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Application of LLP Model in Satellite Supply Chain

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Abstract

The development of space logistics is not solely dependent on technology, it requires interdisciplinary collaboration. Meanwhile, terrestrial logistics have undergone a significant transformation, shifting from subcontracting to Omni-channel approach among which LLP model is recognized as a model that integrates multiple capabilities to continuously improve the operations. Given that the success of the emerging space economy hinges on a self-sustaining ecosystem, this research aimed to analyse the satellite supply chain for application of LLP.
Currently, there are barriers impacting application of LLP in the satellite supply chain; however, there is a noteworthy development in the form of MicroLLP, employed for microsatellites.

1. Introduction

Previously, the challenge was international logistics. Now, the major new trend for the next 30 years and beyond is interstellar logistics. [19]

The international space industry context is changing fast; global competition is increasing with new entrants bringing new ambitions in space and space activities are becoming increasingly commercial with greater private sector involvement. Major technological shifts, such as digitalization, miniaturization, 3D printing, artificial intelligence and reusable launchers are disrupting traditional business models in the space sector, reducing the cost of accessing and using space [21].

On the other hand, terrestrial logistics operations has transformed through the past decades in response to a variety of business drivers from subcontracting and globalization towards e-commerce and omni-channel growth. Solutions for these challenges have also been strongly driven by transformations in the past, starting from the planning of locations and vehicle routing towards advanced ICT, cross-docking, and advanced pooling.

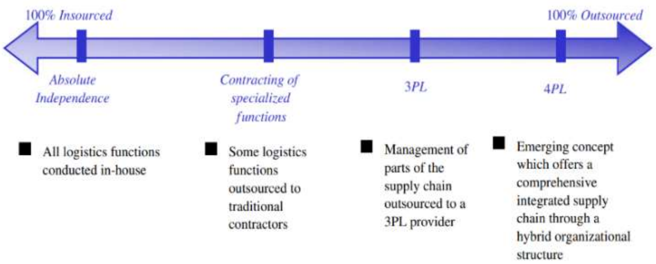

Fig. 1 : Variations on logistics outsourcing [13]

1.1. Motivation

In the recent years, the space sector is experiencing great dynamics due to technology development, private initiatives and lots of new prospects and one of the challenges ahead, is high logistics cost in space supply chain which is transforming rapidly. Also the space economy will require a self-sufficient ecosystem that includes capital, strategic partnerships and evolving business models.

The space race is being powered not just by government but by a new crop of startups and visionaries. Although entrepreneurs, strategic partnerships and venture capital have been leading the charge on funding, the success of this nascent phase of the new space economy will require a self-sufficient ecosystem; [4] e.g. the large LEO constellations are deployable, if one critical factor stands out: cost reductions across the value chain, from satellite manufacturing through launch and operations. [2]

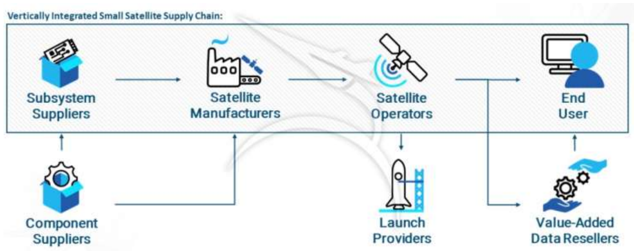

Fig. 2 : Satellite value chain [35]

But accessibility of space assets is still very costly, therefore; this research aimed to study and analyze satellite logistics, as the leading sector in space

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industry, to explore drivers, barriers, gains and pain points, as well as logistics operating model maturity compared with terrestrial models and the readiness of satellite industry to apply LLP (Lead Logistics Provider) model, all in order to improve the operations.

Having said the above and regarding very strategic importance of space industry and the leading role of satellites in the industry, improvement of satellite supply chain can help a lot to deliver the best product and service to all stakeholders in the value chain.

1.2. Background

Terrestrial logistics operations has evolved through the past decades; according to a classification, to identify terrestrial LSPs (Logistics Service Providers), 1PL (First Party Logistics) exclusive activity is the outsourcing of transport or warehousing, the 2PL is responsible for the sole outsourcing of transport and warehousing, the 3PL groups together the first two families mentioned above [6] and finally, 4PL that manages all aspects of a supply chain and serves as the single point of contact to the client and 3PLs.

4PLs are also often referred to as LLPs. They manage everything to do with supply chain, including resources, technology, and infrastructure. Lead Logistics Provider services is a partnership relationship with the customer, with a self-funded team, working as part of, or an extension of, the customers' SCM (supply chain management) team, to provide visibility, optimization, cost savings for the customer. The following figure 3 illustrates the evolution of logistics outsourcing to 4PL. [13]

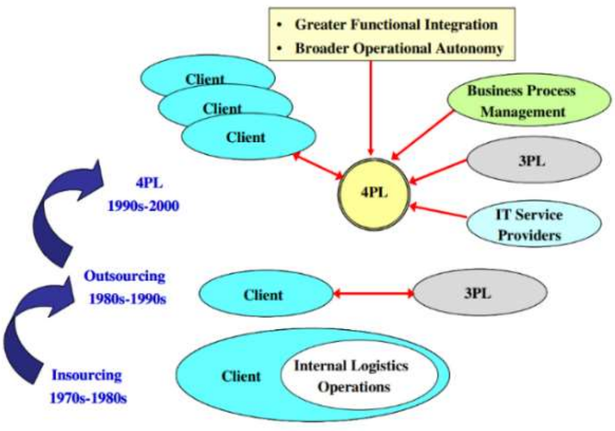

Fig. 3 : Evolution of outsourcing in logistics

On the other hand, the commercial space has got a push and logistics play a key role in the sector as a major concern for the overall strategy of the space companies.

1.3. Goals

The research helps to study and analyse the end to end satellite supply chain including identify trends, pain points, driving factors, gains, barriers, supply chain maturity and future needs in order to provide a ground to offer solutions and improvements in the logistics operations of satellite industry.

In this regard satellite market study has been presented in section 2 including (i) industry segmentations, (ii) trends, (iii) market drivers, (iv) space economy and (v) global market value estimates.

Then satellite value chain has been reviewed in section 3 including (i) satellite manufacturing industry, (ii) launch vehicle manufacturing and services, (iii) testing, (iv) satellite operators, (v) in-orbit services and manufacturing, (vi) ground segment terminals and equipment, (vii) value added service providers and (viii) end users.

Literature has been reviewed in section 4 including (i) logistics outsourcing, (ii) logistics evolution, (iii) 4PL/LLP, (iv) 4PL operating models and (v) 4PL benefits.

In section 5, research methodology has been presented.

Finally, findings and results&conclusions are presented in sections 6 and 7 respectively.

2. Market study

Earth Observation was one of the early applications of spaceflight. When the first rockets were launched into space after World War II, science and reconnaissance were the main drivers. Over time, space has seen an ever-increasing military utilization showcased by purposes such as navigation, space reconnaissance (especially observation of ICBM, foreign intercontinental ballistic missiles), communication and so on. While governments were the driving forces in the 20th century (e.g. the Apollo program, International Space Station and the Global Positioning System), commercial activities are now setting the pace, accounting for several hundred billion Euro of the global space economy. [21]

Through this section space market segmentations, trends, drivers and value have been reviewed.

2.1. Space Industry Segmentations

Similarly, to other industries, companies in the space sector are referred to as "*upstream*" or "*downstream*", depending on their location in the supply chain. [21] The upstream segment includes all activities that focus on the design, manufacture, assembly, launch, functioning, maintenance, monitoring and repair of satellites destined to be sent out to space as well as the products and services related to them; whereas downstream segment refers to all activities that employ data and knowledge that are derived from the space for Earth-related objectives as well as the products and services that support them. In other words, the upstream segment can be seen as the provision of space

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technology, whereas the downstream segment can be seen as the exploitation of space technology. [1]

Further details concerning segmentations e.g. institutional space v. commercial space, new space v. traditional space (established space), established segments v. emerging segments, and functional segmentations can be seen in figure 4.

