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# Spatiotemporal visualization of unit prices of major cost items of transportation projects across Iowa using geographic information systems (GIS)

Deepanshi Jain  
Iowa State University

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**Spatiotemporal visualization of unit prices of major cost items of transportation  
projects across Iowa using geographic information systems (GIS)**

by

**Deepanshi Jain**

A thesis submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of  
**MASTER OF SCIENCE**

Major: Civil Engineering (Construction Engineering and Management)

Program of Study Committee:  
H. David Jeong, Major Professor  
Douglas D. Gransberg  
Kevin Kane

Iowa State University

Ames, Iowa

2015

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## DEDICATION

The thesis is dedicated to all the people who lost their lives in Nepal Earthquake on April 25<sup>th</sup>, 2015.

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## ABSTRACT

Unit price contracting is a standard contracting method for transportation projects. In such contracts, State Department of Transportation (DOT) estimators prepare an Engineer's estimate of construction cost, which is used to compare the bids received and select the winning bid. This Engineer's estimate is mostly dependent on historical bid data available from projects completed by the DOT in the past and experience of an estimator. The estimators adjust the unit prices of construction cost items to reflect project characteristics such as size, quantity of material, location etc. The historical data available to estimators contain unit prices of major construction cost items for some geographic locations where projects have been recently completed. However, the location of an upcoming project is highly likely to be different from any locations of recently completed projects. Hence, the estimator must use unit price data of different project locations to estimate unit prices for an upcoming project at a new location. The reliability of such estimate is questionable since there is no clearly defined procedure or methodology or technique that the estimators may use to adjust unit price for new locations. Geospatial interpolation is a promising method for quantifying the unit price for new locations from known values at various locations. The platform of geographic information systems (GIS) has tools for powerful spatial interpolation using techniques like inverse distance weighting (IDW), kriging, spline, natural neighbor, etc. In this study, the unit prices of five major highway construction pay items from the locational bid data obtained from Iowa Department of Transportation are visualized in GIS environment and spatially interpolated across the geographical map of Iowa using IDW. The difference in estimated and interpolated values of input points gives the error in interpolation and the average error is used to compare the interpolation techniques. Various factors are employed in the techniques to improve the resulting

interpolation surface. Lower average error signifies the interpolation surface is better for that particular cost item.

The geo-statistical interpolation methods have an interactive layer, which can be used to obtain a unit price at any location by just clicking on that location. Other than acting as a tool to quantify unit prices GIS platform is used to identify best parameters for each item, which improve the unit price interpolation.

This study is an effort to make the unit price estimation process more visual, quantified, reliable, and also to facilitate effective use of data from the past. Validation is performed by conducting interviews with contractors that have performed paving works in Iowa on projects of Iowa DOT.

## CHAPTER I

### INTRODUCTION

#### 1.1 Overview and Problem Statement

Unit Price Contracting is common in the highway construction industry and is used in projects where quantity of material is uncertain (Hendrickson and Au 1989). The unit prices are important because in case of change in quantity due to any reason the contractor is paid for the excess quantity amount by multiplying change in quantity to unit price (Marion 2007). In such contracts, estimators at highway agencies prepare a detailed final estimate using the plans and specification of a project to determine the construction cost of the project (Hendrickson and Au 1989), and competing bidders each prepare and submit a bid. This final estimate is known as engineer's estimate which is used by highway agencies for preparing budgets and evaluating bids from contractors. Hence, it is important that Engineer's estimate be as accurate as possible to allow fair judgment of the winning bid.

In order to prepare Engineer's estimate, it is required that unit price of each pay item be decided. The unit price estimation of a highway project is typically based on experience of the DOT estimator (Anderson et al. 2007) and historical bid data from past projects (Moon et al. 2007). The historical bid data has the unit price information of projects completed in the past and a new project is likely to have many different characteristics from previous projects. The unit price estimation guidelines of highway agencies specify that the estimator must carefully consider variables like project size, location, availability of materials, etc. to adjust unit prices for a new project by using the historical data of similar projects (Anderson et al. 2009), but the guidelines lack proper methodology to perform this adjustment (Anderson et al. 2009).

Inaccurate cost estimation has been a source of error for a long time in highway construction(Wilmot and Cheng 2003). Cost estimation has many variables associated that can go wrong and result in inaccuracy. One of such factors is negligence about intelligently incorporating project specific variables while preparing the estimate. According to Joint Federal Government / Industry Cost Predictability Taskforce (2012), “the best that should reasonably be expected from such pre bid estimate is a reasonable approximation of costs that reflect many variables including the size, scope, complexity, and locality of a specific project.”

The challenge is to obtain the unit price for a new location using the bid data of available locations. Thus, a proper interpolation is the most appropriate option to obtain unit prices for any location from available data. Interpolation available in geographic information System (GIS) is a reasonable approximation of unit prices according to location and thus it is known as spatial interpolation. This spatial interpolation is based on Tobler’s First Law of Geography, which means that points closer together in space are more likely to have similar values than points that are farther away (Eberly et al. 2004).

In order to improve the cost estimation process for DOT estimators, there is a need to explore options that can improve unit price adjustment process. GIS offers some promising solutions with the available geo-spatial interpolation tools that quantify the location effect to visually show the unit prices on the digital map, which can be used as a great support tool for DOT’s estimator. This study shows a new advancement in the area of estimation by using GIS as a tool to map the unit prices and spatially interpolate it to obtain unit prices for unknown locations.

## 1.2 Objectives

The overall objective of the study is to develop a process and a GIS tool that can appropriately use and interpolate historical unit price data to visually present unit price information on a digital map. To accomplish this overall goal, the research has the following three sub-objectives.

- a) Integrate bid data into ArcGIS platform and spatially interpolate unit prices using the inbuilt interpolation techniques.
- b) Test interpolation techniques by interpreting data exploration results, and evaluation of interpolation surface with different weight options of quantity of material using cross validation results.
- c) Develop a procedure that DOT estimators can use when they need to develop a unit price map for a certain work item

## 1.3 Research Scope and Methodology

The study presents a visual, quantifiable, and structured approach to adjusting unit price of pay items for location, using spatial interpolation techniques in GIS. The scope is limited to analysis of major pay items of Hot Mix Asphalt Pavements (HMA) and Portland Cement Concrete (PCC) Pavements of Iowa Department Of Transportation (IaDOT) projects from 2011 to 2014. The major pay items used for this study are selected based on repeated occurrence in the IaDOT bid data having higher item cost. The top items for HMA pavements consist of asphalt binder PG 64-22, asphalt binder PG 58-28, and hot mix asphalt mixture 1,000,000 ESAI, surface course. The top items for PCC pavement type considered in the study are standard or slip form Portland cement concrete and excavation class 10 - roadway and borrow.

After selecting the top pay items they are exported in the ArcMap platform and data exploration tools are applied for each year. The main focus is to analyze these top items of interest and apply interpolation method(s) to decide a better technique, which is easy to apply, and gives more

reliable interpolation surfaces. Quantity of pay items is considered by using it as a weight in two different forms for generating the interpolation surfaces in inverse distance weighting (IDW).

#### **1.4 Expected Results and Contributions**

The advancement in GIS technology for spatial analysis of data has offered many promising tools out of which geostatistical analysis is used in this study. The spatial interpolation of unit price to get reliable surfaces with ability to provide unit price for any location across Iowa is a quick, easy, and innovative way to adjust unit prices for estimation. DOT estimators can easily put the available data from past projects in ArcGIS and obtain an approximate adjustment for any new location with just few clicks. The study can be used as a guide to develop the unit price surfaces by using the process explained in chapter 5.

The maps are more interactive, and provide visual, easy to understand surfaces, which is advantageous. The broad level asset management decisions using the maps is one more advantage of using GIS for unit price estimation.



## CHAPTER II

### LITERATURE REVIEW

This chapter provides necessary background information on cost estimating practices of DOTs, and lists the factors that affect unit price adjustment in highway construction. The challenges DOT estimators face in preparing the final engineer's estimate are also included after careful study of previous works in the research area. Use of GIS to solve different types of construction problems are discussed in brief, followed by the description of geostatistical analyst toolbar and spatial interpolation methods available in GIS.

#### 2.1 Cost Estimation Practices of DOTs

As described in Anderson et al. (2009), DOT estimators mostly adopt following techniques for preparing cost estimates:

- Parametric Estimating
- Historical percentage Estimating
- Historical Bid – Based Estimating
- Cost – Based Estimating

The detail and accuracy of an estimate depend on the phase of project at which the estimate is prepared.

Parametric estimating is mainly used during the initial planning stage of the project and it is based on one or more project parameters such as cost per lane mile, cost per interchange, or cost per square foot from the historical database(Washington State Department of Transportation 2015).

In historical percentage estimating the historical percentages of project segments based on major project parameters are used to roughly estimate the project cost in the planning stage(Anderson

et al. 2007). For example contingency, yearly inflation, right-of-way cost, mobilization, and utilities cost are determined as percentage of construction cost (Anderson et al. 2009). Iowa DOT and Caltrans use 5% and 10% of the total project cost respectively as mobilization cost as specified in the design manuals.

In historical bid based estimating, after determining the quantities from the project plans the estimator matches these quantities to historic unit bid prices (average, low bid, all bids, reasonable bid amount, etc.) to obtain appropriate unit prices. The unit prices are adjusted to fit current project condition (location, size, etc.) and the general market conditions(Anderson et al. 2007). This is relatively straightforward as well as quick (Schexnayder et al. 2003), and the most commonly used estimation approach (Anderson et al. 2007).

In cost based estimating, it is necessary to have knowledge about construction methods, supply systems, labor markets, and productivity specific to the area where the project is located(Anderson et al. 2007). This estimating method is mainly used for major projects(Anderson et al. 2006), which are classified by Federal Highway administration (FHWA) as projects with a total estimated cost of \$500 million or more. According to AASHTO practical guide to estimating by Molenaar et al. (2011) an independent team of experts is formed to review an existing project estimate for these major projects. The prices for cost based estimating are obtained from various sources like vendor price sheets, pricing services, historical data records etc. and adjusted according to location and the scope of the current project. The estimator adjusts the prices according to project location by using factors that are a result of extensive bid data analysis (Schexnayder et al. 2003). This approach is casually termed as contractor's approach of estimating to prepare bids, and according to the guidelines of Ohio DOT(2009)this method can

provide more accurate and reliable costs to select the winning bid and any future price negotiations with the contractor after the contract is awarded.

Table 1 specifies the type of estimate developed during project phases, their intended purpose and the method of estimation used.

**Table 1 Phase of project and intended purpose of estimate**

Project Phase	Name of Estimate	Purpose	Method of Estimation
Planning	Conceptual estimate	<ul style="list-style-type: none"> <li>• Provide an order-of-magnitude estimate of the anticipated funds.</li> <li>• Benefit-cost-analysis for ranking projects to be included in the 25 year planning horizon.</li> <li>• Point of departure for next phase cost estimation.</li> </ul>	<ul style="list-style-type: none"> <li>• Parametric Estimating</li> <li>• Historical percentage estimating</li> </ul>
Scoping and Preliminary Design	Baseline project estimate/ Design estimates	<ul style="list-style-type: none"> <li>• Establishes the project budget.</li> <li>• Updating project cost during the phase.</li> <li>• Used for advertising the project.</li> </ul>	<ul style="list-style-type: none"> <li>• Historical Bid Based and Parametric Estimating</li> </ul>
Final design	Engineer's estimate	<ul style="list-style-type: none"> <li>• Used to compare with bid prices from contractors.</li> <li>• To allocate funds for construction.</li> </ul>	<ul style="list-style-type: none"> <li>• Historical bid based mostly and Cost based estimating for large scale project</li> </ul>

An appropriate level of accuracy in estimate at any stage is necessary so that transportation planning within any DOT is efficient and funds are allocated to economically feasible projects. Engineer's estimate is used finally to decide the budget and winning bid, hence it is important to improve the reliability of such estimate.

## 2.2 Factors Affecting Unit Prices

Estimating unit prices is a challenging task; one of the reasons is the large number of factors that affect it. According to cost estimating guidelines of Caltrans (2014), factors that affect unit prices are: fluctuation of costs, traffic conditions, restrictive work hours or method of work, quantities

of work, separate operations, handwork and inefficient operations, accessibility, geographic locations, construction season, material shortages. It is well explained in the guidelines for construction cost estimating for dam engineers and owner by United States Society of Dams (2012) that estimating unit price requires consideration of numerous factors that influence the cost like geographical location of work, wage rates, market conditions, economic trends, etc.

Hegazy and Ayed (1998) developed a neural network model to effectively manage construction cost data for parametric estimating where project location was one of the factor used as an input for model. Al-Tabtabai et al. (1999) also focused on parametric cost estimating using the neural networks where project location was identified as an influential factor by the experts interviewed and it is used as an input for the model developed. Contract location is used in developing a neural network sub model in the study conducted by Wilmot and Mei (2005) and these neural network models were used to estimate values of a highway construction cost index to understand the change in overall highway construction costs over time in Louisiana.

Other studies conducted by Schexnayder et al. (2003), Choi (2004), and Chou (2009) also consider project location as an important factor influencing project cost. Thirty-eight state highway agencies (SHAs) in the study by Schexnayder et al. (2003) reported wide variation in bid prices within their states and thus these SHAs adjust estimates based on location. Choi (2004) acknowledges the importance of project location for heavy civil engineering construction like highway, dams, tunnels, etc. The urban and rural attribute is utilized to account for location in a quantity model developed by Chou (2009), but the conclusion of the urban and rural attribute producing no significant effect on quantity based models is surprising for preliminary estimating using Texas DOT projects.

Cost estimating manual and guidelines from various SHAs like Iowa DOT (2015), Washington DOT(2015), Ohio DOT(2009), Connecticut DOT (2015), Montana DOT by Alavi et al. (2009),and U.S. DOT guidelines by FHWA (2004) include project location as an influential factor in estimating bid unit prices.

### **2.3 Current Practices and challenges in adjusting historical unit price for location**

Caltrans(2014)state that estimating price for pay items is all about diligently using all available data, modifying that data with good judgment, and a measure of experience. At present, AASHTOWare Project Estimator® is the principle tool used to estimate pay items (Connecticut DOT 2015) . As highlighted in the Cost estimating guidelines by Connecticut DOT (2015), for items in the bid history catalogue that are repeated less than 15 times, Project Estimator® calculates an average for the number of times the pay item is repeated and does not take into account any project specific factor. Only if the occurrence of the pay item is more than 15 times it performs regression on several factors like quantity, location, letting date, work type.

Iowa DOT(2015)specifies that the unit prices are achieved by combination of statistical results of historical unit prices and research on data not available.

Anderson et al. (2009) used an online survey to identify the cost estimation practices of SHAs. The responses from 36 state agencies show that 26 state agencies used a weighted average technique to determine unit costs. Average unit price for an upcoming project is calculated from historical unit- bid price data, by considering projects completed in the past with similar quantities of bid line items (Anderson et al. 2006). The variation in practices among the SHAs is not only limited to different methods of determining unit costs but the use of bid data is different for each SHA. Out of the 50 SHAs, 20 SHAs use low bids to determine the average unit price (Anderson et al. 2006).

It should be noted that guidelines for preparing engineer's estimate by FHWA (2004) specifies that the final engineer's estimate should be within +10 % of the low bid for at least 50% of the projects of a particular SHA. To achieve such confidence interval a structured approach to adjust unit prices should be used to help estimators and improve the overall cost estimate.

It has been identified by Paulsen et al. (2008) that very few DOTs have conducted in depth investigation to identify why estimates exceeded the actual cost. An in depth investigation of Virginia DOT is estimating practices conducted by Kyte et al. (2004) and Audit (2001), suggest that one of the reasons of cost overruns is that the method used to estimate the costs is incompletely or inconsistently applied.

Cost estimating guidelines do specify the need to consider location factor and estimate project specific unit prices, but any formal methodology to quantify the adjustment of unit prices is absent (Anderson et al. 2006). According to Chou and O'Connor (2007) the lack of properly treated historical data has increased the inaccuracy of estimates.

#### **2.4 Better Engineer's estimate**

The study by Martin et al. (2009) on megaprojects concluded that the Engineer's estimate must accommodate any recent technology advances while identifying and allowing for risk factors. The paper recommends following contractor's estimating approach while preparing Engineer's estimate on megaprojects, which is also used in transportation projects as the cost based estimating method. As the contractors are using actual market rates and estimating unit prices based on actual project location costs, it would be better to move forward by adopting useful technological advancements. Guidelines for preparation of Engineer's estimate by Federal Highway Administration (2004) also incorporates the need to prepare estimates using the same level of detail as the contracting industry.

## **2.5 Geographic Information System (GIS) in Construction**

The construction industry has successfully utilized GIS for a variety of problems like, to improve public interaction, to digitize and visualize data, for tracking construction equipment, and to solve problems of spatial and descriptive data.

One of the earliest uses of GIS in the construction industry was done by exploring potential construction applications that can benefit by using the GIS technology (Jeljeli et al. 1993). Jeljeli et al. (1993) identified department of transportation's (DOTs) as potential benefiter of pre-qualification GIS, which basically means using various data layers from different sources to perform numerous spatial and descriptive queries.

Development of Progress Monitoring System with GIS (PMS-GIS) to provide information pertaining to the spatial aspects of a construction project helped to effectively communicate the schedule information to the parties involved in the project due to the visual 3D rendering developed (Poku and Arditi 2006). This 3D rendering showed in detail the spatial aspects of the project alongside the schedule (Poku and Arditi 2006).

The study conducted by Dierkes and Howard (2008) presented innovative uses of established GIS technology to provide simple construction tracking tools and share digital project data with stakeholders.

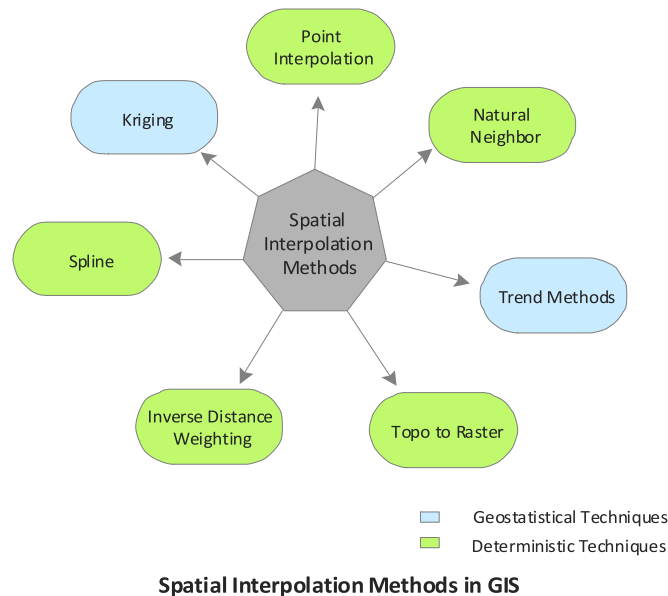
## **2.6 Interpolation Methods Available in GIS**

GIS more appropriately called Geospatial Information System (GIS), has been gaining importance due to its vast potential to position properties on a local map in terms of their geographic coordinates (Din et al. 2001). GIS environments are not only extensions of capabilities of conventional database systems but a dynamic environment which is able to

accommodate and handle complicated geographic data structures and provide comprehensive information (Clementini and Di Felice 1995). As described by Eberly et al. (2004) spatial interpolation is a very important component of many GIS.

The ArcGIS Geostatistical Analyst toolbar is an important part of exploratory spatial data analysis to create a statistically valid surface (Johnston et al. 2001). Toolbar is used to create a continuous interpolation surface or map, from the measured sample points taken at different locations, to visualize, analyze, and understand spatial phenomena (Johnston et al. 2001). The advancement over previous spatial interpolation tools is that with geostatistical analyst it is possible to quantify the error of the predicted surface and decide a better interpolation surface (Johnston et al. 2001). According to Johnston et al. (2001) various methods that are available in the toolbar to perform spatial interpolations are shown in Figure 2, and can be classified into two types:

- Geo-statistical techniques
- Deterministic techniques.



**Figure 1 Methods of spatial interpolation in GIS (Johnston et al. 2001)**



Geo-statistical techniques are based on statistics and the prediction surface includes some measure of certainty or accuracy of predictions while deterministic techniques create surfaces based on measured points or mathematical formulas (Childs 2011).

GIS has been gaining importance due to its vast potential to position properties on a local map in terms of their geographic coordinates (Din et al. 2001). This ability of GIS has been utilized in the past in many aspects of construction like for processing, analyzing, and modeling housing and mortgage data sets (Can 1998), for estimating commercial property prices through spatial interpolation methods (Montero and Larraz 2011), for validation of geographically based surface interpolation methods for adjusting construction cost estimates by project location (Zhang 2014). All these studies have used GIS as a promising advancement in technology that can be used to solve problems in the construction industry.

