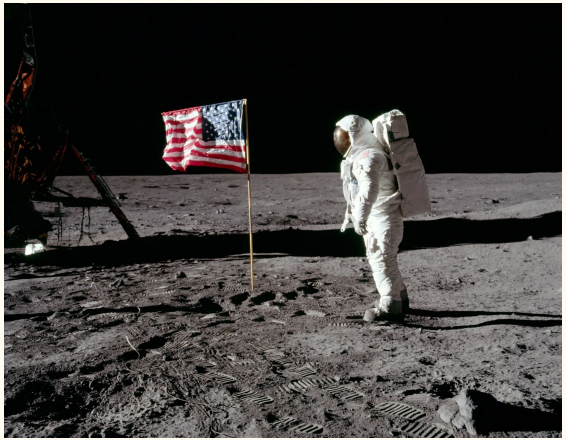
Lecture 8

Use Case: Blockchain in Space

From moon walk to SpaceX



Traditional space (1900s):

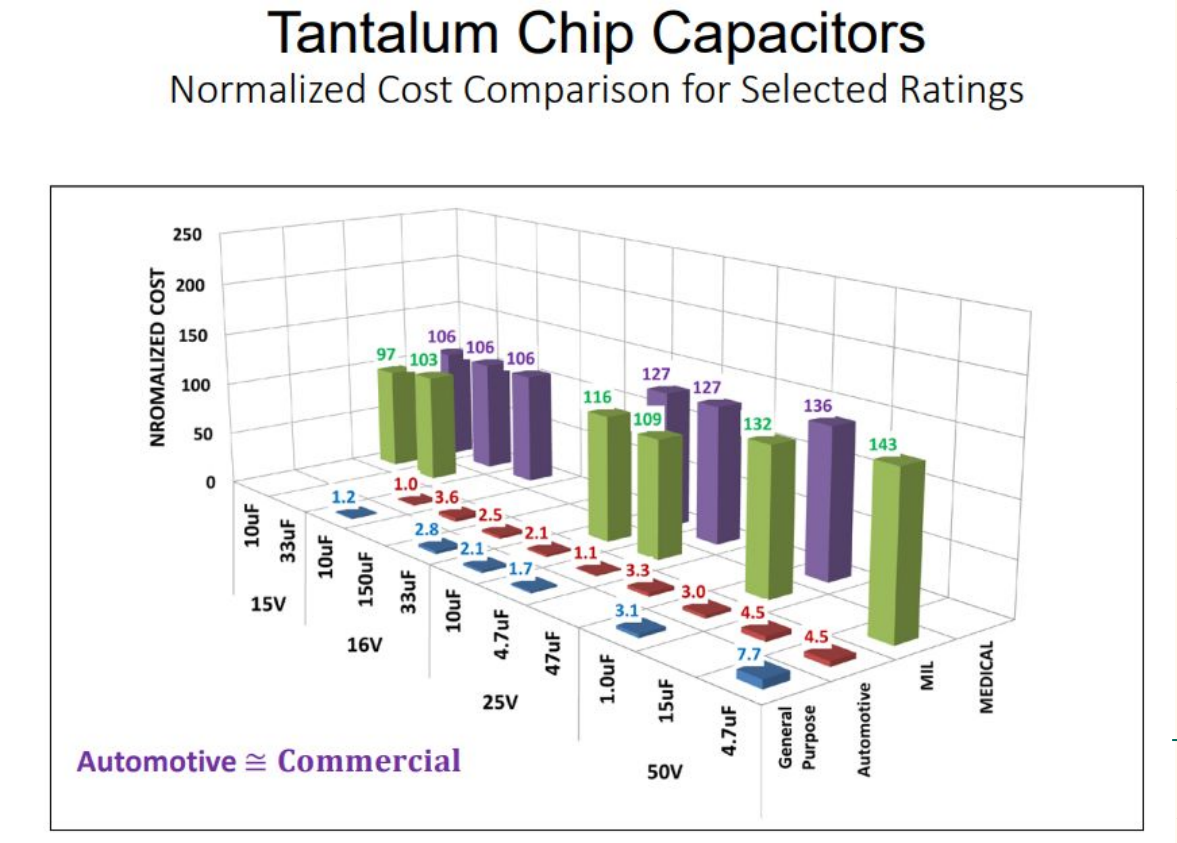
- Defense focused, space sovereignty
- Expensive, Apollo mission cost $355Mil ($3Bn today)
- Long schedule (1960 - 1969)
- Monolithic and complex
- Deep space, manned missions (GEO orbit)
- Focused on **reliability**

