26th annual INCOSE international symposium

Edinburgh, UK
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Maintenance Scheduling Using Systems Engineering Integration

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Research Abstract

Maint scheduling of USAF F-15D fighter aircraft mapped through an adaptive, general loss function and weighted by operational and maint costs. New technique proposed to schedule maint personnel based on min economic loss – validated against actual maint data

F-15D Used by 25 Air Forces

- Upgraded/enhanced after 40 yrs service
- Wing ripped off in mid-air collision – pilot noticed a small vibration

Purpose of Research

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Everyday an F-15D is being repaired or waiting for repair, results in quantifiable loss to USAF

Develop a quantitative approach to consider the system-level consequences of scheduling maintenance personnel for the F-15D in USAF matrix organization

Workforce Planning is Critical

- 4-6 times > expense than aircraft flow in past 20 yrs (on a per hr basis)
- Annual maint=$21.6 mil,which is $8mil< replacement price
- Main=$17.4k/hr (2008 $) to aging airframes

www.Robins.af.mil

Maint. = Anticipate Future Work

Perspective–scheduling of personnel requires systemic view which integrates the needs of **all** stakeholders, to include those *in addition to* the scheduling org

- Military Techs orgs (Reserves)
- Other USAF groups contributing to work

Program Managers Decide

- Unfilled positions/absence of MTs drive PMs to request MTs to mitigate surges in operational requirements
- Conflicting needs of orgs resolved by highest military rank

Reserve Military Technicians

- Sustainment of military systems is carried out by military technicians (MTs), government employees, and contractors
- Conflicting needs of orgs are resolved by highest military rank
- End-strength, pay, rules for MTs fluctuate with actions by U.S. Congress

MTs – the Backbone of Maint.

- Reserve duty same as their duties as federal civilian employees/contractors
- 22,568 Air National Guard techs, 8,992 AF Reserve techs = total workforce of 31,560 USAF reservists(12% of maint Workforce)
- MTs, government employees, and contractors sustain military systems

MTs Key to F-15D Maint.

- Annual Comp = $100k; MTs Budget impact=$163mil (2014) up from $30mil (1998)
- 2014 amount represents a net reduction of 81% in MTs working in 1998
- Nat. Guard MTs (Technician Act, Title 32) mandates no additional comp for irregular or overtime work

Maint. Decision Calculus

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- Requisite level of aircraft availability
- Availability in peacetime operations ranges from 43% to a goal of 83% **(GAO 1982; 2003; NSIAD 1991)**
- Availability = percentage mission capable
- **Increase in MTs correlates with increase in mission capable F-15Ds** **(GAO 1982)**

Reassignment & Emergence

- Economic losses that incur when MTs move between orgs not accounted for when scheduling/performing maint – One org loses $
  - Small training reserve unit - $2,700/hr(14.4%)
  - Depot maint unit - $17,400/hr
- Concerned about ***Total*** Loss to USAF

Competing Demand for MTs

- Losses incurred when MT(reservist capacity)assigned to different org during annual 14-day work period (212 labor yrs)
- Assignment often based on either the MTs need for promotion in reserve rank or to augment workforce of another org that has high priority maint skills of the MT

Primary & Reserve Orgs Lose

- MT's labor lost during time away from POrg. And, if the MT's labor hours are not used to support the maint work of the ROrg, then ROrg experiences a loss.
- Levels of loss reflect duration of reservist's recall period and labor hours expended in the POrg and the ROrg.

USAF Costs Increased

- Priority-based assignments fail to capture “real” costs, reducing availability in era of declining budgets (**PROBLEM – Gaps in Coverage Cause People to Die**)
- Economic loss increased by inefficient use of maint labor and low MT retention
- Min loss to orgs captured by loss function

Model of POrgs – Small Unit

- Difference between POrg and Rorg determined by respective O&M costs
- POrg - small training unit, remote low cost training for few pilots in F-15D. Has inventory stock to support light maint

www.defencetalk.com

Model of ROrgs – Depot

- ROrg (Langley Air Force Base, VA) is a large depot maint facility
  - 500 maint technicians
  - 150 administrative personnel
  - 40 certified pilots

DynCorp International LLC.

