



**RESEARCH & DEVELOPMENT**

# **Development of a Maintenance Cost Index**

**John C. Hildreth, PhD  
Austin Riccio**

**Dept. of Engineering Technology and Construction Management  
University of North Carolina at Charlotte  
9201 University City Blvd.  
Charlotte, NC 28223**

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# **Development of a Maintenance Cost Index**

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by

John Hildreth, Ph.D.  
Associate Professor

Austin Ricco  
Graduate Research Assistant



**UNC CHARLOTTE**

*The WILLIAM STATES LEE COLLEGE of ENGINEERING*

**Department of Engineering Technology and Construction Management**

9201 University City Boulevard  
Charlotte, NC 28223

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## EXECUTIVE SUMMARY

Maintenance activities account for a substantial portion of the life cycle costs of a roadway. The nature and timing of in-house maintenance tasks can be planned based on currently available asset performance models, but estimating the cost of future work requires knowledge of the current costs and trends in maintenance costs. Costs of maintenance tasks generally increase from year to year due to escalation in resource costs and a cost index pertaining to roadway maintenance tasks is not available. The typical cost indices that are currently available are based on construction work items that do not accurately represent maintenance tasks.

Cost indices were developed for maintenance work performed in-house for the Roadside, Maintenance, Traffic, and Bridge categories of the Standing Maintenance budget and a composite index for overall Roadway Maintenance. The indices were developed in the fixed base, Laspeyres index form because the selection of maintenance to be performed is not heavily influenced by cost and there is little need for the index to account for substitution of tasks. An added benefit of the fixed base index form are the minimal data collection and management requirements.

Work order records from 2012 to 2015 were reviewed and 20 maintenance tasks were selected for the representative basket of tasks: 3 each for Roadside and Traffic, 5 for Maintenance, and 9 for Bridge. The basket tasks collectively accounted for 76 percent of all maintenance costs recorded in 2014. The magnitude of costs by task and the relative ranking of tasks by cost were relatively consistent over the 2012 to 2015 period.

Work order records were also used to establish the unit cost and total quantity parameters for each basket task in the 2014 base year. The distribution of unit costs was observed to be heavily right skewed. Therefore, the median value was selected as the representative unit cost. The total base year quantity for each task was found by summing the recorded quantity for each work task and adding an estimated quantity for records containing only cost data. The total cost for records without quantity data was summed and divided by the median unit cost to estimate the quantity.

Work order data was used to calculate the index values for each year in the period 2012 to 2015. A spreadsheet tool was developed to facilitate calculating and archiving index values. The tool uses a report of work order records generated from the Maintenance Management System and automatically summarizes the records, calculates the index values, and provides a mechanism to archive the values in tabular and chart forms.

The index value for the Roadside tasks in 2012 was heavily skewed upward by an anomalously large unit cost for task *2914 Vegetation Management at Stationary Objects*, and by extension the overall Roadway Maintenance index was similarly skewed. Results from the 2013 to 2015 period demonstrate an overall increase in maintenance costs and a varying rate of change by maintenance category. Overall roadway maintenance costs increased 9.4 percent annually over the period, with the largest annual growth in bridge tasks at 10.9 percent and the smallest in traffic tasks at 4.1 percent. Both roadside and maintenance tasks grew at just over 9 percent annually.

The relationship between unit cost and quantity of work performed was evaluated for maintenance tasks and unit cost was found to be inversely proportional to the quantity of work performed. The relationship was best modeled by the power curve and was statistically significant at the 95 percent level of confidence for 42 of the 44 studied tasks. However, the observed variability in unit cost data for many tasks indicated the influence of factors beyond quantity and limited the practical significance, or ability to accurately predict unit cost based on quantity.

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## **1 INTRODUCTION**

Costs incurred throughout the life cycle of transportation infrastructure include construction, rehabilitation, and maintenance costs. Maintenance activities are those activities that do not extend the service life of a roadway, but rather keep the roadway in a usable condition. The costs of these activities are significant, as they total nearly half of the capital outlay (construction) costs. In 2012, roadway maintenance expenditures by all units of government were \$48 billion and capital outlay expenditures were \$105.2 billion nationally (FHWA 2013). In North Carolina in 2012, roadway maintenance expenditures were \$932 million and capital outlay expenditures were \$2,835 million (FHWA 2013).

Maintenance costs are categorized by means of performance: contract maintenance by outside forces or in-house maintenance by department of transportation (DOT) personnel and equipment. Contract maintenance is solicited through a competitive bidding process and bid price indices similar to those for construction costs can be used to track and trend costs. In-house maintenance work differs in the tasks performed and the exclusion of contractor overhead and profit. Therefore, the bid price indices are not directly applicable.

### **1.1 Research Need**

The North Carolina Department of Transportation (NCDOT) routinely develops multi-year plans including the estimated timing and cost of the future construction work. Recently, NCDOT has started developing similar plans for preservation, rehabilitation, and maintenance work over a 3 to 5 year period. A substantial portion of the work included in these plans consists of in-house maintenance tasks performed by personnel, equipment, and materials provided by NCDOT. While the nature and timing of the work tasks can be planned based on currently available asset performance models, estimating the cost of future work requires knowledge of the current maintenance costs and the trends in maintenance costs.

Costs of maintenance tasks generally increase from year to year due to escalation of resource costs and a cost index pertaining to roadway maintenance tasks is not available. The typical cost indices that are currently available are based on construction work items that do not accurately represent maintenance tasks. Thus, the accuracy of estimated costs of planned maintenance tasks for a multi-year period could be increased through the use of an appropriate maintenance cost index.

### **1.2 Research Objectives and Tasks**

The goal of this research was to develop a set of maintenance cost indices (MCI) that can be updated annually and used to quantify trends of in-house maintenance costs. This goal was achieved through the completion of the following tasks:

1. Identify a representative set of maintenance tasks;
2. Establish a methodology for calculating the annual parameters and calculate the base year parameters;
3. Demonstrate the index calculations using maintenance data from recent years;
4. Quantify relationships between maintenance task quantity and unit cost; and
5. Develop a spreadsheet tool for calculating and archiving index values.

## 2 LITERATURE REVIEW

### 2.1 Introduction

A cost index is a ratio of the cost at one time or location to another and is used to quantify the proportionate changes in cost (Hill 2004). Cost indices are also used to adjust cost estimates from one geographic location and/or time period to another (Qasim et al. 1992). Indices may be developed to reflect the costs of labor, operations, equipment, commodities, maintenance, and other types of costs (Remer et al. 2008). A cost index may be composed of multiple goods, known as a basket of goods, in order to establish a single composite measure of cost that is representative of the costs of all related goods.

### 2.2 Cost Indices

There are three common forms of cost indices: Laspeyres, Paasche, and Fisher. Each is calculated based on the unit cost and quantity for goods in the defined basket of goods. The Laspeyres index uses quantities of goods from the base year (price reference period), while the Paasche index uses quantities from the current period. The Fisher index is the geometric mean of the Laspeyres and Paasche indices and uses quantities from both the base year and the other period. Sharma et al. (2013) noted the importance of applying the correct index when developing cost updates.

#### 2.2.1 Laspeyres Index

The Laspeyres index is based on the cost of purchasing a fixed basket of goods, in terms of type and quantity, representing the base period and then the present cost of the same basket (Diewert 1998). It is calculated as:

$$I_{Lt} = 100 * \frac{\sum_{j=1}^n p_{jt} q_{j0}}{\sum_{j=1}^n p_{j0} q_{j0}} \quad \text{Equation 1}$$

Where:  $I_{Lt}$  = Laspeyres cost index in year  $t$

$p_{jt}$  = unit cost of good  $j$  in year  $t$

$p_{j0}$  = unit cost of good  $j$  in the base year  $0$

$q_{j0}$  = quantity of good  $j$  in the base year  $0$

$n$  = the number of goods included in the basket of goods

The Laspeyres index is a commonly used cost of living measure and the Consumer Price Index (CPI) is essentially a Laspeyres price index (Braithwait 1980). It is widely noted that the Laspeyres index is a biased estimate of the cost of living and over estimates cost increases because it does not consider a change in the quantity of goods over time due to relative price changes (Braithwait 1980; Fisher and Shell 1972; Diewert 1998; and Hill 2004). However, the magnitude of this bias is reduced when goods are not substituted or when the relative change in cost for all goods is equal.

A noted advantage of the Laspeyres index is that implementation requires quantity data be collected only for the base year and cost data collected on an ongoing basis (Hill 2004). In many applications, data regarding the quantity of goods consumed is much more difficult to obtain in a timely manner.

### 2.2.2 Paasche Index

The Paasche index is based on the cost of purchasing a fixed basket of goods, in terms of type and quantity, representing the present period and then the base year cost of the same basket (Diewert 1998). It is calculated as:

$$I_{pt} = 100 * \frac{\sum_{j=1}^n P_{jt} q_{jt}}{\sum_{j=1}^n P_{j0} q_{jt}} \quad \text{Equation 2}$$

Where:  $I_{pt}$  = cost index in year  $t$

$p_{jt}$  = price of good  $j$  in year  $t$

$p_{j0}$  = price of good  $j$  in the base year  $0$

$q_{jt}$  = quantity of good  $j$  in year  $t$

$n$  = the number of goods included in the basket of goods

The Paasche index is also a biased estimate of changes in cost and underestimates cost increases. While it considers changes to quantity of goods due to price changes, it does not account for consumer preferences (Diewert 1998).

### 2.2.3 Fisher Index

The Fisher index is an attempt to consider the effects of both substitution and preference and is the geometric mean of the Laspeyres and Paasche indices. It is calculated as:

$$I_{Ft} = \sqrt{I_{Lt} * I_{Pt}} \quad \text{Equation 3}$$

Where:  $I_{Ft}$  = cost index in year  $t$

$I_{Lt}$  = Laspeyres index in year  $t$

$I_{Pt}$  = Paasche index in year  $t$

The noted advantages of the Fisher index include the consideration of both substitution and preference effects, it is a homogeneous symmetric average of the Laspeyres and Paasche indices, and it satisfies the time reversal test (Diewert 1998 and Hill 2004). However, Bowley (1901) noted that when the Laspeyres and Paasche indices are approximately equal there is no difficulty, which implies there is no significant advantage to using the Fisher index in such circumstances.

## 2.3 Construction Cost Indices

There are a number of cost indices currently available to track changes in construction costs. These indices vary in both index type (Laspeyres, Fisher, etc.) and industry sector focus. The two most common construction cost indices are the Building Cost Index (BCI) and the Construction Cost Index (CCI) published by the Engineering News Record (ENR). These indices reflect national trends in construction labor and material costs from all industry sectors. Remer et al. (2008) noted that the indices maintained by ENR are the oldest indices used by engineers, with the CCI and BCI dating to 1908 and 1915, respectively. These indices are based on the assumption that past conditions remain constant in future trends and typically used for short term budgeting (Wilmot et al. 2003).

The Federal Highway Administration (FHWA) has maintained an index of national roadway construction costs since 1933. The initial index, officially titled *Price Trends for Federal-Aid Highway Construction*, was more commonly referred to as Bid Price Index (BPI) and also known

as Contract Price Index or Composite Bid Price Index. It was maintained and used until 2006 when it was replaced with the National Highway Construction Cost Index (NHCCI).

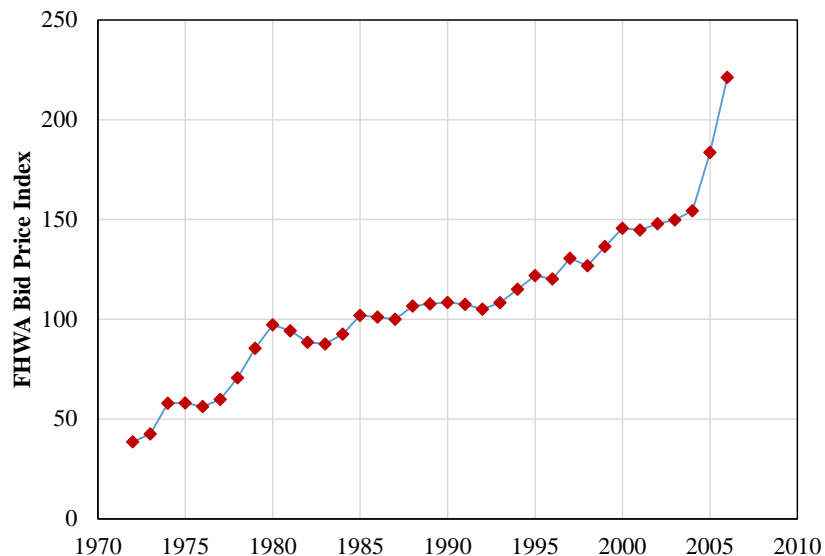
Three Laspeyres indices were initially developed to reflect cost trends in excavation, structures, and surfacing, and they were combined into a fourth index for a “composite mile” of roadway (Harrison 1933). Stern (1961) noted that the Laspeyres (fixed base) index was subsequently found to be more stable and more reliable than a Paasche (changing base) index. A five year base period (1925 to 1929) was selected to account for variations across states in terms of both prices and quantities. Harrison (1933) discusses in detail the selection of five bid items for inclusion in the indices:

- Common excavation to represent excavation costs,
- Portland cement concrete pavement to represent surfacing costs, and
- Reinforcing steel, structural steel, and structural concrete to represent structures costs.

The indices remained in essentially their initial form, but were updated as follows:

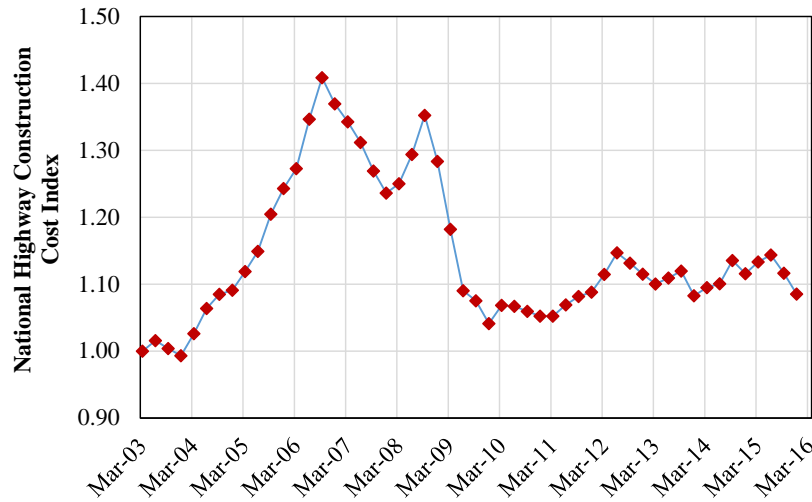
1. In 1961, bituminous concrete was included in the surfacing costs (Harrison 1961).
2. From 1977 forward, bid price data was collected only from the award of contracts over \$500k for Federal aid highway projects (Mirack 1981).
3. The base period was revised to 1957 to 1959 (Harrison 1961), and the subsequently on an approximate 10 year interval to 1967 (Stern 1970), to 1977 (Mirack 1981), and finally to 1987. Revision of the base period revises the base period quantities, which effectively adjusts the relative weights of each item.

The Composite Bid Price Index (BPI) from 1972 to 2006, as shown in Figure 1.



**Figure 1: FHWA Composite Bid Price Index (1987 base year)**

FHWA replaced the BPI in 2006 with the National Highway Construction Cost Index (NHCCI) (White and Erickson 2011). The NHCCI is intended to both track roadway construction price changes and for conversion of current dollar expenditures to constant dollar expenditures (FHWA 2015). It is a Fisher index based on all successful bids, not only those valued at over \$500k. Index values are provided in Figure 2.



**Figure 2: FHWA National Highway Construction Cost Index (2003 base year)**

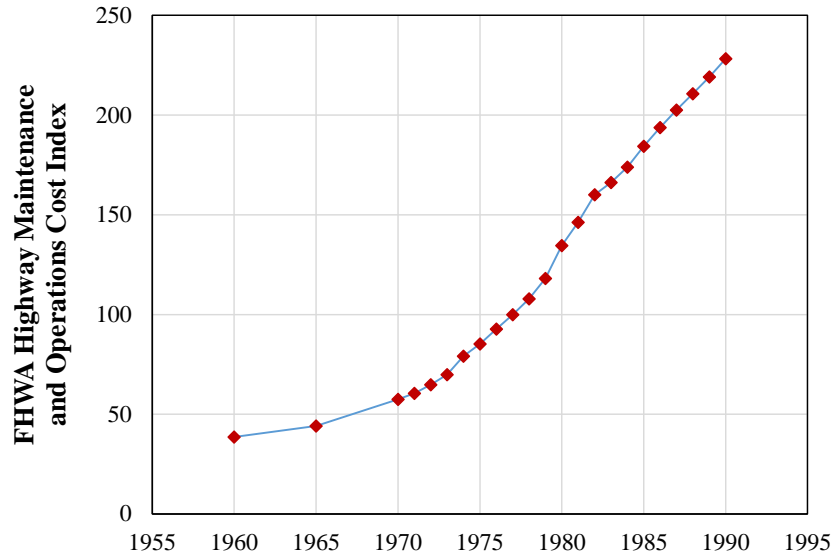
Some state DOTs, including NCDOT, maintain state specific indices of construction costs. Shrestha et al. (2016) surveyed DOTs and reported 21 state indices are maintained, with two additional states planning to develop indices. Walters and Yeh (2012) synthesized information regarding DOT indices and found:

1. Most state indices are similar in form to the FHWA BPI and were developed from 1987 to 1990, and many anticipated changes to reflect the NHCCI
2. Most states found that weights are largely stable over time
3. Update periods vary from monthly to annually

## 2.4 Highway Maintenance Cost Indices

FHWA developed the Highway Maintenance and Operations Cost index in 1947 and published data annually until 1990. The basket of goods was developed to include 34 items and was not revised over the 43 year life of the index. Markow et al. (1990) evaluated the index to determine whether it should be maintained, revised, or discontinued. They surveyed nine DOTs and found varying levels of reliance and use. The principal conclusion drawn from the study was that the basket of goods needed to be revised in content and number to alleviate the data reporting burden. It was proposed to reduce the number of good to between 10 and 20, update the units in which data was reported, and to provide guidance regarding which goods were included in each category. Based on this work, FHWA decided to discontinue the index in 1990.

Figure 3 provides index data from 1960 to 1990 (data prior to 1960 is unavailable).



**Figure 3: Highway Operations & Maintenance Cost Index (1977 base year)**

Despite the discontinuation of the index over 20 years ago, the need for a cost index in estimating maintenance costs has continued. Transportation agencies have attempted to meet this need through the use of other available indices. The CPI published by the US Bureau of Labor Statistics has been applied to highway maintenance costs (Litman 2011 and Adams 2011) despite representing all goods and services purchased. Highway construction cost indices have also been applied (CalTrans 2011 and Ozbek 2007). However, Ozbek noted that such an index is less than ideal because it is not specific to highway maintenance.

It is clear from the literature that a cost index specific to highway maintenance is useful in developing plans and budgets. The need for such an index is also clear from the use of other less relevant indices by transportation agencies.



### **3 DEFINING THE MAINTENANCE COST INDEX**

The MCI is defined in terms of its form and content. As described in the previous section, cost indices may be in the form of a Laspeyres (fixed base), Paasche (changing base), or Fisher (combination of fixed and changing base) index. The content of the index refers to the work, roadway maintenance work in this instance, that the index represents. The Standing Maintenance budget for maintenance tasks was selected to be represented by the MCI and 2014 was selected as the base year.

#### **3.1 Index Form Selection**

The Laspeyres index form was selected for the MCI because:

1. As a fixed base index, the data collection and management requirements are most manageable. Quantity data is needed only for the base year and only cost data is required on an on-going basis.
2. It is the most common form of cost index and was the form of the BPI and Highway Maintenance and Operations Cost index formerly maintained by FHWA.
3. The intended use of the index is to aid in estimating maintenance costs 3 to 5 years in the future, and fixed base indices have generally been applied (Wilmot and Mei 2005).
4. The selection of type of roadway maintenance to be performed is not heavily influenced by cost, and therefore there is little need for the index to account for substitution of tasks.

#### **3.2 Standing Maintenance Data**

Maintenance work tasks included in the Standing Maintenance budget are categorized based on type of work into:

1. Pavement Seals
2. Roadside
3. Traffic
4. Maintenance
5. Bridge
6. Miscellaneous

The Roadside, Traffic, Maintenance, and Bridge categories were selected for the study. An index was developed for each category and the categories were also combined to develop a composite index.

The Pavement Seals and Miscellaneous categories were excluded from the study. Maintenance work associated with Pavement Seals is planned to transition from in-house to contract work in the near future. Tasks in the Miscellaneous category are not directly related to the performance of roadway maintenance.

Individual work order records by maintenance task performed in-house were provided for the period 2012 to 2015. Work order records included the maintenance task, dates of performance, quantity, and costs. These records were reviewed and it was found that the annual number of records for individual tasks varied from less than 10 to over 6,000. Most records included both the quantity and cost of maintenance work performed, but a relatively small number of records were lacking one or both pieces of data. Of the work order records from base year 2014, 84 percent contained both quantity and cost data. Only 1 percent of records contained quantity and no cost

data, and only 9 percent contained cost and no quantity data. A summary of work order records for Roadside tasks in 2014 is provided in Table 1. Summaries for the Maintenance, Traffic, and Bridge tasks are provided in Appendix A.

**Table 1: Summary of 2014 Roadside Maintenance Task Work Order Records**

Roadside Work Task	No. of Work Order Records			
	Total	Cost & Quantity	Cost Only	Quantity Only
2900-Grass Mowing	413	317	33	22
2904-Turf Management	197	180	5	0
2906-Control of Invasive Species	35	21	6	0
2908-Brush and Tree Control /Herbicides	383	93	7	0
2912-Brush and Tree Control / Mechanical/ Other	2,731	2,236	288	50
2914-Vegetation Management at Stationary Objects	978	824	109	5
2916-Roadside Vegetation Enhancement	130	110	1	0
2918-Seeding and Mulching and Fertilization	670	541	58	0
2920-Rest Areas & Welcome Centers Operations	16	12	0	0
2924-NPDES Mntc and Installation of Strmwtr BMPs	7	1	4	0
2926-Maint of Strmwtr BMPs	20	18	1	0
<b>Total Roadside Tasks</b>	<b>5,580</b>	<b>4,353</b>	<b>512</b>	<b>77</b>

The total annual cost from 2012 to 2015 was calculated for each task and maintenance category. The percentage of the 2014 total category cost contributed by each task was also calculated. Cost data for Roadside work tasks, sorted by base year 2014 cost, is shown in Table 2. Data for the Maintenance, Traffic, and Bridge categories is provided in Appendix B.

The total recorded cost for maintenance categories and individual tasks were fairly consistent through the 2012 to 2015 period. With the exception of bridge tasks, the set of tasks with highest cost in each maintenance category were consistent across the study period. In the bridge category, task *3300 Install/Replace NON NBIS > 48" up to NBIS Structures* had a total cost substantially greater than other tasks, followed by a set of nine tasks that ranged in annual cost from \$1 to \$2 million. These tasks, while relatively consistent in cost year to year, varied in rank over the study period.

**Table 2: Summary of Recorded Annual Total Cost for Roadside Tasks**

Roadside Work Task	Annual Total Cost				Percent of 2014 Category Cost	Cumulative Percentage
	2012	2013	2014	2015		
2912-Brush and Tree Control/Mechanical/Other	\$ 11,202,344	\$ 9,331,991	\$ 8,927,551	\$ 9,353,086	39%	39%
2900-Grass Mowing	\$ 6,417,859	\$ 5,889,190	\$ 6,854,438	\$ 7,318,895	30%	69%
2914-Vegetation Management at Stationary Objects	\$ 2,192,501	\$ 2,344,208	\$ 2,471,619	\$ 2,073,611	11%	80%
2916-Roadside Vegetation Enhancement	\$ 938,877	\$ 1,679,746	\$ 1,561,983	\$ 1,322,202	7%	86%
2918-Seeding and Mulching and Fertilization	\$ 2,061,582	\$ 2,009,481	\$ 1,473,619	\$ 1,284,639	6%	93%
2904-Turf Management	\$ 797,934	\$ 1,006,185	\$ 642,778	\$ 524,969	3%	96%
2908-Brush and Tree Control /Herbicides	\$ 524,420	\$ 802,242	\$ 504,874	\$ 533,391	2%	98%
2920-Rest Areas & Welcome Centers Operations	\$ 146,896	\$ 249,170	\$ 287,603	\$ 560,274	1%	99%
2906-Control of Invasive Species	\$ 166,243	\$ 120,990	\$ 137,423	\$ 133,229	1%	100%
2924-NPDES Mntc and Installation of Strmwtr BMPs	\$ 20,954	\$ 35,276	\$ 43,558	\$ 126,044	0%	100%
2926-Maint of Strmwtr BMPs	\$ 22,710	\$ 24,726	\$ 18,829	\$ 39,021	0%	100%
<b>Total Roadside Tasks</b>	<b>\$ 24,492,767</b>	<b>\$ 23,493,913</b>	<b>\$ 22,924,274</b>	<b>\$ 23,269,363</b>		

## 4 DEVELOPMENT OF THE INDICES

Development of the indices involved selecting the basket of goods (representative set of tasks) for each maintenance category and determining the base year parameters for the selected tasks. In selecting the basket, the objective was to identify a small number of tasks to represent each category. While the indices could be developed from all tasks, this would be inefficient and create a more burdensome data and index management process. The base year parameters required to develop the Laspeyres index were the unit cost and total quantity for each task in the baskets.

### 4.1 Selection of Basket Goods

A basket of goods consisting of individual tasks was selected for each maintenance category. Tasks were selected based on total recorded cost in 2014. Starting with the task with greatest total cost, additional tasks were added to the basket until the total recorded cost for basket comprised approximately 75 percent of the total recorded cost in each category.

Tasks in each basket were then reviewed to ensure that:

1. The tasks were related to roadway maintenance – some tasks, such as *3240 Electricity for Traffic Control Devices* are not related to maintenance
2. The task was not “funded off of the top” – funds for some tasks are set aside at the start of the year, such as task *3100 Snow and Ice*
3. The task was measured in an appropriate quantity unit – some tasks, such as *3110 Beaver Control* are measured as lump sum (units of dollar)
4. A sufficient volume of task records were available – tasks with less than 50 work records were neglected

Based on these criteria, the tasks shown in Table 3 were selected for each category. A total of 20 tasks were selected: 3 each for Roadside and Traffic, 5 for Maintenance, and 9 for Bridge. These tasks accounted for a significant portion of the total costs recorded for each category. In 2014, the selected tasks collectively accounted for over \$82.7 million in maintenance cost, which represents 76 percent of all recorded costs in the four categories.

