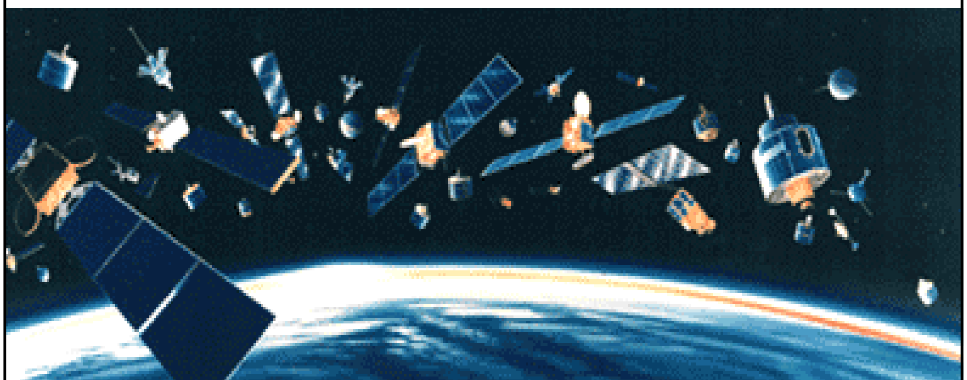
Case Study

Architectural Flexibility in Commercial Communication Satellite Fleets



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Reference

- Value-at-Risk Analysis for Real Options in Complex Engineered Systems,
- Hassan, R., de Neufville, R., de Weck, R., Hastings, D. and McKinnon, D.,
- IEEE Conference on Large-Scale Infrastructures, Hawaii, 2005

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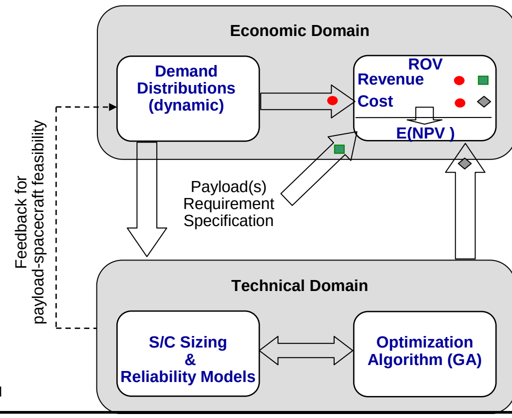
Fleet Architecting Framework

- Objective: to integrate spacecraft engineering design with economic analysis for the purpose of maximizing the financial value of a fleet to the operator under uncertain, evolving market conditions.



Dynamic Demand Uncertainty

- Hypothetical case investigating demand forecasts in areas similar in size to Continental Europe and South America

- Coverage Area I
  - Demand for a Ku-Band service
  - Coverage Area: 40 deg^2
  - Required EIRP: 55 dBW
  - Expected initial bandwidth capacity required : 60 100 W TWTAs
  - Demand decreases over the satellite lifetime (demographics, competition, etc..)

- Coverage Area II
  - Demand for the same Ku-Band service is estimated to start in 5 years
  - Coverage Area: 52 deg^2
  - Required EIRP: 55 dBW
  - Expected initial bandwidth capacity required : 15 100 W TWTAs
  - Demand increases over the satellite lifetime (market matures)

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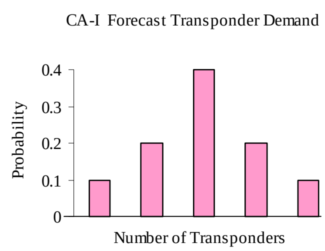
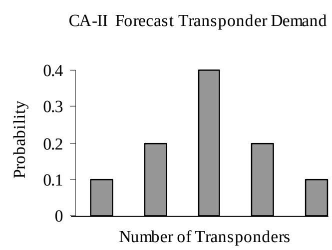
Dynamic Demand Uncertainty



Y1:Y5	40	50	60	70	80
Y6:Y10	10	20	30	40	50
Y11:Y15	5	10	15	20	25
Y16:Y20	0	0	0	0	0



Y1:Y5	0	0	0	0	0
Y6:Y10	5	10	15	20	25
Y11:Y15	10	20	30	40	50
Y16:Y20	40	50	60	70	80

Forecast transponder demand distributions for a fixed satellite service in two hypothetical markets over 20 years

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Economic Models

- Discount Rate 10%
- Revenue
  - Transponder Price $ 1,510,000
  - Annual Price Decrease 4%
- Cost
  - Satellite $ 1,000,000 x No. of Transponders + Bus Cost (see table)
  - Launch (see table)
  - Insurance 10% of (Satellite Cost + Launch Cost)
  - Ops + Marketing + Admin $ 5,000,000 / year for a large satellite
    $ 3,500,000 / year for a small satellite
    $ 500,000 / year for co-located satellites

