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DEFINING THE FUTURE

An Enterprise Model of Rising Ship Costs: Loss of Learning Due to Time between Ships and Labor Force Instability

The Advanced Learning Model

Briefing to:
NPS's 4th Acquisition Research Symposium
Monterey, CA – 17 May 2007

Also being briefed to:

SCEA
The Society of Cost Estimating and Analysis

SCEA 2007, New Orleans

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ALM "World Tour"

Date	Senior Attendee(s)	Variant	Organization	Position
Sept 21, 2004	Mr. Brian Cuccias	DDG Prelim	NGSS	DD(X) VP
Sept 22, 2004	Ms. Patti Tisone & NG Pricing Council	DDG	NG HQ	Corporate Director
Feb 14, 2005	Mr. Paul Robinson	DDG/LHD	NGSS	Sector VP
March 2, 2005	Capt. Goddard	DDG/LHD	Navy	DD(X) PM
March 2, 2005	Dr. Tze-Nan Lo; Dr. P. Bronson	DDG/LHD (abbr)	CAIG	DD(X) Analyst
April 4, 2005	Dr. Phil Dur & NGSS Management Council	DDG/LHD	NGSS	(Former) President NGSS
April 5, 2005	Mr. Richard Greco Jr., Capt. Sean Stackley	DDG/LHD	DoN Secretariat	ASN(FM&C), LPD PM
April 7, 2005	Capt. John D. Ingram	DDG/LHD	Navy	DDG PM
April 14, 2005	Capt. Rich Hooper	DDG/LHD	Navy	LHD PM
May 2, 2005	Ms. Allison Stiller	DDG/LHD	DoN Secretariat	DASN (Ships)
May 2, 2005	RADM Charlie Hamilton	DDG/LHD	Navy	PEO (Ships)
May 20, 2005	Bob Spiker, Bat Robinson, Mark Carroll	LPD	NGSS	Sector VP, Sector VP, VP
June 3, 2005	Mr. Tom MacKenzie, Mr. Creighton Greene	DDG/LHD	SASC	Senior staffers
June 29, 2005	VADM Crenshaw	DDG/LHD	OPNAV	N8
August 5, 2005	Mr. Tom Johnston	CVN	NGNN	Sector VP
Sept 7, 2005	Mr. Chris Deegan/ Capt. Rich Hooper	DDG/LHD	Navy	Dir. NAVSEA 017/ LHA 6 PM
Sept 27, 2005	LTC John Thurman, Fred Janicki, Capt. Hooper	DDG/LHD	OSD CAIG/NAVY	OSD CAIG, LHA 6 PM
Oct 7, 2005	Mr. Gary Bliss, Mr. Chris Deegan, Mr. Ed Foster, Mr. Brian Cuccias	DDG/abbr LHD	OSD CAIG/NAVY	Branch Head OSD CAIG
Nov 8, 2005	Mr. John Young & NG C&P Leadership Council	DDG/LHD	NG	VP, C&P
May 24, 2006	Capt. Rich Hooper	ALM 2	Navy	PMS 377
Jul 19, 2006	Management Council	ALM 2	NGSS	Pres, NGSS
May 17, 2007	NPS's 4th Acquisition Research Symposium	ALM 3	NPS	-
Jun 12, 2007	ISPA/SCEA 2007	ALM 3	SCEA	-

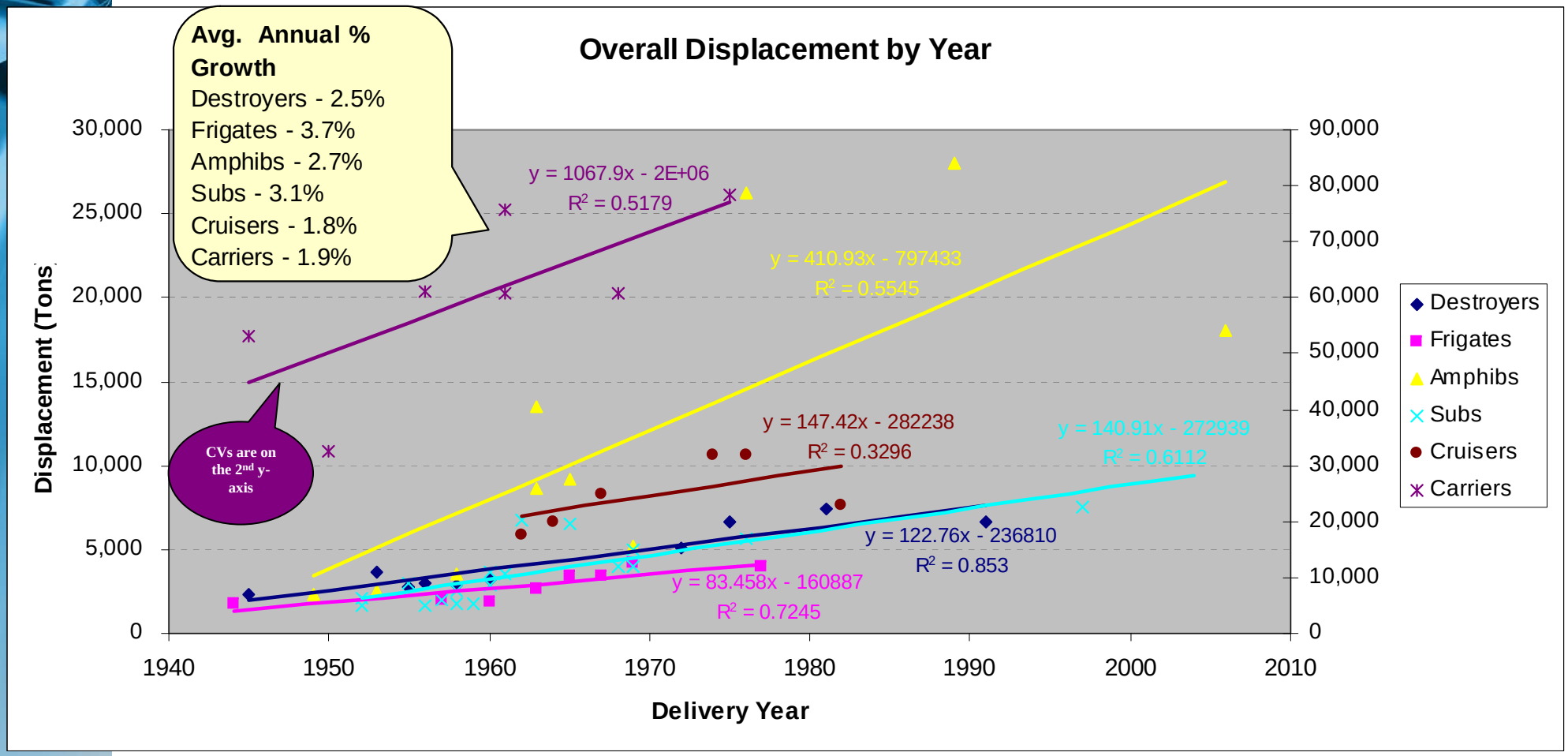
Outline*

- **ALM 1 – Loss of learning for 2 classes (days between start Fab)**
  - The Base Case – the DDG Advanced Learning Model
    - DDG Learning Curve
  - The Validation Case – The LHD Advanced Learning Model
    - LHD Learning Curve
  - Meta-analysis and Mutual Confirmation
- **ALM 2 - The Enterprise Model – a predictive model for an entire shipyard complex**
- **ALM 3 – Percent overlap**
  - Shift of ALM 1 days-between-start-Fab to percent overlap
  - Prediction of the learning curve based upon the percent overlap alone
- **Conclusions**