Operations & Maintenance $

	Organization Rate	Labor Rate
POrg (Primary Org – Small)	$2,375/hour	$328/hour
ROrg (Reserve Org – Depot)	$17,000/hour	$400/hour

Maint Data Metrics

- Avg maint/hrs of flight time is 34.78 hrs (22 hrs maint/flight of 1.58 hrs (avg flight)
- Avg F-15D flies 237 flights (375 flight hrs) per year, for 8,285 labor hrs maint
- Equals 43.45 hrs/day maint/120 days, or 5.43 maint people/day/120 days
- Maint & repair work done by teams of 5-6

Maint. Situation

- Planning Rule: unscheduled maint is half scheduled maint workload
- Flights exceed speed & endurance goals, to operational limits
- Flight times avg longer, maint is higher than planned, achieving mission avail. is weeks to months versus days

Depot Maint Issues

- Front-line supervisors manage 20 teams based on specialty mech skills
- 2-3 work shifts typical – 2 for routine work, 3 for priority tasks
- Repairs on 1 aircraft delay other aircraft
- Always need resources; rivalry for labor

Maintenance Planning

- Similar maint standards for Mil aircraft and commercial airline
  - Level A: inspect and check emerg equip
  - Level B: perform light maint
  - Level C: inspect structure and maintain equip
  - Level D: inspect airframe, test all equip, replace engines

Maint 4-Level Approach

- Identifies problems early
- Minimizes expensive repairs
- Schedules for planning labor and resources

Level	Occurs Every	Maintenance Location	Expense
Level A	6 days	Tarmac or Hangar	$923,312
Level B	11 days (includes A)	Hangar	$2,519,950
Level C	180 days	Hangar	$3,693,250
Level D	490 days	Depot	$14,773,000

Sequencing Maint Levels

- Level A determines flight-worthiness
- If no issues found in Level A, then Level B is scheduled after next 2 flights
- If issues found in Level B, then Level C is scheduled before another flight
- After any inspection, Level A is scheduled

