

A Practical Approach to Programming-Level Cost Estimation

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Introductions

A Practical Approach to Programming-Level Cost Estimation

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Magic

- **“Any sufficiently advanced technology is indistinguishable from magic.”**
 - AKA Clarke's 3rd Law
 - Source: *Profiles of the Future*, Arthur C. Clarke
 - Good statement of our model philosophy



Magic

- **The magic actually starts in the middle of the chronology**
 - Post – “need identification & model development”
 - Pre – “model utilization”
- **Practical: from here we’ll show both development and utilization (we’ll demonstrate our model’s chronology)**



Gadget Value

- **We all like gadgets –**
 - Smart Phones
 - Bluetooth
 - Juicers
 - Bullet blenders
 - Home theater
- **Most make something in our lives easier**



Gadget Value

- **Not a fan of home theater – too much trouble keeping coordinated with TV controls – I should consider “rent-a-geek” service**
- **What’s the point? If we have something with gadget value and it works like magic:**
 - WE WILL USE IT
 - WE WILL SHARE IT (most of us, anyway ...)



Gadget Value

- **Again, if we have something with gadget value and it works like magic:**
 - WE WILL USE IT
 - With all this USE, it had better work right!
 - Otherwise
 - Someone will have egg on their face
 - The use will die out
 - Like this slide, for instance ...
 - ...



Downside (magic has one?)

- “If it seems too good to be true it probably is”
 - A popular sentiment, and one that says even the appeal of “magic” won’t guarantee model usage
 - However:
 - We buy smart phones anyway
 - We buy tablets anyway
 - We even buy home theater anyway
 - So, it seems trust can be built - by
 - Sharing
 - Word of mouth
 - Presentations (this one, for instance)



Initially, (fill in the blanks ...)

- Initial model – A _____ project costs X per square foot
 - Add ____% for R/W
 - Add ____% for MOT
 - Add ____% for Mobilization
 - Add ____% for Contingencies; and so on ...
 - Rules-of-thumb were (are?) everywhere
- The message to project developers was “If you know more about your project, use it.”
- The answer: “We know the size, and ...”



