Using commercial cost estimating tools to analyse the life-cycle cost of reusable space launch systems

Fabian Eilingsfeld[1], Nicolaus Millin[1], Pascal Gendrot[2]

[1]PRICE Systems Deutschland GmbH, Germany
[2]PRICE Systems Limited, France

2nd ESA - CNES SPACE COST ENGINEERING CONFERENCE

CNES, Toulouse, France
16–17 September 2021

Estimate with Confidence™

“The earth is covered by two-thirds water and one third space launch studies.”

—Secretary of the Air Force Sheila A. Widnall, December 1992

1) Situation:
Reusable Space Transportation

In the past, life-cycle cost estimating of reusable launchers was done using simulation models.
Parametric cost models were deemed insufficient, lacking in detail.

First, some history: In the old days, life-cycle costs of reusable launchers were estimated with simulation tools and models

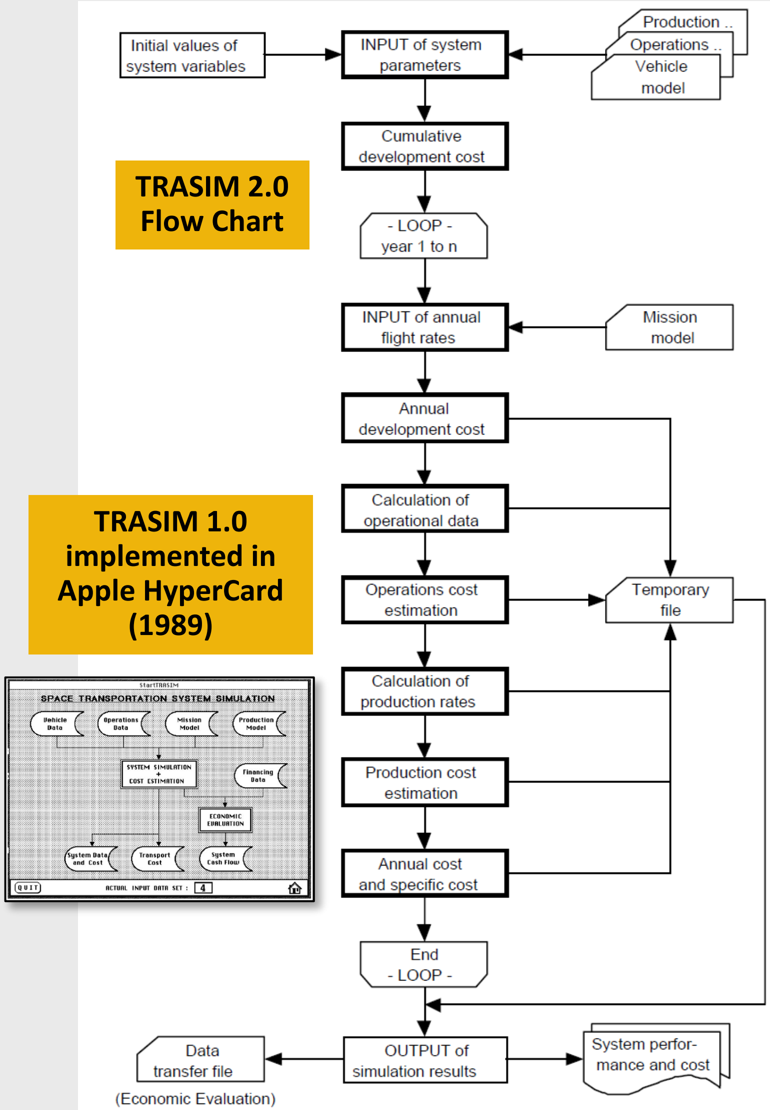


Fig. 4.2: Flow graph of the program module for system simulation and cost estimation

TRASIM 2.0 Flow Chart

TRASIM 1.0 implemented in Apple HyperCard (1989)

A single three stage vehicle operating in one mission mode with one payload only, at a constant launch and production rate, including one space operation center, requires the following number of inputs:

system parameters	5
space operations center	20
space vehicles & payloads	92
mission mode specifications	12
general cost parameters	16
specific cost parameters development	51
specific parameters production	144
specific parameters operation	72
total number of values	412

