The trouble with the System Readiness Level (SRL) index for managing the acquisition of defense systems

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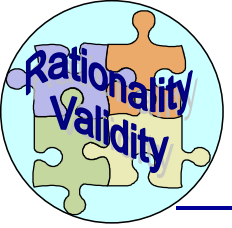


Acknowledgments & Disclaimers

- I thank the conference technical committee for the opportunity to make this presentation. I commend them for their courage and good technical judgment .

- Work supported in part by the Acquisition Research Program at the Naval Postgraduate School.

- Heartfelt thanks to three of my NPS colleagues, Tom Huynh, Gary Langford and Greg Miller, for their moral support.

- Being an educator and practicing systems engineer, it is my duty and responsibility to speak out against serious errors in my field of expertise.

- The presenter's opinions, findings, and recommendations are not necessarily shared by the NPS, the NDIA, and/or the DoD; but they should be!

My communications with B. Sauser

From: Brian Sauser
To: Kujawski, Edouard (CIV)
Subject: Re: NDIA presentation on SRL
Date: Thursday, September 02, 2010 10:08:23 AM

"Ed:
First, thank you for sharing your presentation and thoughts with us prior to NDIA. We respect that decision greatly.
Second, we are encouraged that you have chosen to look into what we have published and find ways to make it better or do further research. This is a true academic spirit that can advance a knowledge base in an area.
Third, while you argue that what we have done is flawed, we can equally present counter arguments as why it is not. So while you may not find it "pleasant" to do what you did, we are enthusiastic that you did. .....
Stephen Hawking said, if no one criticized my research, it could not be right.....
We would feel remorse at your presentation and ideas if it was not for the fact that the application of the SRL as a managerial tool has been working well with all of our customers and stakeholders, who have graciously offered to discuss with you how it has worked for them. Let me know, we can provide their contact information. Some will also be at NDIA. ....."

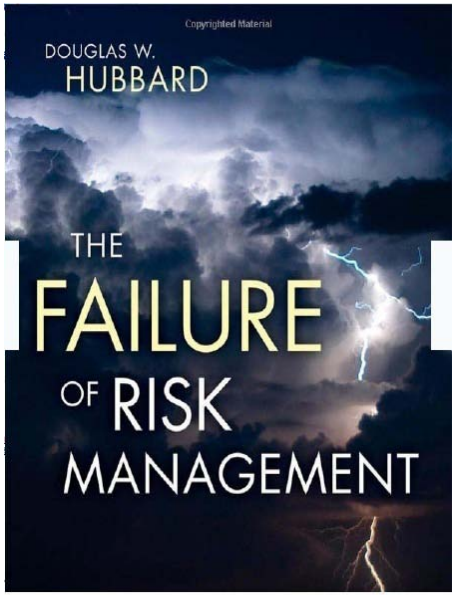
- Two of my thoughts reading the above email

1. The Law of Excluded Middle. A proposition is either true or false; it cannot be anything in between.
2. Einstein's reply when he heard of the book "100 Authors Against Einstein"

"If I were wrong, one would be enough."

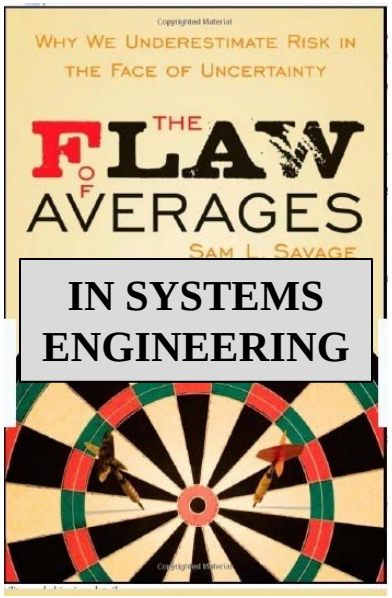
- B. Sauser DID NOT provide the contact information that I requested!

Imagine SE in these titles



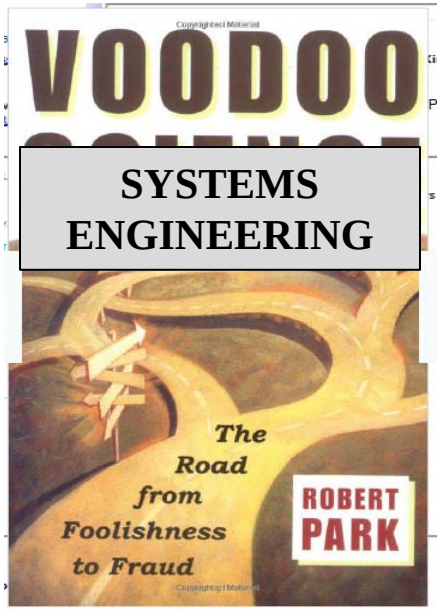
35 Reviews

5 star:	(27)
4 star:	(2)
3 star:	(2)
2 star:	(1)
1 star:	(3)



39 Reviews

5 star:	(18)
4 star:	(7)
3 star:	(7)
2 star:	(3)
1 star:	(4)

