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hybrid event

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Case Studies for Complexity Pattern Identification

Authors

- **Andy Pickard, Rolls-Royce Corporation (retired)**
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- Dean Beale, Bristol University
- Dorothy McKinney, Lockheed Martin (retired)
- Rudolph Oosthuizen, University of Pretoria
- Dave Stewart, CACI
- Kenneth Cureton, University of Southern California
- Chandru Mirchandani, Leidos

Presenters

Andrew Pickard joined Rolls-Royce in 1977 after completing a Ph.D. at Cambridge University in Fatigue and Fracture of Metals and Alloys. He retired from Rolls-Royce at the end of 2022 after 45 years with the Company. He is a Rolls-Royce Associate Fellow in Systems Engineering, a Fellow of SAE International, a Fellow of the Institute of Materials, Minerals and Mining, a Chartered Engineer and a member of INCOSE. He is an Emeritus member and past Chair of the SAE Aerospace Council, and was Chief of Staff for INCOSE from 2016 to 2024

Richard Beasley worked at Rolls-Royce plc, predominantly in the Defence Aerospace area, from 1986 to May 2024. He joined with a BSc in Physics from Bristol University, and (as a part of RR professional development program) gained a MSc in Gas Turbine Engineering from Cranfield University.

Richard initially worked in Installation Aerodynamics, moving on to lead the UK Engine Stealth research program. He moved on (in 2001) to work in Safety, Reliability, Engine Health Monitoring, focusing on “design for service” and life cycle cost issues. Then in 2006 he moved on to start to lead an explicit focus on Systems Engineering implementation in Rolls-Royce, becoming a Rolls-Royce Associate Fellow in Systems Engineering in 2011.

Richard retired from Rolls-Royce in May 2024, and is now providing Systems advice via a sole-trading advisory company (RB Systems).

Richard has been a member of INCOSE since 2006, contributing to a range of technical products including the SEBoK (2012) and being a lead author on the first issue of the INCOSE SE Competency Framework (2018). He has served INCOSE as President of the UK Chapter (2014-16) and was the Director of Services on the main INCOSE Board (term finishing January 2024). Richard’s professional qualifications are both a (UK) CEng and the INCOSE ESEP. He was a visiting fellow at the Bristol University Systems Centre whilst it was operating.

AP

Agenda

- Purpose of Paper / Work
- Description of the Investigation Methodology
- Heuristics overview
- Overview of the Complexity Difficulty Assessment Tool (DAT)
- Summary of Case Studies
- Limitations of Analysis
- Outline of Results
- Observations (from exercise)
- Conclusions/Next Steps

RB

Purpose / Content of Paper

Initial investigation / assessment of the effectiveness and usefulness of the Difficulty Assessment Tool (DAT) developed by the INCOSE Complex Systems WG to help choose appropriate heuristics for complex situations

- Complex Systems WG selected 67 Principles and Heuristics relevant to complex systems, and developed the DAT to prioritize which most relevant
- We choose eight (existing) case studies to try to validate the tool
- Applied the DAT – in five separate assessment teams (using problem description of case study only)
- Correlated results from the separate teams
- Checked the relevance of the DAT recommended Complexity Principles and Heuristics (knowing outcome from case study)
- Made recommendations for further assessment of the DAT

Investigation Methodology

Eight Case Studies

Developing World Incubators	Foot and Mouth
Fuel Vent Valve	Product Lines
Scott & Amundsen	Steam Blast
Supplier Relationships	Turbine Tip Clearance

Assessors read Background

Case Study – Developing World Incubators

IS 2020 Paper 14 "How Systems Engineering and Systems Thinking Enable innovation"

Background

The majority of this material is taken from chapter 1 (The Adjacent Possible) of the book "where Good Ideas come from" (Johnson, 2010). An example of innovation given is the development of incubators for human babies.

The idea for an incubator came to Dr Stephane Tarnier (a Parisian obstetrician) when observing chicken egg incubators at the Paris Zoo in the 1880s. In the terms Johnson uses this was an "adjacent possible". The problem of infant mortality was clear and was a growing concern, and there was the technology in manufacturing available to make safe and reliable devices. The concept that was developed was highly effective. The death rate for low weight babies went from 66% to 38% if the baby was housed in Tarnier's box.

Throughout the 20th Century medical science and proactive continued to evolve the incubator concept. Supplemented with Oxygen therapy, they are standard equipment throughout the Western world. The uptake between 1950 and 1998 led to a 75% reduction in infant mortality in the USA. The benefit to public health, in terms of the sheer numbers of extra years of life provided (a baby that survives in an incubator for first few weeks of life goes on to live full life span), make incubators rival any other medical advance in 20th century for medical impact benefit

In the developing world there is still a bleak situation. In 2000 there were death rates approximately 100 / 1000 babies in countries like Ethiopia and Liberia. Modern Developed World Incubators are expensive and costly to maintain. In times of crisis the West is generous with medical donations. As a specific example after the 2004 tsunami, Meulaboh in Indonesia was donated 8 new, modern incubators. In 2008, whilst on a visit Dr Timothy Prospero found they were all out of order – humidity and an inability to understand the repair and operating manual were the root causes.

So something needed to be done – how could incubators be developed that were affordable, robust to the environment and easy to maintain for the developing world?

Assessors read Outcome

Solution / Outcome

The solution came from observing what could / was done in these developing countries. A Boston doctor, Jonathan Rosen, observed that in the developing world there was great expertise and ingenuity used to keep automobiles running for years and years. For this there was a level of technical / mechanical expertise available. So the idea was to make an incubator from car parts. This innovation (for example an incubator from NeoNature) used headlamps to provide warmth, dashboard fans to circulate the air, power via a motorcycle, and use of the local supply of spare parts and car repair know how. These were incubators that could be useful, and they remained available. The NeoNature incubator was included in Time's 2010 list of top 50 innovations (Park, 2010).

This is an example of innovation falling into the trap of thinking the context for a product is the same – and not recognising the different levels of mechanical support for an incubator – failure to understand / appreciate the collaborating and realisation systems for the product, and so not applying Systems Thinking to the reality / totality of the problem – so not avoiding typical traps that prevent successful innovation (Ingram and Beasley, 2020)

References

Johnson, S., 2010 Where Good ideas come from – The natural history of innovation, Riverhead books, New York, ISBN 9781594487712

Ingram, C., and Beasley, R., 2020, How Systems Engineering and Systems Thinking Enable innovation, INCOSE IS 2020 – Virtual Conference

Park, Alice, 2010, NeoNature Incubator NeoNurture Incubator - The 50 Best Inventions of 2010 - TIME (accessed 6th September 2011)

Assessors perform Heuristic Usefulness Assessment

Heuristic Usefulness - Developing World Incubators

A	B	C	D	E	Score
12	12	12	12	12	10
F	F		F	F	8
16	16	16	16	16	7
Principle 1	Principle 1	Principle 1	Principle 1	Principle 1	6
Principle 3		Principle 3	Principle 3		6
Principle 10		Principle 10	Principle 10	Principle 10	6
		8	8	8	6
Principle 2		Principle 2	Principle 2		4
Principle 6		Principle 6			4
Principle 8		Principle 8			4
11				11	4
13	13				4
22		22			4
		34		34	4
Principle 7		Principle 7			3
		21	21	21	3
		33		33	3
				B	2
	E				2
		G			2
	3				2
	4				2
	6				2
9	9			9	2
				10	2
	14				2
				24	2
	25				2
	31				2
	C4				2
		C15			2
Principle 9		Principle 9			1
	7				1
		19		19	1
					117

Heuristic Usefulness - Developing World Incubators

A	B	C	D	E	Score
E		E	E	E	-2
31		31	31	31	-2
	C10		C10		-2
	C9				-1
	C11				-1
	C13				-1
	Principle 3				0
	Principle 4				0
Principle 5	Principle 5	Principle 5	Principle 5	Principle 5	0
4		4	4	4	1
5		5	5	5	1
7		7	7	7	1
3		3	3	3	2
					-4

Assessors perform DAT Assessment

Heuristics

41 “complex” heuristics used in the initial case study screening & incorporated in the DAT tool

- Group 1 Top-down heuristics: The group of 7 Heuristics, A to G, were developed by considering founding principles of complexity and their implications for how to reduce or handle complexity.
- Group 2: Initial bottom-up heuristics; This group of 18 (1-18) heuristics were processed or inspired from searching the INCOSE Fellows heuristics database of 600+ heuristics using “complex” and “complexity” as search terms
- Group 3: Additional bottom-up heuristics: This group of 16 (19-34) heuristics were processed or inspired by searching the INCOSE Fellows heuristics database of 600+ heuristics using 32 search terms that were closely related to complex and complexity.

10 principles and 16 additional “complicated” heuristics added in the DAT tool

- Principles: A group of 10 principles developed by the “Bridge” team
- “Complicated” heuristics: A group of 16 (C1 - C16) heuristics were processed or inspired from searching the INCOSE Fellows heuristics database of 600+ heuristics using a number of search terms that were related to complicated and complicatedness but were equally applicable to complex and complexity