IDW was adjudged as a best technique for smooth surface interpolation of Construction Cost Index (CCI) in the study by Zhang 2014. In the same study, spline worked better when the range of sample values may not include the extremes of the phenomenon being interpolated and produced better surfaces than IDW with sparse sample dataset (Zhang 2014). Another study showed that kriging had advantages over classical interpolation methods used for commercial property prices in a touristic city (Montero and Larraz 2011). Each spatial interpolation method has its own advantages and disadvantages depending on the type of data used to interpolate. The surface interpolation methods are described in brief below:

1. Inverse Distance Weighted: This is one of the most frequently used deterministic technique of spatial interpolation (Lu and Wong 2008), which was originally called an approach using weighted averages (Shepard 1968). As the name suggests, the attribute value of an unsampled point is the weighted average of known values within the

neighborhood, and the weights are inversely related to distance between the prediction location and the sampled locations (Lu and Wong 2008). The advantages of this method are it is relatively fast and easy to compute, and relatively straightforward to interpret (Lu and Wong 2008).

2. Kriging: It is a geostatistical technique i.e. it is based on statistics and are often used for more advanced prediction surface modeling that also includes some measure of certainty or accuracy of prediction (Childs 2011), this method is often used in fields related to construction. The theory behind this surface interpolation technique was developed by Krige (1952). Like IDW interpolation, kriging forms weights from surrounding measured values to predict values at unmeasured locations. The weights however are more sophisticated than those of IDW, kriging weights are generated from semi-variogram developed by viewing spatial structure of the data unlike a simple algorithm based on distance in IDW. Kriging not only uses distance of the available points but also the statistical relationships among the available points. It considers the spatial arrangements in the weights of the available points to perform the interpolation. Kriging requires the user to fit a line or a model that is the best fit through the points, and it is also necessary to remove any directional influences that are present in the points before prediction surfaces are made. The process of fitting a model requires detailed understanding of the semi-variogram modeling which is similar to regression analysis where a continuous line or curve is fit into the available data. The directional influence in the data at a particular angle can be observed from the trend analysis, and is known as anisotropy. It is a characteristic of a random process that shows higher spatial influence in one direction. It

is necessary to de-trend any such observation in the data with detailed analysis of available models, which can be fit to remove the trend.

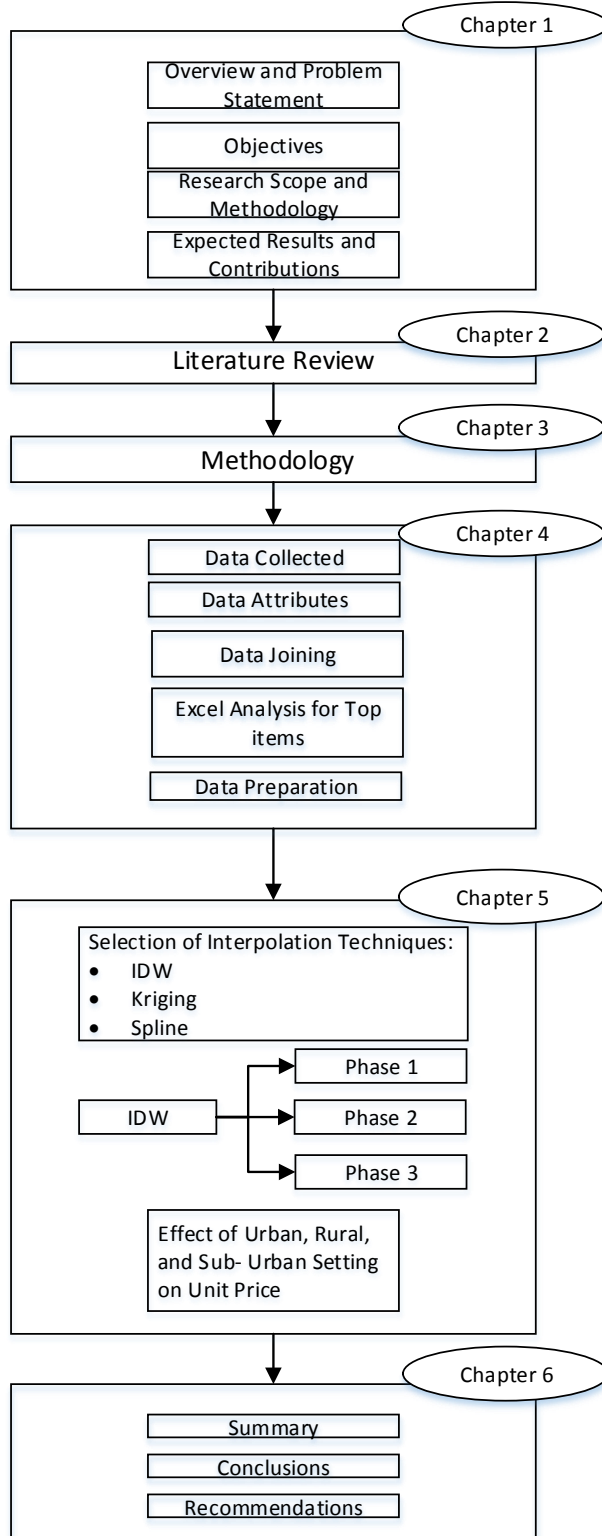
3. Spline: It estimates grid cell values by fitting a minimum- curvature surface to the sample data (Childs 2011). This results in a smooth surface that passes exactly through the input points (Childs 2011). Spline is a radial basis function method in which the surface must pass through each available data point. As the surface passes through all the available points there is no measured error available in the cross validation results. A user has to select a basis function and this technique is better for gently varying surfaces rather than surfaces that have large changes in the surfaces. Spline has 5 basis functions: thin-plate spline, spline with tension, completely regularized sample, multiquadric function, and inverse multiquadric spline. It is important to understand the variation of data in detail to select the radial basis function and perform spline interpolation. Spline in general is more appropriate in following cases:

- a. For sample values which do not include the extremes of phenomenon being interpolated,
- b. For smaller sample size,
- c. For obtaining a smoother surface distribution of values.

### CHAPTER III

#### RESEARCH METHODOLOGY

Figure 1 shows the overall research methodology, the literature review of cost estimating practices and guidelines of various SHAs in Chapter 2 introduced to the lack of tried and tested methodology to adjust unit prices for location. Some previous studies that used GIS for spatial interpolation were studied and the top three interpolation methods that will suit unit price data were decided out of the available methods in GIS. Chapter 4 introduces the data collection and preparation procedure in detail. The sources of data and data attributes are described in detail and the data preparation section consists of the detailed steps of obtaining the top items using basic excel operations. It further explains the steps followed to prepare the data for further GIS analysis. Chapter 5 describes the development of interpolation surface using GIS starting with the selection of interpolation techniques and discussing the results obtained using IDW in phase 1, 2, and 3. The validation of all the GIS processes performed on unit price data is carried out by the cross validation results obtained from the spatial interpolation techniques to decide which interpolation surface or condition is better for each major item. So, the interpolation surfaces are considered better if predicted value at sampled location is almost equal to the available value at that location since then, the difference between available and predicted values will be less and thus error in measurement would be least. Lesser the measured error, better the interpolation surface is considered. The final section of Chapter 5 discusses the use of urban, rural, and sub-urban attribute available in the bid data to study if this classification of project location according to Iowa DOT has any relation with unit prices. Chapter 6 makes a brief summary of the study with conclusions and recommendations for future research.



**Figure 2 Research Methodology**

## CHAPTER IV

### DATA COLLECTION, CLEANING, AND PREPARATION

#### 4.1 Data Collection

##### 4.1.1 Iowa department of transportation (DOT) bid data

Iowa DOT- office of contracts is contacted for the bid data, which was received in four parts.

The four data sets each having 4 years of information are:

1. Bidders: This dataset consists of information about the contractors or vendors that have submitted bids for the contract including the dollar amount of the bid, details of the vendor.
2. Bidtabs: This dataset consists of details about the contract like the estimated quantity, unit bid price, item number, extended amount.
3. Project: The project dataset consists of detailed information about the project such as location of the project, urban/rural class, project length etc.
4. Proposal: The proposal dataset includes details about the contract including the letting date, date of award, type of highway, etc.

##### 4.1.2 Iowa department of natural resources (Iowa DNR) versus U.S. census bureau shape files

To use as a background layer a shape file of Iowa with county lines is used. It is important to consider the coordinate systems when working with different layers. The county map from Iowa DNR is added but the point data does not overlap with this map of Iowa. The issue was identified that the coordinate system for the location data is in the World Geodetic System (WGS) 1984 while the Iowa DNR shape file is in North American Datum (NAD) 1983 system. Thus, a WGS 1984 shape file of Iowa with county lines is obtained from United States Census Bureau website and the data points are seen over the map of Iowa.

## 4.2 Data attributes

Once the data is obtained all the data attributes are studied and important ones, which will be used for the study are selected. The important data attributes that are necessary for the analysis include:

1. Latitude and longitude: One of the most important attributes is the location information of the project. The location information has latitude and longitude measure in decimal degrees but requires longitude to be multiplied by -1 to correctly represent coordinates that fit into Iowa Regional Coordinate System (IaRCS) (Miller et al. 2014). The latitude and longitude data is used to position the project on Arc Map and perform further analysis using other data attributes.
2. Item number and item description: There are more than 400 bid items after excluding the special bid items and non-lump sum special bid items. The special bid items include lump sum items other than the unquantified bid items and are either measured as some fixed percentage of the total project as specified in the contract or may use quantity and unit cost also. The non-lump sum cost special bid items do not have a unit of lump sum and have unit price of \$0.01. Each is associated with a unit identification number and name and these two attributes are essential to find out the most common and important items in each pavement type.
3. Quantity: The amount of each item used for the project is specified in this column of the bid data. Each item has a specific unit in which the quantity of the material is measured. The units are decided based on method of measurement (MOM) and basis of payment (BOP). Some common units of quantity in the bid data are ton, square yard, cubic yard, miles etc.

4. Unit price: One more important attribute around which the study revolves around is the unit price of bid items. The price of the item per unit quantity is the unit price.
5. Extended amount: The dollar amount for each line item calculated by multiplying unit price and quantity is known as the extended amount. This is used to decide the top item in terms of cost for further GIS analysis.
6. Urban/ Rural: There is a classification of each project as urban, rural, and sub-urban depending on its location. This attribute is used to test if the urban or rural setting of a project has any effect on unit prices.
7. Identification number: It is important to have an identification number to be able to link the attributes together and backtrack information when required.

#### **4.3 Data joining**

Three out of the 4 data sets received from IaDOT have a contract number as an identification number, but the project dataset has both contract number and project number. The location attribute of a project is in the project dataset and one contract may have multiple project locations across the state and thus, one contract may have more than one project under it. In the project dataset the contract number is same for such projects. Hence, to include data from all the projects it is necessary to join the data according to project numbers. Due to unavailability of project number in any other dataset it is a lengthy process to join the 4 datasets by linking each project number with associated contract. Hence, the DOT office of contracts was contacted with this issue and they confirmed that it is going to be more of a manual process for them to join the various data attributes in bidders, bidtabs, and proposal with project dataset. Thus, the dataset was joined by office of contracts and new data set of two main project types of Iowa DOT i.e.



Hot Mix Asphalt (HMA) pavements and PCC pavements containing only winning bid cost information was obtained.

#### 4.4 Data Preparation

The joined dataset has a varying number of projects for each year. The short summary on the number of projects and contracts in each year is shown in Table 2 below

**Table 2 Number of projects and contracts in joined dataset**

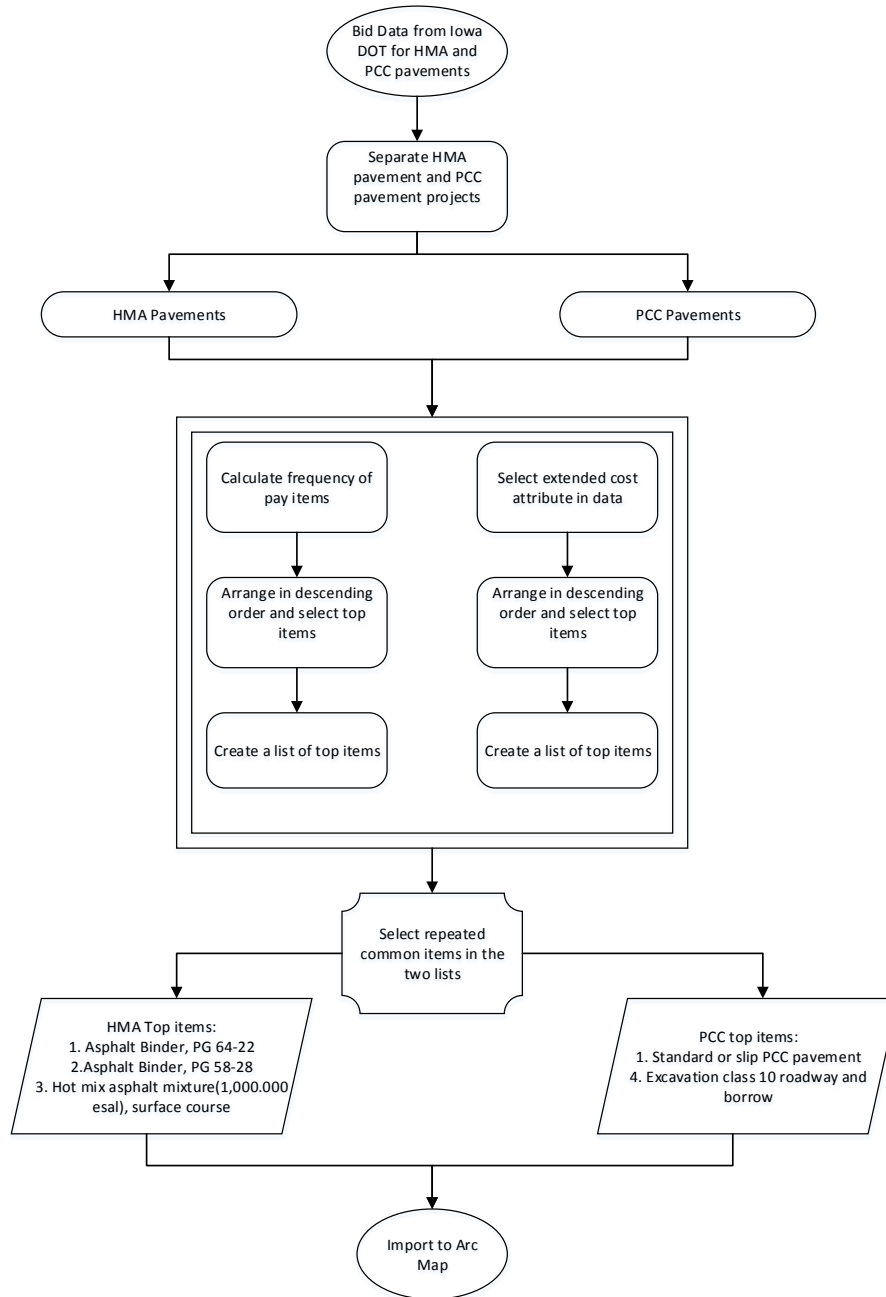
Year	Number of Projects	Number of Contracts
2011	222	180
2012	398	374
2013	190	157
2014	166	133

Figure 4 depicts the detailed excel analysis process followed to obtain the list of top items. First, the two pavement types were separated for each pavement type, frequency of each pay item was calculated and arranged in descending order and items on top, which were most frequent, were listed down. On the other hand, extended cost column in the data is also arranged in descending order, and top items were listed. Common items in both lists were selected and the top item list for HMA pavement projects consist of the following construction items:

- Asphalt Binder, PG 64-22
- Asphalt Binder, PG 58-28
- Hot Mix Asphalt Mixture (1,000,000 ESAL), surface course

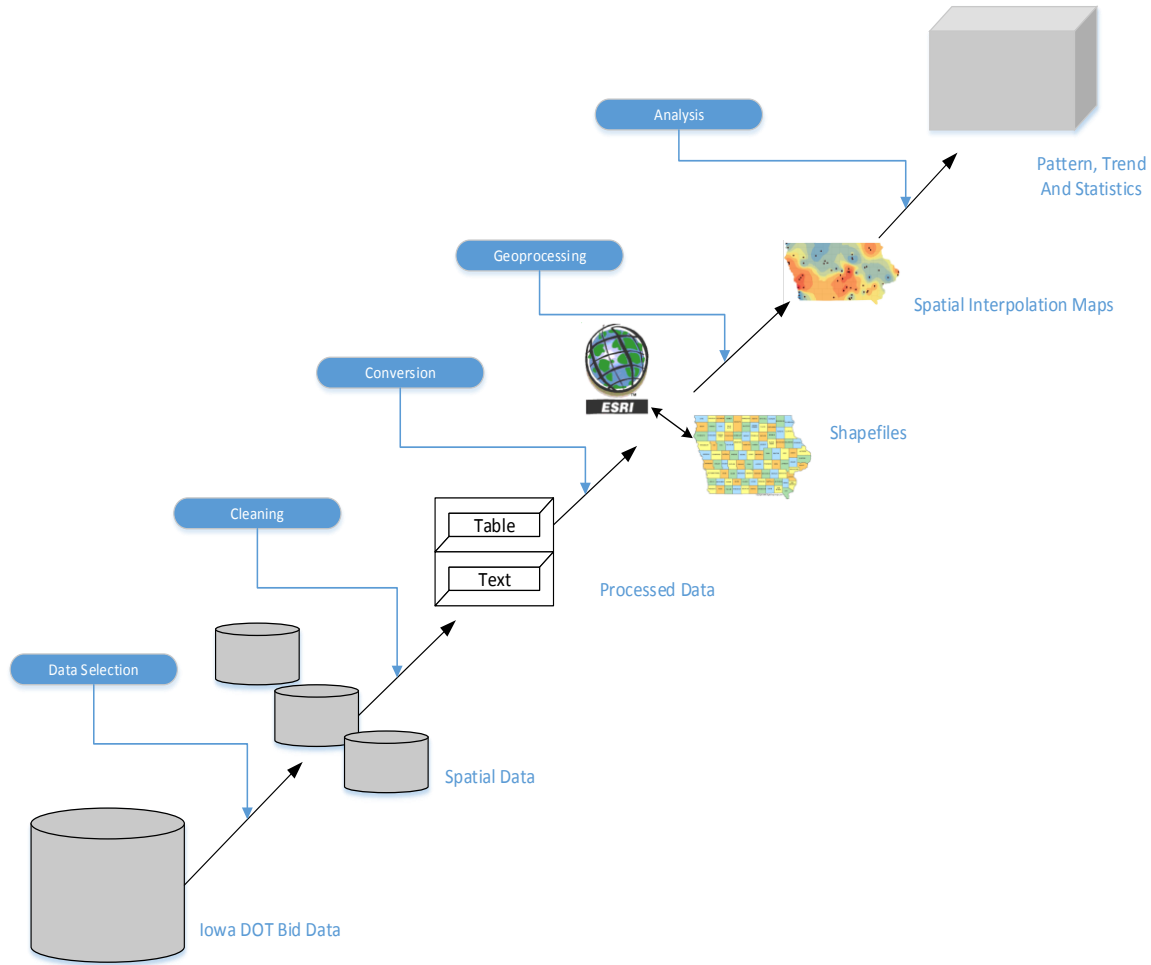
The top item list for PCC pavement projects frequently consisted of the following construction items:

- Standard or slip form Portland cement concrete pavement
- Excavation class 10, roadway and borrow



**Figure 3 Excel Analysis Methodology**

For each top item the year wise excel sheets are imported to Arc Map platform. Figure 5 shows basic steps followed in the data mining and preparation.



**Figure 4 Data Preparation**

The top items are selected from the bid data and then each item is kept in a separate excel sheet. These excel sheets are cleaned by keeping only the necessary data attributes. A geodatabase is created and the excel file of a particular item is imported in ArcMap using the importing table option. Separate layers are created and added in the table of contents to import each year excel file under these separate layers. The latitude and longitude attributes in the imported excel file is used to display data on ArcMap platform. The project locations are then seen as point data on the Arc Map.