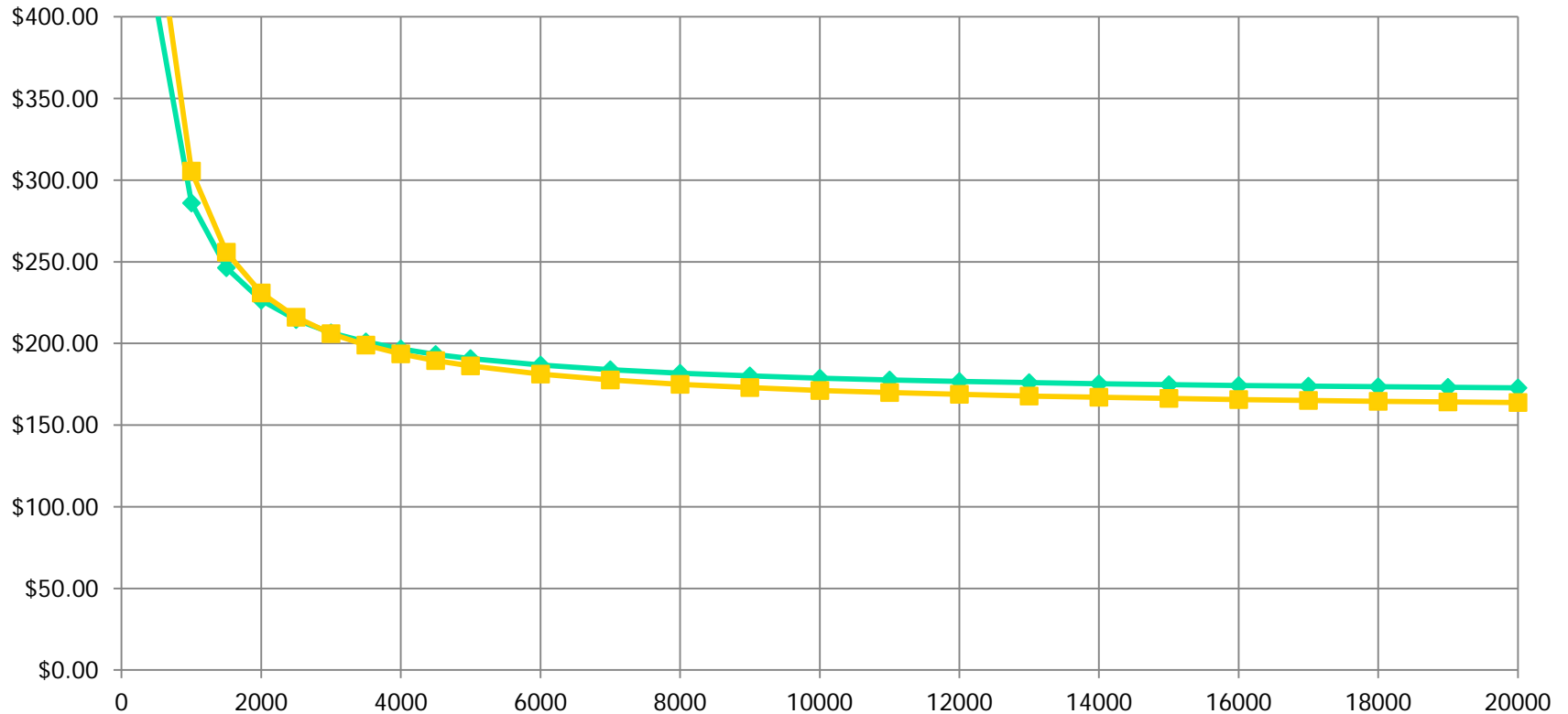
From humble beginnings ...

- Project size correlates with efficiency
 - As size increases cost goes down, but how?
 - Specifically, the UNIT COST decreases
- Uncertainty abounded from “filling in the blanks” (per previous slide)
- SO: A model was developed that simply had the characteristic shape representing declining per-unit-area cost
- BUT: This initial model was simply an amalgam of various rules of thumb



Oh, so humble ...

Average Cost/SF (w/o Runaround, assuming all scenarios equally likely)



Still beginning ... hang on!

- Those first models had multiple outputs
 - Some project knowledge had to be applied to a confusing array of outputs, from which the user had to choose
 - An “average” output was provided for the unsure
- These early models, being heuristically based, also lacked statistical validity, though still providing reasonable outputs
- The community of users provided good input, and the use of statistics helped move forward



Still hanging ...