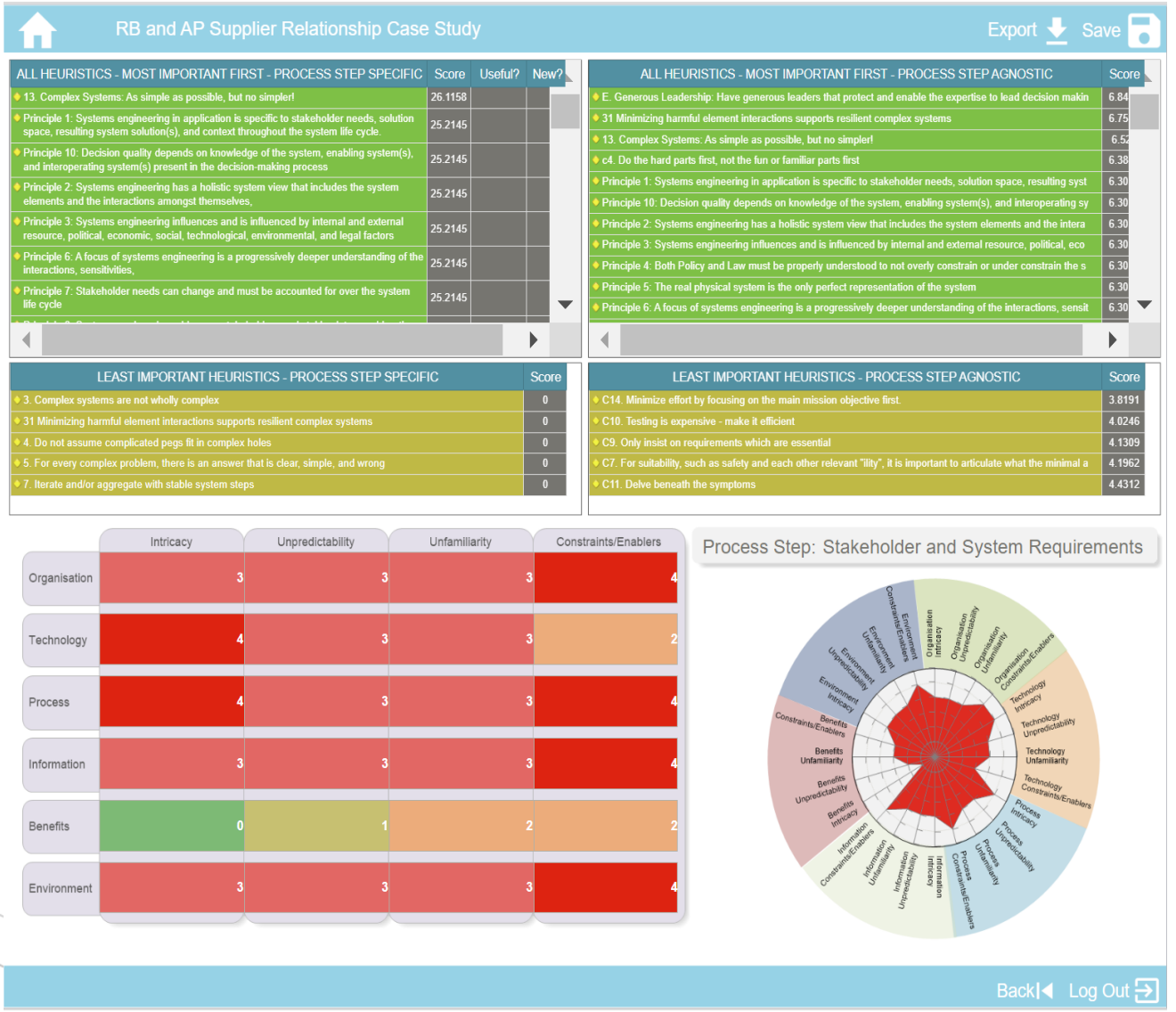
Heuristics

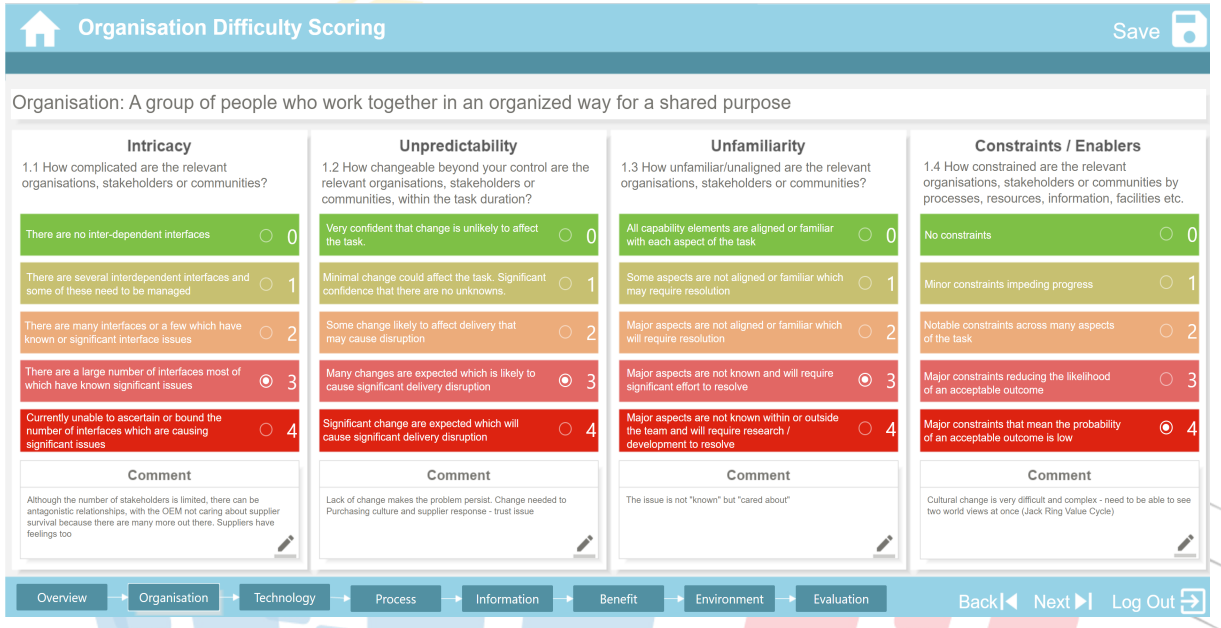
Group	#	Description	CSS?*	DAT?**	CC? ***
Group 1	7	Top-down heuristics: The group of 7 Heuristics, A to G, were developed by considering founding principles of complexity and their implications for how to reduce or handle complexity.	Yes	Yes	Blue
Group 2	18	Initial bottom-up heuristics; This group of 18 (1-18) heuristics were processed or inspired from searching the INCOSE Fellows heuristics database of 600+ heuristics using “complex” and “complexity” as search terms	Yes	Yes	Amber
Group 3	16	Additional bottom-up heuristics: This group of 16 (19-34) heuristics were processed or inspired by searching the INCOSE Fellows heuristics database of 600+ heuristics using 32 search terms that were closely related to complex and complexity.	Yes	Yes	Green
Principles	10	Based on the Principles established in the Bridge Study	No	Yes	Black
Complicated	16	Complicated System Heuristics that are equally applicable to complex systems were added to the 41 Complexity Heuristics	No	Yes	Grey

* Case Study Selection exercise ** Included in the Difficulty Assessment Tool (DAT) *** Color Code

Difficulty Assessment Tool

System Elements	Difficulty Elements: Intricacy	Unpredictability	Unfamiliarity	Constraints/Enablers
Organization	0	1	4	0
Technology	0	3	4	0
Process	0	3	4	0
Information	0	2	4	0
Benefits	0	3	4	0
Environment	0	4	4	0





Case Studies

Case Study	When	Heuristic A	B	C	D	E	F	G	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Count
Combustor Casing Design for Environment	IS 2008			Y																										Y													2
Detection of Software Flaws	IS 2010		Y						Y																																			2
Learned Hand Probabilistic Calculus	IS 2011																		Y								Y		Y														3
Handling Bleed Valve	IS 2011								Y			Y										Y											Y											4
Modulating Air System	IS 2011											Y										Y											Y											3
Aircraft Carrier Power Supply	IS 2011	?											Y											Y																				2
Standard Requirements Models	IS 2012		Y							Y																																	2
Incremental Software Builds	IS 2012		Y						Y																																		2
Steam Blast	IS 2012													Y							Y					Y																	Y	4
Detection of Software Flaws	IS 2013		Y						Y																																		2
Systems Engineering Competency Model	IS 2013																	Y						Y																			2
Do you understand the interfaces?*	IS 2014							Y		Y											Y									Y									Y				5
Change the component or the system?*	IS 2014		Y					Y				Y							Y			Y	Y										Y						Y				8
Scott and Amundsen - consequence of failed test!	IS 2014													Y										Y											Y						Y		4
Graves Model	IS 2015																										Y												Y	Y			3
Detection of Software Flaws	IS 2015		Y						Y																																		2
Process steps and order	IS 2015																						Y																				1
Foot and Mouth in the UK	IS 2015		Y	Y																	Y	Y																					4
UK Financial Crises	IS 2015													Y																													1
Sweet Spot - Implementing SE in a Company	IS 2016						?								Y		Y										Y							Y									4
Project Performance in a Company	IS 2018					Y																																					1
Walkie-Talkie Building	IS 2018		Y										Y															Y		Y													4
Heroic Failure	IS 2019					Y	Y																					Y															3
Supplier Relationships	IS 2019	Y											Y			Y						Y					Y																	5
Traps for Innovation	IS 2020	?				Y				Y						Y									Y						Y	Y											6
Developing World Incubators	IS 2020											Y							Y													Y											3
FADECs and Product Lines	IS 2020		Y					Y						Y	Y		Y					Y					Y								Y				Y				9
Piston Engine Igniters*	IS 2020													Y															Y		Y											3
Fuel Metering Unit*	IS 2020		Y																Y											Y												3
Vent Valve*	IS 2020									Y			Y	Y																	Y											4
Permanent Magnet Alternators*	IS 2020							Y						Y															Y													3
Disc Spin Testing	IS 2021																		Y									Y										?				2
Secondary Air System - Coupling	IS 2022							Y	Y													Y		Y										Y								5
* = Best Paper example		1	10	2	0	3	1	5	6	4	0	4	4	7	1	3	1	2	5	0	5	5	3	4	0	1	5	3	3	5	4	0	4	1	1	1	0	1	3	1	1	1	

Missing Heuristics: 15%

Case Study	When	Heuristic A	B	C	D	E	F	G	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Count
Steam Blast	IS 2012													Y							Y					Y																Y	4
Change the component or the system?*	IS 2014		Y					Y				Y							Y			Y	Y										Y						Y				8
Scott and Amundsen - consequence of failed test!	IS 2014													Y										Y											Y						Y		4
Foot and Mouth in the UK	IS 2015		Y	Y																	Y	Y																					4
Supplier Relationships	IS 2019	Y											Y			Y						Y					Y																	5
Third World Incubators	IS 2020											Y							Y													Y											3
FADECs and Product Lines	IS 2020		Y											Y	Y		Y					Y					Y								Y				Y				9
Vent Valve*	IS 2020									Y			Y	Y																	Y											4
* = Best Paper example		1	3	1	0	0	0	2	0	1	0	2	2	4	1	1	1	0	2	0	3	3	1	1	0	1	2	0	0	0	2	0	1	0	1	1	0	1	1	0	1	1

Missing Heuristics: 37%

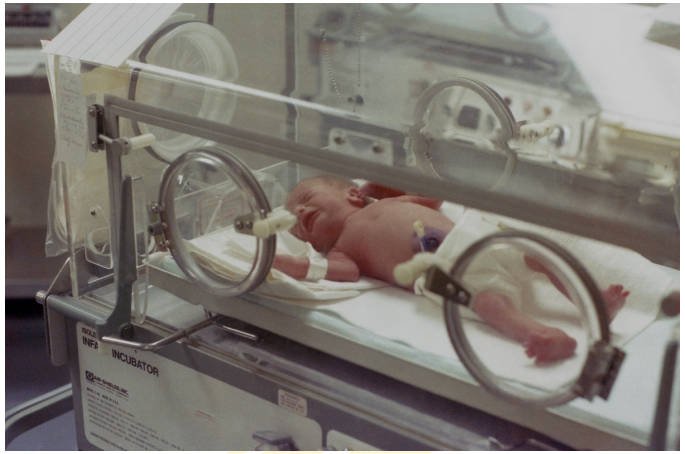
- Richard Beasley and Andy Pickard reviewed Rolls-Royce papers presented at INCOSE Symposia
- 33 potential case studies were identified
- The case studies were scored against the 41 Complex Systems Heuristics (groups 1 through 3)
- From these, 8 were selected based on coverage of the Heuristics and suitability for describing “Problem” and “Outcome”
- Problem and Outcome statements were written for these 8 selected Case Studies

Case Studies

#	Title	Origin
1	Developing World Incubators	The majority of this material is taken from Chapter 1 (The Adjacent Possible) of the book "Where Good Ideas Come From" (Johnson, 2010), which describes the development of incubators for human babies as an example of innovation. An extension to the paper by Ingram and Beasley, 2020 "How Systems Engineering and Systems Thinking Enable Innovation"
2	Foot and Mouth in the UK	This case study was addressed in a systems context in a paper describing different approaches to Systems Engineering needed depending on the type of systems situation (Kemp et al, 2015), with details taken from a subsequent UK National Audit report (Great Britain, 2002)
3	Fuel Vent Valve	This case study is from a paper looking at changes made to resolve problems on in-service products (Dunford and Pickard, 2020). In this outcome, it was determined that no technical change was actually required.
4	Product Lines	This case study is drawn from a paper looking at the application of product lines (Harper and Pickard, 2020).
5	Scott and Amundsen	The full background to this case study can be found in the Wikipedia article "Heroic Age of Antarctic Exploration" (Wikipedia, 2023).
6	Steam Blast	This case study originated in a paper on the Barriers to Systems Thinking (Beasley, 2012)
7	Supplier Relation-ships	This case study originated in a paper on Systems Engineering Professional Competencies (Beasley et al, 2019).
8	Turbine Tip Design	This case study is an example of "Yes" being the wrong answer to the question "can you change the system by changing only one part?" (Beasley et al, 2014).

