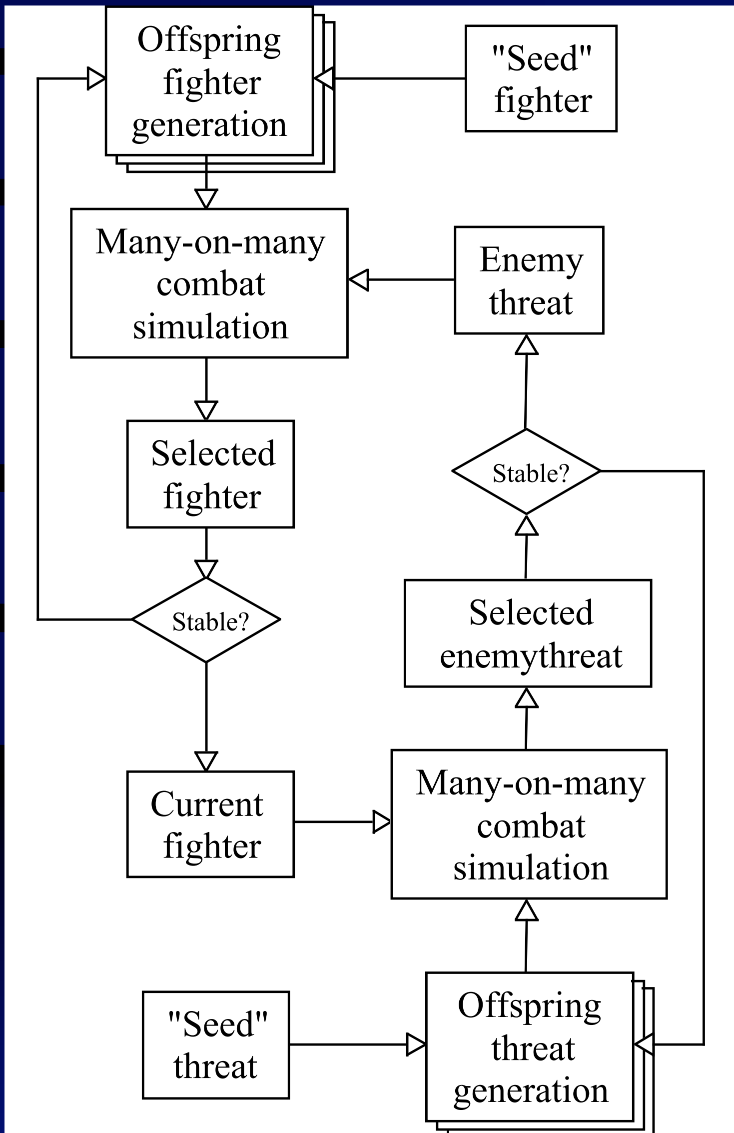
Prove System Solution

Derek Hitchins

Design Ratcheting



- Far left shows cumulative selection of e.g., Blue fighter design, using enemy (Red) fighter threat as a dynamic reference
- When Blue fighter design has reach optimum, Blue fighter becomes seed for Red fighter cumulative selection
- Process can occur over several stages, with each design leapfrogging its predecessor
- Obvious dangers of creating non-feasible designs can be anticipated
  - Insert physical/technological limits into offspring generation processes

Using Non-linear Dynamic Simulation

- It is possible to update the basic systems engineering paradigm
  - To create hundreds, or even thousands of options covering different:—
    - vehicle arrangements: how many, what functions…
    - operational parameters… power, capacity, sensitivity, range, frequency, etc., etc.…
    - Support & logistics…
    - …weapons performance, etc., etc.,
  - To search through the resulting massive n-dimensional solution space efficiently and…
  - To find the optimum (e.g. most cost effective) solution of all the possible configurations
  - To "prove" your solution is the right one.