1994: William Perry's memo to use Commercial Off the Shelf (COTS) components for DoD

New space (2000s):

- Decentralizing space, space travel for all, many startups offering space-as-a-service.
- Cheap, reusable(?)
- Short schedule, frequent launches, short lifespan
- Constellations like Starlink, general SmallSat or Cubesat that are 10cm
- Unmanned, low orbit (LEO orbit)
- Focused on **cost**

Commercial Off the Shelf Components - COTS



Automotive components cost similarly to commercial COTS but is tightly regulated and extensively tested.

IATF - Standardize assessment and production methodologies
AEC-Q: Stress testing for Automotive conditions (harsh)
PPAP: complete documentation from design, testing, failure control to statistical analysis(SPC).

Commercial: phones, laptops
Automotive: cars, trucks
Military, satellites, aircrafts, missile guidance
Medical: imaging, equipment

Manned Rockets to Unmanned Satellites, New Space dominating LEO

GEO, MEO and LEO Satellites

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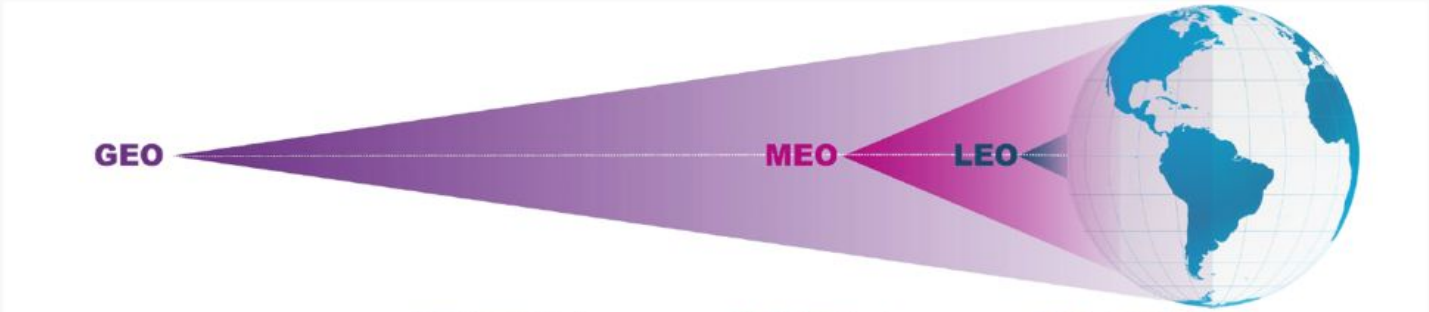
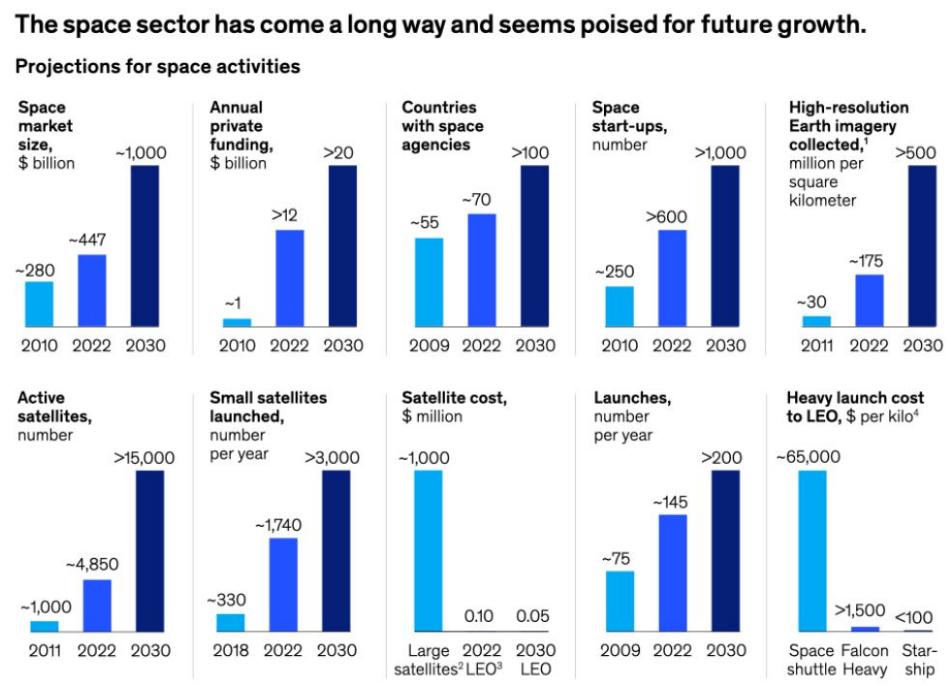