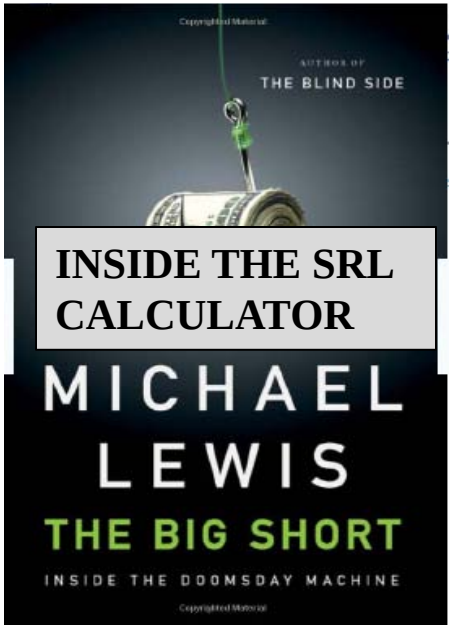


95 Reviews

5 star:	(44)
4 star:	(23)
3 star:	(8)
2 star:	(6)
1 star:	(14)

- Failure of risk management ➔ failure of SE

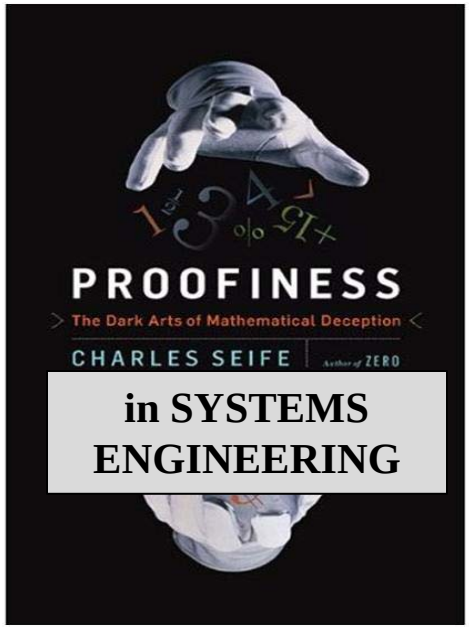
Or these titles!



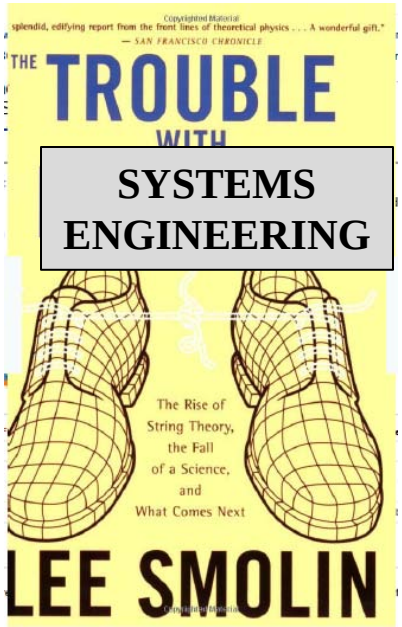
INSIDE THE SRL CALCULATOR

501 Reviews

5 star:	(295)
4 star:	(83)
3 star:	(20)
2 star:	(12)
1 star:	(91)



in SYSTEMS ENGINEERING



SYSTEMS ENGINEERING

130 Reviews

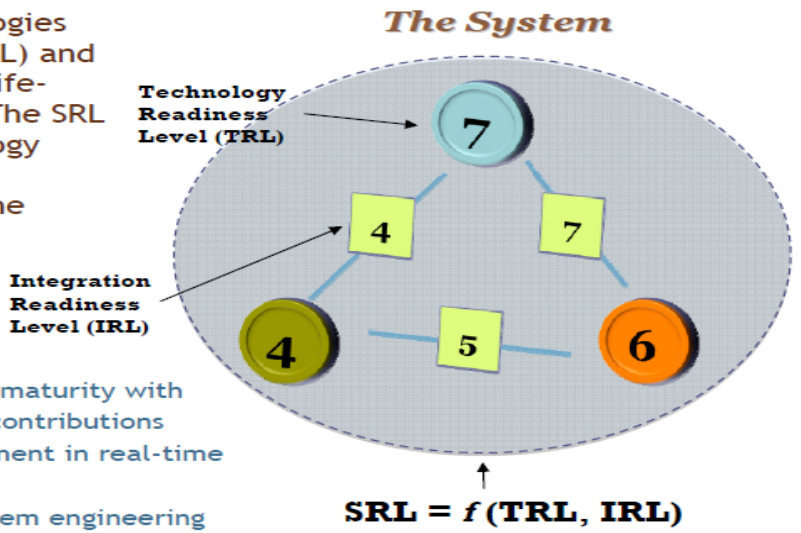
5 star:	(84)
4 star:	(31)
3 star:	(7)
2 star:	(2)
1 star:	(6)

Let's work together to avoid further notoriety!

The B. Sauser & Co. false premise!