TRASIM 2.0
ILR Mitt. 319(1997), p. 25

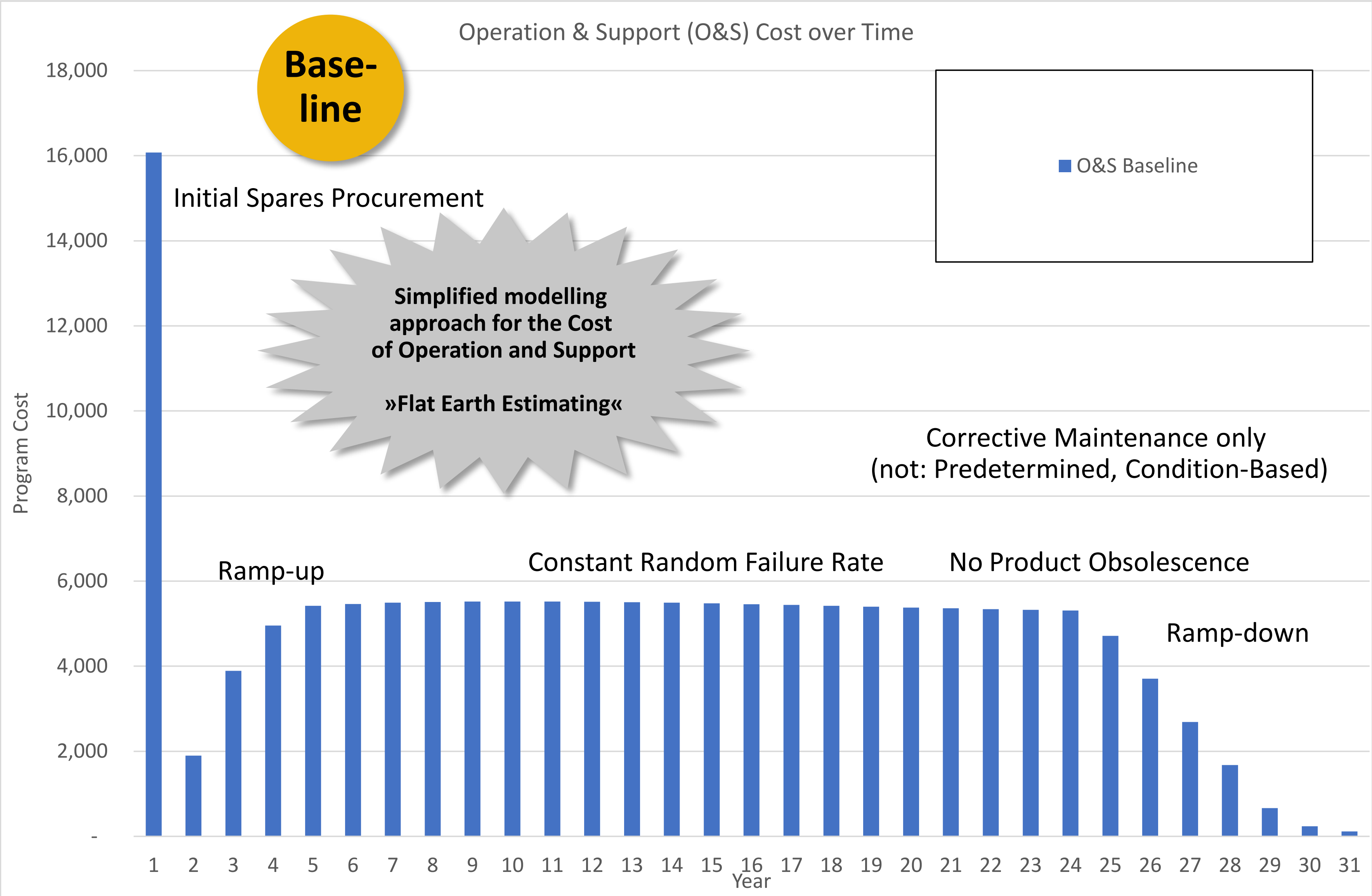
SPACE TRANSPORTATION
SIMULATION MODEL
(TRASIM 2.0)

H.H. Koelle, B. Johenning

- **The TU Berlin developed the Space Transportation Simulation Model (TRASIM) from 1989 onwards**
- **TRASIM combined parametric and deterministic models for simulating reusable space transportation systems plus infrastructure**
- **It has been used in numerous studies on space tourism, lunar base operations, lunar mining, extraterrestrial power infrastructure**
- **In its day, TRASIM was a powerful model with a large fanbase; however, it required numerous inputs to achieve useful results (see above)**

As of 2021, users prefer parametric models for early phase estimates!

Parametric tools are proven for development and production cost, but not so much for operation and support



2) Complication: Parametric models must address known issues in the life-cycle cost of reusable launchers

There is a standard cost structure for reusable launchers. It has been around for over 20 years, is widely accepted and publicized.

However, it does not address some key issues, like aging effects, obsolescence, multiple maintenance types, and amortization of fixed (infrastructure) cost.

The best-known Cost per Flight structure has been around since 1998; however, it is not perfect

PRICE

1. Vehicle Cost (VRC)

(1A) Vehicle Recurring Cost (expendable vehicles only)

(1B) Amortization Share of Vehicle Procurement Cost

(1C) Expendable Elements Cost

(2) Refurbishment and Spares Cost

2. Direct Operations Cost (DOC)

(3) Prelaunch Ground Operations Cost

(4) Flight and Mission Operations Cost

(5) Propellants, Fluids and Consumables

(6) Ground Transportation and Recovery Cost

(7) Launch Facilities User Fee

(8) Public Damage Insurance Fee

(9A) Vehicle Failure Impact Charge (expendable vehicles only)

(9B) Mission Abort and Premature Vehicle Loss Charge

(10) Other Direct Operations Charges (taxes, fees)

Cost Estimating Issues (Model-Internal)

3. Indirect Operations Cost (IOC)

(11) Program Administration and System Management Charge

(12) Marketing, Customer Relations and Contracts Office Charge

(13) Technical Systems Support Charge (incl. spares administration)

(14) Launch/Landing Site and Range Cost

4. Business Charges (BC)

(15) Development Cost Amortization Charge

(16) Nominal Profit

Pricing Issue (Model-External)

5. Insurance Cost (IC: optional)

(17) Insurance against Launch Failure

(18) Insurance against Payload Loss

Source: IAA/IAF Joint Subcommittee for Launch System Economics, 1998, see: Koelle, D.E.: TRANSCOST 8.2 Model Description, 2013.

Issues with the IAF/IAA basic Cost/Price per Flight structure point to some general complications with »life-cycle cost« (LCC)

Vehicle Cost (VRC)	
(2) Refurbishment and Spares Cost	▪ **Infant and age-induced failures** lead to **non-constant failure rates** ▪ Maintenance plans foresee **diverse maintenance tasks with different scope at changing intervals** → maintenance cost over time is not constant ▪ There are **different maintenance types**: corrective, predetermined, condition-based ▪ Long design life (>10 years) will increase **product obsolescence**; this needs to be mitigated and will have an impact on spares cost
Direct Operating Cost (DOC)	
(3) Prelaunch Ground Operations Cost **(4) Flight and Mission Operations Cost** **(7) Launch Facilities User Fee**	▪ Fixed headcount of specialist teams may present a **»standing army« problem** ▪ Infrastructure costs may be very high, sunk, paid for since many years, with no need to recover them; therefore **user fees** charged as part of launch price **may not reflect true cost**, or may be not charged at all ▪ **Very high fixed costs** make average cost per launch highly dependable on launch rate per annum (LpA) ▪ Amortization and overhead costs are variable and depend on **infrastructure utilization**
Business Charges (BC)	
(16) Nominal Profit	▪ Adding a deliberately fixed profit to a known cost of sales to derive a sales price reflects a »cost plus« contract philosophy; **this cannot be applied to launch pricing** ▪ In a real market, launch service providers must deal with very high fixed costs; this supports a **discriminatory pricing approach**, where all customers are charged according to their individual ability and willingness to pay!