	GEO (~36,000 km)	MEO (~8,000 km)	LEO (~1,000 km)
Latency	Medium (~700 m/s)	Low (~150 m/s)	Very low (~50 m/s)
Network size for global services	3 satellites (99% coverage)	6 satellites (96% coverage)	Thousands of satellites (100% coverage)
Data gateways required	Few, fixed	Several, flexible	Numerous, local
Technology readiness level	Proven, deployable technology	Proven, deployable technology	Technology still in development for satellite internet
Cost to deploy network	$1 - 1½bn	Approx. $1½bn	$5 - 15bn
Satellite design life (replacement cycle)	15 years	12 years	5 - 7 years

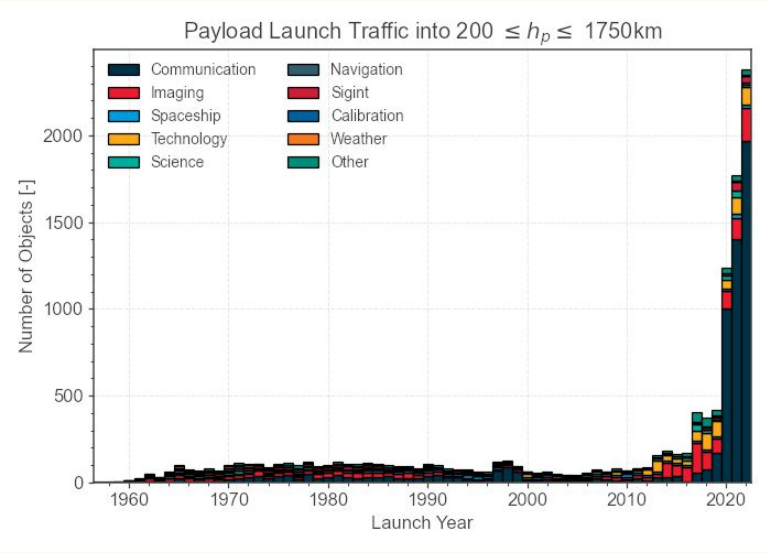
New Space use cases mostly concern Lower Earth Orbit (LEO):
- SpaceX travel around LEO
- Satellites have better communication in lower orbit, easier to launch, cheaper.

Most New Space start ups offer service around launch and reusability while Trad Space still builds the complexer rockets.

Evolution of the Space Market



Source: McKinsey & Co. , 2022



New Space is a trillion-dollar market driven by private funding. The main use cases are communication, navigation and imaging. Satellites are produced at 1/1000 of the price due to COTS components.

Governmental agencies also embracing COTS components


DEFENCE AND SPACE

1. Heritage (use of commercial components)

Commercial EEE parts in European space systems is already a reality since several years !

- CNES programs : more than 20 programs (class 1 to 3) including commercial EEE parts.
- ESA programs : several programs (including class 1), already use commercial EEE parts.
- Airbus-D&S programs : commercial EEE parts introduced in earth observation programs since 2004.
- Some concrete examples
  - Ariane 5 : several operational equipment with 80% of active parts in commercial
  - FNP *(class 1)* : 6 microcircuits in commercial
  - Pleïades *(class 2)* : 36 active devices and some passive parts (resistors, capas, connect) in commercial
  - Myriades *(class 3)* : 80% of parts used in OBC in commercial
  - AS250 *(class 2)* : 6 active devices in commercial
  - Gaïa *(class 1)* : 5 microcircuits in commercial
  - Metop-SG *(class 1)* : several microcircuits in commercial

3

AIRBUS

- 2004: Swift mission flies 40% COTS EEEE parts (with level 3 upscreening)
- 2013-2017: Multiple Spacecube variants with up to 99% COTS EEEE parts (no upscreening)
- Numerous Ames missions, 100% COTS EEEE parts (no upscreening)
- Ingenuity: 99% COTS EEEE parts with focused screening
- SpaceX: Mostly COTS EEEE parts
- SSTL: Mostly COTS EEEE parts(several decades)
- AFRL's Ascent: 100% COTS EEEE parts (GEO)
- Newspace: almost 100% COTS EEEE parts and components

NASA Report, 2021

"Upscreening" is performing the tests that are not performed in the automotive manufacturing process. Why no upscreening?