B.J. Sauser & J. Ramirez-Marquez, Systems Engineering Collaborators Information Exchange (SECIE) Community Event, ***Slide #5***

Development of metrics, tool, and methodologies for determining a systems readiness level (SRL) and potential for making efficient and effective life-cycle acquisition and operational decisions. The SRL Model is a function of the individual Technology Readiness Levels (TRL) and their subsequent integration points with other technologies, the Integration Readiness Level (IRL).



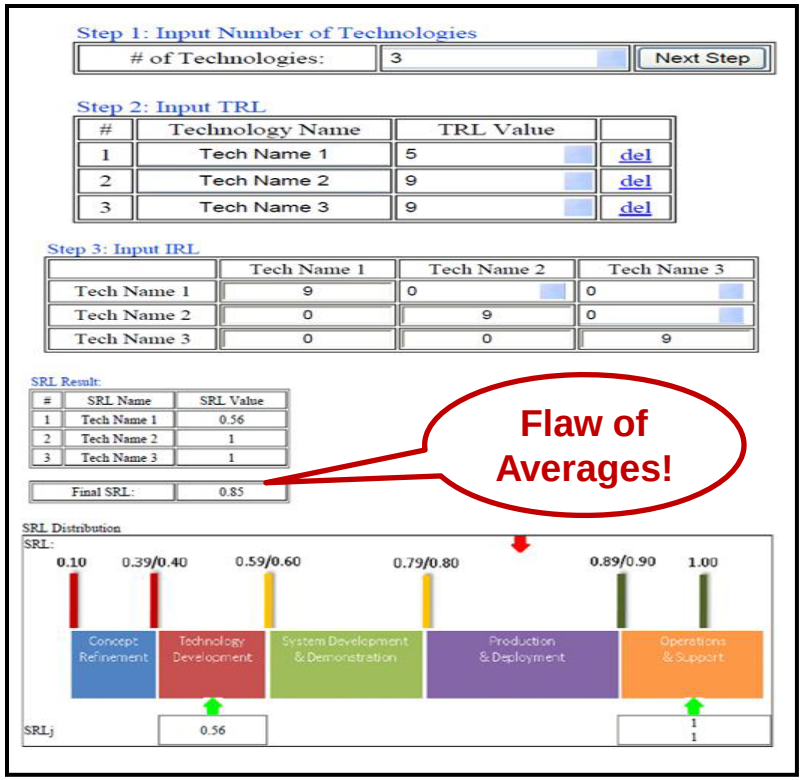
- Value Proposition:
  - Provides a system-level view of development maturity with opportunities to drill down to element-level contributions
  - Allows managers to evaluate system development in real-time and take proactive measures
  - Highly adaptive to use on a wide array of system engineering development efforts
  - Can be applied as a predictive tool for technology insertion trade studies and analysis

The B. Sauser & Co. SRL is predicated on the false premise, SRL = f(TRL, IRL).

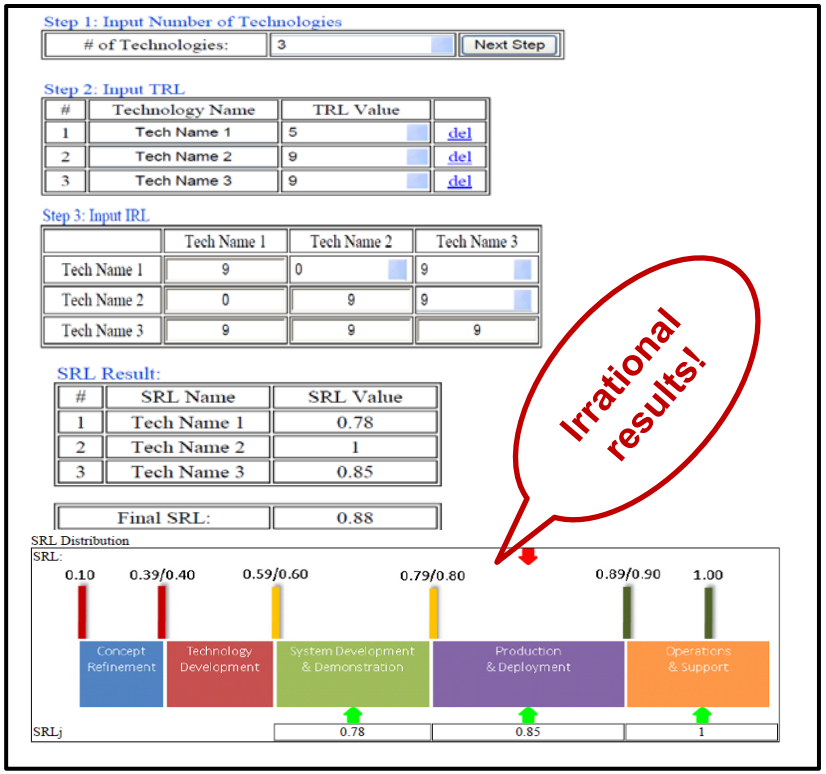
☞ The rest of my presentation is commentary!

The B. Sauser & Co. SRL can do harm!