For LCC estimating of reusable launchers, these issues must be addressed!

3) Solution:
Parametric models introduce new features for estimating life-cycle cost

Recent improvements and pending upgrades in commercial tools promise better life-cycle functionality. These are likely to resolve existing issues with the estimating of reusable vehicles.

4 new lifecycle cost features resolve existing model-internal issues with estimating reusable launchers

PRICE

New Vehicle Cost (VRC) Features:

1. **Variable failure rates can be applied** to estimate infant failures and aging effects
2. **Product obsolescence** and the cost of its mitigation can be modelled; different mitigation strategies may be applied
3. **Maintenance plans** can be entered; the user may link each hardware element to any number of tasks by maintenance type: corrective, predetermined, condition-based

New Direct Operations Cost (DOC) Features:

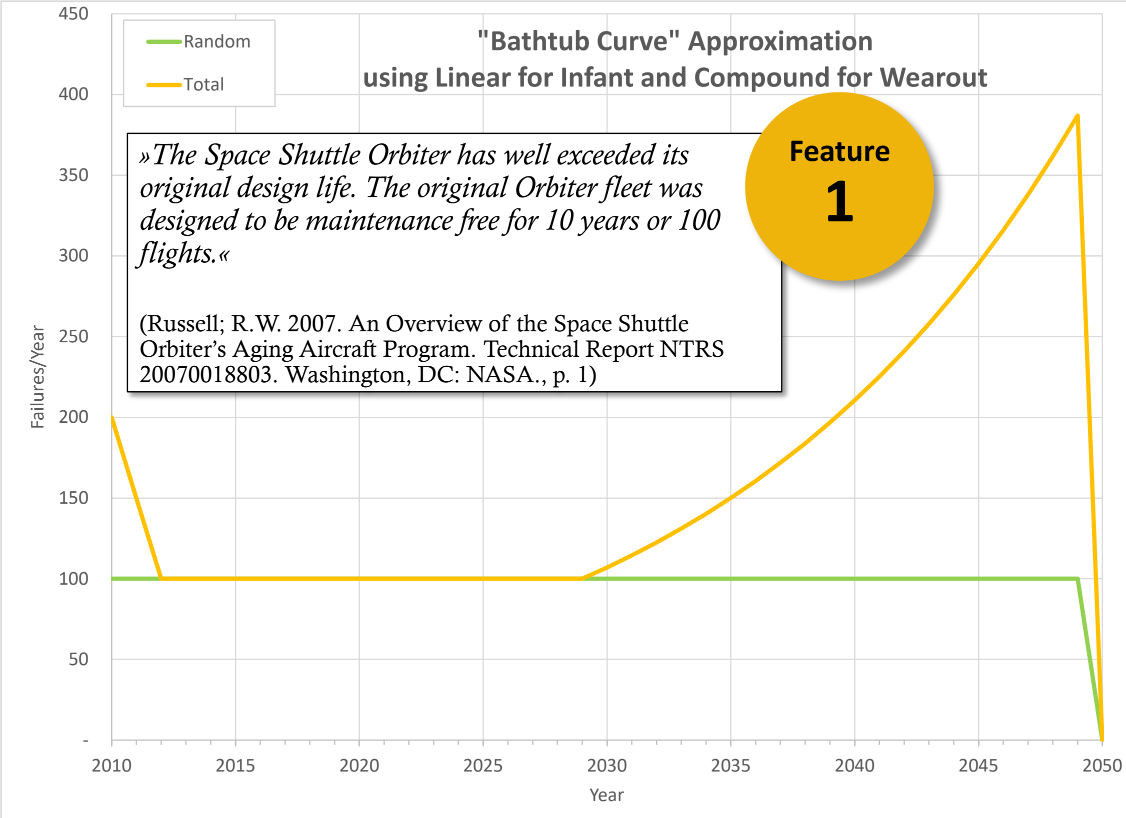
4. **Fixed Cost can be directly accounted for**; either in the form of dedicated resources (»standing army«) or as other direct cost

Benefits of the new life-cycle features in PRICE True Planning®

- **Inject more realism into previously simplistic life-cycle modelling**
- **Increase accuracy of life-cycle cost estimates**
- **Strike a balance between the required level of input detail and achievable output accuracy, compared to simulation tools**

New Features

New feature 1: Variable failure rates enable modelling of infant failures and aging effects (»bathtub curve«)