Using Non-linear Dynamic Simulation

- The key is to use genetic algorithmic methods
- Establish pseudo-genes to code for parameters in solution system
  - i.e., re-create the system solution from a set of genes,
    - e.g., Gene A codes for "radar transmitter power"
      - Gene A can take on a range of values that express as a range of transmitter powers
    - e.g., Gene B codes for "number of weapons type X"
      - Gene B can take on a range of values corresponding to the number of X missiles carried, with an upper limit set by capacity
    - In each case, as the genes code for more or less, there is a consequent cost assessment
      - E.g., more missiles carried = more cost
      - E.g. greater missile Ph = less missile firings…

Using Non-linear Dynamic Simulation

- Design search starts by randomly generating a set of gene values
- These vary the initial parameters in the Blue Model
- These values determine a putative system design
  - number of vehicles, weapons, ranges, missile Ph, etc.
- This system design solution is sent into combat against an unaltered, but still dynamic and interactive, Red force.
- The outcome of the conflict is recorded as e.g., the various forms of effectiveness provided by that particular set of genes

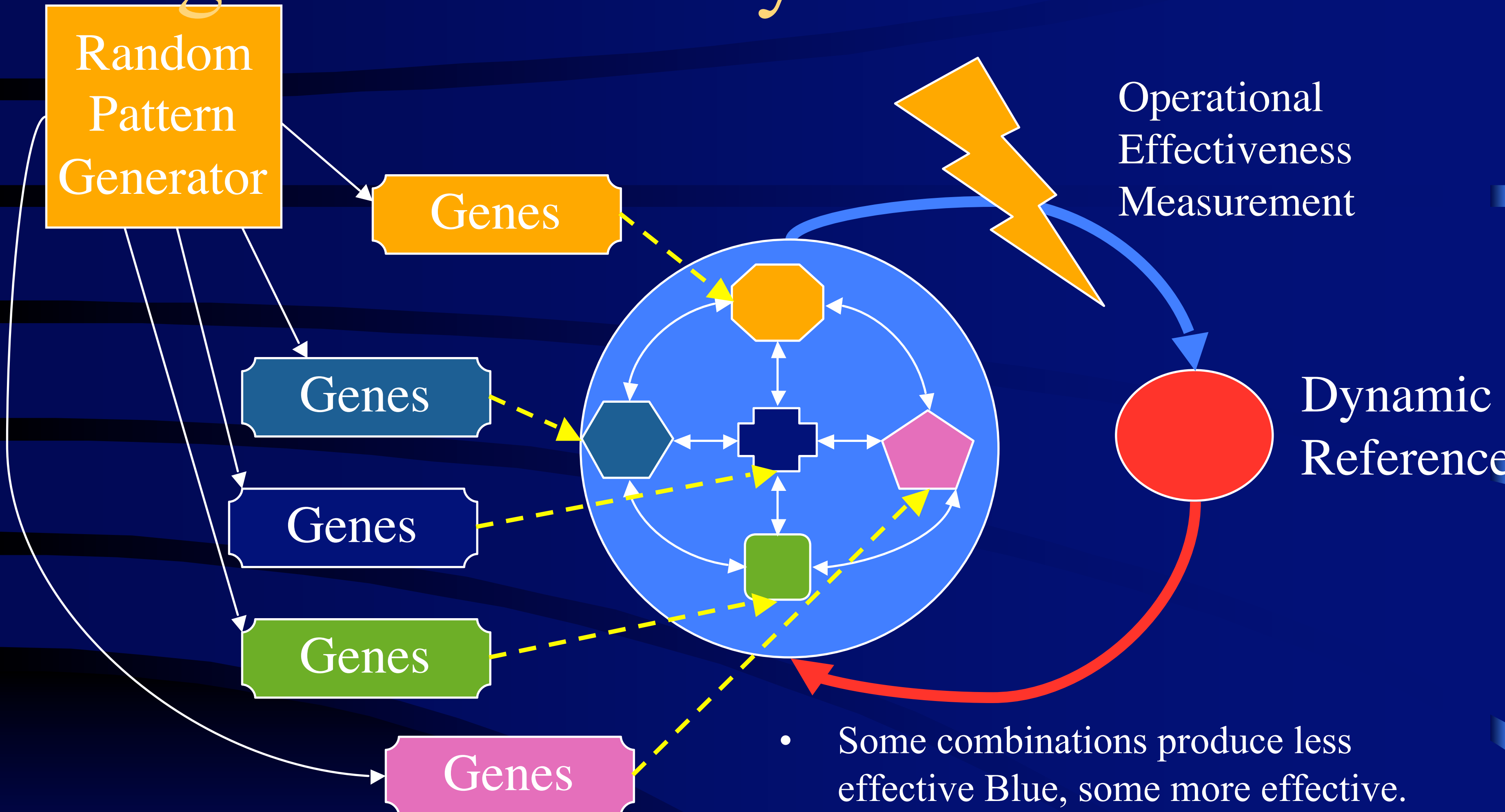
Using Non-linear Dynamic Simulation

- Process is repeated for a significant number of random gene patterns
- Results from, say, 500 runs are compared and the “best” solution is recorded
- The corresponding gene values are set into the design as “radar transmitter power,” “number of missiles,” etc.
- This represents the first level of improved design