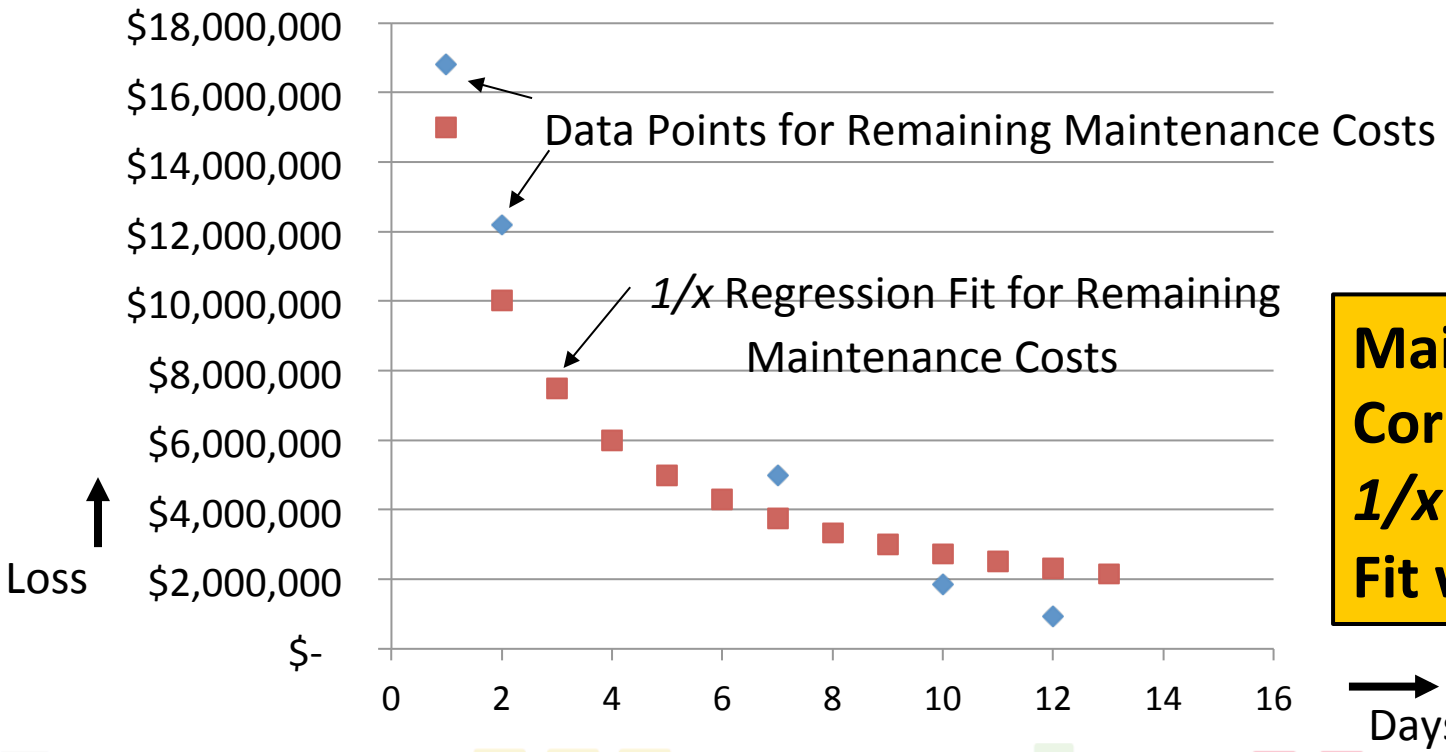
14-Day Model Maint at ROrg

Day	Maint Level	MBaint Level $	Cumulative Maint $	Planned $	Days Maint	$ Remaining from End
1	A	923,313	923,313	4,062,575	1-3	16,804,288
2	B	2,215,950	3,139,263			
3	A	923,313	4,062,575			
4	A	923,313	4,985,888	5,539,875	4-6	11,567,801
5	C	3,693,250	8,679,138			
6	A	923,313	9,602,450			
7	A	923,313	10,525,763	6,278,525	7-10	4,985,888