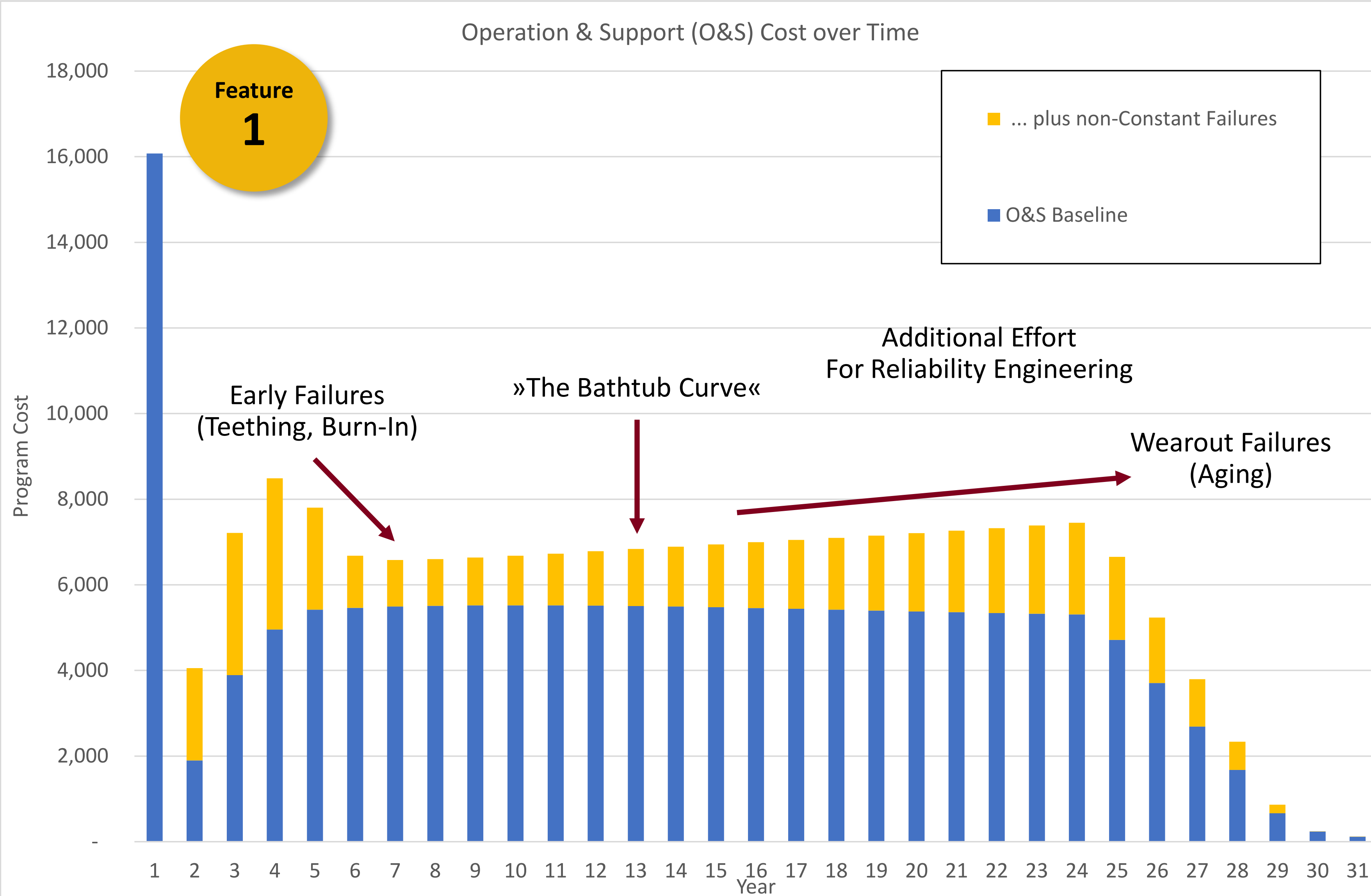
Lessons learned from the Space Shuttle program

- The Space Shuttle had an original design life of 10 years, yet operated for 30 years (**factor 3**)
- One reason for retirement in 2011 was the increasing **concern about the Orbiter's structural wearout**
- Wearout leads to more potential failures and **maintenance cost growth**

	Hardware Lifecyle Inputs	Value	Units
17	**Non-constant Failure Rate (Bathtub Curve) Inputs**		
18	Early Failures - Duration of Burn-in Period	24	months
19	Early Failures - Failure Rate Multiplier	2.00	
20	Wearout Failures - Design Life	**10**	years
21	Wearout Failures - Begin of Wearout (% of Design Life)	75.00%	%
22	Wearout Failures - Annual Failure Rate Increase	2.00%	%
23	Wearout Failures - Annual Failure Rate Increase Type	**Compounding**	

The increasing cost impact of wearout effects (and early failures) can now be estimated!

Implementation of variable failure rates finally gives users the sought-after »bathtub curve« characteristic



New feature 2: Mitigation of product obsolescence in spares supply

PRICE

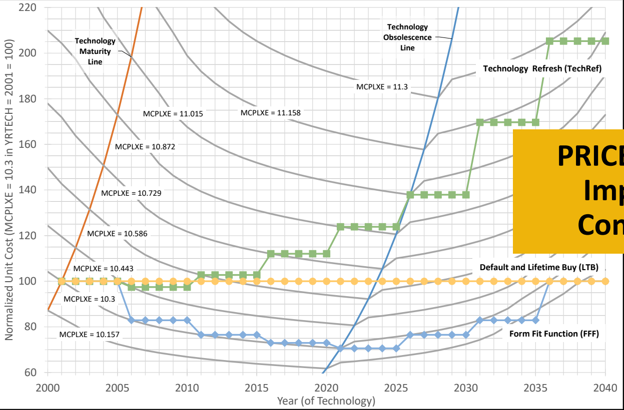
For Parts, NASA Boldly Goes . . . on eBay

NASA needs parts no one makes anymore.

So to keep the shuttles flying, the space agency has begun trolling the Internet -- including Yahoo and eBay -- to find replacement parts for electronic gear that would strike a home computer user as primitive.