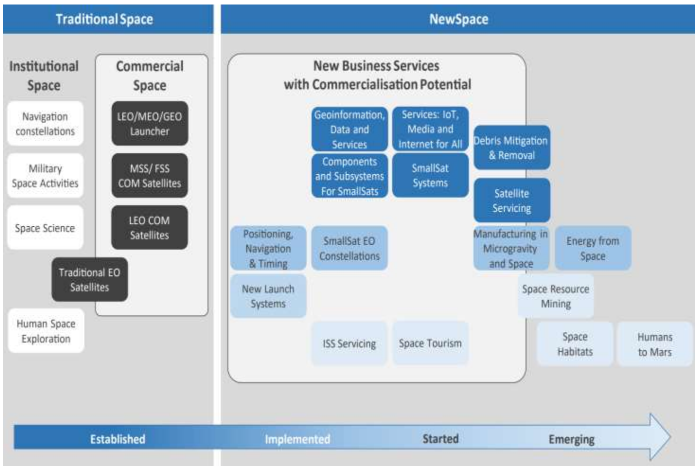

Fig. 4 : Existing and new business services [21]

2.2. Trends

A new space age is dawning, setting technological goals; constellations of satellites, fusion-powered spacecraft, technologies to mine asteroids and 3D printers to replace worn-out equipment. [4]

The first era of space, ‘Space 1.0’, can be considered to be the early study of astronomy (and even astrology). The next era, ‘Space 2.0’, came about with space faring nations engaging in a space race that led to the Apollo moon landings. The third era, ‘Space 3.0’, with the conception of the International Space Station, showed that we understood and valued space as the next frontier for cooperation and exploitation. Space 4.0 represents the evolution of the space sector into a new era, characterized by a new playing field. This era is unfolding through interaction between governments, private sector, society and politics. Space 4.0 is analogous to, and is intertwined with, Industry 4.0, which is considered as the unfolding fourth industrial revolution of manufacturing and services. [33]

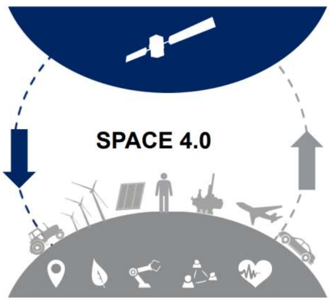

Fig. 5 : Schematic scope of Space 4.0 [34]

Here are further details concerning 3 space trends.

New Space: a global trend encompassing an emerging investment philosophy and a series of technological advancements leading to the development of a private space industry largely driven by commercial motivations.

The so-called “New Space” trend thrives upon technology and business model innovations that permit a significant reduction in cost, the provision of new products and services and a broadening of the customer base.

These are accompanied by increased returns for companies and investors, resulting in the onset of a whole new wave of commercial activities within the space sector. [21]

New Space approach to reliability which considers redundancy at constellation level, making the service resilient to the failure of a satellite subsystem or component, this change of paradigm leads to far less costly satellites at unit level but requires a capability to mass-produce them. An industrial tool capable to output a standard platform that can serve a wide range of application is key to keep the cost low, like in the automotive industry.

New space mega factories need to be capable of assembling the final product, and also to produce and test the subsystems internally to avoid two inefficiencies specific to the old space satellite industry i.e. (i) large mark-ups at each level of the long supply chain and (ii) the outsourcing of testing. [23]

Hundreds of other new start-ups have formed in the past several years to explore opportunities in space infrastructure e.g. satellite manufacturing, launch capabilities, IT hard ware and adjacent areas such as space tourism, satellite broadband, media and even asteroid mining. [4]

Mega smallsat constellations are now a reality. OneWeb has now deployed 50% of its first-generation satellites and SpaceX is now the largest satellite operator in terms of number of assets with more than 1,700 Starlink satellites deployed, but both are small players revenue-wise. In the next 10 years, five constellations (OneWeb, Starlink, GWO Wang, Kuiper and Telesat) will concentrate 58% of total satellite demand over the decade (i.e. 9,900 units), but only 8% in manufacturing value and launch value. [30]

Transition from governments to commercial sector: Until recently, space used to be synonymous with government spending; the enormous costs and risks involved made the sector generally inaccessible to private players. Today, major technology advancements and a new entrepreneurial spirit are rapidly shaping a new space economy. The sector sees the emergence of new private actors who see unrivalled commercial opportunities in space

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exploration and exploitation thanks to frontier technologies and the data revolution. [21]

Technology trends: After years of scientific or technologically driven developments, space systems, products and services have reached a level of maturity that arouses the interest of private enterprises. Space systems or space-based services, in the past developed and handcrafted exclusively for governments, are increasingly being discovered by companies, which are looking to extend their ground-based business with satellite services as a safe and cost-effective element. New production processes (e.g. 3D printing) combined with achievements in miniaturization and digitalization are drastically reducing the prices of high-tech products, while increasing their performance and reliability. [5]

Such a huge growth is to be attributed to Space 2.0, (this is another classification in which the New Space is named Space 2.0) a new paradigm that sees cheaper and faster production and launch of satellites, increasingly smaller and capable of overcoming the traditional trade-off between size and functionality thanks to enhancements in integration and miniaturization techniques. Space 2.0 also describes a new acceptance of risk on the demand side, available to invest in satellites with a shorter expected lifecycle but cheaper. This means that space is progressively becoming a more and more accessible and affordable business environment for a larger number of actors. [1]

The following headlines represent the top technology trends that disrupt the space and space application market. [21]

- Acceleration of generation change/obsolescence
- Advanced manufacturing technologies/3D printing
- Micro- and nanoelectronics/advanced telemetry and telecommand
- Agile development and industrial standard implementation
- Artificial intelligence/man–machine interface
- Change detection and data fusion
- Digital transformation and convergence
- Evolved expendable/reusable launcher systems
- Miniaturisation and nanotechnology
- Optical and ubiquitous communications

2.3. Market drivers

Several market elements have transformed the space industry; they are reviewed in the following.

Competition: The international space context is changing fast; global competition is increasing with new entrants bringing new ambitions in space and space activities are becoming increasingly commercial with greater private sector involvement.

Today, a new space race is occurring, with competition between private companies rather than nations. The new space race was heralded by the emergence of a commercial space industry and has opened previously unexplored avenues to growth and innovation. The role of space has become more apparent as an enabling infrastructure for the digitization of industries, as a basis for new business services, and as an area of economic growth, a trend recognized by governments across the globe. [21]

New Business Models: The space economy will require a self-sufficient ecosystem that includes capital, strategic partnerships and evolving business models. [4] Major technological shifts, such as digitalization, miniaturization, artificial intelligence or reusable launcher, are disrupting traditional business models in the space sector, reducing the cost of accessing and using space. [21]

The digitized economy is a key battlefield; core elements of digitized globalization include the satellite networks, providing communication and data services, positioning information and Earth observation data. [5]

As one of the drivers of globalization, space systems are the carriers for digitalization; Satellites, being objects of innovation through digital technologies, are essential elements for carrying all kinds of sensors to acquire high volumes of data in Earth observation, for positioning purposes, and as the backbone in transmission networks for communication, broadcasting, television, streaming services and the Internet of Things (IoT). They rapidly pass on “Big Data” volumes from one point of the globe to another. Growth and profitability in the space business are currently directly linked to the increasing demands of the digitized society. [5]

Just as technology has evolved, so have revenue sources from internet connectivity. In the 1990s, communications companies generally followed a business model in which revenues came from service fees for bandwidth and access; rates were often based on usage. With relatively low demand, this model was not viable for the satellite concepts of the 1990s. Today, it would also be risky to charge consumers for usage time, but for a different reason: there would probably be little uptake for such plans. The preference for unlimited access is clear from the mobile-phone industry, where per-text or per minute billing has given way to unlimited plans. Fortunately, companies have new options for generating revenue from connectivity. In addition, companies and investors may now be willing to wait longer for profits from large LEO constellations. Instead of expecting an immediate positive cash flow, many are focusing on business models that facilitate the acquisition of customers and the control of ecosystems, so they may initially set low prices for their offerings to attract business, even if that eliminates the possibility of profits. Their goal is to establish themselves as early leaders and to create a foundation for long-term success, following in the footsteps of many high-tech players over the past 20

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years. These businesses first concentrated on creating scale and acquiring a critical mass of users and then shifted their focus to making money from the network. [2]

Interest in satellite constellations springs from a convergence of forces that make both the development and the market success of large LEO communication systems more likely now than in the past: technological advances, the emergence of new business models, better funding, and higher demand for low-latency bandwidth (figure 6). Thanks to these developments, the current situation bears little resemblance to the 1990s, when large LEO concepts failed to gain traction. [2]