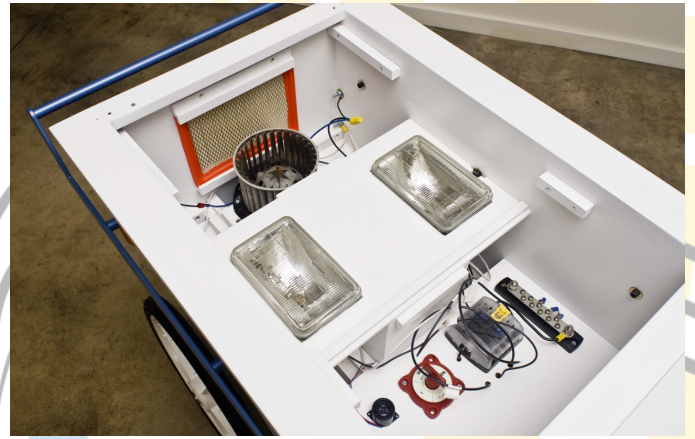
RB

Case Studies



Developing World Incubators

Foot and Mouth



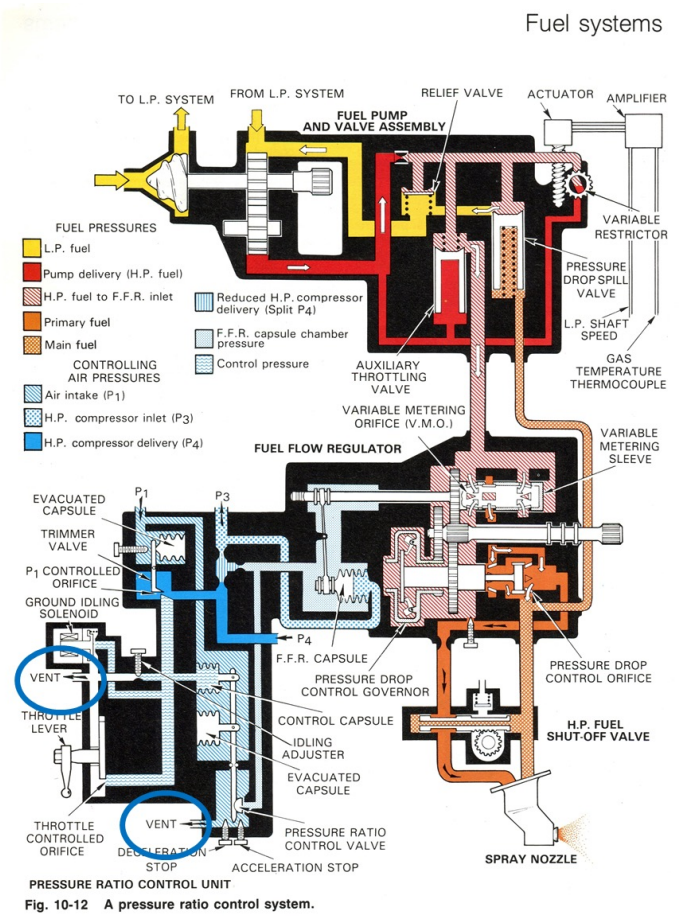


Fig. 10-12 A pressure ratio control system.

Fuel Vent Valve

Case Studies

Feature Model

Modular features and requirements

Selection rules - mandated, with allowable tailoring, optional (select 0 or more) or inclusive/exclusive (AND, OR)

Allowable data ranges

Instantiation Process

PL & application team roles

How to use the feature model

How to validate/verify application

Configuration control of PL & application

Assets

Reqts, design, code, test, safety etc

Correctness on Product Line

Completeness on Application

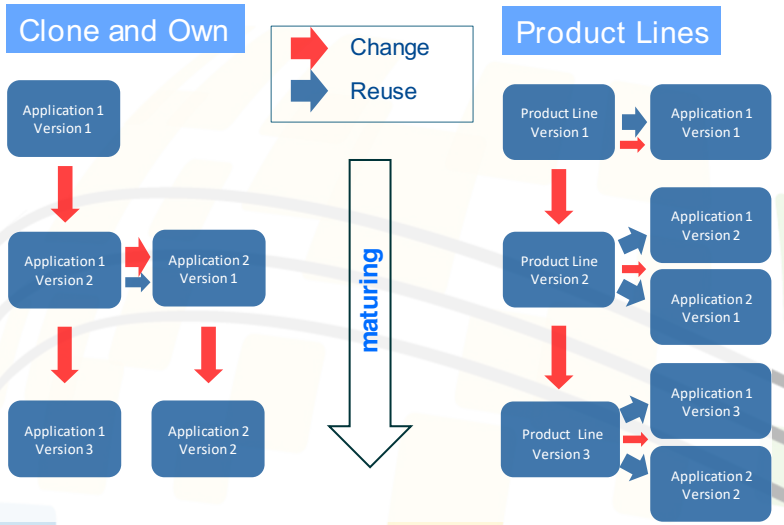
PL & application configured separately

Example

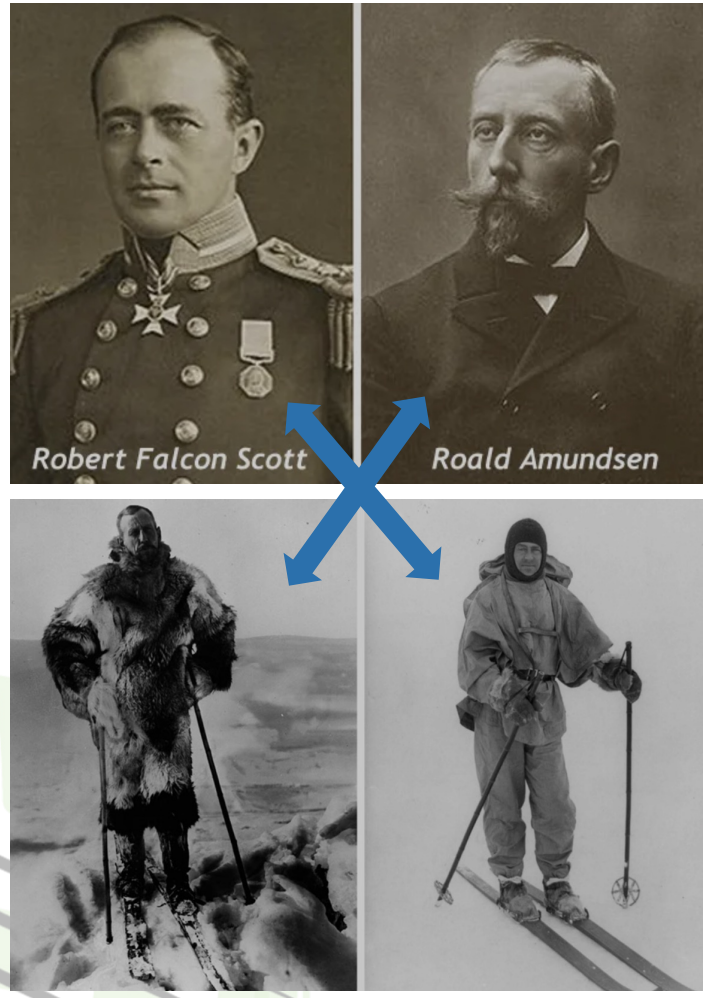
Single Hardware part number with input/output superset

i/o reconfigurable in layered s/w

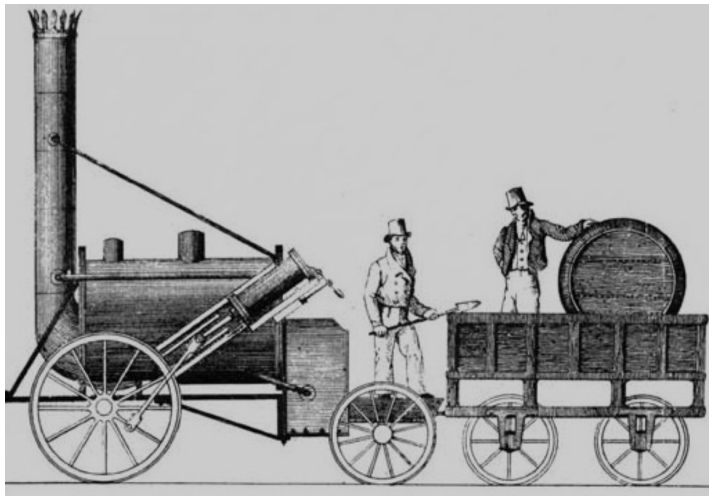
Product Line software with in-built variability (logic and data)



Product Lines

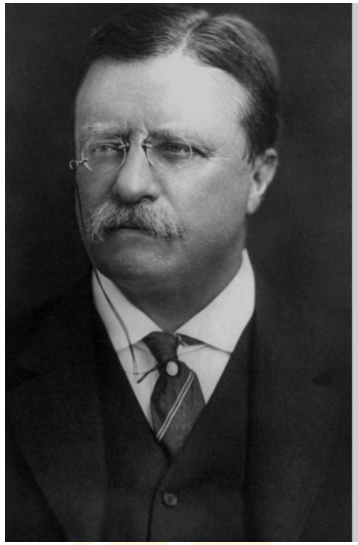


Scott and Amundsen



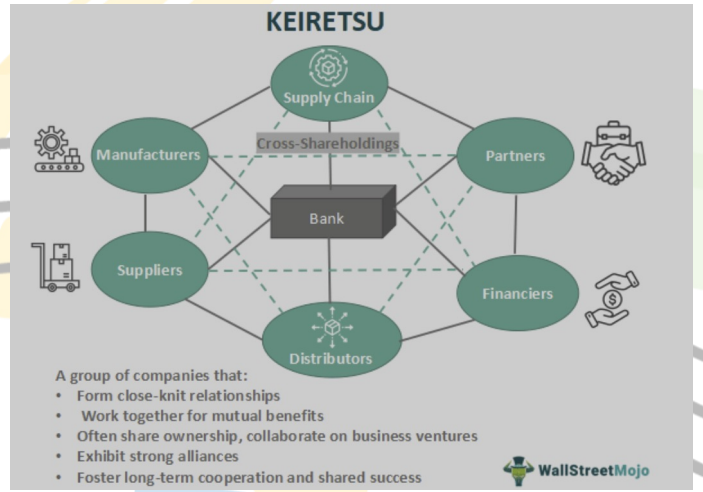
Steam Blast

Case Studies

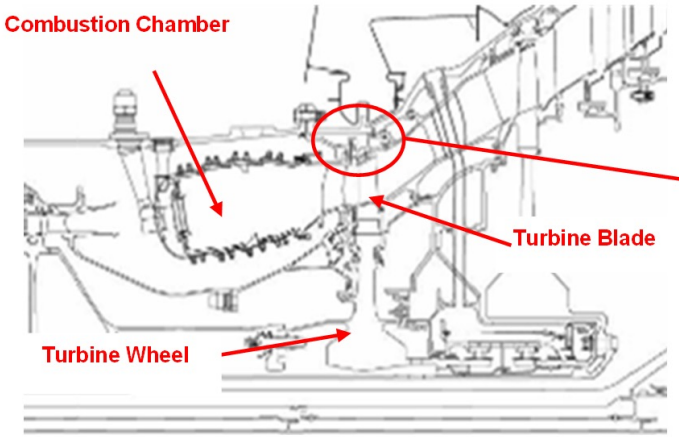


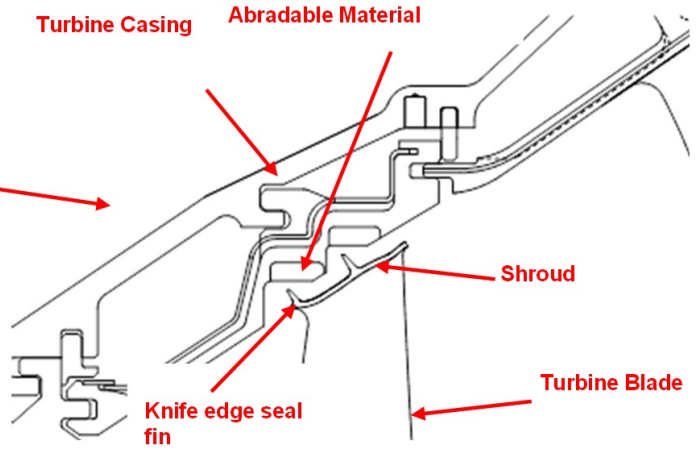
"Speak softly and carry a big stick; you will go far."