New York Times, 12 May 2002, Section 1, p. 24

Feature 2

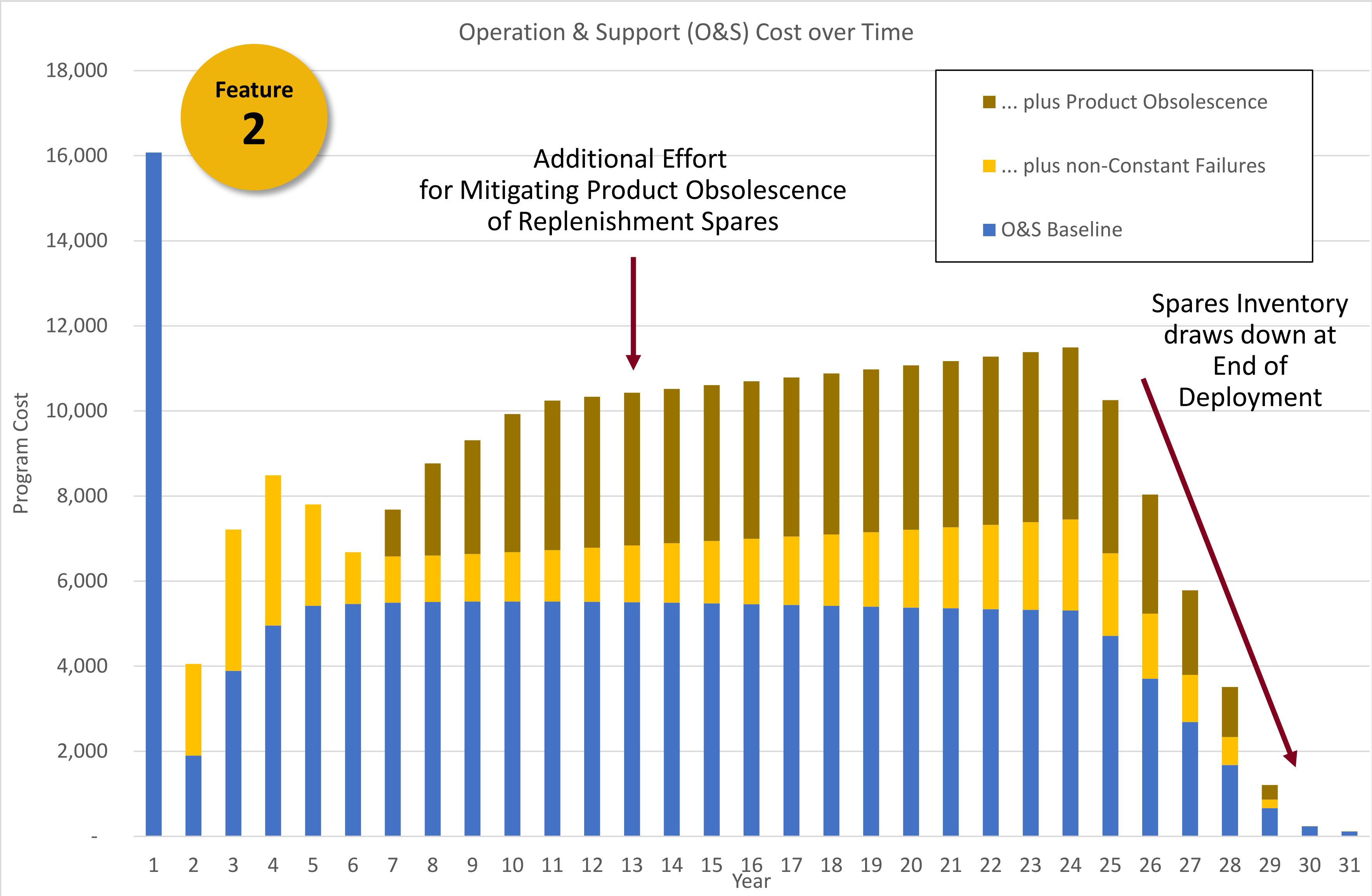


PRICE Technology Improvement Control Model

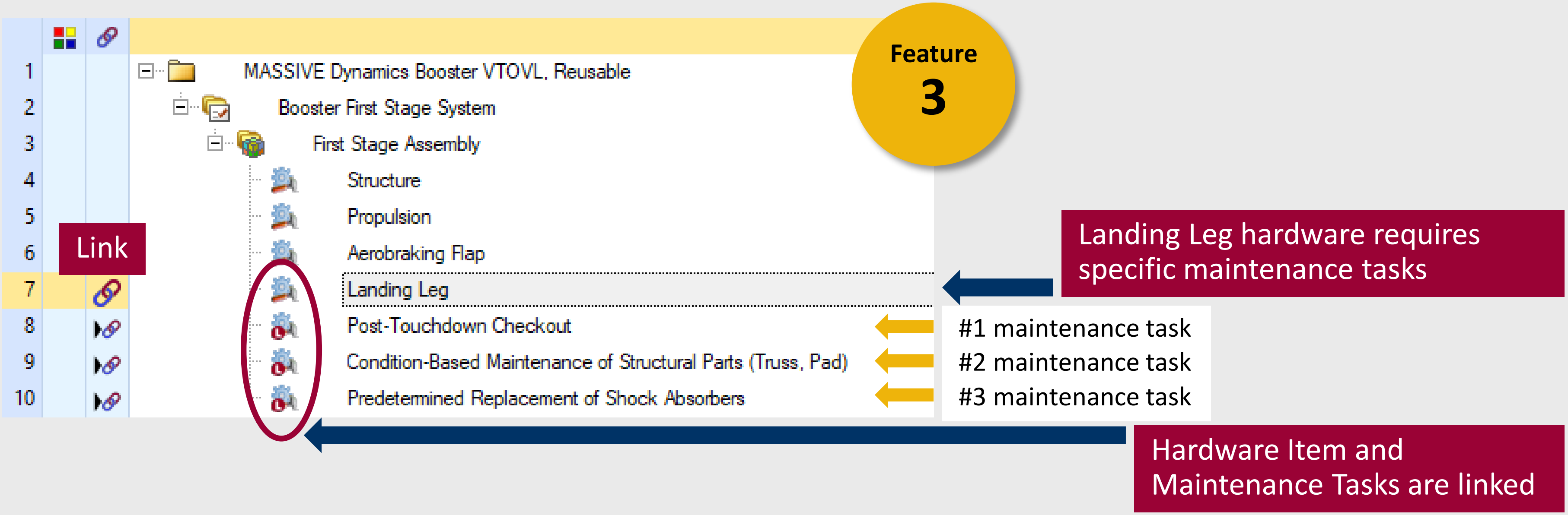
		Hardware Lifecycle Inputs	Value	Units
53		**Obsolescence Mitigation Inputs**		
54		Obsolescence Mitigation Strategy	**Technology Refresh**	
55		Start of Obsolescence Mitigation	**2006**	Year
56		Obsolescence Mitigation Frequency	5	Years
57		Technology Growth for Technology Refresh	1.000	
58		Maximum Number of Technology Refreshments	**5**	
59		LTB Closure for other Mitigation Strategies	**Yes - Occurs on Model-Estimated Year of Obsolescence**	

Pick one of three obsolescence mitigation strategies: Lifetime Buy (LTB), Equivalent in Form-Fit-Function (FFF), and Technology Refresh (TechRef)
→ If obsolete products are replaced, spares cost will be adjusted using the built-in, existing technology improvement model

