and overcome atmospheric drift. As a result, launch costs per kilogram of loads are very high from Earth to Low Earth Orbit (LEO). Much economical and efficient initialization methods are required for applications involving wide area use, such as area colonization. The space tower, which is one of the alternatives to conventional chemical rockets, is proposed as an effective tool to reach the area, with less environmental damage to the atmosphere. A tower can be used as a launch station high enough for the space flight to take place. The work done is considerably less because losses from atmospheric friction and driving efficiency will be eliminated in a space elevator system. Generally speaking, it is expected that this transport system for the space tower should consist of electrically powered cabins that carry loads and tourists vertically along the length of the tower. Fixed observatories can be established at different observation points along the stations in the near observation environment. These stationary stations, which are provided at different heights, will be advantageous to be closer to Earth and fixed compared to earth systems (Seth et al, 2009).

Although this system was a dream product in the past, the invention of new materials such as carbon nanotubes and technological advancements has brought up the possibility of the construction of this project. Hence, work on space lifts is now active throughout the globe (Yamagiwa, 2014).

The Space elevator represents an important paradigm shift in space access, but requires new, untested technologies in most of its subsystems (Laubscher, 2004). In the NASA Advanced Science Institute (NIAC) reports, the construction of a space elevator is analyzed in the several engineering aspects. Even if the need for extremely strong materials is strongly suggested in that report, the dawn of carbon nanotubes has removed some of the skepticism in the scientific community (Popescu and Sun, 2018).

National Aeronautics and Space Administration (NASA), funded the researchers at the Los Alamos National Laboratory in March 2001 and a company called HighLift Systems in 1992. In this projects, for example, NASA funded Brad Edwards by $ 570,000 to work on this. During his Project, Edwards says, quote: "The space elevator is a vertical railway, we want to take it from the lap of fiction-science and make it a reality". The cost of project is estimated to be between $ 7 and $ 10 billion. The most important part of the space elevator is its 100 000-kilometer cable, which will extend from earth to space. The end of the cable on Earth, which will be a high-tech cable, is planned to be connected to a platform floating in the open sea. The other end in the space will depend on the weight of the balancer, which is standard for elevators. An important reason why the space elevator could not be constructed until today was the lack of materials that could be used at this length and meet the needs. We know steel, kevlar, carbon whisker cables etc. They were 100 km long and inadequate with the weight they created (Dinçer, 2003).

2. WHAT IS A SPACE ELEVATOR?

Space elevator is a geostationary connection built from the ground to the Earth's orbit, which is up to the altitude of ≈35.786 km. Its centre of mass will have an orbit of 24 hours and it will stay on a geostationary point above the equator while rotating around the Earth's axis. Its objective is to transport people and cargo from the ground to the space just like a transportation service (Smitherman, 2000).

One of the possible near-earth orbits is a very special path with the orbit of a 36,000-kilometer satellite. If a satellite is launched at this height above the equator, it will orbit the planet every 24 hours. The rotation time every 24 hours will coincide with the Earth's rotation around its axis. This means that the satellite will remain fixed at a certain point in the sky since the period will be the same as that of the Earth. The lowering of cables from the satellite to the earth's surface can be thought of as a cable car (Smitherman, 2004).