## CHAPTER V

### DEVELOPMENT OF UNIT PRICE SURFACES

This chapter presents the process of development of unit prices and discusses the results of the study in a detailed manner. It starts with the explanation of interpolation techniques. The decision for the selection of “data appropriate interpolation techniques” is explained using data exploration results and logical explanations. IDW is used for the study and the reason for eliminating spline and kriging are justified with evidence from the analysis. The results obtained by using IDW are divided into 3 phases described in detail with the help of figures and summary tables from the analysis. The final section tests the relationship of urban, rural, and sub-urban classification on unit price for the top items.

#### 5.1 Selection of Interpolation Techniques

The techniques under consideration for developing interpolation surfaces are Inverse distance weighting (IDW), spline, and kriging. Each spatial interpolation technique has its own unique theory on which it works.

##### 5.1.1 Inverse Distance Weighting (IDW)

IDW is a deterministic method that uses the inverse of distance as a mathematical basis for interpolation, which means that while performing interpolation, the value of a point closer is given more weightage than the value of a point that is farther away. Thus, the weightage of a value of unit price will decrease as the distance increases. It is a common practice in the construction industry to use the nearest available price data while estimating the cost for a project. The basic equation of IDW is:

$$Z_j = \frac{\sum_i \frac{Z_i}{d^{n_{ij}}}}{\sum_i \frac{1}{d^{n_{ij}}}}$$

Where,  $Z_i$  is value of the measured point,

$d_{ij}$  is the distance between measured value and predicted value

$Z_j$  is the value of the predicted point

$n$  is the number of points

Figure 5 shows an example of calculating the predicted value using IDW.

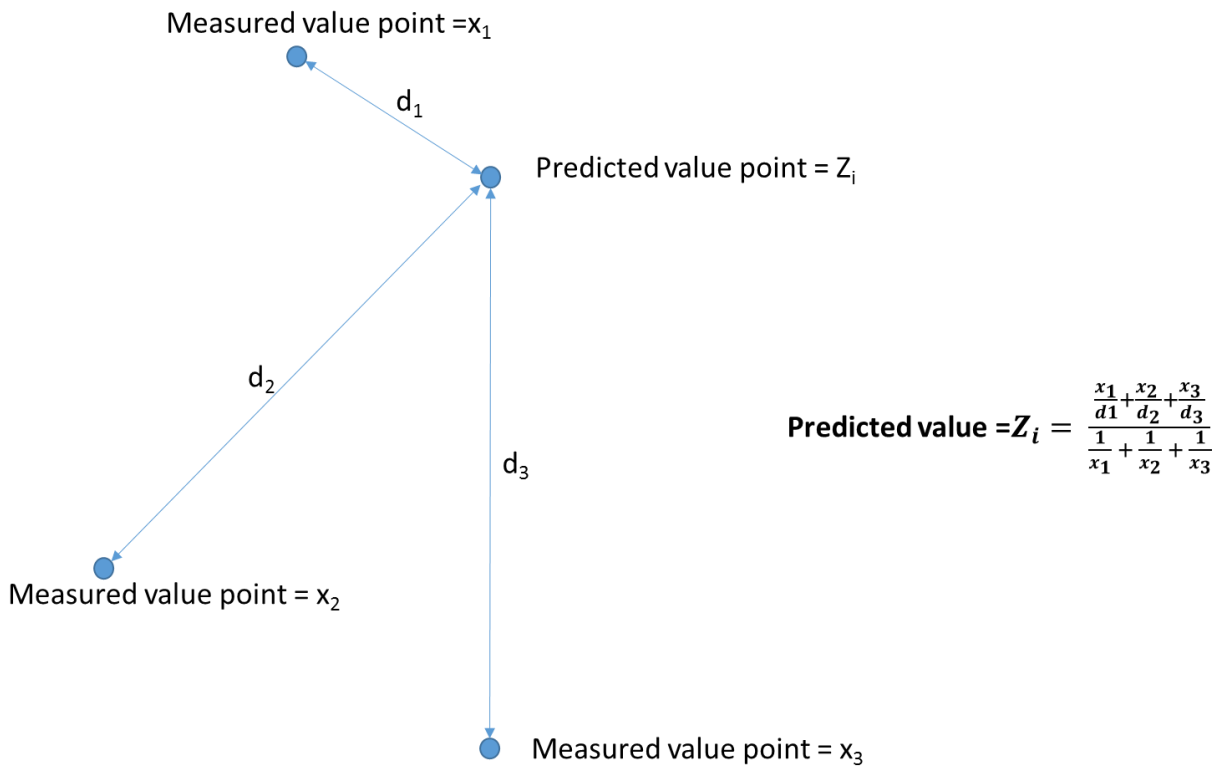


Figure 5 IDW example

**Cross Validation Result:** The interpolation creates a surface by determining values of cells for which there is no measured value, and it used these measured point values and distance between measured points and cells to do so. IDW interpolation tries to fit the surface so that it passes through a maximum number of measured values but not through all the measured values. Thus

the surface has points or locations where the measured value and predicted value are not the same. This difference in measured and predicted value is known as measurement error and it is included in the cross validation results of the method properties of IDW. The average of this error is used as a measure to judge better interpolation surface, the lesser the average error the better is surface of interpolation. Thus for comparing the interpolation surfaces and to decide a better one, the cross validation results are used.

The IDW interpolation results for all the items are attached in Appendix A, which are divided into three phases. Phase 1, shows the year wise interpolation maps for each item. Phase 2, shows the interpolation results with different ways of quantity as a weight. Phase 3, shows the results using the data obtained from approximate index calculation and extrapolation of unit prices for the year 2014.

#### **5.1.1.1 Phase 1 results**

The 4 maps of Iowa in figure 6 for phase 1 results show the interpolation surface using IDW starting from year 2011 on the top to 2014 at the bottom. These maps are color coded according to the index shown at the bottom. The color blue signifies low cost while red signifies high cost. Once the location of a new project is known, the estimated unit price of a work item can be obtained by just clicking on the new project location in the method properties of interpolation surface.

These maps can be used for understanding the yearly trend of the unit prices from year 2011 to 2014. They are visually very convenient to identify any extremes, high or low, in prices. It is possible to identify outliers in the data and eliminate those using similar color-coded maps.

Figures 6, 7, 8, and 9 show an example of how such maps can be used to find outliers in the unit price data. Figure 6 shows the maps of item Asphalt Binder, PG 58-28, from the year 2011 to

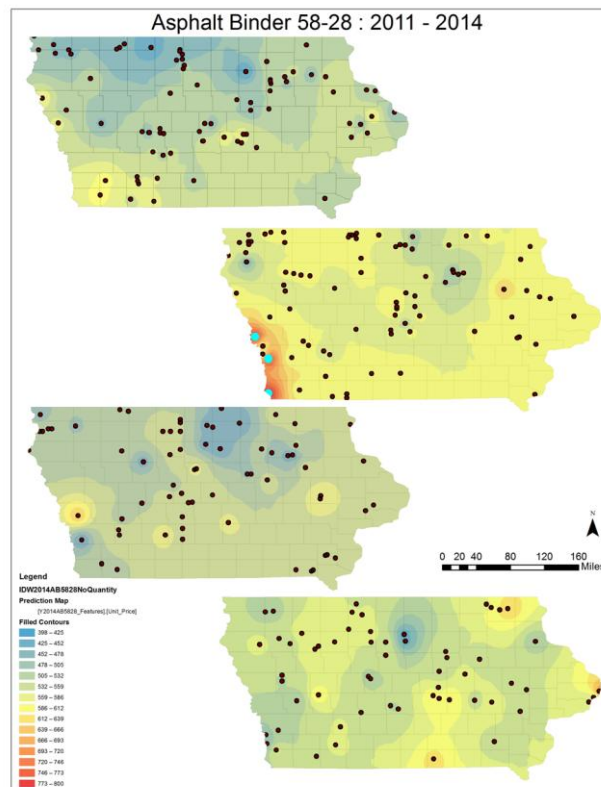
2014. It is clear from the distinct red color that the three highlighted points in the second map have higher unit price as compared to any other location for the same year. An outlier test was performed on the data from the year 2012 for asphalt binder 58-28 using the modified Thompson Tau equation.

$$\tau = \frac{t \cdot (n - 1)}{\sqrt{n}\sqrt{n - 2 + t^2}}$$

Where, n is the number of data points

t is the t value based on  $\alpha = 0.05$  and  $df = n - 2$

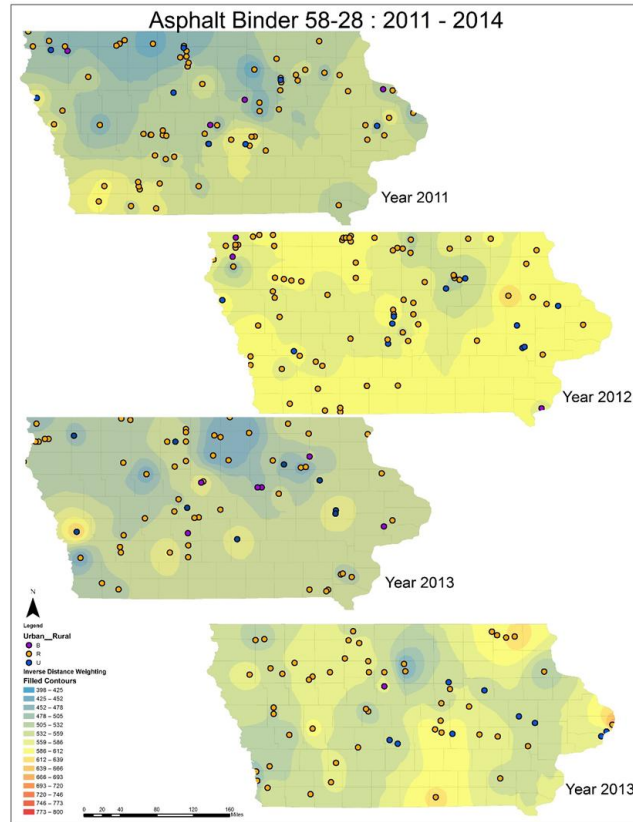
The three points highlighted in the figure were found to be outliers in the data.



**Figure 6 Highlighted outliers in year 2012 for Asphalt Binder, PG 58-28**

Upon backtracking the information about those projects it was found that these three locations had a very small quantity of asphalt binder when compared to quantities used in other projects

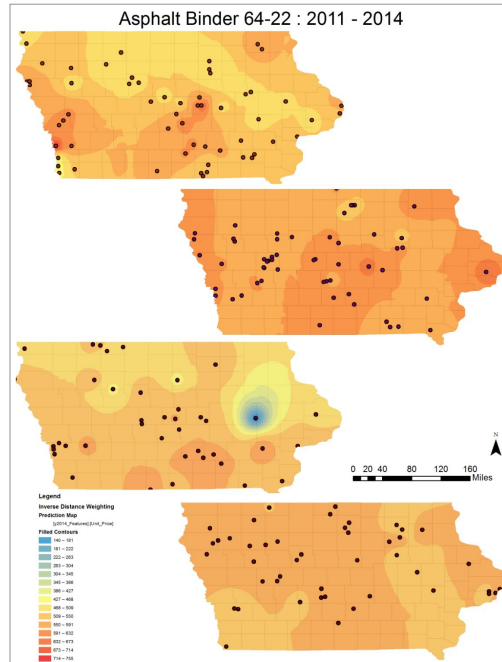
for the same year. Thus these outliers in data are removed and Figure 7 shows better variation of unit prices for the item.



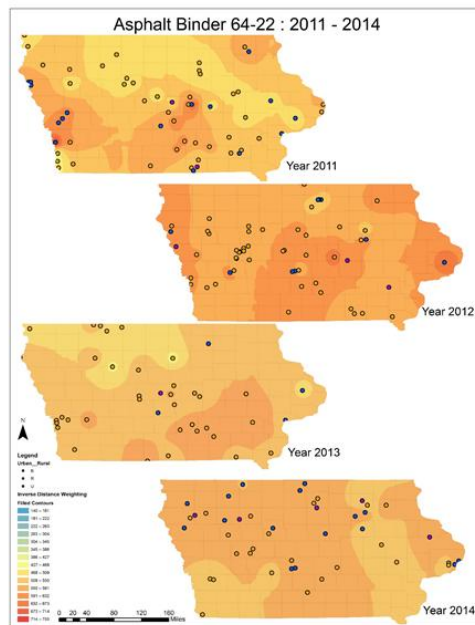
**Figure 7 IDW interpolation for Asphalt Binder, PG 58-28 from 2011 to 2014**

Another such example was found in Asphalt Binder 64-22, Figure 8 shows the result of IDW on the item from the year 2011 to 2014. The third map from the top for the year 2013 had a single location which had surprisingly a low unit price of \$140 and it was found to be an outlier using the modified Thompson Tau test. On searching the DOT website the project was found to be withdrawn due to right of way (ROW) issues and was rescheduled for a later date for letting. Figure 9 shows the IDW results after removing the one withdrawn project and is therefore a better representation of unit price variation.





**Figure 8 Outlier included IDW result for Asphalt Binder, PG 64-22**



**Figure 9 Outlier removed IDW for Asphalt binder, PG 64-22**

The maps are easily interpreted and can be used to convince higher officials for using a particular grade or type of material over other.

### 5.1.1.2 Phase 2 results

The 3 maps in Figure 10 correspond to quantity analysis for the item Asphalt Binder 64-22 in the year 2011 by using the option of weightage in IDW technique. Starting from the top, the first map of Iowa is the interpolation result without giving any weight. The second map from the top shows the interpolation for the same year by giving quantity of material from the bid data as weightage. The third map in the figure shows the interpolation surface by giving the reciprocal of quantity of material as the weight.

The weightage follows the equation below:

$$\hat{z}(x_0) = \frac{\sum_{i=1}^n z(x_i) \cdot d_{ij}^{-p}}{\sum_{i=1}^n d_{ij}^{-p}}, \text{ where } d \text{ is the distance and } z \text{ is the value at un-sampled location.}$$

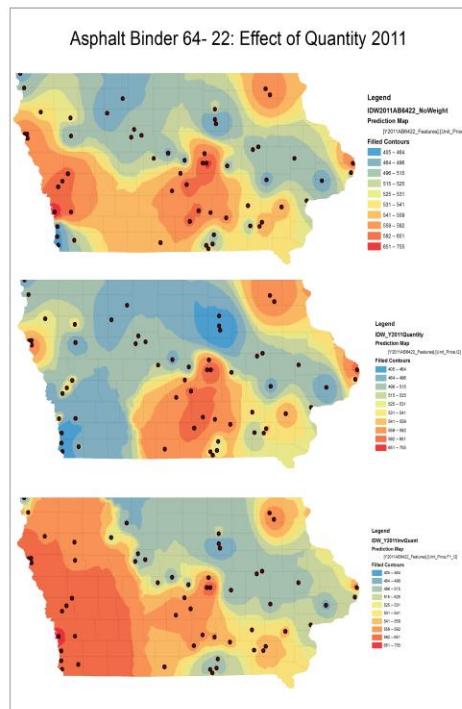


Figure 10 Quantity analyses for Asphalt binder, PG 64-22, year 2011

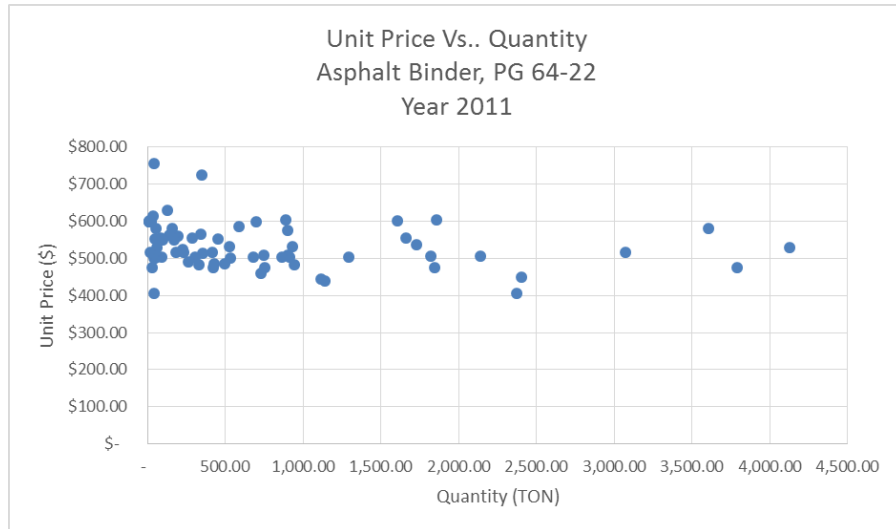
The error is calculated by difference in the measured value and the interpolated value, the average of this error for a particular year are the numbers in Table 3 for HMA pavement items.

Cross validation results show that the interpolation performed without giving quantity as a weight has the least average error out of the three. The cross validation results are summarized in Table 3 for all the HMA pavement items. The lesser the value of the error the better is the case considered.

**Table 3 Cross validation result for all HMA pavement items**

	AVERAGE ERROR IN MEASUREMENT							
	ASPHALT BINDER, PG 64-22				ASPHALT BINDER, PG 58-28			
Cases/Year	2014	2013	2012	2011	2014	2013	2012	2011
Inverse Quantity	5.37	4.77	-5.41	19.17	2.13	1.46	20.26	3.55
<b>No Quantity</b>	<b>0.94</b>	<b>5.59</b>	<b>-2.05</b>	<b>3.51</b>	<b>-1.16</b>	<b>-1.18</b>	<b>-3.46</b>	<b>-1.20</b>
Quantity	-3.04	13.54	-2.39	-11.08	3.07	3.63	-9.27	-1.20
Average Index	0.36				-0.75			
	HMA Mixture (100,000ESAL) SURFACE COURSE							
Cases/Year	2014	2013	2012	2011				
Inverse Quantity	10.50	3.58	13.44	9.99				
<b>No Quantity</b>	<b>2.43</b>	<b>0.37</b>	<b>0.93</b>	<b>0.69</b>				
Quantity	-10.50	-2.68	-7.26	-9.31				
Average Index	-1.98							

The possible reasons for such behavior can be validated by plotting the unit price on Y-axis and Quantity of material on X-axis to observe the relationship in the data in use. Figure 11 shows the plot of unit price versus quantity for asphalt binder, PG 64-22 for the year 2011.



**Figure 11 Unit price vs quantity for asphalt binder, PG 64-22**

It shows that the generalized theory of quantity being inversely proportional to unit price is not always true. The inverse relationship between quantity and unit price is not seen for the HMA pavement items and that is the reason for using inverse of quantity, as weight did not improve the interpolation.