14-Day Model Maint at ROrg

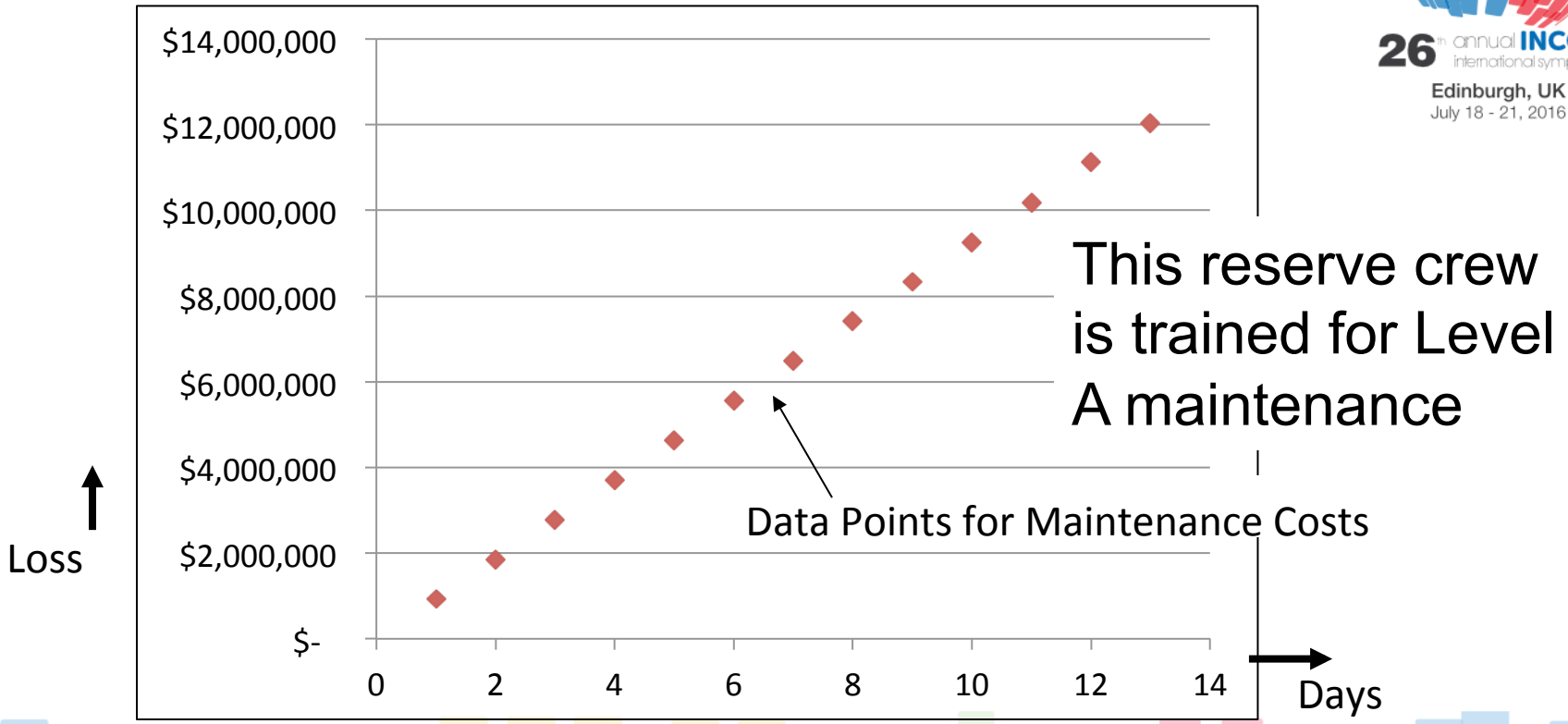
Day	Maint Level	MBaint Level $	Cumulative Maint $	Planned $	Days Maint	$ Remaining from End
8	B	2,215,950	12,741,713			
9	B	2,215,950	14,957,663			
10	A	923,313	15,880,975			
11	A	923,313	16,804,288	4,062,575	11-13	923,313
12	B	2,215,950	19,020,238			
13	A	923,313	19,943,550			
14	A	923,313	20,866,863	923,313	14	0
15	B	2,215,950				