* For logical flow, the order of the brief will be ALM 1,3,2

Historical Ship Growth by Weight

WWII to the Present



Note: Ship weight growth differed before WWII

The DDG & LHD ALM 1
DDG 51 and LHD 1 Class Learning Curve Analyses

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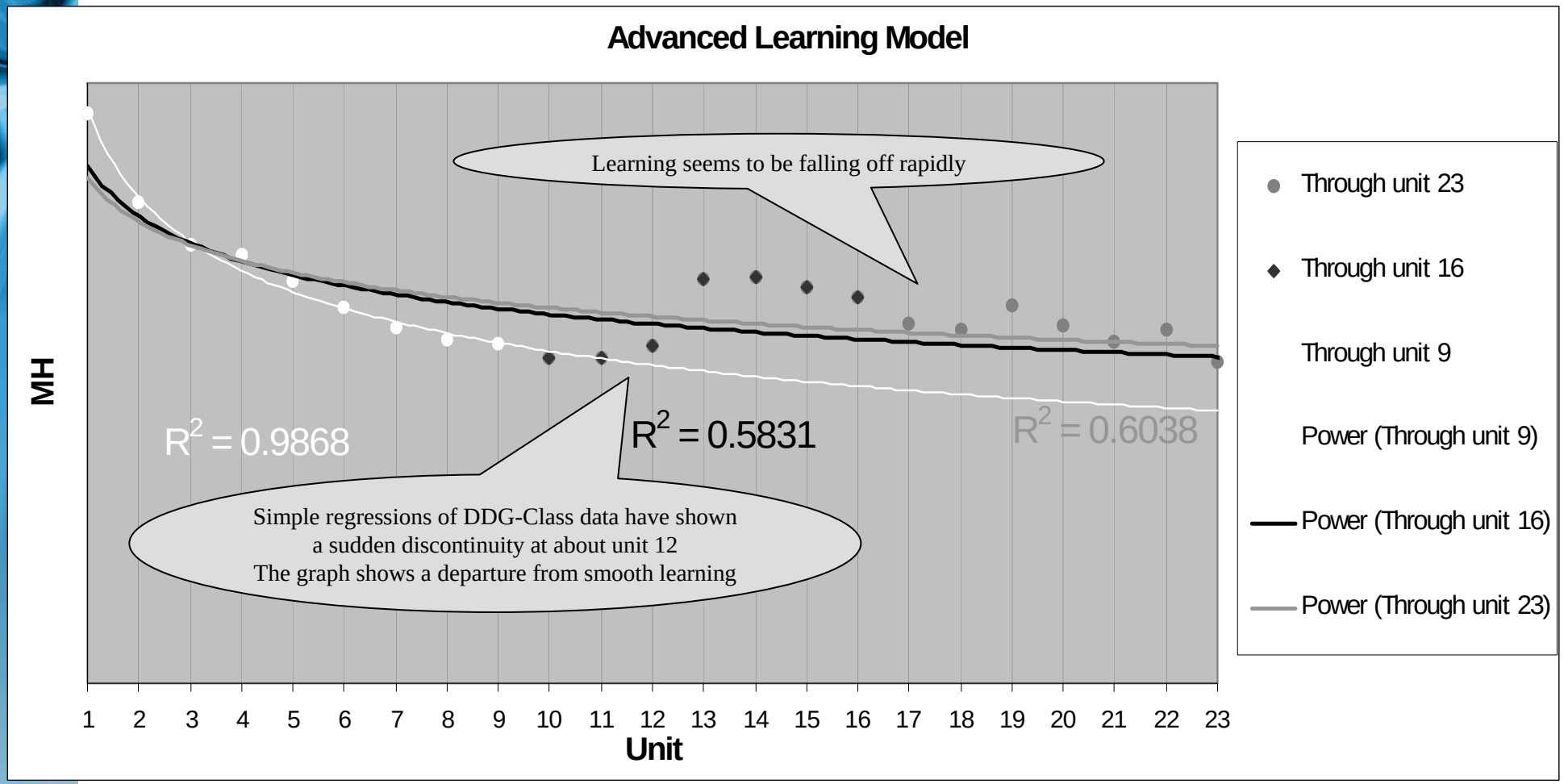
Purpose

- **Describe analysis that demonstrates underlying learning in the DDG class**
  - This is the Advanced Learning Model for DDGs
- **Show how the ALM was applied to the LHD class which validated it**

Original Work (w/ C/O)

Learning Curve Regressions through DDG 69 (9), DDG 86 (16) and DDG 95 (21)



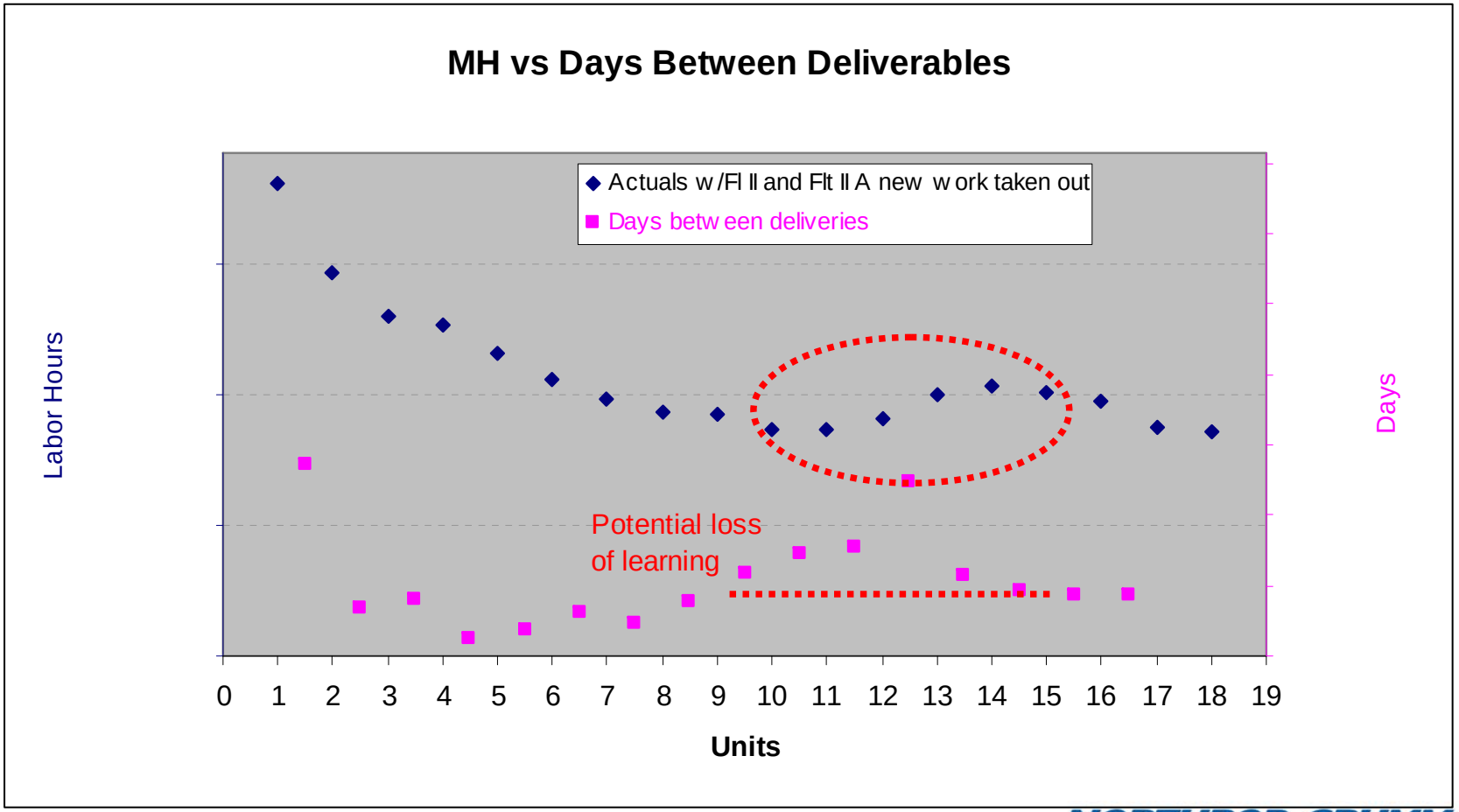
Note: This is not a valid approach – it is a cautionary tale

What is happening?