Using Non-linear Dynamic Simulation

- The process is repeated, only now the extent by which the genes may change from the nominal value may be reduced
  - The intent is to refine the "hill-climbing" process
- After a relatively few cycles the process is unable to improve Blue effectiveness
  - Typically, $15 \leq$ cycles ≤ 30
- The whole exercise may be repeated using different terrain and different Red opposition, until a firm, provable solution is established for all reasonable situations

Using Non-linear Dynamic Simulation



- Genes "code for" different parameter values:
  - Tx power, Rx sensitivity, DTDMA capacity, number of vehicles in a set.

- Some combinations produce less effective Blue, some more effective.
- Record genes leading to better Blue, repeat the runs, watch Blue's Effectiveness gradually grow and grow
- Red is held as a dynamic reference.

Typical Non-Linear Dynamic Simulation

- Following program employs STELLA™
  - Could use any non-linear dynamic tool
- Such programs look at function and behaviour, but…
- …lack spatial dimension
- Full solution requires bespoke tool with terrain cover, line-of-sight, obstacles, tracks, etc.

Optimize LF2020

Typical Simulation Run—”Genes”

Setup #2 Fri, Apr 9, 2004 2:17 PM

Input Variables

Run #	Blue Ph	Blue Tx Power	Equipment Quantit...	BD Crews	Decision Delay[Fir...	Intelligence Transit Time
1	0.29	6.1e+07	38.8	12.5	0.00	0.0282
2	0.447	1.2e+08	32.7	21.7	0.0625	3.18
3	0.159	7.6e+07	38.5	0.745	0.125	0.8
4	0.302	8.3e+07	31.7	13.8	0.188	1.17
5	0.295	1e+08	36.9	16.2	0.25	2.02
6	0.446	8.8e+07	30.6	12.4	0.312	1.40
7	0.346	8.8e+07	29.5	11.6	0.375	1.42
8	0.28	8.5e+07	23.0	13.7	0.438	1.26
9	0.43	9.6e+07	33.8	5.96	0.5	1.82
10	-0.00658	8e+07	34.4	28.6	0.562	1.00
11	0.589	1.2e+08	45.3	16.2	0.625	3.10
12	0.346	9.3e+07	34.0	24.5	0.688	1.63
13	0.365	9.2e+07	41.7	11.8	0.75	1.60
14	0.335	8.9e+07	40.0	10.6	0.812	1.43
15	0.226	1.2e+08	32.8	16.4	0.875	2.80
16	0.423	7.6e+07	30.3	13.4	0.938	0.822
17	0.328	8.8e+07	36.0	25.6	1.00	1.38
18	0.332	1.1e+08	38.7	24.4	1.06	2.37
19	0.382	1.3e+08	29.9	7.20	1.12	3.36
20	0.458	8.7e+07	30.2	15.7	1.19	1.37
21	0.494	8e+07	39.5	11.3	1.25	1.01
22	0.326	1.2e+08	30.1	21.6	1.31	3.09
23	0.541	1.1e+08	44.8	4.18	1.38	2.48
24	0.419	1e+08	39.3	13.6	1.44	2.23
25	0.374	1.4e+08	40.5	17.8	1.50	3.92

Differing Effectiveness Viewpoints

Run 3 economizes on Battle Damage Repair, has fast intelligence and plenty of weapons…

