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DON'T GET CAUGHT IN THE LEARNING CURVE VACUUM

Exploring the Impact of Commonality on Cost Estimates

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AGENDA

- BACKGROUND AND INTRODUCTION
- PROBLEM IDENTIFICATION
- COMMONALITY DEFINED
- PRODUCTION STEADY STATE
- PROPOSED METHODOLOGY
- EXAMPLE
- CONCLUSIONS AND FUTURE CONSIDERATIONS
- Q&A

BACKGROUND & INTRODUCTION

BACKGROUND

While many key variables are considered when developing learning curve models in an integrated production environment, commonality is often overlooked and not accounted for

METHODOLOGY

- Identify Common Occurrences
- Define Commonality
- Identify Integration Approach/Production Steady State
- Develop Complete Solution
- Test Using Examples
- Identify Challenges

PROBLEM IDENTIFICATION – WHY IS COMMONALITY OVERLOOKED?

WHY DOES THIS HAPPEN?

- Different contracts and different cost estimators
- Finished end items may look drastically different
- Schedule uncertainty
- Minimize risk (Contractor Estimate)
- Unfamiliarity with production process (Government Estimate)

EXAMPLES

- Weapon systems with multiple platforms and/or variants
- Legacy systems overlapping with replacement systems
- Substantial configuration modifications made during production of a legacy vehicle
- Reset programs for legacy vehicles

PROBLEM IDENTIFICATION – WHY IS COMMONALITY OVERLOOKED?

EXAMPLE: STRYKER FAMILY OF VEHICLES

- 18 Variants (11 Flat Bottomed, 7 Double-V-hull (DVH))
- Common chassis for all variants except MGS and NBCRV variants

ICV	MGS	NBCRV
		
- ICV (Flat and DVH) - CV (Flat and DVH) - MEV (Flat and DVH) - MC (Flat and DVH) - ATGM (Flat and DVH) - FSV (Flat and DVH) - ESV (Flat and DVH) - RV (Flat Bottom Only) - ICVD (Flat Bottom Only)	- MGS (Flat Bottom Only)	- NBCRV (Flat Bottom Only)

Source - asc.army.mil/web/portfolio-item/gcs-stryker-family-of-vehicles/

PROBLEM IDENTIFICATION - WHY IS COMMONALITY OVERLOOKED?

WHAT IS THE IMPACT?

- End items with independent learning curve models
- Common work content, learning and efficiencies are ignored
- Overestimation or underestimation of hours
- High variance between actual hours and estimates
- Inaccurate staffing
- Can impact Forward Pricing Rates

COMMONALITY DEFINED

PRODUCT COMMONALITY

Considers the standardization of components, materials and subassemblies used to produce an end item

- Product Commonality Pros
  - Can range in complexity in terms of calculation
  - Can be calculated as soon as BOM is established for each end item

	Variant 1	Variant 2	Variant 3
Total Parts in BOM	800.0	920.0	980
Parts Common to All Variants	520	520	520
% of Common Parts in BOM	65%	57%	53%

- Product Commonality Cons
  - Material content can be misleading in terms of work content required
  - Difficult to integrate into a learning curve

COMMONALITY DEFINED

PROCESS COMMONALITY (PREFERRED)

Considers the standardization of the machines, tools and production processes used to produce an end item

- Process Commonality Pros
  - Detailed, task-oriented labor estimates (Standard Hours or Budgeted Work Standards (BWS))
  - Utilize work measurement techniques including time studies, Predetermined Motion Time Systems (PMTS) or work sampling
  - Can be based on and integrated with work instructions
  - Can be easily integrated into learning curve models
- Process Commonality Cons
  - Can be time-consuming
  - Requires expertise in efficiency ratings, particularly when observing prototype or LRIP units

