TACOM
The Soldier and Ground Systems
Life Cycle Management Command

Tactical Wheeled Vehicle (TWV) Fuel Economy Improvement Breakeven Analysis

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Agenda

- Background
- Data
- Analysis
- Output
- Future Use
- Refinements
- Questions

Background

- Tasked by Program Manager Tactical Vehicles (PM TV) to develop a flexible, Excel-based model to calculate breakeven times (savings/investments) for upgrading/modifying existing TWV fleet with fuel efficiency technology.
- Primary purpose would be to have a method to inform industry and rate/compare commercial technologies based on efficiency improvements and breakeven goals.

Data

- Initially, only road-load/full-load fuel tests.
  - standard tests
  - lock the transmission gear, vary speed
  - not adequate for mission-level fuel economy
- Second round saw course testing
  - Hybrid Electric Vehicle Evaluation and Analysis (HEVEA) program tested all major government-owned tactical vehicles, across all vehicle classes (light/medium/heavy) on a variety of test courses

HEVEA Data

Test Vehicles (17 vehicles across 6 systems)

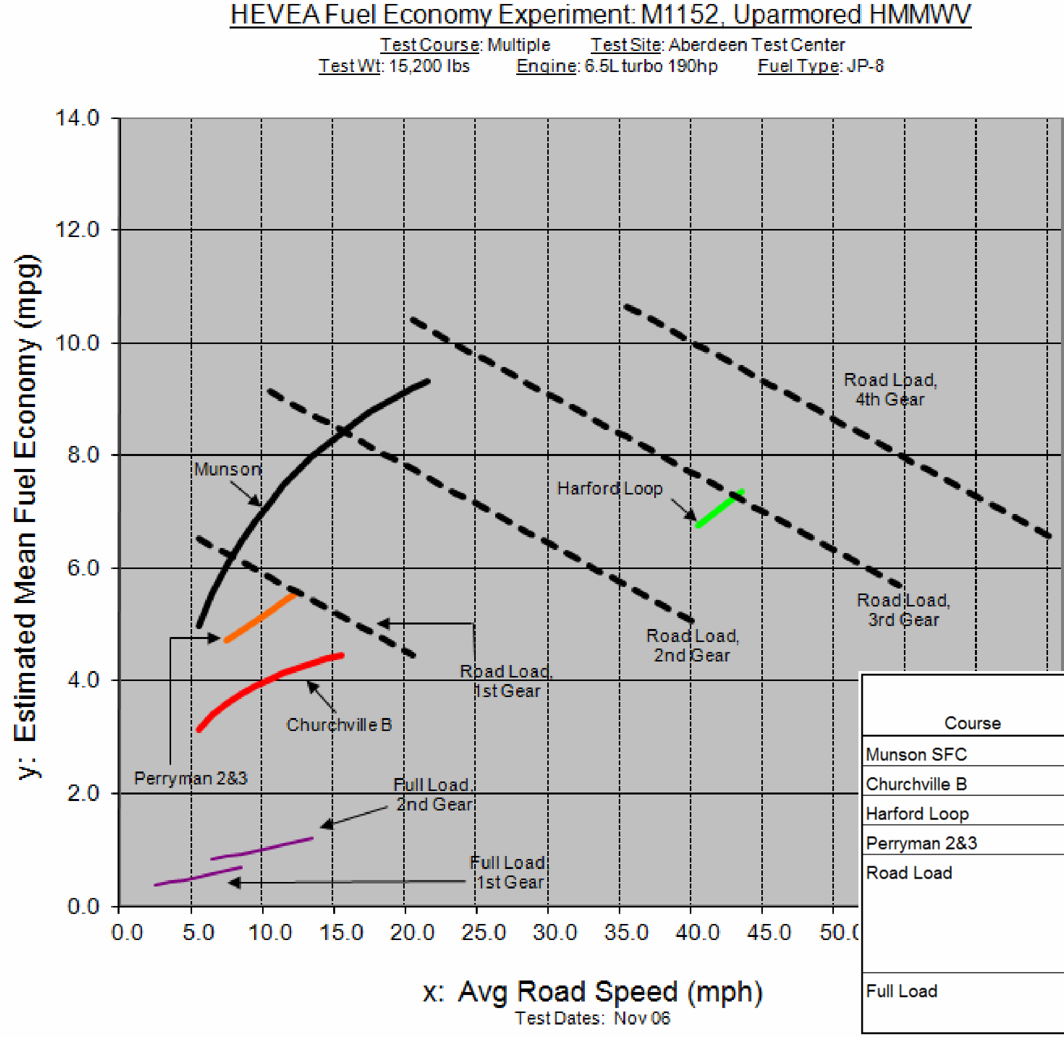
- HMMWV
  - M1113
  - M1152 Up-Armored HMMWV (UAH)
  - HMMWV XM1124, Hybrid Electric HMMWV
- Remote Surveillance Targeting Vehicle (RSTV) (Hybrid Electric), GDLS
- Future Tactical Truck System (FTTS)
  - Utility Variant (UV) - AM General, International MG, Lockheed Martin
  - Maneuver Sustainment Vehicle (MSV), BAE
- Heavy Expanded Mobility Tactical Truck (HEMTT)
  - A2 (base and UA)
  - A3 OTC UA
  - A4
- Family of Medium Tactical Vehicles (Light Medium Tactical Vehicle (LTV) & Medium Tactical Vehicle (MTV))
  - M1078 (LMTV, 2.5T) – Base, LSAC, and Continuous Variable Transmission (CVT) BAE
  - M1084 (MTV, 5T)
  - M1086 – HE BAE