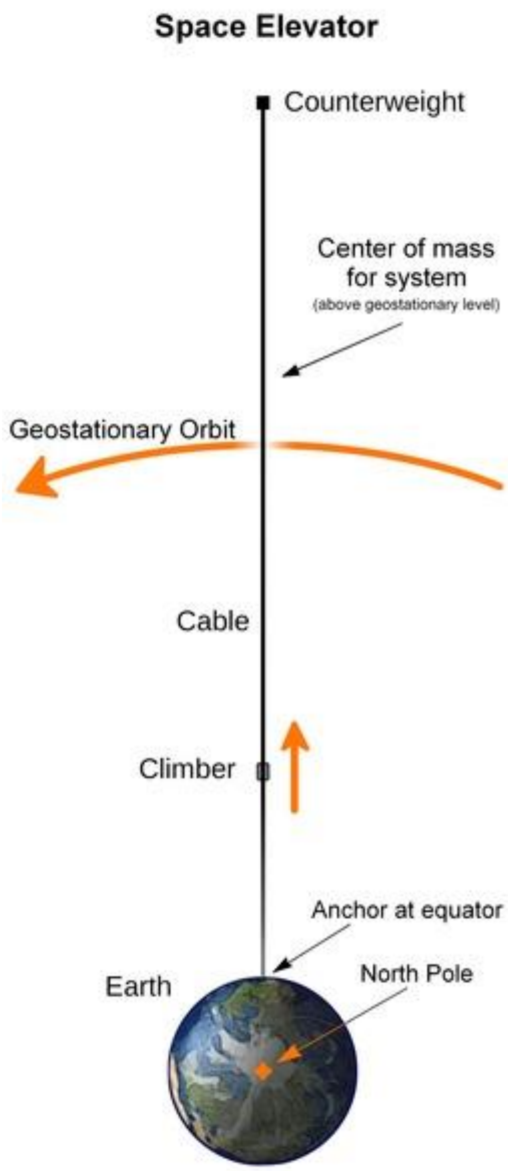

Figure 1. Basic Space elevator concept
Source: (Campbell et al, 2009:29).

Space elevator is preferred to rocket propulsion system as it can provide easier, safer, faster and economic access to space. Using a rocket propulsion system, launching a satellite to geosynchronous orbit costs about $ 400 million. The space elevator can reduce these launch costs by up to $ 10 per kg of material transported to space. Not only does it provide an economic passage to space, the space elevator is a much safer alternative to rockets (Kaithi, 2008).

2.1. Brief History

It was Constantine Tsiolkovsky, a Russian physicist, who first coined the term 'space elevator' in 1895 (Tsiolkovsky, 2004). Tsiolkovsky dreamt of a tower like the Eiffel Tower from the ground to the space at an altitude of 35.876 km. Yet, he had some reservations. For instance, when the tower moved upwards, the object moving in line with the Earth's rotational speed can accelerate horizontally and it can have a horizontal speed in geostationary orbit if disentangled (NASA Science News, 2008). On the other hand, Yuri N. Artsutanov offered a different point of view in 1959. The Russian engineer suggested the use of geostationary satellite while coming down from the space to earth. Landing can be done through a cable over the geostationary orbit by using counterweight. The counterweight is sent away from the Earth over the satellite in order to keep the cable stationary on a particular point on Earth (Artsutanov, 1960; Artsutanov,1967). In 1966, four American engineers discovered that the cable would last twice long if it was made out of an available material such as graphite, quartz or diamond and they published their findings in an article titled "Satellite Elongation into a True 'Sky-Hook'" in Science magazine (Isaacs et al, 1966).

Jerome Pearson, an American scientist, designed a profile for altitude with a tapered cross-sectional area, which will be a more suitable method to design the elevator. Balanced tower synchrony has the maximum tension in the balance point and this tension lowers down towards the tips. In order to reduce the tower's weight to the minimum and to maintain a fixed stress; latitudinal cross-section should be tapered as a function of gravity and inertial force. On the other hand, Pearson suggested using a counterweight to be slowly stretched out up to 144.00 km (Pearson, 1975).

It was David Smitherman who came to realize the use of carbon nanotubes, suggested an applicable notion for a high-strength space elevator and organized a workshop at the Office of Advanced Projects in NASA/Marshall in 1990. He called for many scientists and engineers to discuss the notion as well as to compile a concept into a reality. In 2000, Bradley C. Edwards, another American scientist, suggested creating a thin line of 100.000 km made out of carbon nanotube composite materials (Edwards, 2003).

2.2. Space Elevator Concepts

Man has witnessed significant technological reformations ranging from the introduction of internet and notebooks to mapping human DNA and creating hybrid plants. It all takes a small step to start a great advancement. And space elevator can be the first step into a mass-journey to space. It can work like a catalyst.