INTEGRATION OF COMMONALITY

THE "SO WHAT?" TEST

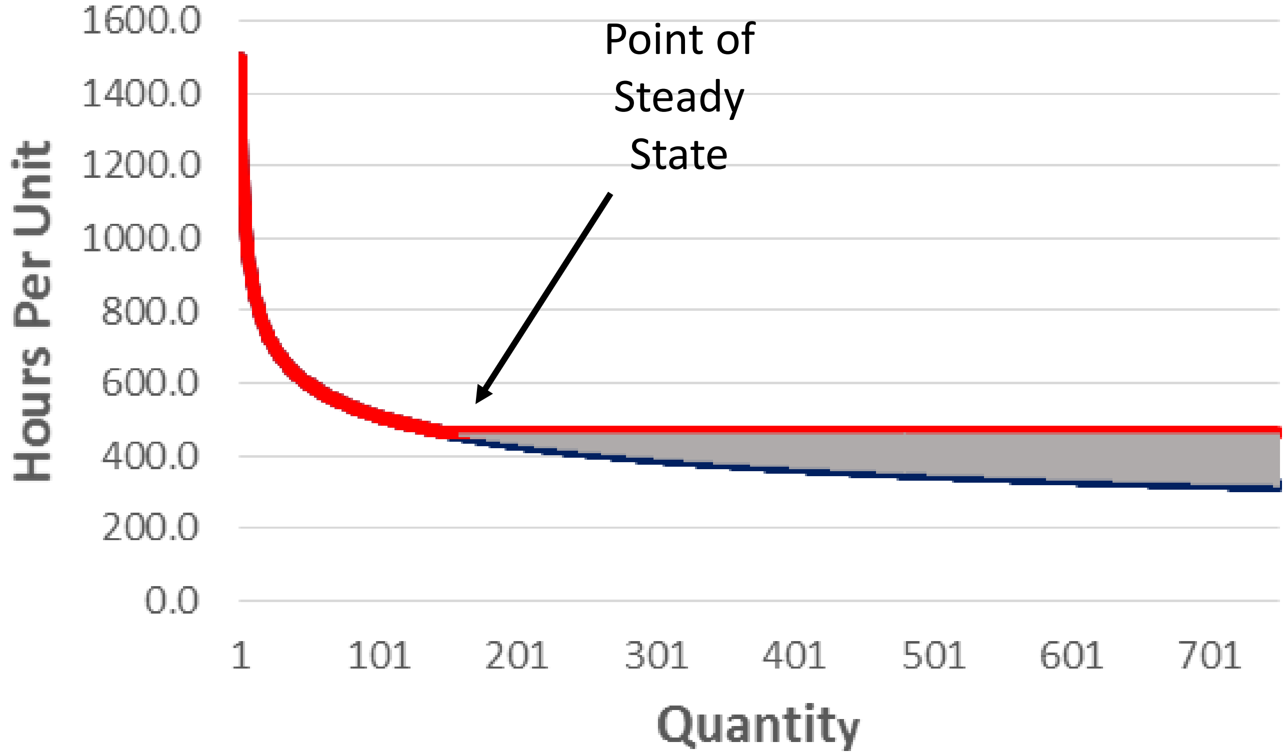
Identifying commonality will only enhance the estimating process if we can integrate these findings into the learning curve models

INTEGRATION GOALS

- Identify a baseline point on independent curves where common work content can be compared
- Enable a process which will allow common and unique work content to be separated