HEVEA Data

Test Courses (4 terrains, road/full loads, and idling)

- Terrains
  - Harford Loop – Primary Roads
  - Munson Standard Fuel Course (SFC) – Secondary Roads
  - Churchville B – Cross Country
  - Perryman 2 & 3 - Trails
- Road/Full Loads
  - Road Load measures fuel consumption against rolling, wind, and grade forces
  - Full Load also adds in a residual towed force
- Idling
  - Stationary vehicle in neutral
  - Varies engine speeds from rated idle to governed engine speed

HEVEA Data Example



Graph of fuel economy data accompanied by regression equations for each plot as well as appropriate bounds on speed, and resulting fuel economy.

Course	Statistical Model	Speed Range (mph)	Mean FE mpg over range Min	Avg	Max
Munson SFC	y = x / (0.078x + 0.615)	5.1 - 20.6	5.0	7.7	9.3
Churchville B	y = x / (0.177x + 0.714)	5.6 - 14.9	3.3	4.0	4.4
Harford Loop	y = -1.325 + 0.202x	40.2 - 42.6	6.8	7.0	7.3
Perryman 2&3	y = 3.496 + 0.174x	7.5 - 12.4	4.8	5.2	5.7
Road Load	y = 7.22 - 0.138x (1st gear)	5.1 - 19.8	4.5	5.5	6.5
	y = 10.518 - 0.138x (2nd gear)	10.4 - 39.4	5.1	7.1	9.1
	y = 13.153 - 0.138x (3rd gear)	20.5 - 54.0	5.7	8.0	10.3
	y = 15.476 - 0.138x (4th gear)	35.1 - 64.8	6.5	8.6	10.6
Full Load	y = 0.252 + 0.055x (1st gear)	2.0 - 7.5	0.4	0.5	0.7
	y = 0.493 + 0.055x (2nd gear)	5.7 - 13.1	0.8	1.0	1.2

Analysis

- Converted all fitted equations to polynomial (quadratic) form
  - some were constant/linear/quadratic
  - did it for consistency reasons only
  - fits were "identical" (99.7% R^2 vs 99.8% R^2)
- Now have a set of polynomial equations in one variable (speed)
- Created a surface of random points in (weight, speed) space using this set of equations
  - created surface for each terrain (primary, secondary, etc.)
  - best fit a power model to surface
- Excellent fits across all weight and speed ranges
  - R^2 in excess of 99%
  - CV no more than 6%
  - Adjusted for Heavy fleet and operating over/under designed weight

Weight Adjustment

- Added in over/under weight factor to account for vehicles operating at other than ideal weights for which they were designed.
- Issue presented itself with the variance between the HMMWV M1113 and M1152.
  - Basically, a HMMWV operating at two different weights – 11,500 and 15,200 pounds
  - AMSAA had initially validated (ca 2006) a linear relationship (best case scenario) from +/- 20% weight changes.
- Found a linear relationship on primary roads, but a substantial difference on cross-country and trails in excess of a quadratic term.