**Table 3: Basket Tasks in each Maintenance Category**

Category	Maintenance Work Task	Portion of Category Cost Captured by the Tasks
Roadside	2912-Brush and Tree Control / Mechanical/ Other	80%
	2900-Grass Mowing	
	2914-Vegetation Management at Stationary Objects	
Maintenance	3112-Shoulder Maintenance / Reconstruction	78%
	3108-Drainage Ditch Maintenance	
	3126-Install Pipes (<=48")	
	3128-Maint/Repair Pipes (<=48")	
	3102-Removal of Hazards/Debris From ROW	
Traffic	3250-Install/Replace Ground Mounted Signs	77%
	3222-Long Line Painted Pavement Markings	
	3252-Repair Ground Mounted Signs	
Bridge	3300-Install/Replace NON NBIS > 48" up to NBIS Structures	71%
	3302-Maintain/Repair NON NBIS > 48" up to NBIS Structures	
	3352-Maint Slope Protection	
	3314-Maintain Steel Superstructure Components	
	3344-Repair/Replace Timber Substructure Components	
	3326-Maintain Concrete Deck	
	3310- Maint/Repair/Replacement of Std Bridge Exp Joints	
	3366-Drift and Debris Removal	
	3348-Maintain Concrete Substructure Components	

**4.2 Base Year Parameters**

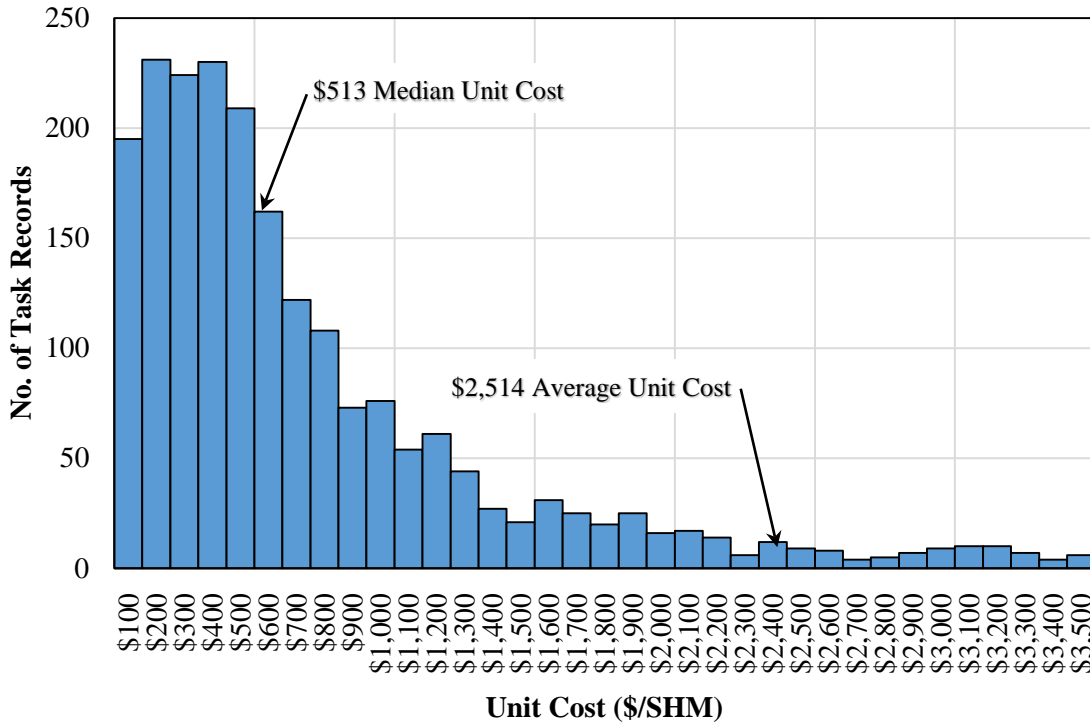
The parameters required for the 2014 base year were the unit cost and quantity for each task in the baskets, and were calculated from the work order records. To produce an accurate cost index, the unit cost should be representative of the task and the quantity should be the total quantity of the task performed throughout the base year.

In reviewing the work order records, it was noted that extraordinarily large quantities were occasionally recorded. Some of the records with extraordinarily large quantities appear to be an aggregate of multiple individual work activities based an associated performance period spanning several months. However, not all records had long performance periods and extraordinarily large quantities were not always associated with extraordinarily high costs. It was determined that at least a portion of these records may be the result of data entry errors.

To address this issue, only records where quantity was less than the 98<sup>th</sup> percentile of all quantities recorded for the task were used. In effect, the 2 percent of records for each task with the greatest recorded quantity were neglected. The 2 percent of records with the least recorded quantity were not neglected because these records could not be clearly determined to be made in error.

#### 4.2.1 Unit Cost

The unit cost was calculated for each work record that contained both cost and quantity data. The distribution of unit costs was investigated to determine an appropriate method for calculating a unit cost that represents each task. The median value was selected because the costs were not normally distributed, which prevented use of the average unit cost. The distribution of unit costs for task 2912 *Brush and Tree Control/Mechanical/Other* was typical of other tasks and is shown in Figure 4. The distributions for each task were heavily right skewed and it should be noted that the unit cost axis in Figure 4 was truncated to \$3,500 per SHM.



**Figure 4: Distribution of Unit Cost for Task 2912 Brush and Tree Control/Mechanical/Other**

The median unit cost was less than the average unit cost for all tasks in the basket. The ratio of median cost to average cost was between 0.25 and 0.60 for most tasks, but was less than 0.01 for two tasks and greater than 0.90 for three tasks. Where the median was very small relative to the average, the average unit cost was heavily influenced by a small number records with extremely large unit costs. Tasks where the work is measured in units of hours had nearly equal median and unit costs. The median and average unit costs for basket tasks are provided in Table 4.

**Table 4: Median and Average Unit Cost of Basket Tasks in 2014**

Category	Maintenance Work Task	Unit	Unit Cost	
			Median	Average
Roadside	2900-Grass Mowing	SHM	\$ 73.29	\$ 281.05
	2912-Brush and Tree Control / Mechanical/ Other	SHM	\$ 530.39	\$ 2,571.75
	2914-Vegetation Management at Stationary Objects	LFT	\$ 0.38	\$ 181.09
Maintenance	3102-Removal of Hazards/Debris From ROW	HR	\$ 44.35	\$ 46.66
	3108-Drainage Ditch Maintenance	SHM	\$ 17,711.33	\$ 31,012.42
	3112-Shoulder Maintenance / Reconstruction	SHM	\$ 7,626.54	\$ 26,871.19
	3126-Install Pipes (<=48")	LFT	\$ 83.15	\$ 1,219.81
	3128-Maint/Repair Pipes (<=48")	EA	\$ 565.30	\$ 954.91
Traffic	3222-Long Line Painted Pavement Markings	LFT	\$ 0.04	\$ 0.08
	3250-Install/Replace Ground Mounted Signs	SFT	\$ 8.03	\$ 11.71
	3252-Repair Ground Mounted Signs	EA	\$ 41.04	\$ 67.05
Bridge	3300-Install/Replace NON NBIS >48" up to NBIS Structures	LFT	\$ 1,093.88	\$ 7,845.30
	3302-Maintain/Repair NON NBIS >48" up to NBIS Structures	LFT	\$ 124.14	\$ 470.17
	3310-Maint/Repair/Replacement of Std Bridge Exp Joints	LFT	\$ 50.76	\$ 142.47
	3314-Maintain Steel Superstructure Components	LFT	\$ 223.03	\$ 602.13
	3326-Maintain Concrete Deck	SFT	\$ 140.52	\$ 257.68
	3344-Repair / Replace Timber Substructure Components	LFT	\$ 267.59	\$ 503.08
	3348-Maintain Concrete Substructure Components	LFT	\$ 134.54	\$ 280.42
	3352-Maint Slope Protection	SFT	\$ 14.55	\$ 45.33
	3366-Drift and Debris Removal	HR	\$ 37.47	\$ 41.49

#### 4.2.2 Total Base Year Quantity

The total base year quantity for each task was found by summing the recorded quantity for each work order and adding an estimated quantity for records containing only cost data. The total cost for records without quantity data was summed and divided by the median unit cost to estimate the quantity. The recorded, estimated, and total quantities for basket tasks are provided in Table 5.

Estimating quantity based on median unit cost introduces some error into the total quantity parameter due to the variability in the unit cost values. However, the estimated portion of total quantity was typically less than 10 percent, with the exception of bridge tasks. The error resulting from a small estimated quantity is considered negligible.

Bridge tasks had a relatively large portion of records containing cost but not quantity data, and thus a larger portion of estimated quantities. In the base year, 12.9 percent of records for the selected bridge tasks lacked quantity data, compared to 4.9 percent for all other basket tasks. Across all bridge tasks, nearly 31 percent of costs were recorded without an associated quantity. A majority of costs were recorded without quantity data for three tasks:

- 3314 Maintain Steel Superstructure Components
- 3348 Maintain Concrete Substructure Components
- 3352 Maintain Slope Protection.

This majority of cost did not translate directly to a majority in estimated quantity. The estimated quantity was greater than recorded quantity for tasks 3314 and 3352, as well as task 3302 *Maintain/Repair NON NBIS >48" up to NBIS Structures*. This brings into question the validity of both the unit cost and the total quantity values for these tasks because the unit cost was determined from a relatively small portion of the work for the task, and the total quantity was heavily influenced by the unit cost.



**Table 5: Recorded, Estimated, and Total Quantity of Basket Tasks in 2014**

Category	Maintenance Work Task	Unit	Recorded Quantity	Estimated Quantity	Total Quantity
Roadside	2900-Grass Mowing	SHM	138,664	1,372	140,035
	2912-Brush and Tree Control/Mechanical/Other	SHM	14,289	1,709	15,997
	2914-Vegetation Management at Stationary Objects	LFT	22,444,169	176,982	22,621,151
Maintenance	3102-Removal of Hazards/Debris From ROW	HR	47,040	294	47,334
	3108-Drainage Ditch Maintenance	SHM	961	44	1,005
	3112-Shoulder Maintenance/Reconstruction	SHM	2,478	159	2,637
	3126-Install Pipes (<=48")	LFT	42,299	12,930	55,230
	3128-Maint/Repair Pipes (<=48")	EA	5,447	1,082	6,528
Traffic	3222-Long Line Painted Pavement Markings	LFT	58,234,631	2,341,061	60,575,692
	3250-Install/Replace Ground Mounted Signs	SFT	336,215	9,460	345,675
	3252-Repair Ground Mounted Signs	EA	21,365	1,025	22,390
Bridge	3300-Install/Replace NON NBIS > 48" up to NBIS Structures	LFT	7,930	1,970	9,900
	3302-Maintain/Repair NON NBIS > 48" up to NBIS Structures	LFT	5,646	6,443	12,089
	3310-Maint/Repair/Replacement of Std Bridge Exp Joints	LFT	24,851	4,043	28,894
	3314-Maintain Steel Superstructure Components	LFT	3,525	3,772	7,297
	3326-Maintain Concrete Deck	SFT	63,079	1,235	64,315
	3344-Repair/Replace Timber Substructure Components	LFT	2,782	1,716	4,498
	3348-Maintain Concrete Substructure Components	LFT	13,196	3,756	16,952
	3352-Maint Slope Protection	SFT	45,148	66,552	111,700
3366-Drift and Debris Removal	HR	20,167	89	20,256	

#### 4.2.3 Summary of Base Year Parameters

The base year parameters for the cost indices are the unit cost and total quantity for each task in the base year 2014. A threshold of the 98<sup>th</sup> percentile of recorded quantity was applied to minimize the undue influence of potential data entry errors. Median unit cost was selected as the representative unit cost due to the heavily right skewed distributions observed. The total quantity for each task was calculated by summing the recorded quantity and an estimated quantity for records containing only cost data. The calculated base year parameters for the baskets are provided in Table 6.

**Table 6: Base Year Parameters for Preliminary Basket Tasks**

Category	Maintenance Work Task	Unit	Unit Cost	Total Quantity
Roadside	2900-Grass Mowing	SHM	\$ 73.29	140,035
	2912-Brush and Tree Control / Mechanical/ Other	SHM	\$ 530.39	15,997
	2914-Vegetation Management at Stationary Objects	LFT	\$ 0.38	22,621,151
Maintenance	3102-Removal of Hazards/Debris From ROW	HR	\$ 44.35	47,334
	3108-Drainage Ditch Maintenance	SHM	\$ 17,711.33	1,005
	3112-Shoulder Maintenance / Reconstruction	SHM	\$ 7,626.54	2,637
	3126-Install Pipes (<=48")	LFT	\$ 83.15	55,230
	3128-Maint/Repair Pipes (<=48")	EA	\$ 565.30	6,528
Traffic	3222-Long Line Painted Pavement Markings	LFT	\$ 0.04	60,575,692
	3250-Install / Replace Ground Mounted Signs	SFT	\$ 8.03	345,675
	3252-Repair Ground Mounted Signs	EA	\$ 41.04	22,390
Bridge	3300-Install / Replace NON NBIS >48" up to NBIS Structures	LFT	\$ 1,093.88	9,900
	3302-Maintain / Repair NON NBIS >48" up to NBIS Structures	LFT	\$ 124.14	12,089
	3310- Maint/Repair/Replacement of Std Bridge Exp Joints	LFT	\$ 50.76	28,894
	3314-Maintain Steel Superstructure Components	LFT	\$ 223.03	7,297
	3326-Maintain Concrete Deck	SFT	\$ 140.52	64,315
	3344-Repair / Replace Timber Substructure Components	LFT	\$ 267.59	4,498
	3348-Maintain Concrete Substructure Components	LFT	\$ 134.54	16,952
	3352-Maint Slope Protection	SFT	\$ 14.55	111,700
3366-Drift and Debris Removal	HR	\$ 37.47	20,256	

## 5 CALCULATED INDEX VALUES

For each year in the period 2012 to 2015, the unit cost and total quantity for each basket task was calculated in the manner previously described and used to calculate the cost index for each maintenance category and overall Roadway Maintenance. Annual index values are provided in Table 7.

**Table 7: Calculated Cost Index Values for 2012 to 2015 Period**

<b>Year</b>	<b>Cost Index</b>				
	<b>Roadside</b>	<b>Maintenance</b>	<b>Traffic</b>	<b>Bridge</b>	<b>Roadway Maintenance</b>
2012	164.6	66.3	100.0	91.6	99.0
2013	94.2	80.5	104.5	99.3	90.2
2014	100.0	100.0	100.0	100.0	100.0
2015	112.0	96.1	113.3	122.1	107.9

An interpretation of the resulting cost index values requires an understanding of and is based on the underlying work order records from which they were derived. The unit cost and total quantity for each basket task for the period 2012 to 2015 is provided in Table 8. Discussion is organized to focus first on the index for each maintenance category, then on the overall Roadway Maintenance index.

**Table 8: Median Unit Cost and Total Quantity of Basket Tasks for 2012 to 2015**

Category	Maintenance Task	Median Unit Cost				Total Quantity			
		2012	2013	2014	2015	2012	2013	2014	2015
Roadside	2900-Grass Mowing	\$ 67.53	\$ 51.23	\$ 73.29	\$ 69.74	122,251	133,057	140,035	157,583
	2912-Brush and Tree Control / Mechanical/ Other	\$ 370.10	\$ 412.21	\$ 530.39	\$ 525.48	23,172	17,852	15,997	16,430
	2914-Vegetation Management at Stationary Objects	\$ 1.31	\$ 0.53	\$ 0.38	\$ 0.55	20,268,059	20,605,271	22,621,151	23,707,793
Maintenance	3102-Removal of Hazards/Debris From ROW	\$ 36.51	\$ 40.09	\$ 44.35	\$ 43.86	34,957	53,876	47,363	41,869
	3108-Drainage Ditch Maintenance	\$ 12,881.10	\$ 15,537.36	\$ 17,711.33	\$ 17,548.69	1,593	982	1,005	1,067
	3112-Shoulder Maintenance / Reconstruction	\$ 4,364.36	\$ 5,712.65	\$ 7,626.54	\$ 6,956.99	4,868	3,441	2,639	2,887
	3126-Install Pipes (<=48")	\$ 59.15	\$ 63.38	\$ 83.15	\$ 92.49	99,945	85,322	55,230	47,002
	3128-Maint/Repair Pipes (<=48")	\$ 391.12	\$ 427.64	\$ 565.30	\$ 496.40	9,485	7,259	6,528	8,849
Traffic	3222-Long Line Painted Pavement Markings	\$ 0.04	\$ 0.04	\$ 0.04	\$ 0.04	87,645,339	63,850,636	60,575,692	43,796,528
	3250-Install / Replace Ground Mounted Signs	\$ 8.45	\$ 8.65	\$ 8.03	\$ 10.31	363,543	278,488	345,675	183,141
	3252-Repair Ground Mounted Signs	\$ 34.61	\$ 43.73	\$ 41.04	\$ 42.25	47,514	20,508	22,390	21,049
Bridge	3300-Install/Replace NON NBIS >48" up to NBIS Structures	\$ 927.79	\$ 878.80	\$ 1,093.88	\$ 1,209.15	6,019	4,340	9,900	6,528
	3302-Maintain/Repair NON NBIS >48" up to NBIS Structures	\$ 107.67	\$ 7.23	\$ 124.14	\$ 141.97	7,486	68,239	12,089	6,457
	3310- Maint/Repair/Replacement of Std Bridge Exp Joints	\$ 12.83	\$ 47.45	\$ 50.76	\$ 46.30	23,680	18,244	28,894	15,108
	3314-Maintain Steel Superstructure Components	\$ 236.03	\$ 262.79	\$ 223.03	\$ 348.71	12,484	8,595	7,297	7,149
	3326-Maintain Concrete Deck	\$ 119.09	\$ 130.47	\$ 140.52	\$ 164.45	23,212	42,161	64,315	24,220
	3344-Repair / Replace Timber Substructure Components	\$ 285.65	\$ 254.94	\$ 267.59	\$ 216.71	9,675	6,959	4,498	4,153
	3348-Maintain Concrete Substructure Components	\$ 230.53	\$ 299.02	\$ 134.54	\$ 292.71	9,444	5,463	16,952	5,342
	3352-Maint Slope Protection	\$ 14.40	\$ 23.70	\$ 14.55	\$ 19.70	97,006	75,242	111,700	39,611
	3366-Drift and Debris Removal	\$ 36.74	\$ 38.92	\$ 37.47	\$ 36.84	14,959	21,290	20,256	17,706

## 5.1 Roadside Category

The Roadside index, shown in Figure 5, indicates a substantial decrease in costs from 2012 to 2013. The index value in 2012 was heavily skewed upward by a large unit cost for task *2914 Vegetation Management at Stationary Objects*. The 2012 unit cost was \$1.31/LFT, while the 2014 base year unit cost was \$0.38/LFT. This base year unit cost was also less than the \$0.53 and \$0.55/LFT unit costs for 2013 and 2015, respectively.

Over the 2013 to 2015 period, the Roadside index indicates a moderate increase in cost. This is reflective of the increase in unit costs for tasks *2900 Grass Mowing* and *2912 Brush and Tree Control/Mechanical/Other*.

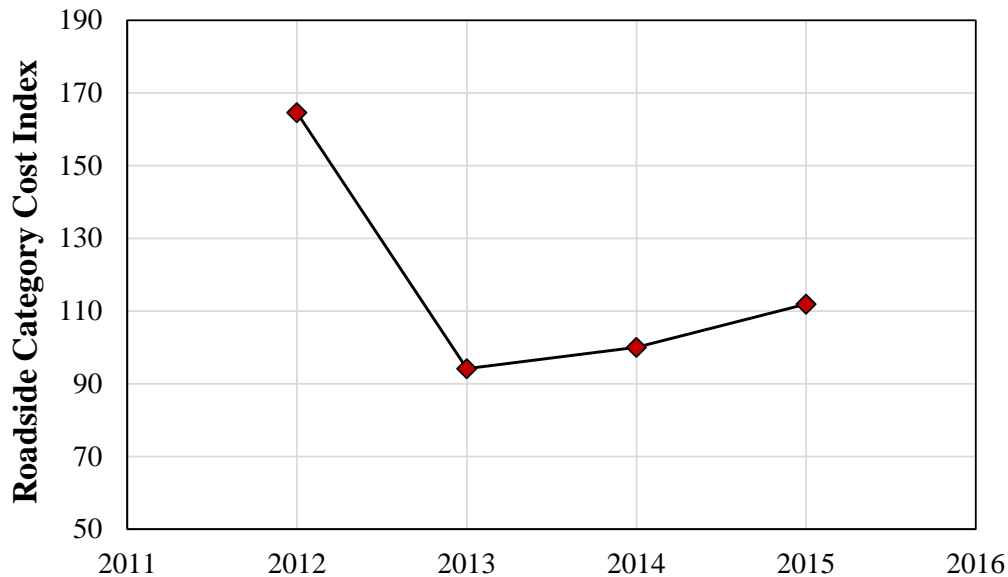
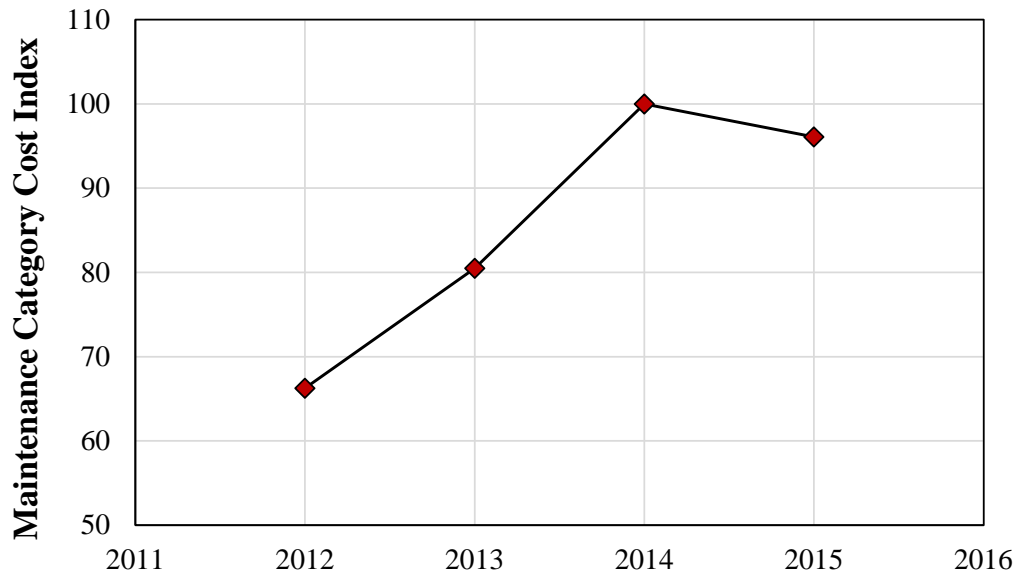


Figure 5: Annual Maintenance Cost Index for Roadside Category

## 5.2 Maintenance Category

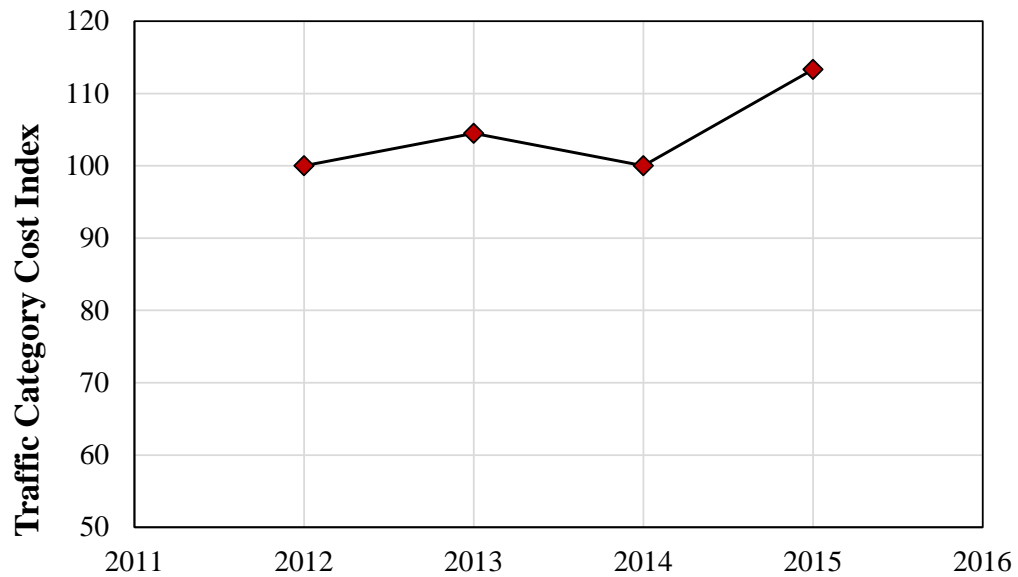
The Maintenance index, shown in Figure 6, indicates a substantial increase in costs from 2012 to 2014, followed by a moderate cost decrease from 2014 to 2015. The unit cost of all Maintenance tasks increased greatly from 2012 to 2014, with increases ranging from 21 to 75 percent. Costs receded from 2014 to 2015, and only task *3126 Install Pipes (<=48")* slightly increasing in unit cost.



**Figure 6: Annual Maintenance Cost Index for Maintenance Category**

### 5.3 Traffic Category

The Traffic index, shown in Figure 7, indicates relatively stable costs and a moderate increase from 2014 to 2015. This increase is largely reflective of an approximate 25 percent increase in the unit cost for task 3250 *Install/Replace Ground Mounted Signs*.

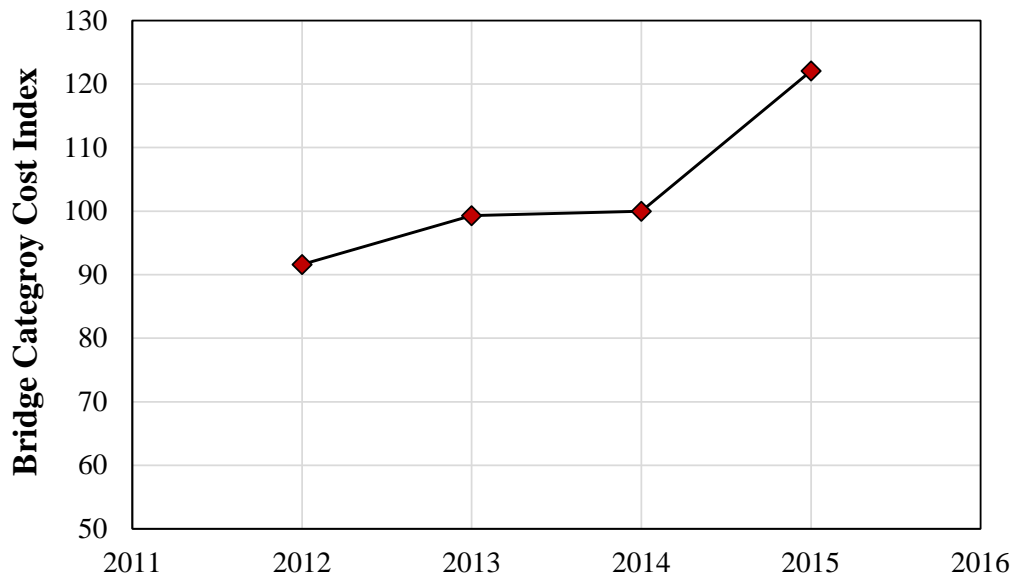


**Figure 7: Annual Maintenance Cost Index for Traffic Category**

## 5.4 Bridge Category

The Bridge index, shown in Figure 8, indicates moderate cost growth from 2012 to 2013, effectively no growth from 2013 to 2014, and substantial growth from 2014 to 2015. The index value in 2013 is skewed downward by an extraordinarily low unit cost of \$7.23/LFT for task 3302 *Maintain/Repair NON NBIS > 48" up to NBIS Structures*. In other years, the unit cost for this task ranged from \$108 to \$142/LFT. However, the influence of this task on the index is small due to the relatively small total quantity.