Enter Deck Area Here -->		9,900	SF		Note that all cells with the heavy black borders are "named" cells, so that the formulas using them can appear more intuitive.	Average of scenarios 1-6 \$1,770,817 \$1,696,867 MOT % MOT Fixed
MOT	Closed (detour)	MOTc =	\$25,000	5.00%		
	Under Traf	MOTt =	\$50,000	10.00%		
	RWunaround (min)	MOTr =	\$150,000	20.00%		
	Appr Work	AppWrk =	\$100,000			
	Mob/DeMob eMOTc	MobNothr =	7.50%			
	Basic	SF _c =	\$140			
	Cost	Size =	9900			
	Right-of-W	None	RWz =	0.00%		
		RW _r	RWr =	5.00%		
		Urban	RW _u =	7.50%		
					Runaround cost formula: (MOTr+25*max(Size-5000,0))	
					Formulas are shown below for illustration only	
					(Note that fixed vs pct computation for Runaround needs a two	
			MOT %	MOT Fixed		
1	Closed, No R/W		\$1,671,750	\$1,622,450	=MOTc+(AppWrk+SF _c *Size)*(1+RWz+MobNothr)	
2	Closed, Rural R/W		\$1,746,050	\$1,696,750	=MOTc+(AppWrk+SF _c *Size)*(1+RW _r +MobNothr)	
3	Closed, Urban R/W		\$1,783,200	\$1,733,900	=MOTc+(AppWrk+SF _c *Size)*(1+RW _u +MobNothr)	
4	Under Traf, No R/W		\$1,746,050	\$1,647,450	=MOTt+(AppWrk+SF _c *Size)*(1+RWz+MobNothr)	
5	Under Traf, Rural R/W		\$1,820,350	\$1,721,750	=MOTt+(AppWrk+SF _c *Size)*(1+RW _r +MobNothr)	
6	Under Traf, Urban R/W		\$1,857,500	\$1,758,900	=MOTt+(AppWrk+SF _c *Size)*(1+RW _u +MobNothr)	
7	Runaround, No R/W		\$1,894,650	\$1,869,950	=(MOTr+25*max(Size-5000,0))+(AppWrk+SF _c *Size)*(1+R	
8	Runaround, Rural R/W		\$1,968,950	\$1,944,250	=(MOTr+25*max(Size-5000,0))+(AppWrk+SF _c *Size)*(1+R	
9	Runaround, Urban R/W		\$2,006,100	\$1,981,400	=(MOTr+25*max(Size-5000,0))+(AppWrk+SF _c *Size)*(1+R	

From $c=a+bx$ to $C = A + Bx^n$

- (Now, there's an intimidating title!)
- Intuition says a project should cost some combination of a constant and a product of a price and a quantity ($c=a+bx$)
- Consideration of the impact of size on project cost favors the other half of the title, with a value of $n < 1$
 - So, A represents items that are independent of size
 - B represents the cost of items of known size
 - n represents the cost efficiency of larger projects