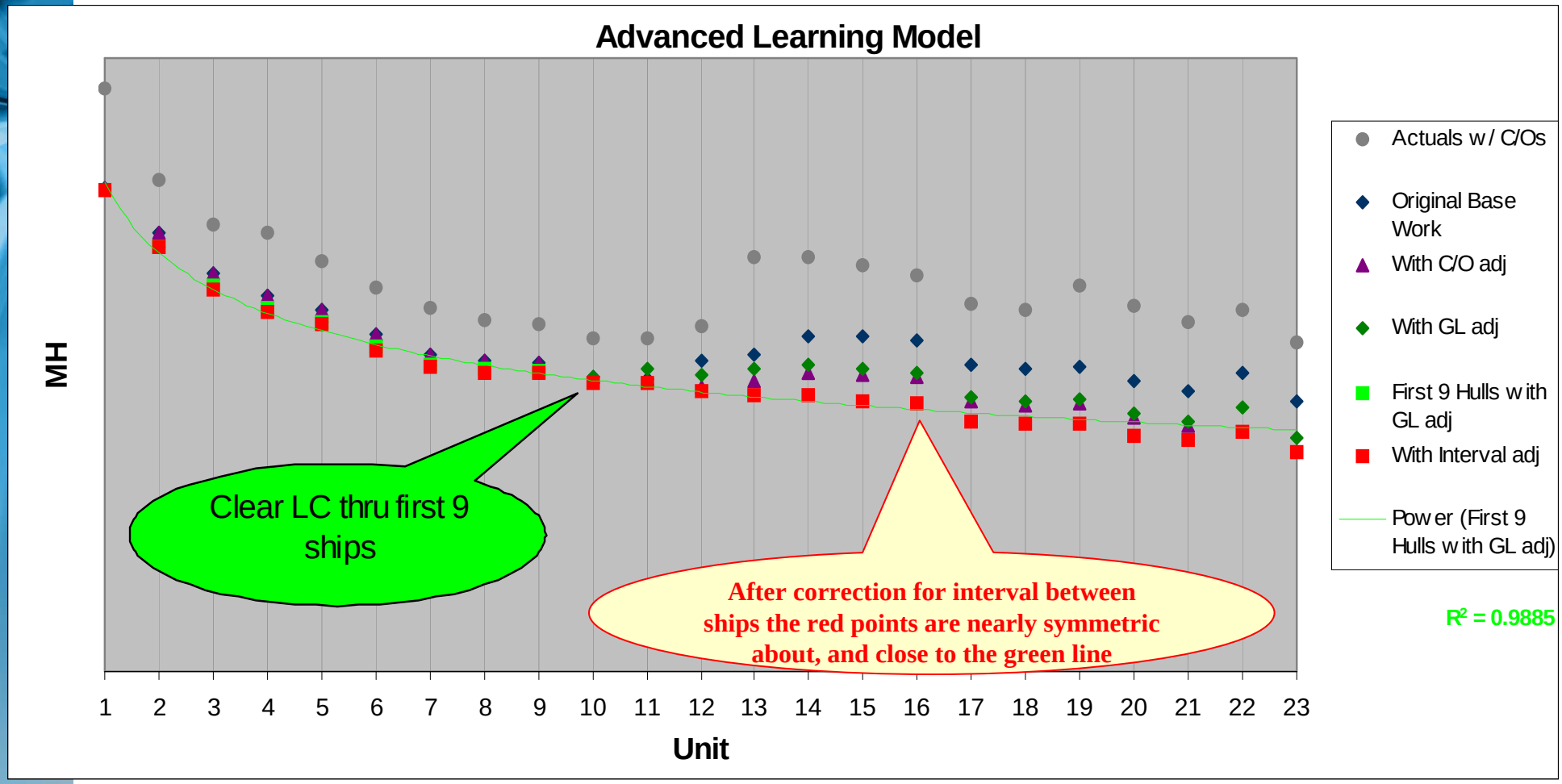
- **Learning curve theory requires:**
  - A steady work force
  - Building the same product multiple times
  - No significant interruptions or pauses
- **The DDG program wasn't like that, nor was the LHD program**
- **If these conditions are not fulfilled, there is discussion in the literature of loss of learning, but no closed-form statistically based method to predict how much learning is lost**
  - The Anderlohr Break-in-Production Model quantifies the effects of production breaks, but it requires expert opinion and so is not defensible – it is only useful when mutually agreed to
- **We will now look at the DDG case and show the ALM approach by "peeling the onion"**

The Key Graphic
How One Graph Changed the Whole Approach

- **The below graphic, one of many scatterplots, proved to be the breakthrough**
- **Vessel Labor is plotted on the left axis, and interval between deliveries on the left**
  - The measure was later changed (on advice from NGSS) to Time Between Start Fab to avoid impacts of duration increases



The Advanced Learning Model

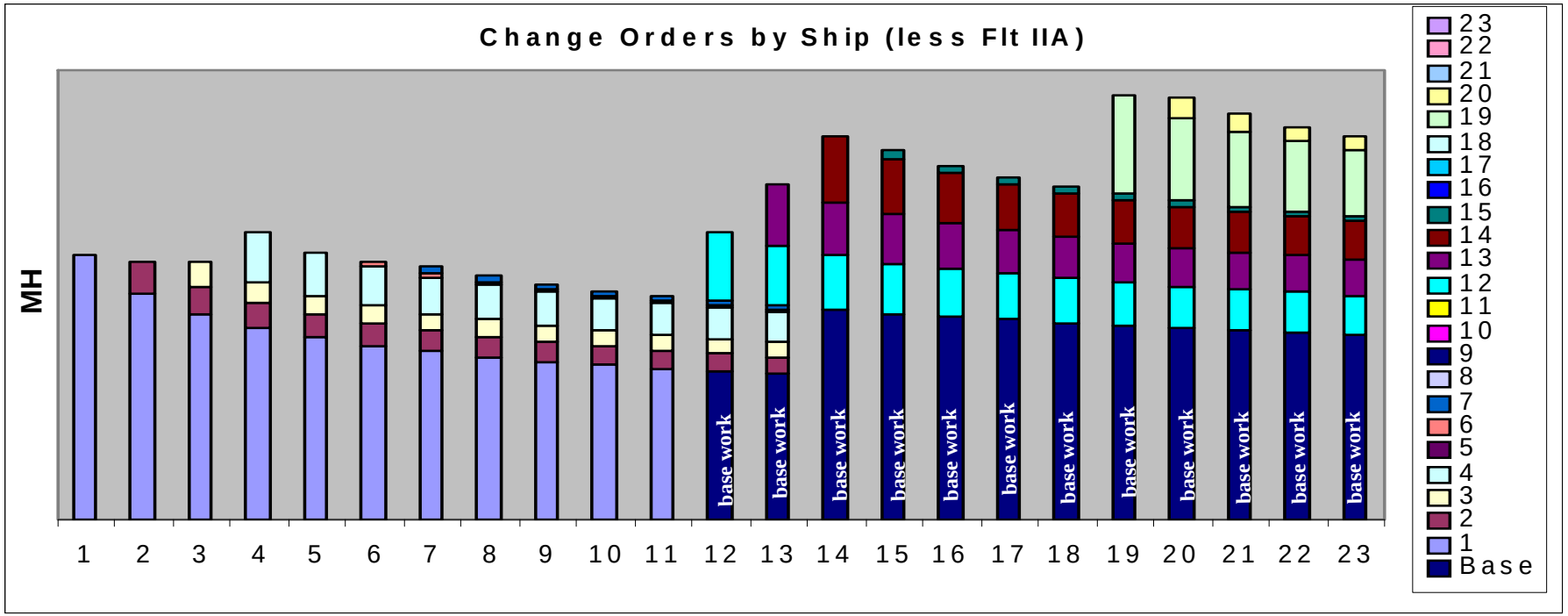


- **We progressively applied adjustments to go from the original gray data points with “all effects in” to the final data points with “all effects out”**