Analysis Summary

- Based on parametrics already fitting raw data. Same degree of fit (99%/6%), but would slightly change analysis from raw data. Hope to refine my equations by obtaining raw data from tests.
- Heavy Tactical Vehicles (HTV) were different enough from the Light and Medium fleets to require a dummy variable to separate them out.
- Added in factor to take over/under weight operation into account – a very real occurrence, especially on the overweight side.

Final Equations

	Weight		Speed		Equation	
Road Type	Min	Max	Min	Max	Base Equation	Wt Adj Exponent
Primary	10000	75000	35	45	$MPG = 615.8 \cdot W^{-0.5393} \cdot S^{0.2331} \cdot 0.9608^{HTV}$	1.000
Secondary	10000	75000	5	25	$MPG = 1143 \cdot W^{-0.6203} \cdot S^{0.3859} \cdot 0.8132^{HTV}$	0.000
Cross Country	10000	75000	5	15	$MPG = 334.0 \cdot W^{-0.5187} \cdot S^{0.3006} \cdot 0.6207^{HTV}$	2.333
Trails	10000	75000	5	15	$MPG = 826.4 \cdot W^{-0.6068} \cdot S^{0.4864} \cdot 0.7566^{HTV}$	2.125

Additional Data

- OPTEMPO
  - Utilized Operating & Sustainment Management Information System (OSMIS) – Army O&S online database
  - Gathered 3-year peacetime (w/o CONOPS) and wartime (ONLY CONOPS) data
  - Used 99% of the mileage data to estimate OPTEMPO for each variant (e.g. M1152) and also for each system (e.g. all HMMWVs).
    - Chose to use the most representative 99% of the activity (miles) to compute fleet OPTEMPOs
    - Removed 1% of data. Considered extreme outlier data that consists of unused HMMWVs or those awaiting repairs at depots
- Idle fuel economy
  - Cannot be estimated via a simple equation and must be entered as a value for each specific vehicle.

OPTEMPO Example

MDS	MDSNAME	PT3Y99	WT3Y99
M878A1	5 TON YARD TRACTOR	2608	148
M878A1-2102	5 TON YARD TRACTOR	452	392
M878-5579	5 TON YARD TRACTOR	176	92
M1028A1	CUCV SERIES	944	1568
M1028	CUCV SERIES	1300	1420
M1009	CUCV SERIES	1300	1512
M1008A1	CUCV SERIES	1356	1584
M1008	CUCV SERIES	1312	1028
CUCV-5368	CUCV SERIES	636	808
M1010	CUCV SERIES	320	232
CUCV-0822	CUCV SERIES	356	0
F5070	DUMP TRUCK 20 TON	504	100
M1113	ECV HMMWV	812	884
M1113P1	ECV HMMWV	500	840
M1097	HEAVY HMMWV	2840	2156
M1097A2	HEAVY HMMWV	1356	1432
M1097A1	HEAVY HMMWV	1424	1404
M1097A2P1	HEAVY HMMWV	1528	928
M1097P1	HEAVY HMMWV	796	840
M1097A1P1	HEAVY HMMWV	584	784
M984A1P1	HEMTT SERIES	9804	4432
HEMTT-1326	HEMTT SERIES	1084	2080

MDSNAME	PT3Y99	WT3Y99
Construction/General Duty	1232	1052
ECV HMMWV	812	884
OTHER HMMWV	1768	1680
LMTV SERIES	1704	1932
MTV SERIES (Truck/Wrecker)	1532	1456
M915/16/17/20 Transport Vehicles	2436	2196
HEMTT SERIES	1392	1476
HET	836	852
M939/2.5-5 Ton Cargo Trucks	1068	1224
PLS SERIES	1544	1900

Will be including distributions around these averages. Based on years, systems, MACOMS, etc., there can be a significant variance for OPTEMPO. This variance will be one source for uncertainty in the model, allowing ranges for breakeven times, not just a single year value.

