

System Maturity Estimation During Program Execution

Dr. John Kamp^{1,2}, Dr. Ebrahim Malalla²

The George Washington University

Washington, DC

How are maturity, execution, and schedule related?

- Maturity and schedule growth
 - Mature → nearly ready-for-use
 - Less mature → may mitigate future threats → time to mature → schedule growth
 - Hypothesis: system maturity is correlated to program schedule growth
- Execution measure
 - Relative Schedule Change (RSC)
- Maturity measures
 - Technology Readiness Levels (TRLs)
 - GAO Technology Maturity

Maturity-related terms

- *System maturity*
 - System satisfies *design requirements*
- *Technology maturity*
 - How well a technology is understood
- *Readiness*
 - Context-specific system suitability for use
- *Product maturity*
 - A product's market position
- *Product quality*
 - How well a product meets *customer requirements*

Dataset and research methodology

- Dataset
 - Selected MDAPS 2007-2017
 - GAO, DOT&E and Selected Acquisition Report Summaries
 - Continuous and categorical variables
 - Created testing-event variables using word frequency analysis
 - Mapped event completion to an estimated TRL
 - Dataset available upon request
 - Excel format
 - Includes data dictionary
- Quantitative analysis
 - Logistic and linear regression
 - 151 observations
 - Dependent variables
 - GAO Technology Maturity
 - Estimated TRL
 - Predictors
 - Resources
 - Programmatic
 - Testing event related
 - Schedule

GAO Technology Maturity regression affected by resources, schedule and testing predictors

- Binary logistic regression
 - Significant at $\alpha = 0.05$
- Significant findings
 - Top 3 predictors
 - Testing event = 1 → Not mature
 - GAO Technology Maturity correctly predicted for 11/14 withheld observations (78.6%)

Term	Coef	Contribution	P-Value	VIF	Odds Ratio
Regression		39.85%			
Constant	7.500		0.000		
LN.RD.M	-0.944	7.89%	0.000	1.60	0.389
C.ev	-0.381	8.12%	0.000	1.87	0.683
[Req_Uns=1]	-1.461	1.46%	0.009	1.57	0.232
[COML=1]	-1.303	1.29%	0.024	1.50	0.272
[Prototype=1]	1.404	2.46%	0.015	1.67	4.070
[SW=1]	2.536	7.11%	0.000	1.56	12.632
[C3I=1]	1.404	0.99%	0.010	1.29	4.071
[INTEG=1]	-1.217	3.15%	0.013	1.21	0.296
[DEPEND=1]	-1.271	3.71%	0.014	1.26	0.281
[Joint=1]	-1.814	3.67%	0.009	1.38	0.163

Goodness-of-Fit Tests						Model Summary		Measures of Association	
Hosmer-Lemeshow	Observations	Model α	DF	Chi-Square	P-Value	R-Sq	R-Sq(adj)	AIC	Kendall's Tau-a
Table 6 model	151	0.05	8	6.85	0.552	39.85%	35.06%	147.42	0.39
Accuracy test model	137	0.05	8	5.4	0.714	40.25%	34.98%	135.26	0.40

Association is between the response variable and predicted probabilities

Schedule predictors significant for TRL regression

- Ordinal Logistic Regression

- Significant at $\alpha = 0.05$
- SPSS and Minitab
- Predicted/actual TRL
 - Immature [TRL= 5,6,7]
 - mature [TRL -=8,9]

- Significant findings

- Relationship between TRL and relative schedule change (RSC)
 - RSC odds ratio 8.97
- Predicts ± 1 TRL level ~ 85%

TRL Ordinal Logistic Regression Table

Minitab results					Odds	95% CI		SPSS results					95% CI		
Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper	Estimate	Std. Error	Wald	df	Sig.	Lower	Upper	
[TRL=5]	-6.609	0.955	-6.92	0.000				[TRLe = 5]	-7.219	1.002	51.883	1	0.000	-9.184	-5.255
[TRL=6]	-2.499	0.675	-3.70	0.000				[TRLe = 6]	-3.109	0.728	18.246	1	0.000	-4.536	-1.683
[TRL=7]	-1.341	0.656	-2.04	0.041				[TRLe = 7]	-1.951	0.701	7.745	1	0.005	-3.325	-0.577
[TRL=8]	1.475	0.662	2.23	0.026				[TRLe = 8]	0.864	0.692	1.559	1	0.212	-0.492	2.220
Cycle.Mo	0.030	0.007	4.47	0.000	1.03	1.02	1.04	Cycle.Mo	-0.030	0.007	19.950	1	0.000	-0.043	-0.017
ev.st	-0.561	0.075	-7.50	0.000	0.57	0.49	0.66	ev.st	0.561	0.075	56.224	1	0.000	0.414	0.708
B.st	0.523	0.131	4.00	0.000	1.69	1.31	2.18	B.st	-0.523	0.131	15.999	1	0.000	-0.779	-0.267
C.B	0.180	0.070	2.59	0.010	1.20	1.04	1.37	C.B	-0.180	0.070	6.683	1	0.010	-0.316	-0.044
RSC	2.194	0.673	3.26	0.001	8.97	2.40	33.55	RSC	-2.194	0.673	10.631	1	0.001	-3.513	-0.875
[COML=1]	-0.819	0.396	-2.07	0.038	0.44	0.20	0.96	[COML=0]	-0.819	0.396	4.286	1	0.038	-1.594	-0.044
[SEN.W=1]	-0.809	0.368	-2.20	0.028	0.45	0.22	0.92	[SEN.W=0]	-0.809	0.368	4.846	1	0.028	-1.530	-0.089
[INTEG=1]	1.018	0.363	2.80	0.005	2.77	1.36	5.63	[INTEG=0]	1.018	0.363	7.863	1	0.005	0.306	1.729