Supporting analysis to follow

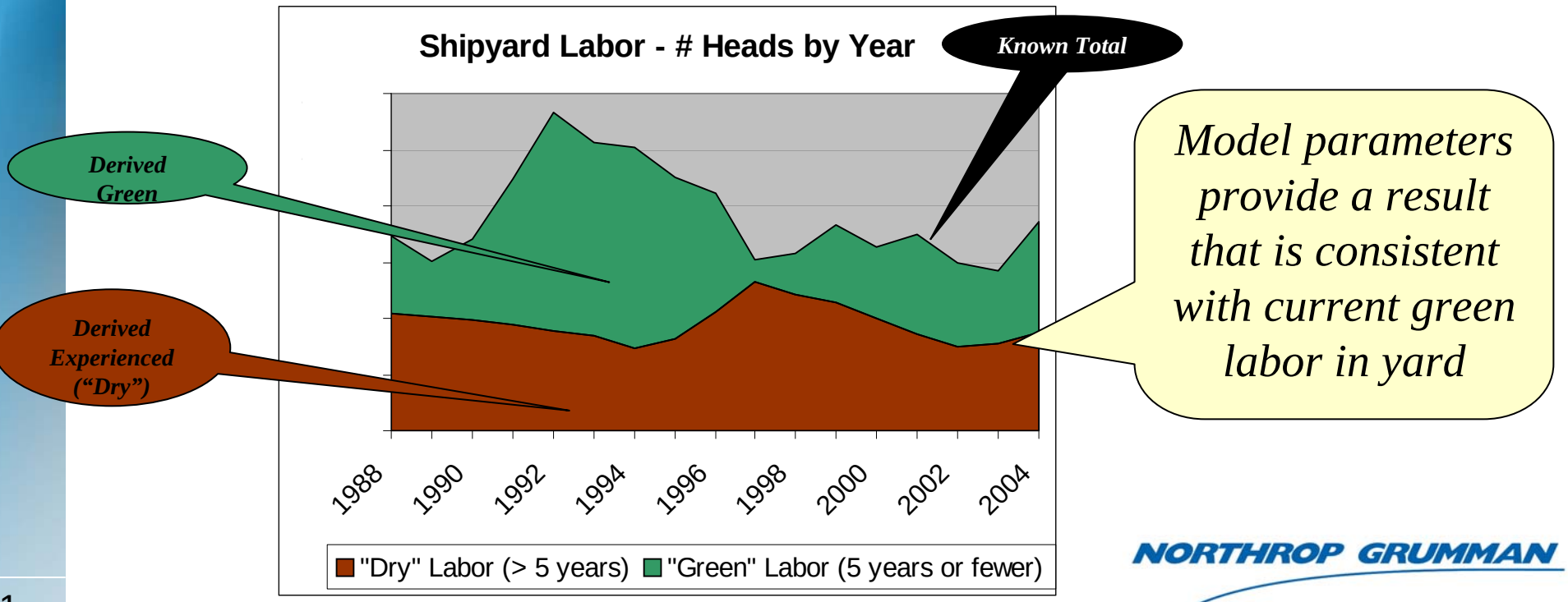
Change Order Model
Analysis for Step 2

- **Worked with Ingalls Change Order Estimators to adjust total C/O values for Ripout, Disruption, and One-time changes, as well as absorption into base work**
- **Applied underlying % learning and used iterative process to determine "first-time changes" in work scope for each ship, these values were <u>not</u> recorded**
- **Interviewed senior engineers at Ingalls to determine where C/Os were absorbed into base work (reconciled with DDG RFPs)**
- **Results:**



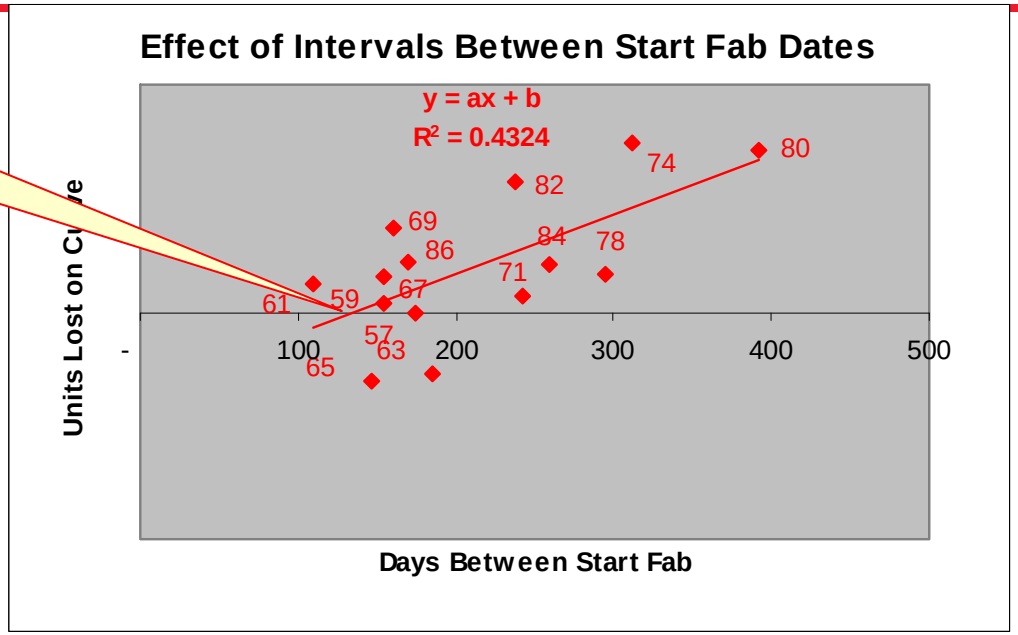
Green Labor Model
Analysis for Step 3

- **Assumptions:**
  - Green Labor is defined as a worker with less than 5 years experience; after 5 years, “Green Labor” becomes “Dry/seasoned Labor”
  - Green Labor is only partly as effective (% effectiveness = P) as Dry Labor (Ingalls study)
    - Newport News study shows a similar (lower)
    - Percentages probably differ with type of ship, yard, etc.
  - Green Labor is always hired and fired before Dry Labor
- **Using Ingalls Labor Data from 1988-2004 and third assumption above, derived average % Green Labor for each DDG**
  - Labor is split evenly throughout the shipyard with each class of ship receiving the same distribution of Green and Dry Labor
- **Adjusted all DDG hulls to notional Green Labor as follows:**
  - ((%DL + (P*%GL)) / (Notional%DL + (P*Notional%GL)) * MH
  - For example for a notional ship where average GL is 52.8% and initial manhours XXX the adjustment would be:
    - ((47.2% + (P*52.8%)) / (49.2% + (P*50.8%)) * XXX MH = YYY MH
    - Thus: If the notional ship had been built with notional Green Labor, it would have taken YYY MH



Interval Model
Analysis for Step 5

No-loss-of-learning point



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6575657
R Square	0.4323927
Adjusted R	0.3850921
Standard Ei	0.6206015
Observatior	14

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	3.5207673	3.5207673	9.1413771	0.0105944
Residual	12	4.6217552	0.3851463		
Total	13	8.1425225			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.905235	0.4945857	-1.830289	0.0921419	-1.982844	0.1723748
X Variable		0.0021824	3.023471	0.0105944	0.0018434	0.0113535

Regression is significant at $\alpha = 0.05$ (p-value = 0.01)

**Note: DDG 52 was omitted from the regression because DDG 52 has no interval by definition (there is no previous ship). DDG 55 was omitted because second ships have inordinately long gaps always, and do not seem to belong to the rest of the family. DDG 88-95 are omitted because the regression is meant to assess the impact of interval gaps and since DDG 88-95 are thought to have impacts due to facilities improvements, lean and six-sigma, etc in them, including them would have skewed the regression. In order to isolate the effect of the interval, we only regressed the "clean" points, 57-86.*

The LHD ALM: Validation of the DDG ALM LHD Class Learning Curve Analysis

- **The DDG ALM is complete and statistically valid**
- **We now turn to a second class of ship to ascertain whether the DDG ALM was an accident**
  - The science of statistics guards against this, but it is nevertheless customary to do a second independent trial to validate *important* studies