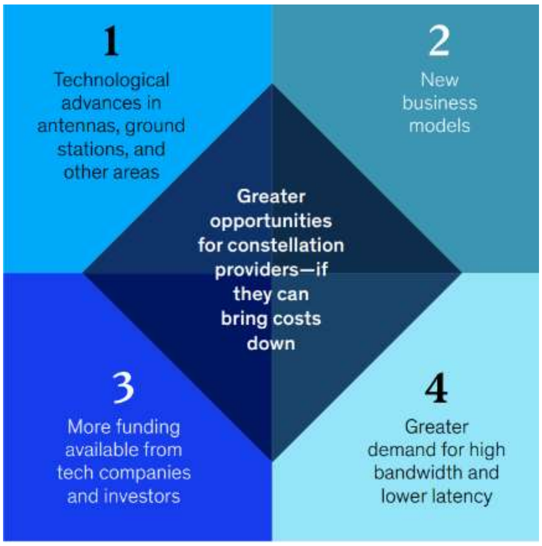

Fig. 6 : Forces created new opportunities for LEO constellations [2]

The startups need time to develop business models that work. Considering space is tremendously complex, it’s going to take time for the ecosystem to develop. [4] Time will tell whether New Space will lead to a diminishing upstream–downstream gap and whether the integral business model will prevail. [21]

Investment: The funding picture is different from what it was 20 years ago. Some companies have enough cash available to build and deploy a constellation outright. In the 1990s, many companies could not find enough investors to fund their satellite constellations.

Estimates for deploying a large LEO satellite constellationgenerally range from \$5 billion to \$10 billion. Annual operating costs will be high; the cost of replacing satellites alone will total \$1 billion to \$2 billion for a large constellation if their life span is about five years. [2]

Launch prices: Even though miniaturization has helped to reduce some of the costs, satellites and spacecraft used to weigh hundreds to thousands of kilograms, and hence the launch into space became a major cost item. For several decades, satellite communication was the only sector that could commercially afford launch prices.

The advent of small satellites (with a mass less than 180 kilograms and about the size of a large kitchen fridge [26]) and CubeSats (CubeSats are built to standard dimensions of 10 cm x 10 cm x 10 cm. They can be 1U, 2U, 3U, or 6U in size, and typically weigh less than 1.33 kg per U.[25]) offering good performance at a mass in the tens of kilograms (and hence at a fraction of a classical big space mission) has changed the ecosystem considerably. With increased demand, rocket launch start-ups such as SpaceX, Rocket Lab, Vector Space Systems, Blue Origin and Virgin Galactic/The Spaceship Company moved into the launch sector, aiming to compete with Arianespace, ILS (International Launch Services), ULA (United Launch Alliance) and others. While SpaceX, Blue Origin and Virgin Galactic/The Spaceship Company aim to create synergies with their space tourism activities, Rocket Lab, Vector Space Systems and others focus entirely on the Micro Launcher segment, which deliberately provides launch services for very small satellites with masses of a few hundred kilograms. Optimized for this specific part of the launch service market segment, Rocket Lab et al. offered dedicated launch capabilities, but at a price tag of the order of USD 25,000/kg or more (much more expensive than the USD 10,000/ kg launch cost benchmark).

Similar to the economy of scale, rockets become more cost effective the bigger they are, a rocket that can launch twice the payload mass will not be twice as expensive in operational costs, while engineering costs will not scale 1:1. [21]

It is anticipated that the average launching price will be divided by a three-fold factor. New vendors have emerged, ranging from dedicated smallsat access to space to super-heavy reusable launchers with various design-to-cost value propositions. With a new generation of launchers expected, the market will experience a challenging transition.

Reusability, cur

rently mastered by SpaceX, is gradually endorsed by competitors. It continues to test Starship as the first fully reusable launcher (among other players), paving the way for launch at marginal cost, which could disrupt current market standards. [30]

As the competition unfolds due to new entrants, launch prices drop. The below table 1 shows launch costs drops of launchers.

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Table 1: Dropping specific launch costs for the next generation of launchers [21]

Prior generation		Next generation		Change
Rocket	USD/kg to LEO	Rocket	USD/kg to LEO	%
Proton	4.565	Angara A5	4.167	–9 %
Ariane 5	8.476	Ariane 6	4.762	–44 %
Falcon 9*	4.654	Falcon 9 FT*	2.719	–42 %
N/A	N/A	Falcon Heavy*	1.654	N/A
H-IIA/B	6.818	H3	5.000	–27 %
GSLV	9.400	LVM3	7.500	–20 %
Saturn V	22.857	SLS	3.268	–86 %
Atlas V/Delta IV	11.093	Vulcan	6.378	–43 %

A single large LEO constellation will require anywhere from three to 40 launches a year (depending on the size of the constellation and rocket type), both initially and during maintenance. For constellation operators, even those that build their own rockets, these launch costs will be significant. To ensure a viable business, launch providers will probably need to reduce the cost to orbit below $2,000 per kilogram. Large LEO constellations are deployable, if one critical factor stands out: cost reductions across the value chain, from satellite manufacturing through launch and operations. [2]

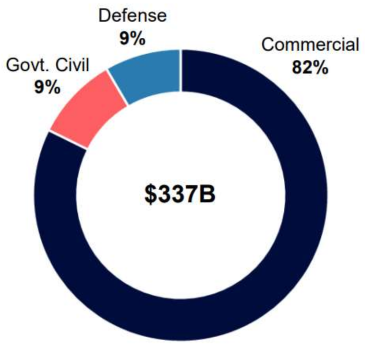
It remains to be seen whether presumed specific launch costs of USD 1654/kg for SpaceX's Falcon Heavy are sufficiently low to allow a rollout of space-based solar power systems, lunar bases, asteroid mining concepts and a crewed mission to Mars. [21]

2.4. The Space Economy Size

The global space economy is estimated at a total value of $ 370 billion in 2021. It consists of:

• The space market ($337B in 2021) which includes commercial space revenues and government procurement for their space activities contracted to the private sector; and

• Other spending from government organizations ($33B) to conduct their space activities (internal costs and R&D). [14]



Graph 1 : Space market by client type [14]

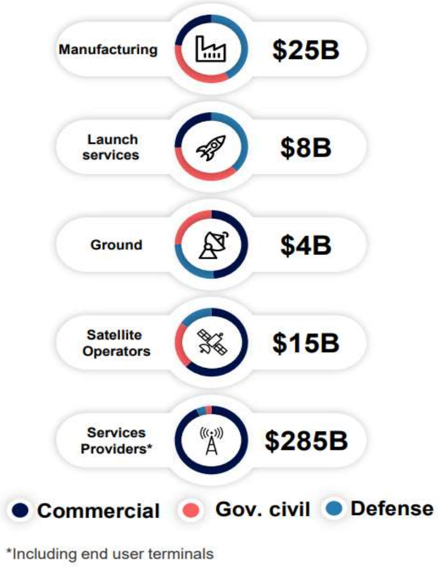
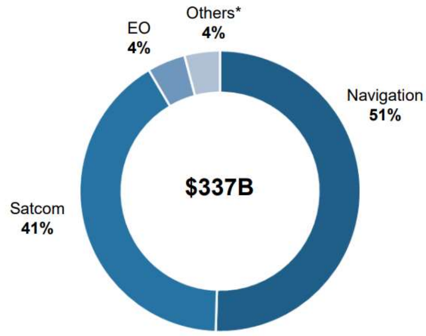


Fig. 7 : Space market value chain [14]

The global space market in 2021 is up 6% v. 2020, i.e. a market value comparable to 2019 prior to COVID crisis which impacted satellite service revenues in 2020. The largest revenue drivers remain satellite navigation and communications which account for 50% and 41% of the total market value respectively, driven by B2C applications. In comparison, EO still accounts for a marginal 5% of the total value but with a much higher proportion upstream. [14]



Graph 2 : Space market by application [14]

2.5. Global Market Value Estimates

The global space economy is expected to hit US$ 2.7 trillion by 2045 as estimated by Bank of America. [1]

On the other hand, Morgan Stanley estimates that the global space industry could generate revenue of more than $1 trillion or more in 2040. Yet, the most significant short and medium-term opportunities may come from satellite broadband Internet access (i.e. second order impact in the following graph 3). [3]