Mitigation of product obsolescence adds another layer of operation and support cost detail



New feature 3: Assign detailed maintenance plans to subsystems and equipment

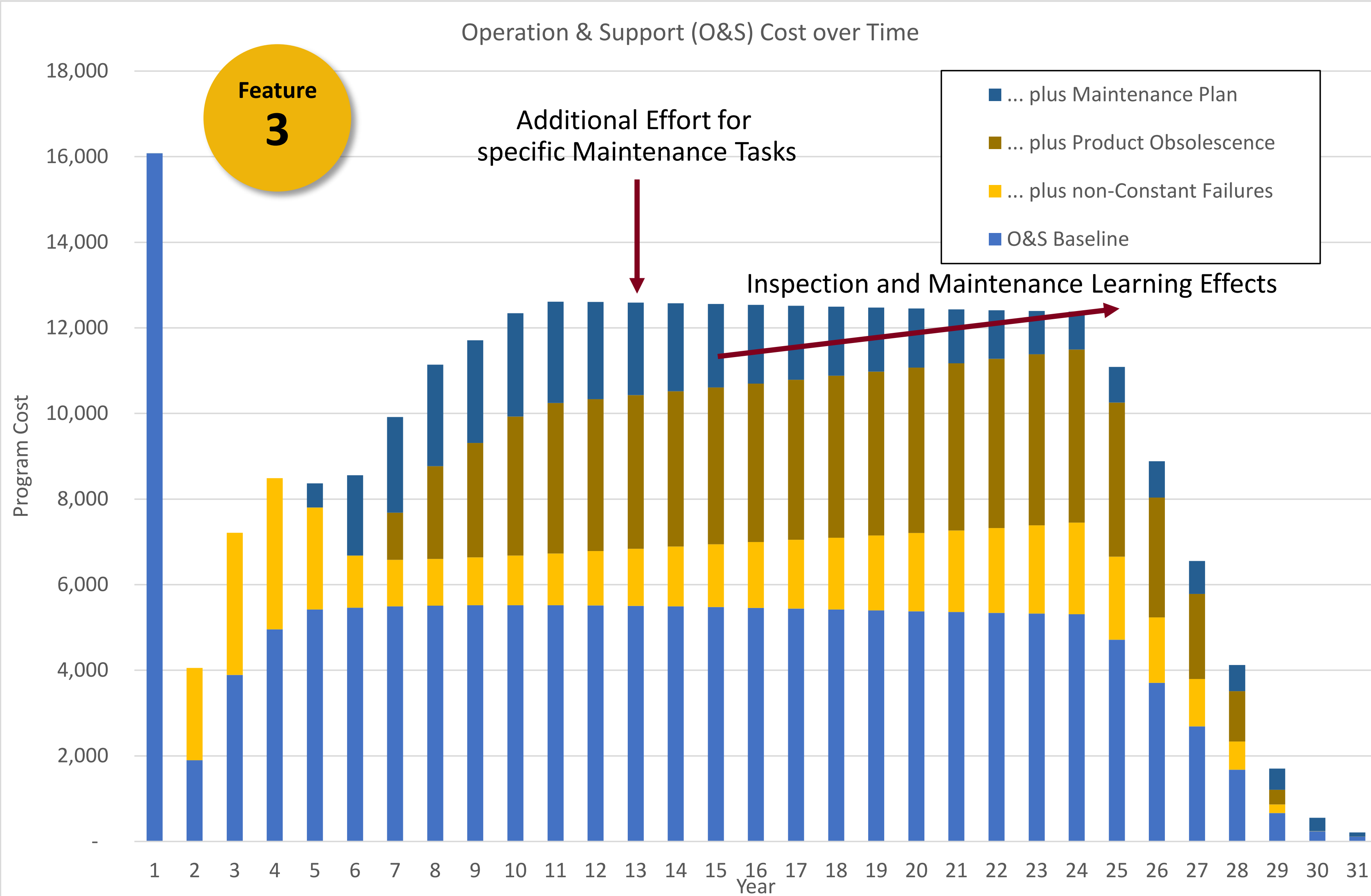


Example: Three different maintenance tasks have been linked to the Landing Leg hardware.