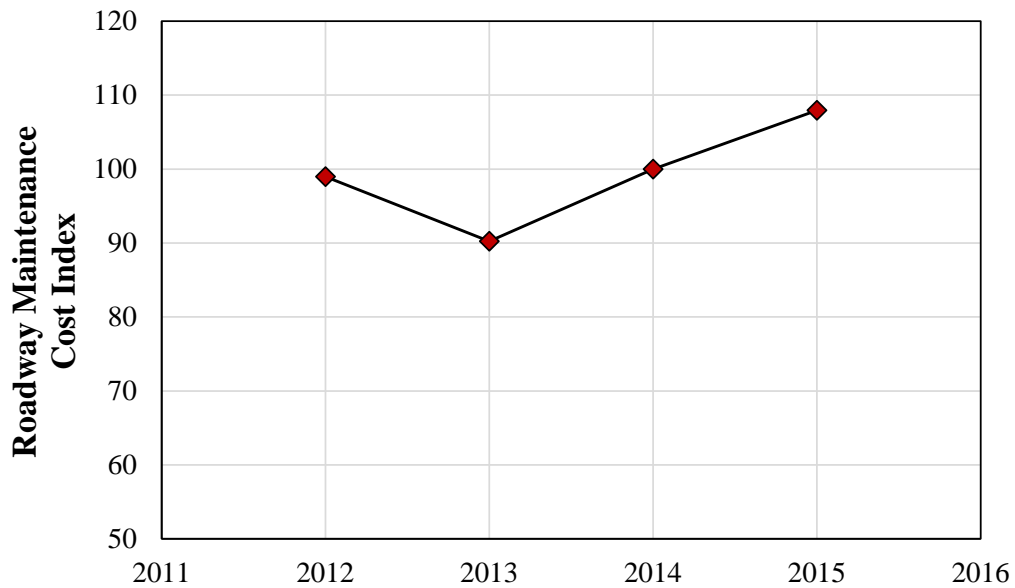
An abnormally low unit cost for task 3348 *Maintain Concrete Substructure Components* contributed to both the lack of cost growth from 2013 to 2014 and the substantial growth from 2014 to 2015. The unit cost in 2014 was \$134.54/LFT, which was much lower than the \$250 to \$300/LFT unit costs in other years. It is important to note that tasks 3314 *Maintain Steel Superstructure Components* and 3352 *Maintain Slope Protection* showed unit cost increases of 56 and 35 percent, respectively, from 2014 to 2015.



**Figure 8: Annual Maintenance Cost Index for Bridge Category**

## 5.5 Overall Roadway Maintenance

The overall Roadway Maintenance index, shown in Figure 9, indicates a decrease in costs from 2012 to 2013 and moderate increases in costs from 2013 to 2015. As described in section 5.1, the Roadside index value for 2012 was skewed upward. By extension, the overall Roadway Maintenance index for 2012 was similarly skewed. The cost growth from 2013 to 2015 is reflective of the growth observed for each maintenance category.



**Figure 9: Annual Maintenance Cost Index for All Roadway Maintenance Categories**

## 5.6 Summary

Results from the 2013 to 2015 period demonstrate an overall increase in maintenance costs and a varying rate of change by maintenance category. Overall roadway maintenance costs increased 9.4 percent annually over the period, with the largest annual growth in bridge tasks at 10.9 percent and the smallest in traffic tasks at 4.1 percent. Both roadside and maintenance tasks grew at just over 9 percent annually. Annual changes in costs are presented in Table 9.

**Table 9: Annual Percent Change in Maintenance Costs**

Category	Annual Percent Change		
	2013 - 2014	2014 - 2015	2013 - 2015
Roadside	6.16%	11.96%	9.02%
Maintenance	24.25%	-3.91%	9.27%
Traffic	-4.30%	13.33%	4.14%
Bridge	0.70%	22.09%	10.88%
<b>Roadway Maintenance</b>	<b>10.83%</b>	<b>7.94%</b>	<b>9.37%</b>



## 6 RELATIONSHIP BETWEEN UNIT COST AND QUANTITY

The relationship between unit cost and quantity of work performed was evaluated for maintenance tasks. Regression analysis techniques were applied to work order records for the 44 tasks with a minimum of 50 records containing unit cost and quantity data. It was apparent from the data that a relationship existed and it was best modeled by the power curve:

$$UC = aQ^k \quad \text{Equation 4}$$

Where:  $UC$  is unit cost  
 $Q$  is quantity  
 $a$  and  $k$  are coefficients estimated through regression

Every effort was made to preserve the original data and only a very small number of outlying data points were removed from the analysis. Outlying data points were those with undue influence and leverage and were identified based on residual value and Cook's distance.

The regression results indicated that the relationship between unit cost and quantity was statistically significant at the 95 percent level of confidence for 42 of the 44 tasks. While most relationships are statistically significant, many are not practically significant. Statistical significance indicates that there is a relationship between the variables that can be appropriately quantified. However, practical significance indicates that the variability, or change, in the unit cost can be reasonably explained by changes in quantity.

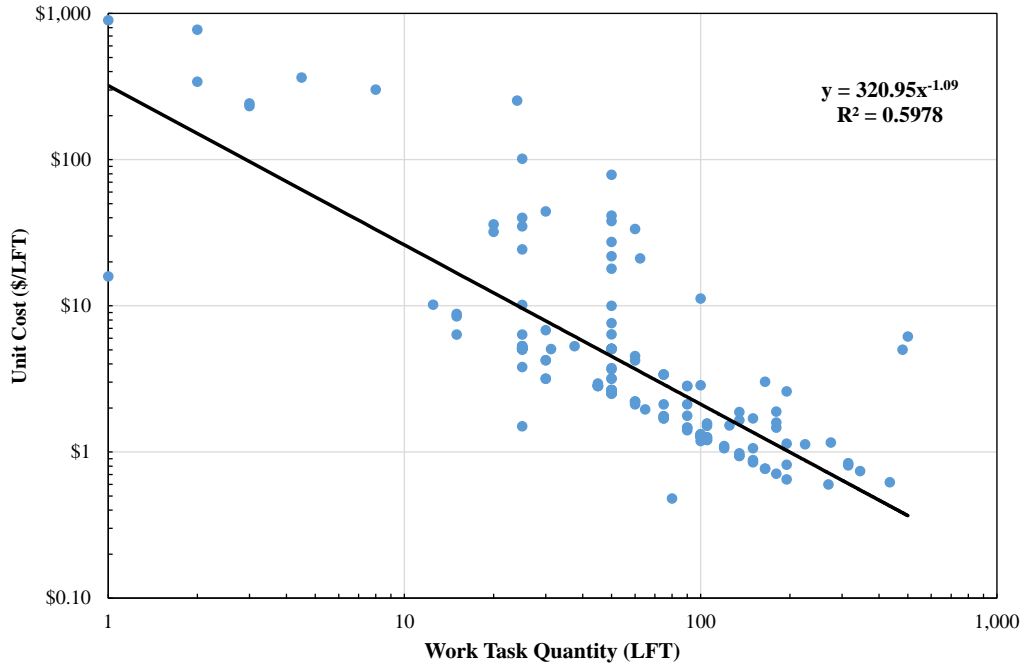
The degree to which changes in unit cost can be explained by changes in quantity is measured by the  $R^2$  value. A minimum  $R^2$  value of 0.50 was selected to delineate practical significance. While this value may appear low, it is appropriate given that the data was collected from the field under variable conditions rather than experimental data collected under carefully controlled conditions. Of the 44 analyzed tasks, 14 were found to have practically significant relationships based on an  $R^2$  value greater than 0.50

Regression results for all tasks are provided in Table 10. For all tasks with a statistically significant relationship, the  $k$  value was less than zero which indicates that unit cost decreases as quantity increases. The magnitude of the  $k$  value reflects the degree to which unit cost changes with quantity. Of the tasks with statistically and practically significant relationships, task *3120 Repair/Maintain Barriers*, shown in Figure 10, had the largest magnitude  $k$  value of -1.09. For this task, an increase in quantity from 1 to 100 LFT (two orders of magnitude) resulted in a decrease in unit cost from \$300 to \$3/LFT (two orders of magnitude). Task *2916 Roadside Vegetative Enhancement*, shown in Figure 11, had the smallest magnitude  $k$  value of -0.44 and a quantity increase from 1,000 to 100,000 SYD (two orders of magnitude) resulted in a decrease in unit cost from \$1 to \$0.12/SYD (slightly less than one order of magnitude).

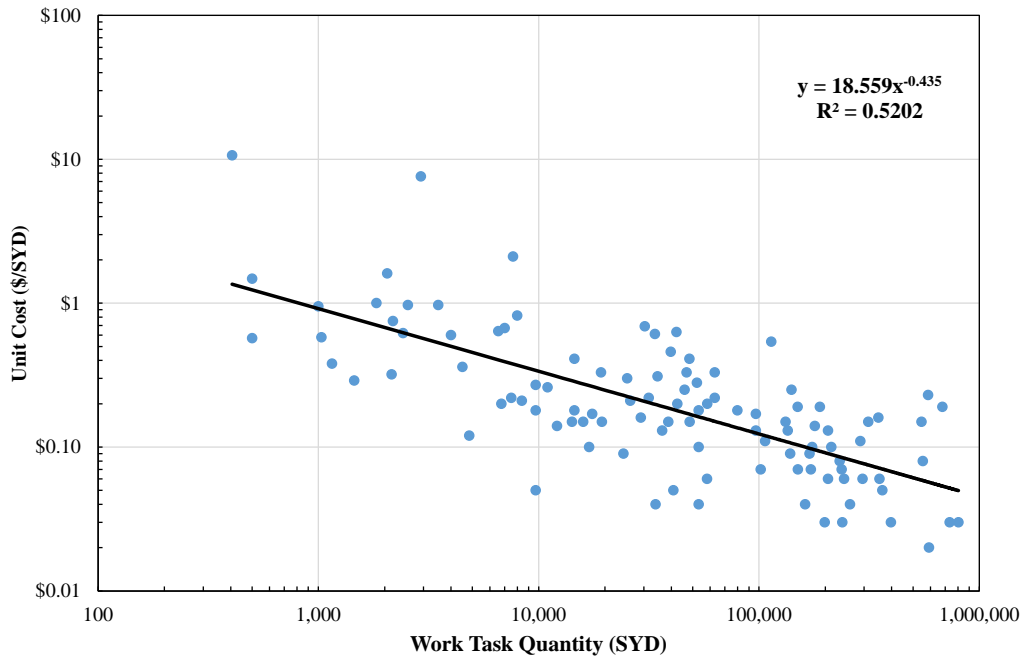
**Table 10: Summary of Regressing Unit Cost on Quantity**

Maintenance Task	Units	k	a	R <sup>2</sup>
3228-Words and Symbols - Painted	SFT	-0.67	140.15	0.77
2914-Vegetation Management at Stationary Objects	LFT	-0.72	104.96	0.77
3376-Clean/Wash Bridge Decks	SFT	-0.62	45.54	0.72
3112-Shoulder Maintenance / Reconstruction	SHM	-0.64	2,929.32	0.68
3220-Preline	LFT	-0.81	57.00	0.64
3108-Drainage Ditch Maintenance	SHM	-0.73	2,892.00	0.63
3348-Maintain Concrete Substructure Components	LFT	-0.63	867.72	0.61
3326-Maintain Concrete Deck	SFT	-0.54	666.40	0.60
3120-Repair / Maintain Barriers	LFT	-1.09	320.95	0.60
3324-Maint / Repair / Replace Timber Deck Components	SFT	-0.46	415.44	0.58
3130-Install/ Maintain / Repair of Misc. Drainage Structures	EA	-1.06	1,046.71	0.58
3306-Maintain Concrete Superstructure Components	SFT	-0.73	1,330.70	0.54
2916-Roadside Vegetation Enhancement	SYD	-0.44	18.56	0.52
3230-Words and Symbols - Specialty Materials	SFT	-0.51	64.64	0.52
3352-Maint Slope Protection	SFT	-0.67	480.70	0.47
3370-Maintenance and Repair of NBIS Pipes and Culverts	LFT	-0.64	799.10	0.46
3310-Maint/Repair/Replacement of Std Bridge Exp Joints	LFT	-0.62	894.30	0.46
3314-Maintain Steel Superstructure Components	LFT	-0.60	1,244.39	0.46
3300-Install / Replace NON NBIS > 48" up to NBIS Structures	LFT	-1.32	259,113.87	0.44
2912-Brush and Tree Control / Mechanical / Other	SHM	-0.52	814.26	0.40
2918-Seeding and Mulching and Fertilization	ACR	-0.50	1,704.43	0.39
3250-Install / Replace Ground Mounted Signs	SFT	-0.42	26.15	0.39
3252-Repair Ground Mounted Signs	EA	-0.55	74.04	0.38
3132-Sweep / Wash Roadway	SHM	-0.51	773.29	0.37
3346-Repair / Maintain Timber Wings & Blkhds	SFT	-0.52	381.55	0.37
3128-Maint/Repair Pipes (<=48")	EA	-0.66	872.39	0.36
2900-Grass Mowing	SHM	-0.36	234.53	0.34
3124-Install/Repair/Replace Roadway Fences	LFT	-0.45	72.95	0.34
3138-Machining Unpaved Road	RML	-0.39	311.28	0.32
3222-Long Line Painted Pavement Markings	LFT	-0.42	2.86	0.32
3104-Litter Removal	SHM	-0.47	267.08	0.30
3140-Unpaved Road Stabilization Surface Maintenance	TON	-0.27	93.50	0.26
3344-Repair / Replace Timber Substructure Components	LFT	-0.46	946.51	0.23
3316-Maint to Timber Handrail	LFT	-0.48	241.05	0.20
3302-Maintain / Repair NON NBIS > 48" up to NBIS Structures	LFT	-0.44	672.49	0.18
3106-Bagged Litter and Trash Can Pickup	EA	-0.29	18.10	0.13
3366-Drift and Debris Removal	HR	0.07	29.99	0.06
3214-Adopt-A-Highway Program	HR	-0.14	51.92	0.04
3126-Install Pipes (<=48")	LFT	-0.20	178.92	0.04
3102-Removal of Hazards/Debris From ROW	HR	-0.03	48.08	0.02
*2904-Turf Management	ACR	0.11	18.66	0.01
*2908-Brush and Tree Control /Herbicides	SHM	-0.08	181.58	0.01
*3244-Temporary Traffic Control	HR	-0.03	42.42	0.01
*3200-Route Surv & Incid Detect & Response	HR	-0.02	42.84	0.00

\* *Not statistically significant at the 95 percent level of confidence*



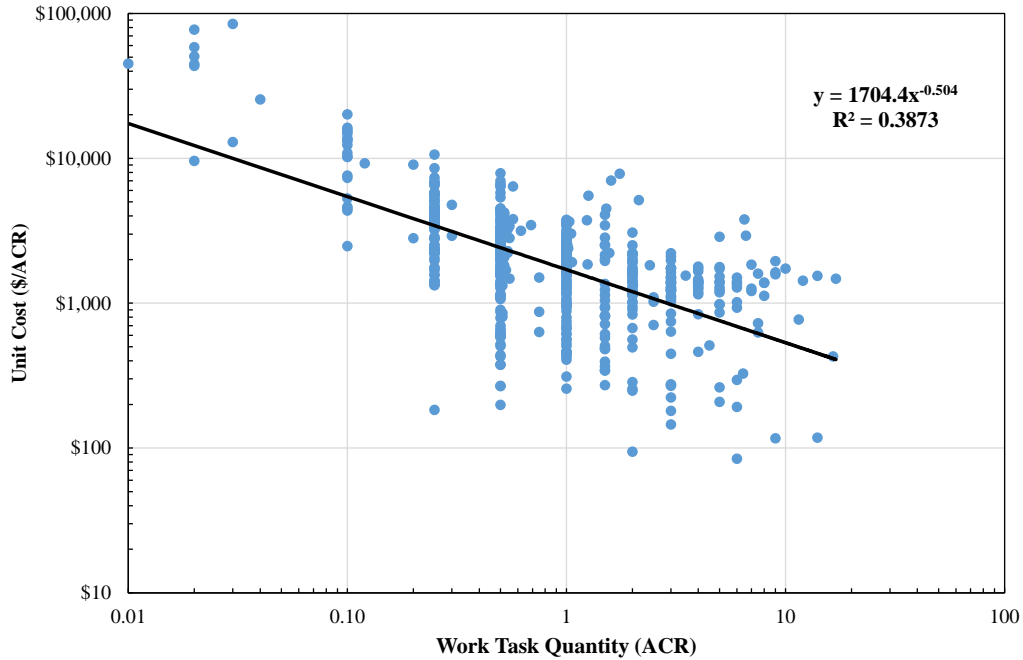
**Figure 10: Relationship between Unit Cost and Quantity for Task 3120 Repair/Maintain Barriers**



**Figure 11: Relationship between Unit Cost and Quantity for Task 2916 Roadside Vegetative Enhancement**

For tasks where the relationship was not considered practically significant, such as task 2918 Seeding and Mulching and Fertilization shown in Figure 12, the low  $R^2$  value generally resulted from large variability in the unit cost data. There is a clear relationship between quantity and unit cost, but the unit costs consistently ranged from approximately \$200 to \$2,000/ACR as quantity

ranged from 0.5 to 10 acres. This indicates that other factors beyond quantity had a substantial influence on unit cost.



**Figure 12: Relationship between Unit Cost and Quantity for Task 2918 Seeding and Mulching and Fertilization**

Graphs for all other analyzed tasks are provided in Appendix C.

In summary, nearly all maintenance tasks exhibited an inversely proportional relationship between unit cost and quantity. The relationship was statistically significant for the vast majority of tasks, but was masked by variability in unit cost data for approximately two-thirds of the tasks.

## 7 SPREADSHEET TOOL

A spreadsheet tool was developed in Microsoft Excel to facilitate calculating and archiving index values. The spreadsheet was designed to allow the user to generate a work order report for basket tasks from the Maintenance Management System (MMS) and paste the resulting data into the spreadsheet. The spreadsheet contains the base year parameters for the basket tasks and necessary formulae to summarize work order records by task and calculate the index values. The spreadsheet consists of the following worksheets:

- *Main* – contains identifying information and brief instructions
- *Data* – work order data used to calculate the cost indices is pasted onto this worksheet
- *Data Summary* – a summary of the work order records on the *Data* worksheet
- *Index Summary* – presents the calculated index values and contains tables and charts of archived values
- *Base Year Parameters* – the unit cost and total quantity data for basket tasks in the base year
- *Index Calculations* – the background calculations necessary to calculate the indices
- *SQL* – the SQL query code to produce the work order report from the MMS

### 7.1 Calculating Indices

The cost indices are automatically calculated based on work order data provided by the user for the subject year. The work order records for the subject year are summarized on the *Data Summary* worksheet, as shown in Figure 13. This summary includes:

- *Quantity Threshold* (column G) – the 98<sup>th</sup> percentile of recorded quantity for the task
- *Number of Work Order Records*
  - *Total* (column H) – number of work orders recorded for the task
  - *Quantity & Cost* (column I) – number of work order records containing both quantity and cost data
  - *Quantity Only* (column J) – number of work order records containing quantity data, but not cost data
  - *Cost Only* (column K) – number of work order records containing cost data, but not quantity data
- *Total Work Order Cost* (column L) – sum of recorded total cost for the task
- *Median Unit Cost* (column M) – median value of unit cost for work orders with both cost and quantity data
- *Recorded Quantity* (column N) – sum of quantity recorded for the task
- *Estimated Quantity* (column O) – quantity estimated for work orders with only cost data; sum of recorded cost (without quantity data) divided by median unit cost
- *Total Quantity* (column P) – sum of recorded and estimated quantity for the task

The product of unit price and quantity for each task in the base and subject year are calculated on the *Index Calculations* worksheet, as shown in Figure 14.

**Summary of Basket Tasks**

Category	Work Task	Unit	Task	Fiscal Year	Quantity Threshold	No. of Work Order Records				Total Work Order Cost	Median Unit Cost	Recorded Quantity	Estimated Quantity	Total Quantity
						Total	Quantity & Cost	Quantity Only	Cost Only					
Roadside	2900-Grass Mowing	SHM	2900	2012	6,188	498	466	27	5	\$ 4,070,285	\$ 67.53	121,057	1,194	122,251
	2912-Brush and Tree Control / Mechanical/ Other	SHM	2912	2012	83	3,809	3,691	56	62	\$ 8,737,394	\$ 370.10	20,774	2,398	23,172
	2914-Vegetation Management at Stationary Objects	LFT	2914	2012	252,045	1,108	1,081	9	18	\$ 1,714,508	\$ 1.31	20,207,516	60,543	20,268,059
Maintenance	3102-Removal of Hazards/Debris From ROW	HR	3102	2012	451	1,370	1,356	0	3	\$ 1,269,107	\$ 36.51	33,832	1,126	34,957
	3108-Drainage Ditch Maintenance	SHM	3108	2012	22	3,346	3,281	1	62	\$ 8,272,682	\$ 12,881.10	1,556	37	1,593
	3112-Shoulder Maintenance / Reconstruction	SHM	3112	2012	18	3,422	3,334	2	85	\$ 12,818,914	\$ 4,364.36	4,725	143	4,868
	3126-Install Pipes (<=48")	LFT	3126	2012	200	2,506	2,424	3	79	\$ 9,226,420	\$ 59.15	82,448	17,497	99,945
	3128-Maint/Repair Pipes (<=48")	EA	3128	2012	44	1,999	1,944	0	54	\$ 3,123,572	\$ 391.12	8,661	824	9,485
Traffic	3222-Long Line Painted Pavement Markings	LFT	3222	2012	253,371	2,238	2,171	49	18	\$ 3,420,645	\$ 0.04	85,087,742	2,557,598	87,645,339
	3250-Install / Replace Ground Mounted Signs	SFT	3250	2012	360	9,598	9,541	12	44	\$ 2,676,680	\$ 8.45	359,020	4,524	363,543
	3252-Repair Ground Mounted Signs	EA	3252	2012	114	6,124	6,073	2	49	\$ 1,141,017	\$ 34.61	45,022	2,491	47,514
Bridge	3300-Install / Replace NON NBIS > 48" up to NBIS Structures	LFT	3300	2012	568	74	63	0	11	\$ 5,500,326	\$ 927.79	4,558	1,461	6,019
	3302-Maintain / Repair NON NBIS > 48" up to NBIS Structures	LFT	3302	2012	1,932	73	68	0	5	\$ 1,253,498	\$ 107.67	5,017	2,469	7,486
	3310-Maintenance/Repair/Replacement of Standard Bridge Expansion Jo	LFT	3310	2012	872	83	70	0	13	\$ 550,621	\$ 12.83	11,133	12,547	23,680
	3314-Maintain Steel Superstructure Components	LFT	3314	2012	637	139	119	0	19	\$ 2,420,963	\$ 236.03	9,869	2,615	12,484
	3326-Maintain Concrete Deck	SFT	3326	2012	11,839	120	112	1	7	\$ 950,916	\$ 119.09	20,589	2,623	23,212
	3344-Repair / Replace Timber Substructure Components	LFT	3344	2012	495	190	184	0	6	\$ 2,749,715	\$ 285.65	7,395	2,280	9,675
	3348-Maintain Concrete Substructure Components	LFT	3348	2012	881	136	127	1	8	\$ 1,747,726	\$ 230.53	6,760	2,684	9,444
	3352-Maint Slope Protection	SFT	3352	2012	3,820	165	154	1	10	\$ 1,336,437	\$ 14.40	58,857	38,150	97,006
3366-Drift and Debris Removal	HR	3366	2012	358	253	251	0	2	\$ 600,290	\$ 36.74	14,954	5	14,959	

**Figure 13: Data Summary Worksheet**

Category	Work Task	Base Year		2012	P <sub>cy</sub> *Q <sub>by</sub>	P <sub>by</sub> *Q <sub>by</sub>
		Unit Cost (P <sub>by</sub> )	Quantity (Q <sub>by</sub> )	Unit Cost (P <sub>cy</sub> )		
Roadside	2900-Grass Mowing	\$ 73.29	140,035	\$ 67.53	45,010,923	27,344,078
	2912-Brush and Tree Control / Mechanical/ Other	\$ 530.39	15,997	\$ 370.10		
	2914-Vegetation Management at Stationary Objects	\$ 0.38	22,621,151	\$ 1.31		
Maintenance	3102-Removal of Hazards/Debris From ROW	\$ 44.35	47,363	\$ 36.51	32,012,959	48,310,389
	3108-Drainage Ditch Maintenance	\$ 17,711.33	1,005	\$ 12,881.10		
	3112-Shoulder Maintenance / Reconstruction	\$ 7,626.54	2,639	\$ 4,364.36		
	3126-Install Pipes (<=48")	\$ 83.15	55,230	\$ 59.15		
	3128-Maint/Repair Pipes (<=48")	\$ 565.30	6,528	\$ 391.12		
Traffic	3222-Long Line Painted Pavement Markings	\$ 0.04	60,575,692	\$ 0.04	6,118,902	6,117,687
	3250-Install / Replace Ground Mounted Signs	\$ 8.03	345,675	\$ 8.45		
	3252-Repair Ground Mounted Signs	\$ 41.04	22,390	\$ 34.61		
Bridge	3300-Install / Replace NON NBIS > 48" up to NBIS Structures	\$ 1,093.88	9,900	\$ 927.79	27,783,742	30,329,112
	3302-Maintain / Repair NON NBIS > 48" up to NBIS Structures	\$ 124.14	12,089	\$ 107.67		
	3310-Maintenance/Repair/Replacement of Standard Bridge Expansion Joints	\$ 50.76	28,894	\$ 12.83		
	3314-Maintain Steel Superstructure Components	\$ 223.03	7,297	\$ 236.03		
	3326-Maintain Concrete Deck	\$ 140.52	64,315	\$ 119.09		
	3344-Repair / Replace Timber Substructure Components	\$ 267.59	4,498	\$ 285.65		
	3348-Maintain Concrete Substructure Components	\$ 134.54	16,952	\$ 230.53		
	3352-Maint Slope Protection	\$ 14.55	111,700	\$ 14.40		
	3366-Drift and Debris Removal	\$ 37.47	20,256	\$ 36.74		
<b>Overall</b>					<b>110,926,527</b>	<b>112,101,266</b>

Category	Base Year P <sub>cy</sub> *Q <sub>by</sub>	2012 P <sub>by</sub> *Q <sub>by</sub>
Roadside	45,010,923	27,344,078
Maintenance	32,012,959	48,310,389
Traffic	6,118,902	6,117,687
Bridge	27,783,742	30,329,112
Roadway Maintenance	110,926,527	112,101,266

Figure 14: Index Calculations Worksheet

The calculated indices for each maintenance category and the index for overall Roadway Maintenance are presented on the Index Summary worksheet, as shown in Figure 15.

Category	2012 Index Value
Roadside	164.6
Maintenance	66.3
Traffic	100.0
Bridge	91.6
<b>Roadway Maintenance</b>	<b>99.0</b>

Figure 15: Calculated Indices on the *Index Summary Worksheet*

## 7.2 Archiving Indices

The cost indices can be archived in tables and charts provided for each index on the *Index Summary* worksheet, as shown in Figure 16. It is necessary for the user to copy the calculated index values from the top of the worksheet and paste each value into the row corresponding to the year in each maintenance category table. The associated charts were designed to update automatically as additional data are entered into each table.