2:26 PM Fri, Apr 9, 2004 Table 1 : p3 (Untitled Ta

Time	.00	Final
1 : Blue Cost Effectiveness	97.89	48.14
2 : Blue Cost Effectiveness	97.71	21.35
3 : Blue Cost Effectiveness	97.88	81.58
4 : Blue Cost Effectiveness	97.68	39.24
5 : Blue Cost Effectiveness	97.84	41.11
6 : Blue Cost Effectiveness	97.64	26.01
7 : Blue Cost Effectiveness	97.61	33.76
8 : Blue Cost Effectiveness	97.36	32.81
9 : Blue Cost Effectiveness	97.75	26.71
10 : Blue Cost Effectiveness	97.77	66.69
11 : Blue Cost Effectiveness	98.05	22.65
12 : Blue Cost Effectiveness	97.75	37.42
13 : Blue Cost Effectiveness	97.96	41.81
14 : Blue Cost Effectiveness	97.92	42.68
15 : Blue Cost Effectiveness	97.72	43.49
16 : Blue Cost Effectiveness	97.63	29.77
17 : Blue Cost Effectiveness	97.81	40.10
18 : Blue Cost Effectiveness	97.89	39.11
19 : Blue Cost Effectiveness	97.62	25.09
20 : Blue Cost Effectiveness	97.63	23.73
21 : Blue Cost Effectiveness	97.91	29.91
22 : Blue Cost Effectiveness	97.63	29.05
23 : Blue Cost Effectiveness	98.04	27.43
24 : Blue Cost Effectiveness	97.90	34.06
25 : Blue Cost Effectiveness	97.93	34.06

Run 3 does not perform well w.r.t. Casualties:1.0 is equal Blue and Red 1.53/∞ would be preferred…

2:26 PM Fri, Apr 9, 2004 Table 1 : p4 (Untitle

Time	.00	Final
1 : Casualty Exchange Ratio	1.00	0.92
2 : Casualty Exchange Ratio	1.00	1.29
3 : Casualty Exchange Ratio	1.00	1.15
4 : Casualty Exchange Ratio	1.00	1.29
5 : Casualty Exchange Ratio	1.00	1.00
6 : Casualty Exchange Ratio	1.00	1.53
7 : Casualty Exchange Ratio	1.00	1.53
8 : Casualty Exchange Ratio	1.00	1.20
9 : Casualty Exchange Ratio	1.00	1.20
10 : Casualty Exchange Ratio	1.00	0.00
11 : Casualty Exchange Ratio	1.00	1.41
12 : Casualty Exchange Ratio	1.00	1.53
13 : Casualty Exchange Ratio	1.00	1.53
14 : Casualty Exchange Ratio	1.00	1.41
15 : Casualty Exchange Ratio	1.00	0.92
16 : Casualty Exchange Ratio	1.00	0.92
17 : Casualty Exchange Ratio	1.00	1.41
18 : Casualty Exchange Ratio	1.00	1.17
19 : Casualty Exchange Ratio	1.00	1.38
20 : Casualty Exchange Ratio	1.00	1.53
21 : Casualty Exchange Ratio	1.00	1.53
22 : Casualty Exchange Ratio	1.00	1.14
23 : Casualty Exchange Ratio	1.00	1.41
24 : Casualty Exchange Ratio	1.00	1.50
25 : Casualty Exchange Ratio	1.00	1.00