Space Debris - Does New Space have a future?

The future of Space is in connecting other industries like science, agriculture and automotive, collecting data to be applied in AI models for many day to day decisions.

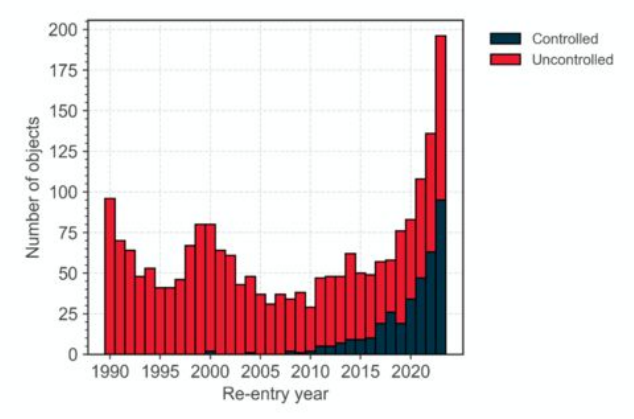
Debris is generated through explosions of unsuccessful missions, deliberate anti-satellite missile testing, or simply lack of clean up after end of life. Debris may orbit for decades or centuries given the lack of atmospheric drag slowing the speed. Lastly, debris enlarges the ozone hole.

SpaceX launches alone have doubled the number of LEO orbiting satellites and even though the Kessler effect is not proven to have began, the Space industry must "clean up its act".

Kessler Effect - Collisions cause remnants to explode outwards at high speed, causing further chain explosions.

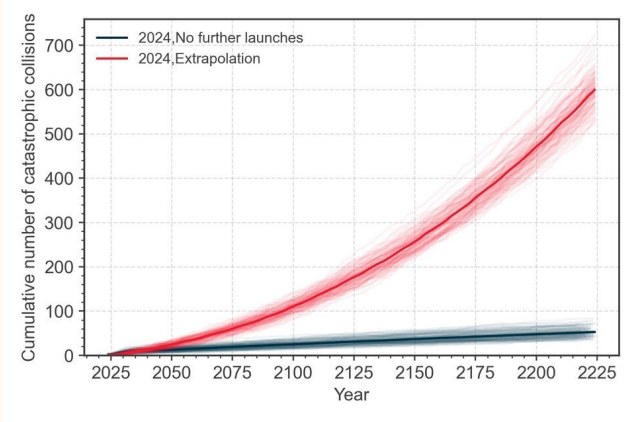
Launches will also be increasingly difficult once collision occurrence and debris density reaches higher levels

An uncertain outlook



All satellites experience orbital decay, but very slowly. Responsible de-orbiting methods being developed:

- A "drag sail" payload which activates at end of life and dramatically slows the speed of the satellite, causing it to fall.
- Electric Tethering, rods attached to rocket, generates a slowing electric current when interacting with Earth's magnetic fields.
- Active assistance of either onboard propulsion or external vehicle which either propels object into a graveyard orbit or descent to Earth.



Controlled de-orbiting is gaining momentum. For example, SpaceX's Starship "Chopstick" landing. SmallSats can also be burnt upon atmospheric reentry.

Catastrophic Kessler events in LEO will exponentially rise with current rate of deployment.

SCM - Space vs Automotive

COTS in Space

SCM for Space - Manufacturers

Process

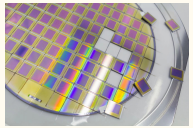
Documentation

Foundries have contracts with mines to source Si, GaN and other semiconductive metals.

RoHS - Restriction of Hazardous Substances used in electronics. Must meet reqs to supply to EU.
Conflict minerals compliance

Order is placed by Space customer.

Wafers are radiation tested and the circuit internals are imprinted through a variety of methods - doping, etching, photolithography



Wafers are assigned a **wafer number, Fab ID**.

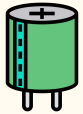
Radiation testing results recorded.