Payload Power (kW)	Bus Cost
4 – 5.5	$ 35,000,000
5.5 – 7	$ 50,000,000
7 – 8.5	$ 70,000,000

Satellite Mass (kg)	Launch Cost
2,000 – 3,500	$ 90,000,000
3,500 – 5,000	$ 110,000,000
5,000 <	$ 120,000,000

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Architectural Configuration of Fleet Solutions

- Technical flexibility levers:
  - Number of spacecraft
  - Payload size onboard each spacecraft
  - Payload flexibility switch
  - Timing or relative sequencing of deployment

Architectural Parameters	Rigid Fleet	Flexible Fleet I	Flexible Fleet II	Flexible Fleet III
Number of spacecraft	2	1	2	2
Active transponders	S/C I in CA-I: 60 S/C II in CA-II: 60	60	S/C I: 30 S/C II: 30	S/C I: 30 S/C II: 30
Payload flexibility	none	yes	both yes	both yes
Deployment stage	S/C I in CA-I: stage I S/C II in CA-II: stage II	stage I	S/C I: stage I S/C II: stage I	S/C I: stage I S/C II: stage II

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Parameters of Optimal Spacecraft Designs

	Rigid Fleet		Flexible Fleet I	Flexible Fleet II		Flexible Fleet III	
Optimized Design Parameter	S/C I in CA-I	S/C II in CA-II	Flexible S/C	Flexible S/C I	Flexible S/C II	Flexible S/C I	Flexible S/C II
Total Launch Mass (kg)	4,541	4,888	5,962	2,725	2,725	2,725	2,725
Payload							
Active HPAs*	60	60	60	30	30	30	30
Available HPAs	72	72	72	36	36	36	36
HPA efficiency (%)	58	58	55	55	55	55	55
Payload Power (W)	6,960	6,960	7,326	3,663	3,663	3,663	3,663
Bus							
Solar Array Area (m^2)	69.7	69.7	73.3	36.7	36.7	36.7	36.7
Battery Mass (kg)	240	240	338	127	127	127	127
Radiator Area (m^2)	9.9	9.9	10.7	5.5	5.5	5.5	5.5

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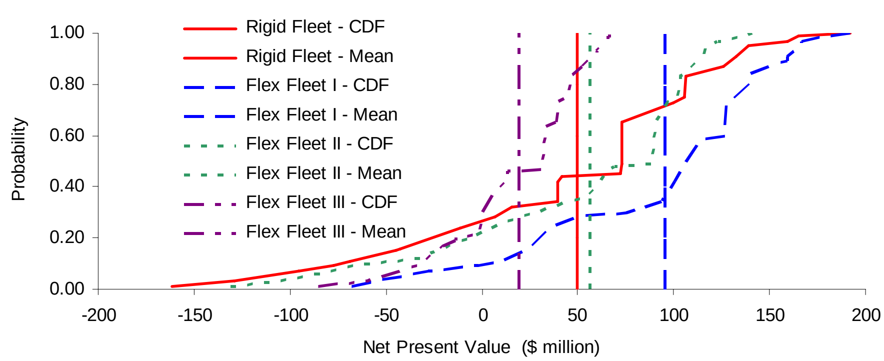
Real Options Valuation Results



Value-at-Risk Distributions (CDFs) for Fleet Architectures

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Economic Values of Fleet Architectures

Architectural Value Parameter ($ million)	Rigid Fleet	Flexible Fleet I	Flexible Fleet II	Flexible Fleet III
E(NPV)	49.94	95.81	56.20	19.40
Std(NPV)	3.69	4.63	3.74	1.63
Flexibility Value	-	45.86	6.26	-30.55
Fixed cost, pay year 1	242	275	341	170
Fixed cost, pay year 6	242	-	-	170
PV(fixed cost) at year 1	392	275	341	276
Maximum possible gain	192	193	142	73
Maximum possible loss	162	68	131	86

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Design Philosophy Take-aways

- Ultimate Objective of Design is to provide value. Technical excellence is a means to this end, not end in itself.
- Fixed design cannot adjust to circumstances that develop, thus may perform badly in unfavorable conditions (see value-at-risk curves).
- Flexible designs can be adjusted to conditions that develop, and avoid downside results, exploiting upside opportunities
- At the least, we can reduce the range of the possible economic outcomes, and thus reduce the necessary risk premium (via CAPM).
- In general we can also increase Expected Value of System, sometimes dramatically.

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