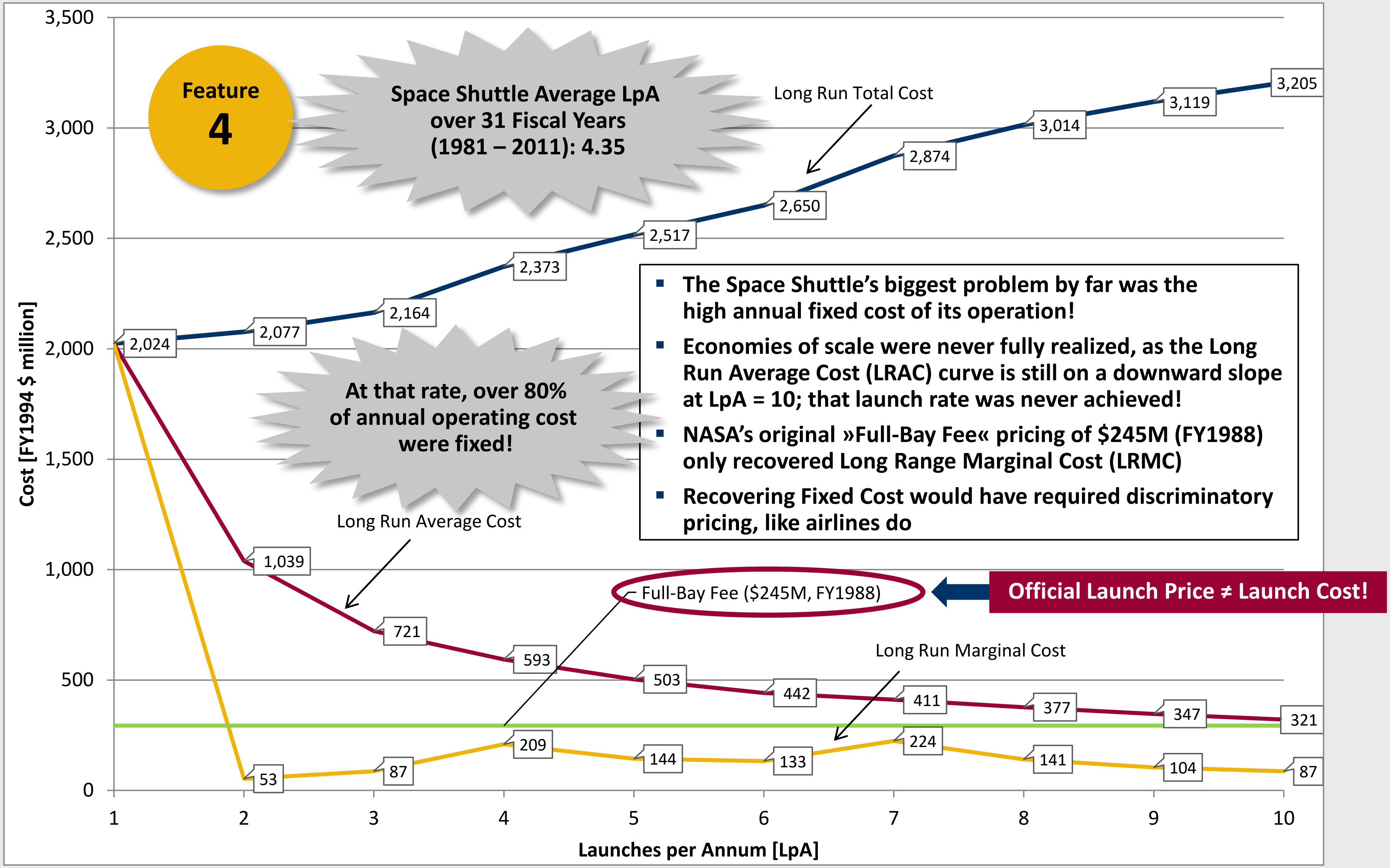
- The **checkout (=inspection)** of the whole Landing Leg after each landing
- The **condition-based maintenance** of structural parts (Truss, Pad), using built-in tests; whenever signs of impending failure are detected, the parts will be replaced
- The **predetermined replacement** of the Landing Leg's Shock Absorbers, either after a given maximum number of landings or by calendar time (e.g. once per year), whichever comes first

The user may combine each hardware element with any number of maintenance tasks, whether corrective, predetermined, condition-based; any given maintenance plan can be directly entered!

The modelling of specific maintenance tasks has been a frequent requirement for cost estimation tools

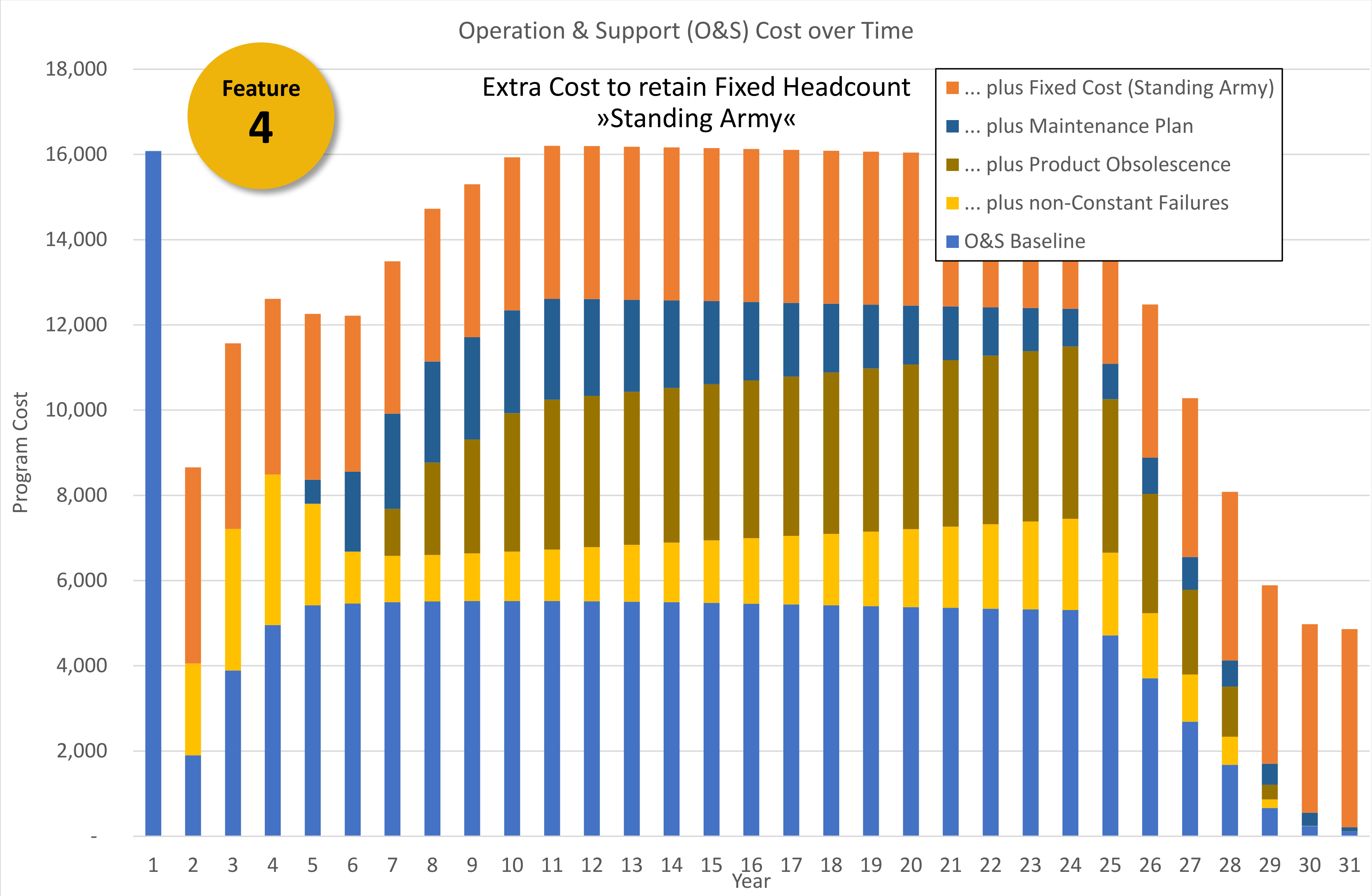


New feature 4: Amortize fixed cost of infrastructure and staff



All values in FY1994 dollars. Source: Shuttle Operations Zero Base Cost Study, NASA, 1991

