Space Cost Engineering – SCE 2022
ESA-ESTEC, 2022/09/15-16

Cost comparison of IoT constellation scenarios

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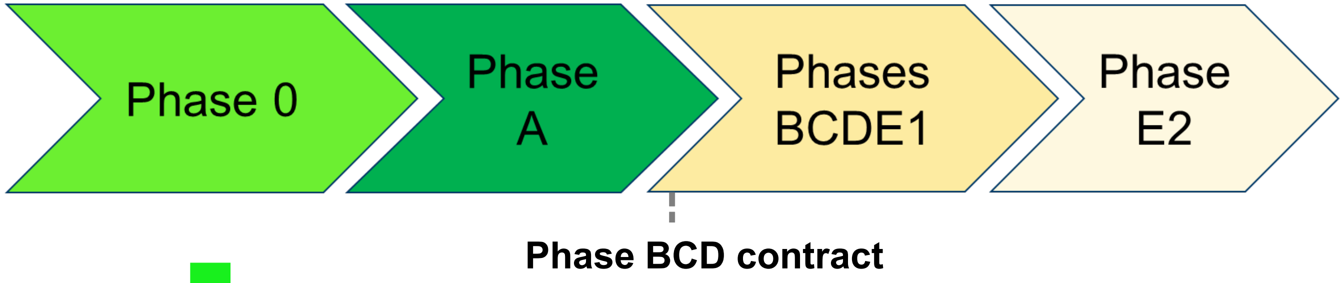
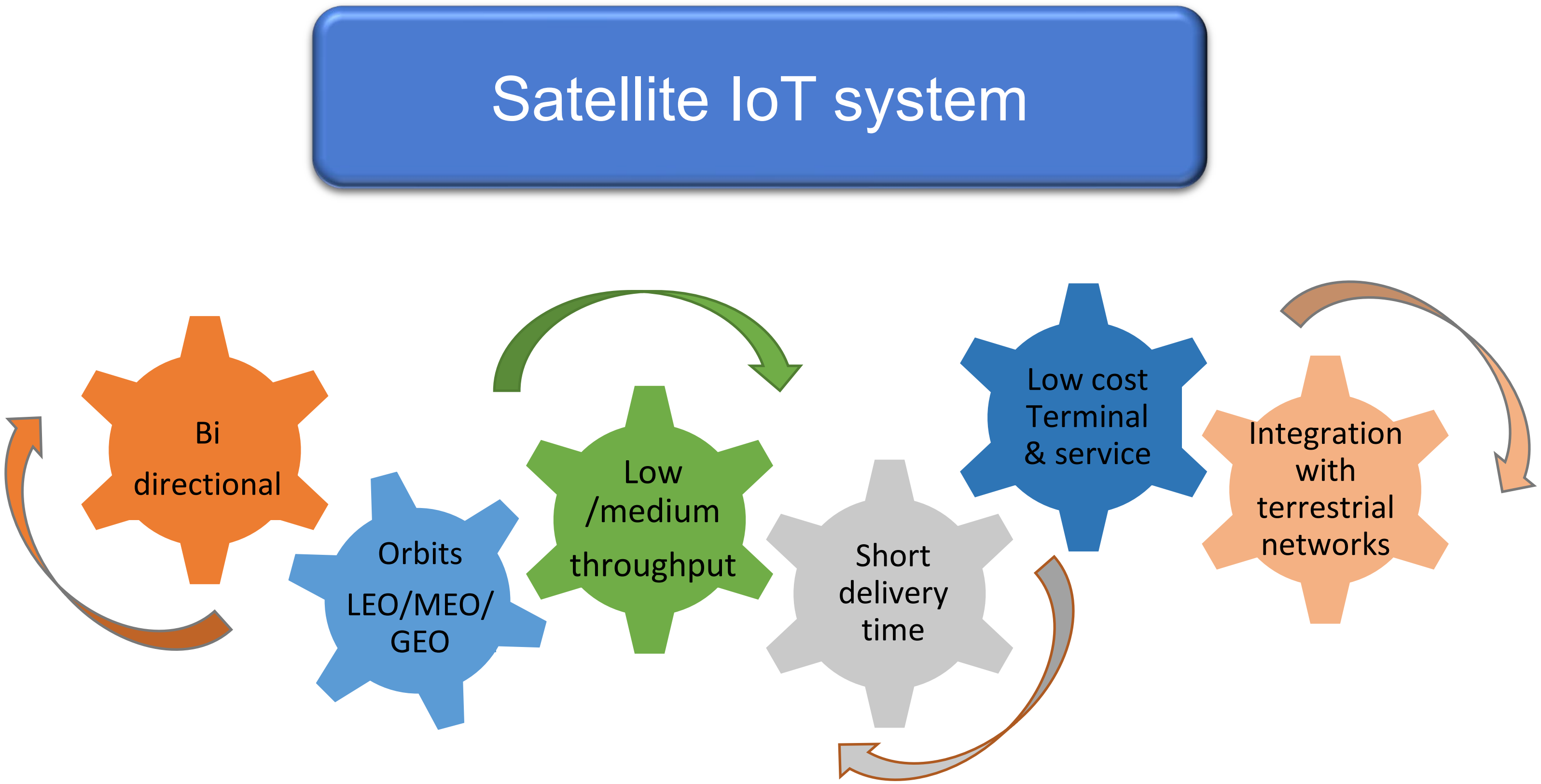
Phase 0 analyses