Maint Scheduled at ROrg



Maint Costs Correlate with *1/x* regression Fit with data

Maint Scheduled at POrg



4 Maint Sequences (A,B,C,D)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Day	Scheduled Maintenance	Scheduled Maintenance	Scheduled Maintenance	Scheduled Maintenance
1	A	A	A	A
2	B	A	B	B
3	A	A	A	A
4	A	C	A	A
5	C	A	A	A
6	A	A	A	A
7	A	B	A	A
8	B	B	D	A
9	B	A	A	A
10	A	A	A	A
11	A	B	A	A
12	B	A	A	A
13	A	A	A	A
14	B	B	B	B

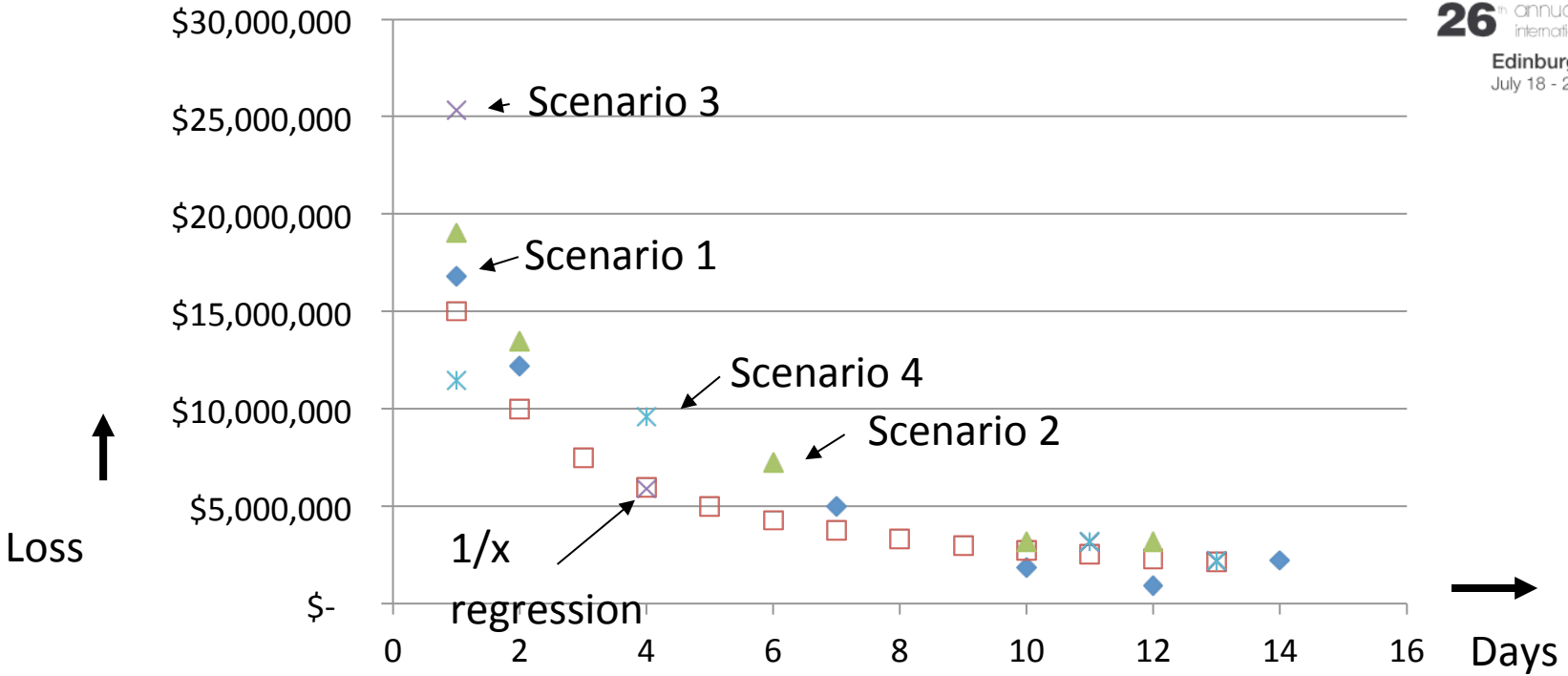
Maint $ Sequences (A,B,C,D)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	*1/x Regression*
Day	Scheduled Maintenance	Scheduled Maintenance	Scheduled Maintenance	Scheduled Maintenance	$30,000,000
1	$16,804,288	$19,020,238	$25,298,764	$11,449,077	$15,000,000
2	$12,187,725	$13,480,363			$9,999,900
3					$7,500,000
4			$5,909,201	$9,602,452	$6,000,000
5					$4,999,980
6		$7,201,838			$4,287,000
7	$4,985,888				$3,750,000

Maint $ Sequences (A,B,C,D)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	*1/x Regression*
Day	Scheduled Maintenance	Scheduled Maintenance	Scheduled Maintenance	Scheduled Maintenance	$30,000,000
8					$3,333,000
9					$3,000,000
10	$1,846,625	$3,139,263			$2,727,000
11			$3,139,263	$3,139,263	$2,499,000
12	$923,313	$3,139,263			$2,307,000
13			$2,215,950	$2,215,950	$2,142,000
14	$2,215,950				

Likely Maint Events for F-15D



Adaptable Loss Function

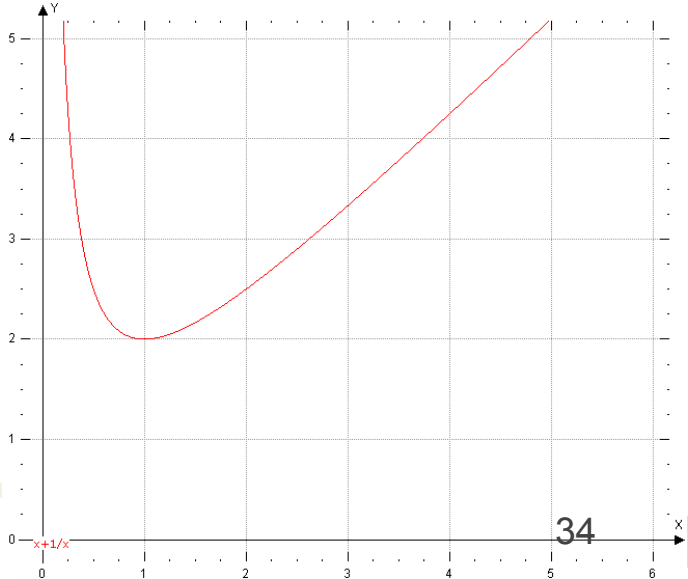
- Loss function maps economics of events to capture key performances of stakeholders (in this case, maint)
- Loss functions reflect manner in which the economics are mapped according to normative principles (Murphy 1994), rather than how stakeholders view the situation