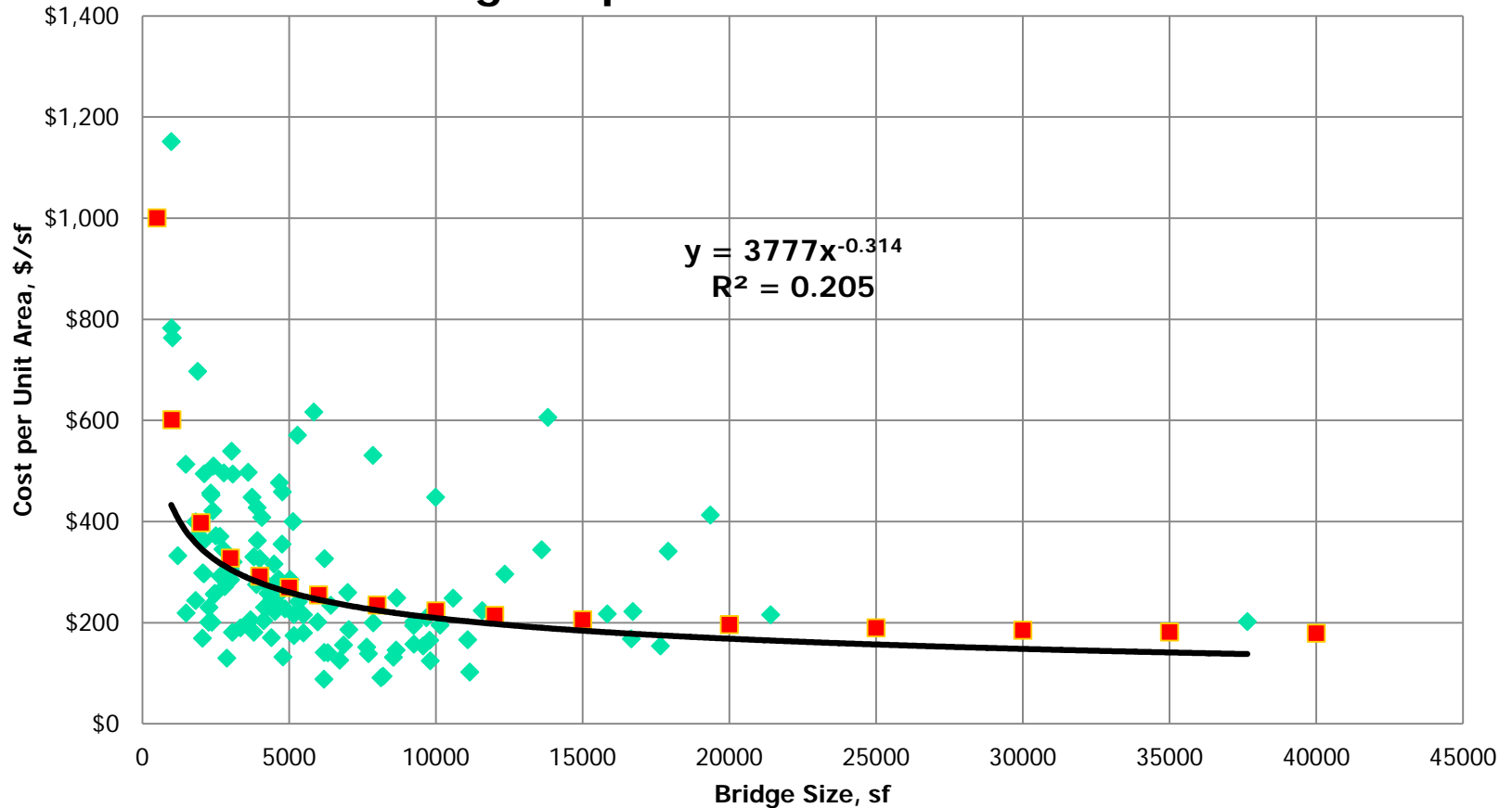
Statistics – first, trendlines

- So, if intuition says $C = A + Bx^n$ represents a reasonable approach to costs, how do we leave heuristics and embrace statistics?
- I promised a “practical approach” so ...
- MS Excel (and its competitors) provides built in graphing capabilities, including curve fitting
- Trendline forms available are limited:
 - Linear, polynomial, exponential, power, logarithmic
 - Moving average



Statistics – power trendline

Bridge Replacement Cost Model



From power to $C = A + Bx^n$

- From the previous chart you can see the power function trendline (solid black line) gives the characteristic shape we seek
- The model we use (red squares) approximates most of the trendline



Cutting to the chase ...

- **Model development – finding the A, B and n in $C = A + Bx^n$**
- **Trial & error, initially**
 - Cumbersome and time-consuming
- **Next, use of MS Excel Solver tool**
 - Requires an objective function to minimize
 - Unconstrained, shows tendency to converge to power trendline solution ($A = 0$)
 - Sensitive to starting values



Objective Function for Solver

- To match historical project costs, we wish to minimize $\sum(C_m - C_a)^2$, where C_m is the modeled cost of a given size project and C_a is the actual project cost (inflated to the present date)
- This value is, essentially, a SSE value of common use in statistics
- This does not, in and of itself, eliminate the use of trial and error



Grid Search of SSE Values

- To replace the use of Solver, “grids” were created, holding n constant and varying A and B , to find the “best” A and B combination for a given n
- Each cell in the grid is a sum of several hundred terms, and was initially calculated, copied into the grid, then repeatedly recalculated, copied, and so on