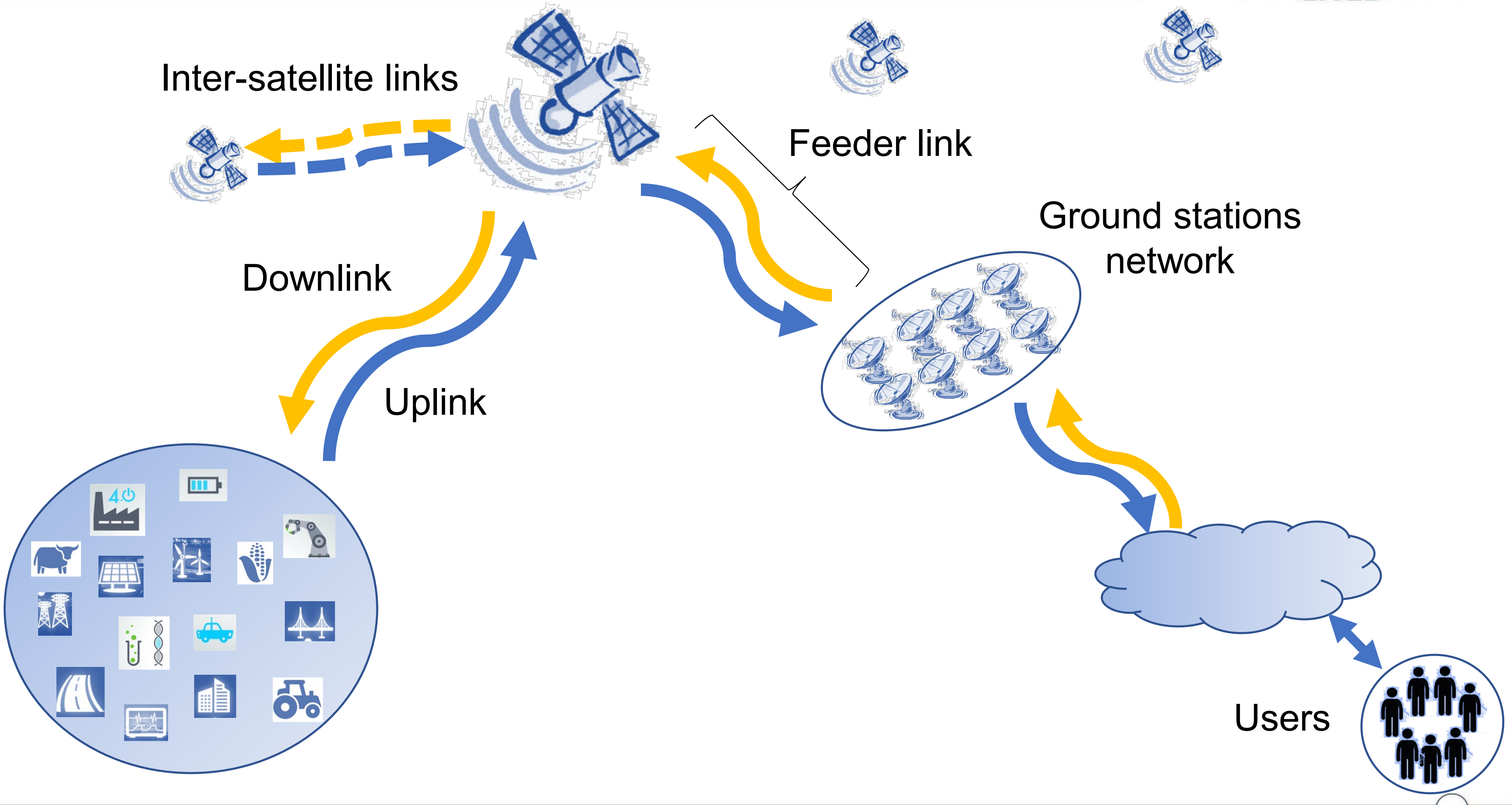


- Analysis in the frame of PASO (Department within CNES Future preparation sub-directorate)
- More and more new projects based on nanosatellites and/or constellations
- SIROCO : IOT system assessed in 2021 with several constellation scenarios

SIROCO phase 0



SIROCO system



Phase 0 process - Identification of scenarios

Preliminary mission analysis

19 scenarios

11 LEO
- altitudes
- with of without ISL
- ISL intra and/or inter plan

4 MEO
- altitudes

4 GEO
- GEO only
- GEO + LEO constellation
- GEO + HEO satellites

Phase 0.1

10 scenarios

7 LEO
2 MEO
1 GEO only

Phase 0.2

4 scenarios

3 LEO
1 GEO only

Design
Performance budgets
Feasibility
Risks
Cost estimation

Scenario to be estimated

Scenario	Orbit	Altitude	Inclination	Satellites (plans)	Type of platform
S0	LEO	600 km	87.6 °	162 (9)	Existing nanosat PF
S1	LEO	774 km	86.4 °	66 (6)	Existing LEO PF
S2	LEO	1414 km	64 °	48 (8)	Existing LEO PF
S3	GEO	35 786 km	0 °	3 (1)	Existing GEO PF

Main hypotheses and objectives

- Compare the 4 scenarios : LEO nanosat, LEO small satellite and GEO satellite
- Timeframe perpective 2030
- 15 years of operations
- Reliability analysis to take into account the need of renewal satellites
- No particular technological risk at bus and payload levels

- **Initial objective to use existing platforms with as less as possible non recurring costs → will be challenged**

Reliability analyses

- Lifetime hypothesis
- Reliability analyses (launcher and satellite)
- Deployment scenarios taking into account in-orbit spares and acceptable mission degradations

➔ **Scenarios with many satellites**

➔ **Best strategy to reuse existing platformes ?**

Satellites	Lifetime (spec) (lower hyp.)	Lifetime (spec.) (upper hyp.)
Nanosatellite	5 years	7,5 years
Small	10 years	15 years
Geostationnary	15 years	15 years

Scenario	Nominal constellation	Satellites		Launchers	
		Hyp min	Hyp max	Hyp min	Hyp max
S0	162	456	777	42	43
S1	66	101	206	12	19
S2	48	65	144	11	24

In 1936, TP Wright published a paper entitled "*Factors affecting the costs of airplanes*".