INTEGRATION OF COMMONALITY - PRODUCTION STEADY STATE

PRODUCTION STEADY STATE DEFINED

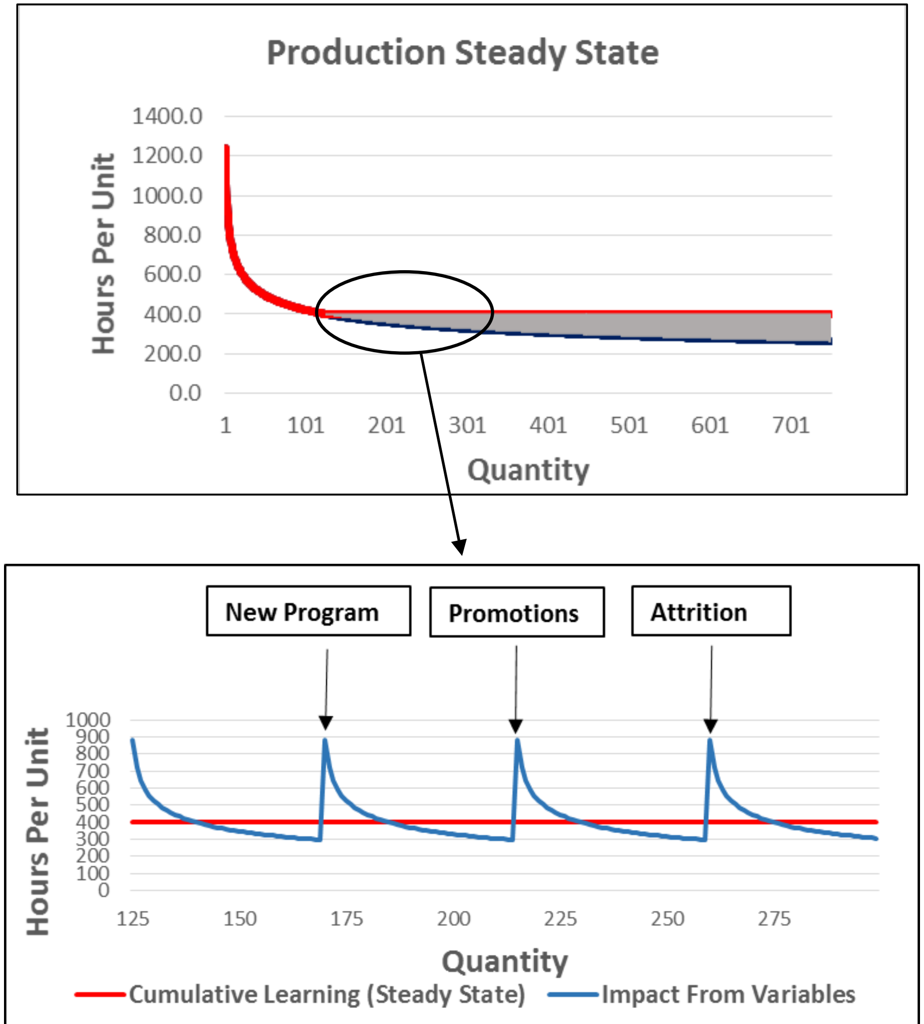


INTEGRATION OF COMMONALITY - PRODUCTION STEADY STATE

WHY DOES THIS OCCUR?

- Maximum efficiency is approached or achieved
- Quality metrics are consistently met
- Uncontrollable and unpredictable variables that can impact efficiency gains
  - Attrition
  - Promotions
  - Business Base Variability
- Consult with various organizations in order to understand all aspects of the plant dynamics
  - Production Management
  - Industrial Engineering
  - Human Resources
  - Quality
  - Design Engineering and Others

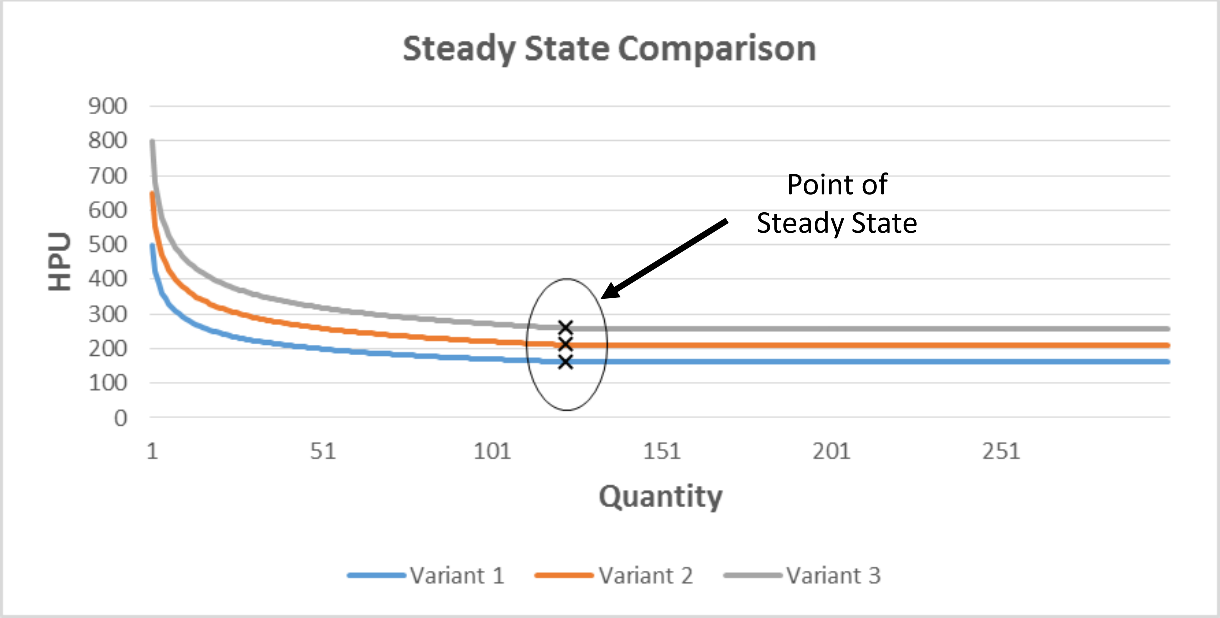
INTEGRATION OF COMMONALITY - PRODUCTION STEADY STATE



PRODUCTION STEADY STATE

WHAT IS THE IMPACT?