Experts think that carbon nanotubes are the key components of space elevators since they are light and highly strong. Although steel has a tension strength of about 5 Gpa and Kevlar has 3.6 Gpa; carbon nanotubes have a tension strength of 130 Gpa. As their densities are compared; steel has a density of 7900 kg/m^3, Kevlar has 1440 kg/m^{3,} whereas the carbon nanotubes have the lowest density of, 1300 kg/m^3. In other words, a 3 mm cable made of carbon nanotubes is capable of carrying 41 tons of load without being deformed (Dinçer, 2003).

Undoubtedly, the Space elevator will be the new mega structure for mankind if it is achived. It will be constructed from graphene and diamond nano fibres and be able to resist tons of load. It is estimated to have a cost of about 50.000 $ per pound (Yazici, 2018).

The most challenging part of designing a space elevator is to calculate its stretch from the ground to GEO (Geosynchronous) orbit. Its station for central mass is GEO orbit and its tether structure will lean onto the Earth from 35.000 km without a relative horizontal speed and then, connects to a high tower built on an ocean-based platform. The design of the structure includes integrated track system for the structure to move up and down. When the load in LEO (Low Earth Orbit) breaks free, a pushing device from GEO orbit (3.1 km/sec) to LEO (7.7 km/sec) will be needed to accelerate the orbit speed. If it is released in an altitude of 47.000 km along the upper part of the connection; it will be easier for it to be sent away from Earth. The bottom structure will have the greatest impact on the structural requirements and diameter of the system as the structure gets closer to Earth. Therefore, it is better for the structure to be built as tall as it can be (Smitherman, 2000).

Right now, French Guiana, Central Africa, Sri Lanka and Indonesia are considered as the most suitable locations for the platform (NASA, 2000).

In order to speed up the development of the space elevator in the 21st century, the supporters organized competitions for the related technologies, similar to the Ansari X Award (Boyle, 2004). In 2012, Obayashi Corporation announced in 38 years that could build a space elevator by using the carbon nanotube technology (Phys.org, 2012). At 200 kilometers per hour, the 30-person climber of the design is planned to reach GEO orbit after a 7.5-day journey. (Chatterjee, 2012). No cost estimation, financing plan or other details were made. This implied that, along with the timing and other factors, the announcement was largely made to provide promotion for the opening of one of the company's other projects in Tokyo along with the timing and other factors (Boucher, 2012). In 2018, researchers at Shizuoka University launched STARS-Me, two CubeSat tied with a rope that a mini elevator would travel (Barber, 2018). In 2019, Space International Academy "Space Elevator Era Road to" was published. In a study report summarizing the evaluation of the space elevator as of 2018, they gathered with a large group of experts and evaluated the subject (Holger, 2016).

3. CARBON NANOTUBES

Perhaps, one of the biggest obstacle aganist the development of humanity throughout the solar system is the prohibitive cost of escaping Earth's gravitational attraction. As it is well-know, rocket engines are pushing the mass in one direction and producing thrust for another spacecraft. This requires a large volume of propulsion, which is finally thrown but also needs to be accelerated with the spacecraft. Obviously, this is more expensive than going to Moon and beyond. Therefore, it requires developing different ideas about finding economic ways to orbit. One idea is to build a space elevator. A cable that stretches from Earth to orbit, providing a way to climb into space. Its biggest advantage is that the climbing process can be powered by solar energy, and therefore it does not require built-in fuel. But there is also a big problem. Such a cable must be incredibly strong. Carbon nanotubes are a potential material if they can be made long enough. However, the options available today are very weak (Penoyre and Sandford, 2019).

Carbon nanotubes have attracted the attention of material scientists and technologists due to their unique one-dimensional structures with their superior electrical, mechanical and chemical properties (Jariwala et al, 2012).