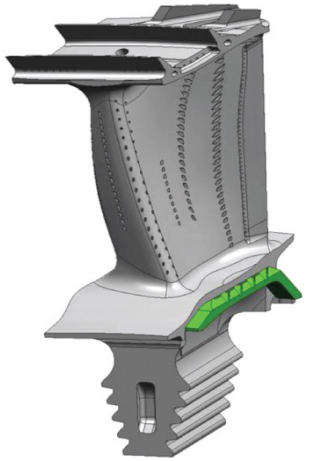
Theodore Roosevelt



Supplier Relationships







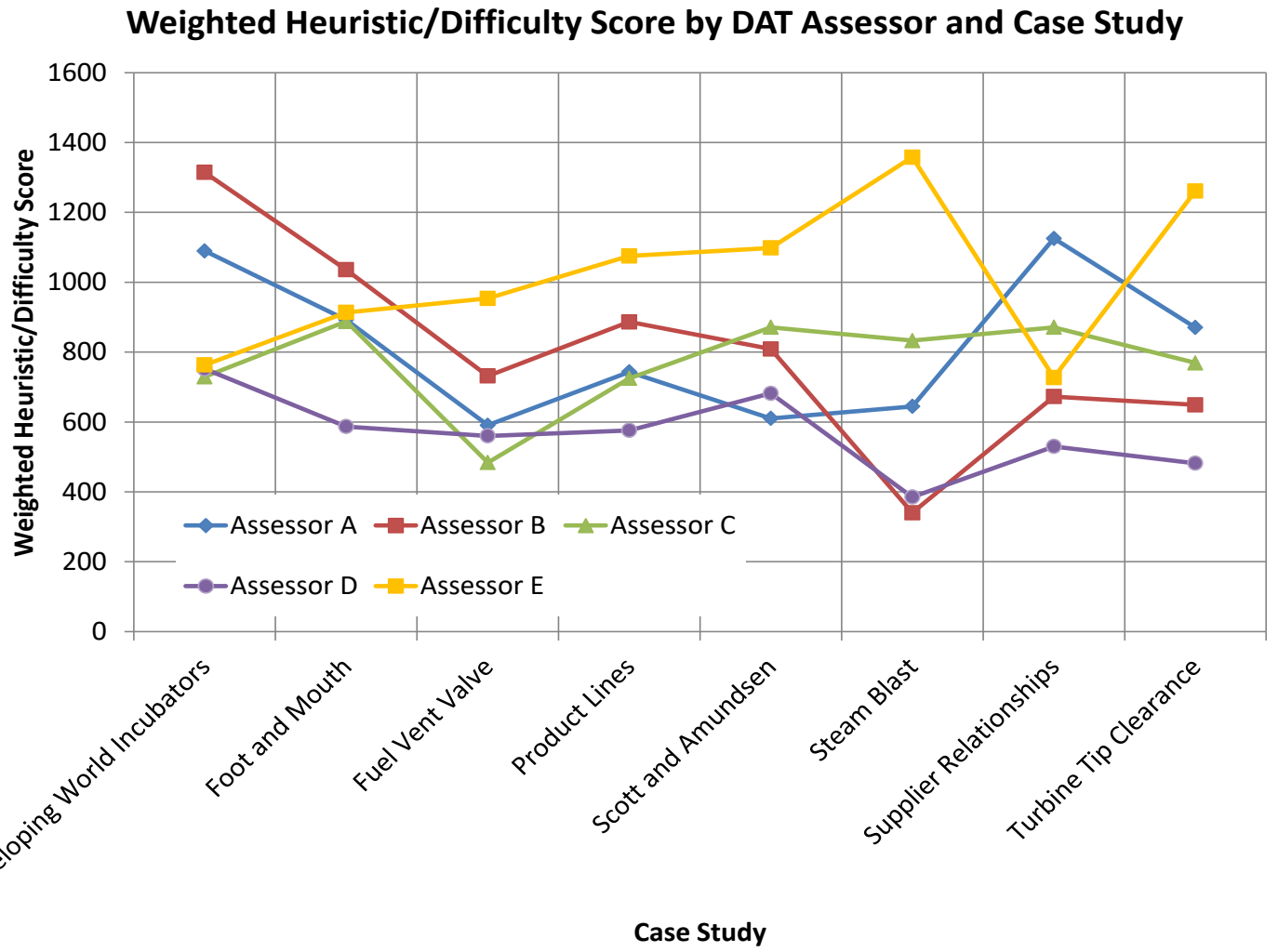
Turbine Tip Clearance

Limitations of the Analysis

Limitation	Impact	Opportunity
# of Assessments	Only 5 assessments of each Case Study	Perform additional assessments. Capture rationale for scoring of the DAT elements and add this to the analysis
# in Assessment Team	Only 2 team assessments; 3 were individual assessments. Too few to be able to separate out the impact of assessment team size	Encourage more multi-participant teams to perform assessments
Familiarity	One team was more familiar with the case studies and was working with hindsight	Encourage more teams and individuals to perform assessments
Interpretation	Two of the case studies are reflections of events rather than classic Systems Engineering activities; the questions in the DAT had to be interpreted	Potential to update the DAT to address “event” based assessments
Bias	Bias in the case studies selected based on the ability to describe them	Add more Case Studies to assess (see Addendum B for an example)