The grid – a sample

	"Grid Search" for Model (C = A + Bx^n) Solutions using n =										0.930
	Coefficient (B) Values										
Constant (A) Values	\$240	\$260	\$280	\$300	\$320	\$340	\$360	\$380	\$400	\$420	\$440
\$320,000	\$2,841,720	\$2,650,669	\$2,488,595	\$2,355,497	\$2,251,376	\$2,176,231	\$2,130,063	\$2,112,870	\$2,124,655	\$2,165,415	\$2,235,153
\$330,000	\$2,782,084	\$2,598,187	\$2,443,267	\$2,317,323	\$2,220,356	\$2,152,365	\$2,113,350	\$2,103,312	\$2,122,250	\$2,170,165	\$2,247,056
\$340,000	\$2,724,979	\$2,548,236	\$2,400,470	\$2,281,680	\$2,191,867	\$2,131,030	\$2,099,169	\$2,096,285	\$2,122,377	\$2,177,445	\$2,261,490
\$350,000	\$2,670,406	\$2,500,817	\$2,360,205	\$2,248,569	\$2,165,909	\$2,112,226	\$2,087,519	\$2,091,789	\$2,125,035	\$2,187,258	\$2,278,456
\$360,000	\$2,618,364	\$2,455,929	\$2,322,471	\$2,217,989	\$2,142,483	\$2,095,954	\$2,078,401	\$2,089,825	\$2,130,225	\$2,199,601	\$2,297,954
\$370,000	\$2,568,854	\$2,413,573	\$2,287,268	\$2,189,940	\$2,121,588	\$2,082,213	\$2,071,814	\$2,090,391	\$2,137,945	\$2,214,476	\$2,319,982
\$380,000	\$2,521,874	\$2,373,747	\$2,254,597	\$2,164,422	\$2,103,225	\$2,071,003	\$2,067,758	\$2,093,490	\$2,148,198	\$2,231,882	\$2,344,542
\$390,000	\$2,477,427	\$2,336,453	\$2,224,457	\$2,141,436	\$2,087,393	\$2,062,325	\$2,066,234	\$2,099,119	\$2,160,981	\$2,251,819	\$2,371,634
\$400,000	\$2,435,510	\$2,301,691	\$2,196,848	\$2,120,982	\$2,074,092	\$2,056,178	\$2,067,241	\$2,107,280	\$2,176,296	\$2,274,288	\$2,401,257
\$410,000	\$2,396,125	\$2,269,460	\$2,171,771	\$2,103,058	\$2,063,322	\$2,052,563	\$2,070,780	\$2,117,973	\$2,194,142	\$2,299,288	\$2,433,411
\$420,000	\$2,359,271	\$2,239,760	\$2,149,225	\$2,087,667	\$2,055,084	\$2,051,479	\$2,076,849	\$2,131,196	\$2,214,520	\$2,326,820	\$2,468,096
\$430,000	\$2,324,949	\$2,212,592	\$2,129,211	\$2,074,806	\$2,049,378	\$2,052,926	\$2,085,451	\$2,146,952	\$2,237,429	\$2,356,883	\$2,505,313
\$440,000	\$2,293,158	\$2,187,955	\$2,111,727	\$2,064,477	\$2,046,202	\$2,056,905	\$2,096,583	\$2,165,238	\$2,262,869	\$2,389,477	\$2,545,061



Spreadsheet example

- “Model” below refers to $C = A + Bx^n$;
“Best-Fit” refers to power trendline;
“Previous Model” refers to previously referenced crude amalgam of heuristics
- Left side of second row is top of several hundred data entries; right side is SSE value copied from bottom of table

Model Cost per SF	Model Diff	Model Diff^2	Excel Best-Fit Cost per SF	Best-Fit Diff	Best-Fit Diff^2		SSE Model	SSE Best-Fit	Previous Model
\$263.72	\$91.67	\$8,403.82	\$252.78	\$102.62	\$10,531.02		\$6,219,369	\$6,967,637	\$6,219,183

One last formulation feature

- The need to individually calculate SSE values to fill the cells in the grids was a heavy burden – nearly five thousand SSE values were calculated for the most recent modeling effort!
- First, this is very tedious, done one at a time
- Second, INDOT pays me to work smarter, not harder
- So, I wrote a simple macro to drive the calculations a full grid at a time



Some comments from macro:

The GridSearch Macro is developed as an aid to viewing "layers" of the solution space of a 3-variable model. The basic idea is to lay out two of the variables in a 2-D grid, with the third variable held constant for each "filling" of the grid. The grid variables are listed in the top and left side borders, and accessed for computing values for an objective function, of course with the third variable held constant during the computation. In the case for which this macro was developed, a cost model of the form $C = A + Bx^n$ is being developed for programming-level estimates of bridge replacement and rehabilitation projects. Various A and B values are listed in the left-hand-side and top borders, respectively, while the value for n is placed conspicuously in the table heading.