Test Case 1*



Test Case 2*



** Results obtained with the Systems Development & Maturity Laboratory (B. Sauser & Co.) SRL calculator*

Proceeding with "Production & Deployment" ➔ Program Failure

The B. Sauser & Co. SRL is misleading and therefore worse than useless!

Types of measures

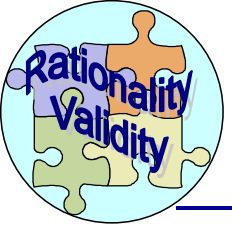
- **Natural measures:** In general use and have a common interpretation to everyone.
  - Speed: Miles/hr; Cost: $; Weight: tons; Volume: m^3...
- **Constructed measures:** Integrates multiple numerical and/ or verbal descriptions into a single description of the state of a fundamental objective.
  - Subjective scale
  - Context dependent
  - Utility

Constructed measures can be hazardous to your program's health.

Levels of measurement

- Numbers **MUST** be assigned to observations/attributes according to the following rules:

Level of Measurement	Rules
Nominal	Put data in **categories**.
Ordinal	Put data in **rank order**.
Interval	Put data in rank order with **equal intervals between each unit**.
Ratio	Put data in rank order with equal intervals between each unit, and anchor with a **true zero point**.



TRL & IRL are ordinal scales

J.C. Mankins, Technology readiness levels, NASA, Houston, TX,1995.

TRL	Definition	Description [DoD, 2005]
9	Actual System Proven Through Successful Mission Operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.
8	Actual System Completed and Qualified Through Test and Demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
7	System Prototype Demonstration in Operational Environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft
6	System/Subsystem Model or Prototype Demonstration in Relevant Environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
5	Component and/or Breadboard Validation in Relevant Environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
4	Component and/or Breadboard Validation in Laboratory Environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
3	Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
2	Technology Concept and/or Application Formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
1	Basic Principles Observed and Reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.

Sauser, B.J., D. Verma, J. Ramirez-Marquez, and R. Gove. (2006). From TRL to SRL: The Concept of Systems Readiness Levels. Conference on Systems Engineering Research, April 7-8, Los Angeles, CA

IRL	Definition	Description
9	Integration is **Mission Proven** through successful mission operations.	IRL 9 represents the integrated technologies being used in the system environment successfully. In order for a technology to move to TRL 9 it must first be integrated into the system, and then proven in the relevant environment, so attempting to move to IRL 9 also implies maturing the component technology to TRL 9.
8	Actual integration completed and **Mission Qualified** through test and demonstration, in the system environment.	IRL 8 represents not only the integration meeting requirements, but also a system-level demonstration in the relevant environment. This will reveal any unknown bugs/defect that could not be discovered until the interaction of the two integrating technologies was observed in the system environment.
7	The integration of technologies has been **Verified and Validated** with sufficient detail to be actionable.	IRL 7 represents a significant step beyond IRL 6; the integration has to work from a technical perspective, but also from a requirements perspective. IRL 7 represents the integration meeting requirements such as performance, throughput, and reliability.
6	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.	IRL 6 is the highest technical level to be achieved, it includes the ability to not only control integration, but specify what information to exchange, unit labels to specify what the information is, and the ability to translate from a foreign data structure to a local one.
5	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.	IRL 5 simply denotes the ability of one or more of the integrating technologies to control the integration itself; this includes establishing, maintaining, and terminating.
4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.	Many technology integration failures never progress past IRL 3, due to the assumption that if two technologies can exchange information successfully, then they are fully integrated. IRL 4 goes beyond simple data exchange and requires that the data sent is the data received and there exists a mechanism for checking it.
3	There is **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.	IRL 3 represents the minimum required level to provide successful integration. This means that the two technologies are able to not only influence each other, but also communicate interpretable data. IRL 3 represents the first tangible step in the maturity process.
2	There is some level of specificity to characterize the **Interaction** (i.e. ability to influence) between technologies through their interface.	Once a medium has been defined, a "signaling" method must be selected such that two integrating technologies are able to influence each other over that medium. Since IRL 2 represents the ability of two technologies to influence each other over a given medium, this represents integration proof-of-concept.
1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.	This is the lowest level of integration readiness and describes the selection of a medium for integration.

"TRLs …do not indicate the difficulty in achieving the next TRL level."

DoD, TRA Handbook, July 2009, p. C-3

The B. Sauser & Co. SRL scale

Tan, W., Sauser, B. and Ramirez-Marquez, J.E. (2010) "Analyzing Component Importance in System Maturity Assessment" *IEEE Transactions on Engineering Management* (conditionally accepted for publication)

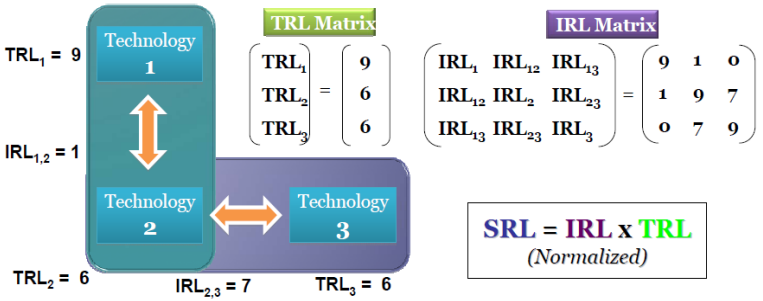
SRL	Acquisition Phase	Definitions
0.90 to 1.00	**Operations & Support**	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle.
0.70 to 0.89	**Production**	Achieve operational capability that satisfies mission needs.
0.60 to 0.79	**System Development & Demonstration**	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
0.40 to 0.59	**Technology Development**	Reduce technology risks and determine appropriate set of technologies to integrate into a full system.
0.10 to 0.39	**Concept Refinement**	Refine initial concept; Develop system/technology strategy.