Assessment Method 1: Comparison of the sum of the weightings

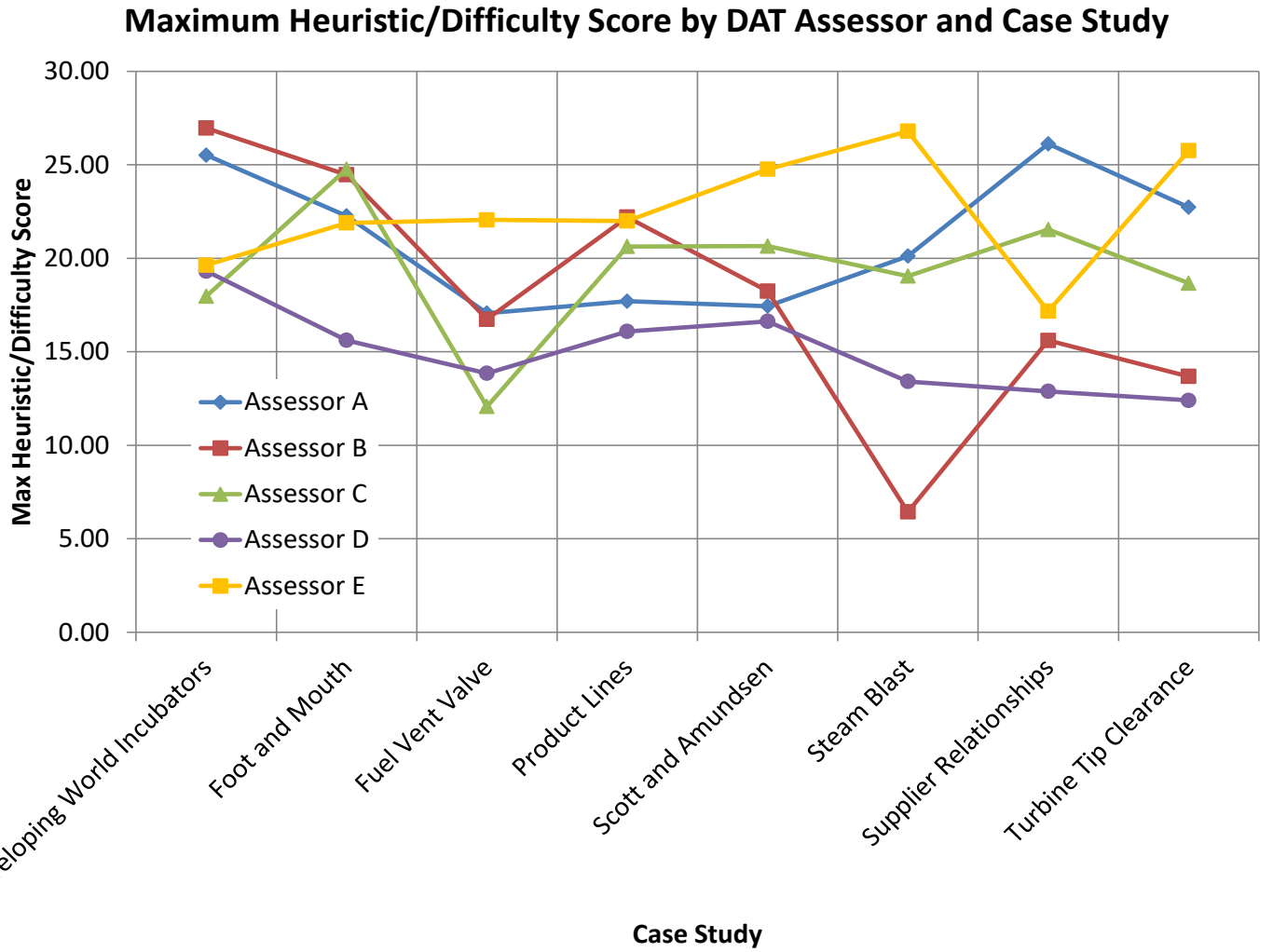
A	A	B	B	C	C	D	D	E	E
13	26.1158	C3	15.607	19	21.5429	Principle 1	12.8755	Principle 1	17.167
Principle 1	25.2145	Principle 1	15.0214	8	21.4592	Principle 10	12.8755	Principle 10	17.167
Principle 10	25.2145	Principle 10	15.0214	21	20.8515	Principle 2	12.8755	Principle 2	17.167
Principle 2	25.2145	Principle 2	15.0214	33	20.6861	Principle 3	12.8755	Principle 3	17.167
Principle 3	25.2145	Principle 3	15.0214	12	20.5718	Principle 6	12.8755	Principle 6	17.167
Principle 6	25.2145	Principle 6	15.0214	10	19.9670	Principle 7	12.8755	Principle 7	17.167
Principle 7	25.2145	Principle 7	15.0214	24	19.9670	Principle 8	12.8755	Principle 8	17.167
Principle 8	25.2145	Principle 8	15.0214	16	19.7837	Principle 9	12.8755	Principle 9	17.167
Principle 9	25.2145	Principle 9	15.0214	34	19.7678	22	11.6083	21	16.932
16	24.3629	G	14.827	9	19.3133	2	11.5842	9	16.738
C3	24.2532	22	14.7055	2	18.8603	G	11.5823	16	16.702
9	23.8197	12	14.2916	G	18.7444	19	11.536	12	16.581
12	23.8099	9	14.1631	Principle 1	18.5085	33	11.4888	33	15.979
21	23.6938	33	14.1222	Principle 10	18.5085	12	11.0534	13	15.951
22	23.4928	16	13.8458	Principle 2	18.5085	9	10.9442	19	15.65
33	23.2108	2	13.8307	Principle 3	18.5085	10	10.8842	10	15.1
F	23.0266	21	13.6219	Principle 6	18.5085	24	10.8842	24	15.1
10	22.8156	19	13.5001	Principle 7	18.5085	21	10.7554	8	15.021
24	22.8156	13	13.3862	Principle 8	18.5085	34	10.7024	tion, prioritiz	15.013
B	22.729	10	13.2987	Principle 9	18.5085	C3	10.5649	11	14.987
G	22.4412	24	13.2987	22	18.1686	C11	10.3813	G	14.972
19	22.0262	34	12.8826	F	17.8559	16	10.3764	22	14.291
11	21.9969	28	12.7487	B	17.3394	28	10.1276	F	14.129
34	21.8306	C15	12.6465	28	16.2961	B	9.7453	B	13.788
8	21.4592	B	12.5972	C15	16.2751	C14	9.7434	C15	13.725
C1	21.2987	C2	12.5792	6	16.0944	C15	9.7053	2	13.205
C15	21.0482	C1	12.4063	11	16.0876	8	9.6566	C3	13.058
C12	20.6922	F	12.0992	C14	15.1302	Principle 4	9.6566	C16	12.988
26	20.6071	C12	11.9514	20	14.6052	C2	9.2849	Principle 4	12.876
2	20.074	11	11.9306	17	14.5994	C16	9.2082	C14	12.639
C16	19.9926	8	11.8025	C16	14.4664	C12	9.0895	28	12.615
C2	19.3042	C16	11.6125	26	14.4284	6	8.8519	14	12.482
C4	19.1645	Principle 4	11.2661	29	14.4284	C1	8.8001	6	12.473
Principle 4	18.9109	C14	11.1461	A	14.4284	F	8.6452	20	12.454
6	18.1062	C11	11.053	C11	14.3926	C7	8.5031	C1	11.342
14	18.0873	6	10.8637	D	14.2897	26	8.3893	26	11.335
C11	17.7246	C4	10.713	C12	13.9151	29	8.3893	29	11.335
25	17.0125	17	10.4979	Principle 4	13.8814	A	8.3893	A	11.335
26	16.9942	C5	10.3293	C1	13.7420	17	8.3783	17	11.297
29	16.9942	26	10.3199	25	13.5085	11	8.0674	C12	11.184
A	16.9942	29	10.3199	13	12.6356	D	7.9898	25	10.747
20	16.9146	A	10.3199	C3	12.0605	20	7.8421	D	10.109
17	16.8982	C7	10.2759	14	11.4452	13	7.7461	C4	9.8711
C5	16.7862	C9	10.2357	C2	11.0360	C9	7.4515	C11	9.8645
C7	16.7846	20	10.1447	C7	10.3515	C8	7.3101	C5	9.8519
C9	16.5236	C6	10.0447	C4	10.3498	C6	6.9099	C2	9.1638
C8	16.1437	C8	9.6021	C9	10.3419	C4	6.7843	C6	8.8255
D	15.6731	D	9.4498	C5	10.1030	C5	6.7079	C9	8.5187
C14	15.2764	14	9.2634	30	9.7453	25	6.6721	30	8.206
C6	14.7638	15	9.0056	C6	9.6972	30	5.5631	C7	8.0228
15	11.3843	30	7.1024	C8	9.5478	32	5.522	15	7.7323
C13	11.3717	15	7.048	32	9.5436	15	5.5061	32	7.5906
30	11.2222	C13	6.9824	15	9.4937	14	5.4007	C8	7.3364
32	11.023	32	6.9154	1	9.0870	C13	5.1046	1	6.8743
1	10.7047	1	6.1248	C13	8.4084	1	4.9553	C13	6.8193
C	5.66	18	3.4815	18	5.3459	18	2.9379	18	4.0193
18	5.5715	C	3.4243	C	4.9484	C	2.7768	C	3.8498
23	5.1304	23	3.1987	27	4.8275	27	2.7147	23	3.5152
27	4.7106	27	3.0041	23	4.5706	23	2.5792	27	3.2987
C10	4.0246	C10	2.7652	C10	3.5856	C10	2.3724	C10	2.5651
3	0	3	0	3	0	3	0	3	0
31	0	31	0	31	0	31	0	31	0
4	0	4	0	4	0	4	0	4	0
5	0	5	0	5	0	5	0	5	0
7	0	7	0	7	0	7	0	7	0
E	0	E	0	E	0	E	0	E	0
Principle 5	0	Principle 5	0	Principle 5	0	Principle 5	0	Principle 5	0
Total:	1125.19	Total:	672.82	Total:	870.64	Total:	530.83		727.4



Assessment Method 2: Comparison of the Highest Weightings

AP

13	26.1158	C3	15.607	19	21.5429	Principle 1	12.8755	Principle 1	17.167
Principle 10	25.2145	Principle 10	15.0214	21	20.8515	Principle 2	12.8755	Principle 2	17.167
Principle 2	25.2145	Principle 2	15.0214	33	20.6861	Principle 3	12.8755	Principle 3	17.167
Principle 3	25.2145	Principle 3	15.0214	12	20.5718	Principle 6	12.8755	Principle 6	17.167
Principle 6	25.2145	Principle 6	15.0214	10	19.9670	Principle 7	12.8755	Principle 7	17.167
Principle 7	25.2145	Principle 7	15.0214	24	19.9670	Principle 8	12.8755	Principle 8	17.167
Principle 8	25.2145	Principle 8	15.0214	16	19.7837	Principle 9	12.8755	Principle 9	17.167
Principle 9	25.2145	Principle 9	15.0214	34	19.7678	22	11.6083	21	16.932
16	24.3629	G	14.827	9	19.3133	2	11.5842	9	16.738
C3	24.2532	22	14.7055	2	18.8603	G	11.5823	16	16.702
9	23.8197	12	14.2916	G	18.7444	19	11.536	12	16.581
12	23.8099	9	14.1631	Principle 1	18.5085	33	11.4888	33	15.979
21	23.6938	33	14.1222	Principle 10	18.5085	12	11.0534	13	15.951
22	23.4928	16	13.8458	Principle 2	18.5085	9	10.9442	19	15.65
33	23.2108	2	13.8307	Principle 3	18.5085	10	10.8842	10	15.1
F	23.0266	21	13.6219	Principle 6	18.5085	24	10.8842	24	15.1
10	22.8156	19	13.5001	Principle 7	18.5085	21	10.7554	8	15.021
24	22.8156	13	13.3862	Principle 8	18.5085	34	10.7024	tion, prioritiz	15.013
B	22.729	10	13.2987	Principle 9	18.5085	C3	10.5649	11	14.987
G	22.4412	24	13.2987	22	18.1686	C11	10.3813	G	14.972
19	22.0262	34	12.8826	F	17.8559	16	10.3764	22	14.291
11	21.9969	28	12.7487	B	17.3394	28	10.1276	F	14.129
34	21.8306	C15	12.6465	28	16.2961	B	9.7453	B	13.788
8	21.4592	B	12.5972	C15	16.2751	C14	9.7434	C15	13.725
C1	21.2987	C2	12.5792	6	16.0944	C15	9.7053	2	13.205
C15	21.0482	C1	12.4063	11	16.0876	8	9.6566	C3	13.058
C12	20.6922	F	12.0992	C14	15.1302	Principle 4	9.6566	C16	12.988
26	20.6071	C12	11.9514	20	14.6052	C2	9.2849	Principle 4	12.876
2	20.074	11	11.9306	17	14.5994	C16	9.2082	C14	12.639
C16	19.9926	8	11.8025	C16	14.4664	C12	9.0895	28	12.615
C2	19.3042	C16	11.6125	26	14.4284	6	8.8519	14	12.482
C4	19.1645	Principle 4	11.2661	29	14.4284	C1	8.8001	6	12.473
Principle 4	18.9109	C14	11.1461	A	14.4284	F	8.6452	20	12.454
6	18.1062	C11	11.053	C11	14.3926	C7	8.5031	C1	11.342
14	18.0873	6	10.8637	D	14.2897	26	8.3893	26	11.335
C11	17.7246	C4	10.713	C12	13.9151	29	8.3893	29	11.335
25	17.0125	17	10.4979	Principle 4	13.8814	A	8.3893	A	11.335
26	16.9942	C5	10.3293	C1	13.7420	17	8.3783	17	11.297
29	16.9942	26	10.3199	25	13.5085	11	8.0674	C12	11.184
A	16.9942	29	10.3199	13	12.6356	D	7.9898	25	10.747
20	16.9146	A	10.3199	C3	12.0605	20	7.8421	D	10.109
17	16.8982	C7	10.2759	14	11.4452	13	7.7461	C4	9.8711
C5	16.7862	C9	10.2357	C2	11.0360	C9	7.4515	C11	9.8645
C7	16.7846	20	10.1447	C7	10.3515	C8	7.3101	C5	9.8519
C9	16.5236	C6	10.0447	C4	10.3498	C6	6.9099	C2	9.1638
C8	16.1437	C8	9.6021	C9	10.3419	C4	6.7843	C6	8.8255
D	15.6731	D	9.4498	C5	10.1030	C5	6.7079	C9	8.5187
C14	15.2764	14	9.2634	30	9.7453	25	6.6721	30	8.206
C6	14.7638	15	9.0056	C6	9.6972	30	5.5631	C7	8.0228
15	11.3843	30	7.1024	C8	9.5478	32	5.522	15	7.7323
C13	11.3717	15	7.048	32	9.5436	15	5.5061	32	7.5906
30	11.2222	C13	6.9824	15	9.4937	14	5.4007	C8	7.3364
32	11.023	32	6.9154	1	9.0870	C13	5.1046	1	6.8743
1	10.7047	1	6.1248	C13	8.4084	1	4.9553	C13	6.8193
C	5.66	18	3.4815	18	5.3459	18	2.9379	18	4.0193
18	5.5715	C	3.4243	C	4.9484	C	2.7768	C	3.8498
23	5.1304	23	3.1987	27	4.8275	27	2.7147	23	3.5152
27	4.7106	27	3.0041	23	4.5706	23	2.5792	27	3.2987
C10	4.0246	C10	2.7652	C10	3.5856	C10	2.3724	C10	2.5651
3	0	3	0	3	0	3	0	3	0
31	0	31	0	31	0	31	0	31	0
4	0	4	0	4	0	4	0	4	0
5	0	5	0	5	0	5	0	5	0
7	0	7	0	7	0	7	0	7	0
E	0	E	0	E	0	E	0	E	0
Principle 5	0	Principle 5	0	Principle 5	0	Principle 5	0	Principle 5	0
Total:	1125.19	Total:	672.82	Total:	870.64	Total:	530.83		727.4