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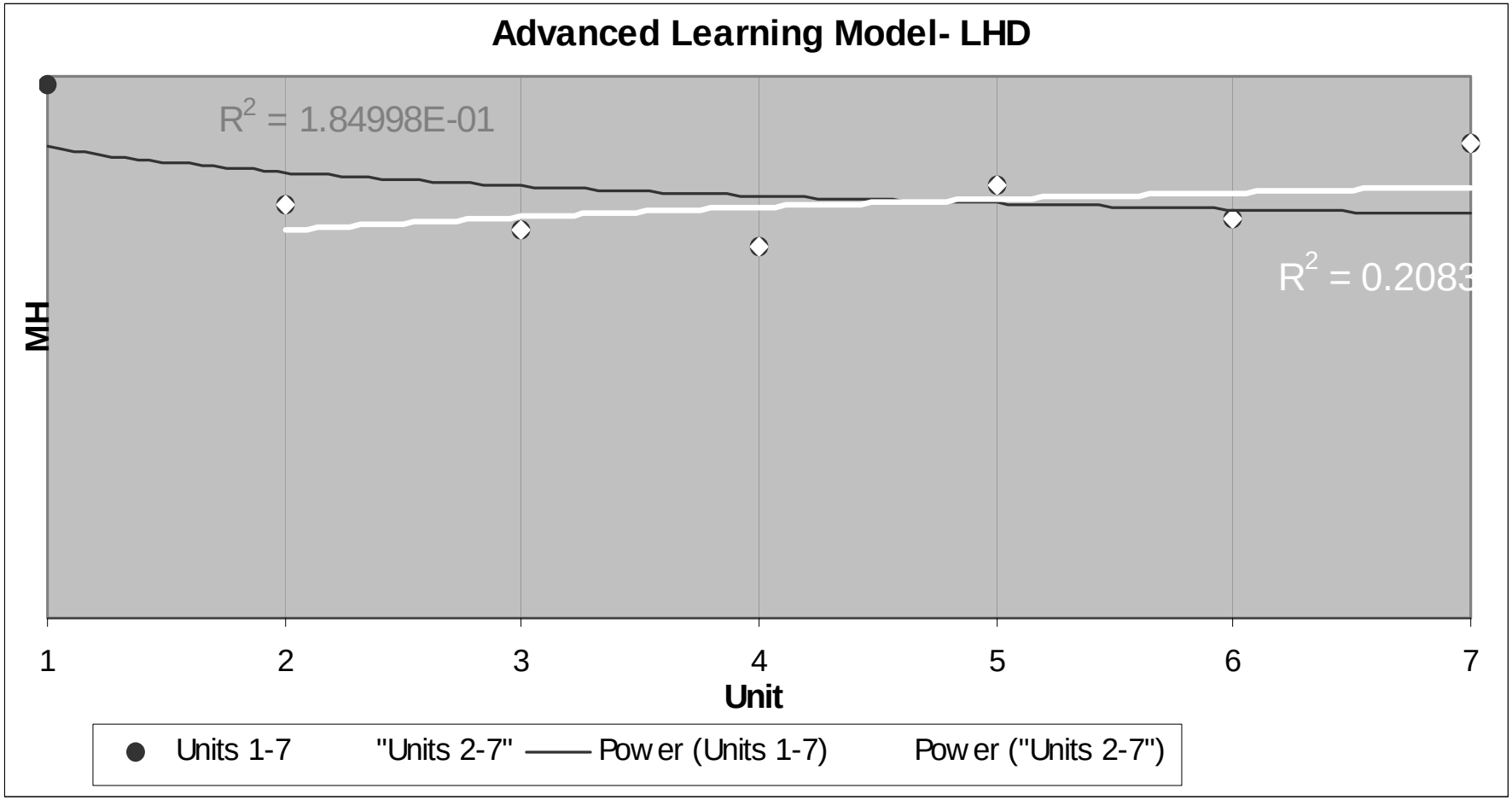
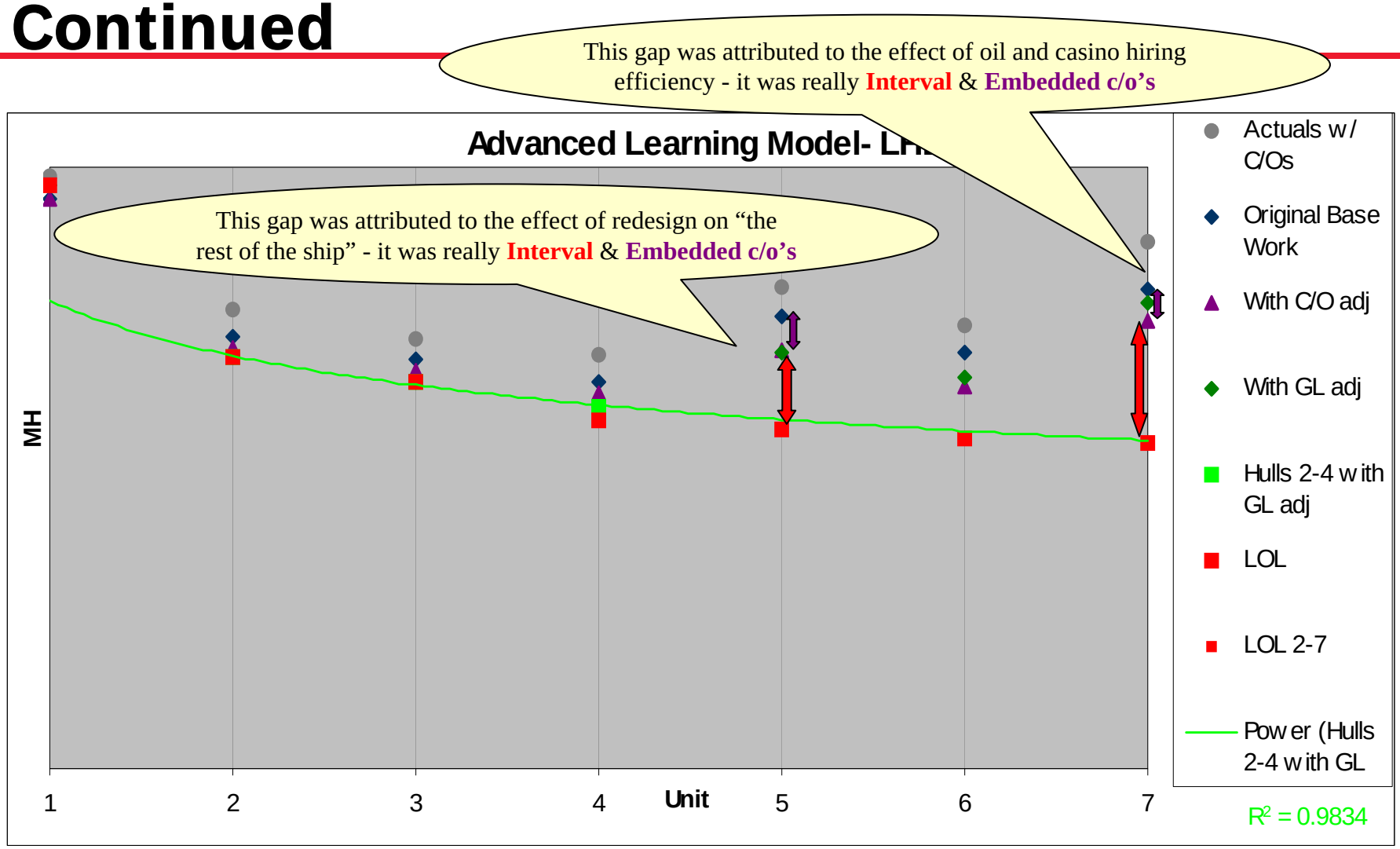
Original Work (w/o C/O)