The point here is not the detail, but rather the importance of commenting one's code very well



Macro (first half)

- **Sub GridSearch()**

' Testing of Model: $C = A + Bx^n$

' Set parameter n - location may require updating

Range("DK1").Select

ActiveCell.Formula = Cells(24, 114)

' Establish Loop Indices - requires updating to match the size of the desired table

For I = 1 To 14

For J = 1 To 14

' Define Row and Column Values - requires updating to match locations in file used

Row = I + 26

Col = J + 106



Macro (second half)

- *' Set parameter A - location may require updating*
Range("DG1").Select
ActiveCell.Formula = Cells(Row, 106)
- ' Set parameter B - location may require updating*
Range("DI1").Select
ActiveCell.Formula = Cells(26, Col)
- ' Set grid cell SSE value - location may require updating*
ActiveSheet.Cells(Row, Col).Formula = Cells(113,
95).Value
Next J
Next I
End Sub



Macro wrap-up

- **Note only 15 “executable” lines in the macro!**
- **Still another level of sophistication that could be obtained with additional programming effort**
- **However, too much sophistication in the macro could lead to becoming overly detached from the results!**
- **And the current result is ...**



The (current) finished product

Enter NBI # Here -->	6350		
Structure #:	025-79-06562	Location:	
Route:	SR 25	WEACREEK, 1.01 mi S US 231	
RP:	29 + 86		
County:	079 - TIPPECANOE		
District:	01 - CRAWFORDSVILLE		
Length:	264	Width:	46.5
Existing Deck Area:	12,276	Enter Deck Area (in SF) if override is needed -->	12,276
MOT plus approach paving costs:			\$392,000
Mobilization / Demobilization costs:			\$173,000
Cost of bridge replacement , including removal of the existing bridge			\$2,048,000
TOTAL PROJECT COST (CN only!)			\$2,613,000
Note: Use SSR cost model for Precast Concrete Box Culvert & similar installations!			
Adjustments (enter brief description & costs):			
1)	location adjustment (for example ...)		(\$50,000)
2)	note parentheses () and red font for negative \$		
3)	adjustment for special circumstances (ADA??)		\$900,000
4)			
5)			
ADJUSTED TOTAL PROJECT CN ESTIMATE			\$3,463,000
RIGHT OF WAY	Select project setting -->	Rural	R/W Cost Estimate -->
	Enter Number of R/W Parcels -->	6	

Created by R E Montgomery for INDOT use as of 7/21/2014 - secured 9/26/2014 - updated formulas 10/23/2014



Demonstration

- We interrupt this program to bring you the following special announcement ...
- (Here's where we interrupt "death by powerpoint" to actually demo the software)



Other Models

- **Though less flashy, we actually get more use from models for Large Culvert replacement and pipe liners**
- **We have also developed models for “underfill” bridge replacements and for several categories of pavement preservation treatment**
- **ALL of these models are of the same form, $C = A + Bx^n$**



Pipe Liners

- **Two models, actually, and we use the higher resulting cost**
 - Model 1:
 - $A = \$20,000$, $B = \$500$, $n = 0.7$
 - Model 2:
 - $A = \$15,000$, $B = \$150$, $n = 0.825$
 - For both, the value of x is the total volume of the structure being lined