Thorough electrical testing before encapsulation.

An inspection is performed by a representative of the Space agency.

Component is encapsulated.

Further radiation, environment and electrical tests carried out. Some tests, like 1000h burn in, requires months to complete, causing a long mission schedule.



Lot number and **date code** assigned.

Further radiation, environment and electrical tests carried out.

A buyoff inspection from the Space agency before shipment.

Certificate of Conformance is compiled with all testing data.

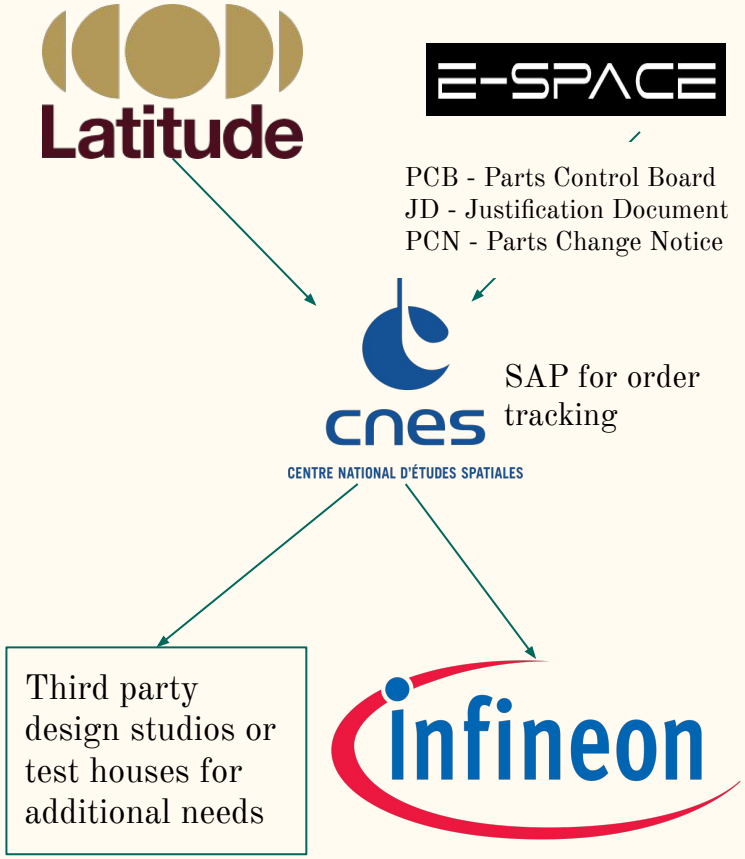
Shipped according to safe transport and storage policies.

SCM for Space - Component Users

In traditional Space, either a large monolithic rocket is made, therefore not many repeated parts, or a series of smaller satellites, which do not require so many different components. This leads to orders of **small quantities**. Most manufacturers impose a Minimum Order Quantity (MOQ) or a penalty if the order falls below that. Manufacturers also do not keep any storage of wafers given the extremely low and infrequent orders, requiring a reactive sourcing and increasing duration of production.

Therefore, a larger company often acts as a "project manager" for smaller companies who require Space components.The orders are then aggregated together into a larger BOM (Bill of Materials). A further step of consolidation is performed by the central procurer called "parts standardization". The project manager tries to reduce the number of different components on the BOM by combining similarly performing components together and increasing the quantity of individual components and reducing different manufacturing lines.

Testing incurs a significant cost in its setup, eg. radiation test chambers, and per unit testing fee. Some tests destroy the component so having larger batches and similar test groups is crucial in reducing cost and time of manufacture.

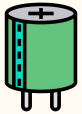


SCM for Automotive

Process

Manufacturers source raw materials from foundries

Produce a sample of the component



Automotive companies review several PPAPs and select the best one

Manufacturers produce the component in the magnitude of millions.

Current statistical methods ensure failure rates of under 10 ppm!

Small orders may only be made through distributors.

PPAP

RoHS or other certification

Production process, failure management, test certifications and statistical control methods recorded in PPAP.

Lot number and week code is combined into a **trace code**. Not unique!

All tests carried out on a reel is detailed in the PPAP.

A Datasheet is available publicly or requires an additional payment.

Challenge 1 - Traditional Space lacks control over the manufacturing process and cannot obtain documentation

- Only Automotive, Healthcare and Governmental COTS have established certifications like AEC-Q, JEDEC, providing any reliability indicators.