Learning Curve Regressions through LHD 1-7 & LHD 2-7



Note: This is not a valid approach – it is a cautionary tale

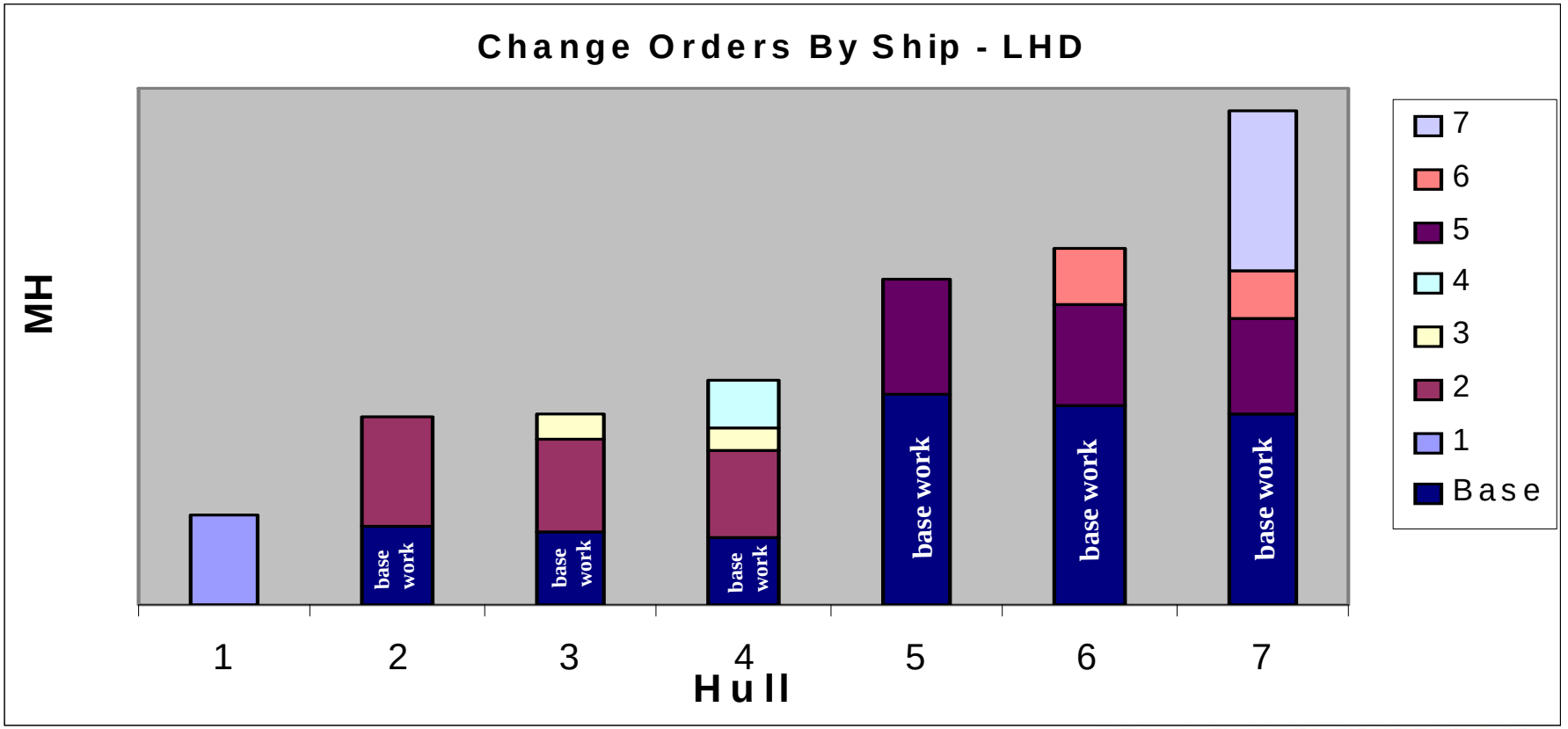
Advanced Learning Model: LHD Analysis Continued



6) Notionalize interval between starts (dark green to red)

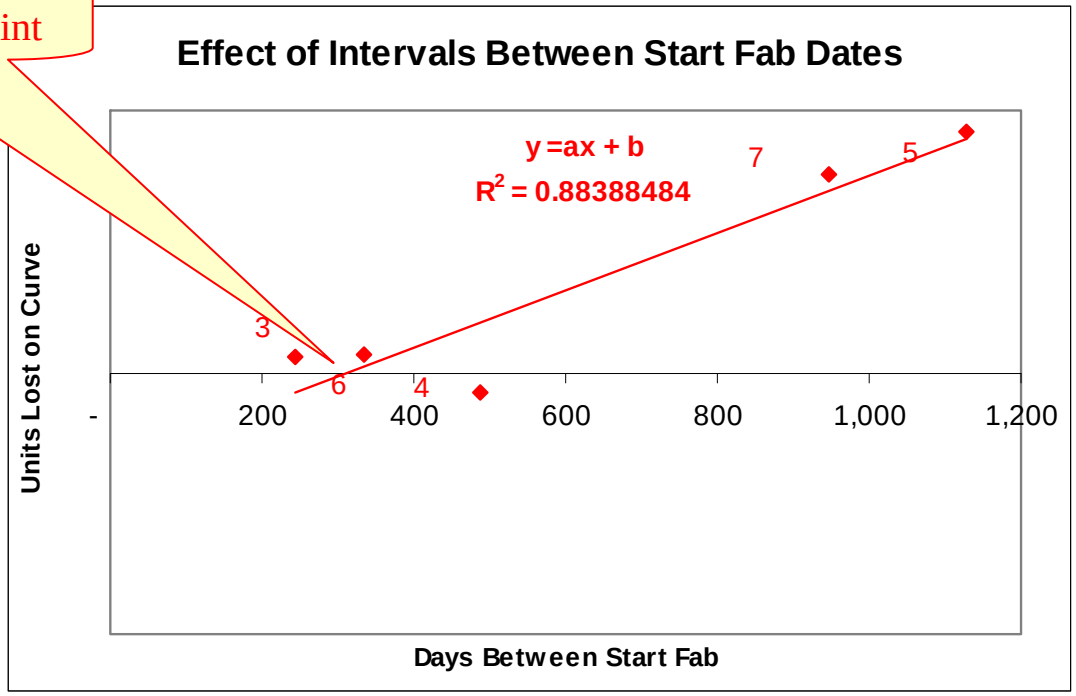
Change Order Model
Analysis for Step 2

- **Worked with Ingalls Change Order Estimators to adjust total C/O values for First Time Changes, Ripout, Disruption, and One-time changes**
- **Interviewed senior engineers at Ingalls to determine where C/Os were absorbed into base work (reconciled with LHD RFPs)**
- **Results:**



Interval Model
Analysis for Step 5

No-loss-of-learning point



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9421793
R Square	0.887701833
Adjusted R Sq	0.850269111
Standard Erro	0.623900889
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	9.230961	9.230961	23.71459	0.016545
Residual	3	1.167757	0.389252		
Total	4	10.39872			

Regression is significant at $\alpha = 0.05$ (p-value = 0.017)

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-1.238166072	0.575543	-2.1513	0.12056	-3.0698	0.593468	-3.0698	0.593468
X Variable 1		0.000802	4.869763	0.016545	0.001354	0.006461	0.001354	0.006461

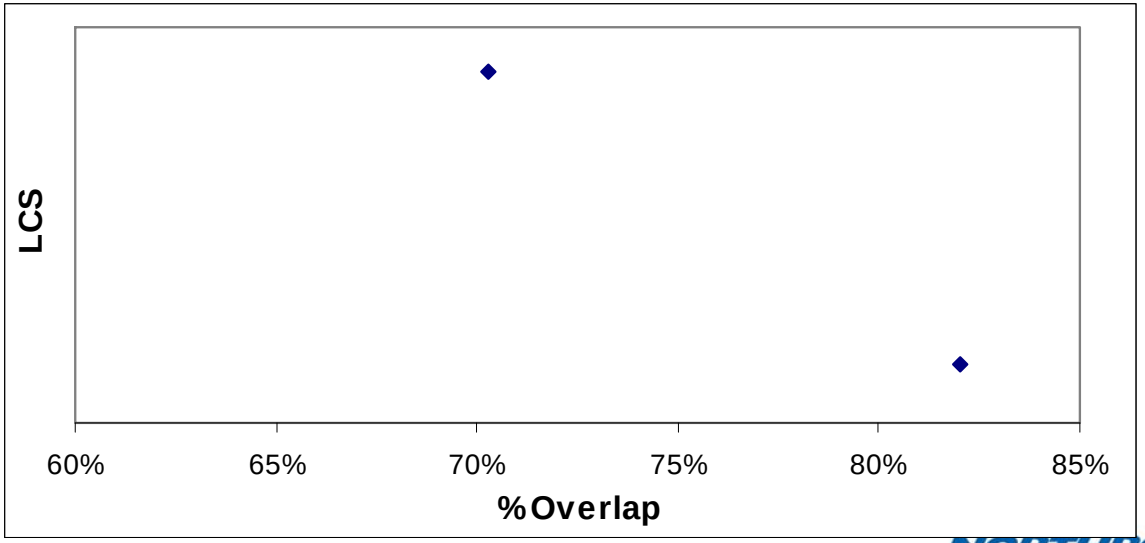
**Note: LDH 1 was omitted from the regression because LHD 1 has no interval by definition (there is no previous ship). LHD 2 was omitted because second ships have inordinately long gaps always, and do not seem to belong to the rest of the family*