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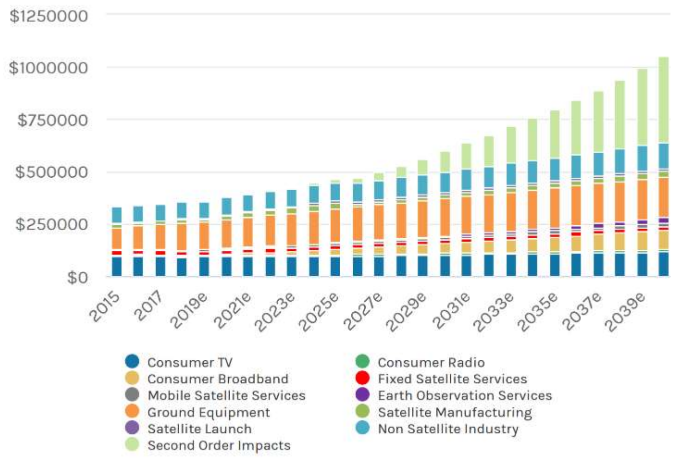
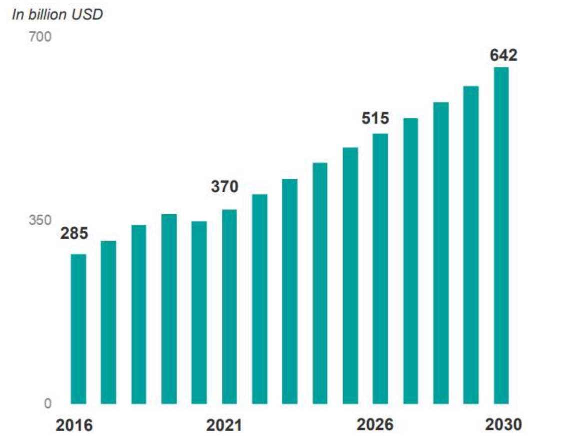


Graph 3 : Global space economy [3]

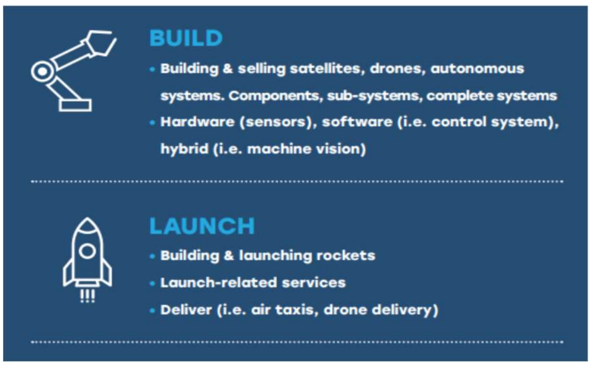
As per a recent estimate by Euroconsult, the space economy is expected to grow by 74% by 2030 to reach $642 billion (6.3% annual gross rate) renewing it's strong growth pattern following a 4% decrease in 2020 under the effect of the COVID crisis impact on commercial space services. [14]



Graph 4 : Evolution of the space economy 2016-2030 [14]

3. Satellite value chain

At a high level, satellite value chain can be categorized in Building, Launch, Data collection, Downlink data, Analysis data and Product. The below figure illustrates further details in space value chain. [11]



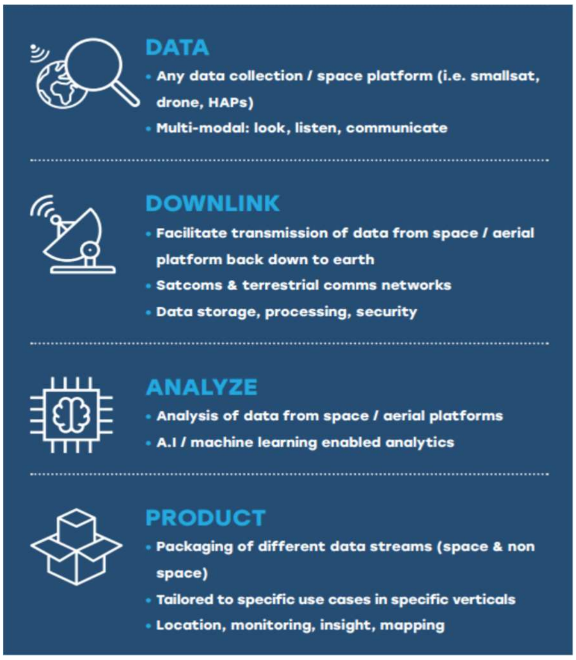


Fig. 8 : Space value chain

By another approach, satellite lifecycl can be defined as follows: Design, Fabrication, Assembly, Integration, Testing or Verification and Qualification, Deployment, Maintenance, Upgrade and Repair, Recycling or Repurposing, and De-orbiting or Decommissioning. The factors incorporated include traditional satellite lifecycle, primarily driven by Earth satellite-based industry, as well as emerging elements such as on-orbit servicing and additional activities to expand lifecycle. Figure 9 shows satellite value chain. [11]

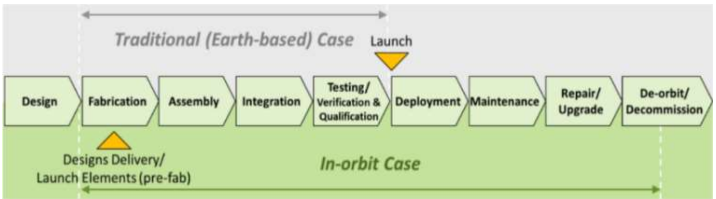


Fig. 9 : Spacecraft manufacturing value chain - traditional and in-orbit case [11]

In the following review, activities have been grouped based on similarity or adjacency, in order to simplify the chain and analysis.

3.1. Satellite manufacturing industry

Globally, there are approximately 30 companies which manufacture satellites. Satellite manufacturing is a difficult and challenging endeavor as it involves thousands of components and sub-systems for Assembly, Integration and Testing (AIT). The design of every satellite is different based on past experience and designers always strive for improvisation. [12]

Satellites have traditionally been more to handcrafted items than to mass-produced goods. That kind of

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customization, combined with long life-span requirements, explains why a typical large communications satellite costs from $50,000 to $60,000 per kilogram. [2]

Historically, communication involved geosynchronous satellites (GEO, the volume of space encompassed by 35,786 km +/- 200 km in altitude and +/- 15 degrees in inclination [28]), large systems that have become increasingly capable over the years [2]. However, market is changing now and satellite industry has experienced a paradigm shift with the rise of small satellites and mega constellations. The numbers are huge, i.e. thousands of satellites, each over 50 kg; emerging several commercial constellations launching a total of 1,6000 small satellites by 2030. [12]

Now the Non-GeoSynchronous-Orbit (NGSO) communications constellations, including Low-Earth-Orbit (LEO, Earth-centered orbits with an altitude of 2,000 km or less [27]) and Medium-Earth-Orbit (MEO, region between LEO and GEO is commonly referred to as Medium Earth Orbit [28]) satellites, are getting launched to space, and their number could soon soar. Even if the most ambitious plans do not come to pass, the satellites will be manufactured and launched on an unprecedented scale. [3]

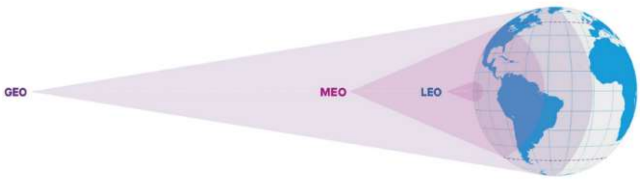
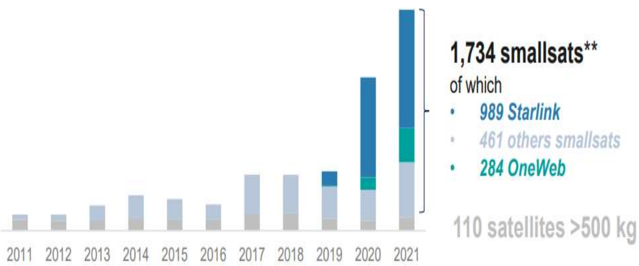


Fig. 10 : Schematic of orbital altitudes and coverage areas [32]