The Sauser & Co. SRL = f(TRL, IRL) is a deeply flawed entrance index for the various acquisition phases!

The B. Sauser & Co. SRL calculator

Visit us at http://www.systems-development-maturity.com http://www.SystemReadinessLevel.com

SRL Calculation Example



Component SRL = $\begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} 0.54 & 0.43 & 0.59 \end{pmatrix}$

Component SRL_x represents Technology "X" and its IRLs considered

Composite SRL = 1/3 (0.54 + 0.43 + 0.59) = 0.52

The Composite SRL provides an overall assessment of the system readiness

Sauser, B., J. Ramirez-Marquez, R. Magnaye, and W. Tan. (2008). "A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition." International Journal of Defense Acquisition Management, 1:39-58

← B. Sauser & Co. provide a SRL calculator

Step 1: Input Number of Technologies

# of Technologies:	3	Next Step

Step 2: Input TRL

#	Technology Name	TRL Value	
1	Tech Name 1	9	del
2	Tech Name 2	6	del
3	Tech Name 3	6	del

Add Row | Reset | Next Step

Step 3: Input IRL

	Tech Name 1	Tech Name 2	Tech Name 3
Tech Name 1	9	1	0
Tech Name 2	1	9	7
Tech Name 3	0	7	9

Reset | Calulation

SRL Result:

#	SRL Name	SRL Value
1	Tech Name 1	0.54
2	Tech Name 2	0.43
3	Tech Name 3	0.59

Final SRL:	0.52

Don't be dazzled by the mathematics;
it's Computationally Accurate But Irrelevant (**CABI**)!

The B. Sauser & Co. SRL violates basic engineering principles

- As shown on slide 7, the B. Sauser & Co. SRL provides irrational results
- Component SRL_x /$ITRL_x$ do not credibly represent "technology X" and ITRLs
  - They depend on the other TRLs
  - Note the change from SRL_x to $ITRL_x$!
- Adding integration can increase SRL_x/ $ITRL_x$ beyond TRL_x.

No integration between TRL1 & TRL3: IRL(1, 3) = 0
ITRL3 = 0.59, SRL = 0.52

	TRL Vector		TRL'		IRL Matrix			IRL' Matrix		
TRL1		9	1.00	9	1	0		1.00	0.11	0.00
TRL2	=	6	0.67	1	9	7		0.11	1.00	0.78
TRL3		6	0.67	0	7	9		0.00	0.78	1.00
		ITRL1		0.54						
		ITRL2	=	0.43						
		ITRL3		0.59						
		SRL =		0.52						

Integration between TRL1 & TRL: IRL(1, 3) = 9
ITRL3= 0.73, SRL = 0.58

	TRL Vector		TRL'		IRL Matrix			IRL' Matrix		
TRL1		9	1.00	9	1	9		1.00	0.11	1.00
TRL2	=	6	0.67	1	9	7		0.11	1.00	0.78
TRL3		6	0.67	9	7	9		1.00	0.78	1.00
		ITRL1		0.58						
		ITRL2	=	0.43						
		ITRL3		0.73						
		SRL =		0.58						

The B. Sauser & Co. SRL fails construct validity!

B. Sauser & Co. flawed rationale (1 of 2)

R. B. Magnaye, B.J. Sauser, and J. E. Ramirez-Marquez, System development planning using readiness levels in a cost of development minimization model, Systems Engineering, published online: 27 AUG 2009.

1. Flawed FMECA RPN Rationale

The approach to estimating SRL is similar to the one used in Failure Mode Effects and Criticality Analysis or FMECA [Becker and Flick, 1996; Deb et al., 1998], where an ordinal datum, Severity, is transformed into a numerical value and combined with the probabilities of Occurrence (O) and Detection (D) to generate a Risk Priority Number (RPN).

2. Flawed AHP Rationale

Transforming ordinal data into numbers is also done in Analytical Hierarchy Process [Saaty, 1988], which allows the use of subjective human judgment to determine the relative importance of variables used in pair-wise comparisons to find an optimal solution to a problem. Sample applications can be found in Bahurmoz [2003] and Tavana [2003].

1. FMECA RPN Truth & Negative Example

1A. The RPN is NOT an integral element of the FMECA (NOT in Mil-Std-1629A)

2B. *S. Kmenta, K. Ishii, "Scenario-Based FMEA: A Life. Cycle Cost Perspective", Proc. ASME Design. Engineering Technical Conf. Baltimore, MD, 2000.*

– "RPN is an inconsistent risk-prioritization technique."