Assessment Method 3: Match – Mismatch Analysis

AP

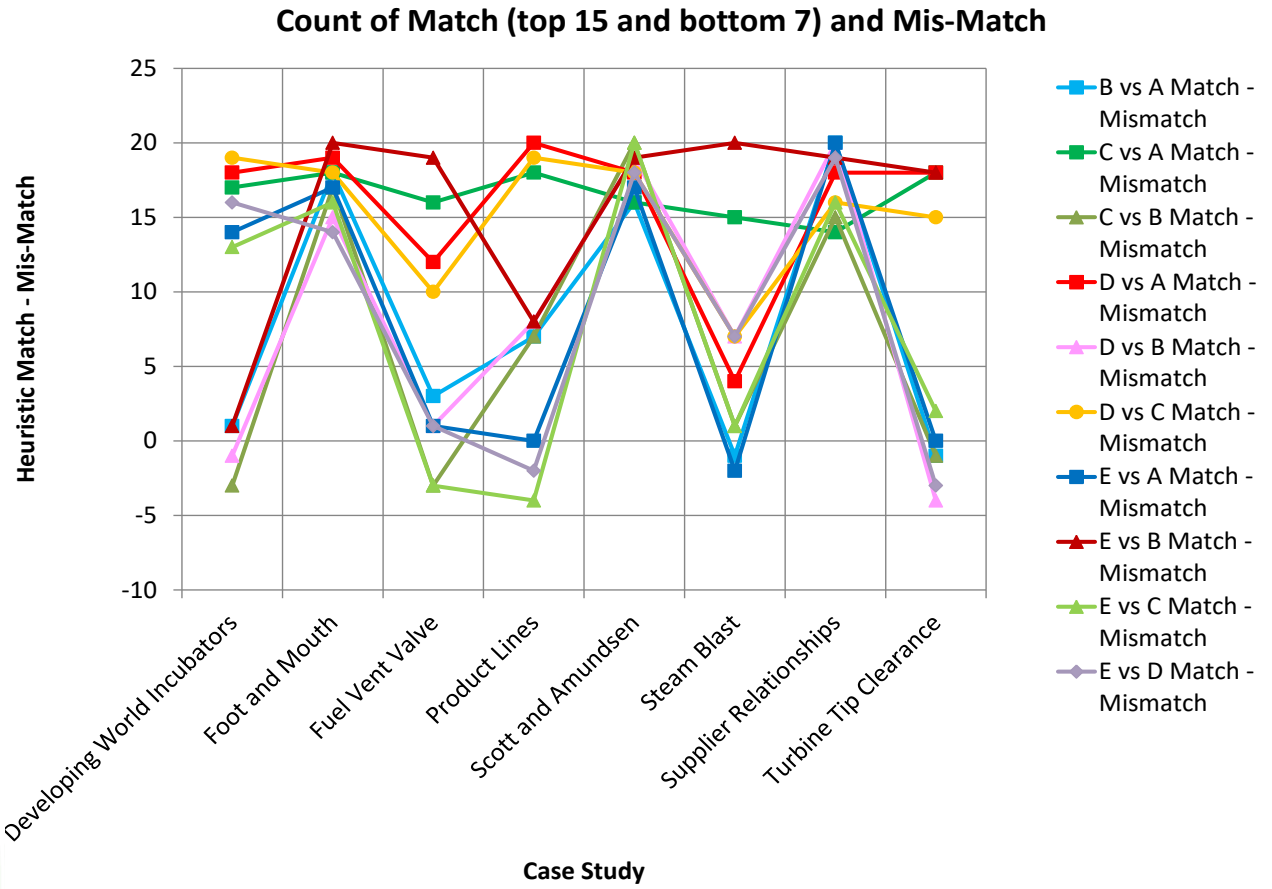
Example Match – Mismatch Matrix for Developing World Incubators

The score is Σ(matches) – Σ(mismatches)

A	A - B	B	B - A	C	A - C	C - A	B - C	C - B	D	A - D	D - A	B - D	D - B	C - D	D - C	E	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
13	A - B	E	B - A	Principle 1	A - C	C - A	B - C	C - B	8	A - D	D - A	B - D	D - B	C - D	D - C	12	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 1	A - B	C4	B - A	Principle 10	A - C	C - A	B - C	C - B	F	A - D	D - A	B - D	D - B	C - D	D - C	10	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 10	A - B	13	B - A	Principle 2	A - C	C - A	B - C	C - B	21	A - D	D - A	B - D	D - B	C - D	D - C	24	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 2	A - B	14	B - A	Principle 3	A - C	C - A	B - C	C - B	16	A - D	D - A	B - D	D - B	C - D	D - C	33	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 3	A - B	16	B - A	Principle 6	A - C	C - A	B - C	C - B	12	A - D	D - A	B - D	D - B	C - D	D - C	19	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 6	A - B	F	B - A	Principle 7	A - C	C - A	B - C	C - B	Principle 1	A - D	D - A	B - D	D - B	C - D	D - C	9	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 7	A - B	3	B - A	Principle 8	A - C	C - A	B - C	C - B	Principle 10	A - D	D - A	B - D	D - B	C - D	D - C	16	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 8	A - B	4	B - A	Principle 9	A - C	C - A	B - C	C - B	Principle 2	A - D	D - A	B - D	D - B	C - D	D - C	21	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 9	A - B	9	B - A	8	A - C	C - A	B - C	C - B	Principle 3	A - D	D - A	B - D	D - B	C - D	D - C	F	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
F	A - B	6	B - A	21	A - C	C - A	B - C	C - B	Principle 6	A - D	D - A	B - D	D - B	C - D	D - C	11	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
16	A - B	7	B - A	19	A - C	C - A	B - C	C - B	Principle 7	A - D	D - A	B - D	D - B	C - D	D - C	34	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
12	A - B	12	B - A	16	A - C	C - A	B - C	C - B	Principle 8	A - D	D - A	B - D	D - B	C - D	D - C	8	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
9	A - B	25	B - A	G	A - C	C - A	B - C	C - B	Principle 9	A - D	D - A	B - D	D - B	C - D	D - C	B	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
22	A - B	31	B - A	12	A - C	C - A	B - C	C - B	10	A - D	D - A	B - D	D - B	C - D	D - C	Principle 1	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
11	A - B	Principle 1	B - A	22	A - C	C - A	B - C	C - B	24	A - D	D - A	B - D	D - B	C - D	D - C	Principle 10	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D

A	A - B	B	B - A	C	A - C	C - A	B - C	C - B	D	A - D	D - A	B - D	D - B	C - D	D - C	E	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
3	A - B	Principle 3	B - A	3	A - C	C - A	B - C	C - B	3	A - D	D - A	B - D	D - B	C - D	D - C	3	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
31	A - B	Principle 4	B - A	31	A - C	C - A	B - C	C - B	31	A - D	D - A	B - D	D - B	C - D	D - C	31	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
4	A - B	C13	B - A	4	A - C	C - A	B - C	C - B	4	A - D	D - A	B - D	D - B	C - D	D - C	4	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
5	A - B	C10	B - A	5	A - C	C - A	B - C	C - B	5	A - D	D - A	B - D	D - B	C - D	D - C	5	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
7	A - B	C11	B - A	7	A - C	C - A	B - C	C - B	7	A - D	D - A	B - D	D - B	C - D	D - C	7	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
E	A - B	C9	B - A	E	A - C	C - A	B - C	C - B	E	A - D	D - A	B - D	D - B	C - D	D - C	E	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D
Principle 5	A - B	Principle 5	B - A	Principle 5	A - C	C - A	B - C	C - B	Principle 5	A - D	D - A	B - D	D - B	C - D	D - C	Principle 5	A - E	E - A	B - E	E - B	C - E	E - C	D - E	E - D

	A vs B	A vs C	B vs C	A vs D	B vs D	C vs D	A vs E	B vs E	C vs E	D vs E
Top	6	10	2	11	4	12	7	5	6	9
Bottom	1	7	1	7	1	7	7	1	7	7
Contra	6	0	6	0	6	0	0	5	0	0
No Match	9	5	13	4	11	3	8	11	9	6
Total	22	22	22	22	22	22	22	22	22	22
Score	1	17	-3	18	-1	19	14	1	13	16