The new LEO satellite concepts, offer faster communications and often provide higher bandwidth per user than GEO satellites do, even more than cable and pre-5G fixed wireless. These concepts will require major changes in satellite operations, including manufacturing and the supply chain, since they ask for more satellites and shorten average life, [2] then satellite mass production could decrease cost from a few hundred million dollars per satellite to a few hundred thousand dollars. [3]



Graph 5 : Satellites manufactured and launched in the last decade [30]

We need to emphasize that 1/3 of market value will be still with GEO satellites and on average 13 GEO satellites will be ordered every year by 2030. [30]

3.2. Launch Vehicle Manufacturing and Services

Globally, there are approximately 10 launch services companies. [12] As launch becomes more refined, cheaper, easier and faster, it will allow for the rest of the ecosystem, from satellites to services, to grow into a broader marketplace. The launch companies are depending on the small and medium satellite manufacturers. The manufacturers are relying on the services companies, who are focused on businesses like satellite broadband, LEO imaging and weather monitoring, and then the loop feeds back on itself. [4]

Improvements leading to Falcon Heavy clearly indicate that logistics is becoming more and more important in space industry. [5] Indeed, the launch business is fundamental to the space ecosystem; no launch, no space and one of the biggest areas of funding. [4]

A single transformative technology shift often can spark new eras of modernization, followed by complimentary innovations. In 1854, when Elisha Otis demonstrated elevator, the public couldn't foresee its impact on architecture and city design. But roughly 20 years later, every multi-storey building in the US was constructed around a central elevator. [3]

Today, development of reusable rockets may provide a similar turning point. Just as further innovation in elevator construction was required before today's skyscrapers could dot the skyline, so too many opportunities in space will mature because of access and falling launch costs. [3]

While reusable rockets as well as mass-production of satellites and the maturation of satellite technology will help drive those costs down. Currently, the cost to launch a satellite (as primary payload) has declined to about $60 million, from $200 million, via reusable rockets, with a potential drop to as low as $5 million. [3]

The biggest turning point in launch industry is entry of SpaceX into the business since 2010. The launch giants in France and Russia have lost their market lead to SpaceX in the US now. Its modular approach and innovation in technology has resulted in cost drop to an extent never visualized before. [12]

Launching small satellites as the secondary payload aboard big launch vehicles has become a thriving sector. But with a dedicated launcher for small satellites, not only would cost reduce drastically but also there will be more opportunities to focus on primary research and delineate big satellite launch from small satellite launch. Dedicated teams are working towards development of Small satellite launch vehicle to meet the specific requirement of launch of

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small satellites with minimum possible lead time [12], as there is increasing demand to launch small sats. [4]

1844 Satellites manufactured and were launched by 144 launchers in 2021. [30]

3.3. Testing

Due to the intense conditions experienced by a launch vehicle as it leaves Earth's atmosphere (as well as the harsh environment in the space), rocket payloads have the potential to be damaged physically, electronically, or chemically. For example, the extreme acceleration of the launch vehicle or a sudden change in the magnitude or direction of the launch vehicle's acceleration could physically disrupt the payload. Similarly, the payload's electronic or chemical composition could be severely disrupted by extreme temperatures, rapid changes in temperature or pressure, contact with fast moving air streams, or radiation exposure.

To prepare for as many unfavorable launch scenarios as possible, all payloads must undergo a series of tests simulating a variety of launch environments. Once these tests have been completed, the rocket is ready for payload integration, or the installation of the payload into the payload fairing. The payload fairing, or the rocket's nose cone, is used to protect payloads from the impacts of dynamic pressure and aerodynamic heating as the rocket leaves the earth's atmosphere (It is worth to say that for series production e.g. constellation satellites, it is not required to redo all the tests for all products, but the tests can be done as per QC sampling plan).

several tests namely Vibration, Thermal Vacuum, Spin Balance, and Electromagnetic Interference are typically conducted during payload integration to ensure the launch vehicle is prepared for a diversity of environments during spaceflight. Here is a few tests the payload may undergo to become launch-ready. [20]

3.4. Satellite Operators

Globally, there are approximately 50 to 60 operators. These players, in the value chain, operate space assets and sell bandwidth capacity or data for various applications like satellite telecommunication, Earth observation, or navigation etc.

The commercial market of telecommunication is mature enough, with a few top players being catering to 60% of the bandwidth requirement worldwide using their respective satellite fleets. The architecture to provide services by a service provider can be either open or closed architecture.

For Earth observation for remote sensing application is mainly societal in nature. Applications like disaster management, agriculture, change detection, disaster mitigation, meteorology, resources science, earth science, space science, and national security are not commercial but prudent for any country.

In satellite-based navigation, the business of private space operators has not yet materialized, since the only existing positioning systems are owned and operated by governmental agencies mainly for military purpose, and the access to the civil signal is free. [12]

3.5. In-Orbit Services

In-Orbit services (IOS) encompasses a wide scope of new activities (table 2) conducted in outer space and addresses an even broader range of technical, technological, industrial, legal and political challenges. In-Orbit Services require space rendezvous and close proximity operations, which could be defined as "orbital maneuvers in which two spacecraft arrive at the same orbit and approach at a close distance". Close proximity operations usually imply that the two space systems are within a few kilometers or less from each other. The main distinction with in-orbit services is the contact and/or communication established with the other spacecraft following the space rendezvous in order to conduct maintenance, inspection or towing.

Table 1 : Types of In-Orbit Services [15]

Maintenance

- **Repair**: repairing or replacing parts of a space system in orbit in order to extend or maintain the system in operational conditions.
- **Reconfiguration**: modifying the spacecraft's payloads or modules in order to repurpose the mission of a space sytem.
- **Refuelling**: providing and transferring propellant, fuel pressurants or coolants from the servicer spacecraft to the target one, in order to keep the system operational.
- **Recharging**: providing electric power to a satellite in orbit through power beaming or docking
- **Upgrade**: replacing or adding components to a space system to improve its capabilities.

Tugging and Towing

- **Station-keeping:** docking of the servicer spacecraft with a target satellite in order to keep the target in a particular orbit or attitude.
- **Orbit correction:** relocating or repositioning a space system to the adequate orbit.
- **Relocation**: modifying the position of the space system
- **De-orbiting:** capturing a space system to relocate it to a graveyard orbit or to accelerate its atmospheric re-entry.
- **Recycling**: retrieving the raw materials of orbiting rocket bodies to transform them into other space components or products.

Inspection

- **In-orbit inspection:** assessing the physical status and conditions of a satellite and potentially detecting anomalies or examining the consequences of an attack or collision.

The market opportunity for in-orbit servicing (IOS) is developing and will become a multi-billion-dollar market by the end of the decade. It is conservatively predicted to be valued at ~$ 4.4 billion in cumulative revenues (within a range of $ 2.3-7.2 billion) by 2030. 60% Of this global market opportunity will be from commercial customers and 40% from governments.

The global IOS market over the next decade will be led by GEO life extension, LEO debris removal services (both active debris removal and end of life servicing), and broader asset relocation. Furthermore, debris removal services protect the entire LEO ecosystem and the space assets. [16]

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Graph 6 : IOS market [16]

The IOS supply chain is complex with stakeholders from industries as diverse as satellite bus design, mission operations, insurance and potentially broadcast TV companies. The below figure 11 shows a simplified IOS value chain including stakeholders such as Regulators, Assembly, Integration and Test facilities and an IOS service provider. [16]

Fig. 11 : IOS supply chain [16]

3.6. Ground segment

A ground segment is the system set up on Earth to manage and control a space mission, and to receive and process the data produced by a spacecraft's instruments, and to send out and archive any generated products [28]; in another word the key functions of the ground system are as follows:

- **Mission Management** (MM) encompasses all functions of the spacecraft and instruments operations and health and safety.
- **Product Generation** (PG) creates products from data provided by MM. Product generation operates on a continuous basis, meeting latency and availability requirements.
- **Product Distribution** (PD) distributes the products created by the PG function through a variety of means. [29]

This sector primarily serves the value-added service providers to establish their ground infrastructures. It includes Network equipment and Consumer equipment. The fate of billions of dollars invested by satellite operators globally effectively lies in the timely success of technologically-economics fit of the ground equipment, as it undergoes transformation, both on the technological and business model fronts. The technology is a key in this segment as satellite network optimization depends on the ground equipment in use. [12]

3.7. Value Added Service providers

This is the downstream part of satellite industry value chain which is generating the highest revenues, and is addressing directly the end users. There are a lot of companies into this sector, starting from established service providers (mainly in telecommunications) to small start-ups companies addressing niche market segments. The market structure is very scattered, in particular in the geo-information services sector.