Model Interface

Mobility Breakdown	%
Moving	75.0%
Non-Moving	25.0%

		O/U Wgt %	15%	11%
		Weight	15200	14700
		Improve	0%	10%
Moving	Moving (hr) %	Speed	Status Quo	Alternative
Primary	20%	45	7.05	8.25
Secondary	40%	30	10.82	12.15
Cross-country	40%	10	3.08	3.82
Trails	0%	15	6.31	7.77

		Improve	0%	5%
Non-Moving	Non-Moving %	Speed	Status Quo	Alternative
Idle (Eng On)	80%	0	1.35	1.29

Gal/Hr	Gal/Hr
3.03	2.60

MPG	MPG
6.18	7.21

- This is the primary view to enter user modified vehicle information such as mission profile (A/C), operating weight (B), fuel improvement % (B), and idling consumption (D).
- Notice that all the variables addressed earlier are identified here: weight, speed, over/under weight %, and terrain.
- The resulting fuel economies (base/improved) are calculated at the bottom (6.18/7.21 mpg) (E).

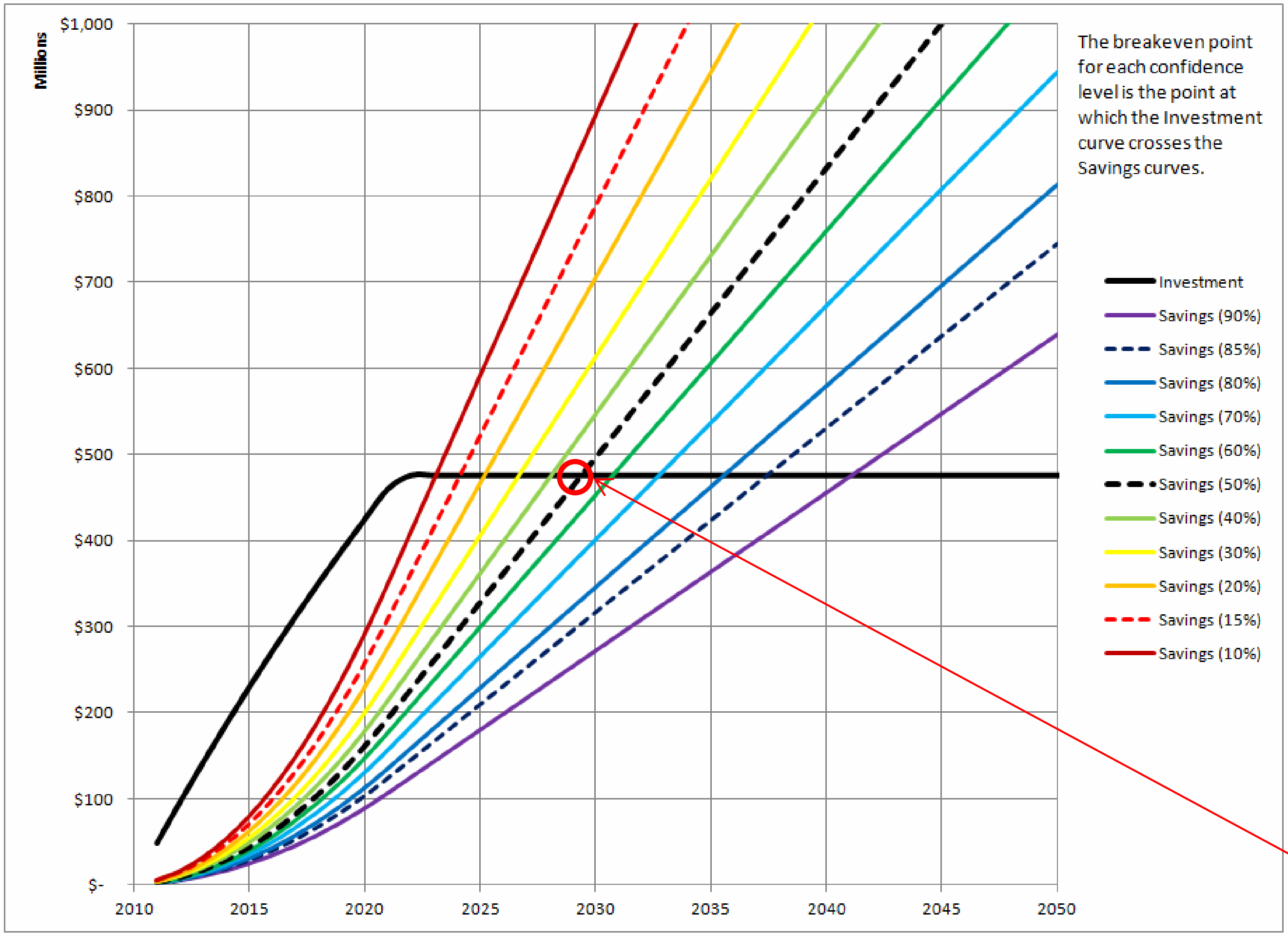
Cost Inputs

	TY11$			Phasing				
$/gal Fuel	$ 3.95							
Investment Cost/Vehicle	$ 2,505							
Variable Investment Cost (per Vehicle)	$ 2,500							
Fleet Fixed Cost	$ 500,000	30%	70%					
Current Fleet Size	100000							
Max Vehicle Mods/Year	10000							
FYYR		**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**201**
Fleet Size		100000	101127	103552	105339	106482	107940	1103
Vehicle Mod Schedule		10000	10000	10000	10000	10000	10000	100
Modded Vehicles in Fleet		10000	20000	30000	40000	50000	60000	700
Unmodded Vehicles in Fleet		90000	81127	73552	65339	56482	47940	403

This sheet allows entering cost specific information. This includes the current cost of fuel, investment/modification costs for both the vehicle and fleet, as well as a modification schedule/phasing of these costs.

This is also the tab where fleet statistics, inflation indices, etc. are kept.