Small Structure Replacement

- For this model, it is intuitive to incorporate the ditch volume into the model, and we have done so
 - $C = A + BV^n$
 - Where
 - $V = (\text{structure volume}) * (\text{cover} + \text{height})$
 - And $A = \$50,000$, $B = \$5,000$, and $n = 0.40$



Underfill Bridge Replacement

- This model is still somewhat under development, and is similar to models used for small structures
- Again, $C = A + Bx^n$
 - Where:
 - $A = \$210,000$, $B = \$6,600$, and $n = 0.46$



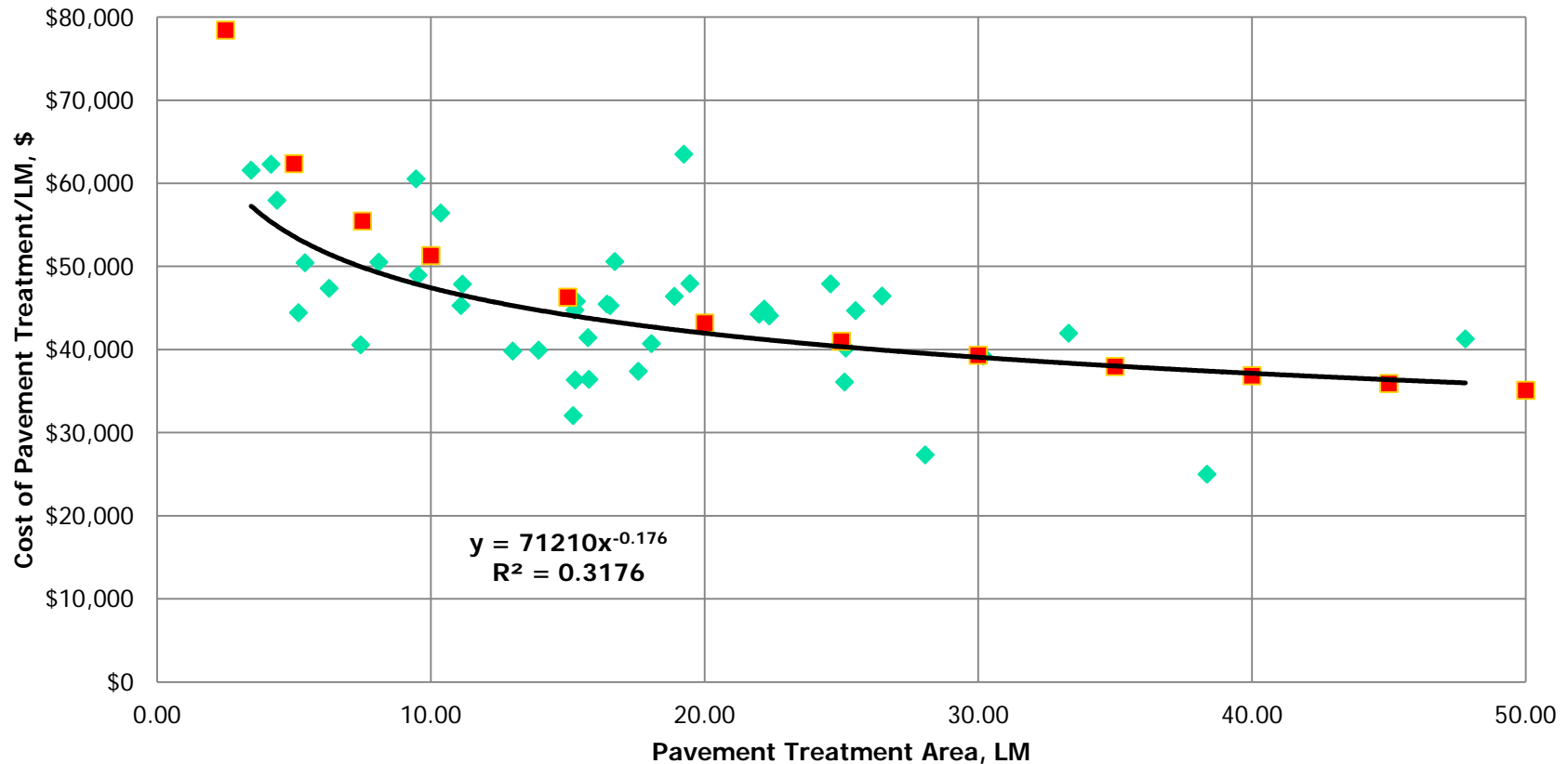
Pavement surface treatments

- I know this is a bridge session, but
- For Microsurface, $C = A + Bx^n$
 - Where x = pavement area in lane-miles, and
 - $A = \$40,000$, $B = \$75,000$ and $n = 0.80$
- For UBWC, the same model form ...
 - $A = \$40,000$, $B = \$400,000$ and $n = 0.25$
 - However, current low sample size suggests this model to be potentially unreliable
- Other models to be forthcoming ...



Some data to show curve form

Cost of Microsurface Treatment per Lane Mile



Now to our other presenter:

- **Jeremy C Hunter, recently appointed Bridge Design Manager**
- **He will present some future directions in project cost estimating within INDOT**
 - Future maintenance of existing models
 - “Micro” models for special cases (e.g. bridge replacement cost by number of spans)
 - ID/IQ contracts – small preservation projects



Maintenance of Models

- **Cost Data Updates**

- Annual calibration of models for updated pricing data

- **Data Trends**

- Evaluation of market conditions that might inform the models
 - Anticipated Specification update impacts
 - Material Pricing Impacts (i.e. oil, steel, concrete)



Micro-Models

■ Project Decisions

- Informed by precise analytical tools
 - Efficient Project Delivery
 - Requires realistic assessment of uncertainty
 - What we end up with is the most educated guess that we can make

■ Project Specifics

- MOT Considerations (i.e. Interstate, Crossovers)
- Risk Factors (i.e. Environmental, utility, constructability constraints)