The ground segment and the value-added service domain have become the most attractive business segments; numerous players compete in these markets, while new services and apps are rolled out at a very high rate. [21] These providers invest few millions on ground and facilitate end to end usage of space segment capacity. [12]

3.8. End User

All the above-mentioned players and setups work towards serving the end user requirements and demands. Likewise, in all segments, customer dominates and dictate the demand.

The entire industry thrives for realizing the wish-list of users and turn it into an application of satellite bandwidth. The ground segment industry aligns its efforts to develop the appropriate consumer equipment. [12]

4. Literature

Firms have directed considerable attention to developing supply chain relationships. Many companies have been in the process of extending their logistics organizations into those of other supply chain participants and facilitators. One way of accomplishing this extension is through the use of a supplier of Third-Party Logistics (3PL) or contract logistics services. 3PLs are external suppliers that perform all or part of a company's logistics functions, including: transportation, warehousing, distribution, and financial services.

In the recent years, there has been some concern expressed by the users of 3PL service providers that they are not being given the expected levels of service and business benefits. Users have also indicated that service providers are not proactive enough in their approach to the contacted operations. On the other hand, service providers claim that they are seldom

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given the opportunity to develop new ideas and offer improvements, because users are not prepared to give them adequate information of their complete supply chain.

One consequence of this has been the idea of using an additional enterprise or organization to oversee and take the responsibility for all the outsourced operations a user might have. This has become known as Fourth Party Logistics (4PL).

4PL is the registered trademark of Accenture Inc. and has been defined by this company as ''A supply chain integrator who assembles and manages the resources, capabilities, and technology of its own organization with those of complementary service providers to deliver a comprehensive supply chain solution''. In other words, 4PLs manage and direct the activities of multiple 3PLs, serving as an integrator. In this way 4PL service provider contributes to the sustainable competitiveness of all the collaborating manufacturing and service companies. Hence, the focus of logistic efficiency is no longer on a local level but in the frame of supply chain activities and network cooperation. [10]

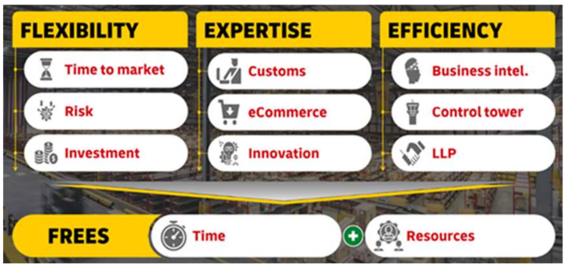
In the following Logistics outsource, Logistics evolution, LLP/4PL, Operating models and 4PL/LLP Benefits are discussed in further details.

4.1. Logistics Outsource

Beyond the strategic dimension of logistics, the emergence of the logistics delivery market is based on the disengagement of companies from activities considered peripheral and by refocusing on the core business, that is, activities deemed essential. This disengagement is reflected by a tendency towards outsourcing.
Businesses first organized their own logistics with their own resources; however, the majority of companies today have outsourced at least the low layers of logistics, starting with transport operations. As a result, the service offered by LSP has expanded considerably, so as to match supply and demand. They evolve from a simple control of operations of the activities to a control of design of the logistic systems.
Based on a contract, outsourcing can include at the same time the transfer of material and/or personnel, the commitment of different parties to a lasting relationship, as well as the reorganization of outsourced services, with the aim of increasing competitiveness. However, it can go beyond the framework of the contract by getting involved into inter-organizational relationships. Applied to the field of logistics, outsourcing is the fact of entrusting all or part of the supply chain, previously provided internally, with a possible transfer of resources, to an external service provider with a view to performance. [6]

In summary, here are the benefits of logistics outsourcing in four areas of flexibility, expertise, efficiency and resources release. [24]

Table 3 : Benefits of outsourcing logistics



4.2. Logistics Evolution

The business challenges have been changing in the past from subcontracting (1PL) and globalization (2PL) towards e-commerce and omni-channel growth (3PL to 5PL). [8]

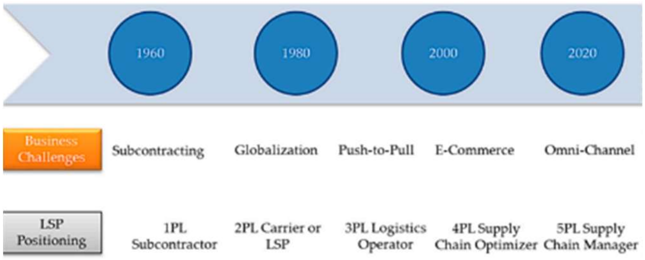


Fig. 12 : LSP's roadmap [8]

Three historical stages of the logistics service can be distinguished: from simple executives and operational actors at the outset, in a second phase, the service provider becomes a real expert to meet the client's request, on more or less complex logistics activities. Finally, in a third phase, the service provider actively participates in the co-definition of processes in a strategic vision of the company. It is even possible to say that the LSP become in a later stage, co-designers or even designers and supply chain managers, in an innovative and creative approach. For their part, logistic service providers were distinguished on the basis of the complexity of their offers; indeed, three families of LSPs: the 2PL, traditional service providers whose only offer is the execution of simple physical operations related to transport, the 3PL which, in addition to transport, offer value-added services including industrial, commercial, informational and administrative operations. In the end, 4PLs, dematerialized actors and having practically no own assets, real "developers of turnkey solutions" are called by mobilizing resources from different partners and ensuring coherence through complete control of information flows.

4PL distinguish themselves from the 3PLs that manage flows using their own means of transport and storage, and aim to provide their customers with tailor-made

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logistics solutions (particularly information) by grouping a network of skills (transport, storage, etc.). They then offer purely informational services by playing the role of intermediary between the shipper, its various service providers and its market. [6]

Another classification is to quote according to the professional press which introduces two other names: LLP (Lead Logistics Providers) and LLM (Lead Logistics Managers). They come together and refer to the case where a single partner, itself using subcontractors, oversees all of the logistics flows of its client in a large area (table 4).

Table 4 : Summary of the typology of LSP [6]

Typologies of LSP	Characteristics and nature of the offer	
1PL	• Subcontracting of transport or storage	3PL
2PL	• Classic provider • Performing simple physical operations related to transportation and storage	
3PL	• Value-added services, including, in addition to transportation, operations of industrial, commercial, informational and administrative characteristics • Uses own resources (means of transport and storage)	
4PL	• Dematerialized LSP • Having virtually no own assets • Mobilize resources from other partners • Total control of information flows • Groups a network of skills • Develops Customized logistics solutions	4PL
LLP et LLM	• Only partner of the principal • Uses subcontractors • Supervises logistics flows over a wide area	

As per another classification, for the logistics industry as such, the business models of shippers and LSPs are categorized by means of their service range and structure. A popular classification scheme is the 1PL to 5PL scheme. Below table 5 gives an overview of this classification scheme and related sustainable logistics practices.

Table 5 : 1PL to 5PL scheme and related sustainable logistics practices [8]

Classification	Description
1PL (Single Service Provider)	Single service providers execute a single logistics services, such as freight carrier (transportation) or stock keeper (warehousing). Accordingly, single service providers should concentrate on methods to decrease the environmental and social impact of their logistical assets (e.g., using cleaner drive technology).
2PL (2nd Party Logistics Provider)	The 2nd party logistics provider executes all classical logistics functions of transportation, handling and warehousing; typical business model for freight forwarders, ocean carriers and parcel services. As they operate different transport modes, the selection of the best modal split becomes an important instrument to increase the environmental performance of their logistical activities.
3PL (3rd Party Logistics Provider)	The 3rd party logistics provider extends the classical logistics function with neighboring logistics services such as cross docking, inventory management and packaging design. In this line, 3rd party logistics providers are often globally acting companies who contract with their customers "at eye level" [20]. Hence, they have the opportunity to implement more advanced, sustainable strategies such as decision support systems to optimize transport mode, route and capacity usage.
4PL (4th Party Logistics Provider) and 5PL (so-called Lead Logistics Provider)	The 4th party logistics provider provides comprehensive solutions to coordinate and integrate all supply chain members using information and communication technologies (ICT). 4th party logistics providers are often specialized consulting companies not carrying out any operations (so-called non-asset-owning service providers). In contrast, lead logistics providers carry out certain operations by owning or buying physical logistics infrastructure. Accordingly, coordination mechanisms and joint decision-making are relevant to achieve more sustainable supply chain configurations.