### 5.1.1.3 Phase 3 results

In an attempt to obtain better interpolation results, the average unit price for each item was calculated for each year data. A cost index was developed using 2014 as a base year and all the unit price data was brought to 2014 by multiplying it by the index. The indices developed are summarized in the Table 4.

$$\text{Cost index for year } X = \frac{\text{Average unit price for year } X}{\text{Average unit price for 2014}}$$

**Table 4 Average unit price and approximate cost index for all HMA and PCC items**

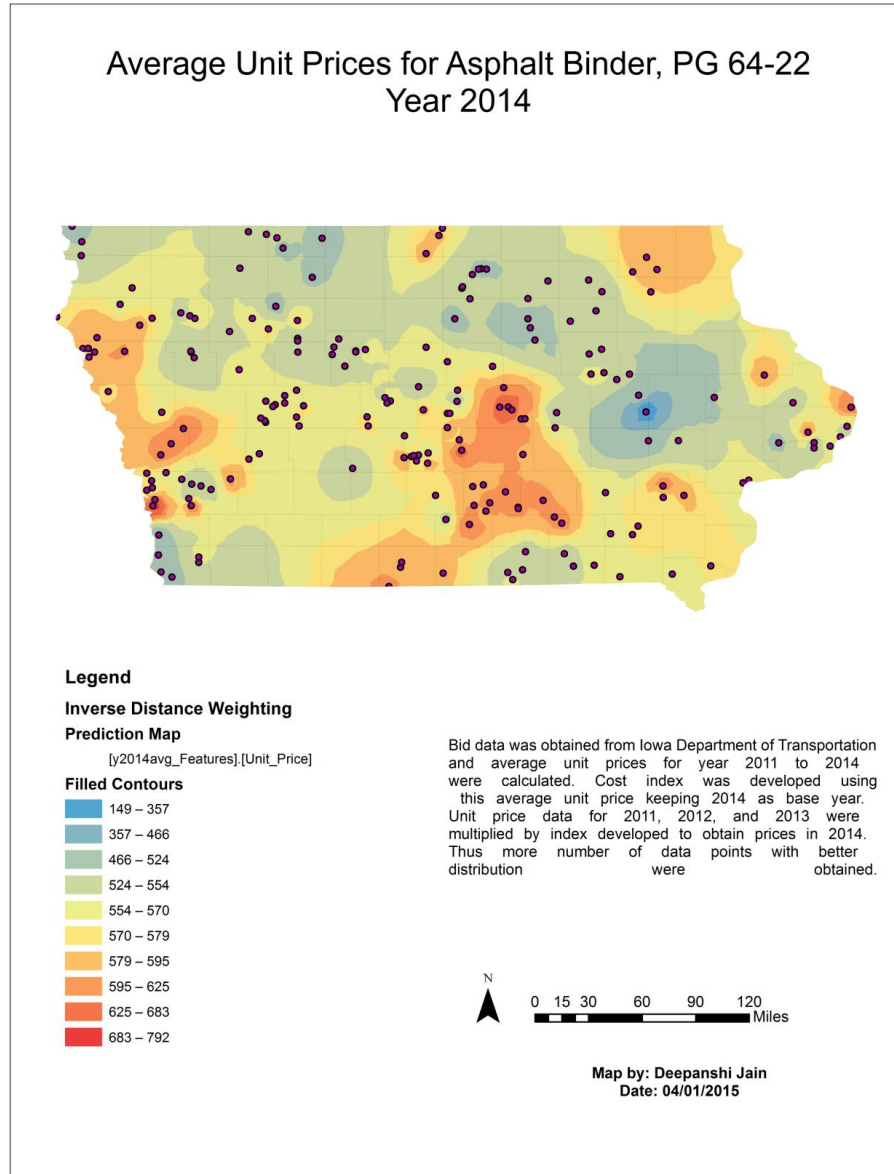
Year	ASPHALT BINDER, PG 64-22		ASPHALT BINDER, PG 58-28	
	Average Unit Price (\$/ton)	Index with base year 2014	Average Unit Price (\$/ton)	Index with base year 2014
2011	533.39	0.95	518.90	0.93
2012	588.10	1.05	585.99	1.05
2013	524.14	0.94	528.69	0.95
2014	559.51	1.00	558.85	1.00

Year	HMA Mixture (100,000 ESAL) SURFACE COURSE		Excavation, Class 10, roadway and borrow	
	Average Unit Price (\$/ton)	Index with base year 2014	Average Unit Price (\$/CY)	Index with base year 2014
2011	38.89	0.89	6.85	0.89
2012	37.24	0.85	7.58	0.98
2013	35.03	0.80	7.43	0.96
2014	43.80	1.00	7.70	1.00

Year	Standard Portland Cement Concrete	
	Average Unit Price (\$/SY)	Index with base year 2014
2011	36.81	0.75
2012	38.52	0.78
2013	40.92	0.83
2014	49.37	1.00

CY= cubic yard  
SY = square yard

The interpolation surface developed using the average data for the year 2014 is show in the Figure 12.



**Figure 12 IDW on average unit price data for asphalt binder, PG 64-22 for the year 2014**

The result of cross validation from the interpolation of average index data is compared with earlier cross validation results when no weight in IDW is used for 2014. Table 5 shows that the interpolation results of IDW are improved by using an average index approximate data for 2014. The results show significant improvement in interpolation and thus confirm the fact that more number of data points, which are well distributed, gives better IDW results.

Table 5 Cross validation result highlighting average index error

	AVERAGE ERROR IN MEASUREMENT							
	ASPHALT BINDER, PG 64-22				ASPHALT BINDER, PG 58-28			
Cases/Year	2014	2013	2012	2011	2014	2013	2012	2011
Inverse Quantity	5.37	4.77	-5.41	19.17	2.13	1.46	20.26	3.55
No Quantity	0.94	5.59	-2.05	3.51	-1.16	-1.18	-3.46	-1.20
Quantity	-3.04	13.54	-2.39	-11.08	3.07	3.63	-9.27	-1.20
<b>Average Index</b>	<b>0.36</b>				<b>-0.75</b>			
	HMA Mixture (100,000ESAL) SURFACE COURSE							
Cases/Year	2014	2013	2012	2011				
Inverse Quantity	10.50	3.58	13.44	9.99				
No Quantity	2.43	0.37	0.93	0.69				
Quantity	-10.50	-2.68	-7.26	-9.31				
<b>Average Index</b>	<b>-1.98</b>							

### 5.1.2 Kriging

Kriging is a geospatial method which using moving average as the basis for generating interpolation surfaces and predicting error in measurement. It basically groups similar distance points and assigns weight to them according to the distance from the prediction point. The general equation governing kriging is shown below:

$$\hat{z}(S_0) = \sum_{i=1}^N \lambda_i Z(S_i)$$

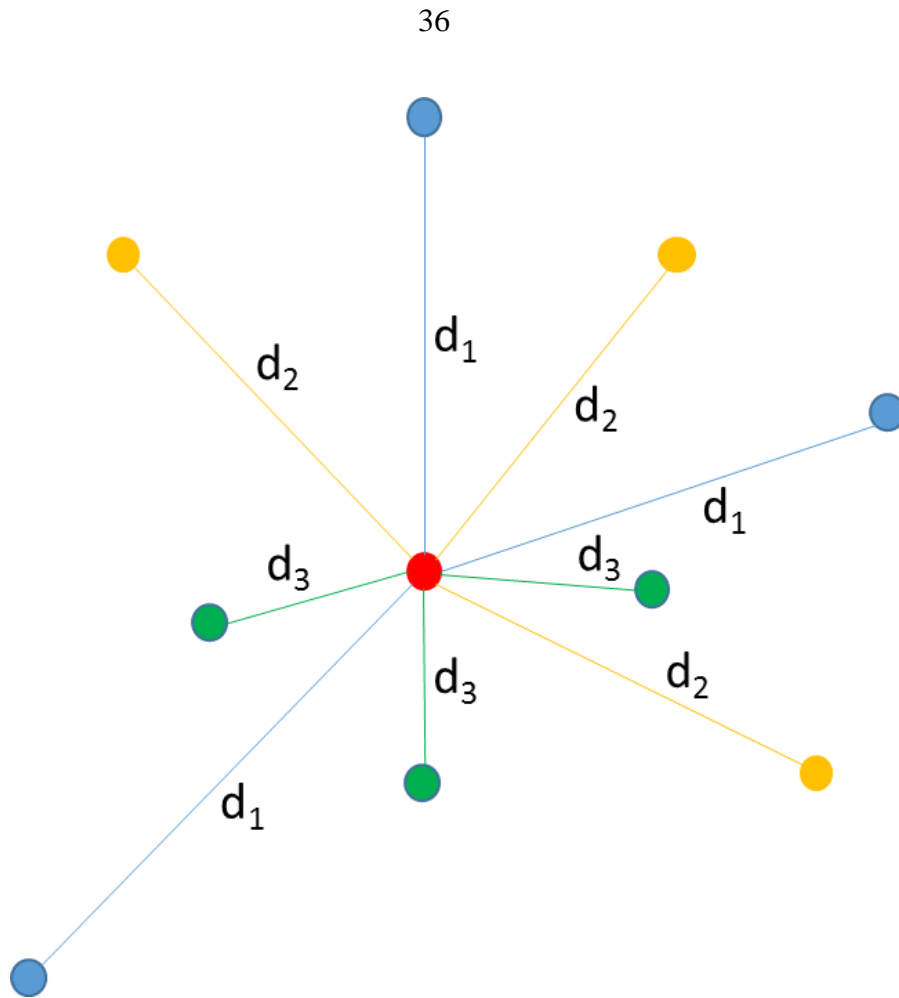
Where,  $Z(s_i)$  = the measured value at the  $i$ th location,

$\lambda_i$  = an unknown weight for the measured value at the  $i$ th location,

$s_0$  = the prediction location,

$N$  = the number of measured values.

Figure 13 shows a working example of kriging, where the similar distance points are grouped together and then the weight is assigned for interpolation similar to IDW.

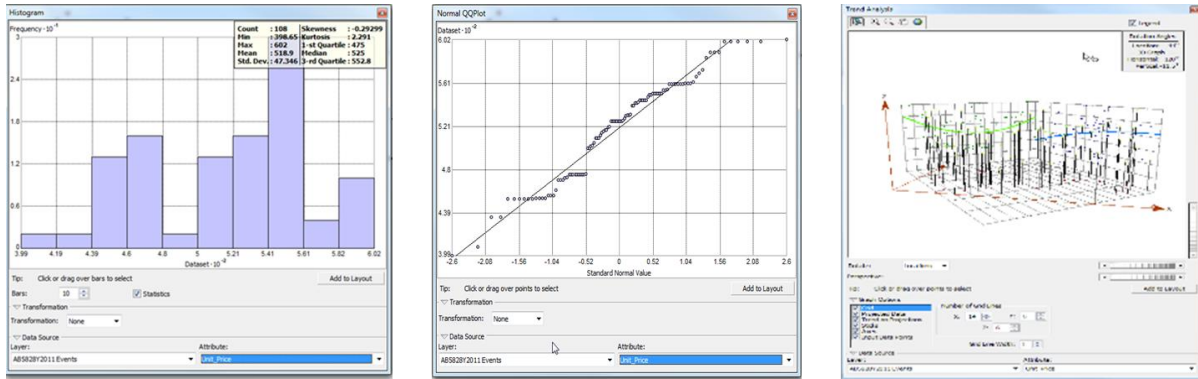


**Figure 13 Kriging example**

The data exploration results attached in Appendix B consists of the histogram, normal quantile plot, and trend analysis for all the 5 items. The histogram and normal quantile plot show that the bid data is neither symmetrical, nor normally distributed. Trend analysis of the data for each year showed that there is a directional trend in a specific direction.

Figure 14 shows the histogram, normal quantile plot, and trend analysis result for asphalt binder 58-28.





**Figure 14 Histogram, normal quantile plot, and trend analysis for asphalt binder 58-28, year 2011**

Due to the above observation, before applying kriging for unit price data, the directional trend needs to be removed and this adds complexity for utilizing the methodology by state DOTs that have limited time resources for generating estimates.

Kriging was applied to Asphalt binder, PG 64-22 and the cross validation results obtained are summarized along with IDW cross validation results in Table 6. Three out of four cases showed that the average error is less than those of IDW. It is evident that apart from the fact that kriging takes considerable efforts; the cross validation results show that IDW performs better. Thus, kriging is not considered for further analysis in the study.

**Table 6 Average errors in measurement for kriging and IDW for Asphalt binder, PG 64-22**

AVERAGE ERROR IN MEASUREMENT Asphalt Binder, PG 64-22		
Year	Kriging	IDW
2011	<b>5.69</b>	<b>3.51</b>
2012	-0.68	2.05
2013	<b>5.80</b>	<b>5.59</b>
2014	<b>-2.49</b>	<b>0.94</b>

### 5.1.3 Spline

Spline is a radial basis function method in which the surface must pass through each available data point. In order to make the surface pass through all the data points, the user has to fit a line or model by selecting an appropriate basis function from the 5 basis functions: thin-plate spline,

spline with tension, completely regularized sample, multiquadric function, and inverse multiquadric spline.

The general equation governing the working of spline is:

$$S(x, y) = T(x, y) + \sum_{j=1}^N \lambda_j R(r_j)$$

Where,  $j = 1, 2, \dots, N$

$N$  is the number of points.

$\lambda_j$  are coefficients found by the solution of a system of linear equations.

$r_j$  is the distance from the point  $(x, y)$  to the  $j^{\text{th}}$  point.

$T(x, y)$  and  $R(r)$  are defined differently, depending on the selected basis function.

It is important to understand the variation of data in detail to select the radial basis function and perform spline interpolation. Also, this technique is better for gently varying surfaces as that is when it is easy to decide a single model or line that fits in all the points. Hence, spline is considered to be better for interpolation surfaces of elevation data (Johnston et al. 2001) and from the histograms and trend analysis as shown in Figure 14 it is observed that the variation is not gentle and also directionally influenced at a specific angle.

Furthermore, the surface obtained from spline interpolation is a raster, which does not have a method property like geospatial layer in case of IDW and kriging where the user can click and obtain the value of unit price for any desired location. The raster layer is an image with pixels that is just a representation of how the unit price is varying, but to obtain the value from the surface for a location is not feasible.

Thus, IDW is selected as the sole method for generation of the interpolation results as it does not require any de-trending of the data, and can be applied directly to the dataset for obtaining a smooth interpolation easily.

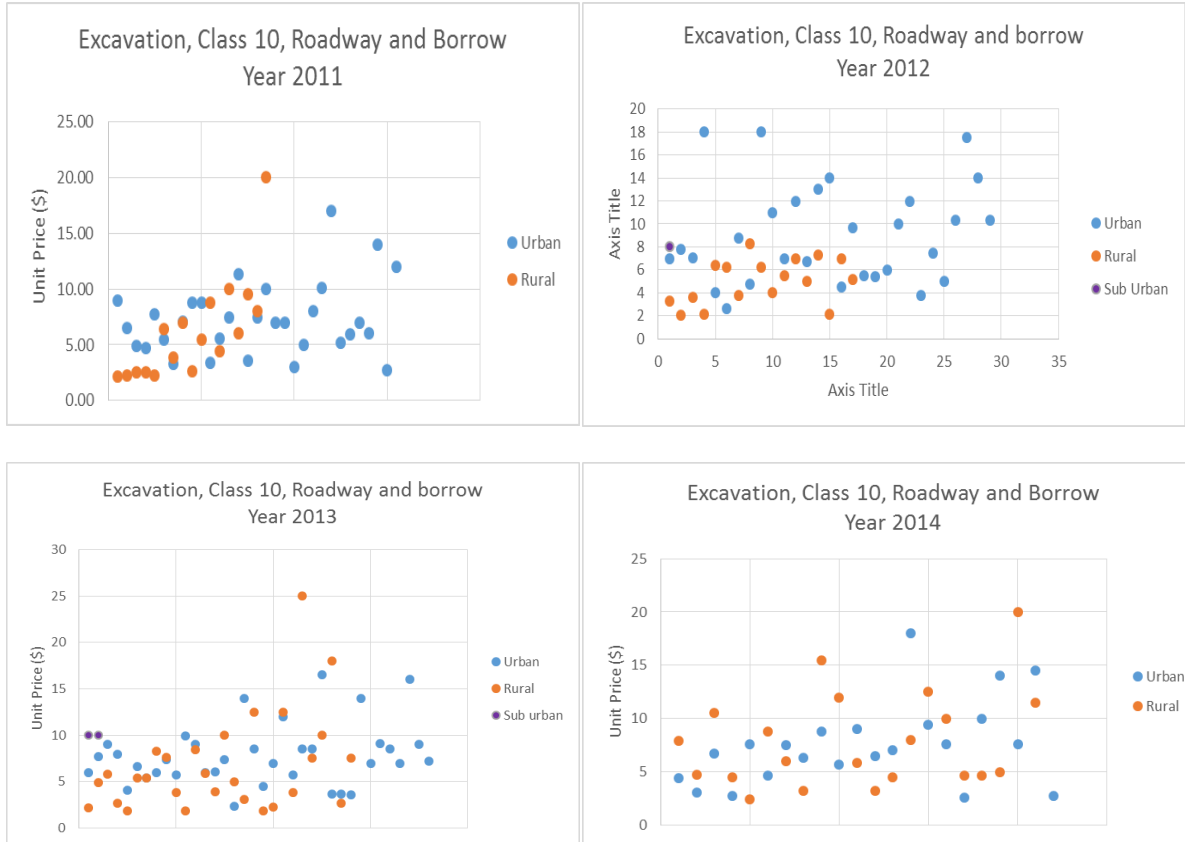
## 5.2 Effect of Urban, Rural, and Sub-Urban Setting on Unit Price

The urban and rural attribute classification included in the bid data should show a clear effect on unit prices. It is believed that the urban setting projects have a higher unit price as compared to sub-urban, and rural. In order to visualize the effect of this attribute on unit price a scatter plot was developed for excavation, class 10 roadway and borrow. Figure 15 shows the plots with Y axis as unit price, blue dots show urban projects, orange dots show rural projects, and purple dots show the sub-urban projects. To test the relationship of variables on unit price, analysis of variance (ANOVA) test is performed where the null hypothesis to be tested is that the variables urban, rural, and sub-urban do not affect the unit prices.

Null Hypothesis:  $H_0: \mu_1 = \mu_2 = \mu_3$ ;

$H_a: \mu_1 \neq \mu_2 \neq \mu_3$

The null hypothesis is rejected if the p- value obtained from the test is insignificant or less than  $\alpha$ , whereas the null hypothesis is accepted if the p-value is significant and not less than  $\alpha$  value used for the test. The rejection of null hypothesis means that there is a relationship that exists between the attribute and unit price. Whereas, if the null hypothesis is accepted it means that relationship does not exist.



**Figure 15 Color coded unit price data of excavation item for urban, rural, and sub-urban attribute**

The ANOVA test is performed in excel using  $\alpha = 0.05$  and results show that the year 2011, 2013, 2014 have a significant P – value which is not less than  $\alpha = 0.05$ , therefore the null hypothesis is accepted i.e. unit prices for the item are not affected by variables urban rural and suburban. Only year 2012 the P- value is not significant and less then  $\alpha = 0.05$  therefore the null hypothesis is rejected which shows that the variables/ attributes have some effect on unit price for the year 2012.

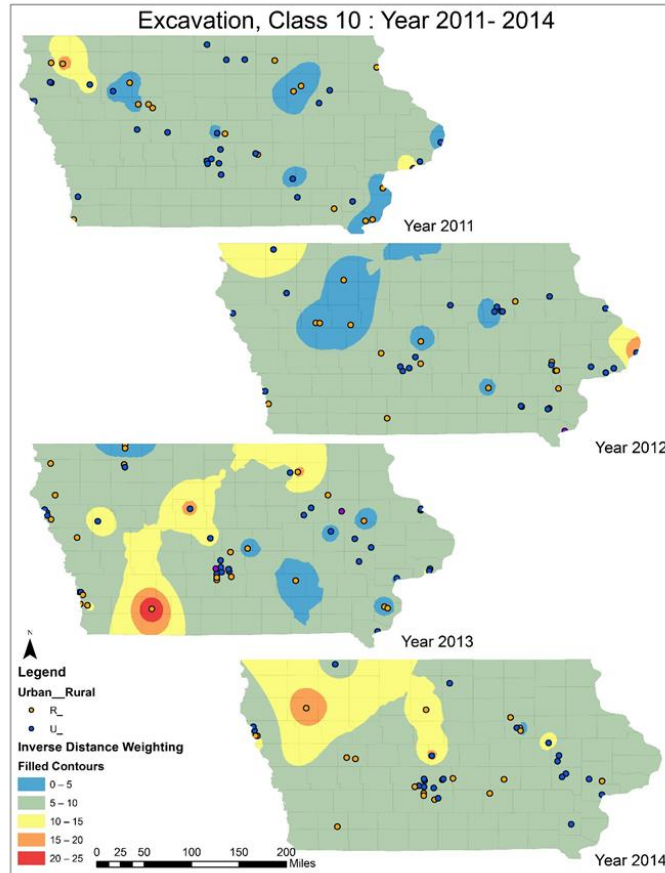
**Table 7 ANOVA test p value for excavation, class 10**

Year	P-value
2011	0.31
2012	0.003
2013	0.44
2014	0.82

All plots except for the year 2012 seem to be unaffected by the attribute under consideration. The year 2012 has unit prices of many urban projects greater than the rural and sub urban projects.

But when we see all other years 2011, 2013, and 2014 there is no such relationship seen between unit prices and the attribute.

The unit price interpolation was performed using IDW for the excavation, class 10 roadway and borrow item. Figure16 shows the result of interpolation surfaces and the points are labeled with unit prices. The blue data points show the urban projects, the orange points show rural project, and the purple points show sub-urban projects.