Output

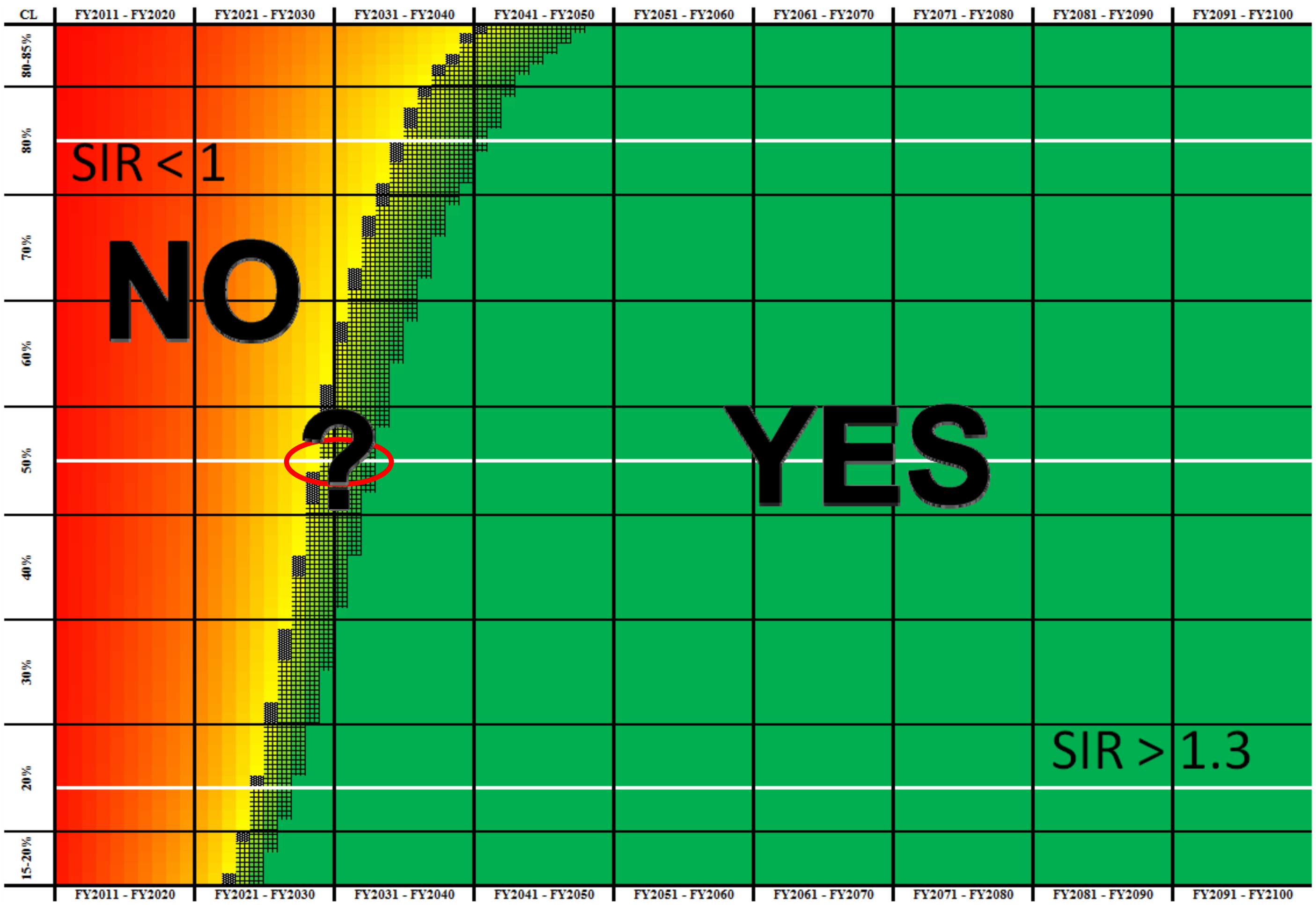


As mentioned earlier, there are confidence levels associated with the breakeven. The only input with variance at this point is the OPTEMPO.

To read this chart, one would simply follow the desired confidence level curve until the investment curve flatlines (total investment reached).

Under the assumptions on the last slide, at the 50% confidence level, the breakeven year is between 2029-2030.

Output



This chart shows a more traditional stoplight chart of investment strategy. When the SIR < 1, the decision to change status quo would never be made for financial reasons. When SIR = 1, you exactly break even.

When SIR > 1.3, a positive decision for financial reasons would be made.

Note, again, that the user can select their level of risk by choosing a confidence level.

At the 50% confidence level, the breakeven would occur between 2029-2030, but most likely not before 2033 (SIR = 1.3).

Future Use

- Potential use of this tool is very open due to the built-in powers/features in Excel.
- Excel is a common platform that most analysts are comfortable using, editing, and expanding.
- Excel contains add-ins such as GoalSeek that will allow many questions to be answered with just a few key strokes.
  - What must investment cost per vehicle be limited to in order to breakeven in 15 years?
  - How much improvement can we buy for $5,000 per vehicle and still breakeven in 12 years?
  - How much should we pay for a 12% improvement if we are required to breakeven in 8 years?
  - Basically, GoalSeek will allow you to calculate ONE unknown automatically by setting the desired value of another.

Refinements

- Currently, the model works for a single vehicle type (one weight, one mission, etc.)
- Would like to expand this to include fleet mixes such as:
  - LTV (All HMMWVs)
  - Only LTV and MTV (HMMWVs, 2.5/5.0T trucks)
  - Tactical Vehicles in Brigade Combat Team (BCT)
  - All Tactical Vehicles (TV)

Questions?

I thank you very much for your attention!

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