Improved Cost Estimating

- **Do not fool yourself into thinking that you know more than you really know**
 - Collaborate with partnership
 - Agency (INDOT, FHWA, Other States)
 - Contractors
 - Consultants
 - Solicit feedback regarding the ever changing cost drivers on projects
 - MOT, Environmental Impact, Letting Season, Material Costs and availability



Preservation Project Process

- **The Small Project Challenge**
 - Contracting & Estimating Challenges
 - High Risk
 - Insufficient Bid Histories
 - Reduced Interest from Contractors
 - Penalties can exceed rewards
 - The Solution
 - Mitigate the Risk
 - Contractor – Bundled Projects
 - Agency – Known Cost refines Asset Management



ID/IQ Contracting

- **We recognized the need to implement construction repairs faster than what our current process allows**
- **After discussing our issue with other State DOT's and FHWA, IDIQ is the solution they recommended.**
 - Currently operating through SEP-14 Experimental Programs, but in the spirit of MAP-21 Sec. 1304: Innovative Project Delivery Methods
- **Practical Design (The 2R Mindset)**
 - Use IDIQ to fix only what needs to be fixed now for preservation purposes
 - The money that would have been spent on secondary considerations can be spent on additional preservation needs.



What is Job Order Contracting?

■ Job Order Contracting (IDIQ)

- A way to get construction projects completed quickly through a multi-year contract .
- Initial Contract is competitively bid through the use of a task catalog.
- Expedites project delivery by eliminating contract procurement and plan development time.
- Contractor provides “on call” construction services from concept to close-out for a wide variety of infrastructure needs.
- Eligible for Federal Funding through SEP-14 Program



IDIQ Program Status

- SEP-14
 - Approved for Federal Funding
 - Document is published on FHWA Website
- Consultant Selection
 - RFP Process is complete
 - Contract is in the Final Approval Stage
- Stakeholder Participation
 - INDOT
 - FHWA
 - Contractors



Questions?