The paper describes that "we learn by doing" and that the cost of each unit produced decreases as a function of the cumulative number of units produced :

" For every doubling of the production volume, the production costs decrease by a constant factor. "

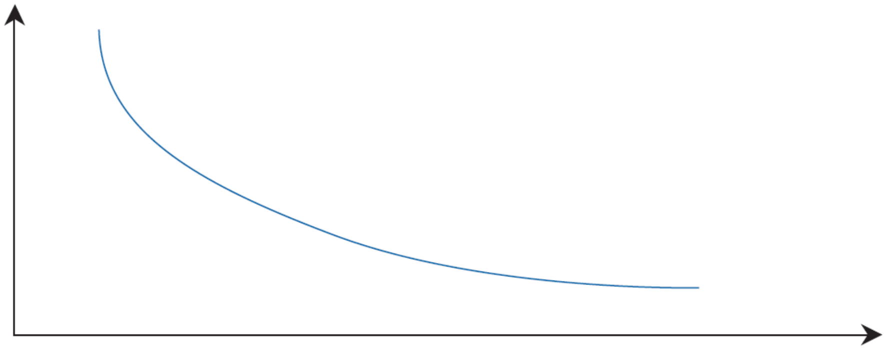
Linear model on a logarithmic scale.

➔ **Simple but very useful model**

TP Wright (1895 – 1970)
(Curtiss-Wright Corporation)

Effect of experience

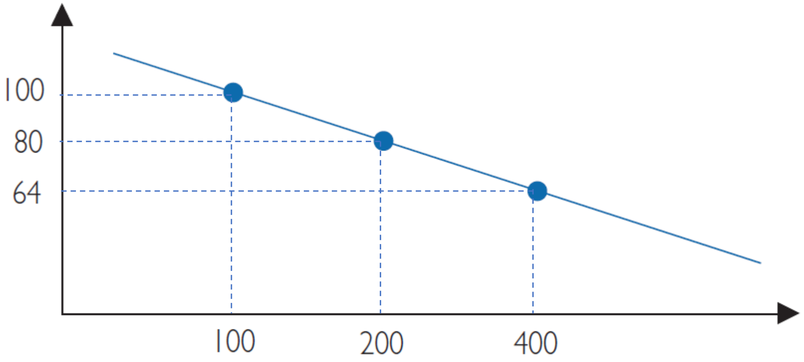
Cost



Cumulative experience

(arithmetic coordinates)

Cost



Cumulative production

(logarithmic coordinates)