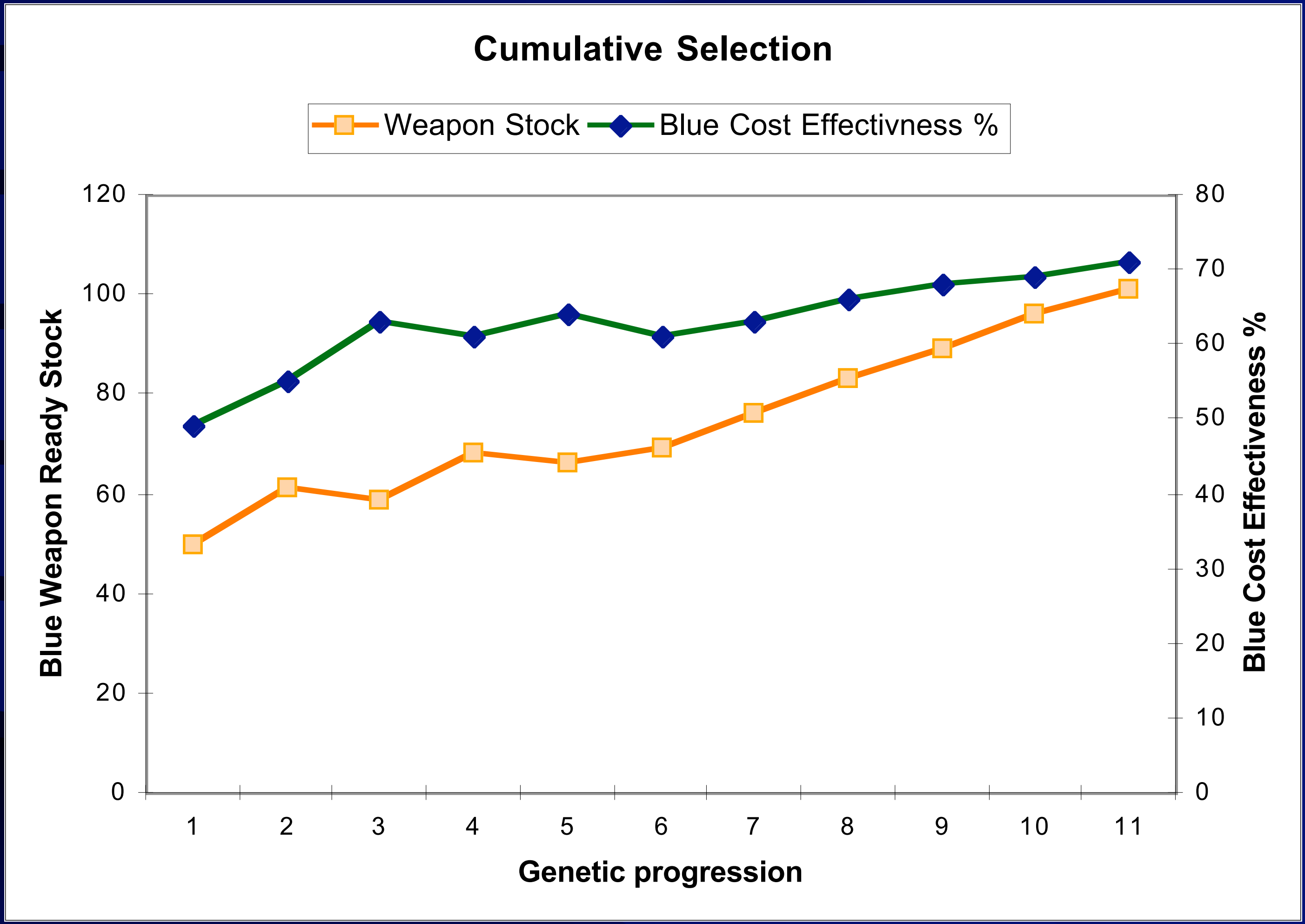
2:26 PM Fri, Apr 9, 2004 Table 1 : p2 (Unt

Time	.00	Final
1 : CE Difference	-0.26	-1.52
2 : CE Difference	-0.44	-15.93
3 : CE Difference	-0.27	1.80
4 : CE Difference	-0.47	-2.84
5 : CE Difference	-0.31	-4.67
6 : CE Difference	-0.51	-11.63
7 : CE Difference	-0.54	-7.58
8 : CE Difference	-0.79	-8.91
9 : CE Difference	-0.40	-14.26
10 : CE Difference	-0.39	11.86
11 : CE Difference	-0.10	-10.00
12 : CE Difference	-0.40	-3.92
13 : CE Difference	-0.19	0.47
14 : CE Difference	-0.23	1.15
15 : CE Difference	-0.43	-6.17
16 : CE Difference	-0.52	-16.19
17 : CE Difference	-0.34	-1.43
18 : CE Difference	-0.26	-2.60
19 : CE Difference	-0.53	-15.52
20 : CE Difference	-0.52	-13.92
21 : CE Difference	-0.24	-4.04
22 : CE Difference	-0.52	-12.85
23 : CE Difference	-0.11	-5.96
24 : CE Difference	-0.25	-7.47
25 : CE Difference	-0.22	-8.20