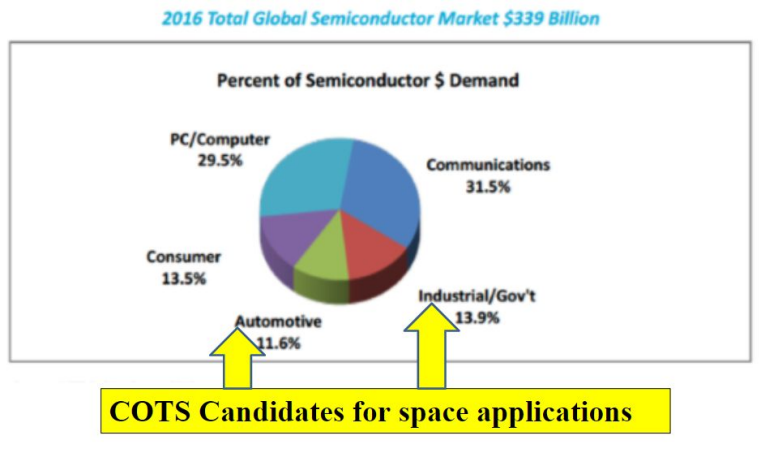
- COTS components for space makes up for **0.1%** demand of the semiconductor market.

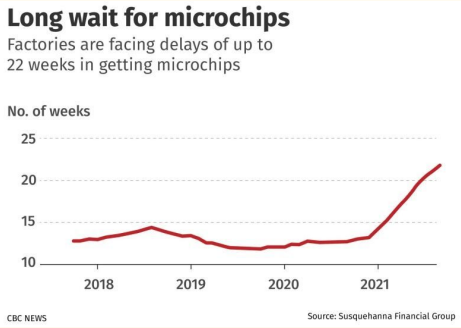
- Manufacturers are limited and many do not want to do business with Space agencies.

- Space agencies cannot acquire any data about the component. Only what is available publicly.

- Space agencies cannot obligate manufacturers to perform specific tests or inspect the manufacturing process on site.

- Susceptible to semiconductor supply issues. Eg. Covid semiconductor shortage lengthens manufacturing times.





Challenge 2 - Testing incurs significant cost

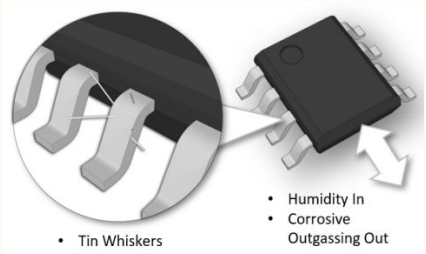
Testing costs a huge amount of money. There is a Non-Recurring Charge for set up of the testing environment and a per unit recurring charge. Sometimes it is cheaper the buy space grade components than perform testing on COTS.

What if we just don't do any testing?

COTS are cheap. Use redundant systems in satellites and switch over to backup once failure is detected. Very wasteful. In LEO and NEO, environmental conditions like temperature and radiation not as severe. Mostly works.

Manufacturers like Infineon are beginning to offer radiation tolerant COTS as an in between product. Good enough.

Radiation testing is almost impossible anyways



Automotive components are designed for road use.
- Lead is prohibited for consumer use but in space pure tin grows "whiskers".
- Other space conditions like outgassing and radiation.
- Temperature tests have smaller range.

Qualifications like AEC-Q and JEDEC allows exemptions from testing!

Challenge 3 - Automotive lacks detailed tracking

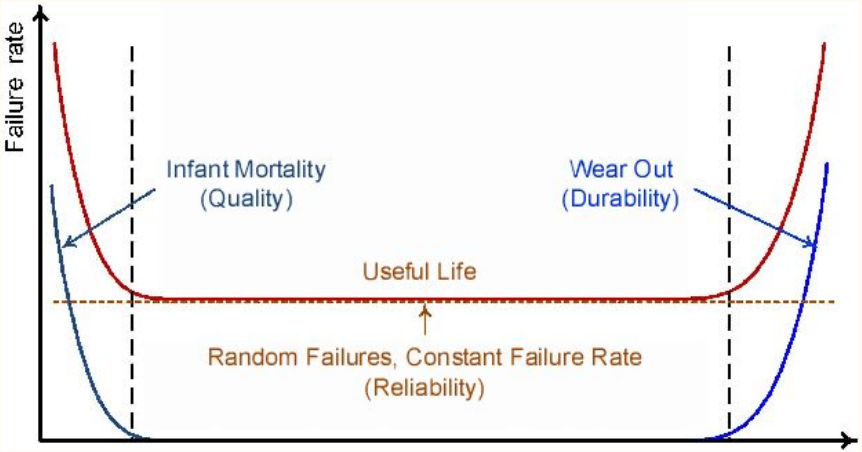
Automotive only creates a tracking code which combines the lot and week codes.