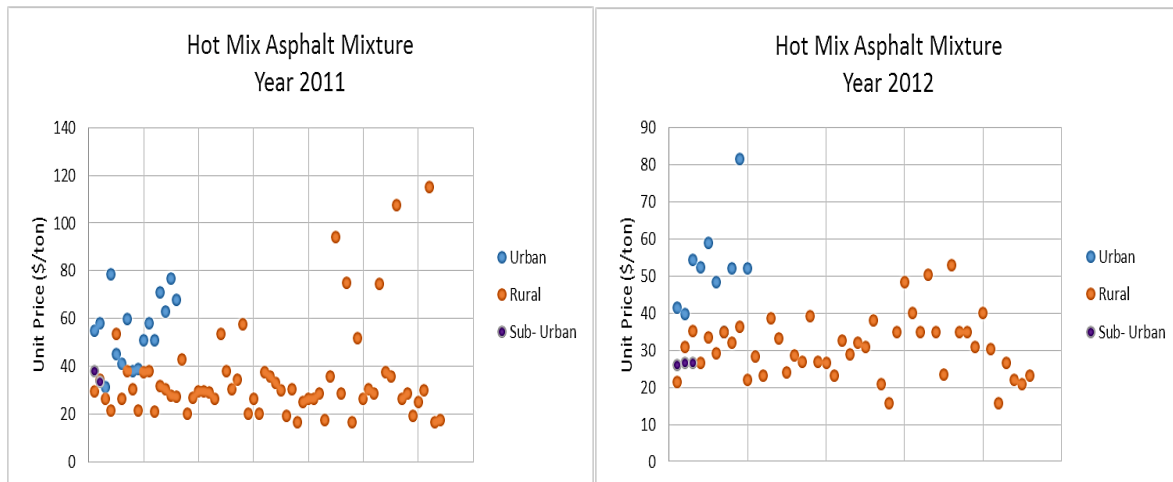


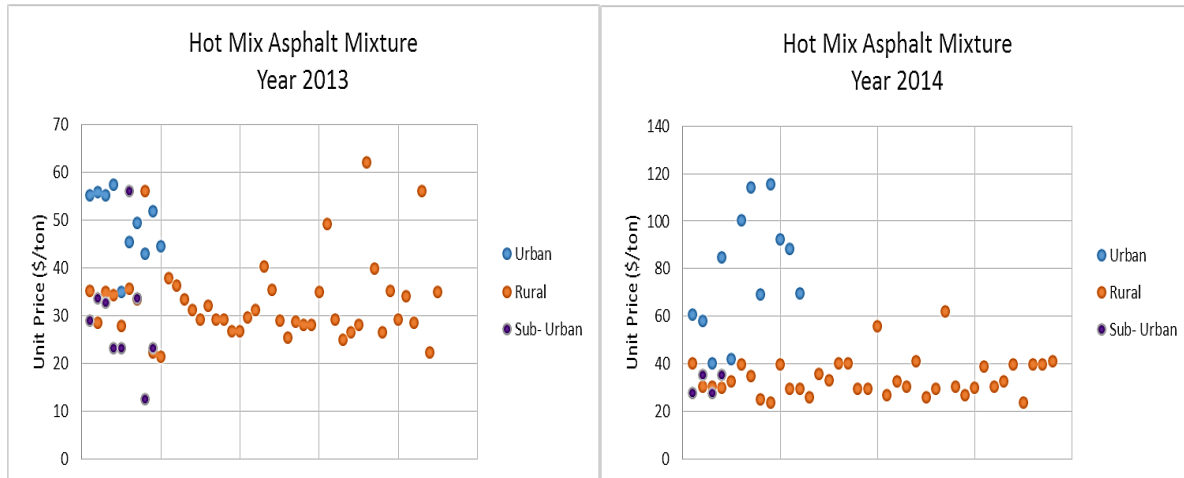
**Figure 16 IDW map color coded according to attribute**

As seen from Figure 16 there is no clear evidence that urban projects lead to higher costs compared to rural ones, as the urban projects have unit price as low as \$3 per cubic yard while rural projects have unit price as high as \$25 per cubic yard.

Hence, it can be concluded that the urban and rural setting of a project show very less evidence of relationship with unit price for excavation item and possible reasons for such behavior may be that the item is heavily dependent on quantity and has generally very large quantity of material. Its unit price is also heavily dependent on the location of the dumpsite of excavated material. If the dumpsite is near the excavation area, the transportation cost would be less, and if it is far away the cost of transportation will be high. These possible characteristics depend on very minute detail about the project site and are difficult to be quantified while performing unit price estimation of the item.

Another item which is considered in the study and shows consistent ANOVA results for all the years is the HMA mixture. Figure





**Figure 17** Color coded unit price data of HMA item for urban, rural, and sub-urban attribute

The P-value for all the years is insignificant and thereby we can conclude that a relationship exists between urban / rural attribute with unit price for this item. The possible reason for such behavior is that HMA mixture item significantly consists of installation costs which depend on regional wages and this may be the reason of unit prices showing a relationship with classification.

**Table 8** ANOVA test p- value for HMA item

Year	P-value
2011	0.000929
2012	0.0000694
2013	0.00000336
2014	0.000000000001723

### 5.3 Discussions

Overall, the Phase 1, 2, 3 and urban/rural analysis results show advancement over using pure judgment as the basis to quantify unit price based on location and provides a clear advantage of using IDW over other methods for interpolation and tests one of the easily available attribute on interesting items of PCC pavements. This advancement in using GIS has multiple uses apart

from aiding the estimators in quantifying unit prices for location factor. In any highway project public involvement and broad decision-making are very important aspects.

The area of asset management of highway projects can be one of the potential application of the interpolation maps. The decision of upcoming projects can be made if a major cost item has a lower cost in one particular region as compared to other using the approach followed to develop visual maps.



## CHAPTER VI

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Summary

The results obtained using GIS as a tool for spatial and temporal visualization of unit price data show that ArcMap platform is capable of performing powerful interpolation for unit prices. By using GIS it is possible to obtain unit price for any new location for which the data is not available from previous projects. It is also evident that the interactive geo-statistical layer of interpolation surface would facilitate obtaining unit price at any location by just clicking on it. But, GIS is a technology, and there is more to unit price estimation than just inserting values and obtaining results. It is required that all the factors that affect unit price be quantified by using the experience and judgment of an estimator and incorporated with technology. Together the quantification of factors along with GIS can lead to more certain cost estimation process.

#### 6.2 Conclusions

The ability to support the broader decision-making is one of the benefits of using a visualization technique to map unit price data in GIS. The visualization along with sound judgment of cost drivers should be incorporated to create powerful maps, which can also facilitate easy communication of project details to upper management.

The study shows the effect of quantity on unit price using weightage option of IDW interpolation and it is evident that using quantity or inverse of quantity as weight does not improve interpolation results and the inverse relationship of quantity versus unit price is absent in data used in the study.

The classification of urban, rural, and sub-urban projects according to location by DOT seems to show effect on some items while the unit price of others seems to be unaffected. This shows that each item has its unique complexity associated with it when it comes to unit price estimation.

This classification of projects is used by a lot of estimators to decide unit price and the study showed that it is not always true for the bid items analyzed that the classification has relation with unit prices.

### **6.3 Future Research**

It is recommended that future research in this area automate adjusting of variables and factors affecting unit price in GIS in order to facilitate easy use of ArcMap for DOT estimators. It is essential that the generation of these maps be automated while integrating with the DOT cost estimation process so that even a person with limited or no knowledge of GIS can input the data, as well as the cost drivers by using knowledge and experience to generate a better, more reliable, and more scientific estimation of unit prices.

Another possible interesting aspect to explore in highway unit price estimation would be to interpolate the unit price along the highway. Some tools available in GIS that have the capability to perform such analysis are proximity analysis using buffer, and network analysis. It will improve the utility of interpolation if cost data point that is more accessible to new location were given proper consideration while performing interpolation.

It is evident that unit price estimation for pay items is not dependent on a single variable but is affected by a lot of variables that need to be incorporated together to have a more scientific estimation. Any technology in use is driven by data rather than real life circumstances and project specific details. It is required that variables like quantity of material be studied and ranges of quantity that have no effect on unit price be identified and documented to improve scope of further data analysis and visualization.

Future studies should consider the use of additional spatial cost influencers such as location of asphalt plants, number of bidders likely to bid in a project in a given location, etc. and other cost influencers to improve the cost certainty.

The limitation of the study is that the overwhelming historical bid database does not have easy to use data attributes which can be utilized to data mine and study the real factors that are used to determine the unit price. There is a need to quantify the major cost drivers and incorporate in data collection procedure in such a way that they can be quickly utilized by DOT estimators to be incorporated along with use of powerful advancements like GIS.

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## APPENDIX A: HISTOGRAMS, NORMAL QUANTILE, AND TREND ANALYSIS RESULTS