- Cumulative learning ceases and Hour Per Unit (HPU) estimates increase
- Accurate assessment of what typically occurs in production environments
- Commonality can be assessed from an apples-to-apples perspective



COMMONALITY INTEGRATION

ASSESSING COMMONALITY AMONG END ITEMS

- Utilize work measurement to provide a baseline of work content required at the steady state for each item
- The common work environment enables the comparison of standard hours across variants
- The historical point of steady state provides a specific unit on the learning curves for comparison

PROPOSED METHODOLOGY

SO HOW DOES THIS WORK?

- Define variables:
  - V_n = Weapon System Variant *n*
  - LCS_n = Learning Curve Slope for Variant *n*
  - LCS_C = Common Learning Curve Slope
  - X_{SS} = Unit *X* at Which Production Steady State Occurs
  - Y_{SSC} = Hours of Steady State Work Content Common to all Variants V_1 through V_n for n = 1, 2,…, *n* (For Process Commonality)
  - $Y_{SSCVn,..,n}$ = Hours of Steady State Work Content Common to any subset of Variants V_1 through V_n for n = 1, 2,…, *n* (For Process Commonality)
  - Y'_{SSn} = Total Hours of Steady State Work Content Unique to Individual Variants V_1 through V_n for n = 1, 2,…, *n*

PROPOSED METHODOLOGY

- Step 1 – Common Curve Development
  - Generate learning curves that will account for work content common to all variants or sub-sets of variants
  - Begin by identifying X_{SS} and Y_{SSC}
  - For subset commonality, identify $Y_{SSCVn,\ldots.,n}$ for any combination of variants greater than 1 and less than *n*
  - Common curves are generated utilizing LCS_C, X_{SS} and Y_{SSC} or $Y_{SSCVn,\ldots.,n}$
  - Specific points on the curves can be calculated as follows:

$$Y_{SSXn} = \frac{Y_{SSC}}{X_{SS}^{\log(\mathrm{LCS}_C)/\log(2)}} \times X_n^{\log(\mathrm{LCS}_C)/\log(2)}, \text{ for } X_n < X_{SS}$$

$$Y_{SSXn} = Y_{SSC}, \text{ for } X_n \geq X_{SS}$$

Note – The equations shown are for the curve common to all variants. The equations are the same for subsets of variants

PROPOSED METHODOLOGY

- Step 2 – Unique Curve Development
  - Define learning curves that will account for work content unique to each variant
  - Remove work content common to all variants (Y_{SSC}) as well as the commonality accounted for in any subsets that include the variant in question:

$$Y'_{SS1\text{-}n} = Y_{SS1\text{-}n} - Y_{SSC} - \left(\sum Y_{SSCVx,\ldots\ldots,n}\right)$$

  - Slopes should be revisited and validated based on the work scope remaining

PROPOSED METHODOLOGY

- Step 3 – Compile Hours
  - If interested in total program hours, sum totals of all curves developed
  - If interested in totals by variant, refer to the production schedule
    - How many units worth of learning will be realized on each curve on a monthly basis (or other period of time) based on the production schedule
    - Calculate the average HPU for those units for each month and curve
    - Multiply the scheduled number of units for that variant by the sum of the HPUs for each curve applicable to that variant
    - Sum monthly totals for each variant