A nanotube consists of one or more cylindrical graphite sheet which was discovered by Sumio Iijima who is an expert on electron microscope (Iijima, 1991); a nanotube consists or more cylindrical graphite sheet. Each sheet includes carbon atoms made up of hexagonal network with no edges. A nanotube is considered as microcrystal in the shape of a graphite tube and it pentagons in a hexagonal order on both tips. Intermediate layers have a weight of 0.34 nanometre, which is typical for turbostratic graphite. (Ebbesen, 1996). Its external diameter is small, hollow, tall, thin and it is much stronger (200 times stronger) than steel (Holister et al, 2003).

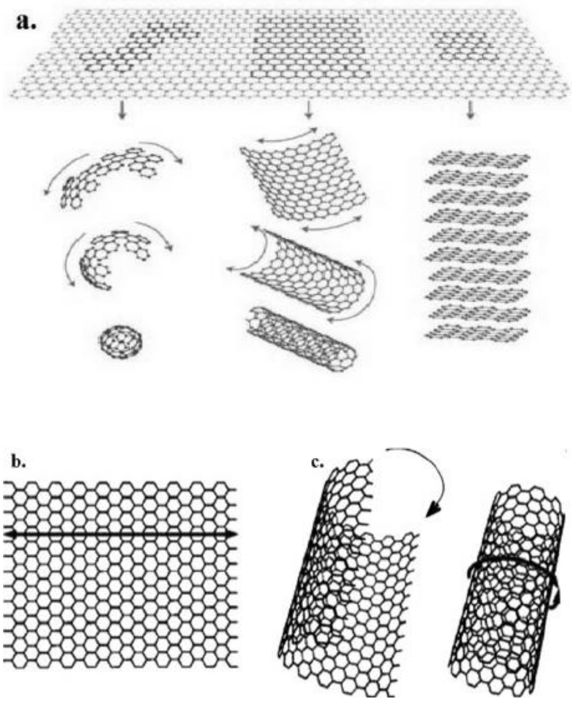

Fig. 2. Carbon Nanotubes
(a) Formation of graphene derivatives. (b) Graphene sheet. (c) Graphene sheets rolled into carbon nanotubes.
Source: (Saeed and Han, 2013:132).

They act as conductors and semiconductors according to their structures. The most robust and best-known C60 nanotype among carbon nanotopes is able to withstand a weight of 300 million times its own weight. Carbon nanotubes can be of different diameters as single or intertwined, open or closed cylinders. As a result of experiments, the tensile strength of single-walled small diameter carbon nanotubes was determined as 45.000 Mpa. Today's technology has reached a level that can regulate atomic dimensions in line with the requirements, so that it can serve as a desired purpose and change the quality of the material. In the future, carbon nanotube fibers made with carbon nanotube bundles will be extraordinary materials that can cover very large surfaces with their superior strength and flexibility. In addition, 34 buildings, which are considered impossible to construct today, will come to life with mixed materials in which carbon nanotube fibers are used as reinforcement materials in concrete and building plastics. In our age, carbon nanotubes will have many functions, from space elevators to drugs, electronic circuits to construction materials (Erdem, 2012).

4. WHY SPACE ELEVATORS?

In this part, we will mainly dwell on the following questions associated to the space elevator; Why do we need a space elevator? What tasks will this space elevator make possible? How much will it reduce costs? Undoubtedly, these questions are among basic questions of why we need a space elevator. Some major missions will be developed or significantly activated the infrastructure of the space elevator. Global communication, energy, Earth's tracking, global / national security, planet defense, and exploration beyond the low Earth orbit are just a few examples of reasons for the formation of an elevator. If we are serious about facilitating access to space and avoiding the limitations on the human spirit, it seems we shall build a space elevator (Swan and Swan, 2006).

Now is the time when mankind turns to space for future expectations. In addition to the space activities carried out by the US, Russia and Europe, China also turns to space and is planning to build its own a space station.