- Wafer level radiation testing impossible.

- Different companies also have no unique identifiers. Different manufacturers can produce lots with the exact same trace code.

- Small components don't have trace codes lasered on. Paper documentation vulnerable to loss.

- Distributors sometimes mix components. Use only authorized distributors.



Reliability in a lot is achieved by eliminating infant mortals and accidental failures. When lots are mixed, more samples are required. Lot deviance varies by manufacturer. Test more samples? Expensive.

Challenge 4 - Different life cycles & processes

Obsolescence

- COTS have a **2 - 3 year** life expectancy. A space mission has 10 - 15 years schedule.
- Part unavailable while still under construction?
- Huge amount of waste produced. Reuse can save millions.
- Inability to build component heritage

Documenting change

- A lot of alerts and change notices are generated.
- Space standards requires documentation of all changes and approval for these changes.
- Would make missions impossibly long to discuss all changes. Part is likely to be obsolete soon anyways.
- On a Blockchain: garbage data?

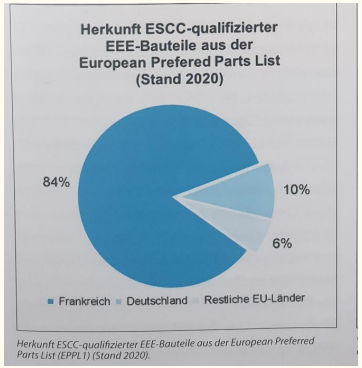
Challenge 5 - Space market inequalities

US produced components used to make up of 80% of a mission, after a few billion euros subsidy now at just below 50%. Foreign dependence subject to ITAR and EAR regulation and political changes.

In the EU, France dominates COTS for space suppliers. Why? The role and history of the agency has an impact.

France has tightly integrated and highly developed Air and Defense sectors. CNES, created under Charles de Gaulle, connects with many ministries and has great diversification of use cases. In comparison, DLR focused on space research and has difficulties collaborating with the developed automotive sector in Germany.

Prime	Land
Airbus Defence and Space SAS	Frankreich
Airbus Defence and Space Ltd	Vereinigtes Königreich
Airbus Defence and Space GmbH	Deutschland
ArianeGroup SAS	Frankreich
Arianespace	Frankreich
Avio SpA	Italien
OHB System AG	Deutschland
Thales Alenia Space France SAS	Frankreich
Thales Alenia Space Italia SpA	Italien

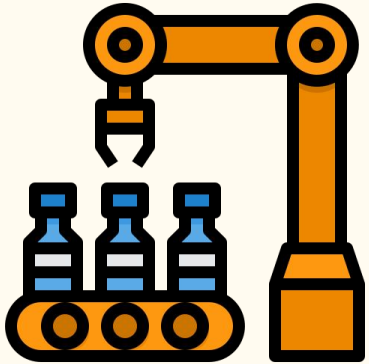


Herkunft ESCC-qualifizierter EEE-Bauteile aus der European Preferred Parts List (EPPL1) (Stand 2020).

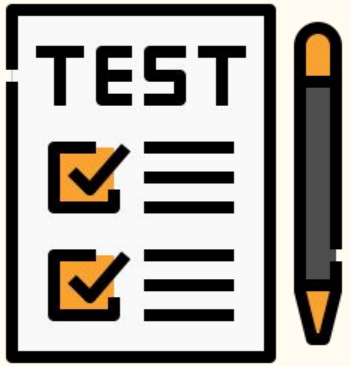
Blockchain solution for COTS procurement

How to bridge the gap?

Aggregate orders on the blockchain in a transparent but anonymous way. IP exposure?



Real time record of component details using DePIN. Manufacturers resistant to process change?



Digitalise and publish test and flight data to boost COTS heritage. Tokenomics here?

How does this look like?

Master Contract