Plot the Loss v. MOPs

- Make-up of generalized and adaptable loss function – loss in dollars plotted as dependent variable and measure of performance plotted as independent variable

$$L_n(x) = -2C_s m^n + C_s x^n + C_s m^{2n} x^{(-n)}$$

$$= -2C_s m^n + C_s x^n (1 + m^{2n} x^{(-2n)})$$

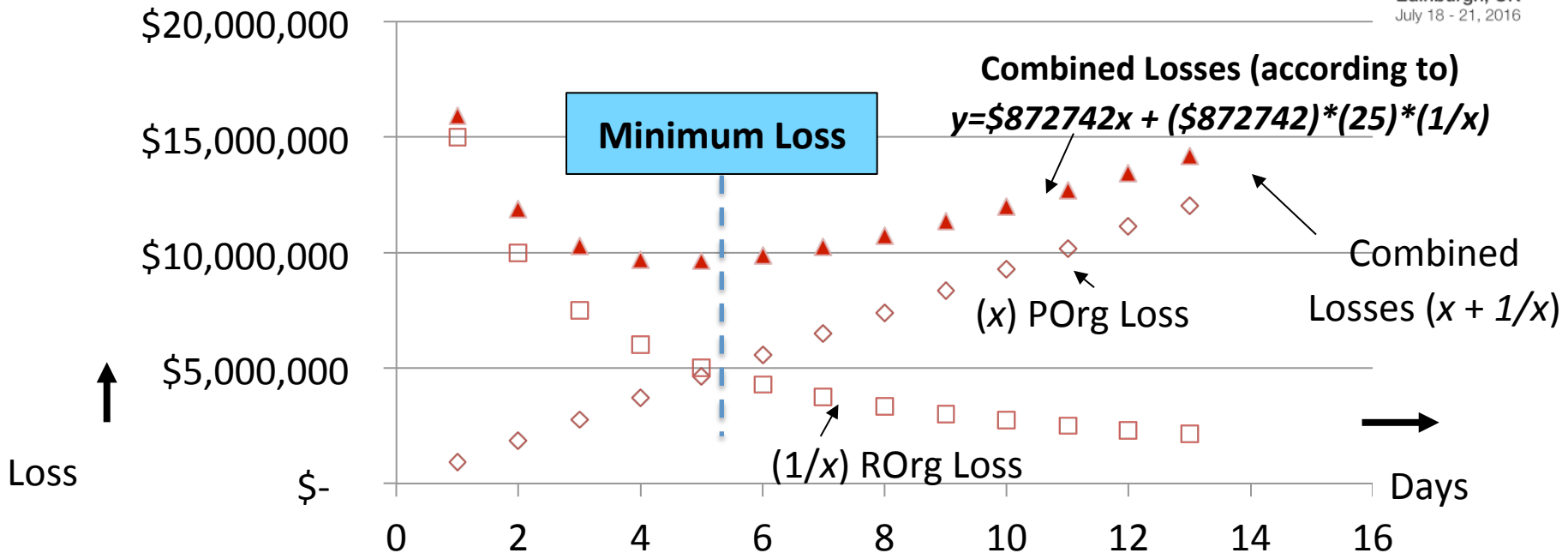


Generalized Loss Function

$L_n(x)$ is the total loss in case of shape parameter n and response x; C_s is proportionality constant that reflects orgs O&M costs; m is temporal variable reflecting minimum loss to stakeholders. Response adaptable by shape parameter n, reduces to asymmetric form $x+1/x$

POrg and ROrg Joint Losses

3-5% difference between regression and model



Loss Function = Negotiation

Loss function is mathematical structure for effects of negotiation/conflict between POrg and ROrg. ROrg's demand is an operational need with priority over POrg's is determinable by the difference in orgs O&M costs, consequence of not achieving or maintaining ROrg's aircraft mission capability