SPSS model performance	Actual TRL estimate					Predicted TRL estimate	Actual TRL estimate				
	5	6	7	8	9		[5,6,7]	[8,9]			
	Count	Count	Count	Count	Count						
Predicted Response Category	5	0	0	0	0	5	[8,9]	28	69	exact	56.3%
	6	4	31	6	13	6	[5,6,7]	41	13	+/- 1	84.8%
	7	0	0	0	0	7					
	8	0	10	18	38	8	[5,6,7]			correct	72.8%
	9	0	0	0	4	9	[8,9]	18.5%	45.7%		
							[5,6,7]	27.2%	8.6%		

Differences between immature and mature systems during execution

- Linear Regression
 - Significant at $\alpha = 0.10$
 - Dependent variable – Relative Schedule Change (RSC)
- Significant findings
 - Procurement funding
 - Schedule duration
 - System of systems fit
 - Type integration process alignment

Systems with TRLe = [5,6,7]					Systems with TRLe = [8,9]				
Source	Coef	Contribution	p	VIF	Source	Coef	Contribution	p	VIF
Regression	0.552	74.27%	0		Regression	0.693	68.58%	0	
LN.RD.M	0.0635	0.25%	0.009	2.82	LN.P.M	-0.1058	10.59%	0	1.65
LN.P.M	-0.0807	16.51%	0	2.02	Eng.2	-0.000414	0.23%	0.008	3.26
Cycle.Mo	-0.004734	27.51%	0	2.74	P_no	-0.000001	3.43%	0.013	1.87
B.st	0.0633	9.63%	0	2.81	C.B	0.0278	0.01%	0.013	2.92
C.B	0.0207	0.48%	0.009	1.5	Restr	-0.3253	2.78%	0	3.05
Restr	0.152	2.14%	0.002	1.49	PM.oth	0.3648	1.64%	0	2.03
PM.oth	-0.1146	1.49%	0.012	1.32	COML	0.1854	1.75%	0.006	2.44
complex_sys	0.3115	0.31%	0	2.68	Prototype	-0.278	2.51%	0	2.23
SoS_part	0.3782	14.22%	0	2.85	NM	0.1334	0.54%	0.039	1.86
DEPEND	-0.1301	0.80%	0.014	1.58	Type	* by factor	37.30%	0	* by factor
OPER	-0.1003	0.92%	0.058	1.73	complex_sys	0.2167	1.73%	0.013	2.00
	S	R-sq	R-sq(adj)	PRESSR-sq(pred)	SoS_part	0.1271	1.68%	0.072	1.86
	0.160606	74.27%	69.30%	2.3534	58.81%	SWAP	0.2466	0.10%	0.003 *
					1.96	RMA	0.1334	4.28%	0
						S	R-sq	R-sq(adj)	PRESSR-sq(pred)
						0.188684	68.58%	59.60%	3.852
									46.03%

	[TRLe= 5,6,7]	[TRLe = 8,9]
Resources	44.27%	14.26%
Program	18.16%	49.93%
OT	1.72%	4.38%
Schedule	10.11%	0.01%
error	25.74%	31.42%

Recommendations

- Use schedule growth as an indicator of *system immaturity*
- If you use mature technologies
 - Get your *system type certification processes right*
 - Integration issues commonly found in DT/OT
- If you use immature technologies
 - Get your resources right (understand your risk in cost and schedule terms)
 - Get your program structure right (requirements, miracles, team)
 - Get your schedule right (allocate your risk in schedule terms)
- Pay attention to
 - GAO maturity estimates – they are an independent check
 - DT/OT results - Test early, test often, and use as progress measures

backup

Results

- This research examined different measures of technology and system maturity, and identifies maturity-related factors.
 - Regression analysis identified statistically significant predictors of program technology and system maturity and schedule growth.
- The hypothesis (*system maturity is correlated to program schedule growth*) is supported by the research
 - Validated for MDAPs with reports issued by both the GAO and DOT&E in the same year from 2007 through 2017.
 - Research findings may not be valid for MDAPs not in these reports, highly classified programs, defense business systems and smaller expenditure acquisition programs.