### ASPHALT BINDER 58-28

Year 2011

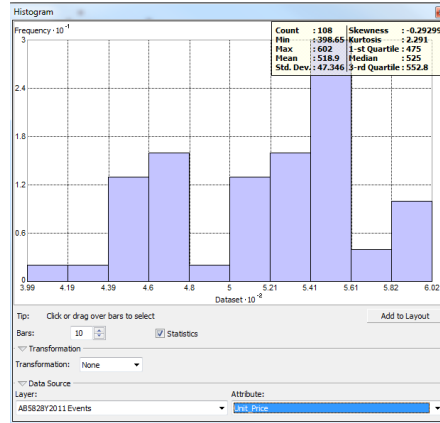


Figure 18 Histogram for Asphalt Binder 58-28, Year 2011

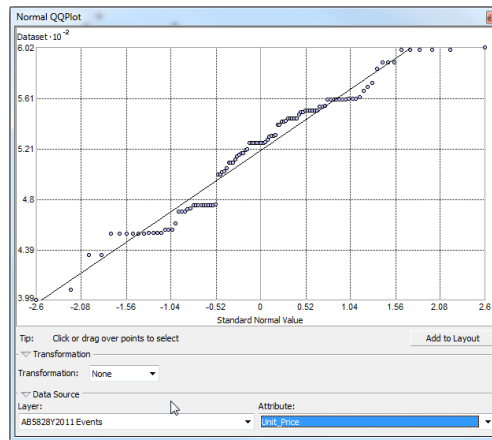


Figure 19 Normal Quantile for Asphalt Binder 58-28, Year 2011

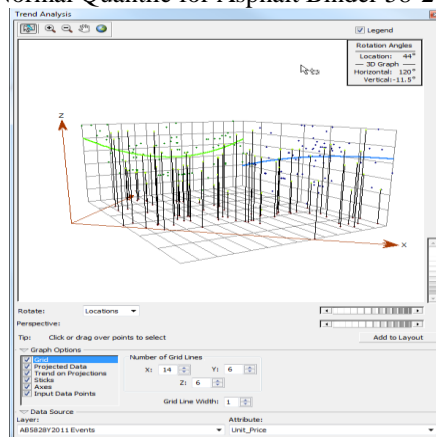


Figure 20 Trend Analysis for Asphalt Binder 58-28, Year 2011



Year 2012

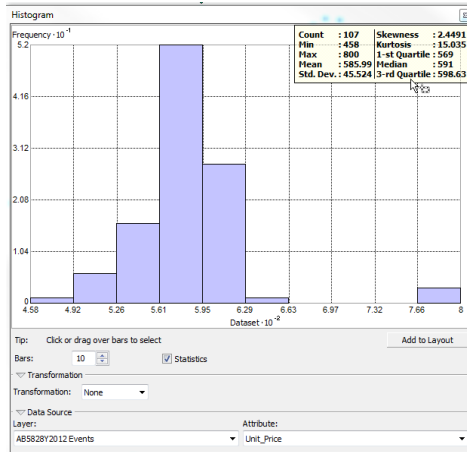


Figure 21 Histogram for Asphalt Binder 58-28, Year 2012

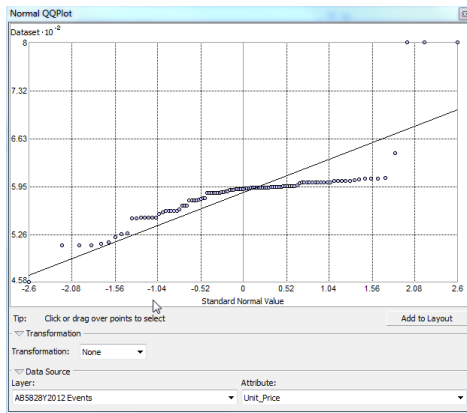


Figure 22 Normal Quantile for Asphalt Binder 58-28, Year 2012

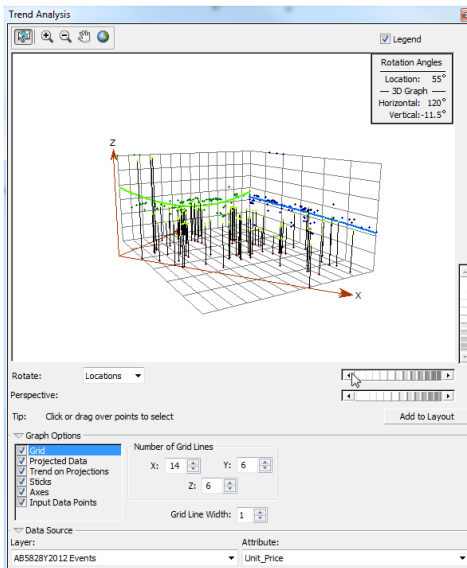


Figure 23 Trend Analysis for Asphalt Binder 58-28, Year 2012

Year 2013

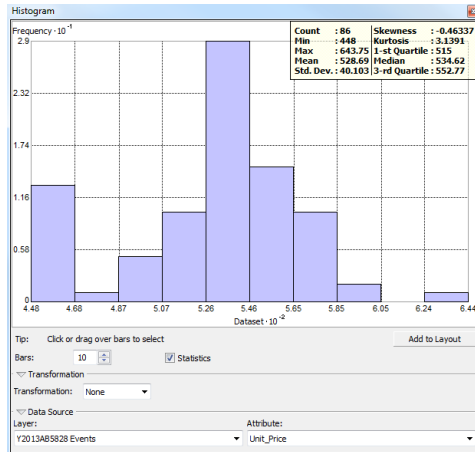


Figure 24 Histogram for Asphalt Binder 58-28, Year 2013

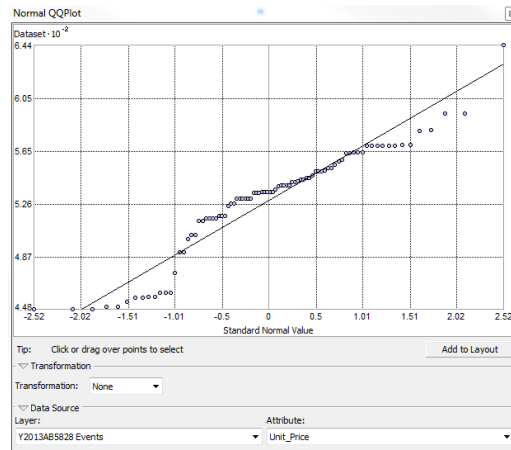


Figure 25 Normal Quantile for Asphalt Binder 58-28, Year 2013

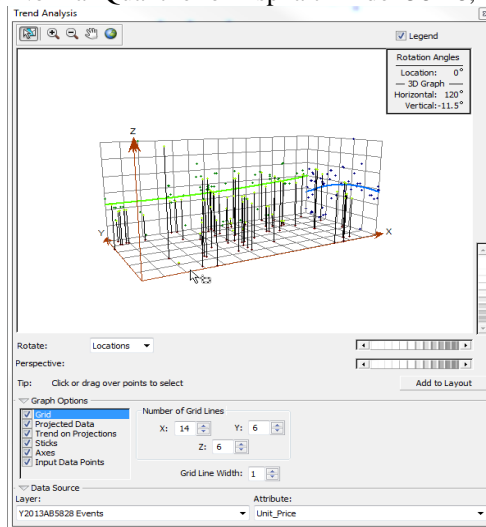


Figure 26 Trend Analysis for Asphalt Binder 58-28, Year 2013

Year 2014

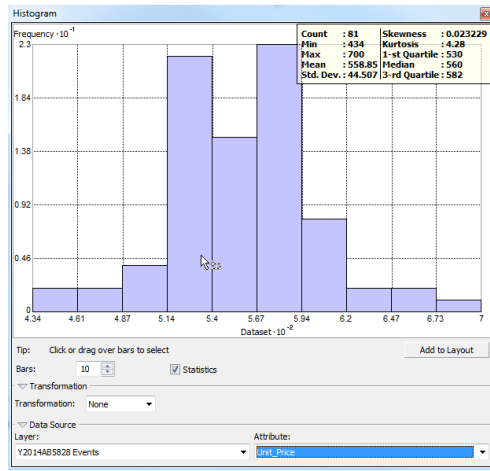


Figure 27 Histogram for Asphalt Binder 58-28, Year 2014

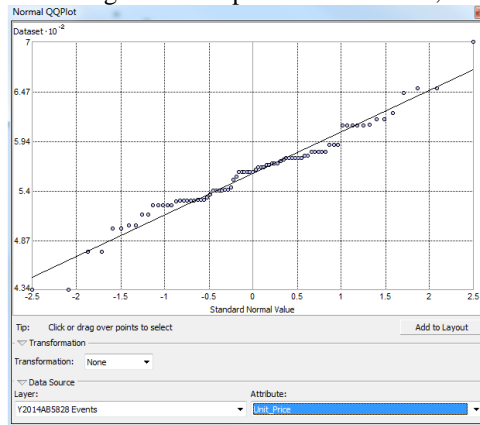


Figure 28 Normal Quantile for Asphalt Binder 58-28, Year 2014

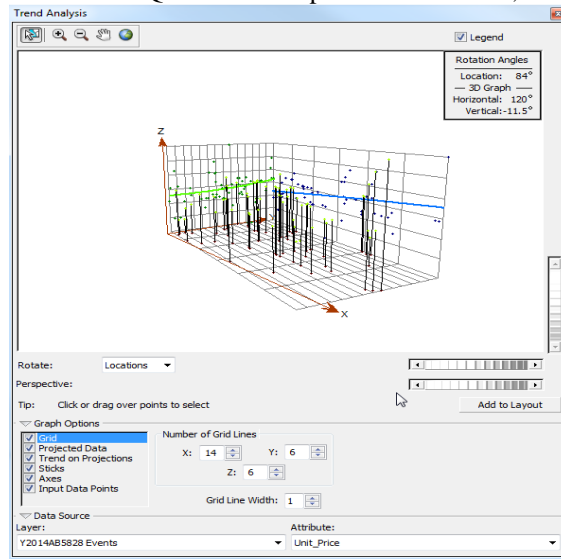


Figure 29 Trend Analysis for Asphalt Binder 58-28, Year 2014

ASPHALT BINDER 64-22

Year 2011

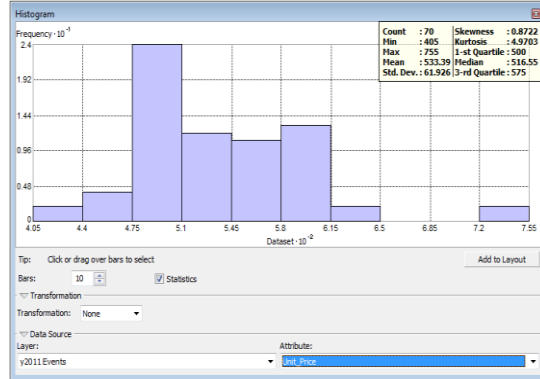


Figure 30 Histogram for asphalt binder 64-22, year 2011

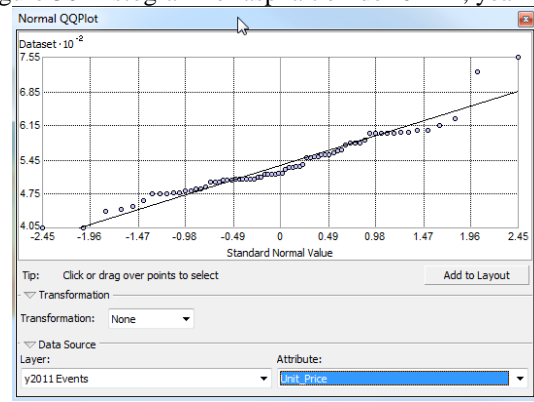


Figure 31 Normal Quantile for asphalt binder 64-22, year 2011

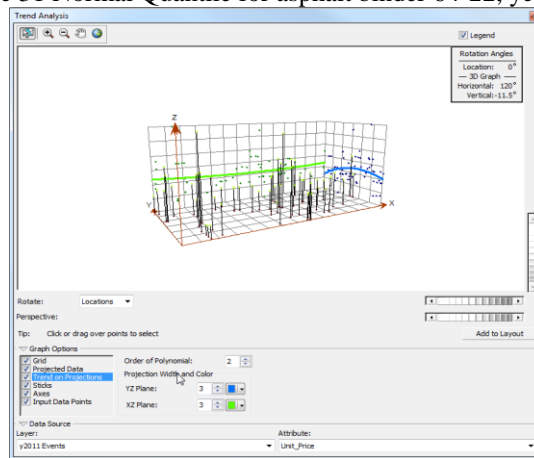


Figure 32 Trend analysis for asphalt binder 64-22, year 2011

Year 2012

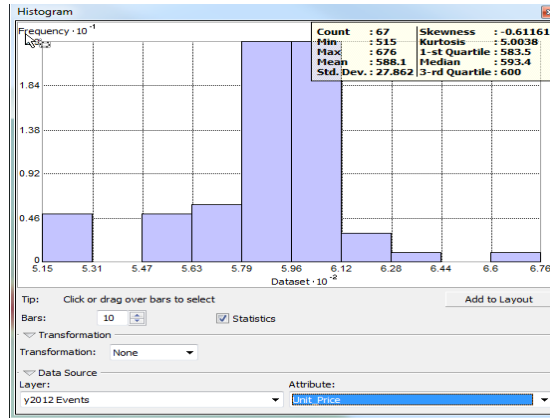


Figure 33 Histogram for asphalt binder 64-22, year 2012

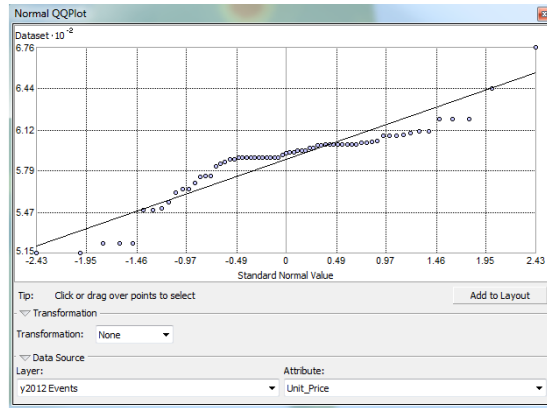


Figure 34 Normal Quantile for asphalt binder 64-22, year 2012

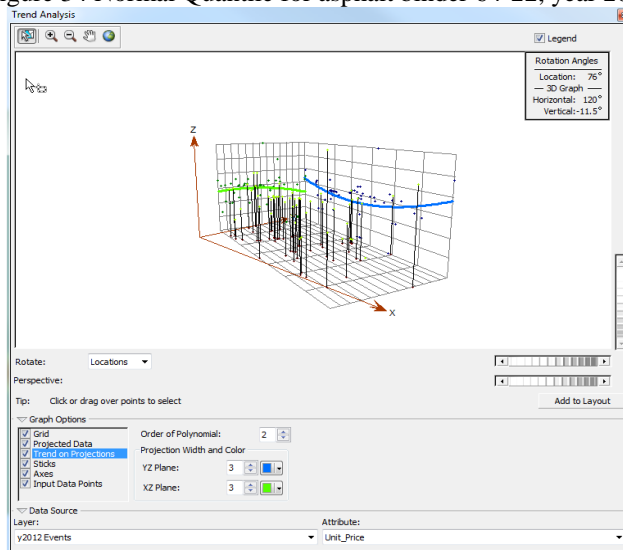


Figure 35 Trend analysis for asphalt binder 64-22, year 2012

Year 2013

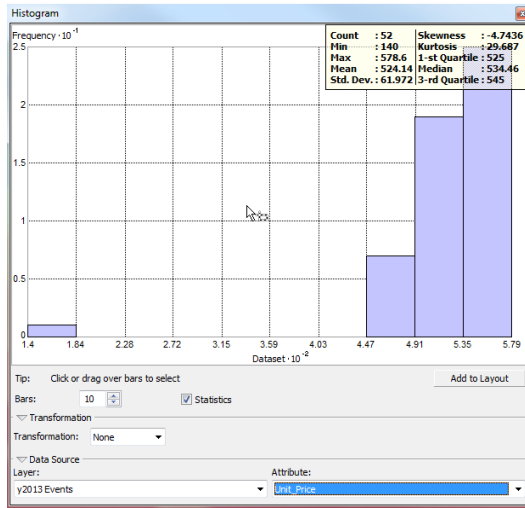


Figure 36 Histogram for asphalt binder 64-22, year 2013

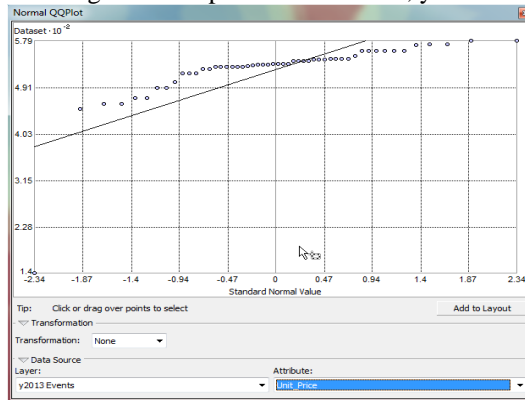


Figure 37 Normal Quantile for asphalt binder 64-22, year 2013

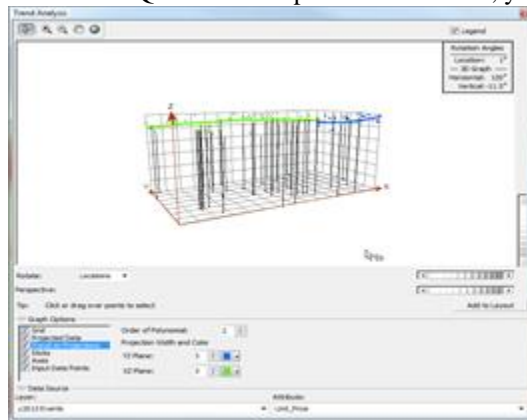


Figure 38 Trend analysis for asphalt binder 64-22, year 2013

Year 2014

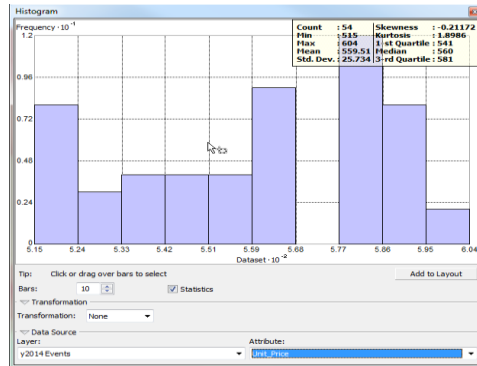


Figure 39 Histogram for asphalt binder 64-22, year 2014

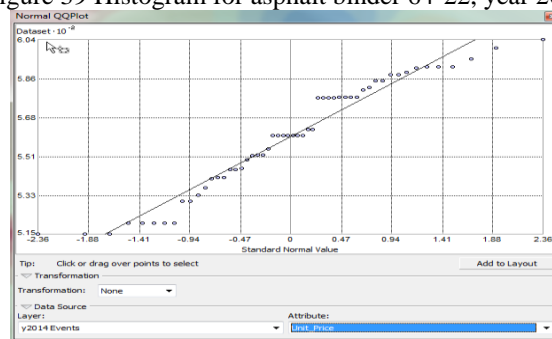


Figure 40 Normal Quantile for asphalt binder 64-22, year 2014

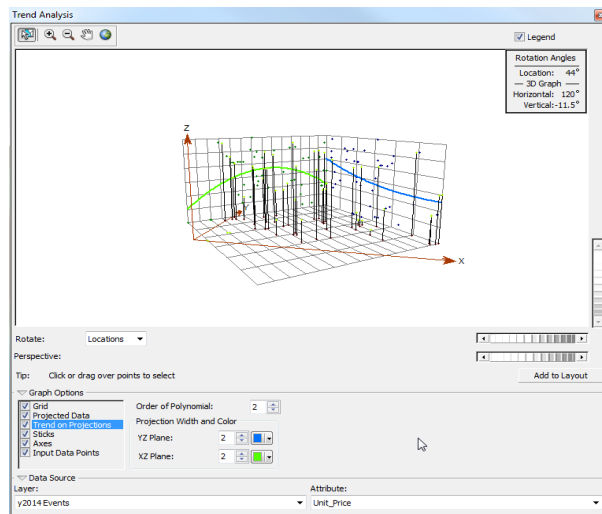


Figure 41 Trend analysis for asphalt binder 64-22, year 2014

## HOT MIX ASPHALT MIXTURE (ESAL 1,000,000) SURFACE COURSE

Year 2011

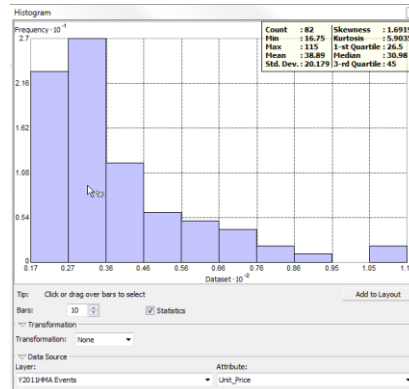


Figure 42 Histogram for Hot Mix Asphalt Mixture Surface Course, year 2011

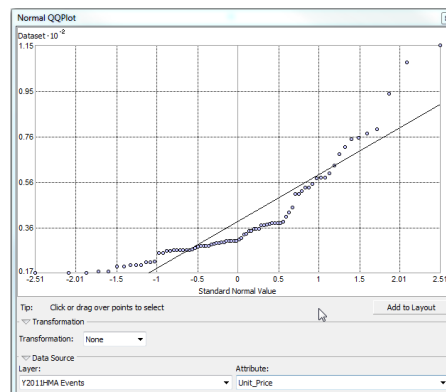


Figure 43 Normal Quantile for Hot Mix Asphalt Mixture Surface Course, year 2011

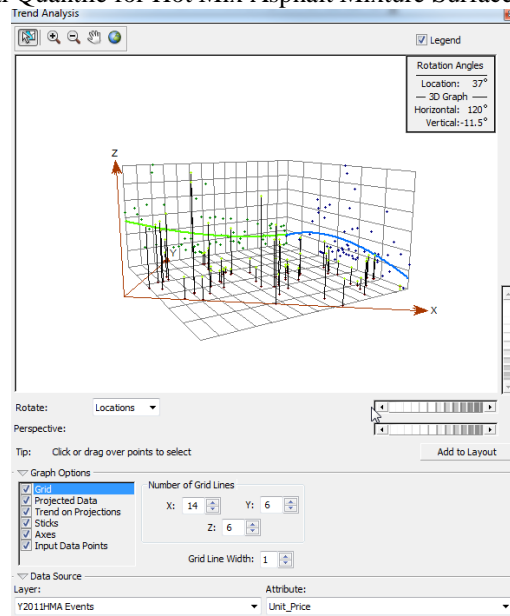


Figure 44 Trend analysis for Hot Mix Asphalt Mixture Surface Course, year 2011



Year 2012

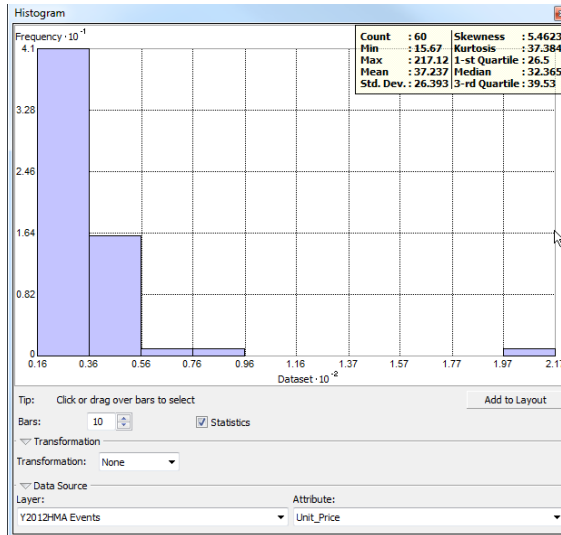


Figure 45 Histogram for Hot Mix Asphalt Mixture Surface Course, year 2012

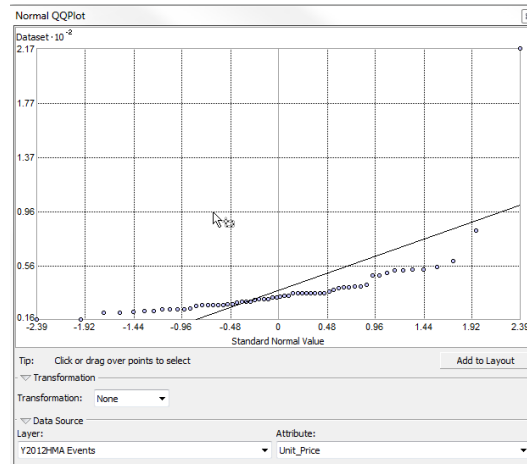


Figure 46 Normal Quantile for Hot Mix Asphalt Mixture Surface Course, year 2012

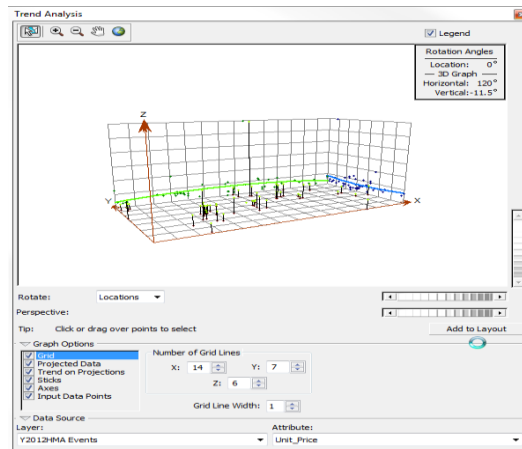


Figure 47 Trend analysis for Hot Mix Asphalt Mixture Surface Course, year 2012

Year 2013

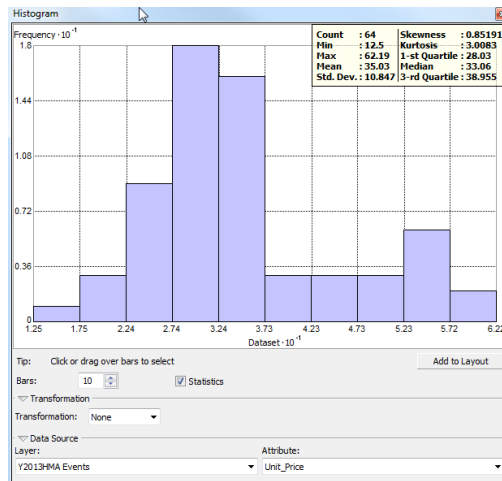


Figure 48 Histogram for Hot Mix Asphalt Mixture Surface Course, year 2013

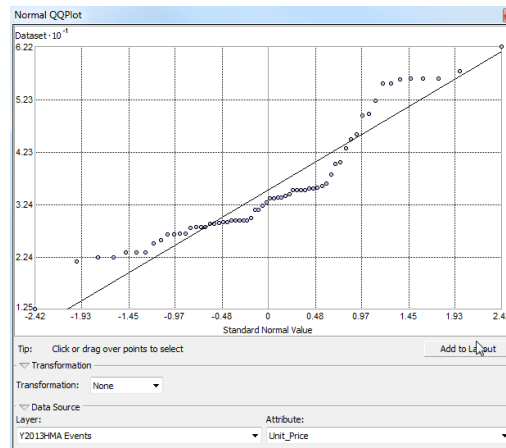