Meta-analysis and Mutual Confirmation

- **To summarize**
  - The DDG model is, as far as statistics can take us, valid
  - The LHD model is also valid
  - We can use either
  - The LHD model represents a second ship class and was undertaken to confirm the DDG model, after the DDG model was complete
- **Taken together, however, the LHD and DDG models are much stronger than either is alone**
- **The models are mutually confirming**
  - Taken alone, the DDG analysis has the weaknesses that "first models" commonly have
    - Although reasonable, the adjustments were taken with a view to arrive at a smooth learning curve
      - Statistically, this amounts to an uncredited "loss of degrees of freedom"
      - Alternatively, a hostile view can arise that the "data was cooked"
    - The LHD model alleviates this concern
      - Since the steps taken with DDG were replicated in LHD and the same result was obtained, it was not dumb luck or manipulation
  - Taken alone, the LHD analysis lacks data across the full spectrum of interval length
    - The DDG model alleviates this concern
- **The significance of the entire analysis is the square of the significance of each: $0.05^2 = 0.0025$**
  - This is called meta-analysis and is a well known statistical technique

Interval Model- % Overlap

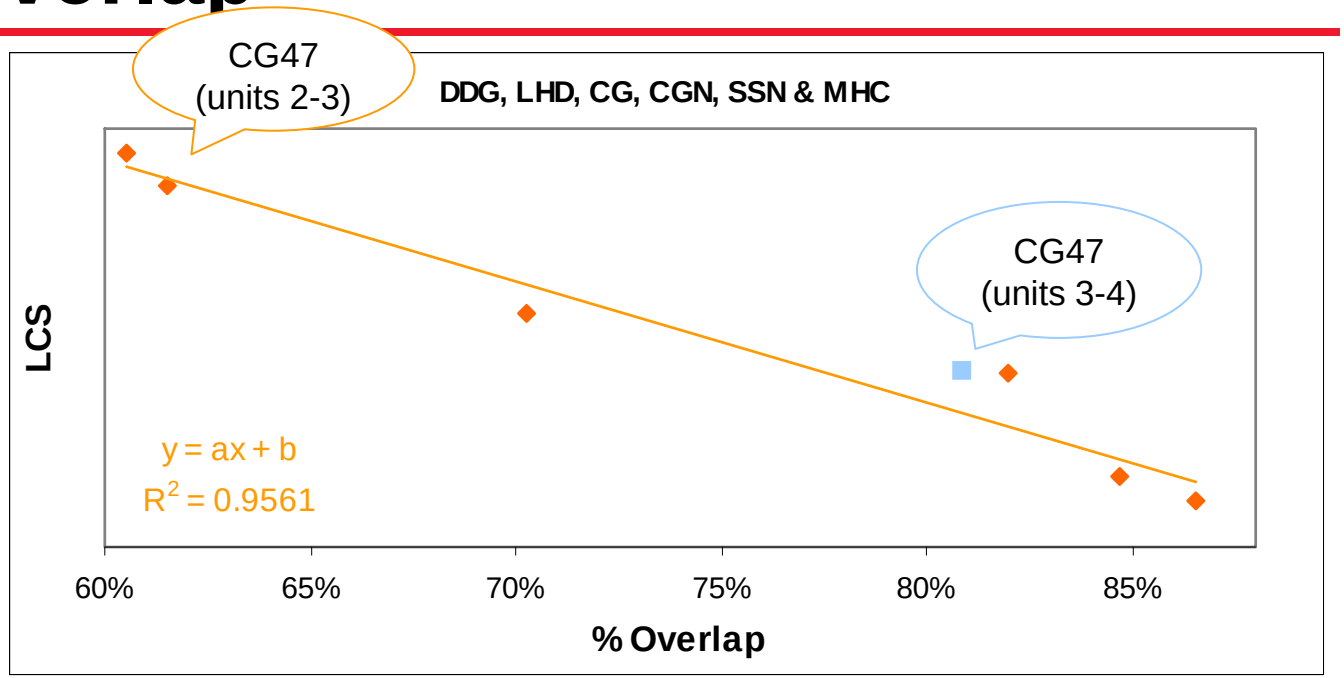
- The Interval Model demonstrates a relationship between schedule and LC slope within a given ship class; in its original form, this model could not be extrapolated for use in other ship classes
- To solve this, "days between ship starts" were translated into "% overlap" for both classes (DDG and LHD)
  - % Overlap: (Delivery Date (lead ship) – Keel Date (follow ship)) / Duration (lead ship)
    - Duration (days): Delivery Date – Keel Date
  - i.e., the % that LHD 4 overlaps with LHD 3 is found as follows:
    - (Delivery Date (LHD 3) – Keel Date (LHD 4))/ Duration (LHD 3)
- The observed learning curve slope was plotted against the average percent overlap of the ships which demonstrated the learning curve
- The graph *suggests* a relationship between % overlap and LCS



ALM 3 - Inputs

- The suggestion from the previous graph prompted an investigation of other ship classes
- A learning curve slope and associated average % overlap were found for: CGN 38, CG 47, MHC and SSN 688.
- When graphed along with DDG and LHD, a relationship between % overlap and LCS was evident
- This relationship can be used to predict the LCS of a future class with a known schedule (absent effects of Change Orders and Green Labor)

LCS vs. % Overlap



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.97778437
R Square	0.95606228
Adjusted R Squar	0.94507785
Standard Error	0.0145826
Observations	6

ANOVA

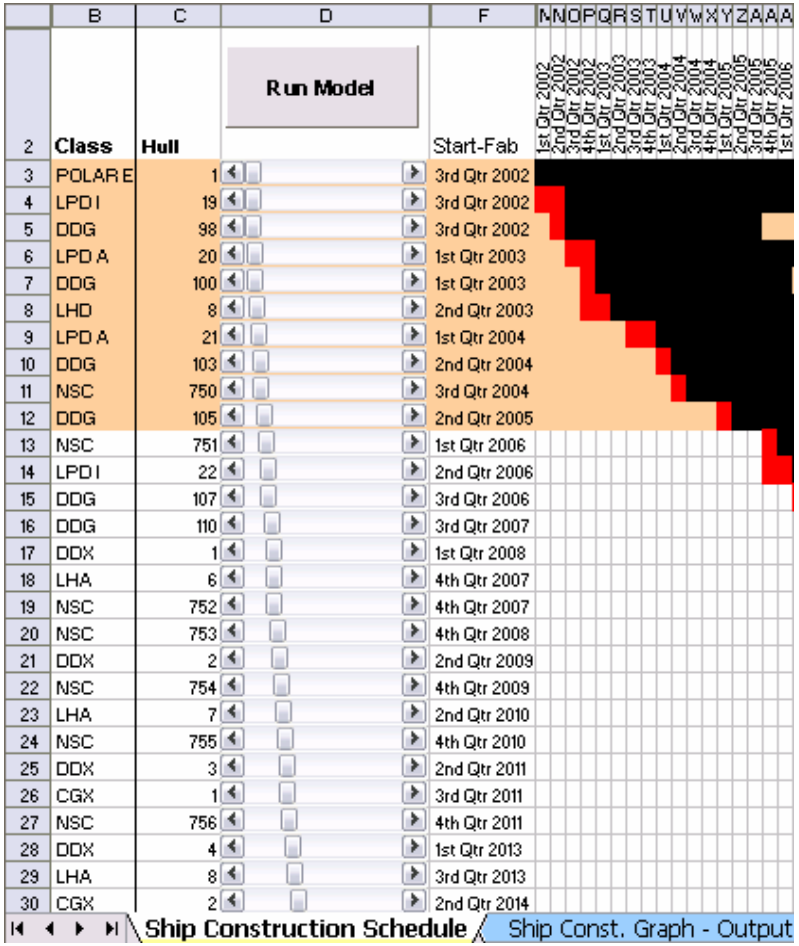
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.018508806	0.01850881	87.037946	0.000734819
Residual	4	0.000850609	0.00021265		
Total	5	0.019359414			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.25779617	0.041795155	30.0943058	7.261E-06	1.14175422	1.37383813	1.14175422	1.37383813
X Variable 1		0.055700939	-9.329413	0.0007348	-0.67430767	-0.3650065	-0.6743077	-0.3650065

The **orange** points were used in the regression; the **blue** point is a second point from the CG47 class which follows the same trend as the other data. **This point** experienced a significantly different LCS and % overlap than the **point** used in the regression.