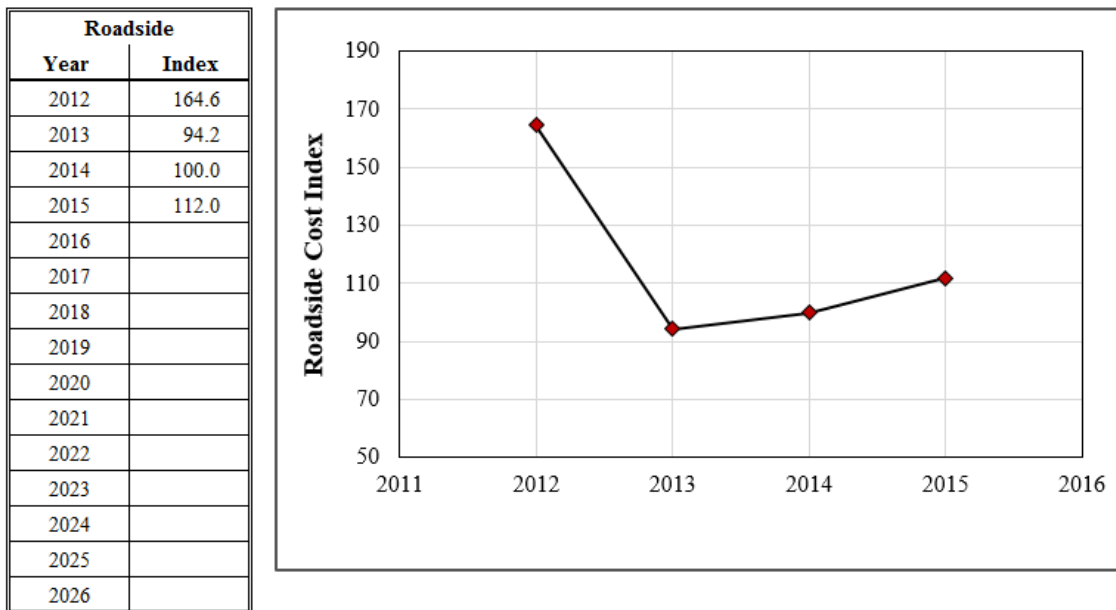


Figure 16: Summary Table and Chart for Roadside Index



## 8 SUMMARY AND CONCLUSIONS

Cost indices were developed for in-house maintenance work in the Roadside, Maintenance, Traffic, and Bridge categories of the Standing Maintenance budget and a composite index for Roadway Maintenance. The indices are fixed based, Laspeyres indices developed from the cost and quantity data of work order records. The base year 2014 was selected and unit cost and total quantity parameters calculated for 20 tasks representing maintenance performed in-house. Work order records from 2012 to 2015 were used to calculate the index values. A spreadsheet tool was developed to facilitate calculating and archiving index values. The relationship between unit cost and quantity of work performed was evaluated to determine whether the economies of scale concept can be appropriately applied to in-house maintenance tasks. The following conclusions were drawn from this work:

1. The quantity and quality of maintenance work order records is sufficient for developing and annually updating the cost indices for in-house maintenance work. For most basket tasks, thousands of work orders are recorded each year. Bridge tasks are typically recorded in fewer numbers, but still number into the hundreds. Only one task, *3372 Bridge Installation & Replacement*, was excluded from the basket because a minimum of 50 work order records were not available. Between 85 and 90 percent, depending on the year, of work order records for basket tasks contained the necessary quantity and cost data.
2. The Laspeyres index form is appropriate for the developed indices because of the stability in the quantities of tasks performed. While variability was observed for a small number of basket tasks, overall the annual task quantities were consistent and not subject to substitution due to cost changes.
3. The 20 basket tasks selected are representative of overall in-house maintenance and maintenance within each category. The basket tasks accounted for between 72 and 76 percent, depending on the year, of total recorded costs. A majority of costs in each maintenance category were also captured by the basket tasks. The magnitude of costs by task and the relative ranking of tasks by cost were relatively consistent over the 2012 to 2015 period.
4. Median unit cost more accurately represents the costs of tasks than average unit cost. The unit cost data were heavily right skewed not and normally distributed. The median unit cost was less than the average for each task, was more frequently observed in the data, and was significantly less than the average value for tasks except those measured in units of hours.
5. A large majority of the quantity of work performed was captured in the work order records for most basket tasks. There was a need to estimate quantity for a portion of the work where only cost was recorded. The estimated portion of total quantity was generally less than 10 percent. It was greatest for Bridge tasks and was over 50 percent for three Bridge tasks.
6. Maintenance costs generally increase over time and the rate of increase varies by maintenance category. Overall roadway maintenance costs increased 9.4 percent annually from 2013 to 2015, with the largest annual growth in bridge tasks at 10.9 percent and the smallest in traffic tasks at 4.1 percent. Both roadside and maintenance tasks grew at just over 9 percent annually over the period.

7. The unit cost of maintenance tasks is inversely proportional to the quantity of work performed. The relationship between unit cost and quantity was best modeled by the power curve and was statistically significant at the 95 percent level of confidence for 42 of the 44 studied tasks. However, the observed variability in unit cost data for many tasks indicated the influence of factors beyond quantity and limited the practical significance, or ability to accurately predict unit cost based on quantity.

## 9 RECOMMENDATIONS

The following recommendations are made based on the results and conclusions of this research:

1. Annual increases in the cost of maintenance tasks performed in-house should be included in multi-year plans and budgets for roadway maintenance activities.
2. Cost changes over a multi-year period, rather than year to year changes, should be used to forecast costs due to year to year variability in median unit costs.
3. Repeated performance of a work task should not be aggregated into a single work task record. Rather, each activity should be recorded separately to increase the accuracy of the unit cost data used to calculate the indices.
4. The importance of accurately recording work order quantity should be communicated to those responsible for creating work order records. Efforts should be made to capture the quantity of work for Bridge tasks, and specifically tasks:
  - *3302 Maintain/Repair NON NBIS > 48" up to NBIS Structures*
  - *3314 Maintain Steel Superstructure Components*
  - *3352 Maintain Slope Protection*
5. The total annual quantity of basket tasks should be monitored for stability over the coming years. If instability is noted in a significant number of tasks, then consideration should be given to adopting a base period spanning multiple years.
6. The base period should be periodically revised, perhaps on a 10 year cycle such as was used for the FHWA Bid Price Index, to adjust the relative weights of basket tasks based on changes in work quantities.

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## APPENDIX A – WORK ORDER RECORD SUMMARIES

**Table A1: Summary of 2014 Maintenance Task Work Order Records**

Maintenance Task	No. of Work Order Records			
	Total	Quantity & Cost	Cost Only	Quantity Only
3100-Snow and Ice	10	6	1	0
3102-Removal of Hazards/Debris From ROW	1,432	1,280	5	37
3104-Litter Removal	754	663	48	0
3106-Bagged Litter and Trash Can Pickup	694	627	38	5
3108-Drainage Ditch Maintenance	3,903	3,343	363	2
3110-Beaver Control	64	58	0	0
3112-Shoulder Maintenance / Reconstruction	2,963	2,380	341	45
3116-Maintenance of Truck Escape Ramps	14	12	0	0
3118-Install Barriers	8	4	3	0
3120-Repair / Maintain Barriers	195	155	24	1
3122-Maintenance Repair and Replacement of Attenuators	7	3	2	1
3124-Install/Repair/Replace Roadway Fences	80	64	11	0
3126-Install Pipes (<=48")	1,572	1,222	258	8
3128-Maint/Repair Pipes (<=48")	2,169	1,731	327	4
3130-Install/ Maintain / Repair of Misc. Drainage Structures	1,148	921	176	2
3132-Sweep / Wash Roadway	150	125	20	0
3134-Roadway Grading	74	71	0	0
3136-Roadway Base Construction	23	13	5	1
3138-Machining Unpaved Road	1,957	1,731	98	21
3140-Unpaved Road Stabilization Surface Maintenance	1,024	789	171	10
<b>Total Maintenance Task</b>	<b>18,241</b>	<b>15,198</b>	<b>1,891</b>	<b>137</b>

**Table A2: Summary of 2014 Traffic Maintenance Task Work Order Records**

Traffic Maintenance Task	No. of Work Order Records			
	Total	Quantity & Cost	Cost Only	Quantity Only
3200-Route Surv & Incid Detect & Response	314	293	1	0
3202-Changeable Message Sign	2	2	0	0
3204-ITS Devices	3	3	0	0
3210-LOGO Sign Program	1	1	0	0
3214-Adopt-A-Highway Program	474	174	27	0
3216-Channelization	30	26	2	0
3218-Curb and Gutter Installation and Repair.	61	48	9	0
3220-Preline	66	52	9	0
3222-Long Line Painted Pavement Markings	1,560	1,402	51	47
3224-Pavement Marking Removal	58	45	11	0
3226-Long Line Specialty Material Pavement Markings	51	18	7	14
3228-Words and Symbols - Painted	70	53	12	1
3230-Words and Symbols - Specialty Materials	269	247	17	0
3232-Install / Replace Pavement Markers	26	17	8	1
3234-Installation / Upgrade of Traffic Signals	1	0	1	0
3236-Traffic Signal Routine Maintenance	2	0	2	0
3238-Emergency Response to Traffic Signals	11	10	0	0
3242-Roadway and Interchange Lighting	9	9	0	0
3244-Temporary Traffic Control	288	276	2	1
3250-Install / Replace Ground Mounted Signs	6,433	6,009	213	15
3252-Repair Ground Mounted Signs	5,431	5,082	127	3
3254-Install / Replace Overhead Signs	5	1	3	0
3256-Repair Overhead Signs	7	4	3	0
<b>Total Maintenance Tasks</b>	<b>15,172</b>	<b>13,772</b>	<b>505</b>	<b>82</b>

**Table A3: Summary of 2014 Bridge Maintenance Task Work Order Records**

Bridge Maintenance Tasks	No. of Work Order Records			
	Total	Quantity & Cost	Cost Only	Quantity Only
3300-Install / Replace NON NBIS > 48" up to NBIS Structures	122	80	31	3
3302-Maintain / Repair NON NBIS > 48" up to NBIS Structures	156	93	55	1
3352-Maint Slope Protection	253	161	78	2
3314-Maintain Steel Superstructure Components	154	74	44	2
3344-Repair / Replace Timber Substructure Components	143	97	36	0
3326-Maintain Concrete Deck	188	135	42	0
3372-Bridge Installation & Replacement	21	11	9	0
3310- Maint/Repair/Replacement of Std Bridge Exp Joints	156	99	21	0
3366-Drift and Debris Removal	346	314	2	8
3348-Maintain Concrete Substructure Components	151	101	45	0
3346-Repair / Maintain Timber Wings & Blkhs	136	82	46	2
3324-Maint / Repair / Replace Timber Deck Components	74	51	19	0
3306-Maintain Concrete Superstructure Components	164	102	26	1
3376-Clean/Wash Bridge Decks	368	198	53	76
3342-Clean and Paint Structural Steel	53	40	13	0
3354-Maintain Steel Substructure Components	18	11	5	0
3318-Maint to Concrete Handrail	60	41	18	0
3370-Maintenance and Repair of NBIS Pipes and Culverts	63	50	11	1
3368-Installation and Replacement of NBIS Pipes and Culverts	7	5	0	0
3336-Moveable Bridges (Maintenance)	6	5	1	0
3316-Maint to Timber Handrail	121	77	42	0
3350-Maint R C Wings and Walls	37	25	9	0
3304-Maintain/Replace Timber Superstructure Components	33	20	12	0
3322-Maint to Steel Handrail	74	46	22	1
3334-Bridge Bearings	39	27	9	0
3328-Maintenance/Repair/ Replace Steel Plank Bridge Floor	33	22	10	0
3362-Maintenance and Repair of Fender System	6	4	2	0
3338-Moveable Bridges (Operations)	4	4	0	0
3332-Maint Drainage System - Bridge	38	25	11	0
3320-Maint to Aluminum Handrail	14	5	8	0
3374-Repair and Maint of Pedestrian Bridges	3	3	0	0
3308-Maint. Of Steel Plate Bridge Joints	7	5	2	0
3330-Maintenance/Repair Open Grid Steel Floor	5	4	1	0
3358-Maintenance of Noise Walls	5	0	2	0
3312-Maint/Replace/Repair Modular Bridge Joints	2	1	1	0
3340-Maint Navigation Lights	3	3	0	0
3360-Maintenance of Structural Walls & Tunnels	1	1	0	0
<b>Total Bridge Maintenance Tasks</b>	<b>3,064</b>	<b>2,022</b>	<b>686</b>	<b>97</b>



**APPENDIX B – TOTAL RECORDED COST SUMMARIES**

**Table B1: Summary of Recorded Annual Total Cost for Maintenance Tasks**

Maintenance Work Task	Annual Total Cost				Percent of 2014 Category Cost	Cumulative Percentage
	2012	2013	2014	2015		
3112-Shoulder Maintenance / Reconstruction	\$ 15,372,016	\$ 13,813,494	\$ 11,502,665	\$ 10,828,084	24%	24%
3108-Drainage Ditch Maintenance	\$ 8,827,846	\$ 9,229,874	\$ 11,256,870	\$ 8,943,515	23%	47%
3126-Install Pipes (<=48")	\$ 10,934,372	\$ 9,386,266	\$ 7,338,559	\$ 6,950,337	15%	63%
3128-Maint/Repair Pipes (<=48")	\$ 3,562,109	\$ 3,562,052	\$ 4,302,434	\$ 4,641,180	9%	72%
3102-Removal of Hazards/Debris From ROW	\$ 2,941,964	\$ 4,525,548	\$ 3,124,937	\$ 3,174,676	7%	78%
3140-Unpaved Road Stabilization Surface Maintenance	\$ 2,309,968	\$ 2,031,428	\$ 2,947,275	\$ 3,161,099	6%	84%
3130-Install/ Maintain / Repair of Misc. Drainage Structures	\$ 2,748,083	\$ 2,441,265	\$ 2,755,236	\$ 2,066,833	6%	90%
3138-Machining Unpaved Road	\$ 2,026,183	\$ 1,564,432	\$ 1,853,107	\$ 2,160,724	4%	94%
3104-Litter Removal	\$ 941,269	\$ 1,178,986	\$ 1,014,951	\$ 1,357,678	2%	96%
3106-Bagged Litter and Trash Can Pickup	\$ 489,043	\$ 365,582	\$ 456,502	\$ 639,282	1%	97%
3134-Roadway Grading	\$ 525,437	\$ 618,169	\$ 361,741	\$ 734,037	1%	98%
3132-Sweep / Wash Roadway	\$ 298,958	\$ 1,010,370	\$ 356,990	\$ 773,179	1%	99%
3136-Roadway Base Construction	\$ 377,275	\$ 247,845	\$ 163,708	\$ 191,329	0%	99%
3110-Beaver Control	\$ 157,964	\$ 279,570	\$ 161,734	\$ 190,149	0%	99%
3120-Repair / Maintain Barriers	\$ 174,370	\$ 159,734	\$ 128,175	\$ 273,030	0%	100%
3124-Install/Repair/Replace Roadway Fences	\$ 123,241	\$ 168,423	\$ 97,606	\$ 98,690	0%	100%
3100-Snow and Ice	\$ 64,846	\$ 39,178	\$ 29,689	\$ 23,100	0%	100%
3116-Maintenance of Truck Escape Ramps	\$ 34,298	\$ 22,401	\$ 26,735	\$ 14,629	0%	100%
3118-Install Barriers	\$ 64,162	\$ 9,585	\$ 25,859	\$ 19,692	0%	100%
3122-Maintenance Repair and Replacement of Attenuators	\$ 16,995	\$ 13,999	\$ 15,687	\$ 21,629	0%	100%
<b>Total Maintenance Tasks</b>	<b>\$ 51,990,400</b>	<b>\$ 50,668,201</b>	<b>\$ 47,920,459</b>	<b>\$ 46,262,870</b>		

**Table B2: Summary of Recorded Annual Total Cost for Traffic Tasks**

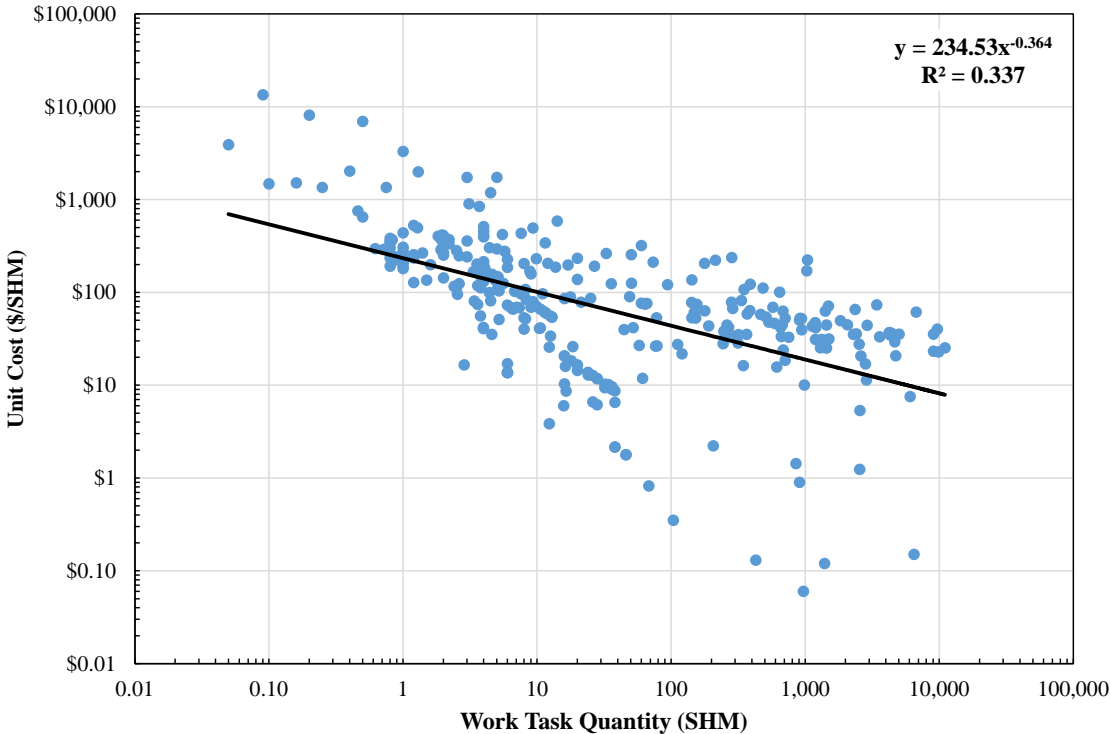
Traffic Work Tasks	Annual Total Cost				Percent of 2014 Category Cost	Cumulative Percentage
	2012	2013	2014	2015		
3250-Install / Replace Ground Mounted Signs	\$ 3,830,083	\$ 2,977,465	\$ 2,610,608	\$ 2,138,947	32%	32%
3222-Long Line Painted Pavement Markings	\$ 3,703,547	\$ 2,629,134	\$ 2,557,023	\$ 1,641,968	32%	64%
3252-Repair Ground Mounted Signs	\$ 1,545,573	\$ 947,358	\$ 1,078,667	\$ 1,040,764	13%	77%
3230-Words and Symbols - Specialty Materials	\$ 578,749	\$ 348,171	\$ 350,546	\$ 313,952	4%	82%
3226-Long Line Specialty Material Pavement Markings	\$ 1,308	\$ 14,436	\$ 342,024	\$ 1,150,455	4%	86%
3200-Route Surv & Incid Detect & Response	\$ 289,267	\$ 509,354	\$ 337,064	\$ 397,607	4%	90%
3218-Curb and Gutter Installation and Repair.	\$ 207,495	\$ 401,352	\$ 290,813	\$ 449,565	4%	94%
3244-Temporary Traffic Control	\$ 287,372	\$ 314,381	\$ 241,389	\$ 217,739	3%	97%
3228-Words and Symbols - Painted	\$ 140,242	\$ 111,678	\$ 55,500	\$ 22,914	1%	97%
3216-Channelization	\$ 33,224	\$ 42,192	\$ 53,084	\$ 47,341	1%	98%
3214-Adopt-A-Highway Program	\$ 23,569	\$ 33,789	\$ 41,677	\$ 78,335	1%	98%
3220-Preline	\$ 61,417	\$ 50,866	\$ 31,933	\$ 18,427	0%	99%
3224-Pavement Marking Removal	\$ 80,250	\$ 46,427	\$ 30,715	\$ 35,253	0%	99%
3256-Repair Overhead Signs	\$ 127,019	\$ 18,370	\$ 18,553	\$ 8,811	0%	99%
3254-Install / Replace Overhead Signs	\$ 0	\$ 2,362	\$ 16,096	\$ 0	0%	100%
3236-Traffic Signal Routine Maintenance	\$ 1,236	\$ 230	\$ 11,761	\$ 610,052	0%	100%
3232-Install / Replace Pavement Markers	\$ 15,137	\$ 16,514	\$ 8,950	\$ 102,429	0%	100%
3242-Roadway and Interchange Lighting	\$ 14,155	\$ 11,831	\$ 6,300	\$ 8,136	0%	100%
3238-Emergency Response to Traffic Signals	\$ 11,476	\$ 6,860	\$ 4,662	\$ 94,001	0%	100%
3204-ITS Devices	\$ 5,718	\$ 0	\$ 1,144	\$ 0	0%	100%
3234-Installation / Upgrade of Traffic Signals	\$ 5,332	\$ 0	\$ 1,110	\$ 44,379	0%	100%
3202-Changeable Message Sign	\$ 0	\$ 536	\$ 783	\$ 1,759	0%	100%
3210-LOGO Sign Program	\$ 113	\$ 32,531	\$ 289	\$ 413	0%	100%
<b>Total Traffic Tasks</b>	<b>\$ 10,962,281</b>	<b>\$ 8,515,838</b>	<b>\$ 8,090,690</b>	<b>\$ 8,423,248</b>		

**Table B3: Summary of Recorded Annual Total Cost for Bridge Tasks**

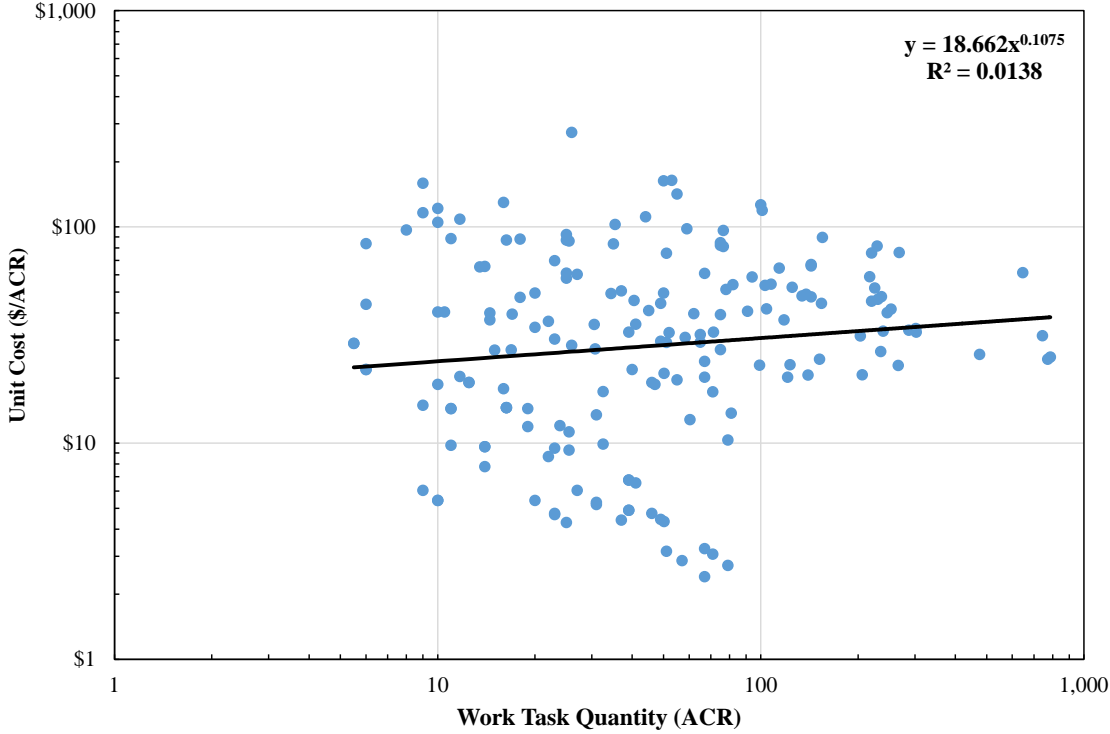
Bridge Work Tasks	Annual Total Cost				Percent of 2014 Category Cost	Cumulative Percentage
	2012	2013	2014	2015		
3300-Install/Replace NON NBIS >48" up to NBIS Structures	\$ 5,795,837	\$ 5,230,130	\$ 9,697,865	\$ 8,718,116	33%	33%
3302-Maintain/Repair NON NBIS >48" up to NBIS Structures	\$ 1,364,589	\$ 1,173,415	\$ 1,964,873	\$ 1,240,791	7%	40%
3352-Maint Slope Protection	\$ 1,343,272	\$ 1,300,360	\$ 1,677,831	\$ 798,804	6%	46%
3314-Maintain Steel Superstructure Components	\$ 2,511,518	\$ 2,352,921	\$ 1,539,516	\$ 1,897,395	5%	51%
3344-Repair / Replace Timber Substructure Components	\$ 2,861,802	\$ 1,832,226	\$ 1,381,301	\$ 1,126,293	5%	56%
3326-Maintain Concrete Deck	\$ 1,014,139	\$ 1,200,222	\$ 1,140,446	\$ 1,031,769	4%	59%
3372-Bridge Installation & Replacement	\$ 1,476,756	\$ 2,608,023	\$ 1,132,112	\$ 576,279	4%	63%
3310- Maint/Repair/Replacement of Std Bridge Exp Joints	\$ 551,685	\$ 844,835	\$ 1,128,289	\$ 593,867	4%	67%
3366-Drift and Debris Removal	\$ 794,603	\$ 1,128,889	\$ 1,092,438	\$ 936,454	4%	71%
3348-Maintain Concrete Substructure Components	\$ 1,816,886	\$ 1,242,161	\$ 1,082,144	\$ 1,479,457	4%	75%
3346-Repair / Maintain Timber Wings & Blkhds	\$ 1,395,301	\$ 1,237,264	\$ 877,620	\$ 808,823	3%	78%
3324-Maint / Repair / Replace Timber Deck Components	\$ 949,385	\$ 656,991	\$ 820,863	\$ 866,177	3%	80%
3306-Maintain Concrete Superstructure Components	\$ 811,996	\$ 897,352	\$ 779,978	\$ 760,555	3%	83%
3376-Clean/Wash Bridge Decks	\$ 838,606	\$ 750,814	\$ 736,876	\$ 698,065	3%	86%
3342-Clean and Paint Structural Steel	\$ 286,759	\$ 547,403	\$ 459,816	\$ 492,005	2%	87%
3354-Maintain Steel Substructure Components	\$ 428,877	\$ 373,724	\$ 395,674	\$ 157,484	1%	89%
3318-Maint to Concrete Handrail	\$ 349,802	\$ 274,301	\$ 354,494	\$ 455,718	1%	90%
3370-Maintenance and Repair of NBIS Pipes and Culverts	\$ 276,417	\$ 360,740	\$ 343,692	\$ 367,425	1%	91%
3368-Installation and Replacement of NBIS Pipes and Culverts	\$ 1,020,631	\$ 1,868,209	\$ 338,873	\$ 1,323,899	1%	92%
3336-Moveable Bridges (Maintenance)	\$ 104,532	\$ 138,676	\$ 311,170	\$ 213,589	1%	93%
3316-Maint to Timber Handrail	\$ 479,615	\$ 374,017	\$ 258,042	\$ 268,760	1%	94%
3350-Maint R C Wings and Walls	\$ 84,086	\$ 96,830	\$ 255,206	\$ 38,222	1%	95%
3304-Maintain/Replace Timber Superstructure Components	\$ 791,891	\$ 272,891	\$ 239,855	\$ 157,320	1%	96%
3322-Maint to Steel Handrail	\$ 302,084	\$ 300,843	\$ 223,666	\$ 185,114	1%	97%
3334-Bridge Bearings	\$ 144,024	\$ 154,918	\$ 216,445	\$ 162,152	1%	97%
3328-Maintenance/Repair/ Replace Steel Plank Bridge Floor	\$ 223,873	\$ 331,904	\$ 209,375	\$ 325,508	1%	98%