Figure 49 Normal Quantile for Hot Mix Asphalt Mixture Surface Course, year 2013

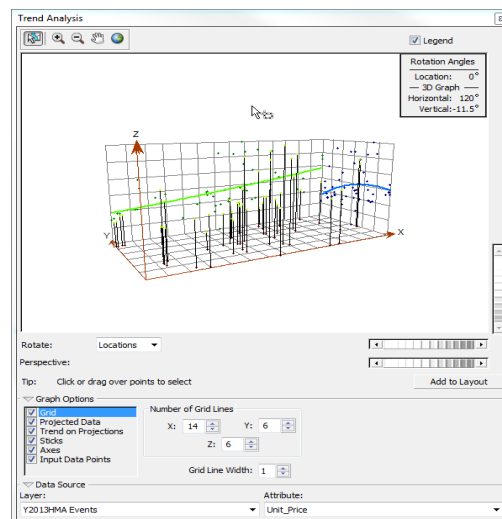


Figure 50 Trend analysis for Hot Mix Asphalt Mixture Surface Course, year 2013

Year 2014

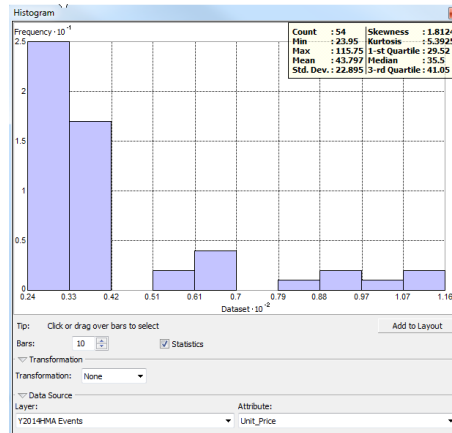


Figure 51 Histogram for Hot Mix Asphalt Mixture Surface Course, year 2014

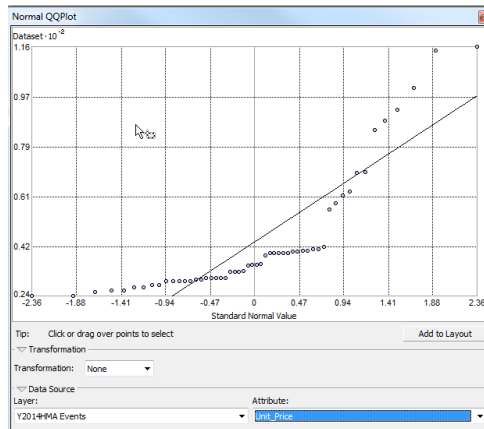


Figure 52 Normal Quantile for Hot Mix Asphalt Mixture Surface Course, year 2014

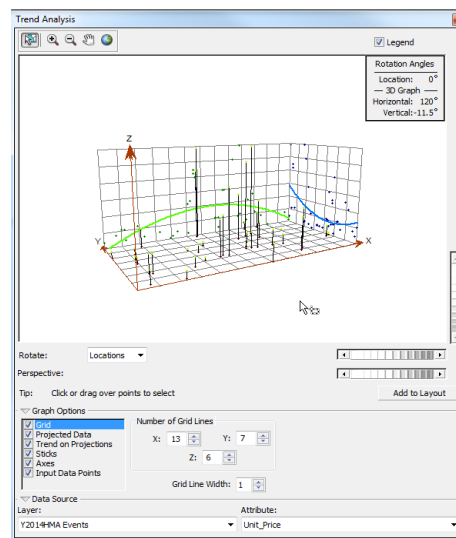


Figure 53 Trend analysis for Hot Mix Asphalt Mixture Surface Course, year 2014

# STANDARD PORTLAND CEMENT CONCRETE

Year 2011

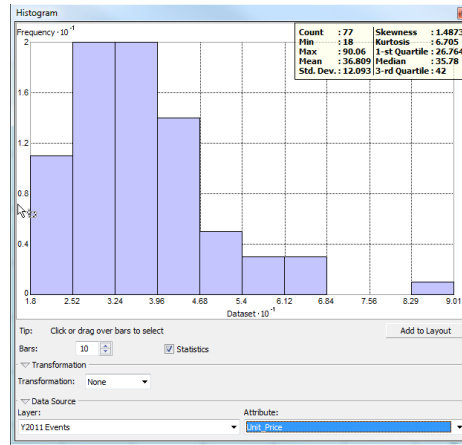


Figure 54 Histogram for Standard Portland cement concrete, year 2011

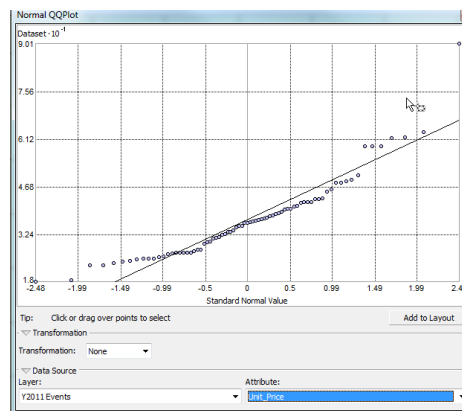


Figure 55 Normal Quantile for Standard Portland cement concrete, year 2011

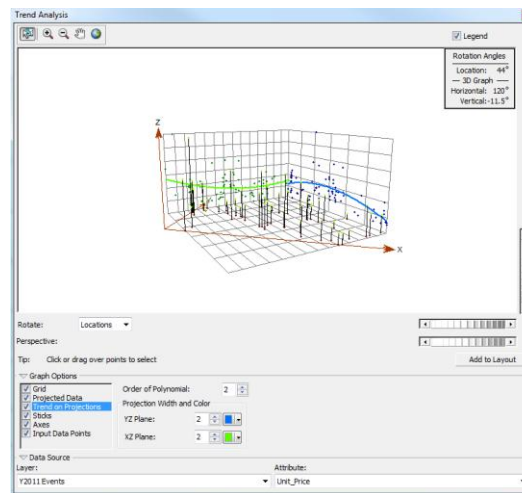


Figure 56 Trend analysis for Standard Portland cement concrete, year 2011

Year 2012

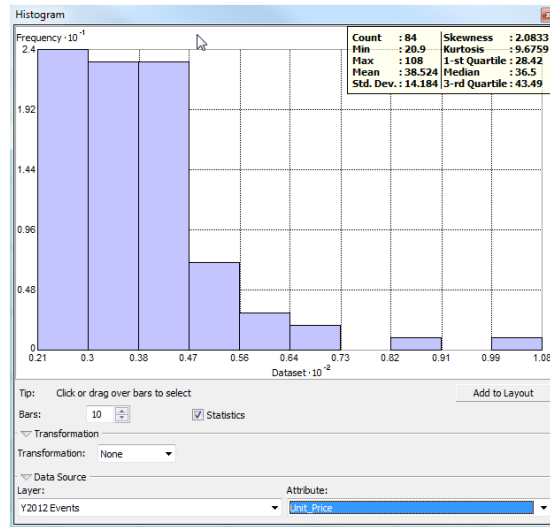


Figure 57 Histogram for Standard Portland cement concrete, year 2012

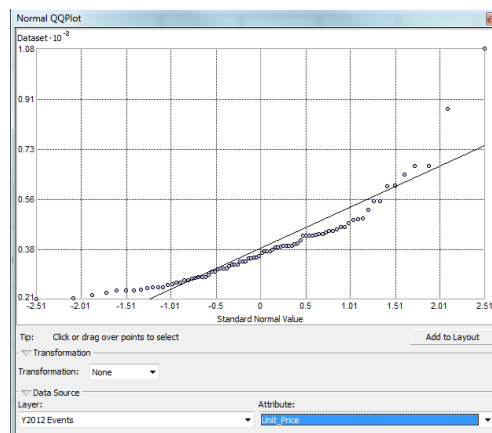


Figure 58 Normal Quantile for Standard Portland cement concrete, year 2012

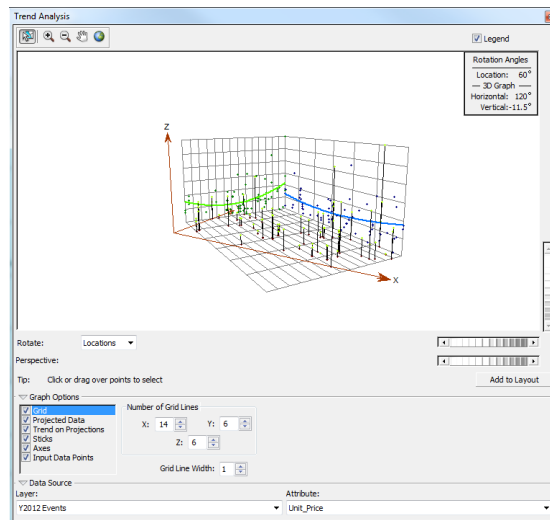


Figure 59 Trend analysis for Standard Portland cement concrete, year 2012

Year 2013

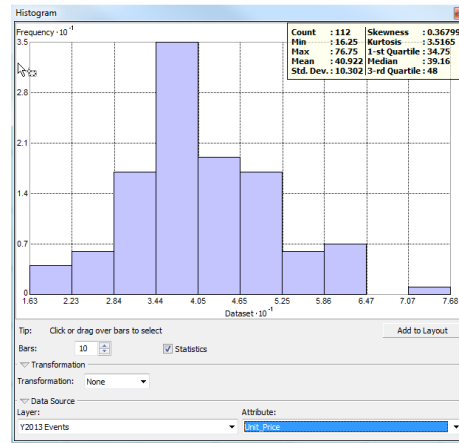


Figure 60 Histogram for Standard Portland cement concrete, year 2013

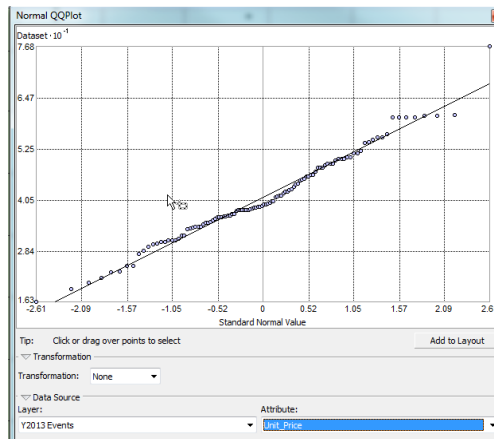


Figure 61 Normal Quantile for Standard Portland cement concrete, year 2013

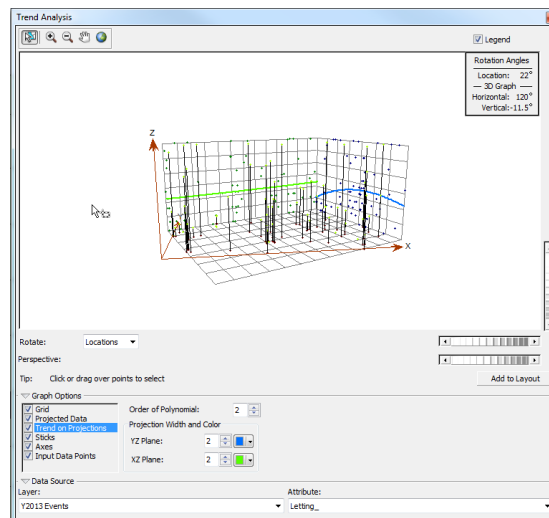


Figure 62 Trend analysis for Standard Portland cement concrete, year 2013

Year 2014

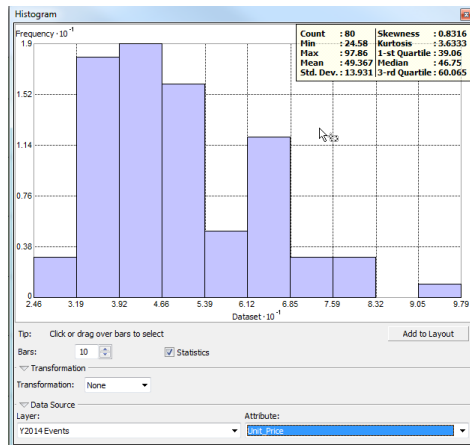


Figure 63 Histogram for Standard Portland cement concrete, year 2014

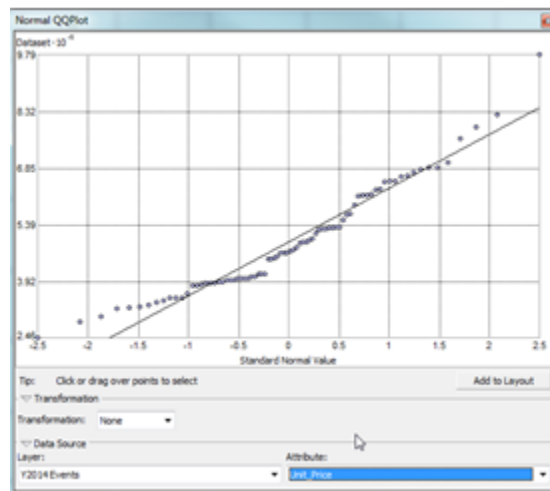


Figure 64 Normal Quantile for Standard Portland cement concrete, year 2014

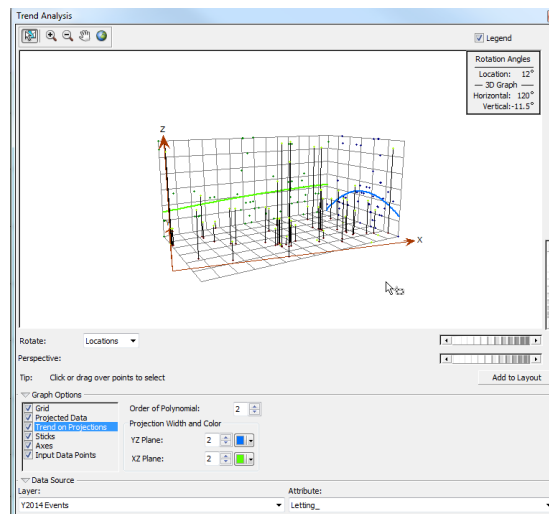


Figure 65 Trend analysis for Standard Portland cement concrete, year 2014

## EXCAVATION CLASS 10 ROADWAY AND BORROW

Year 2011

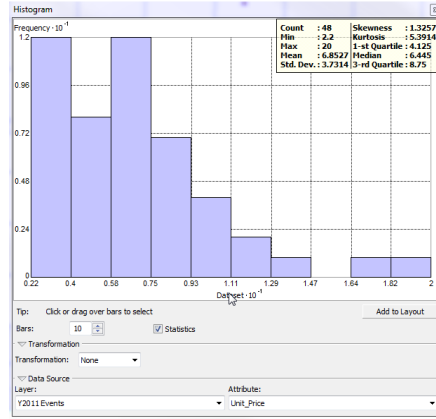


Figure 66 Histogram for Excavation class 10 roadway and borrow, year 2011

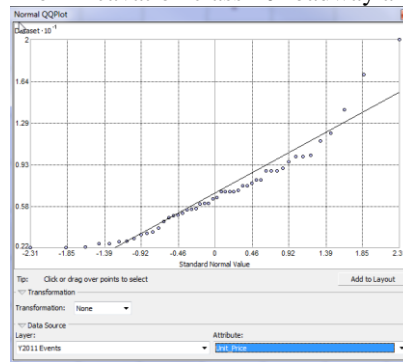


Figure 67 Normal Quantile for Excavation class 10 roadway and borrow, year 2011

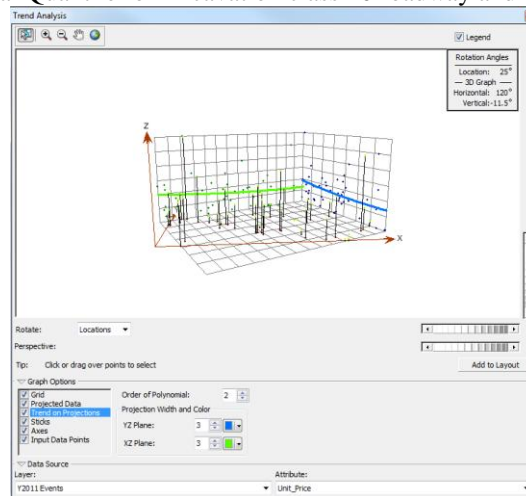


Figure 68 Trend analysis for Excavation class 10 roadway and borrow, year 2011



Year 2012

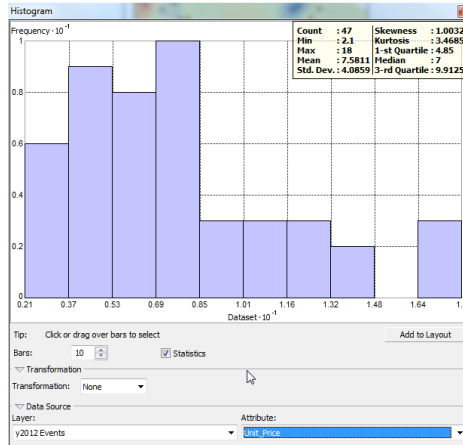


Figure 69 Histogram for Excavation class 10 roadway and borrow, year 2012

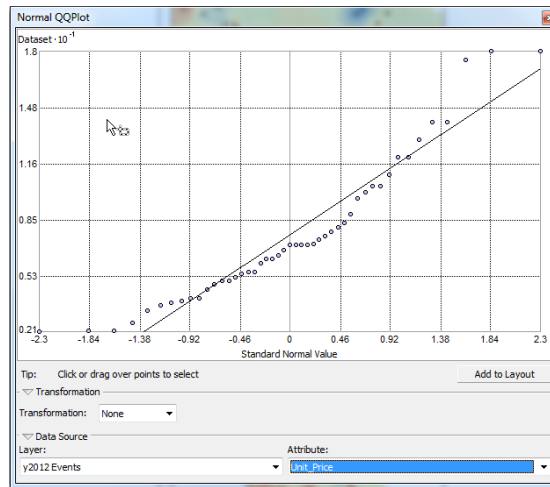


Figure 70 Normal Quantile for Excavation class 10 roadway and borrow, year 2012

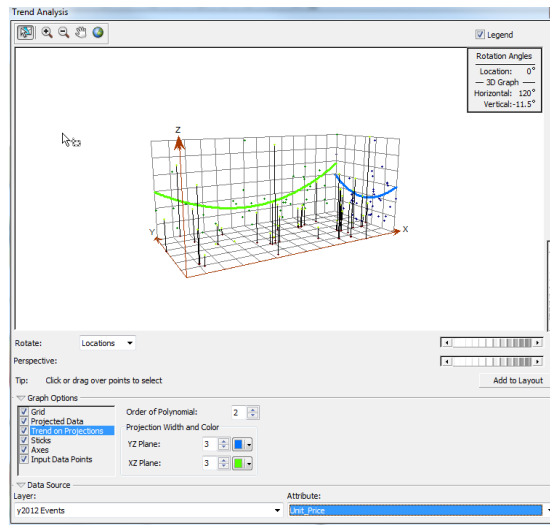


Figure 71 Trend analysis for Excavation class 10 roadway and borrow, year 2012

Year 2013

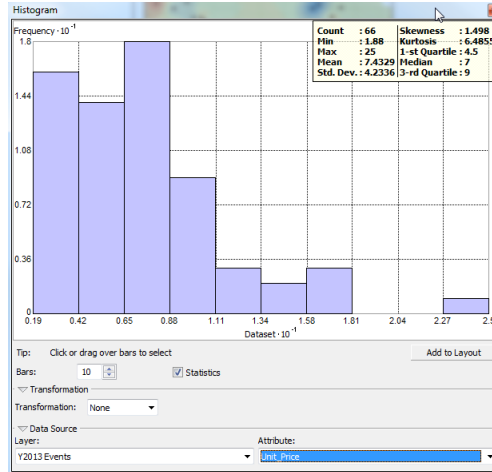


Figure 72 Histogram for Excavation class 10 roadway and borrow, year 2013

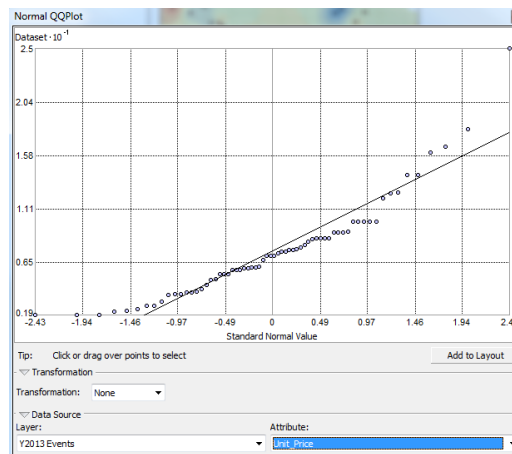


Figure 73 Normal Quantile for Excavation class 10 roadway and borrow, year 2013

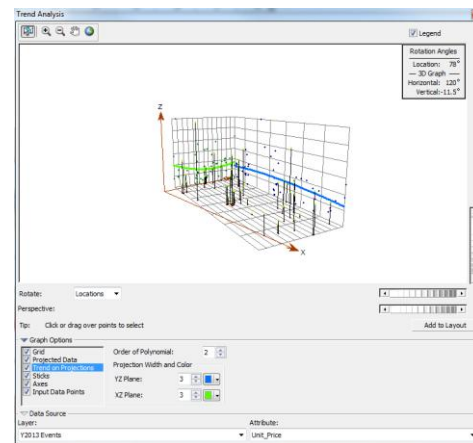


Figure 74 Trend analysis for Excavation class 10 roadway and borrow, year 2013

Year 2014

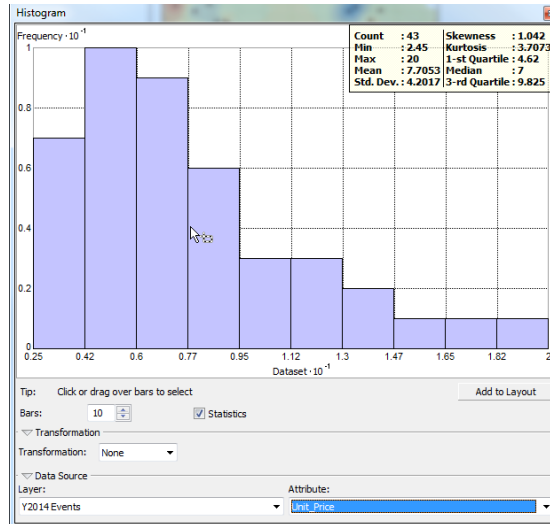


Figure 75 Histogram for Excavation class 10 roadway and borrow, year 2014

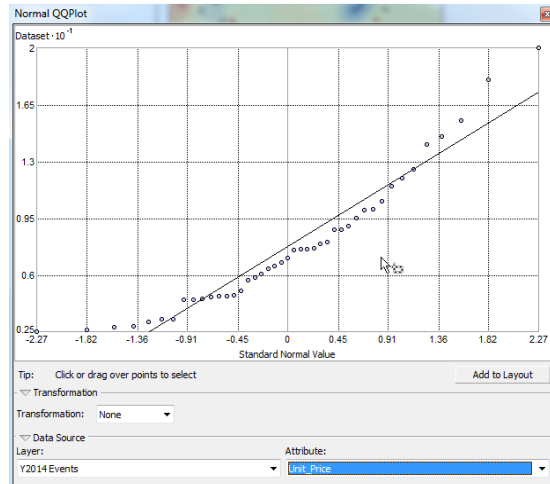


Figure 76 Normal Quantile for Excavation class 10 roadway and borrow, year 2014

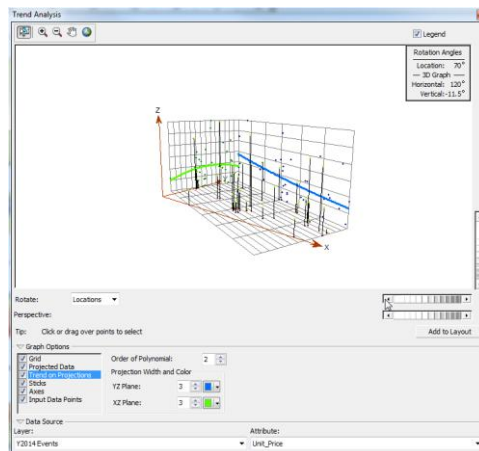
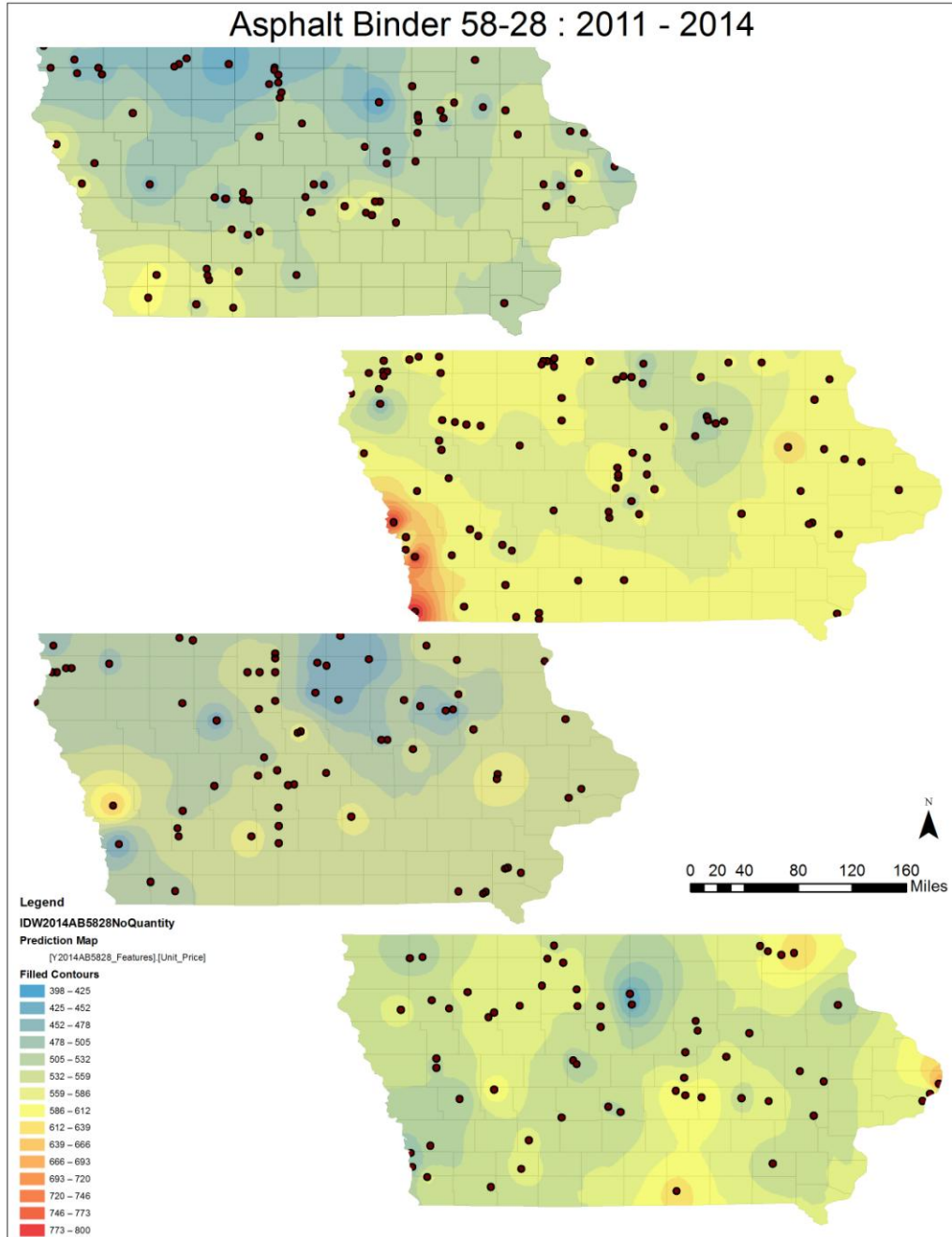