4.3. 4PL/LLP

Pure 4PL is described in the literature on the basis of the famous definition proposed in 1996 by Arthur Andersen (now Accenture Consulting), which originally registered the name as a trademark: "the 4PL is an integrator that assembles its own resources, capabilities and technology and those of other service providers to design and manage complex supply chains". The definition proposed by Accenture, which has been widely circulated, provides us with a first measure of the importance for a company to be considered a 4PL rather than simply a lead logistics provider (LLP) or third party logistics (3PL). [17]

A fourth-party logistics provider that manages all aspects of a supply chain and serves as the single point of contact to the client and third-party service providers. 4PLs are also often referred to as lead logistics providers (LLPs). They manage everything to do with supply chain, including resources, technology, and infrastructure. In many ways, they are the main project managers of the client's supply chain. They may or may not be asset owners themselves, but they have deep expertise and technical knowledge to execute the plan outlined by the client. In other words, the best 4PLs ensure things get delivered, within budget and on time. [7]

By being a supply chain integrator who can assemble and manage the resources, capabilities, and technology of its own organization with those of complementary service providers, fourth party logistics (4PL) providers deliver comprehensive supply chain solutions and form an important option for business outsourcing. The adequate design of the partnership between companies in this type of outsourcing activities is essential. [10]

Figure 13 illustrates the relationship between client and logistics service provider from *transactional* to *partnership* models. [13]

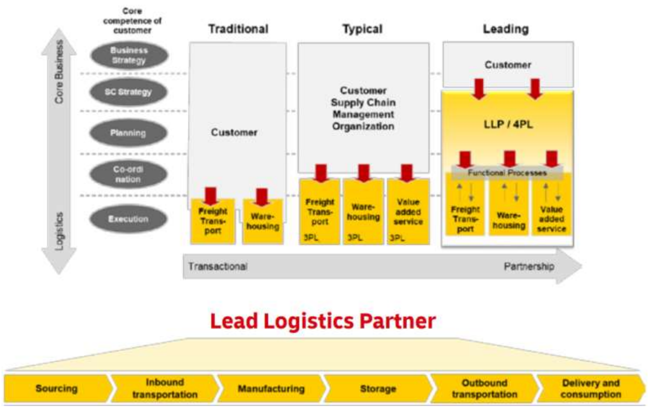

Fig. 13 : LLP partnership relationship [13]

The level of integration up to supply chain strategy of client is a key factor in LLP business model.

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4.4. Operating Models

Like any logistics solution, 4PL models will need to be customized to fit the needs of each company and/or situation. While customization will occur for each client, currently there are three primary operating models that can help in structuring the 4PL relationship based on the needs and resources of all participants.

To attain the expected benefits from the 4PL applications, companies have to identify a suitable 4PL model for the supply chain they will operate. In the following, 3 types of 4PL operating models, have been explained.

- **The synergy plus model** relies on a working relationship between the 4PL organization and a 3PL company and this alliance provides a comprehensive integrated supply chain offering. Both the 4PL and the 3PL collaborate to market supply chain solutions, which capitalize on the capabilities and market reach of both. 4PL provider would offer a wide range of services for the 3PL company (technology, supply chain strategy skills, program management, etc.) and would work within the 3PL organization. The relationship between the two organizations could be similar to a marketing alliance or contractually binding partnership.

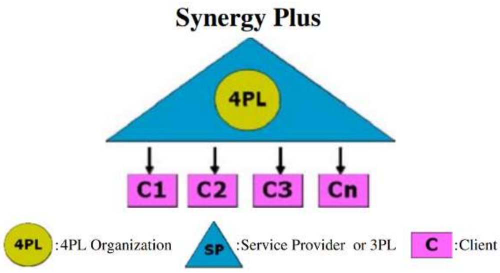

Fig. 14 : 4PL Operating model SP [13]

- **The solution integrator model** is known as the core 4PL model because it focuses on the strength of 4PL as an individual organization which manages a comprehensive supply chain solution for a single client. This model integrates the technology and resources of the 4PL and multiple service providers to establish an integrated supply chain solution that can deliver value for the client throughout the entire supply chain.

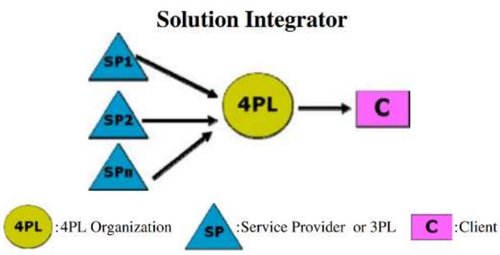

Fig. 15 : 4PL Operating model SI [13]

- **The industry innovator model** is a complex but rewarding operating model within the 4PL environment. As an industry innovator, 4PL provider develops and manages a supply chain solution for multiple industry participants. 4PL organization will focus on synchronization and collaboration between the participants in order to provide efficiency through technology, operational strategies and implementations across the supply chain. It is expected that a 4PL provider will reach this model through growth after mastering the solution integrator model. [10]

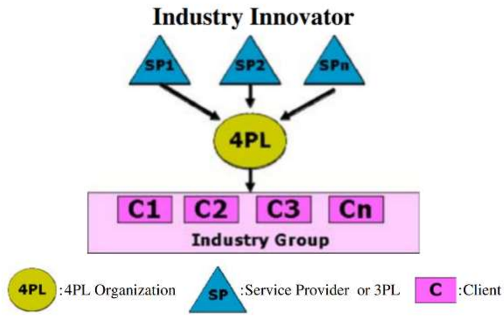

Fig. 16 : 4PL operating model II [13]

4.5. 4PL/LLP Benefits

Here are the benefits of 4PL/LLP:

- Cost reduction: Alternative methods for reducing supply chain costs beyond the typical procurement approach;
- Visibility, Control & Compliance: Improves process efficiency;
- Integration: Integrated end-to-end supply chain (by geography and/or business unit);
- Talent: Access to supply chain best practice and talent that accelerates “time-to-value”;
- Flexibility: Supply chain infrastructure and organization that is “fit for purpose” and responds to changing conditions;
- Digitalization: Technology that will drive digitalization and efficiencies, and facilitates full “end to end” supply chain. [13]

Today, many authors advance the view that a 4PLs network is needed to manage the logistics operations in close cooperation with both the traditional 3PL firms, and the companies that are developing the latest logistics information technology. [10]

5. Research methodology

Within the framework of this research a Qualitative method approach has been applied to explore and analyse trends, supply chain maturity, driving factors, barriers and gains regarding application of LLP model in satellite supply chain considering all the aspects

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including experience and lesson learned from terrestrial logistics.

5.1. Data collection

Data collection was executed through interviews with experts, majority of them were at managerial and C level, from a variety of European and American space sectors. The expert interviews lasted up to 60 minutes.

5.2. Data analysis

The summaries and important quotes of the interviews were analysed with the qualitative content analysis approach in a structured manner and linked to the literature, wherever possible to develop codes and identify themes, patterns and relationships through the following steps:

- **a.** Familiarize further with data;
- **b.** Assign preliminary codes to data in order to describe the content;
- **c.** Search for patterns or themes in codes across the different interviews;
- **d.** Review themes;
- **e.** Define and name themes.

6. Findings

At the end of data analysis, nine themes were identified from the interviews. Here are the 9 themes, each theme is followed and supported by interviewees' quotes.

Theme 1: Compared to other industries e.g. car manufacturing, satellite industry flow is low.

Universal satellite production capacity is limited which means both the production of components and sub-systems are limited on the supply side, while the finished products number (on demand side) is much less so the flow on supply side is limited and on the demand side is even further limited.

When it goes to launch operations, the flow goes much less, because several satellites can be launched together.

The low flow can be considered as a barrier to apply LLP in satellite supply chain, but it is more probable to apply LLP in supply side of satellite manufacturing due to more flow, in large constellations i.e. Kuiper, Starlink and OneWeb.

The benefit of sharing plan with a logistics service provider is very minimal compared to 4 to 5 years of projects timeline.

But the new space economy is stimulating the market.