Bridge Work Tasks	Annual Total Cost				Percent of 2014 Category Cost	Cumulative Percentage
	2012	2013	2014	2015		
3362-Maintenance and Repair of Fender System	\$ 110,450	\$ 32,092	\$ 184,782	\$ 2,174	1%	99%
3338-Moveable Bridges (Operations)	\$ 0	\$ 0	\$ 173,212	\$ 744,046	1%	99%
3332-Maint Drainage System - Bridge	\$ 71,113	\$ 155,026	\$ 110,981	\$ 136,843	0%	100%
3320-Maint to Aluminum Handrail	\$ 43,024	\$ 54,316	\$ 30,335	\$ 63,119	0%	100%
3374-Repair and Maint of Pedestrian Bridges	\$ 14,354	\$ 47,676	\$ 29,810	\$ 23,567	0%	100%
3308-Maint. Of Steel Plate Bridge Joints	\$ 1,780	\$ 8,004	\$ 19,927	\$ 5,140	0%	100%
3330-Maintenance/Repair Open Grid Steel Floor	\$ 2,228	\$ 36,281	\$ 19,605	\$ 5,366	0%	100%
3358-Maintenance of Noise Walls	\$ 64,545	\$ 30,684	\$ 13,770	\$ 18,901	0%	100%
3312-Maint/Replace/Repair Modular Bridge Joints	\$ 45,846	\$ 19,771	\$ 6,049	\$ 149,212	0%	100%
3340-Maint Navigation Lights	\$ 0	\$ 850	\$ 3,285	\$ 0	0%	100%
3360-Maintenance of Structural Walls & Tunnels	\$ 0	\$ 2,190	\$ 1,891	\$ 797	0%	100%
<b>Total Bridge Tasks</b>	<b>\$ 28,372,308</b>	<b>\$ 27,936,950</b>	<b>\$ 29,252,108</b>	<b>\$ 26,829,205</b>		

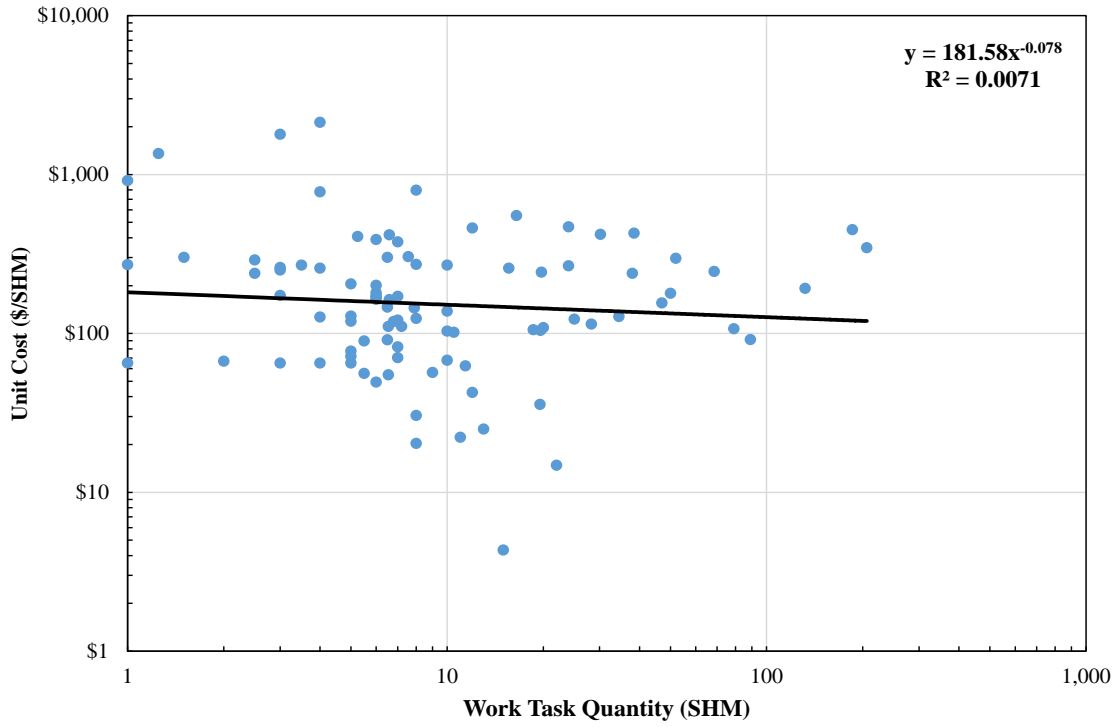
**APPENDIX C – RELATIONSHIPS BETWEEN UNIT COST AND QUANTITY**



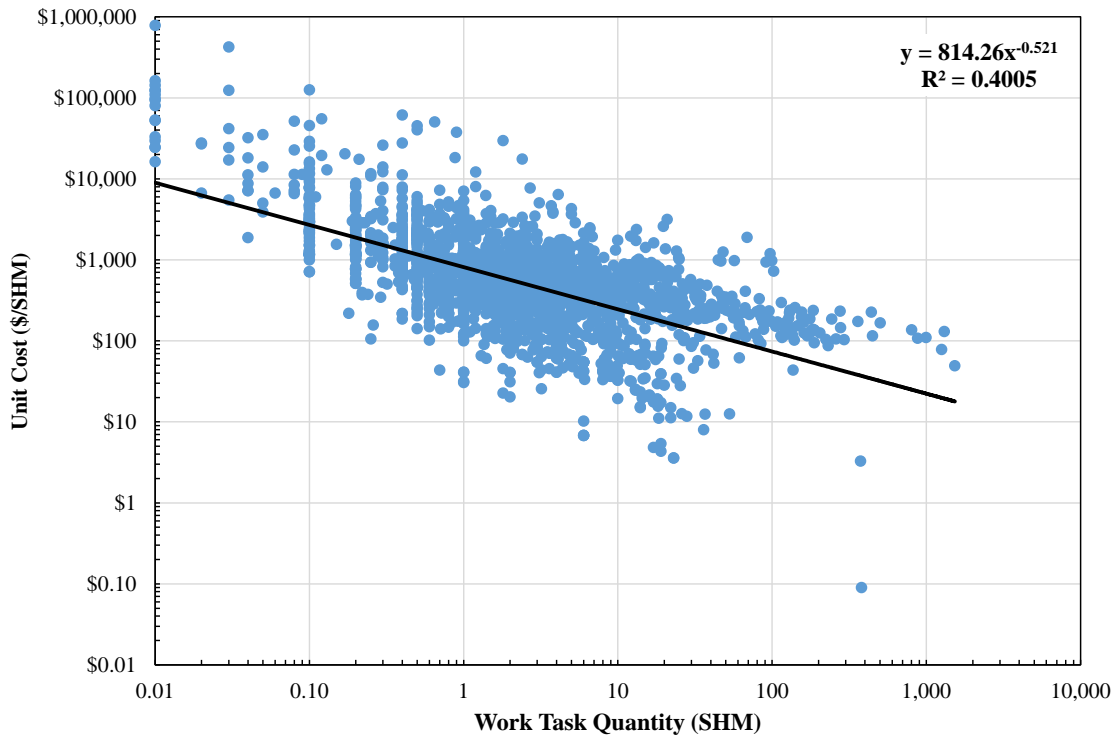
**Figure C1: Unit Cost and Quantity for Task 2900 Grass Mowing**



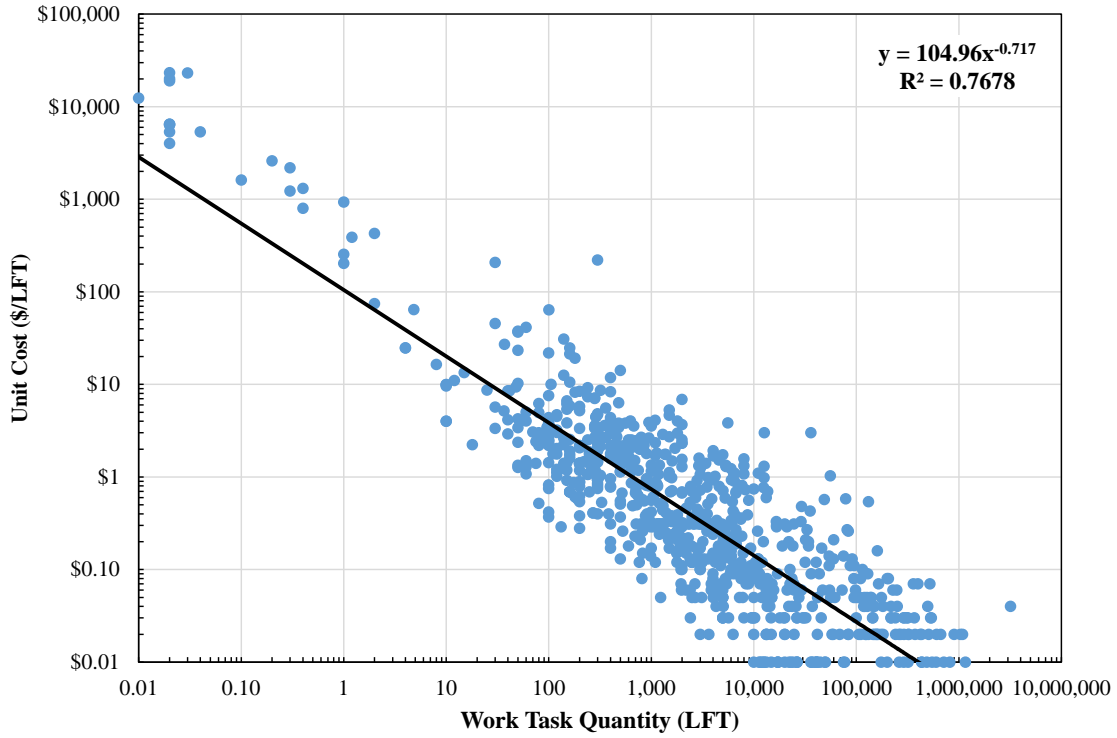
**Figure C2: Unit Cost and Quantity for Task 2904 Turf Management**



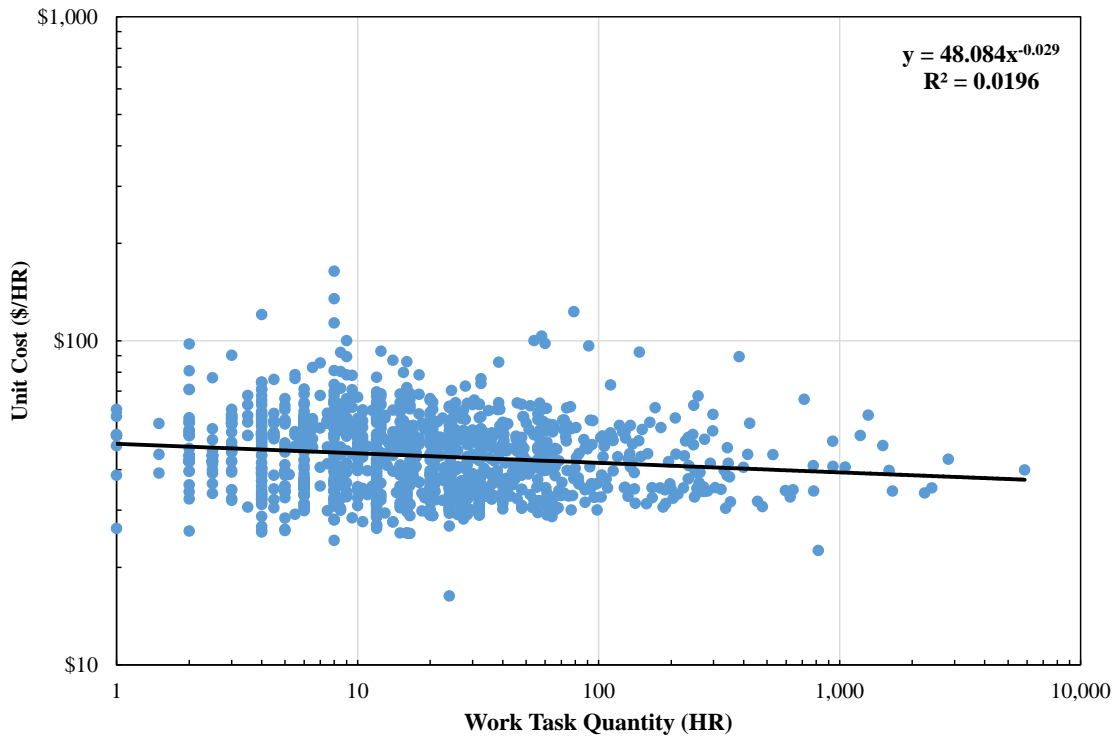
**Figure C3: Unit Cost and Quantity for Task 2908 Brush and Tree Control/Herbicides**



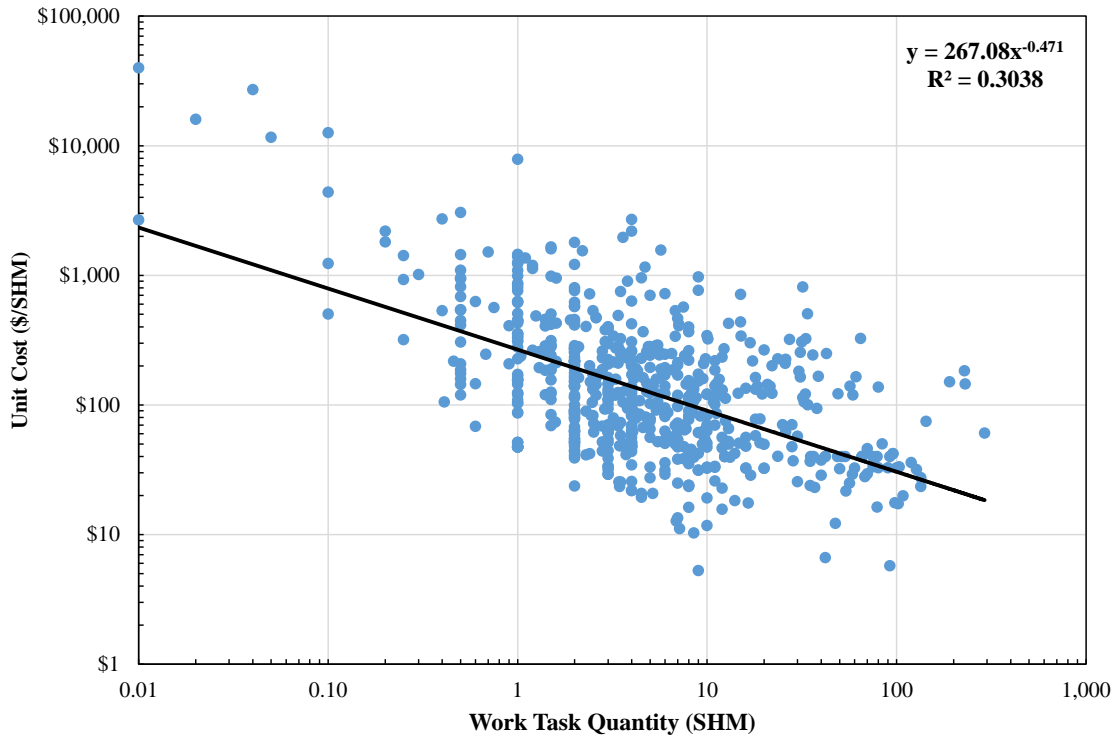
**Figure C4: Unit Cost and Quantity for Task 2912 Brush and Tree Control/Mechanical/Other**



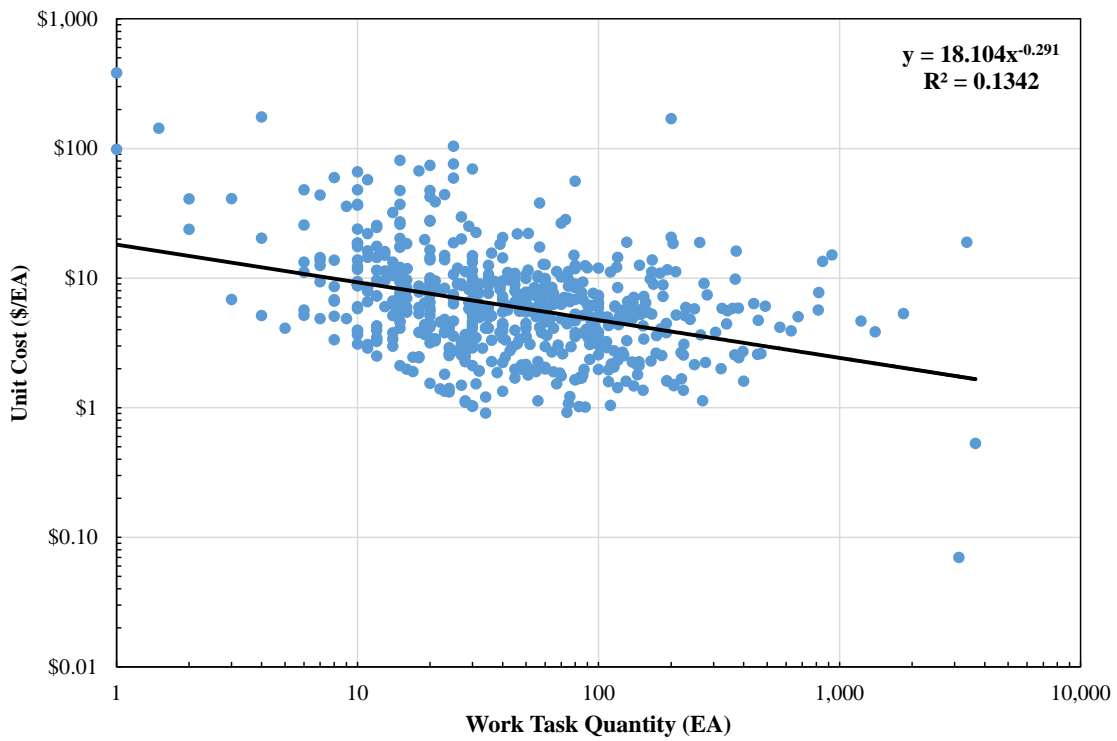
**Figure C5: Unit Cost and Quantity for Task 2914 Vegetation Management at Stationary Objects**



**Figure C6: Unit Cost and Quantity for Task 3102 Removal of Hazards/Debris from ROW**

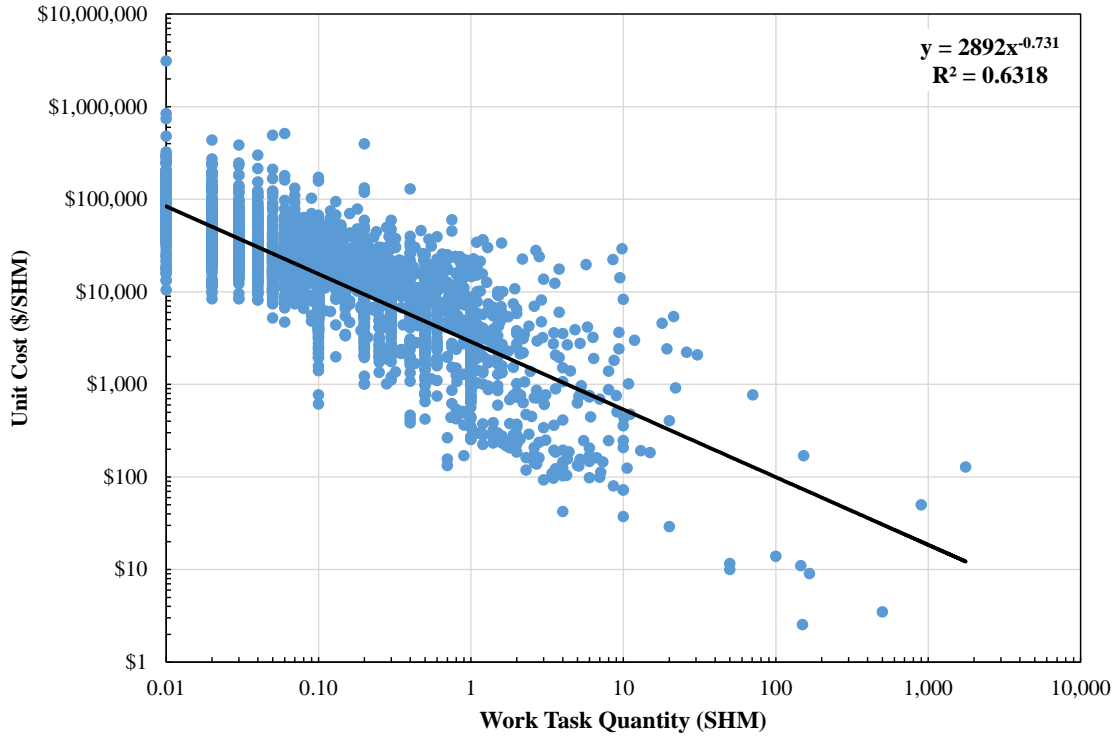


**Figure C7: Unit Cost and Quantity for Task 3104 Litter Removal**

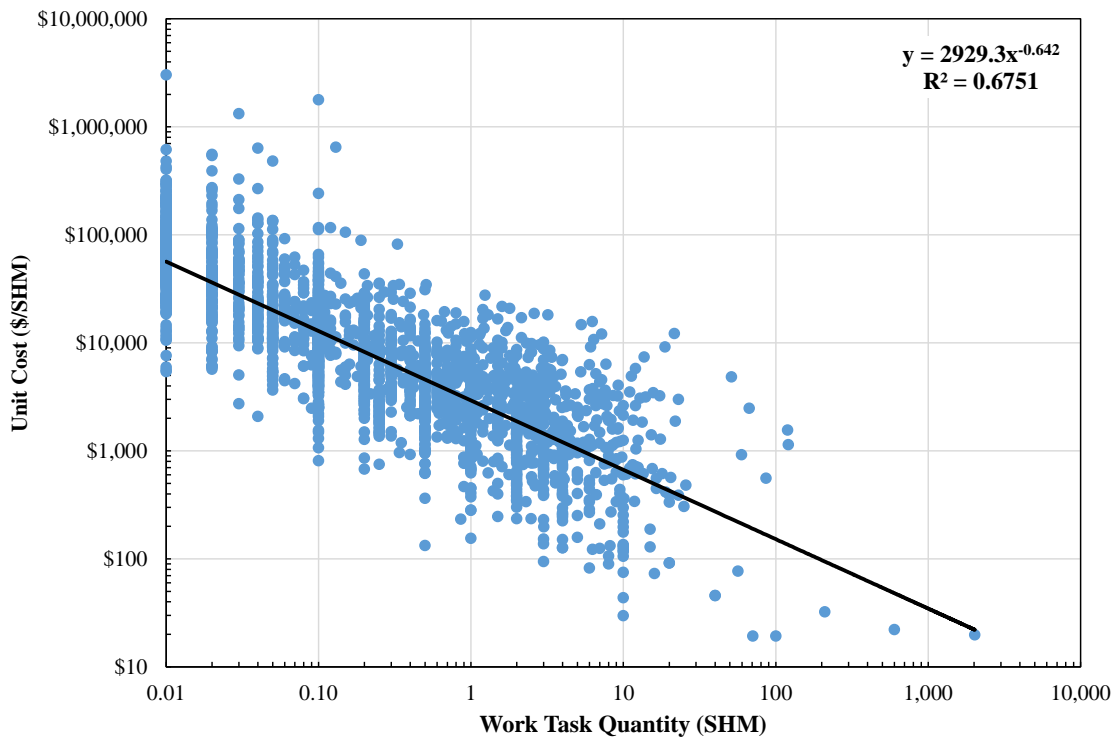


**Figure C8: Unit Cost and Quantity for Task 3106 Bagged Litter and Trash Can Pickup**

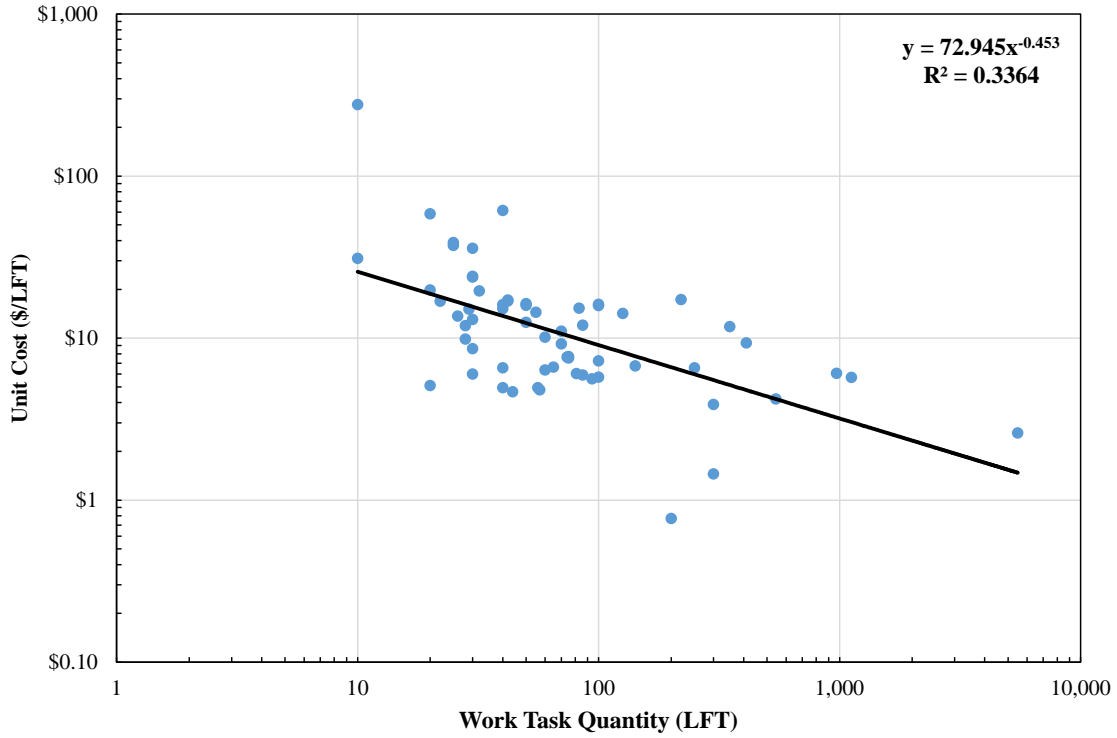




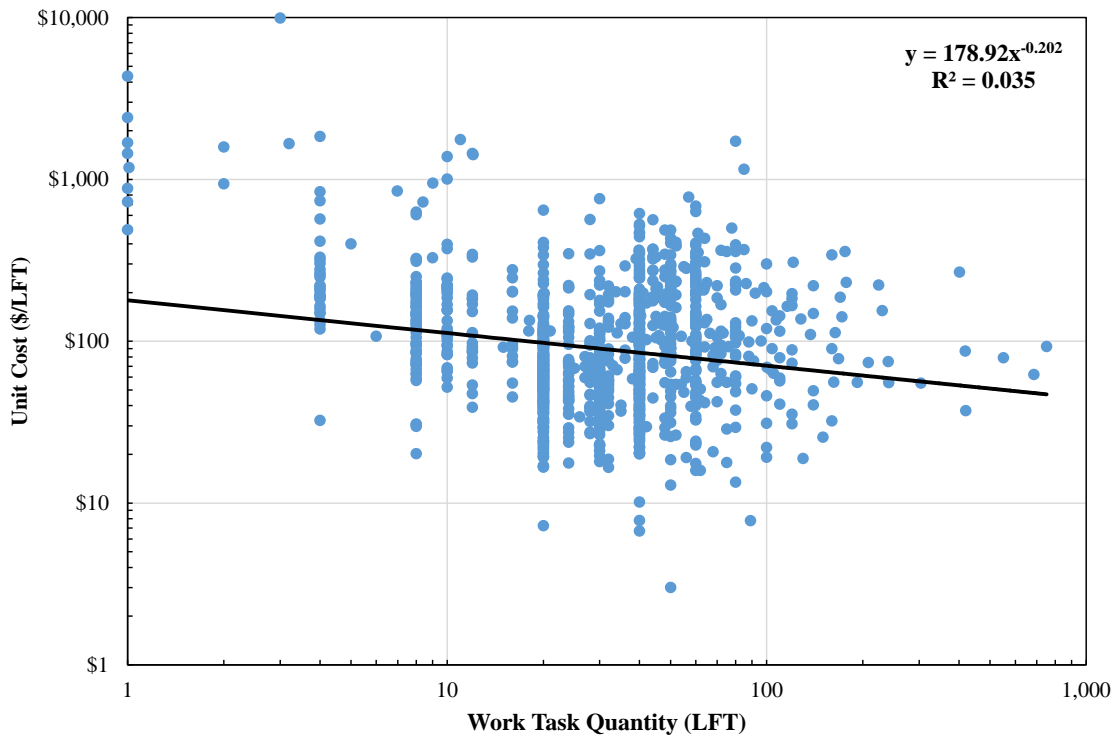
**Figure C9: Unit Cost and Quantity for Task 3108 Drainage Ditch Maintenance**