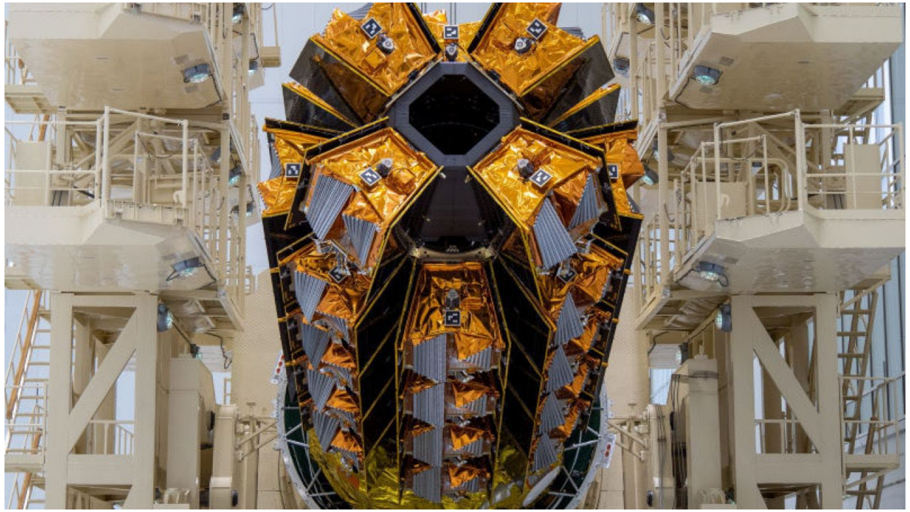
OneWeb - 900 satellites

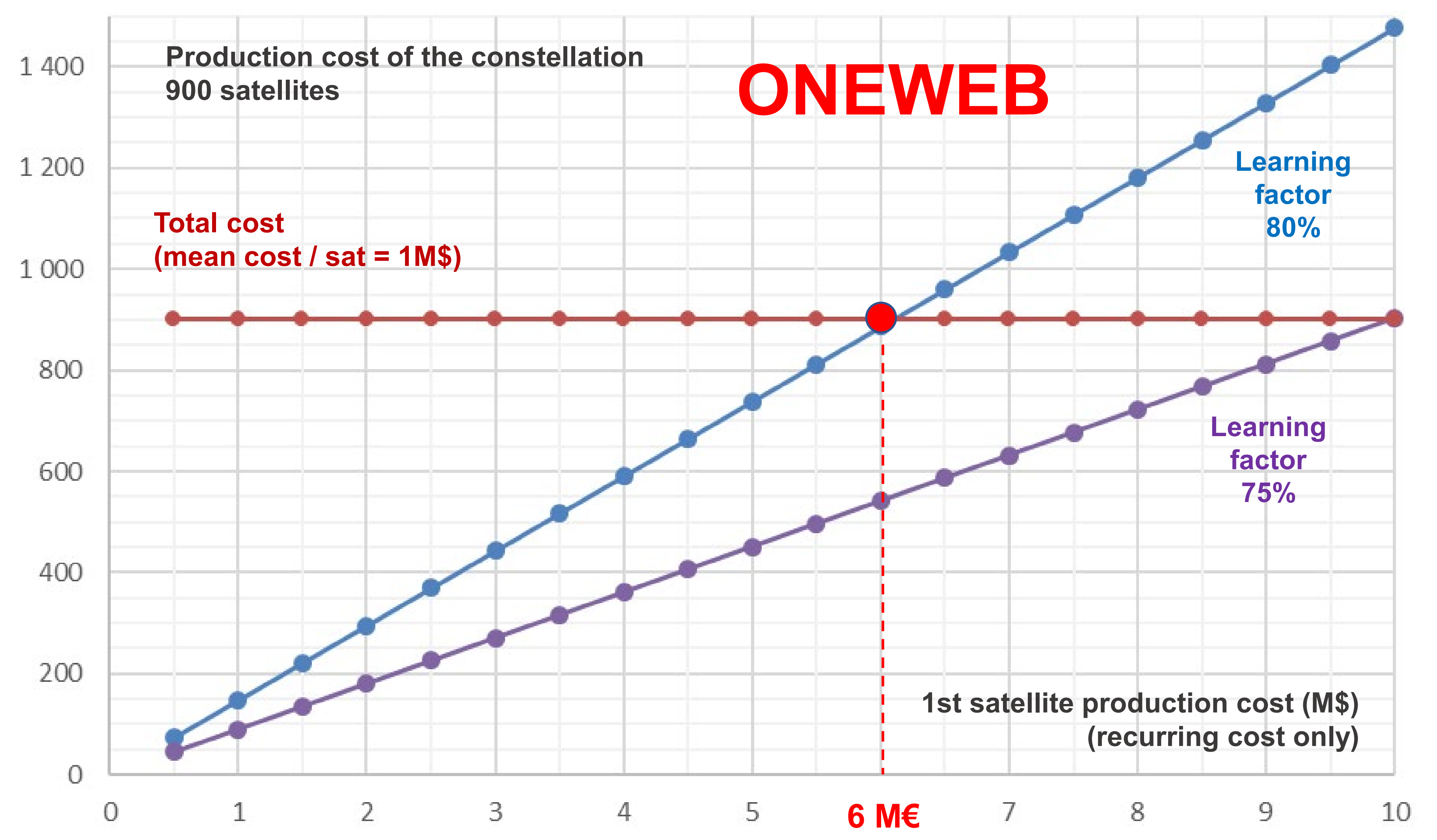
➔ Satellite mean cost announced : 1 M€

➔ Recurring production cost of the 1st model should be :