Blue Cost Effectiveness
- Red Cost Effectiveness

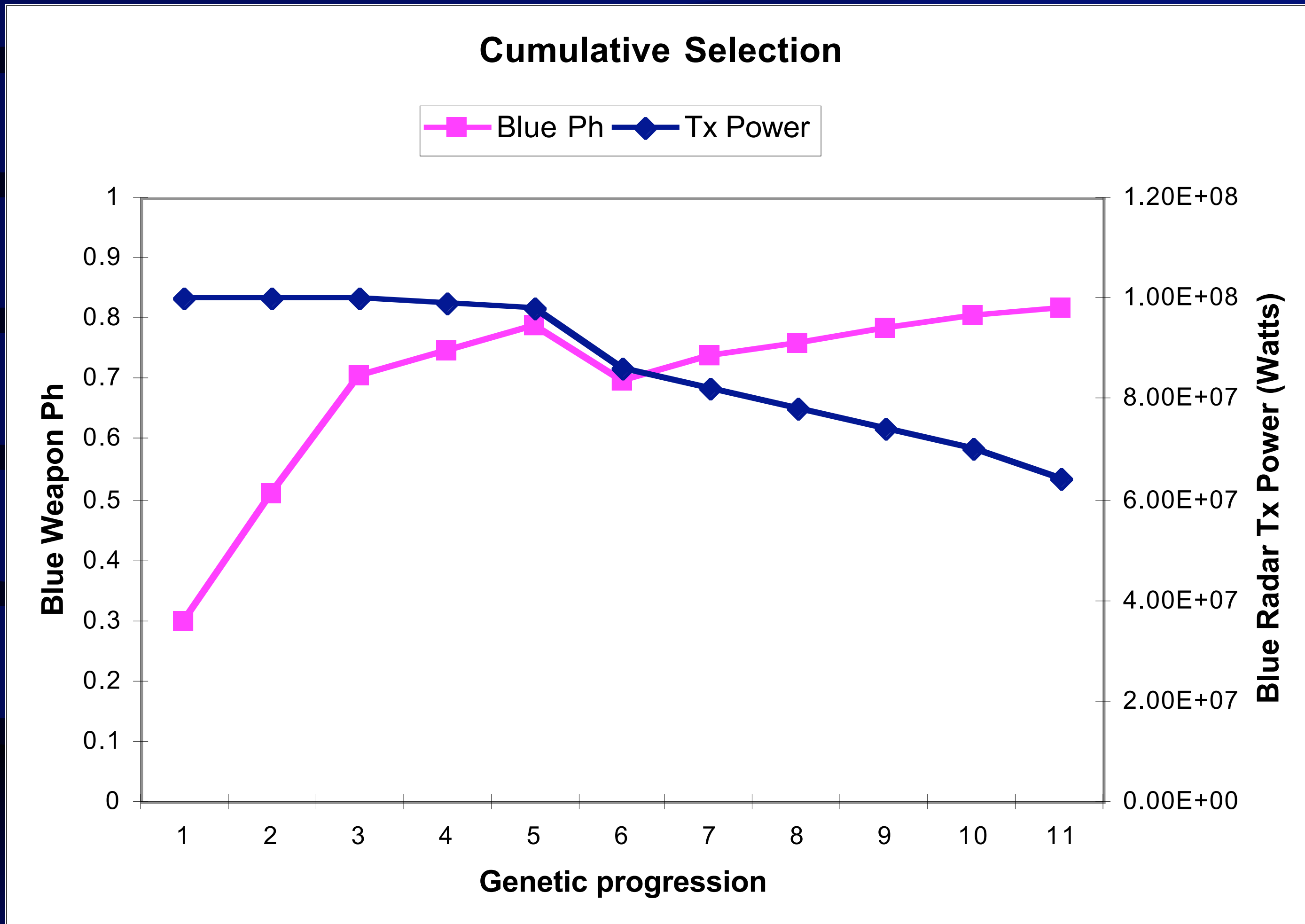
Need more runs…! Insert values for, say, Run 3, and start again. Initial results indicate start point well away from optimum…

Counter-Intuitive Results?



Despite the increased capital cost of having more weapons, more weapons increase Blue Cost Effectiveness (!)

Increasing Cost Effectiveness



Blue Cost Effectiveness increases as the weapon Ph increases (less weapons needed for same effect) and as radar Tx power diminishes (two reasons: cheaper radar, and reduced "observables.")

Non-linear Dynamic Simulation

- Result is a matched set of optimal parameters—specifications— for Blue, in the situation represented by the simulation
  - Great advance on conventional methods
    - Matched specs show each subsystem
      - making best contribution to overall Mission Effectiveness - however measured
      - While operating and interacting with other systems under operational conditions, i.e. organismic synthesis!
    - Solution system parameters contribute to optimum solution
      - not too little, not over the top, but…
      - just right for successful operations
    - Determines optimal support, maintenance, logistics, too

Proving You Have Done It…

- Had we been able to create a variety of terrains…
- …and given that the simulations were reasonable, then…
- We would have established
  - a systems solution,
  - a system design to the first level,
  - a set of research targets
  - a matched set of specifications for subsystems, and
  - a test bed upon which the incredulous—and future contractors—could explore, challenge, and possibly improve, our conclusions
- …and everything can be tracked back to the initial article, the TRIAD, and so on…it works!