EXAMPLE

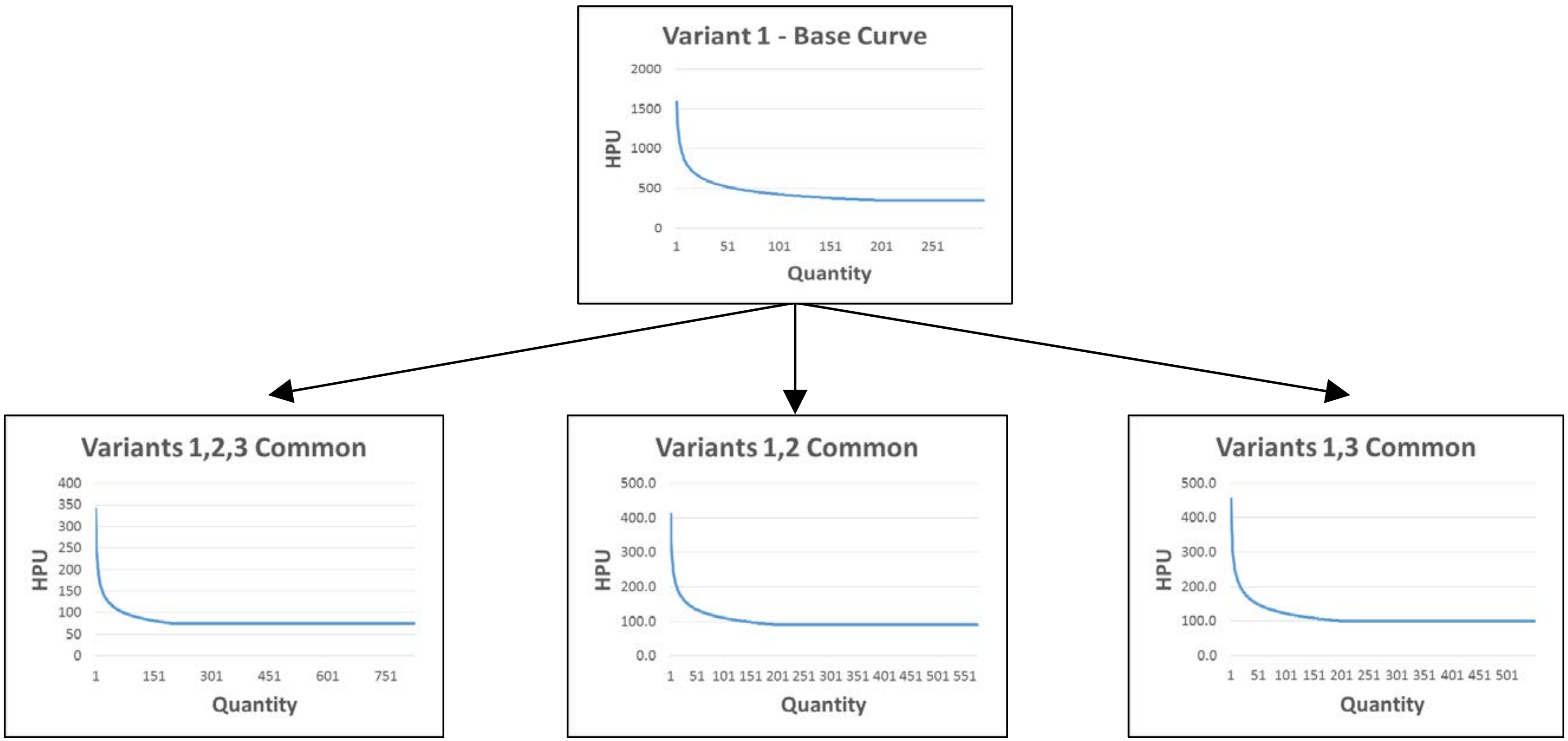
- A new program has three variants with the following data identified through historical data and work measurement performed on prototype units. Data analysis for recent programs indicates production steady state typically occurs around the 200th unit for this facility. The anticipated production schedule is provided as well:

	Variant 1	Variant 2	Variant 3
LCS	**82.0%**	**82.0%**	**82.0%**
Quantities	300	275	250
Steady State Hours	350.0	425.0	466.0
Hours Common to 1,2,3	75.0	75.0	75.0
Hours Common to 1,2	90.0	90.0	0.0
Hours Common to 1,3	100.0	0.0	100.0
Hours Common to 2,3	0.0	200.0	200.0
Variant Unique Hours	85.0	60.0	91.0

Production Schedule			
Month	**Variant 1**	**Variant 2**	**Variant 3**
1	5	4	4
2	12	9	8
3	15	10	10
4	15	13	13
5	19	18	16
6	19	18	16
7	19	18	16
8	19	18	16
9	19	18	16
10	19	18	16
11	19	18	16
12	19	18	16
13	19	18	16
14	19	18	16
15	19	18	16
16	19	18	16
17	15	15	15
18	10	8	8
Total	300	275	250