Right now, there are three major companies investing in asteroid mining resources ever since NASA JPL identified more than 1300 astreoids easily accessible from Earth. Moreover, there is SpaceX, a rocket company making plans to create a colony of more than 10.000 on the surface of Mars (Swan et al, 2013).

In order to make these dreams come true, our way to travel within our own solar system needs to be reformed. Orbit cost should only require a small investment and the space used should be sustainable enough to support other sustainable infrastructures. The concept of space elevator is the solution to these problems. It is future way of travelling in space (Swan and Fitzgerald, 2019).

5. SPACE ELEVATOR CONSTRUCTION

Some technical risks will need to be reduced for the construction of the space elevator. Some progress is required in engineering, manufacturing and physical technology. When the first space elevator is built, the second and others benefit from the previous ones to assist in construction, significantly reducing their costs. Such ongoing space elevators will also benefit from the large reduction in technical risk achieved by the construction of the first space elevator (Edwards, 2002). The production of the cable in space will in principle be done using an asteroid or Near Earth object for the source material. These previous concepts for construction are so that an asteroid can maneuver to its required trajectory on Earth. Since 2001, many studies on space lifts have been devoted to simpler construction methods that require much smaller area infrastructures. In this method, they considered throwing a long cable on a large spool and then placing it in space (Hein, 2012).

For early systems, the transition time from surface to geosynchronous orbit level is about five days. In these early systems, the time spent moving along the Van Allen radiation belts will have to protect the passengers from radiation with the shield, which will add mass to the climber and reduce the load. If the space sensor is located at 45 ° north latitude, the cable turns south and is pulled towards the equator by centrifugal forces. Thus, it travels almost horizontally in the Earth's atmosphere for thousands of kilometers and can weaken air-related stresses in the cable. Another alternative method is to put some kind of radiation shield on the cable. In this way, the elevator can pick it up when it is about to reach the belts. However, such a shield weighs the entire device and disrupts the natural movement of the cable (Young, 2006).

A space elevator could create a travel hazard for both aircraft and spacecraft. The aircraft can be guided by air traffic control restrictions. All objects in fixed orbital deterrent orbits below the maximum altitude of the cable that is out of sync with the cable will affect the cable unless action is taken. One suggestion is to use a moving anchor sea anchor to allow the yarn to bypass any residues that are large enough to trace (Edwards, 2002).

5.1. Advantages And Disadvantages of Space Elevator

This futuristic wonder mega structure has its own advantages and disadvantages which can be enumerated as followa (https://marspedia.org/Space_elevator):

Advantages

- No fuel is required. It may be cheaper than traditional rocketry.
- It is suitable for precision landing, fragile machines.
- Since the movement is a single road, it can have high traffic volume.
- Disadvantages
- Remains heavy.
- Fuel is required to match velocity with the cable. This may use more fuel than direct entry and aerodynamic braking.

The rope of the space elevator must combat enormous forces, gravity in one direction and centripetal force in the other. Another problem is the heat generated by rubbing the lifter to the coupling (Edwards, 2012).

5.2. Hazards and Challenges

The space elevator is not such a simple project, and can be relatively difficult to build and operate. Unaviodably, such a structure will face a number of dangers if it is built. A greater challenge in the short term is to develop the technology required for the elevator itself. Although carbon nanotubes are of great promise, they are produced in relatively small quantities today. Composite fibers containing carbon nanotubes are as strong as steel today, but still far below the strength required for the elevator (Foust, 2003). Right now, experts expect to have ten numbers of these mega structures and with that figure in mind, they will have a logistics capacity of carrying more than 20 tons a day (Skip et al, 2012). Yet, the structure will also be under the threat of meteorites, lightnings, space junks, space storms, heavy electromagnetic areas.

In the event that a cable breaks free, there are two options. It can either crash onto Earth's surface at a tremendous speed or it can rotate around the Earth's axis at least 8 times (Yazıcı, 2019).