Underutilization of assets and fluctuations in production cadence or annual launch rate can be properly modelled

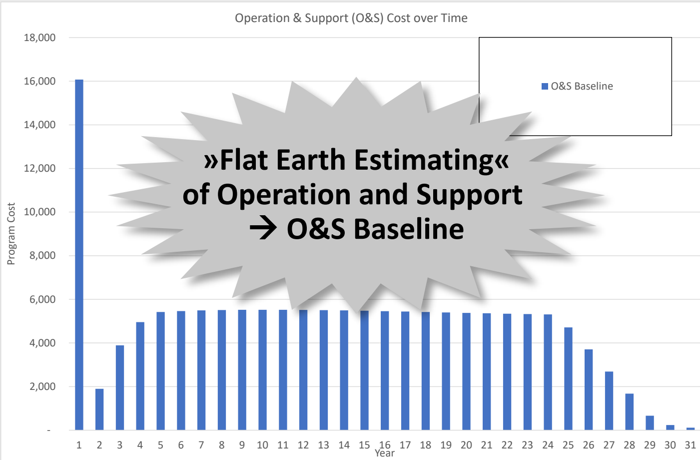


PRICE

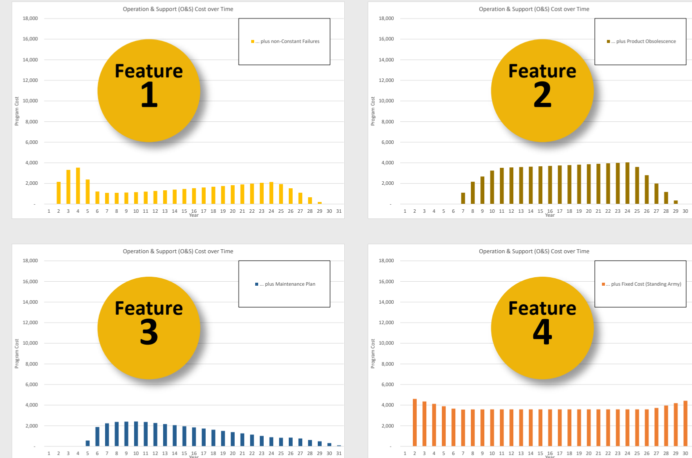
4) Conclusion

The upgraded 2022 LCCM (Life-Cycle Cost Management) release of PRICE True Planning® improves modelling of reusable launch vehicles and their operation and support (O&S) cost.

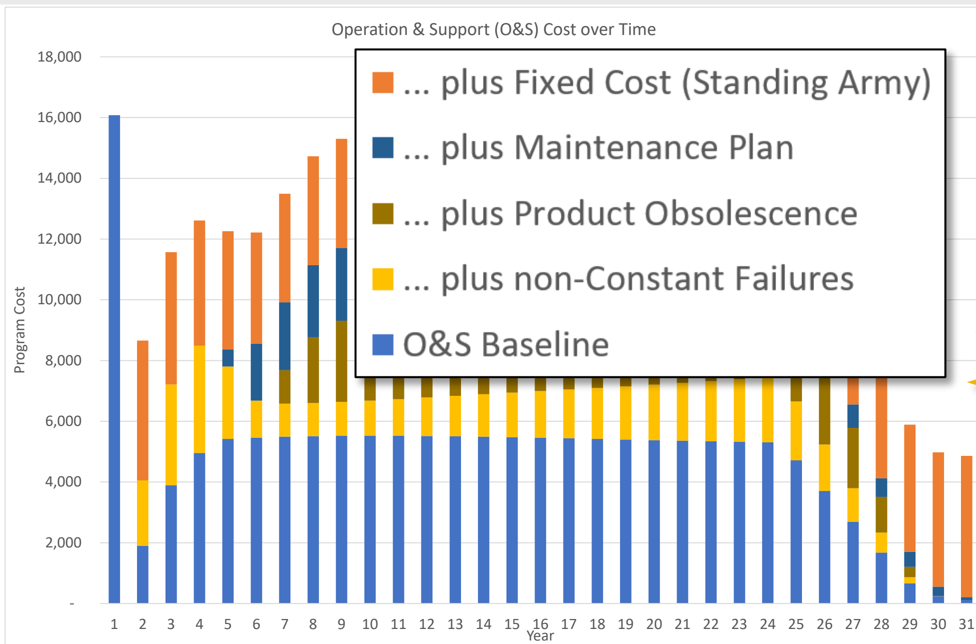
New key features add improved capabilities for life-cycle cost estimating of reusable launch vehicles



+



=



TECHNOLOGY UPDATES

TruePlanning

THANK YOU!

Dr. Fabian Eilingsfeld
Country Manager
PRICE Systems Deutschland GmbH
Eisenstrasse 49
DE-65428 Ruesselsheim

Phone : +49 (6142) 966-081
Fax : +49 (6142) 966-083
Mobile : +49 (175) 433-5067
Email : fabian.eilingsfeld@pricesystems.com
Web : www.pricesystems.com

COST ESTIMATION SOLUTIONS

ISO 9001
Certified Quality Management System
www.tuv-sud.com/ms-cert

PRICE Systems Deutschland GmbH • Registered Office: Ruesselsheim
Managing Director: Georges Teologlou • Authorized Representative: Dr. Fabian Eilingsfeld
Register Court Darmstadt, HRB 99641 • VAT Registration Number: DE 327 096 675