- 1.5 M€ with K=95%
- 6 M€ with K=80% (cf. illustration on next slide)
- 10 M€ with K=75%

OneWeb
ACCESS FOR EVERYONE




Production cost of the constellation
900 satellites
ONEWEB
Learning factor 80%
Total cost
(mean cost / sat = 1M$)
Learning factor 75%
1st satellite production cost (M$)
(recurring cost only)
6 M€
0
200
400
600
800
1 000
1 200
1 400
0
1
2
3
4
5
7
8
9
10

Serial effect for Starlink constellation

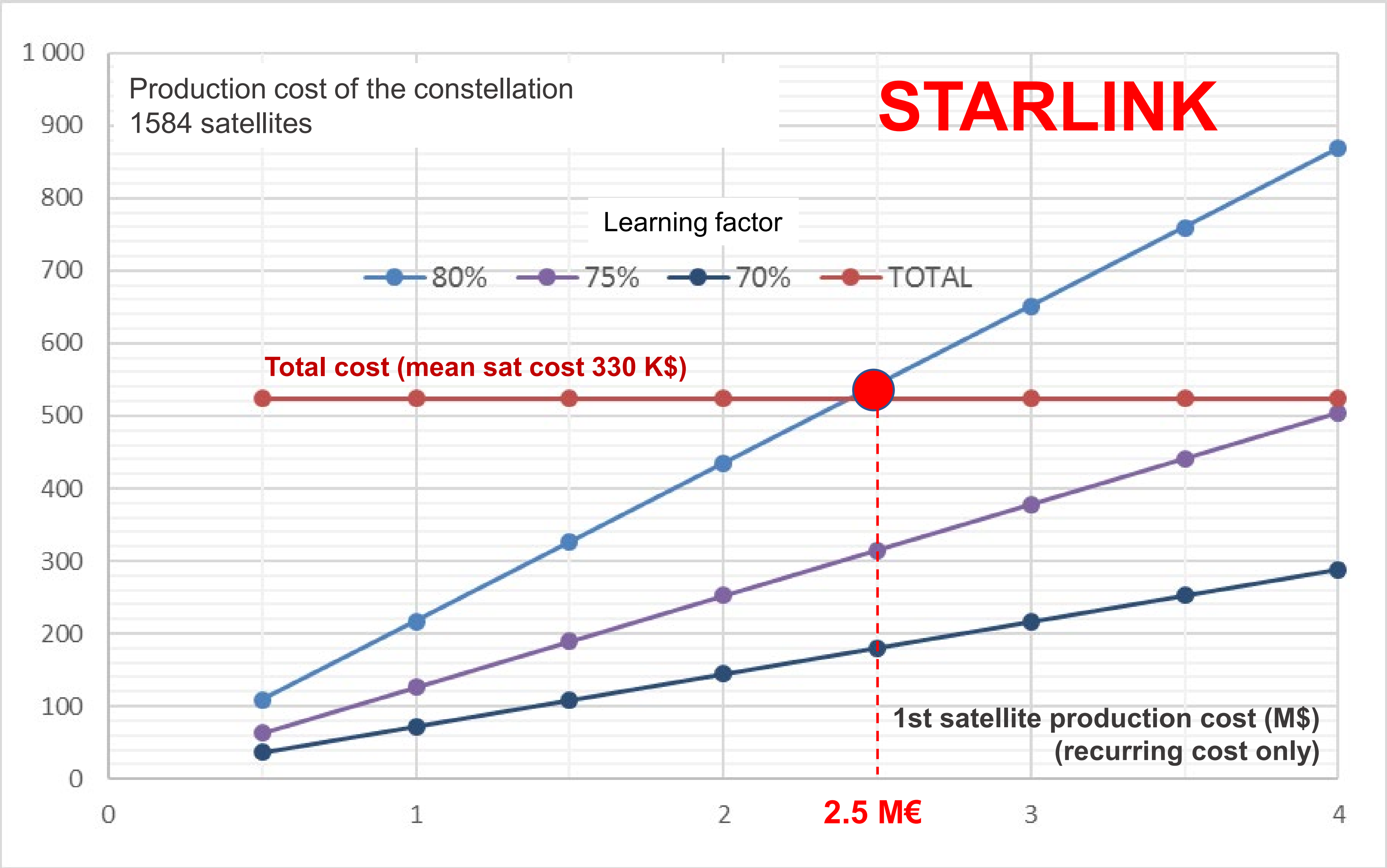
Starlink (Space X) - 1584 satellites

- Optimization for mass production
- Simplicity of the satellite architecture
- Architecture optimized for launch
- Vertical industrial integration within Space X

➔ Satellite mean cost announced : 330 K$

➔ Recurring production cost of the 1st model should be :

- ~ 2,5 M€ with K=80% (cf. illustration on next slide)
- ~ 4 M€ with K=75%



STARLINK
Production cost of the constellation
1584 satellites
Learning factor
80%
75%
70%
TOTAL
Total cost (mean sat cost 330 K$)
1st satellite production cost (M$)
(recurring cost only)
2.5 M€
1 000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4