Theme 2: Considering high value of components, sub-systems and finished products, on-ground logistics share of cost in satellite manufacturing is small.

Since value of components, subsystems and satellites are high, then although the terrestrial logistics are expensive but they compose a small share of the total cost in satellite supply chain; so, we are not sure if it is possible to apply this business model to satellite industry.

Theme 3: LSPs' Competency and reliability is the first priority, and number of competent LSPs is limited.

In satellite supply chain, the driving factors of LSPs are competency and reliability to deliver the required quality and handle the operations despite all restrictions.

Terrestrial logistics service for space industry is a very restricted market in the sense of know-hows and how to deal with the restrictions e.g. export control, handle the goods through different countries which is not super easy to integrate/share the system and planning tools; additionally, many times, the logistics operations are influenced by customers, so it is a different market.

Theme 4: There are non-operational barriers including confidentiality, political issues and human habit.

Supply base is a competitive advantage for satellite manufacturing so they would not tend to inter in such a disclosure through LLP model and it is considered as a high threat to the manufacturer competitiveness because it takes a lot of time to find very good suppliers.

Political issues are considered as barrier to address the problems, out of the political borders, by some solutions e.g. LLP model.

People are used to do in a certain way; so, you must demonstrate how LLP model is going to win in the satellite industry; the industry people are very sensitive to competitiveness.

Theme 5: Launch is a major cost centre and challenge in satellite supply chain.

High launch costs are always a major challenge that is getting changed due to the new comers.

Launch brokers integrate the demand for launch; because there is a gap between rocket generations, rockets are large and new satellites are small.

Theme 6: High insurance premium is considered as a pain point.

Insurance covers (i) launch risk and (ii) operation risk, and it is a pain point in term of cost in satellite supply chain, that can differ depending on reliability of the launcher.

Theme 7: There are several regulatory and contractual restrictions for pure commercial operations.

There are restrictions due to governmental legislation and agencies/prime contractors' contracting models.

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Regarding regulations, they are getting tougher by further law and restrictions.

Depending on the satellite application, you can be subject to Export Control; very often in space industry you fall in that category. In Europe it is not that much problem because export is quite easy, but some areas like the United States are very difficult, they have got ITAR regulations which impose a huge amount of implications on what type of authorization you need, to move the stuff around, and that is a huge break in the space industry.

Regarding institutes e.g. ESA, as the main customer in the space industry, there is a list of membership of countries that finance the missions; same amounts of financing comes back to the countries to build the space economy, that generates artificial supply chain; it reduces the number of options you have in your supply list and that is a problem obviously; so it is not a pure commercial business model to the best cost by supplier.

Finding a way in the supply chain to engage contractors, is of major interest; if the industry applies horizontal integration in the supply chain, it is fundamental to be actually competitive on the market and today most of the contracts are not structured like this.

The other thing is that institutional control procedures have been increased without removing any, which means become more and more heavy in terms of structure and that has an impact on complete process. Therefore, a lot of money is expensed in ineffective control of supply chain (related to control the use of public funding) by space agencies; in space industry, agencies still have a huge vein in what happens in the supply chain.

Space agencies are major customers in terms of revenue, but their traditional contracting model make the LLP model very difficult; The tendency is that the agency defines all the standards for the prime contractor and impose it to the supply chain; this is one of the problems in the supply chain.

Theme 8: Traditional and New SPACE might have different approaches to LLP.

Traditional/established space industry is struggling with prices; they are looking for ways to save money, so they might need LLP model; probably it will be more adaptable in traditional space industry but maybe new space industry needs some time to be a little more mature to apply LLP model.

New space organizations are more open to LLP, but companies want to see the hard facts and the benefit should become evident. Traditional space industry will say why do we need to do it in that way?

Theme 9: Satellite supply chain is getting further adapted to the new market demand.

We (a leading aerospace company) have supply chain responsibility in country level but we are going to upgrade the supply chain from local to global.

Satellite supply chains are long, so launch pads and satellites manufacturers should be in one place. Some major actors went to vertical integration as a solution to simplify the supply chain, make the supply chain faster and cheaper, prevent margins and delays, and produce the exact components.

Microsat launch service providers can be considered like LLP model in launch segment; they provide rideshare (secondary payload) services through the large launch vehicles sluts for microsats. After launch the space logistics service provider can transport microsats in orbit, and provide a cloud-based mission control software to control the microsats.

7. Results and conclusions

7.1. Results Overview

Currently there are strong barriers to apply LLP model in satellite supply chain although a sort of integration is applied for microsats launch (I call it MicroLLP, since it is applied for a part of microsats supply chain); but to perform a further precise analysis we need to segregate space industry into sections namely traditional space and new space, or in another way to before launch and after launch.

On the other hand, the space industry is developing drastically by some drivers e.g. universal competition, technological enablers, available private investment and market demand. In addition, space industry is pioneer of technology development, so we expect that satellite supply chain will evolve to adapt with the market demand, although due to the intrinsic strategic application of the space industry, there may be some barriers to globalize a purely commercial operations in satellite supply chain.

7.2. Summary and Conclusions

The barriers to apply LLP model in satellite supply chain include (i) Low flow, (ii) Regulations, (iii) Limited number of competent LSPs, (iv) confidentiality and (v) political barriers.

Yet another aspect is to achieve greater cost efficiency by vertical integration, so that it can control supply chain and optimize its production to both ensure quality and costs. [17]

Fig. 17 : Benefits of vertical integration [35]

Countries regulations e.g. export control as well as institutional contracting models and procedures are

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considered as barriers to optimize satellite logistics operations.

We need to consider two other barriers to optimise logistics operations through LLP model; first limited number of competent LSPs, and secondly the industry tendency due to (i) unwillingness to disclose supply chain information as well as (ii) human habit.

If we split the operations into before and after launch, the results can be interpreted as following: regarding terrestrial logistics (before launch), the benefits from LLP will compose a very small share of the total cost regarding high value of satellite components, sub-systems and systems, while the satellite manufacturer should disclose a lot of information about its supply chain to the logistics service provider and this threatens its competitiveness.

Regarding after launch logistics (including launch), the launch expenses are a major center of cost and a pain point, in satellite supply chain. Currently new space section is applying a type of MicroLLP model to launch, deploy and operate microsats as second payload or rideshare by large launchers, followed by a cloud-based mission control software to operate the microsats.

If we split the industry into Traditional/Established and New Space, the results can be as following: traditional and New Space might have different approaches to LLP; traditional space might be more conservative but in fact they need to decrease the costs; on the hand new space might be more open to LLP model but they need time to expand.

Also, we can categorize the aforesaid barriers into two groups with respect to satellite supply chain:

- **Internal barriers:** Low flow and Supply Chain Confidentiality.
- **External barriers:** Regulations, Institutional contracting model, limited number of competent LSPs and political issues.

In addition, the major pain point in satellite supply chain is launch cost (including insurance), which is very high, although the industry has successfully decreased the launch costs, but the market expects further reduction. Point of the cause is illustrated in figure 18 through breakdown and prioritize stages method. [22]

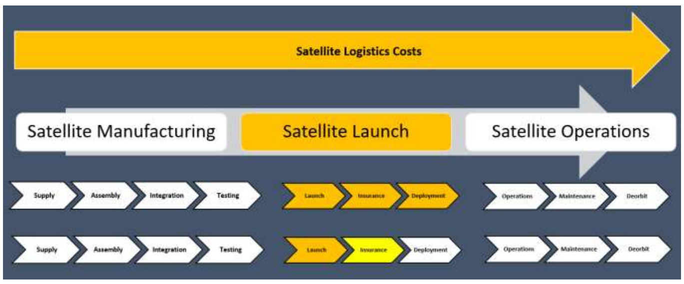

Fig. 181 : Breakdown of the problem

Considering that space industry is pioneer of technology development, as well as fast commercial development of the section, we expect that satellite supply chain adapt with the new market demand, although due to the intrinsic strategic application of the satellites systems, there may be some regulatory barriers to globalize a purely commercial logistics operations in satellite supply chain. The recent development in emerging start-ups, vertical integration of satellite supply chain, microsat launch aggregators as well as technology progress e.g. 3D printing and miniaturization, all are driving the process.

Finally, we need to add that success of the new space economy will require a self-sufficient ecosystem, through continuous improvement of end to end satellite supply chain.

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