EXAMPLE

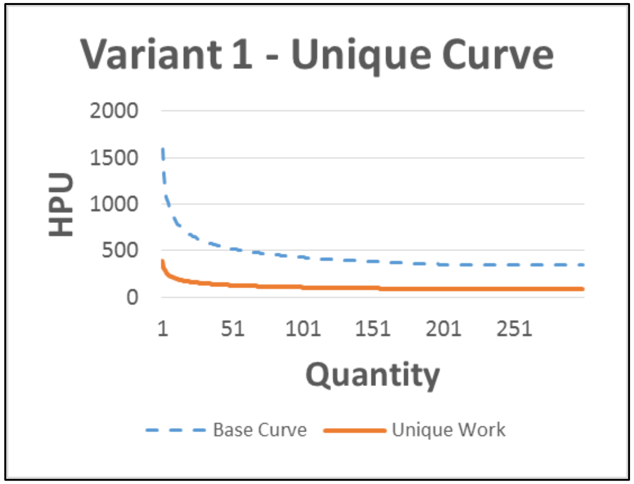
- We begin by extracting the common work content for Variant 1:

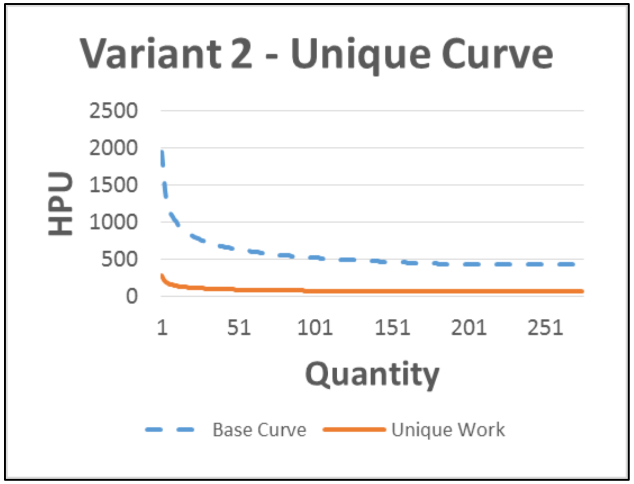


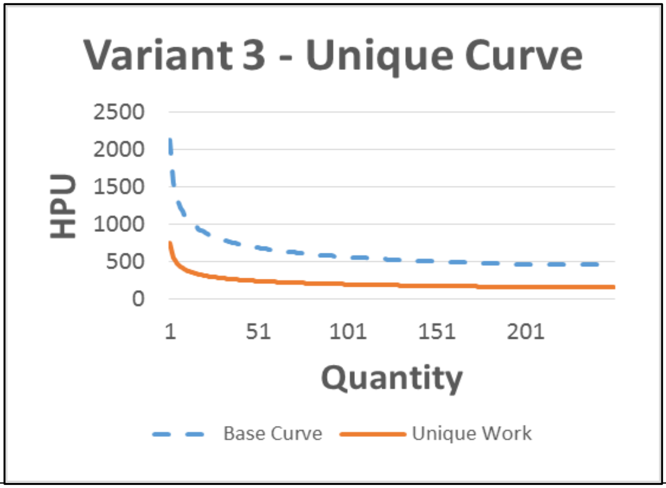
- Repeat process for Variants 2 & 3

EXAMPLE

- Now the unique variant work curves are developed:







NOTE –Base variant curves shown to gauge common work extracted

EXAMPLE

- Compilation of hours

Average Hours Per Unit							
Month	Common 1,2,3 Curve HPU	Common 1,2 Curve HPU	Common 1,3 Curve HPU	Common 2,3 Curve HPU	Unique Variant 1 Curve HPU	Unique Variant 2 Curve HPU	Unique Variant 3 Curve HPU
1	213.0	278.5	309.4	635.4	298.6	220.3	609.6
2	134.1	177.3	198.2	411.9	196.1	148.2	416.0
3	106.4	140.5	157.2	329.7	155.0	119.2	335.1
4	92.2	122.1	136.3	285.2	135.0	103.6	289.4
5	82.4	109.4	122.2	253.2	122.0	91.9	257.5
6	75.9	100.0	112.0	230.4	112.2	83.4	235.1
7	75.0	93.4	104.8	214.7	105.3	77.6	219.6
8	75.0	90.1	100.3	203.1	99.9	73.3	207.8
9	75.0	90.0	100.0	200.0	95.6	69.9	198.4
10	75.0	90.0	100.0	200.0	92.0	67.1	190.6
11	75.0	90.0	100.0	200.0	88.9	64.7	184.1
12	75.0	90.0	100.0	200.0	86.3	62.7	178.4
13	75.0	90.0	100.0	200.0	85.0	60.9	173.5
14	75.0	90.0	100.0	200.0	85.0	60.0	169.1
15	75.0	90.0	100.0	200.0	85.0	60.0	166.1
16	75.0	90.0	100.0	200.0	85.0	60.0	166.0
17	75.0	90.0	100.0	200.0	85.0	60.0	166.0
18	75.0	90.0	100.0	200.0	85.0	60.0	166.0

EXAMPLE

Total Hours Required				
Month	Variant 1	Variant 2	Variant 3	Total
1	5,497.6	5,389.1	7,069.9	17,956.6
2	8,469.0	7,844.2	9,282.3	25,595.4
3	8,387.9	6,958.3	9,285.2	24,631.4
4	7,284.9	7,841.5	10,441.5	25,567.9
5	8,282.3	9,662.8	11,443.3	29,388.5
6	7,602.5	8,814.8	10,455.3	26,872.6
7	7,191.6	8,293.8	9,825.4	25,310.8
8	6,940.0	7,947.1	9,379.5	24,266.6
9	6,850.7	7,828.1	9,173.7	23,852.5
10	6,782.4	7,777.7	9,049.9	23,610.0
11	6,724.4	7,735.2	8,945.2	23,404.8
12	6,674.1	7,698.8	8,854.9	23,227.8
13	6,650.0	7,667.0	8,775.9	23,092.8
14	6,650.0	7,650.1	8,705.8	23,005.9
15	6,650.0	7,650.0	8,658.4	22,958.4
16	6,650.0	7,650.0	8,656.0	22,956.0
17	5,250.0	6,375.0	8,115.0	19,740.0
18	3,500.0	3,400.0	4,328.0	11,228.0
Total	122,037.5	134,183.4	160,445.2	416,666.1

- The base curves for Variants 1-3 on slide 20 total 433,600.7 hours
- Reduction of 3.9% in total hours estimated for the program by accounting for commonality

CONCLUSIONS AND FUTURE CONSIDERATIONS

LIMITATION - AS THE NUMBER OF VARIANTS GROWS, SO DOES THE AMOUNT OF COMMONALITY TO CONSIDER

Possible Combinations For Various End Item Quantities

Subset Size (s)	Number of End Items (n): 2	3	4	5	6	7	8	9	10	$n > 10$
2	1	3	6	10	15	21	28	36	45	$\frac{n!}{(2! * (n-2)!)}$
3	-	1	4	10	20	35	56	84	120	$\frac{n!}{(3! * (n-3)!)}$
4	-	-	1	5	15	35	70	126	210	$\frac{n!}{(4! * (n-4)!)}$
5	-	-	-	1	6	21	56	126	252	$\frac{n!}{(5! * (n-5)!)}$
6	-	-	-	-	1	7	28	84	210	$\frac{n!}{(6! * (n-6)!)}$
7	-	-	-	-	-	1	8	36	120	$\frac{n!}{(7! * (n-7)!)}$
8	-	-	-	-	-	-	1	9	45	$\frac{n!}{(8! * (n-8)!)}$
9	-	-	-	-	-	-	-	1	10	$\frac{n!}{(9! * (n-9)!)}$
10	-	-	-	-	-	-	-	-	1	$\frac{n!}{(10! * (n-10)!)}$
$s > 10$	-	-	-	-	-	-	-	-	-	$\frac{n!}{(s! * (n-s)!)}$

CONCLUSIONS AND FUTURE CONSIDERATIONS

- Schedule and production rate should be considered
  - Consider how frequent (or infrequent) particular variants are integrated and assembled
  - Variants with large time lapses between builds should either not be included or adjusted for lost learning – particularly the variant unique work
- Additional research should be performed in the areas of product commonality and production steady state

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Q&A