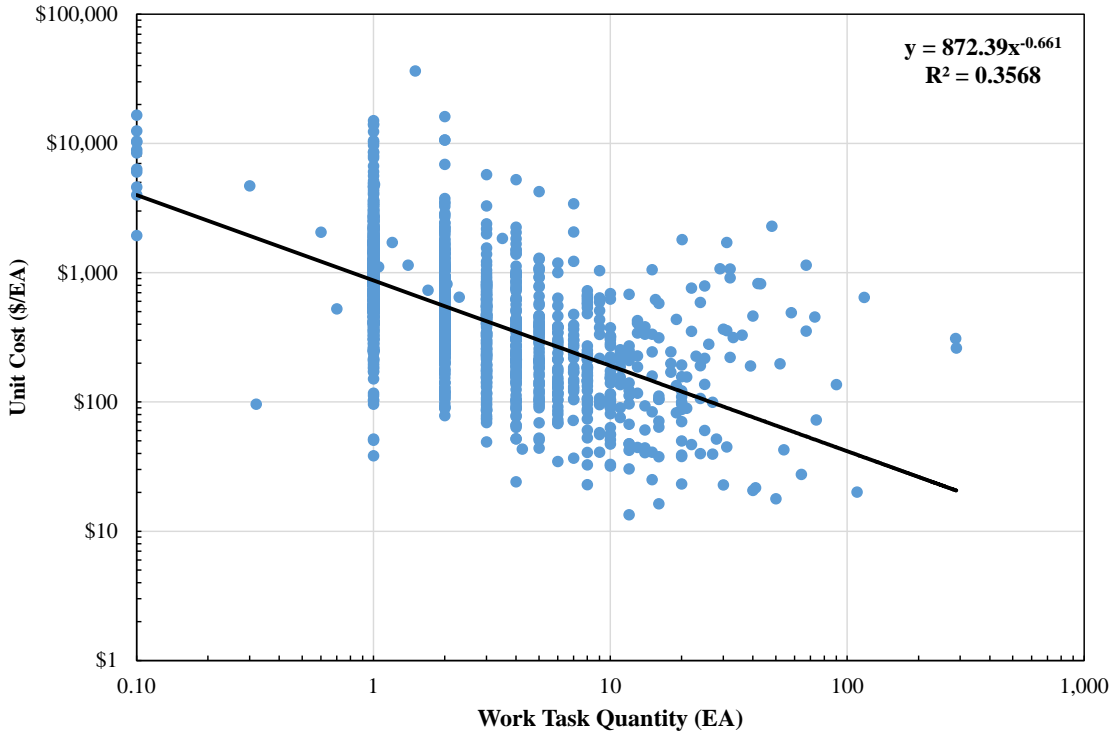
**Figure C10: Unit Cost and Quantity for Task 3112 Shoulder Maintenance/Reconstruction**



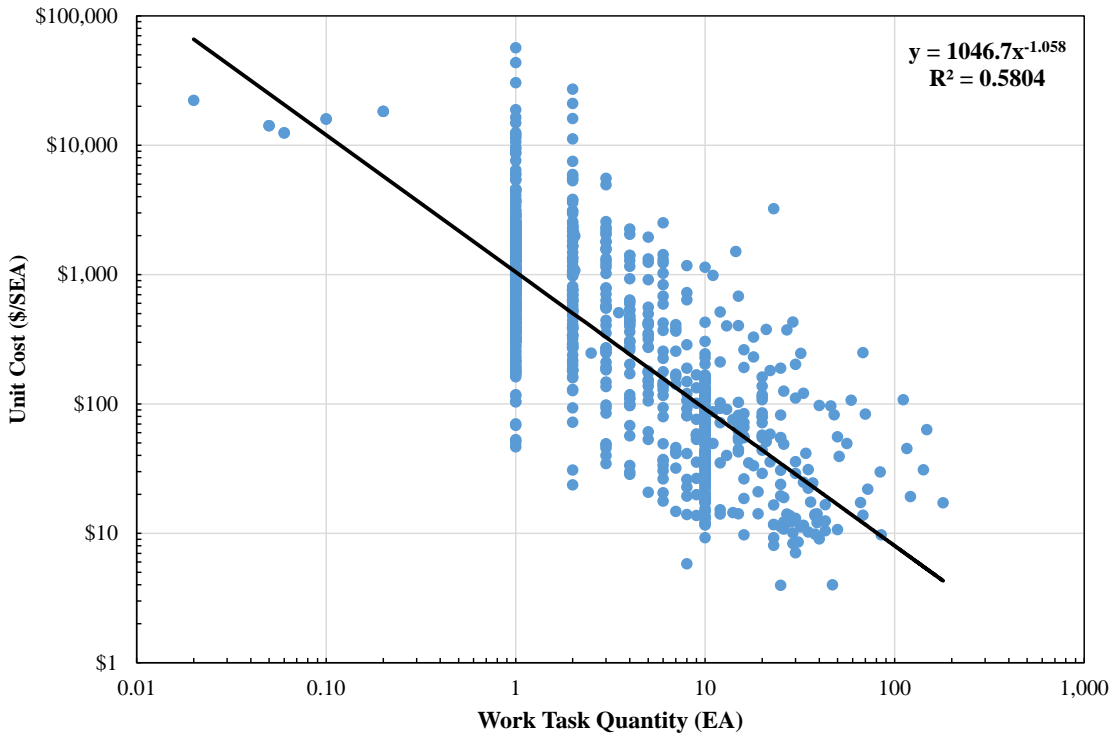
**Figure C11: Unit Cost and Quantity for Task 3124 Install/Repair/Replace Roadway Fences**



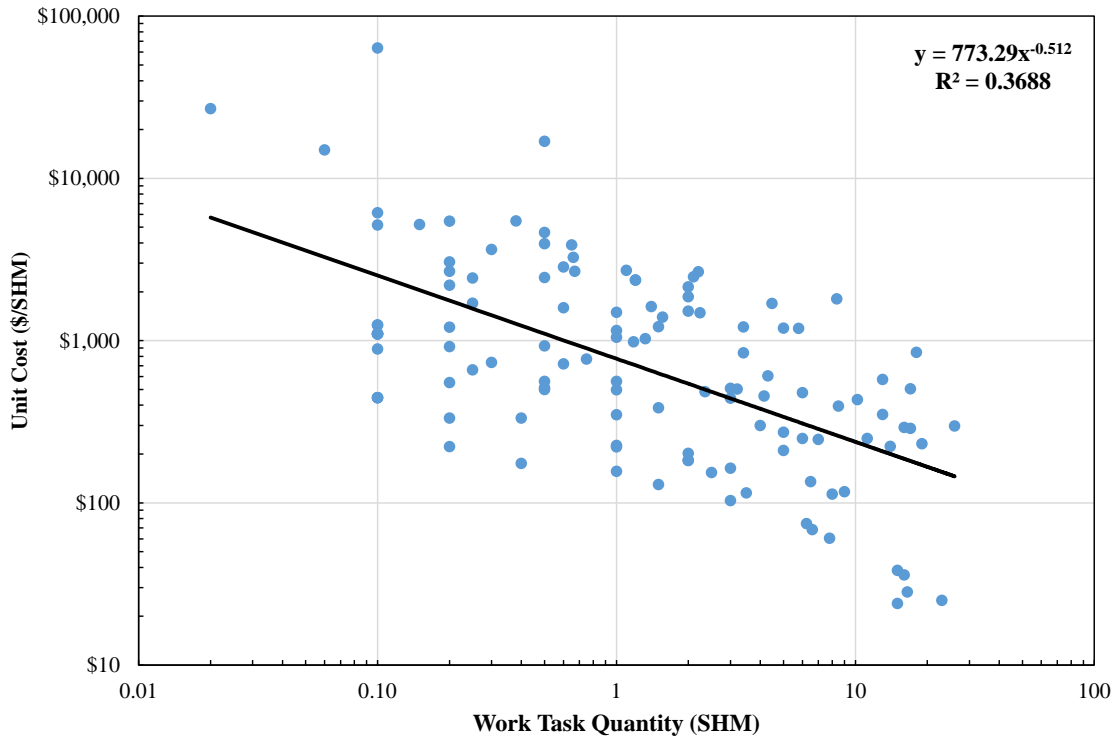
**Figure C12: Unit Cost and Quantity for Task 3126 Install Pipes (<=48")**



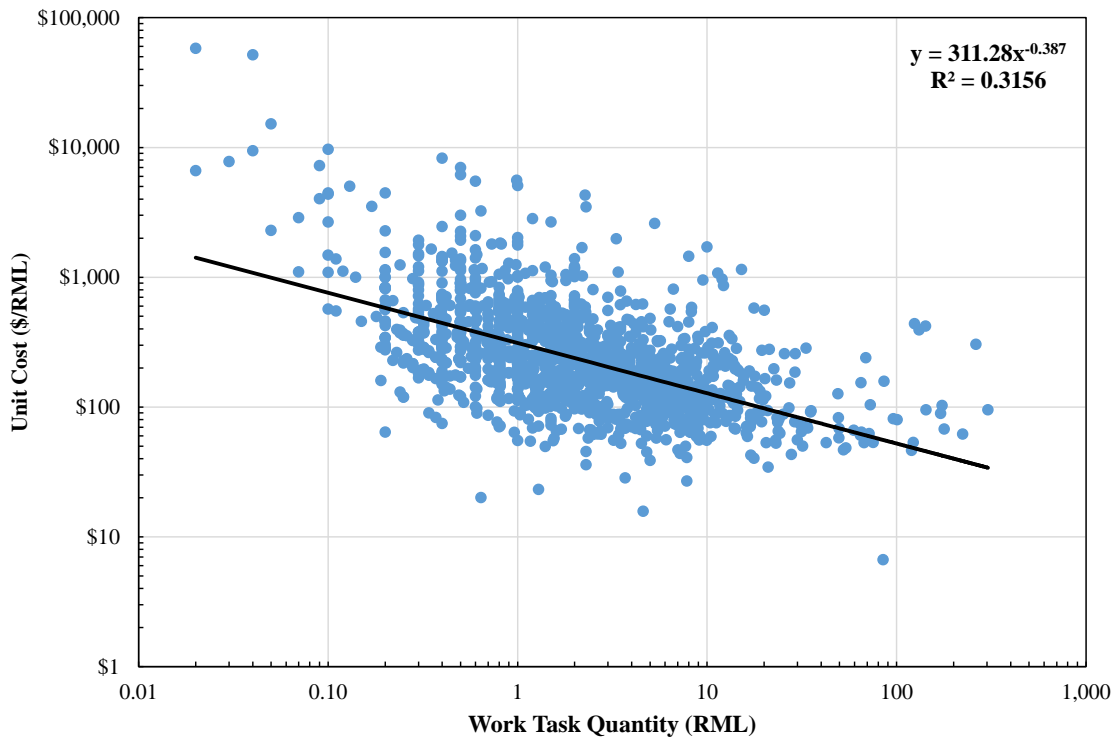
**Figure C13: Unit Cost and Quantity for Task 3128 Maintain/Repair Pipes (<=48")**



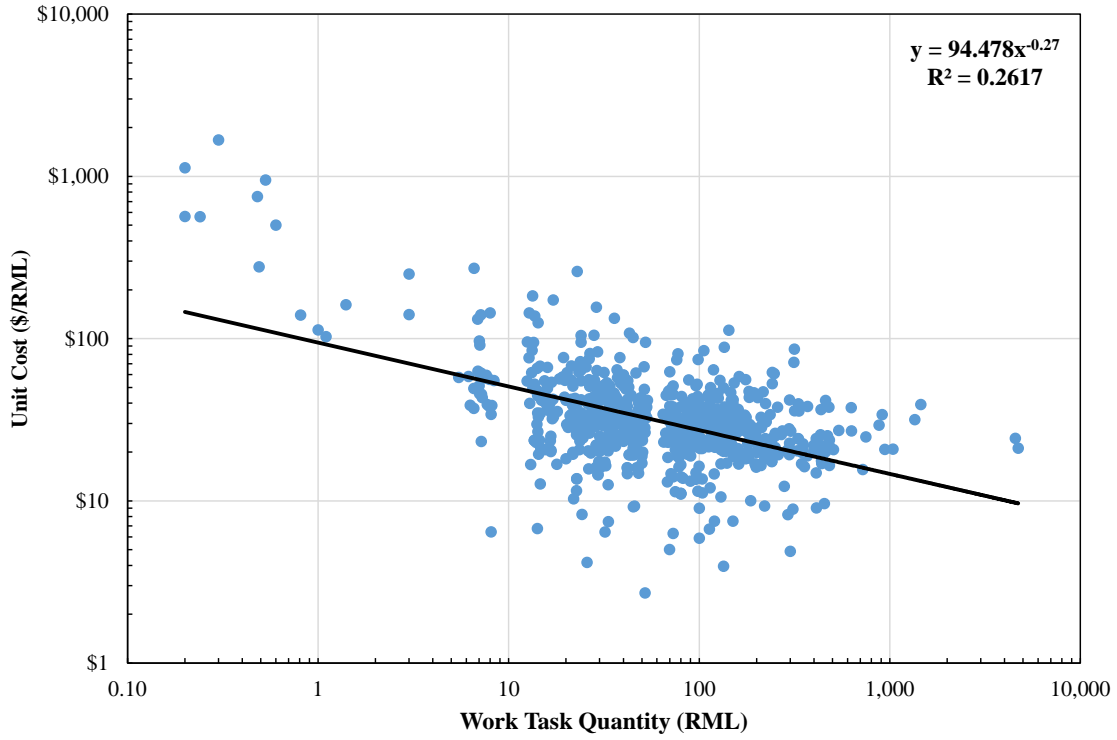
**Figure C14: Unit Cost and Quantity for Task 3130 Install/Maintain/ Repair of Misc. Drainage Structures**



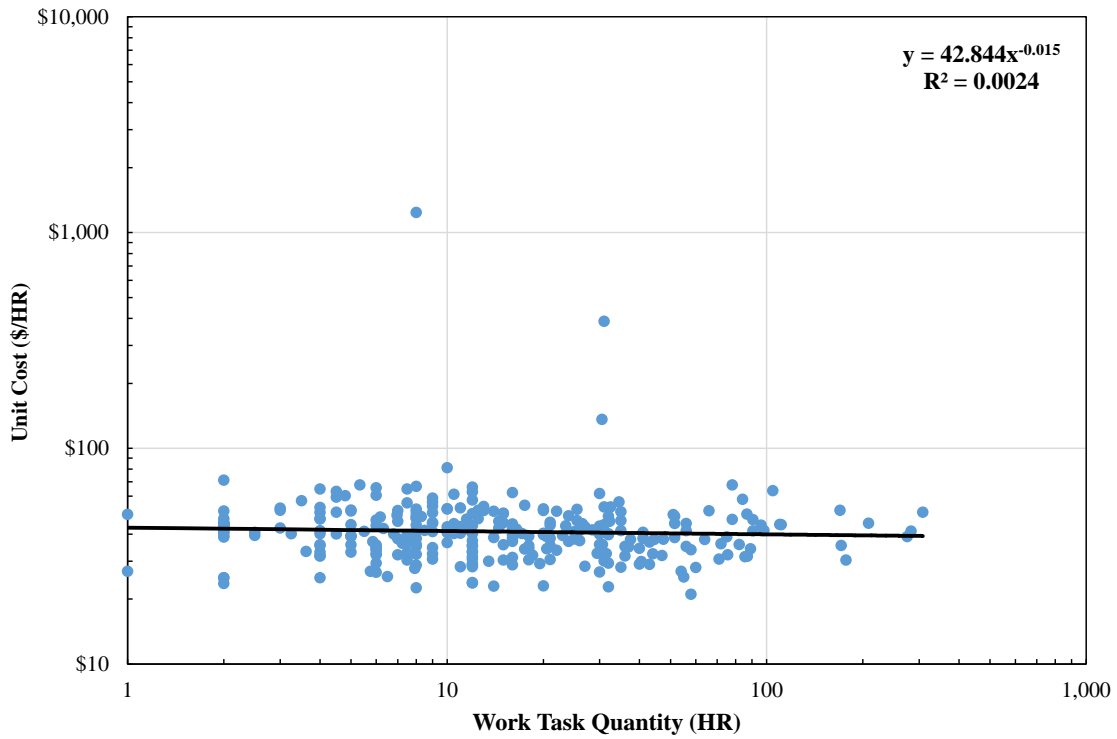
**Figure C15: Unit Cost and Quantity for Task 3132 Sweep/Wash Roadway**



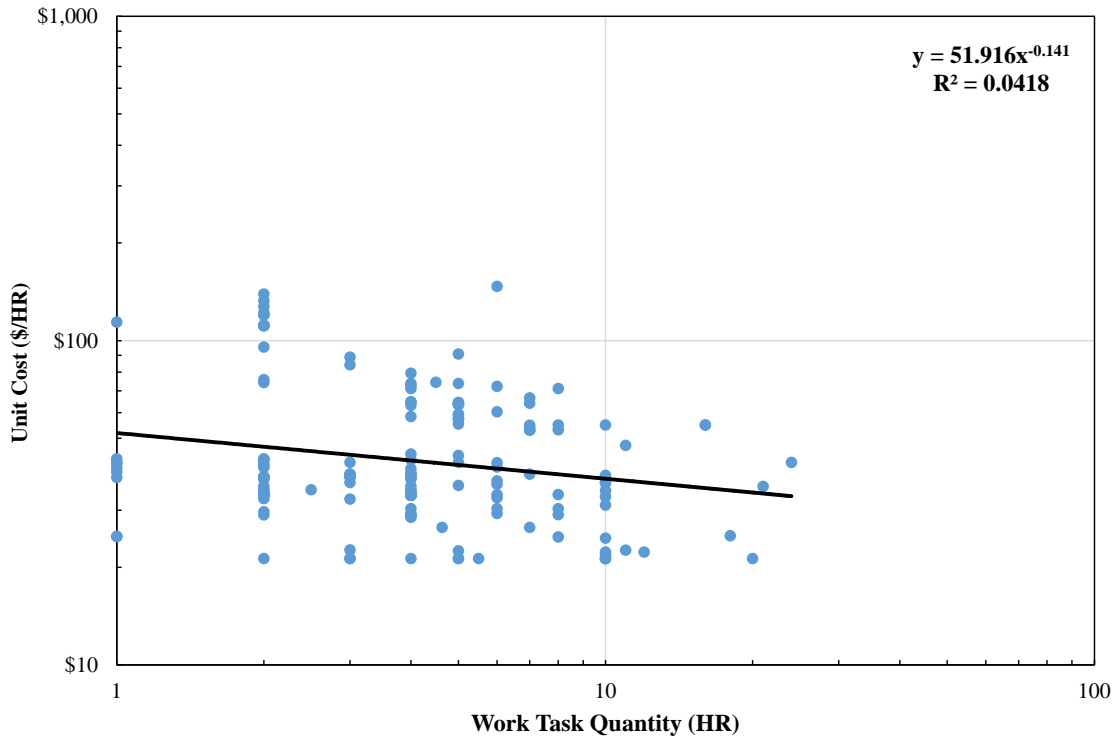
**Figure C16: Unit Cost and Quantity for Task 3138 Machining Unpaved Road**



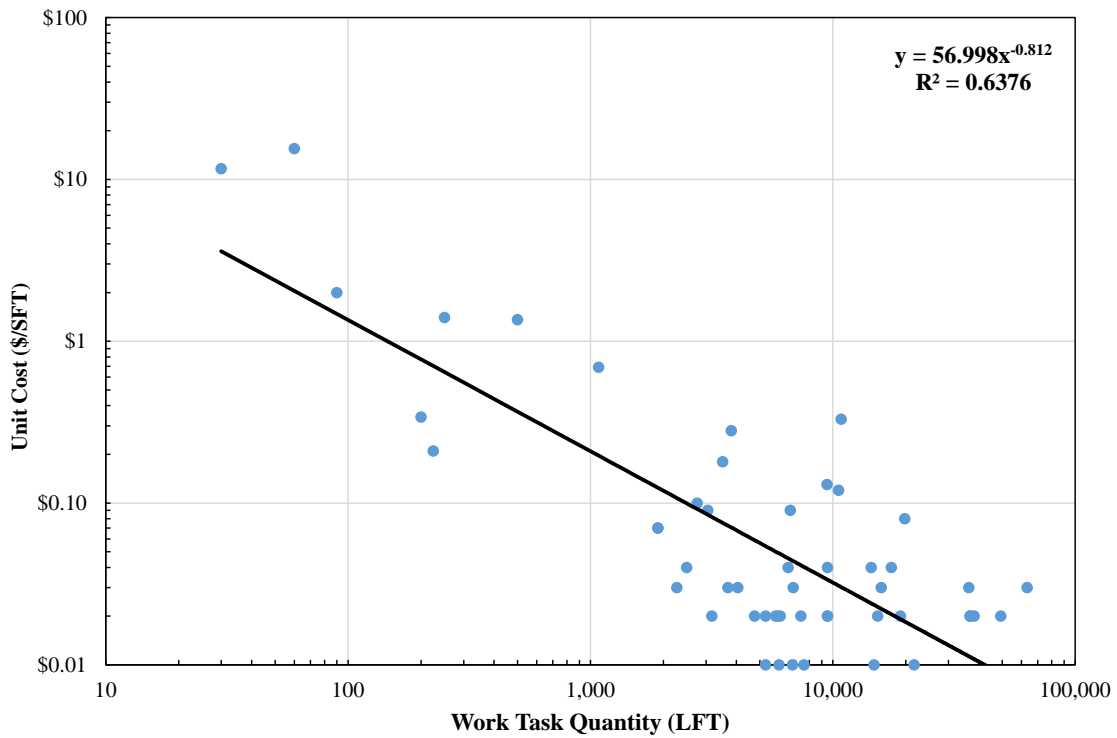
**Figure C17: Unit Cost and Quantity for Task 3140 Unpaved Road Stabilization Surface Maintenance**



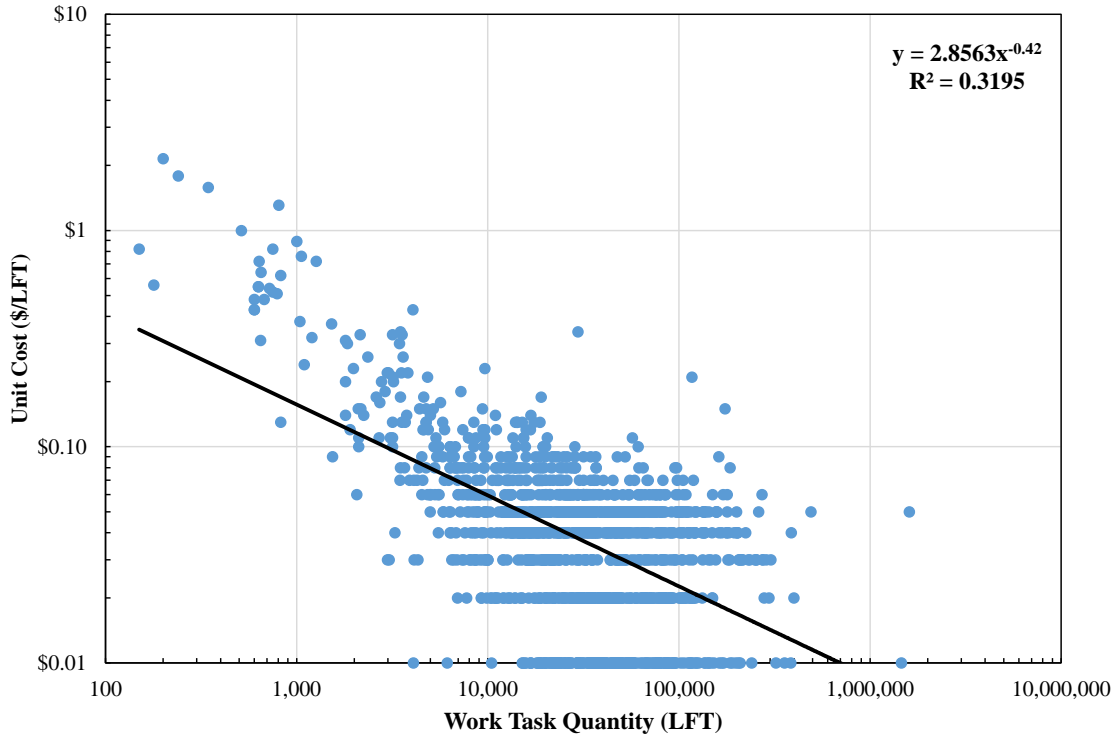
**Figure C18: Unit Cost and Quantity for Task 3200 Route Survey & Incid Detect & Response**



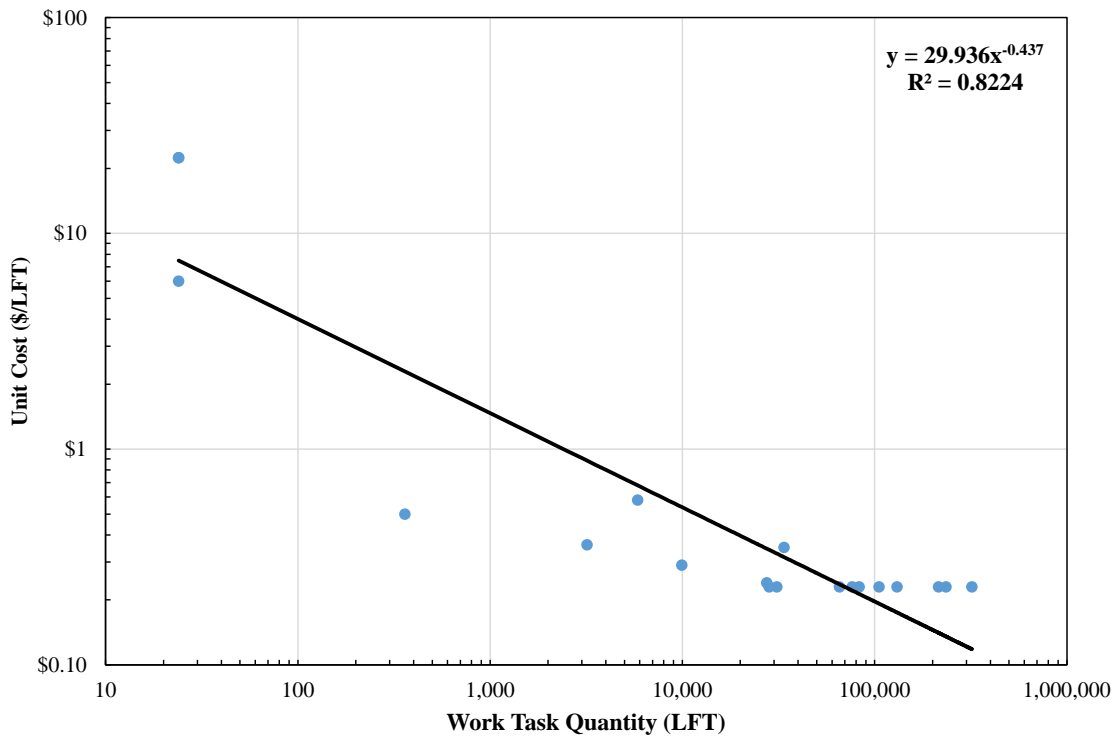
**Figure C19: Unit Cost and Quantity for Task 3214 Adopt-A-Highway Program**