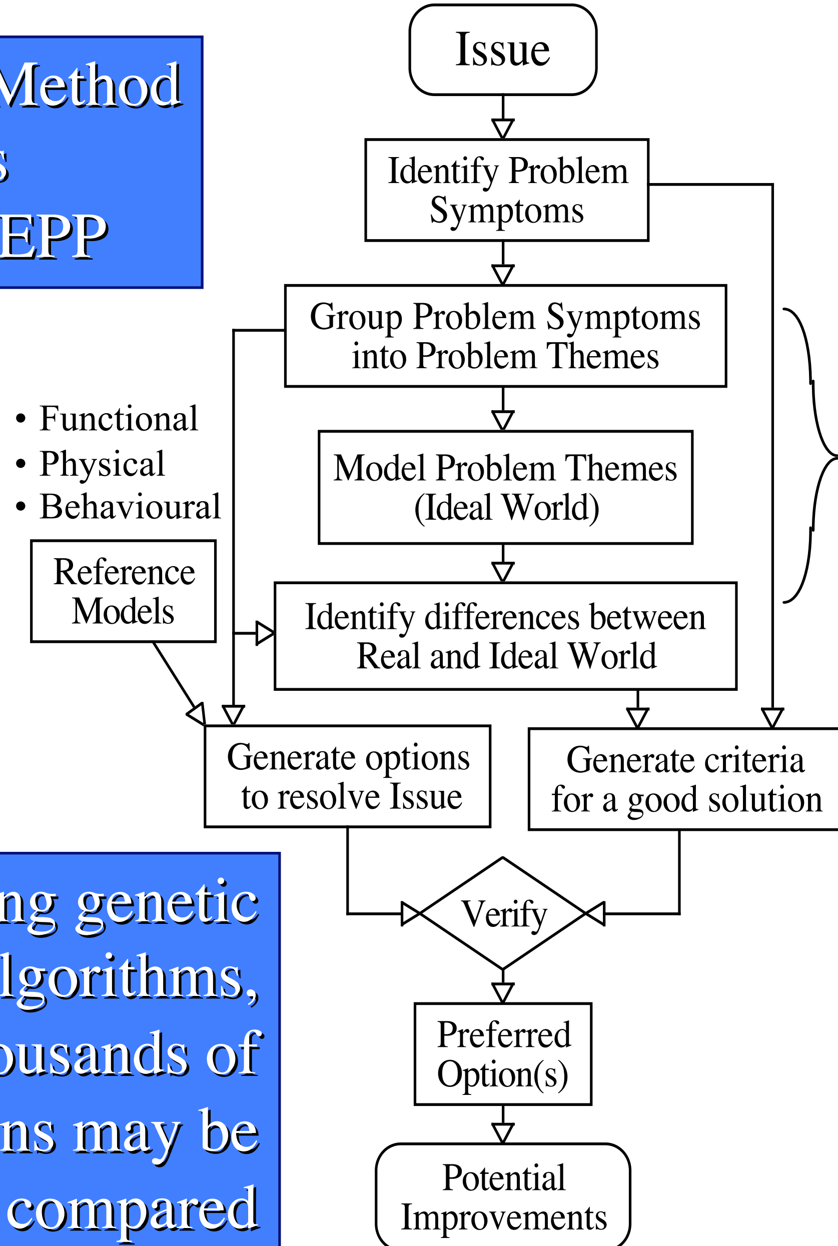
Applicability of Method

- Method used with great success in a variety of walks of life
- Essentially, nothing about the method that is context or technology dependent
- Used for Famine Relief, Reconstruction of Afghanistan, Global socio-economic forecasting, and many, many more…

Afghanistan Peace Operations

Rigorous Soft Method

Rigorous Soft Method combines GPSP and SEPP



Address **all** problem components to avoid (Forrester's) counterintuitive response

Use tools and methods to accommodate complexity

Q.E.D.

Ensure solution completeness—if any solution exists

Logical, consistent, but not necessarily culturally acceptable

Using genetic algorithms, hundreds/thousands of options may be generated and compared