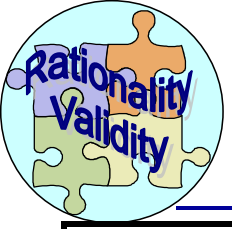
– "It is valid to rank failure along a single ordinal dimension (e.g., "Severity") *but multiplying ordinal scale is not an "admissible transformation."*

2. AHP Truth & Negative/Non-Example

2A. Sauser & Co. don't use pairwise comparison!

2B . *E. Kujawski, A reference-dependent regret model for deterministic trade-off studies, Systems Engineering, Vol. 8, No. 2, 2005, p. 119-137.*

–" Rank reversal in the AHP has been a hotly contested subject for the last 30 years [Dyer, 1990a, 1990b; Harker and Vargas, 1990; Saaty, 1990, 2000; Triantaphyllou, 2000…]."



B. Sauser & Co. flawed rationale (2 of 2)

R. B. Magnaye, B.J. Sauser, and J. E. Ramirez-Marquez, System development planning using readiness levels in a cost of development minimization model, Systems Engineering, published online: 27 AUG 2009.

3. Flawed GPA Rationale

The use of ordinal data in SRL can also be explained by a widely accepted practice in academic administration—the use of Grade Point Average or GPA—to determine the readiness of students to proceed to the next levels of development. The performance of a student is measured using a description of their accomplishments to which letter grades are awarded. For example, distinguished work is assigned an "A," superior work is a "B," satisfactory or average work earns a "C," and so on. To calculate overall performance, numbers are assigned to each letter grade and paired with the corresponding academic credits earned to estimate a weighted GPA. However, when comparing students relative to each other, such as in a group of job applicants, it will only be valid as the absolute criterion when they have the same academic major and come from comparably similar schools.

3. GPA Truth & Negative/Non-Example

– The GPA model is a **COMPENSATORY MODEL** and it does not have universal acceptance.

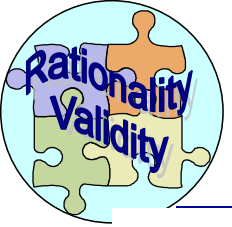
– Based on the educational system in some counties, I would argue that a project with a low SRL_X for a critical technology X should not automatically proceed to the next phase even if the other SRLs and IRLs yield a sufficient high B. Sauser & Co. SRL.

– B. Sauser & Co. multiply TRLs by IRLs. The GPA does not multiply grades.

–Technologies are not equivalent to academic subjects. The effort to advance a sensor with a TRL of 5 to 7 has no relation to the effort to advance a power system from a TRL of 5 to 7.

B. Sauser & Co. SRL rationale fails content validity!

- They use negative examples as positive examples and non-examples.
- They consider a SELECTIVE set of AHP and FMECA/RPN papers; i.e. those that are applications and discard those that investigate fallacies.



There are many simple ways to construct "Rational" system readiness measures

1. Simple tabular summary of technology & integration scores, TRLs/IRLs

Level	1	2	3	4	5	6	7	8	9
TRL_X	$\#_1$	$\#_2$	$\#_3$	$\#_4$	$\#_5$	$\#_6$	$\#_7$	$\#_8$	$\#_9$
IRL_{XY}	$\#_1$	$\#_2$	$\#_3$	$\#_4$	$\#_5$	$\#_6$	$\#_7$	$\#_8$	$\#_9$

– *$\#_i$ is the number of technologies with TRL or IRL = level*

2. Min-Min Principle

$$SRL_{MM} = (\text{Min } TRL_i, \text{Min } IRL_{jk})$$

- *i, j, k denote subsystem technologies and integration elements*

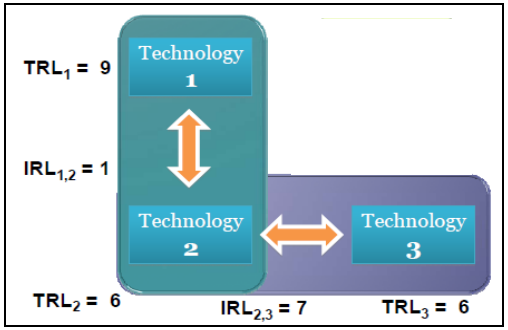
3. Other constructs …..

☺ The tabular summary and the Min-Min principle are rational measures that provide more useful information of system readiness/maturity than the B. Sauser & Co. SRL.

☹ **BUT**, they still DO NOT provide quantitative estimates of the schedule and cost for entering the next stage of the life cycle development including **Performance, Cost, & Schedule Risks.**

"Rational" SRL measures - Illustrations

- Please consider the Slide 12 example



B. Sauser & Co.
SRL = 0.52???

1. Simple tabular summary of technology & integration scores, TRLs/IRLs

Level	1	2	3	4	5	6	7	8	9
TRL_X	0	0	0	0	0	2	0	0	1
IRL_{XY}	1	0	0	0	0	0	1	0	0

2. Min-Min Principle

SRL_{MM} = (6, 1) → Could be a serious problem!