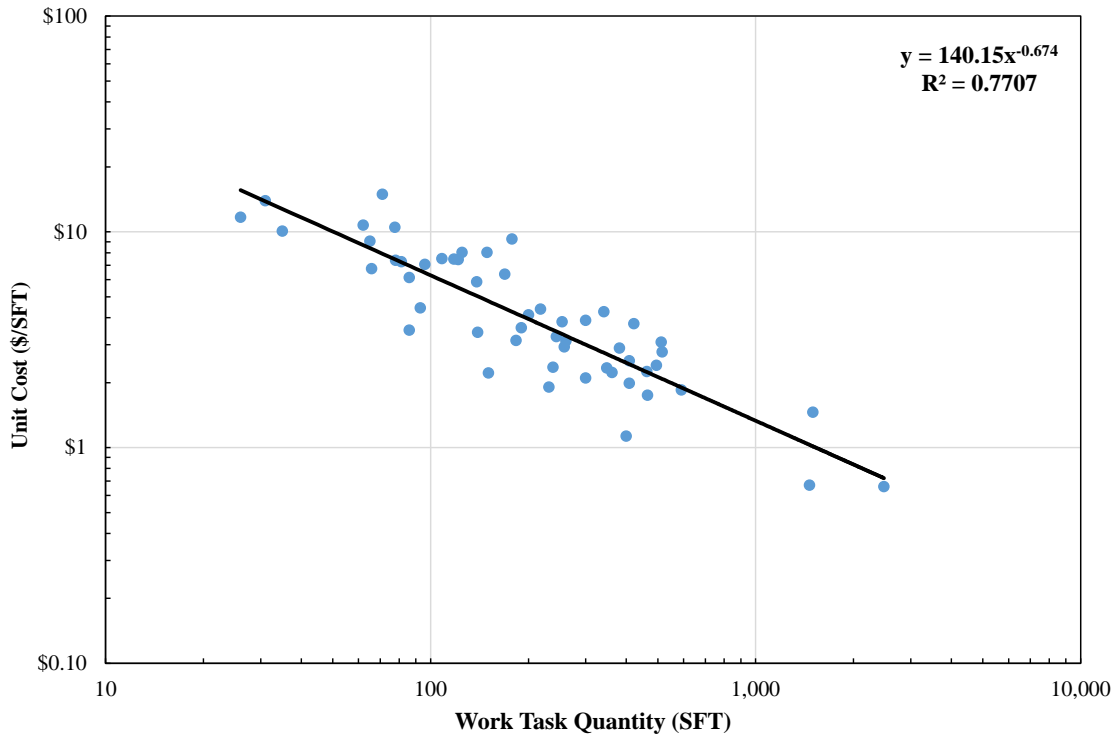
**Figure C20: Unit Cost and Quantity for Task 3220 Preline**



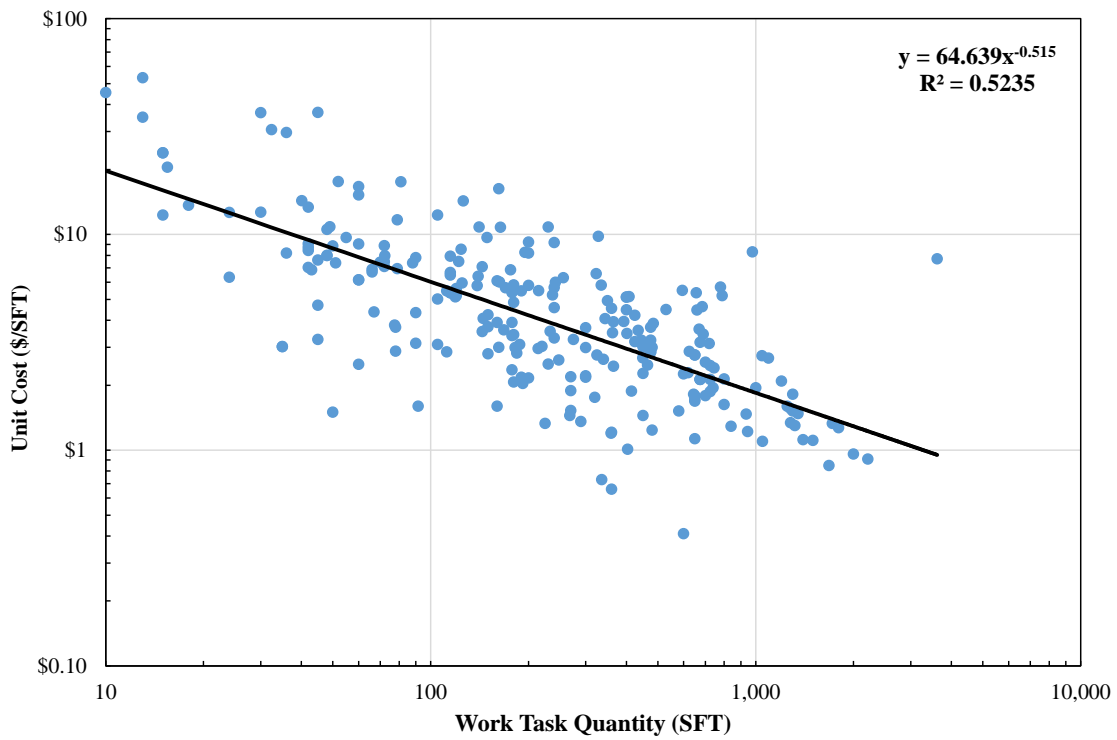
**Figure C21: Unit Cost and Quantity for Task 3222 Long Line Painted Pavement Markings**



**Figure C22: Unit Cost and Quantity for Task 3226 Long Line Specialty Material Pavement Markings**

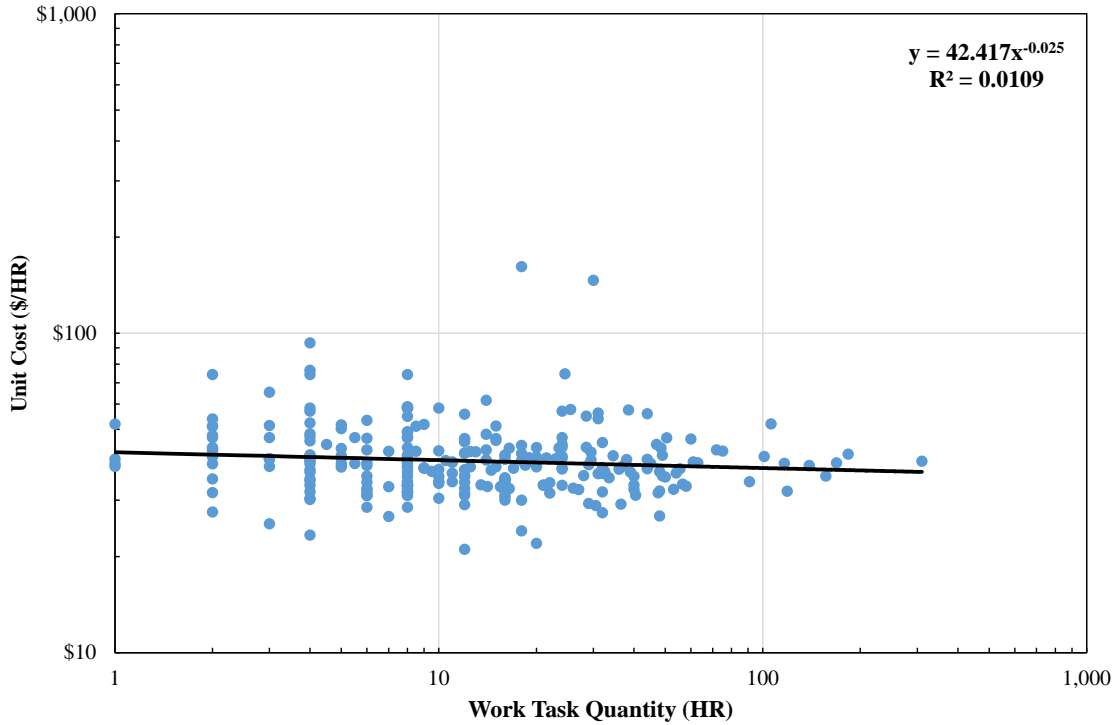


**Figure C23: Unit Cost and Quantity for Task 3228 Words and Symbols - Painted**

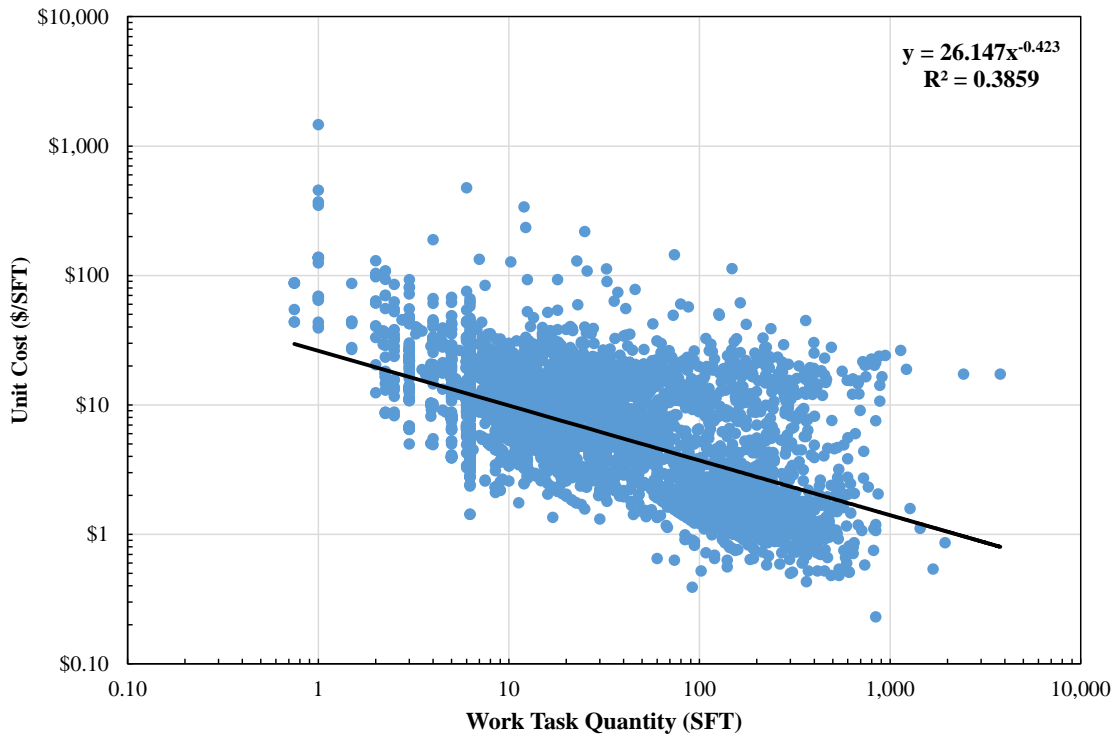


**Figure C24: Unit Cost and Quantity for Task 3230 Words and Symbols – Specialty Materials**

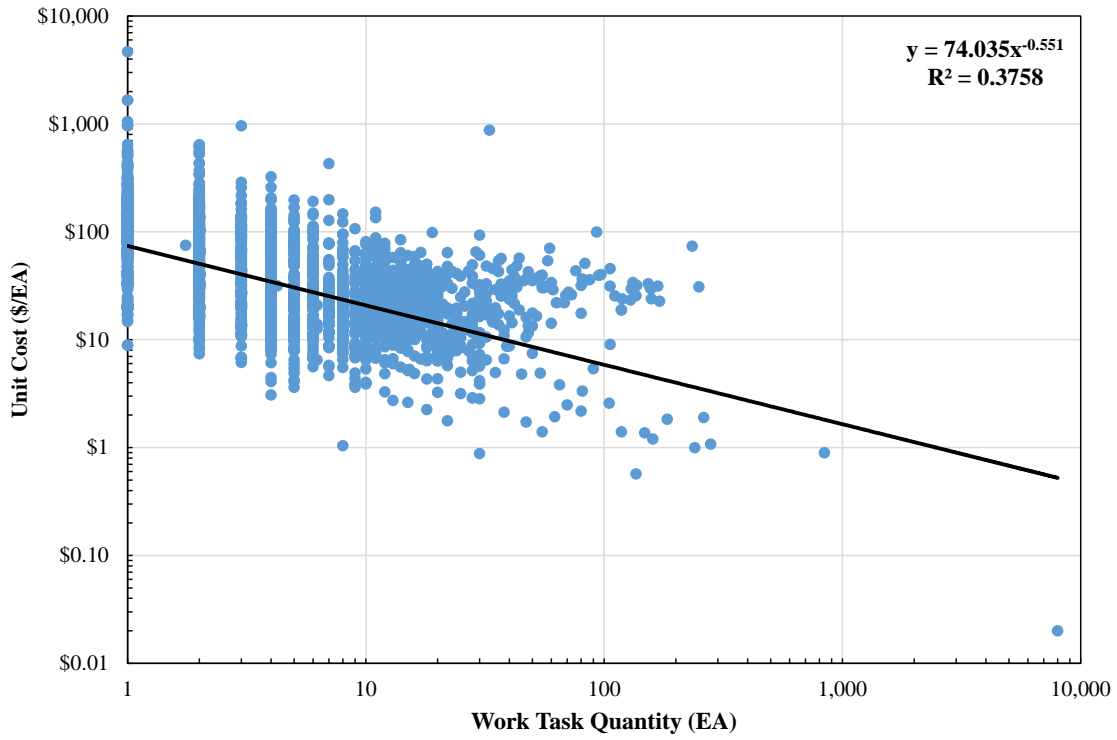




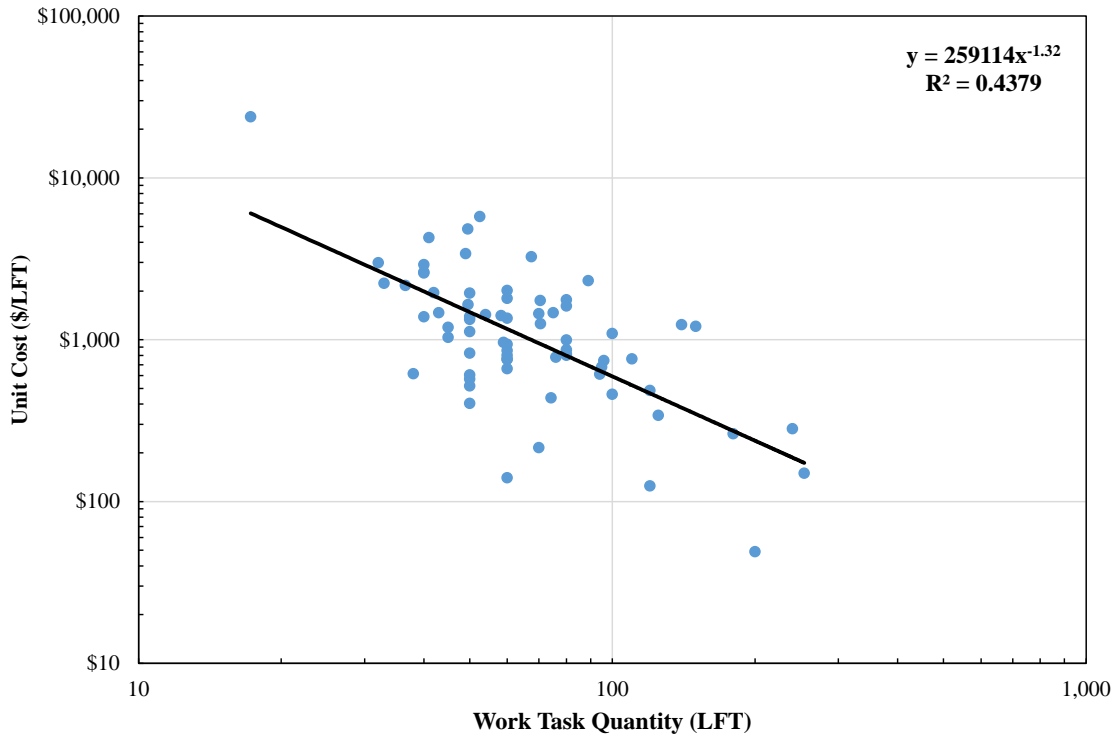
**Figure C25: Unit Cost and Quantity for Task 3244 Temporary Traffic Control**



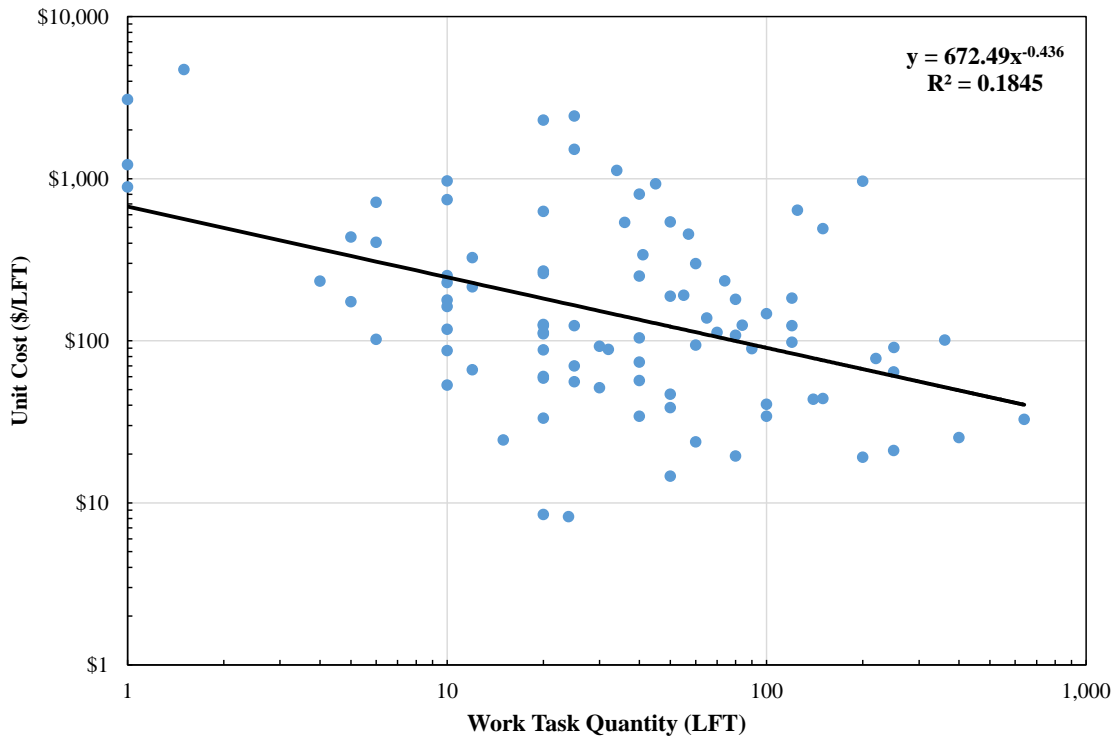
**Figure C26: Unit Cost and Quantity for Task 3250 Install/Replace Ground Mounted Signs**



**Figure C27: Unit Cost and Quantity for Task 3252 Repair Ground Mounted Signs**



**Figure C28: Unit Cost and Quantity for Task 3300 Install/Replace NON NBIS > 48” up to NBIS Structures**



**Figure C29: Unit Cost and Quantity for Task 3302 Maintain/Repair NON NBIS > 48” up to NBIS Structures**

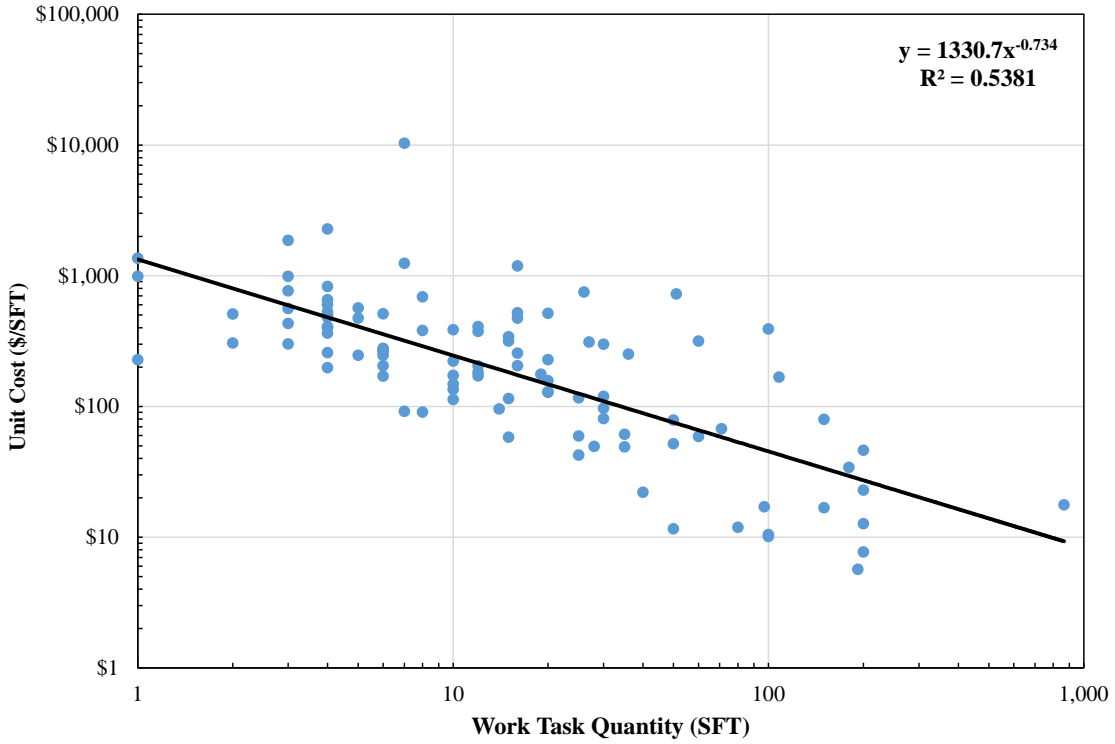


Figure C30: Unit Cost and Quantity for Task 3306 Maintain Concrete Superstructure Components

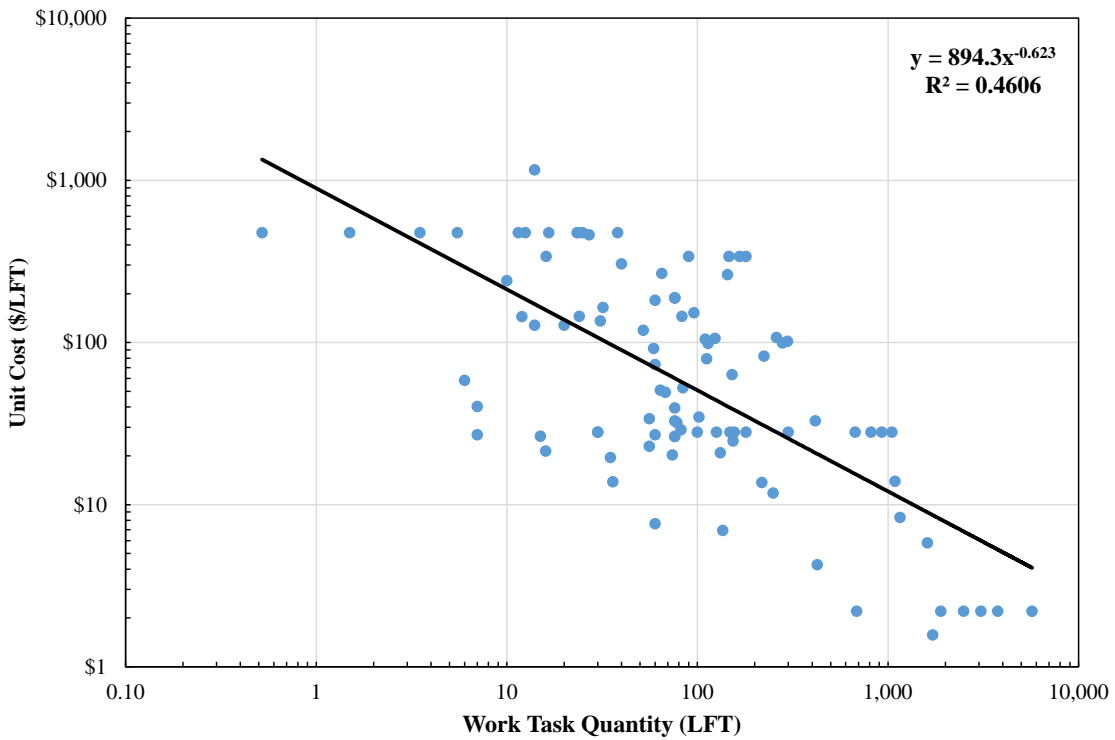
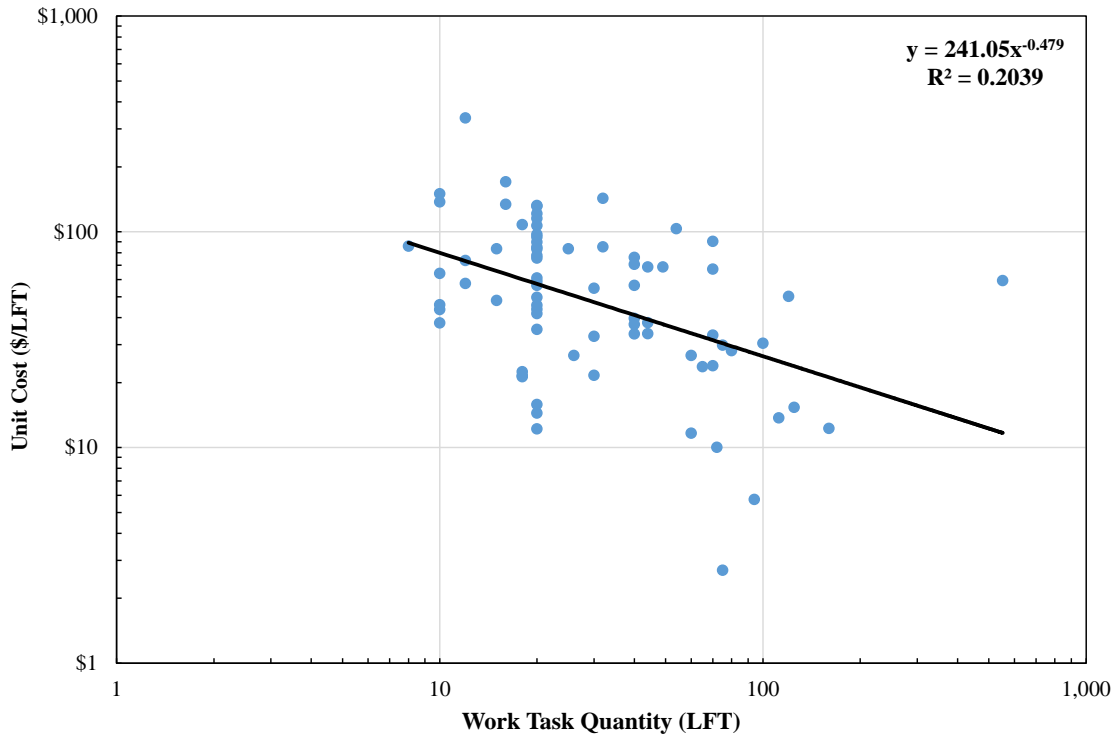
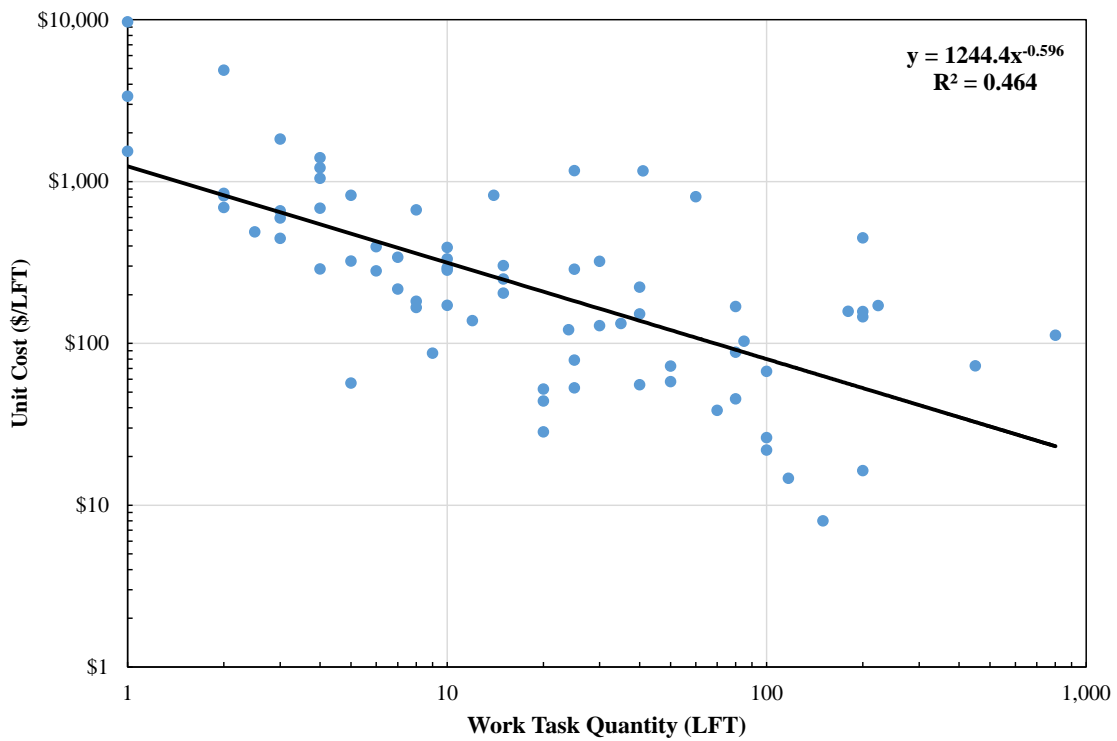