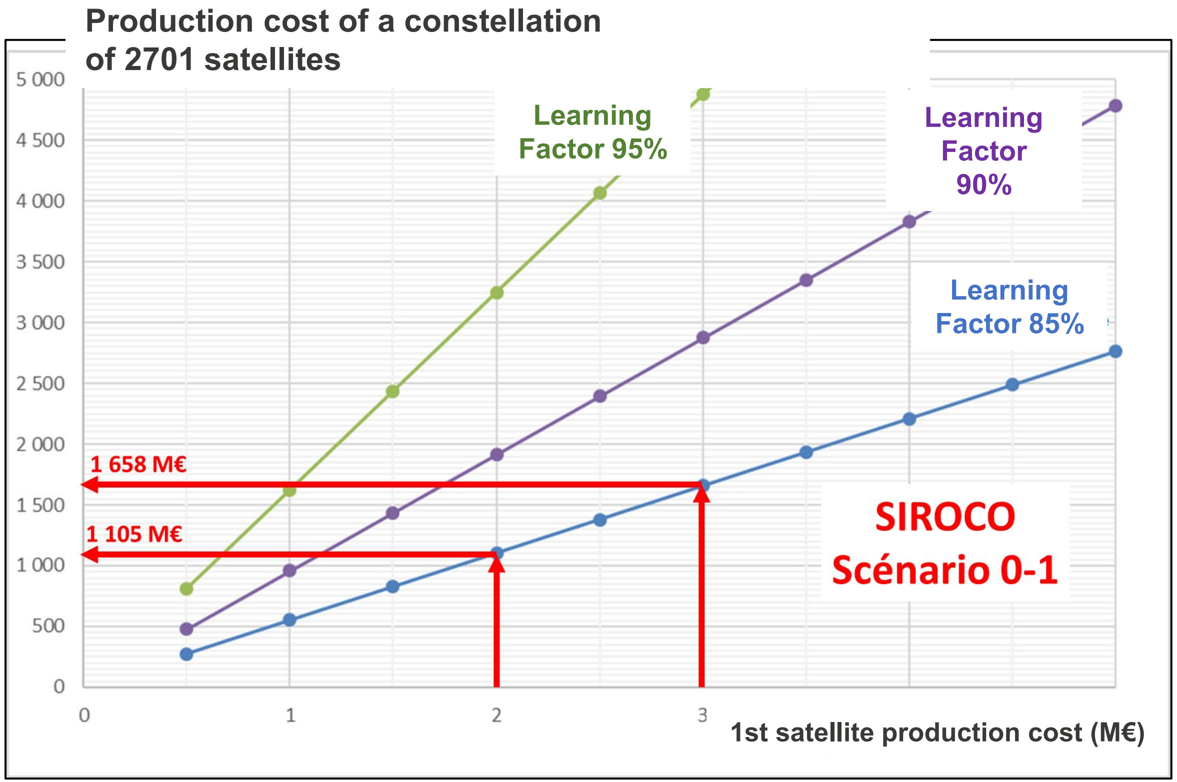
Serial effect for SIROCO

Better strategy than using an existing PF :

- Minimize the production cost
- Adapt the satellite design
  to optimize the cost of the 1st model
- NREC cost used to minimize the cost
  of the first satellite model

1st mode	Constellation
3 M€	1 658 M€
2 M€	1 105 M€

➔ 1658-1105 = **553 M€**
available to optimize the satellite cost !



Scenario (# sat)	1st PF	K=85%		K=90%		K=95%	
		Total prod cost (mean sat cost)	Gain	Total prod cost (mean sat cost)	Gain	Total prod cost (mean sat cost)	Gain
S0-3 min (456)	3 M€	423 M€ (0.93 M€)	141 M€	634 M€ (1.39 M€)	211 M€	938 M€ (2.06 M€)	313 M€
	2 M€	282 M€ (0.62 M€)		423 M€ (0.93 M€)		625 M€ (1.37 M€)	
S0-3 max (777)	3 M€	637 M€ (0.82 M€)	212 M€	998 M€ (1.28 M€)	333 M€	1 537 M€ (1.98 M€)	512 M€
	2 M€	425 M€ (0.55 M€)		665 M€ (0.86 M€)		1 025 M€ (1.32 M€)	
S1 min (101)	25 M€	1 102 M€ (10.9 M€)	221 M€	1 465 M€ (14.5 M€)	293 M€	1 932 M€ (19.1 M€)	387 M€
	20 M€	881 M€ (8.7 M€)		1 172 M€ (11.6 M€)		1 545 M€ (15.3 M€)	