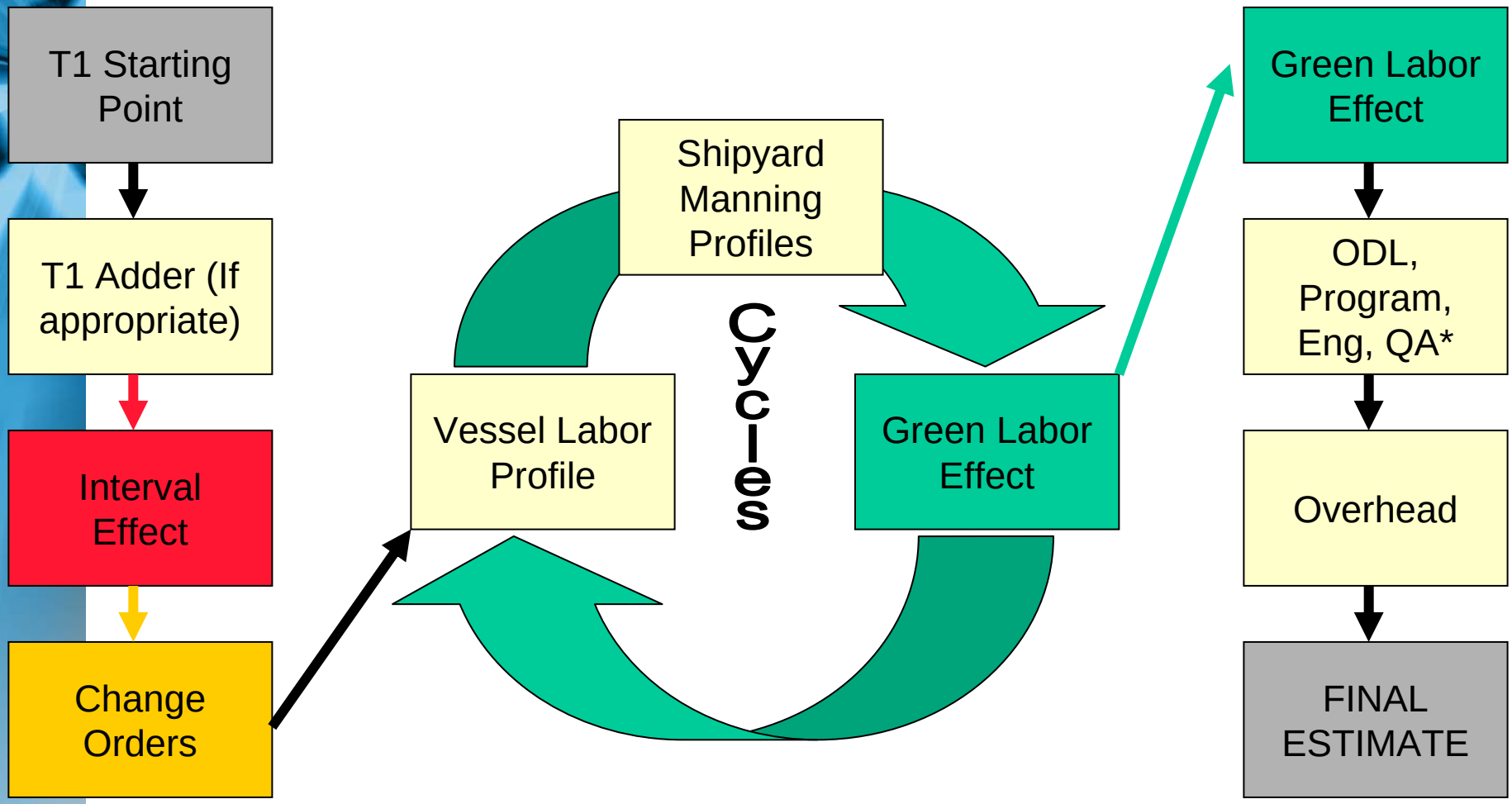
ALM -2 The Enterprise Model Ship Construction Schedule - Inputs

- **For every ship**
  - Pick a class from the drop-down menu
  - Type in a hull number
  - Use the sliders to enter the start-fab date
    - The red boxes represent quarters the ship is in construction before start-fab
  - Go to the right side of the calendar and if applicable:
    - Add a 1 for a T1
    - Add a 1 for a T1 adder
    - Add a 1 for a flight change
    - Otherwise, leave in the 0
- **Then Click on the "Run Model" Button**



	Class	Hull	Start-Fab
3	POLAR E	1	3rd Qtr 2002
4	LPD I	19	3rd Qtr 2002
5	DDG	98	3rd Qtr 2002
6	LPD A	20	1st Qtr 2003
7	DDG	100	1st Qtr 2003
8	LHD	8	2nd Qtr 2003
9	LPD A	21	1st Qtr 2004
10	DDG	103	2nd Qtr 2004
11	NSC	750	3rd Qtr 2004
12	DDG	105	2nd Qtr 2005
13	NSC	751	1st Qtr 2006
14	LPD I	22	2nd Qtr 2006
15	DDG	107	3rd Qtr 2006
16	DDG	110	3rd Qtr 2007
17	DDX	1	1st Qtr 2008
18	LHA	6	4th Qtr 2007
19	NSC	752	4th Qtr 2007
20	NSC	753	4th Qtr 2008
21	DDX	2	2nd Qtr 2009
22	NSC	754	4th Qtr 2009
23	LHA	7	2nd Qtr 2010
24	NSC	755	4th Qtr 2010
25	DDX	3	2nd Qtr 2011
26	CGX	1	3rd Qtr 2011
27	NSC	756	4th Qtr 2011
28	DDX	4	1st Qtr 2013
29	LHA	8	3rd Qtr 2013
30	CGX	2	2nd Qtr 2014

Model Summary



*Overhead computed off of all labor minus QA

Conclusions

- **The ALM 1 gives us a coherent picture of the <u>past</u> in the backward-looking model**
  - DDG ALM is complete
    - Demonstrates underlying LC for DDG
  - LHD ALM is complete and acts to verify the DDG ALM
    - Demonstrates underlying LC for LHD
- **The ALM 1 is also a Forward-looking Model that can handle most likely disturbances to cost improvement in the <u>future</u>:**
    - Green Labor
    - Intervals between Start Fab
    - Change orders – including c/o's absorbed into base work
- **The ALM 2 extends the findings of the ALM 1 to a shipyard-wide enterprise**
- **The ALM 3 is a *minor change* to the ALM 1 and a *major breakthrough* in Learning Curve determination:**
  - Shifts the basis of the ALM 1 from days between Start Fab to percent overlap, and allows us to move to other classes
  - Shows that percent overlap or production durations may be the only variable needed to predict LC for a ship class
    - We are investigating the clearly close resemblance of "Loss of Learning" to "Change in LC slope" … in CG 47 we observed the latter … we may end up changing the entire algebraic model of ALM 1 from the former to the latter

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