Loss Function = Negotiation

Application loss function shows impact of MT's work on POrg's and ROrg's operations. For POrg, a longer reserve recall period results in longer period of absence of its MT, which translates to increase in "loss" it incurs. ROrg, the longer MT works at ROrg, the higher the level of mission capability

Discussion

- Scenarios modeled do not present compelling argument why ROrg would have priority based on relatively high operational cost/hour, only that ROrg would benefit from MT work while loss to POrg does not emphasize mission capability, per se, but rather benefits for MTs

Discussion

- Minimum loss is determined as that experienced by both orgs so that neither has advantage over the other
- Focus is on dollar savings to USAF as the medium of negotiation for scheduling maint of the F-15D Fighter aircraft

Discussion

- Correlating adaptive loss function to typical set of maint schedules, the causal significance of org costs is highlighted and the dependency of time away from POrg is interpretable as economic loss for USAF
- Operational costs are key in determining amount of loss experienced by USAF

Conclusion

- This research shows that amount of time spent by MT at POrg versus ROrg is determined by difference in O&M costs of individual military units. If organizational costs of POrg equal the ROrg, then time spent at both units should be equal. In the model of the F-15D there was a 7 times difference in O&M costs favoring the ROrg

Conclusion

Based on hourly rates, min loss for POrg and ROrg was 5 days. Losses incur when MT away from either org. However, there is period whereby MT can work at both and provide a benefit for both maint efforts. Total dollar loss to USAF may be more important than a priority to accomplish an additional fraction of a % of availability, i.e., a tradeoff

References

Alfares, Hesham. 1999. “Aircraft Maintenance Workforce Scheduling – a Case Study.” Journal of Quality in Maintenance Engineering, University Press, 2, 78-88.

DOD. 2014. “National Guard and Reserve Equipment Report for Fiscal Year 2015.” for Department of Defense Office of the Assistant Secretary of Defense for Reserve Affairs, Deputy Assistant Secretary of Defense (Materiel and Facilities) – Col Denise L. Loring, RefID: 0-43F5A8A, March.

GAO. 1982. “Factors Limiting the Availability of F-15 Aircraft at the 1st Tactical Fighter Wing.” The U.S. General Accounting Office, GAO/PLRD-82-82, 7 June.

———. Military Readiness: DOD Needs a Clear and Defined Process for Setting Aircraft Availability Goals in the New Security Environment. Government Accountability Office. GAO-03-300. http://www.gao.gov/assets/240/237805.pdf.

References

Kapp, Lawrence, and Barbara Salazar Torreon. 2014. Reserve Component Personnel Issues: Questions and Answers. Congressional Research Service. https://www.fas.org/sgp/crs/natsec/RL30802.pdf.

Kinnison, H.A. 2004. *Aviation Maintenance Management*. ISBN 007142251X, McGraw Hill Education, Europe.

Military. 2005. Flight forum. http://www.airliners.net/aviation-forums/military/read.main/103605/

National Productivity Council. 2015. Productivity Portal. Maintenance Management. http://www.productivity.IN/pages/default.aspx

NSIAD. 1991. “Air Force's Ability to Track F-15 Operating and Support Costs.” NSIAD-91-81. 1991. Published: Jan 2, 1991. Publicly Released: Feb 1, 1991.

References

ODUSD(PI)(RQ). 1999. Defense Manpower Requirements Report, Fiscal year 2000. http://prhome.defense.gov/Portals/52/Documents/RFM/TFPRQ/Docs/fy2000.pdf

Periyar Selvam, U., Tamilselvan, T., Thilakan, S., and Shanmugaraja, M. 2013. "Analysis on Costs for Aircraft Maintenance." Advances in Aerospace Science and Applications, 3, Number 3, 177-182.

RAND. 2008. *Insights on Aircraft Programmed Depot Maintenance – An Analysis of F-15 PDM.* Technical Report prepared under Project Air Force by Rand Corporation. http://www.rand.org/paf/.

Rolfsen, B. 2005. "On Lockdown." *Air Force Times*. 25 April, 15

Senate. 2009. Orin Hatch. "F-22 Assertions and Facts." http://hatch.senate.gov/public/_files/F22AssertionsAndFacts.pdf US-CA).