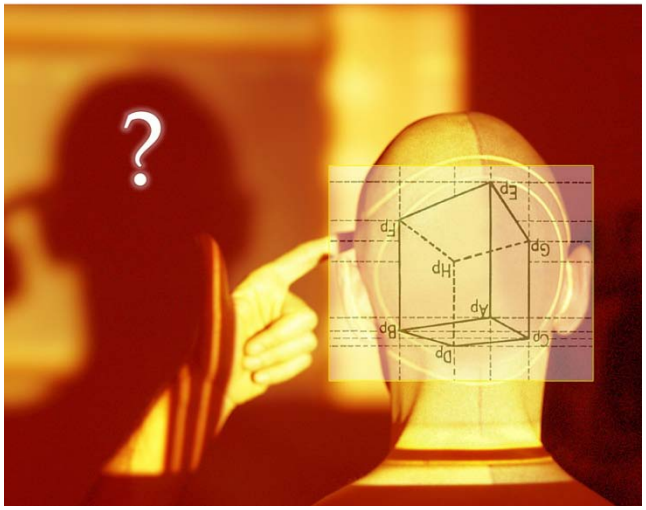
The tabular summary and the Min-Min principle provide visibility as well as valid and useful information of system status and require NO mathematics!

B. Sauser & Co. know that their SRL is flawed!

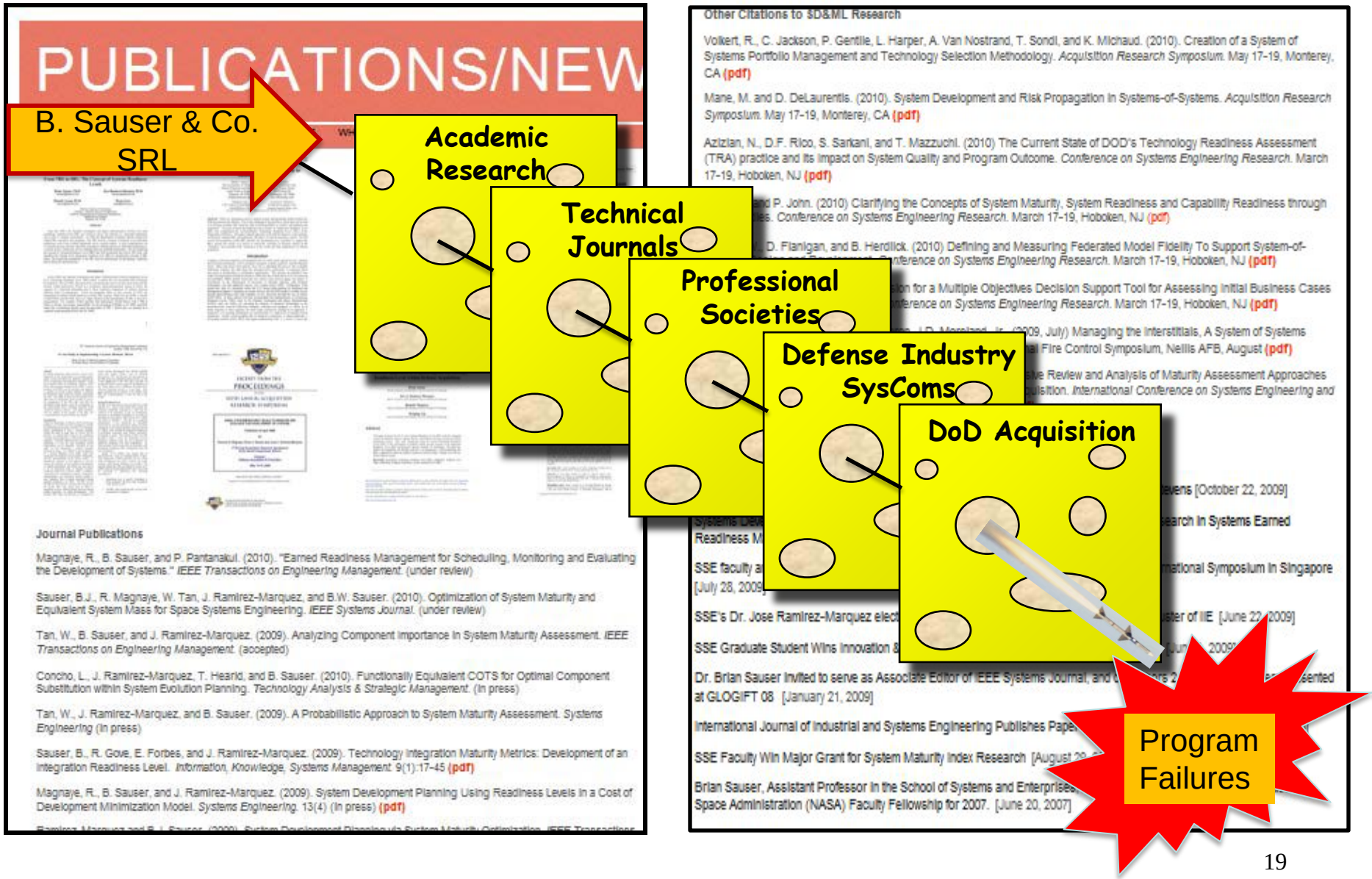
B.J. Sauser & J. Ramirez-Marquez Slide #9
http://www.acq.osd.mil/se/webinars/2009-08-18-SECIE-System-Maturity-Assessment-Sauser-brief.pdf