6. FEASIBILITY OF SPACE ELEVATOR

One of the main problems of modern space studies and space technology today is that the cost of carrying a load from the Earth's surface to space is very high. In the 2000s, the cost of carrying cargos to space was an average of $ 104,106 per kg of cargo. For this reason, different ideas were needed to make the cost of carrying loads to space orbit economic. In 1960, there was a very different idea by Artsutanov. He proposed to build a celestial elevator to a satellite in geostational orbit from Earth's surface by hanging a rope from the satellite to the Earth's surface (Pugno et al, 2009).

Space elevator will create an access for a reclaimable area, and therefore offers great financial benefits. Experts estimate that the launch cost for space elevator will be 250 dollar per kg (Edwards, 2000). Currently, this costs 10.000 dolar per kg.This is a significant amount of saving in launch costs. Besides, the cost will remain the same for any destination point and for any space mission. For interplanetary missions and space colonization, this means a significant saving. Experts estimate that the first elevator can be constructed with a cost of ten billion dollars

(Edwards, 2000). With today's launch figures, this accounts for 1.000 launches to carry 1.000 kg of load with average cost (Sparks, 2014).

Design has a significant effect while constructing a space elevator. Researchers believe that it is possible to have a working space elevator with 5 tons of load bearing capacity to LEO orbit in 15 years. This will lower down the travelling costs to the Moon, Mars, Venus or asteroids from the first orbit to a great extent. Depending on the target and the choice of rocket launch system for the first space elevator; lifting costs are estimated to be decreased down to 100 $. The later extensions and larger elevators will sooner or later make manned and commercial activities possible on large-scale as they will diminish the costs for the elevator (Future Pundit, 2003).

Any object in GEO orbit has a potential gravitational energy of about 50 MJ (15 kWh). A space elevator using 0.5% efficiency of power transportation with wholesale electricity prices from 2008 to 2009 will require 220 US dollar/kg only as the cost of electricity. Edwards, PhD have high hopes for technical advancement to increase the level of efficiency to 2% (Edwards, 2003). Since the space elevators receive a limited efficiency, launching price can be subjected to the market.

In the 55th International Space Congress, it was suggested that a prestigiously acceptable mega project for space elevators has an estimate cost of 6.2 billion US $. This is not much as compared to other mega projects such as bridges, pipelines, tunnels, maglev trains, launching vehicles etc (Raitt and Edwards, 2004).

Edwards also suggests that it will cost 6 billion dollars to build a space elevator. This can be compared with project Skylon – one-layer orbit space plane with a loading capacity of 12.000 kg, which is estimated to require an R&D and production cost of about 15 billion $ (Edwards and Westling, 2002). The vehicle has a tag price of about 3.000$ /kg. Skylon will also be available to launch people and load into LEO orbit and GEO orbit points (Scott-Scott et al, 2003). SpaceX Starship is another alternative designed to be used for a similar purpose. Its cargo capacity is between 100 and 150 tons. Its R&D cost is 10 billion $. Starship crew will also cost about 200 million $ and for Starship tanker, the cost is estimated to be 130 million $ and 230 million dollar for Super Heavy. The system has a price tag lower than 140 $ / kg, which is 47 $ economic (SpaceX, 2012). It can also carry 100 people to Mars (Dinkin, 2017).

7. CONCLUSION

In this paper, the Economic Feasibility of Space Elevator has analyzed to some level. Despite its greatness and complexity, the concept of the space elevator does not seem to be so impossible. These elevators will certainly make the space more accessible and be a mega structure like the Great Wall and the pyramids. Although it requires profound financial investment; its benefits will outweigh the initial financial costs once it is built. They will eventually lower the costs for asteroid mining, space logistics, space tourism, space travel and space colonization; all of which will be the mankind's basic needs to survive soon. Even when this enormous mega structure comes to life, it will bring many possible questions. How will we ever be able to protect this state-of-the-art structure from the external threats? Questions such as how to protect the space elevator from any natural disaster that will suddenly occur in the world will always be the questions to be considered.

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