S1 max (206)	25 M€	1 912 M€ (9.3 M€)	382 M€	2 691 M€ (13.1 M€)	539 M€	3 743 M€ (18.2 M€)	748 M€
	20 M€	1 530 M€ (7.4 M€)		2 152 M€ (10.4 M€)		2 995 M€ (14.5 M€)	
S2 min (65)	25 M€	783 M€ (12.0 M€)	157 M€	1 006 M€ (15.5 M€)	201 M€	1 283 M€ (19.7 M€)	256 M€
	20 M€	626 M€ (9.6 M€)		805 M€ (12.4 M€)		1 027 M€ (15.8 M€)	
S2 min (144)	25 M€	1 451 M€ (10.1 M€)	290 M€	1 983 M€ (13.8 M€)	396 M€	2 686 M€ (18.6 M€)	538 M€
	20 M€	1 161 M€ (8.1 M€)		1 587 M€ (11.0 M€)		2 148 M€ (14.9 M€)	

Conclusion

For scenarios with many satellites

- NREC costs should be minimized rather than REC costs
- Satellite design required to be optimized for mass production

Very significant impact of the learning factor

- Scale factor to be consolidated.

Very significant launch costs:

- Need to optimize the constellation design / launcher capacity (to be done in Phase A)
- In term of cost, interest of scenario S3 (GEO) with very few launches (and a competitive telecom satellite market)