- Analysis may result in rank reversals, where a less mature SRL receives a higher rating than a more mature SRL.
  - The reason for this is that the rankings are ordinal scale numbers, and multiplication is not a valid operation on them. The ordinal rankings only say that one ranking is better or worse than another, but not by how much.

- NEVERTHELESS, B. Sauser & Co. are aggressively promoting their SRL model and it is gaining acceptance as a program management tool.



Educational, Professional, and Organizational Failings



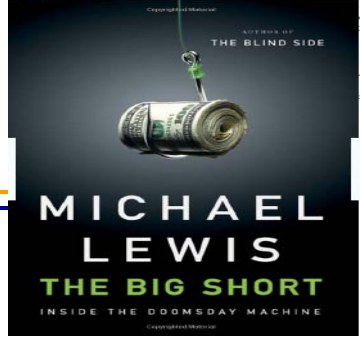
Many unwitting accomplices

A stakeholder's thoughts

r. Kujawski,
requested some thoughts on your presentation
terial and view of SRL follow.
sically, I concur with your view that there are
cs inherent in the use of SRL and that it does not
vide an authoritatively accurate answer for the
theorist. I believe Dr. Sauser would concur with
t statement as well. However, I do believe that
L remains a valid and useful tool for the SE and
practitioner .....
my view, SRL as a single number does provide
ue to a PM, similar to how Risk Rankings
PNs), PRL's, TRL's, or IRL's value as a
ndalone value. Again concurring that all are
jective inputs that can be easily manipulated as
y are not values directly linked to physical
asures but are interpretations of data that can be
wed multiple ways. They are though the tools that
real world of Program Management uses to make
tical and strategically choices. It is the province
the PM and his staff to interpret the available data
l make the best choice possible in an imperfect
rld where accurate data and the ability to predict
ure occurrence precisely seldom
st....."

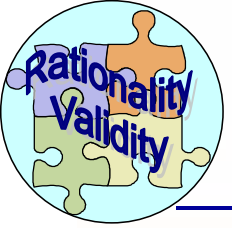
B. SAUSER & CO. SRL TRUMPING RATIONALITY AND VALIDITY!

Flawed ratings: Déjà vu



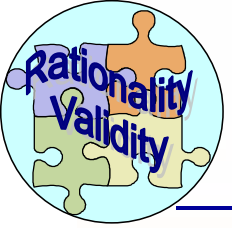
The Doomsday Machine

- “ that average number. And herein lay a huge
  nom had a score of 615 was far less likely to
  mposed of borrowers half of whom had FICO
  scores of 680….”
- “ s entire industry was trusting in the ratings,”
  tings, so they didn’t have to think about it.”…”
- “ aracteristics – the average FICO scores, the
  number of no-doc loan, and so forth – but no
- “ ces suggesting that the rating agencies had
  Grant, along with his trusted assistant, was
  were actually summoned to the rating agency
  s Gertner. “Jim used the term “alchemy” and
  they didn’t like that term. …



Takeaways (1 of 2)

- System readiness (capability, maturity) is too complex a concept to be described by a single number on the interval (0, 1].
- It is necessary to be wary of performing matrix algebra on ordinal information. The B. Sauser & Co. SRL is at best CABI!
- The B. Sauser & Co. SRL is an attractively deceitful model
  - It aggregates technology readiness/maturity scores and therefore it hides important information.
  - It provides invalid and therefore worse than useless information.
  - It removes a degree of decision-making from the acquisition process.
- Cease use of the B. Sauser & Co. SRL
  - Do it before it becomes too widespread and does serious harm.
- Implement quantitative risk analysis
  - Ensure successful acquisition based on performance, cost, & schedule risks for entering the acquisition life-cycle phase.



Takeaways (2 of 2)

- Managers need to build organizations that support good analysis
  - "The softer scoring methods and half-baked, hybrid deterministic methods are of no value – stop using them."
    D. W. Hubbard, The Failure of Risk Management, p. 202.
- Good analysis requires SE operational rationality
  - "It is our observation that much of system engineering practice suffers from a lack of rationality, while a significant body of system engineering *literature* suffers from an attempt to be excessively rational, at the expense of external correspondence (Occasionally practice also suffers from an attempt to be too rational)."
    D.P. Clausing and K. V. Katsikopoulos, Rationality in systems engineering: Beyond calculation or political action, Systems Engineering Volume 11, Issue 4, 2008, p. 309-328.

To those who funded, published, and/or used the B. Sauser & Co. SRL:

Be honest with yourselves! Admit that you have been duped!

Questions/Comments?