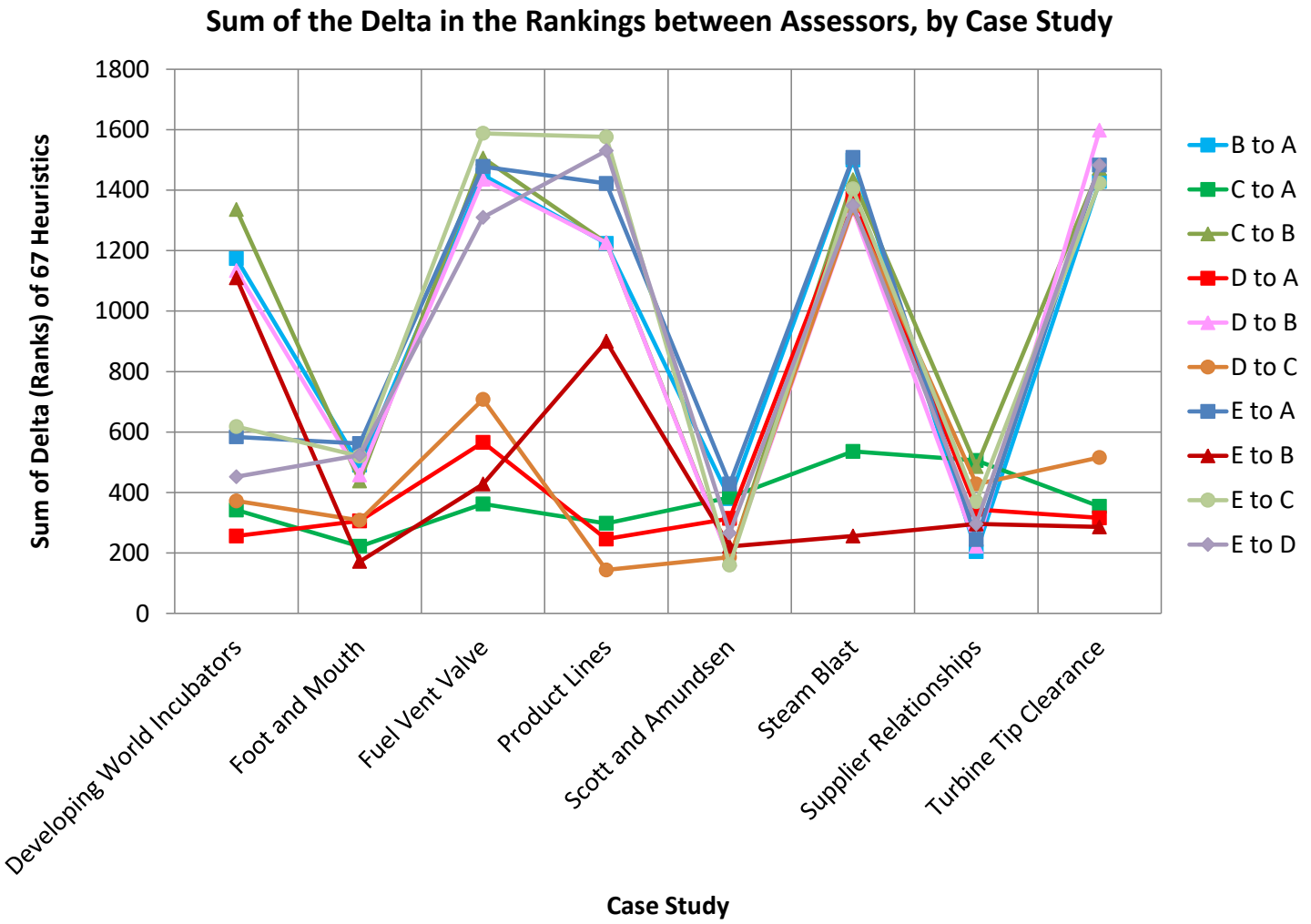


Assessment Method 4: Sum of Delta (Rankings) between Assessor Pairs

AP

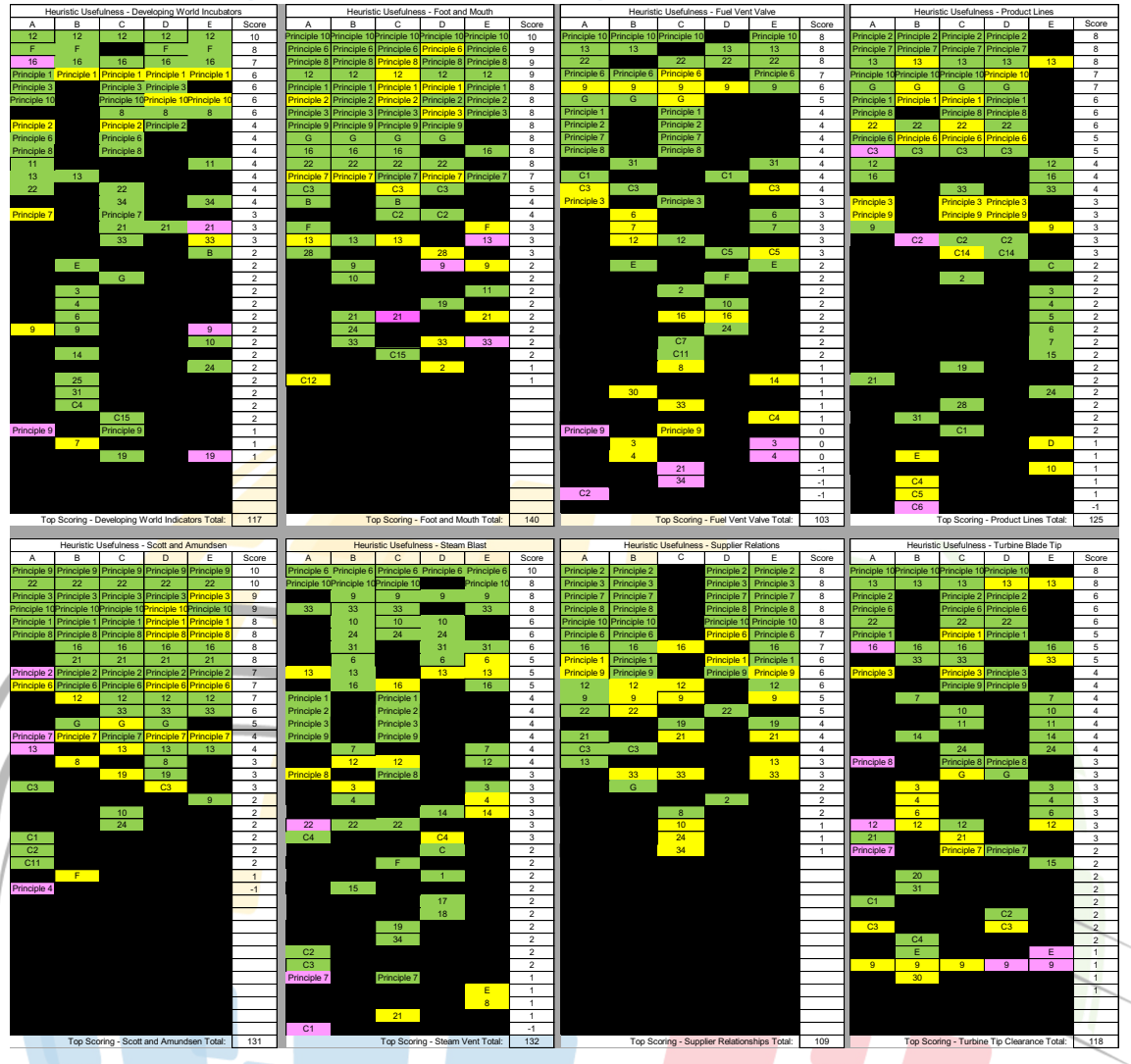
Foot and Mouth									
A		B		C		D		E	
Principle 1	1	9	1	C3	1	C3	1	9	1
Principle 10	2	16	2	13	2	Principle 1	2	21	2
Principle 2	3	12	3	22	3	Principle 10	3	16	3
Principle 3	4	13	4	Principle 1	4	Principle 2	4	12	4
Principle 6	5	33	5	Principle 10	5	Principle 3	5	13	5
Principle 7	6	21	6	Principle 2	6	Principle 6	6	11	6
Principle 8	7	Principle 1	7	Principle 3	7	Principle 7	7	33	7
Principle 9	8	Principle 10	8	Principle 6	8	Principle 8	8	F	8
C3	9	Principle 2	9	Principle 7	9	Principle 9	9	Principle 1	9
13	10	Principle 3	10	Principle 8	10	22	10	Principle 10	10
22	11	Principle 6	11	Principle 9	11	G	11	Principle 2	11
G	12	Principle 7	12	C2	12	2	12	Principle 3	12
16	13	Principle 8	13	G	13	28	13	Principle 6	13
28	14	Principle 9	14	16	14	19	14	Principle 7	14
12	15	10	15	C15	15	C2	15	Principle 8	15
F	16	24	16	12	16	33	16	Principle 9	16
B	17	G	17	B	17	9	17	19	17
C12	18	22	18	21	18	12	18	10	18
C2	19	11	19	C1	19	13	19	24	19
33	20	F	20	33	20	21	20	22	20
2	21	34	21	C12	21	C15	21	G	21
C1	22	19	22	19	22	Principle 4	22	B	22
9	23	8	23	28	23	10	23	8	23
C16	24	B	24	C16	24	24	24	34	24
Principle 4	25	2	25	34	25	16	25	28	25
C15	26	C3	26	F	26	C14	26	2	26
11	27	C1	27	C4	27	B	27	C15	27
10	28	C15	28	2	28	34	28	14	28
24	29	C12	29	10	29	C11	29	C1	29
C11	30	28	30	24	30	C1	30	6	30
21	31	C16	31	9	31	C12	31	20	31
34	32	6	32	8	32	C16	32	C16	32
C4	33	14	33	11	33	C4	33	Principle 4	33
C9	34	C2	34	C11	34	C6	34	25	34
C8	35	20	35	C5	35	F	35	C4	35
C5	36	Principle 4	36	Principle 4	36	C5	36	C3	36
14	37	C14	37	C8	37	11	37	C12	37
19	38	17	38	C7	38	6	38	C14	38
C7	39	26	39	C6	39	26	39	17	39
C6	40	29	40	14	40	29	40	26	40
6	41	A	41	6	41	A	41	29	41
8	42	C9	42	26	42	17	42	A	42
26	43	C4	43	29	43	8	43	D	43
29	44	25	44	A	44	20	44	C5	44
A	45	D	45	20	45	D	45	C2	45
C14	46	C11	46	C9	46	C9	46	C11	46
17	47	C5	47	17	47	C8	47	C9	47
25	48	C7	48	C14	48	C7	48	C6	48
20	49	C6	49	25	49	14	49	C8	49
D	50	C8	50	D	50	25	50	30	50
C13	51	30	51	C13	51	15	51	15	51
30	52	15	52	30	52	C13	52	1	52
15	53	32	53	15	53	30	53	C7	53
32	54	1	54	32	54	32	54	32	54
1	55	C13	55	1	55	1	55	C13	55
C	56	18	56	18	56	18	56	C	56
C10	57	C	57	C	57	C	57	18	57
18	58	23	58	23	58	23	58	23	58
23	59	27	59	27	59	C10	59	27	59
27	60	C10	60	C10	60	27	60	C10	60
3	61	3	61	3	61	3	61	3	61
31	62	31	62	31	62	31	62	31	62
4	63	4	63	4	63	4	63	4	63
5	64	5	64	5	64	5	64	5	64
7	65	7	65	7	65	7	65	7	65
E	66	E	66	E	66	E	66	E	66
Principle 5	67	Principle 5	67	Principle 5	67	Principle 5	67	Principle 5	67

B to A Gap			C to A gap			C to B Gap		
Vlookup	B - A Gap	Abs	Vlookup	C - A Gap	Abs	Vlookup	C - B Gap	Abs
23	22	22	9	8	8	26	25	25
13	11	11	10	8	8	4	2	2
15	12	12	11	8	8	18	15	15
10	6	6	1	-3	3	7	3	3
20	15	15	2	-3	3	8	3	3
31	25	25	3	-3	3	9	3	3
1	-6	6	4	-3	3	10	3	3
2	-6	6	5	-3	3	11	3	3
3	-6	6	6	-3	3	12	3	3
4	-6	6	7	-3	3	13	3	3
5	-6	6	8	-3	3	14	3	3
6	-6	6	19	7	7	34	22	22
7	-6	6	12	-1	1	17	4	4
8	-6	6	13	-1	1	2	-12	12
28	13	13	26	11	11	28	13	13
29	13	13	15	-1	1	3	-13	13
12	-5	5	17	0	0	24	7	7
11	-7	7	31	13	13	6	-12	12
27	8	8	22	3	3	27	8	8
16	-4	4	20	0	0	5	-15	15
32	11	11	18	-3	3	29	8	8
38	16	16	38	16	16	22	0	0
42	19	19	14	-9	9	30	7	7
17	-7	7	24	0	0	31	7	7
21	-4	4	32	7	7	21	-4	4
9	-17	17	16	-10	10	20	-6	6
22	-5	5	33	6	6	43	16	16
26	-2	2	21	-7	7	25	-3	3
18	-11	11	28	-1	1	15	-14	14
14	-16	16	29	-1	1	16	-14	14
24	-7	7	23	-8	8	1	-30	30
41	9	9	42	10	10	23	-9	9
37	4	4	27	-6	6	19	-14	14
19	-15	15	30	-4	4	46	12	12
49	14	14	36	1	1	47	12	12
25	-11	11	25	-11	11	36	0	0
46	9	9	35	-2	2	50	13	13
47	9	9	39	1	1	48	10	10
43	4	4	40	1	1	49	10	10
44	4	4	37	-3	3	33	-7	7
45	4	4	41	0	0	32	-9	9
34	-8	8	43	1	1	39	-3	3
33	-10	10	44	1	1	40	-3	3
48	4	4	45	1	1	41	-3	3
50	5	5	49	4	4	35	-10	10
30	-16	16	34	-12	12	42	-4	4
36	-11	11	47	0	0	38	-9	9
39	-9	9	46	-2	2	37	-11	11
40	-9	9	48	-1	1	44	-5	5
35	-15	15	50	0	0	45	-5	5
52	1	1	51	0	0	55	4	4
53	1	1	52	0	0	51	-1	1
54	1	1	53	0	0	52	-1	1
55	1	1	54	0	0	53	-1	1
51	-4	4	55	0	0	54	-1	1
58	2	2	58	2	2	56	0	0
56	-1	1	56	-1	1	57	0	0
59	1	1	59	1	1	58	0	0
60	1	1	60	1	1	59	0	0
57	-3	3	57	-3	3	60	0	0
61	0	0	61	0	0	61	0	0
62	0	0	62	0	0	62	0	0
63	0	0	63	0	0	63	0	0
64	0	0	64	0	0	64	0	0
65	0	0	65	0	0	65	0	0
66	0	0	66	0	0	66	0	0
67	0	0	67	0	0	67	0	0
		B to A			C to A			C to B
		490			222			438