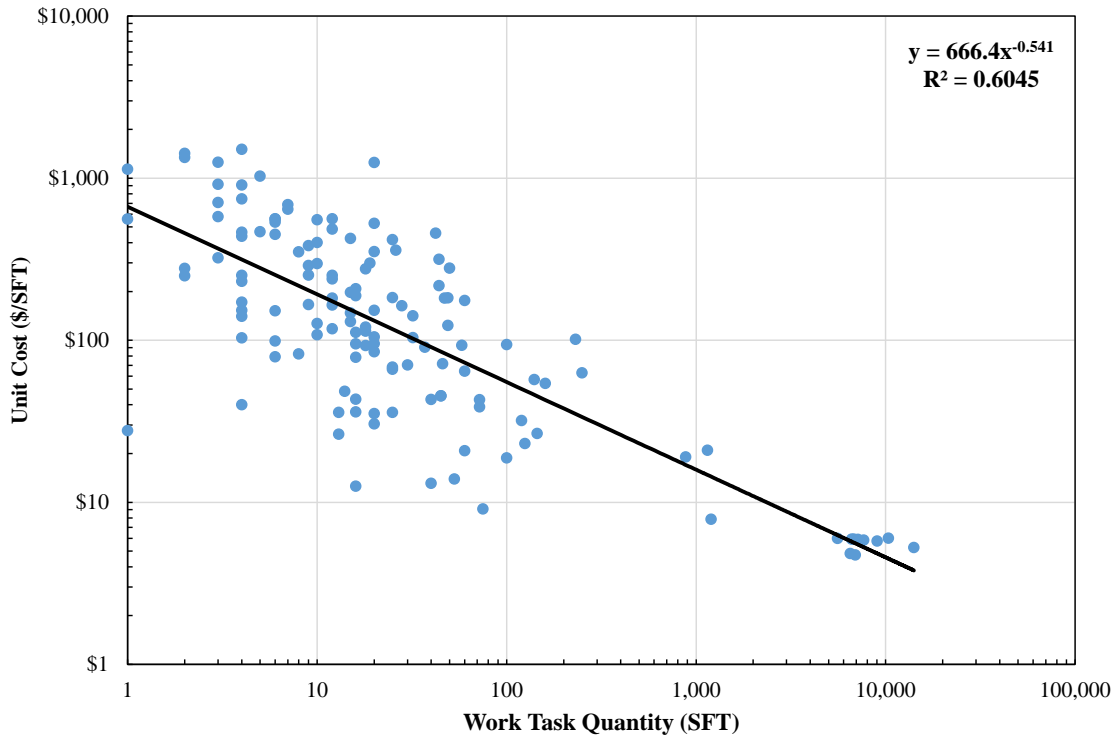
Figure C31: Unit Cost and Quantity for Task 3310 Maint/Repair/Repl of Std Bridge Expansion Joints



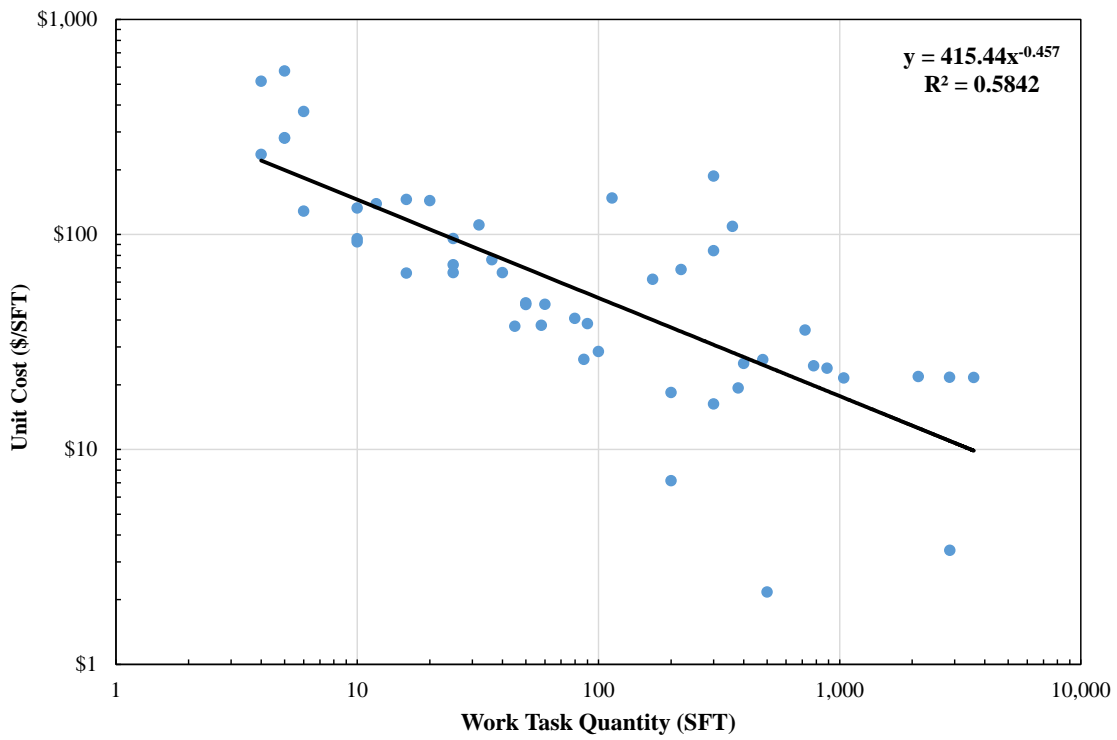
**Figure C32: Unit Cost and Quantity for Task 3316 Maintenance to Timber Handrail**



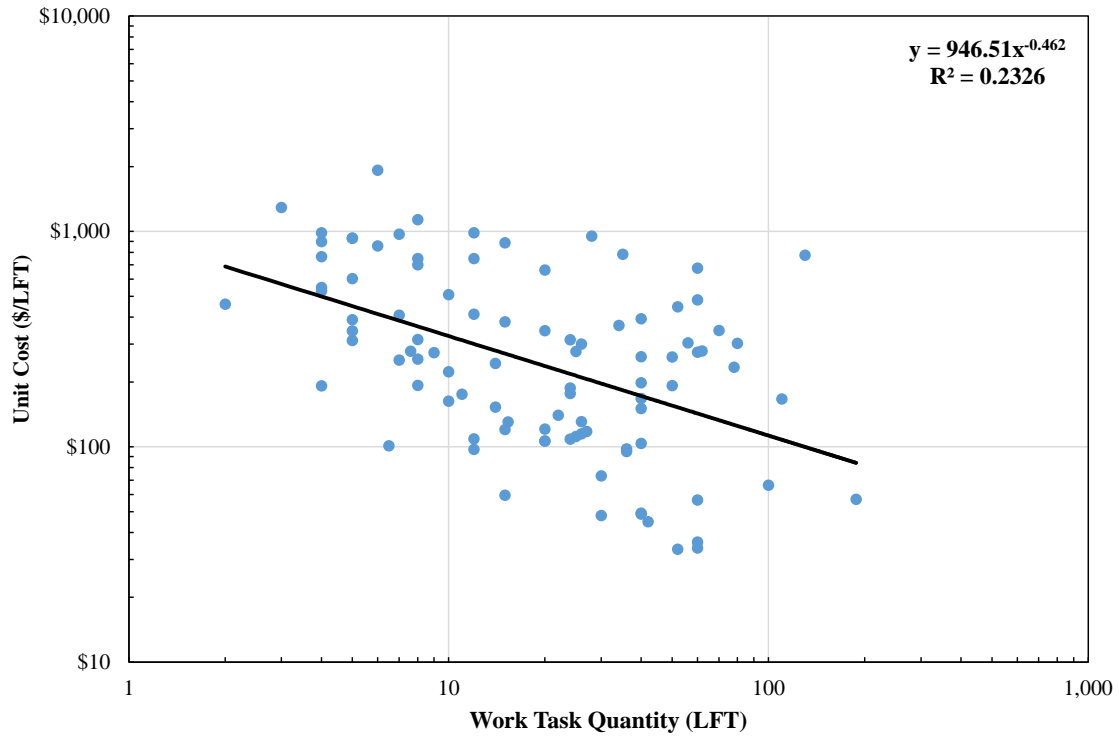
**Figure C33: Unit Cost and Quantity for Task 3314 Maintain Steel Superstructure Components**



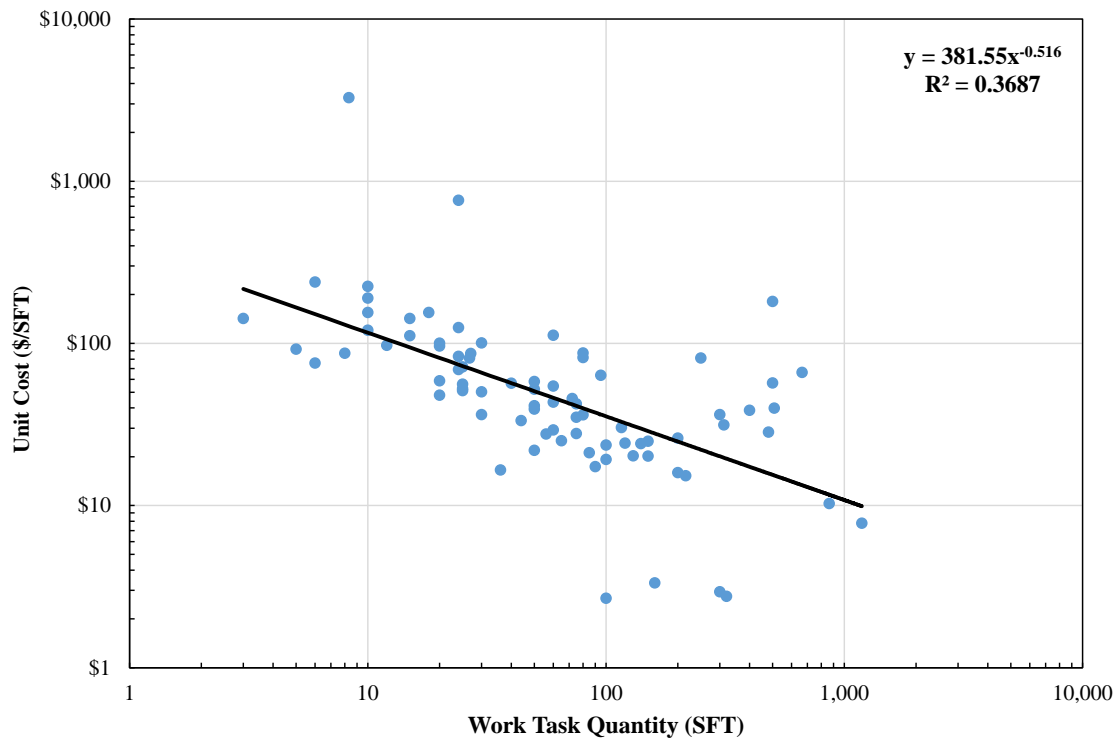
**Figure C34: Unit Cost and Quantity for Task 3326 Maintain Concrete Deck**



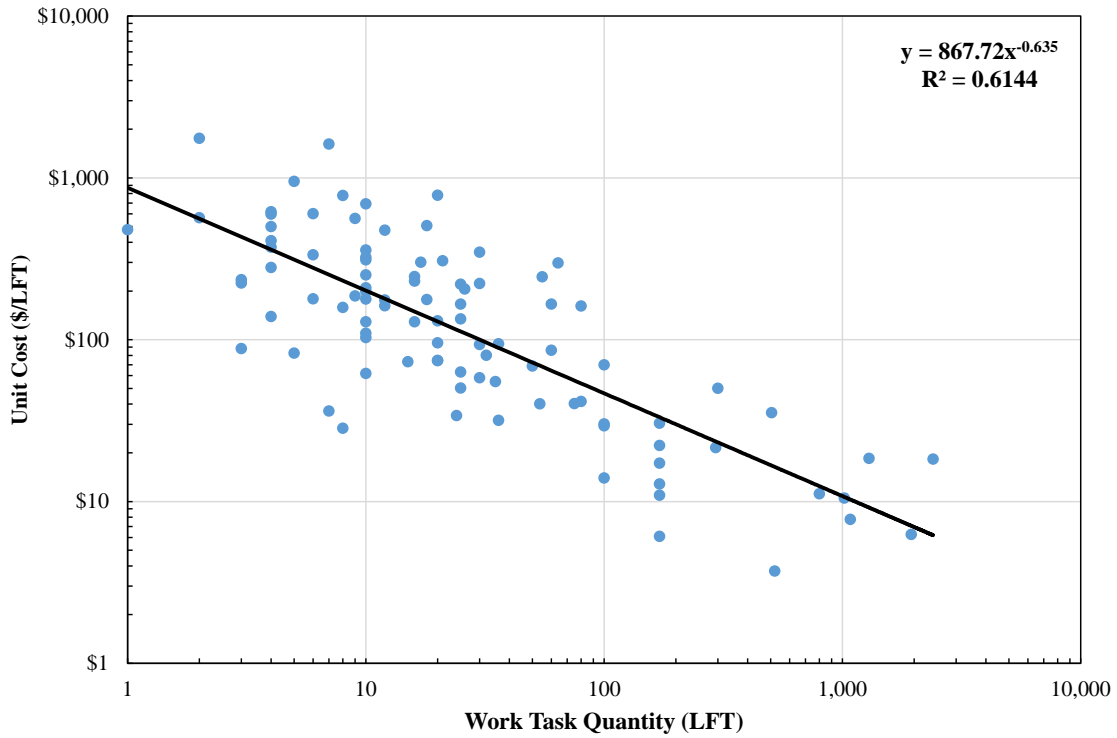
**Figure C35: Unit Cost and Quantity for Task 3324 Maintain/Repair/ Replace Timber Deck Components**



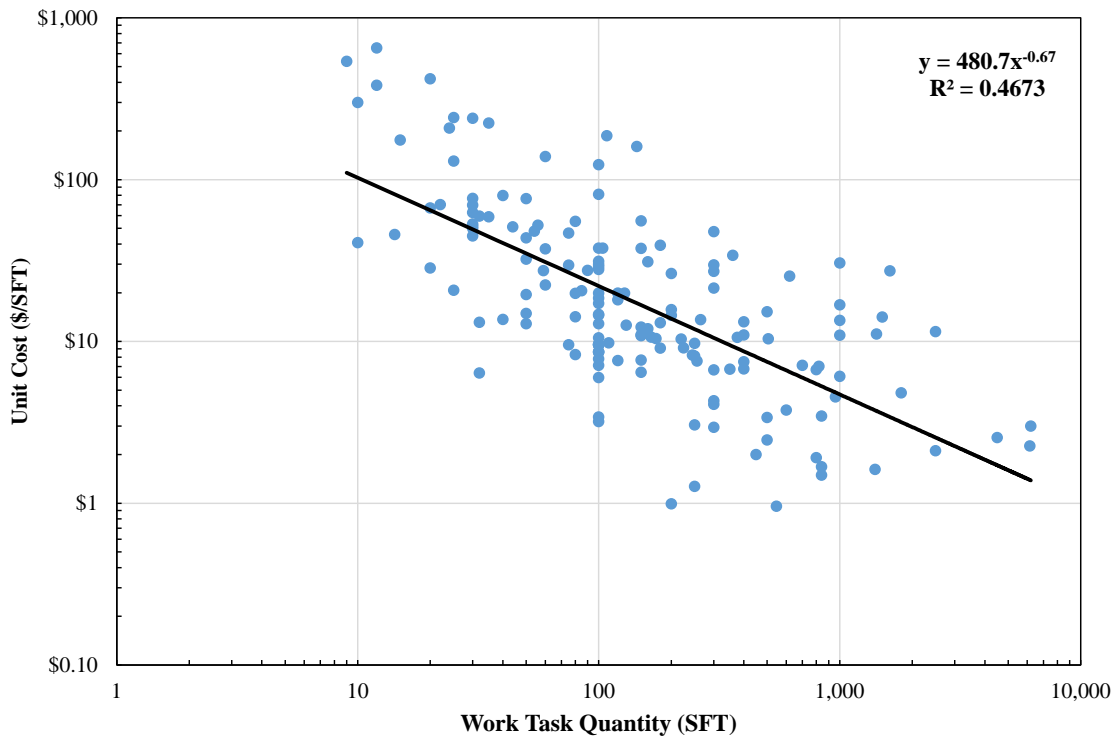
**Figure C36: Unit Cost and Quantity for Task 3344 Repair/Replace Timber Substructure Components**



**Figure C37: Unit Cost and Quantity for Task 3346 Repair/Maintain Timber Wings & Bulkheads**

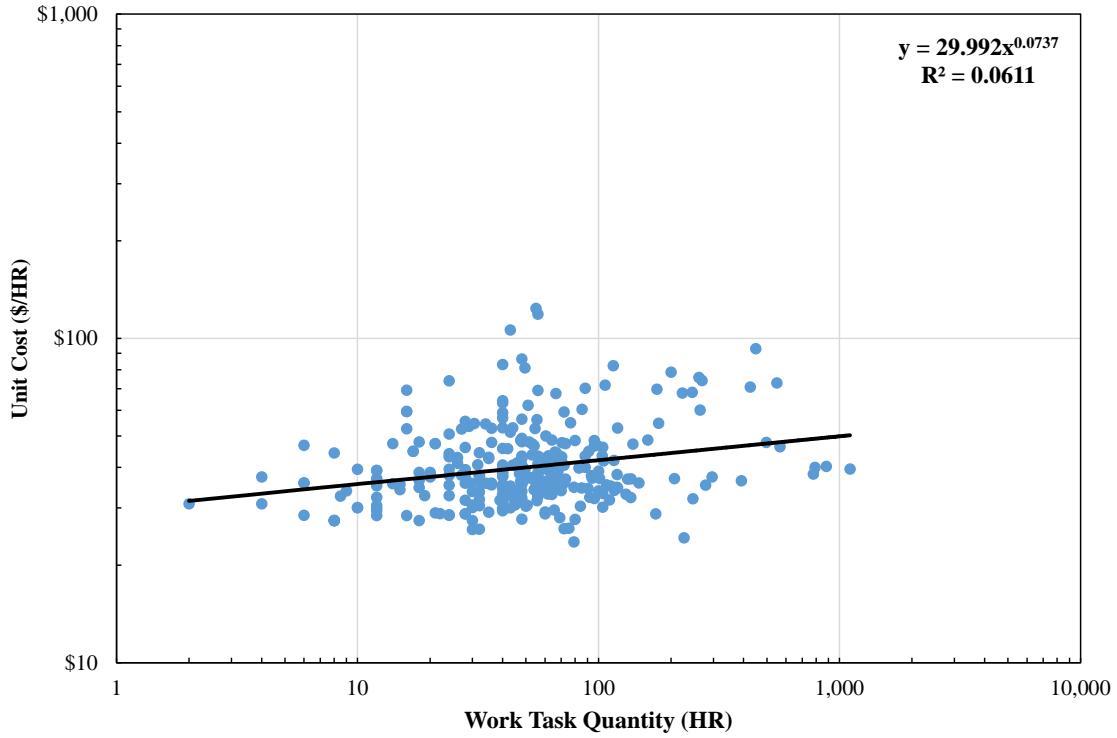


**Figure C38: Unit Cost and Quantity for Task 3348 Maintain Concrete Substructure Components**

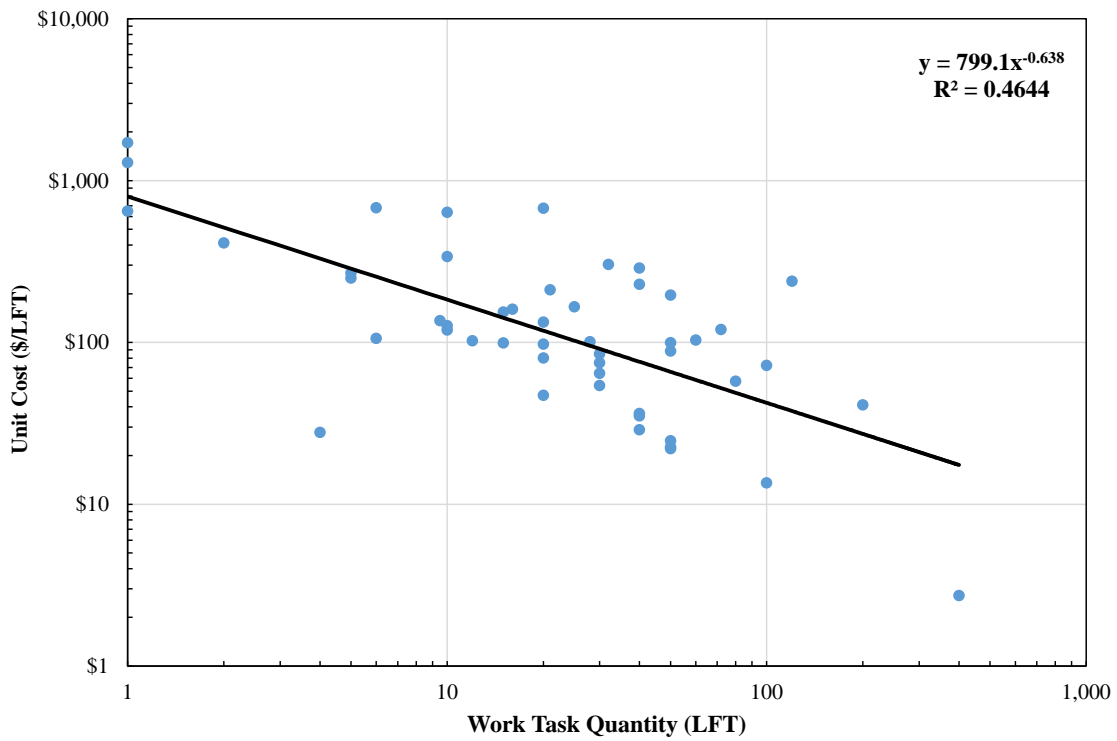


**Figure C39: Unit Cost and Quantity for Task 3352 Maintain Slope Protection**

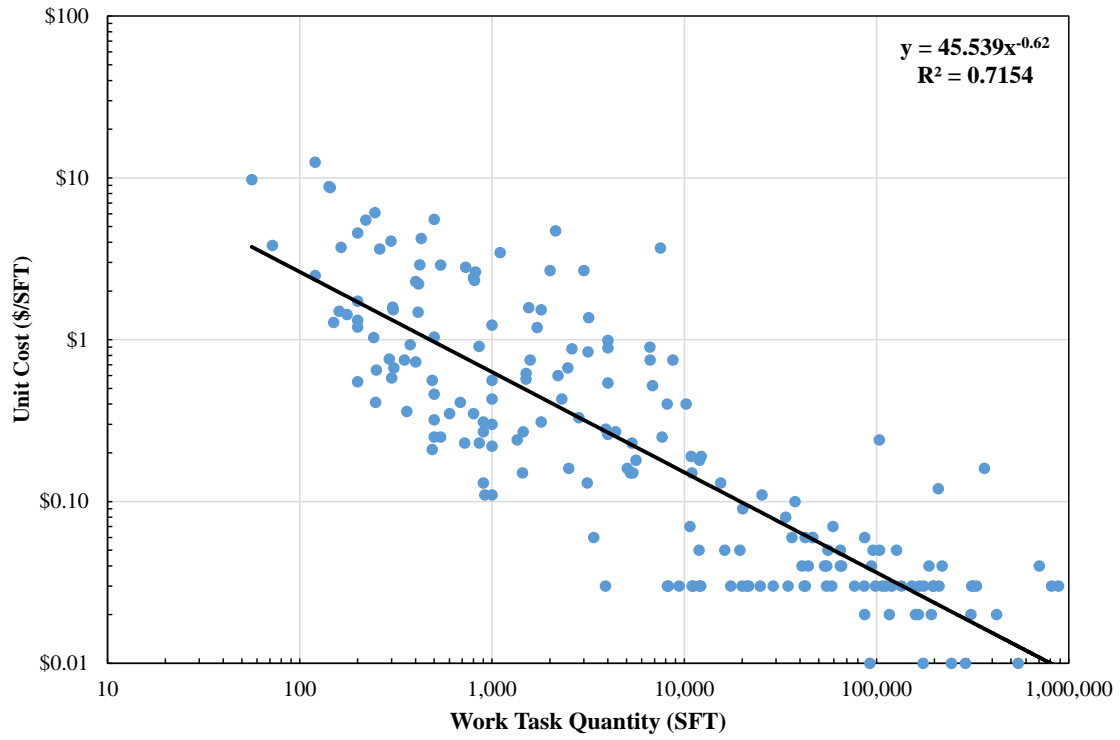




**Figure C40: Unit Cost and Quantity for Task 3366 Drift and Debris Removal**



**Figure C41: Unit Cost and Quantity for Task 3370 Maintenance and Repair of NBIS Pipes and Culverts**



**Figure C42: Unit Cost and Quantity for Task 3376 Clean/Wash Bridge Decks**