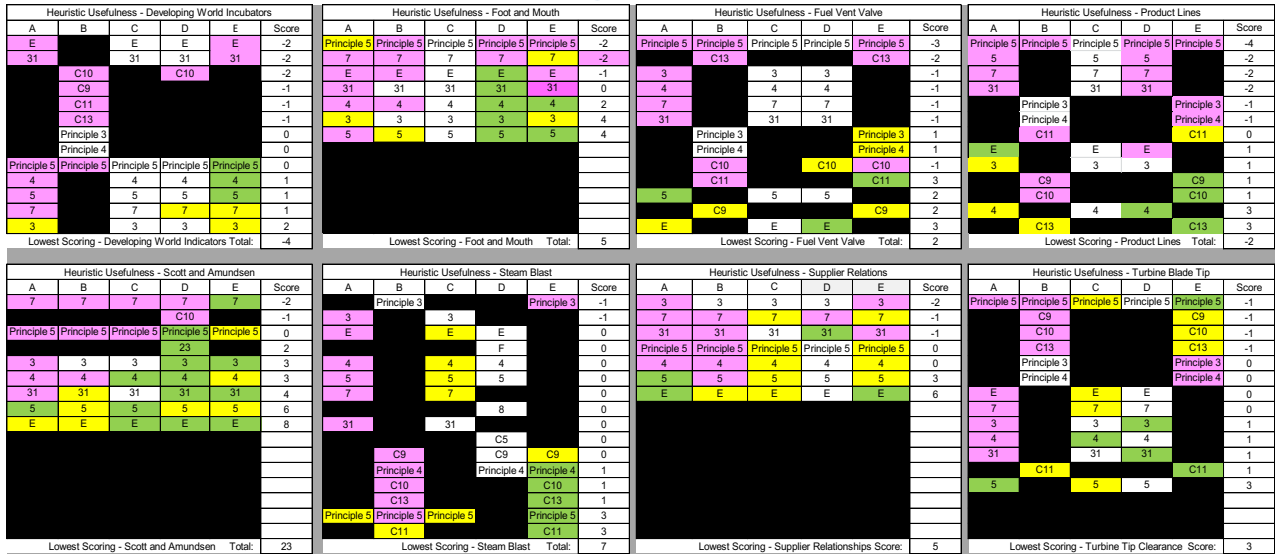


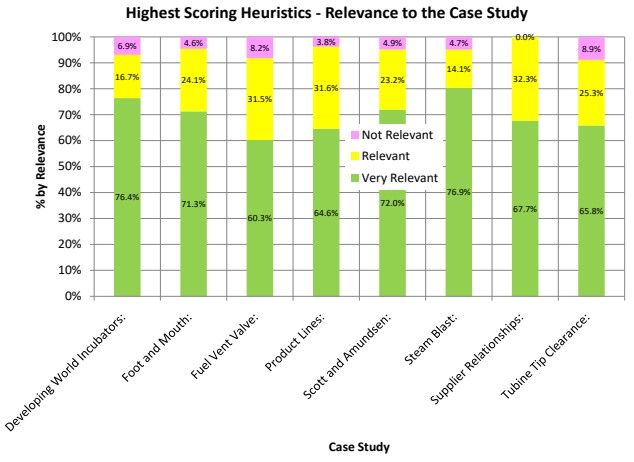
Heuristics Relevance Assessment

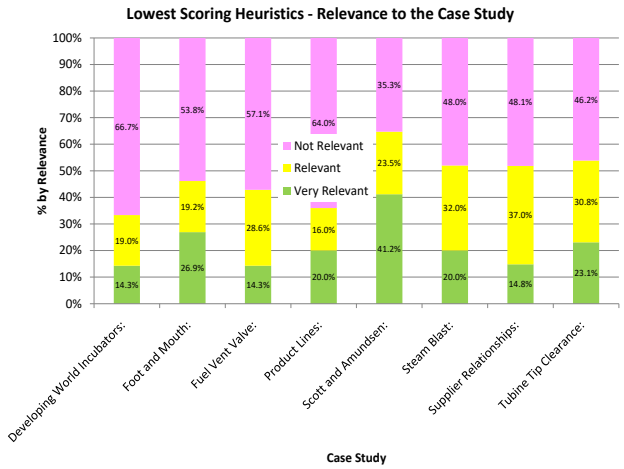
Highest Scoring Heuristics



Lowest Scoring Heuristics

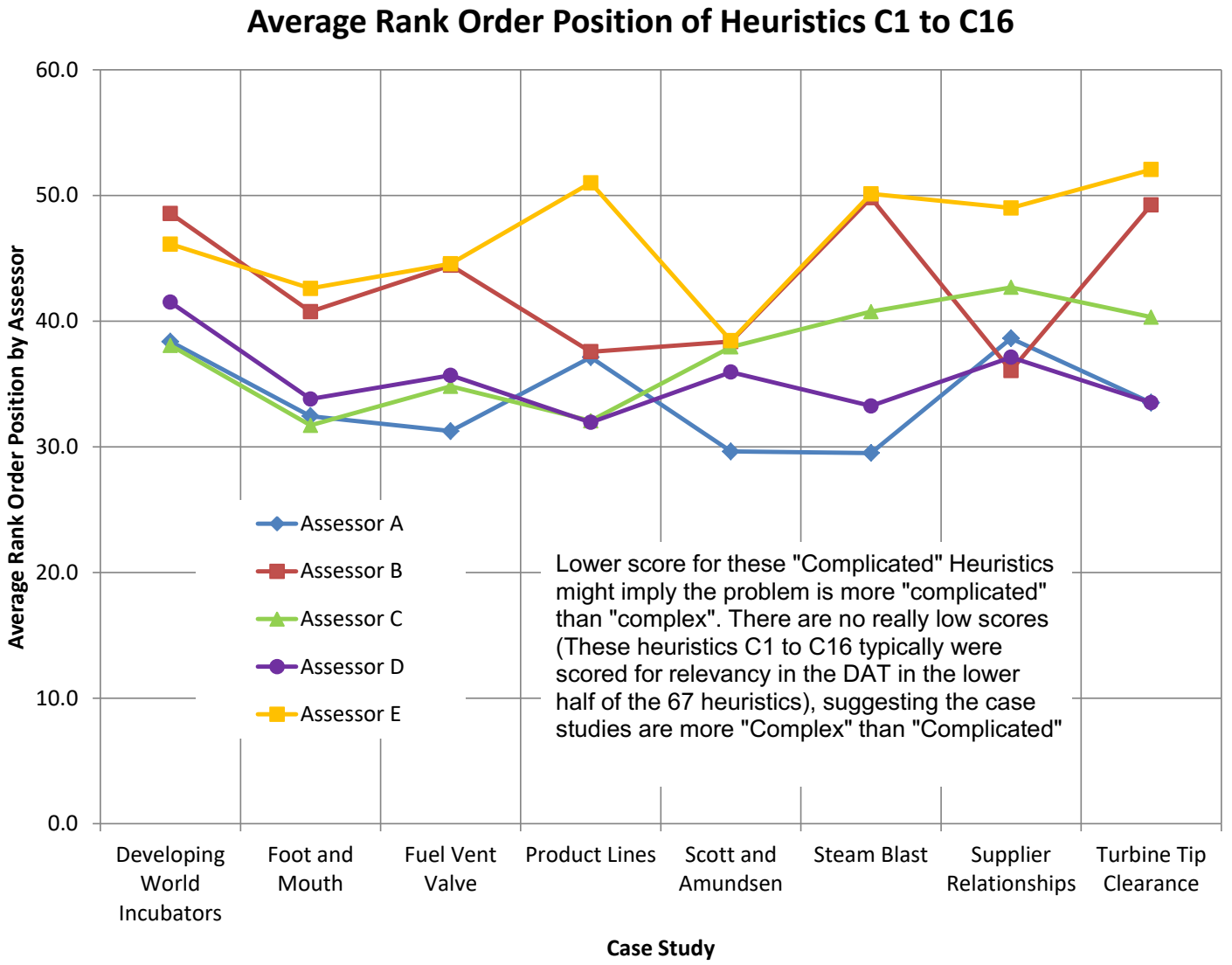






Case Studies – Complex or Complicated?

Heuristics C1 to C16 were selected for their applicability to both Complex and Complicated Systems.
The DAT results showed that the scatter between assessments did not allow the rank order of these heuristics to distinguish between “complex” and “complicated” case studies



RB

Observations

Observation
You have to be careful in interpreting the DAT – there seems to be an inbuilt assumption that change is bad, but there are situations where the inability to change is the problem.
Fixing or avoiding problems can require significant change (to Organization, Process or Technology), but change is hard, and it is difficult to assess the impact of changes, but if you do not change, you continue with the problem.
Definition of Stupidity – Knowing what to do but not doing it (vs Definition of Madness – doing the same thing and expecting a different result).
DAT questions cannot cover everything, particularly different perspectives on the system.
Difficulty in doing the case studies is the timeline, mainly what was known when looking with the benefit of hindsight.
Note the issue of a change in one part of a system affecting the assumptions made elsewhere, e.g. both Foot and Mouth (changes to abattoir locations and size invalidated transmission assumptions), and Turbine Tip Clearance (change in turbine component changed the key attribute concern in the interface between combustor and turbine sub-systems).
Principle 5 applies to the DAT itself - because in the end, this model is only recommending, and reality tells you which heuristics apply.

Conclusions

- "Match – Mismatch Analysis" and "Sum of Delta between Ranking by Assessors" seem to show the most promise for differentiating between types of system issues, but further investigation is needed.
- Team Assessments (Assessors A and C) seem to show more consistency that Individual Assessments (Assessors B, D and E). The study has insufficient assessments to draw a statistically relevant view of Team vs. Individual assessments, but it is hypothesized that the discussion and rationale development in a team environment should produce a more consistent outcome. Just using the tool in a team discussion may be more valuable than the output of the tool!
- There is some consistency in the identification of the most relevant heuristics for all case studies for the five assessments. This gives support to the use of the DAT to provide good recommendations at the start of the development of a complex system
- There is less consistency in the identification of the least relevant heuristics. This may not be an issue in the relevance or applicability of the DAT

Conclusions – Future Work

- To arrange for other teams of various sizes to assess the eight case studies to see if team size is a differentiator.
- To identify additional Case Studies (Appendix B is Problem Statement for an additional example).
- To investigate the nature of the situation (Simple, Complicated, Complex or Chaotic) for each of the Case Studies to see if this has any bearing on the different assessment scores and the consistency of the scores. For example, the Foot and Mouth case study has previously been reported as being a Chaotic situation (Kemp et al, 2015, Table 13, F12)
- Apply the DAT tool to new, real-life problems, apply the recommended Heuristics, and upon completion of the work, assess how useful and applicable the recommended Heuristics were (there is activity in the Working Group looking at this).
- To apply additional analytical approaches (e.g. Large Language Models and Big Data Analytics) to address the subjectivity associated with humans using the DAT tool (in itself a complex system) and/or to improve the DAT tool.

Questions?

Please contact us if you would be prepared to assess the eight case studies, either as an individual assessor or (preferred) to perform a team assessment. We need your help!!!

Please let us know if you have case studies that you would like to add to the analysis. This is not a heavy burden – just a description of the problem (background) and outcome. The hard part is summarizing the case study in an understandable form in a couple of pages. Remember the Churchill story – that was a long speech – yes, I didn't have time to make it shorter!

Please also let us know if you would like to use the DAT GNOSIS tool to assess a current problem, receive Heuristics advice and provide feedback about the value of the advice provided by the tool.

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