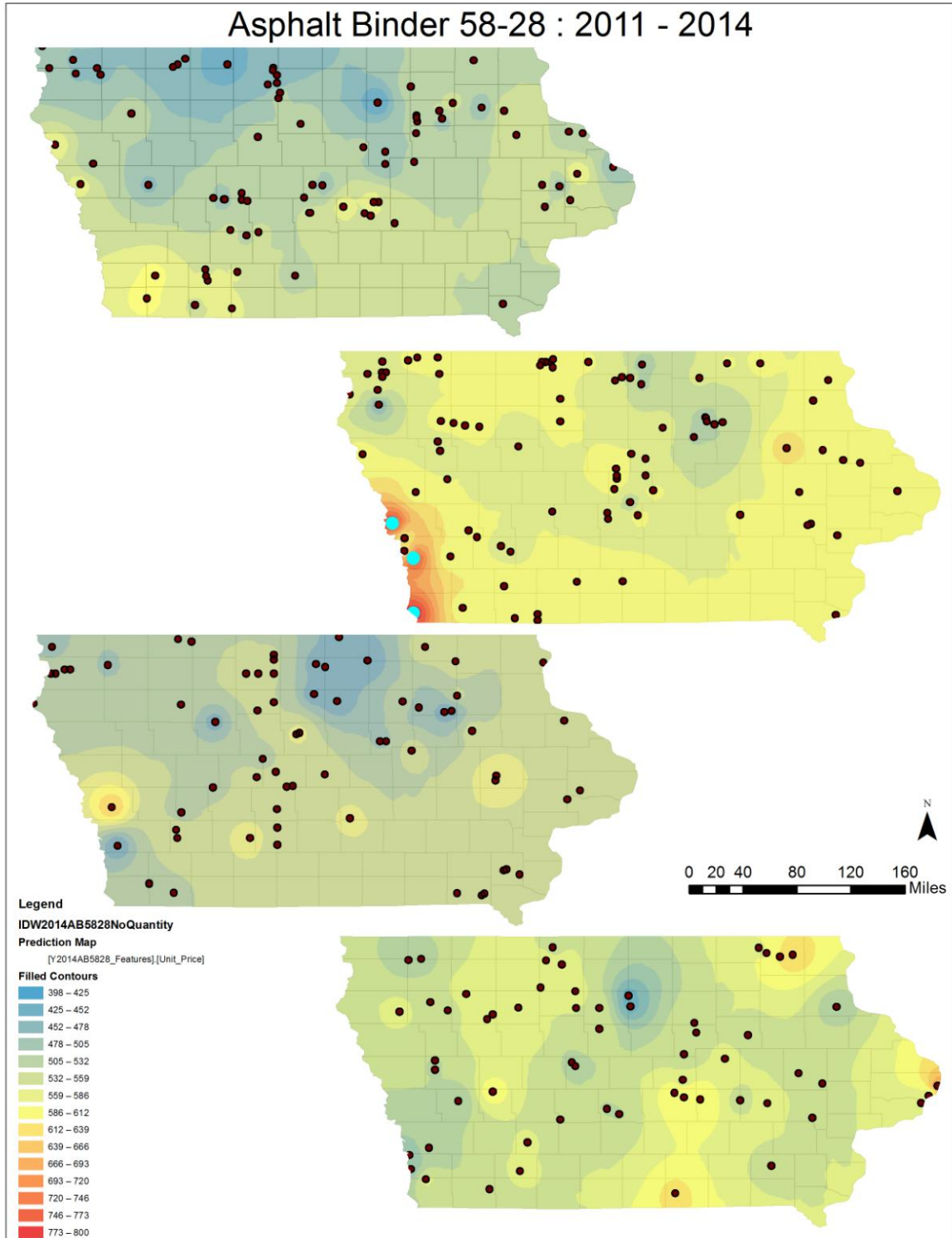
Figure 77 Trend analysis for Excavation class 10 roadway and borrow, year 2014

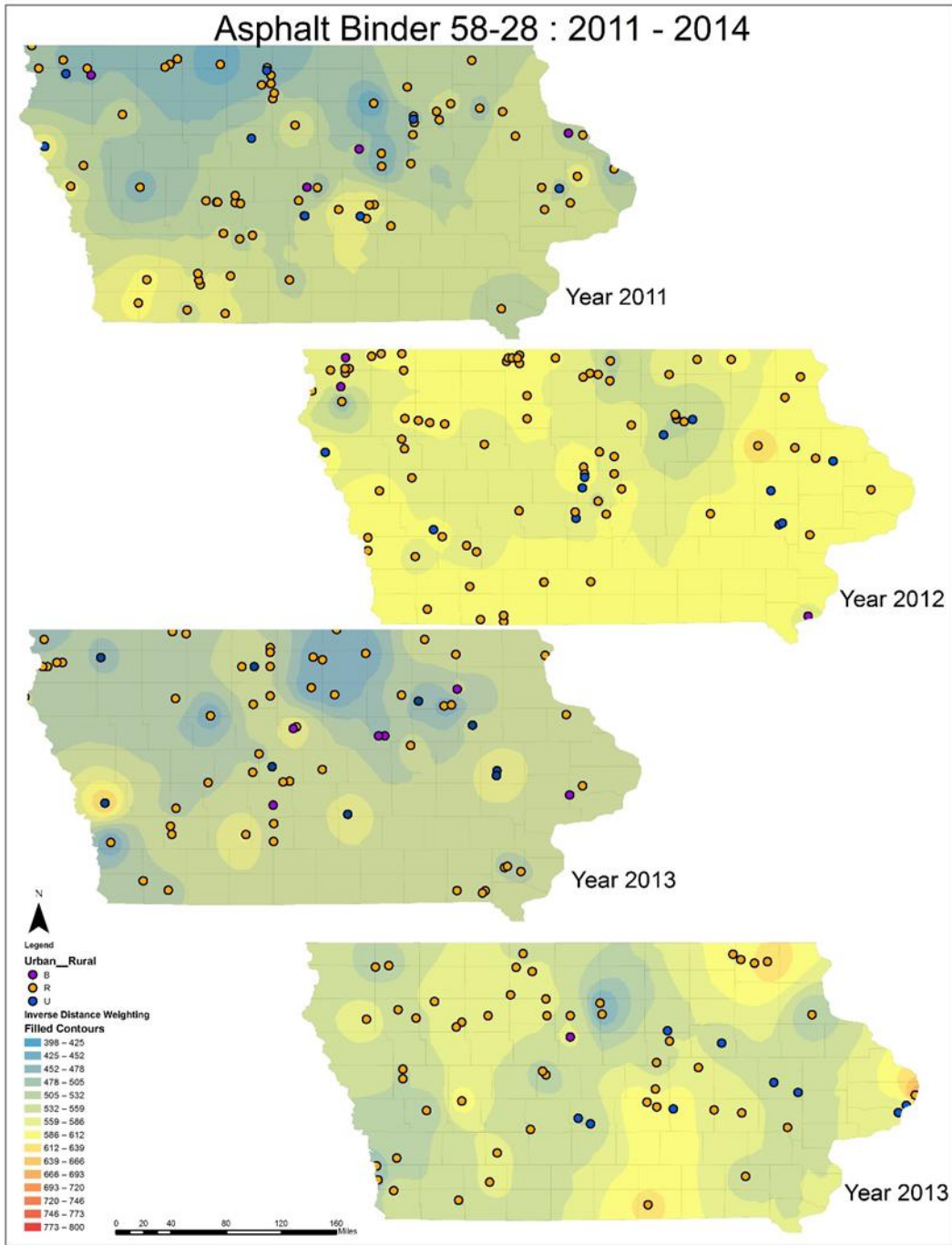
### APPENDIX B: PHASE 1, PHASE 2, AND PHASE 3 RESULTS

#### ASPHALT BINDER 58 28

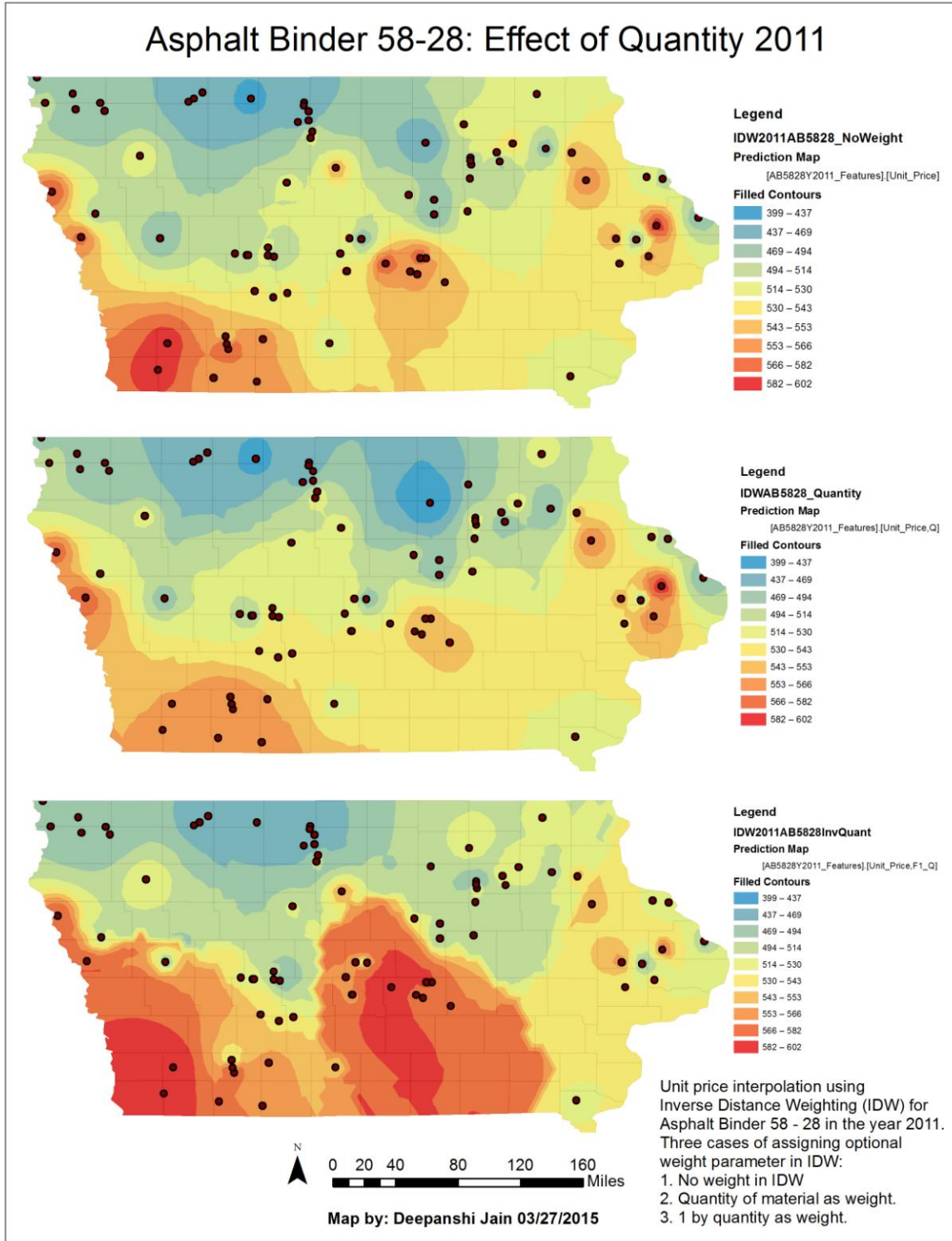
##### Phase 1 Results



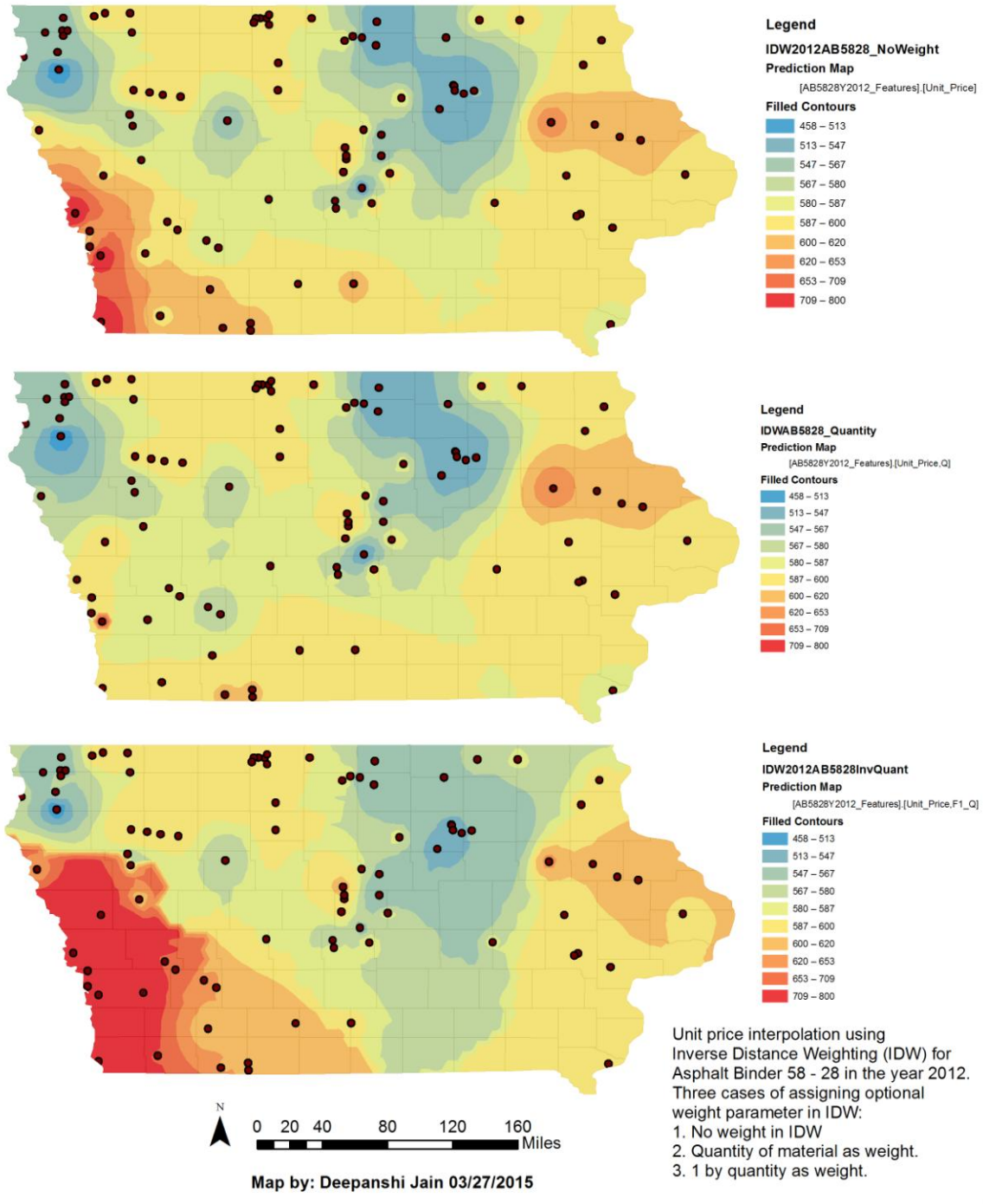




Phase 2 Results

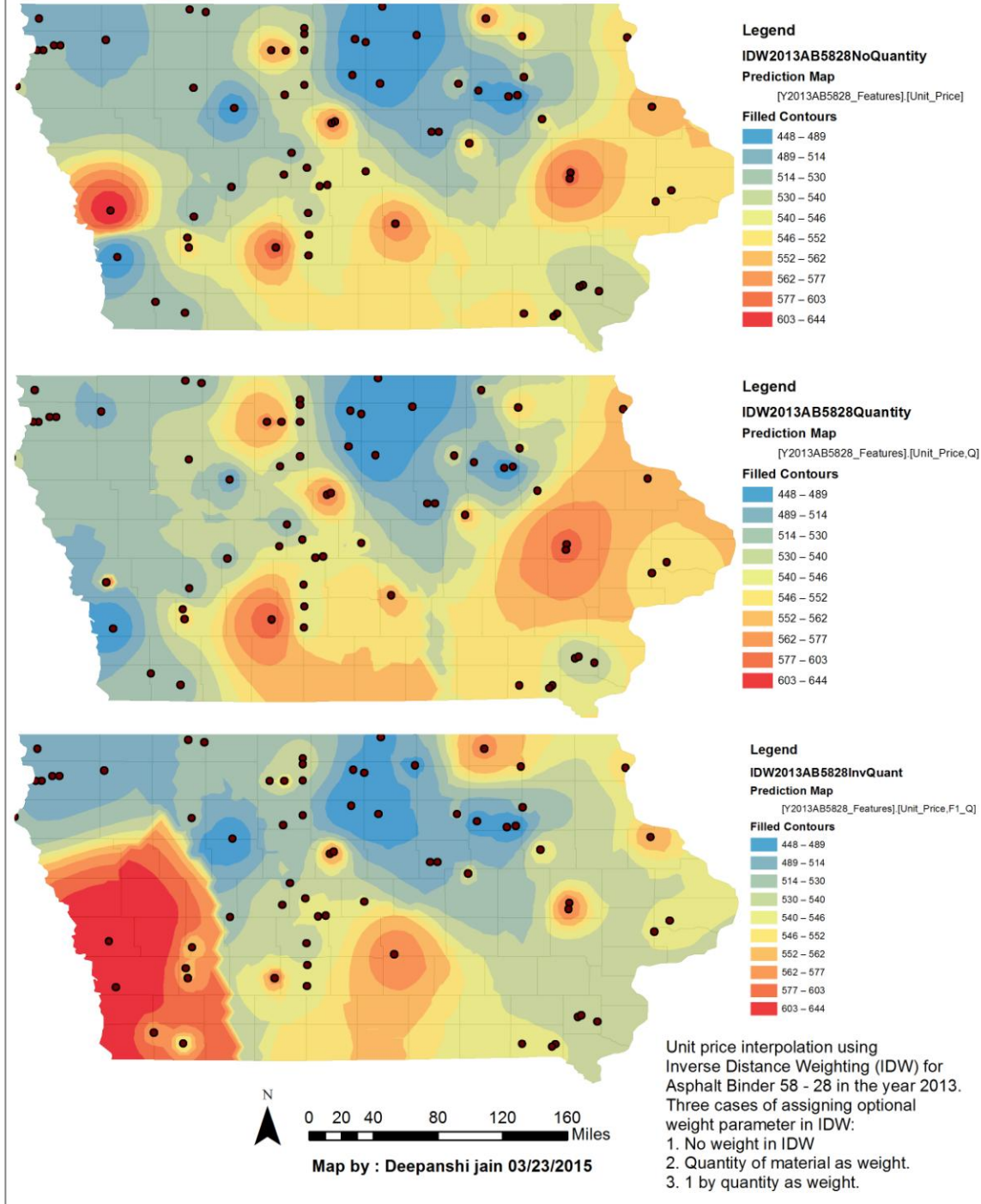


## Asphalt Binder 58 - 28: Effect of Quantity 2012

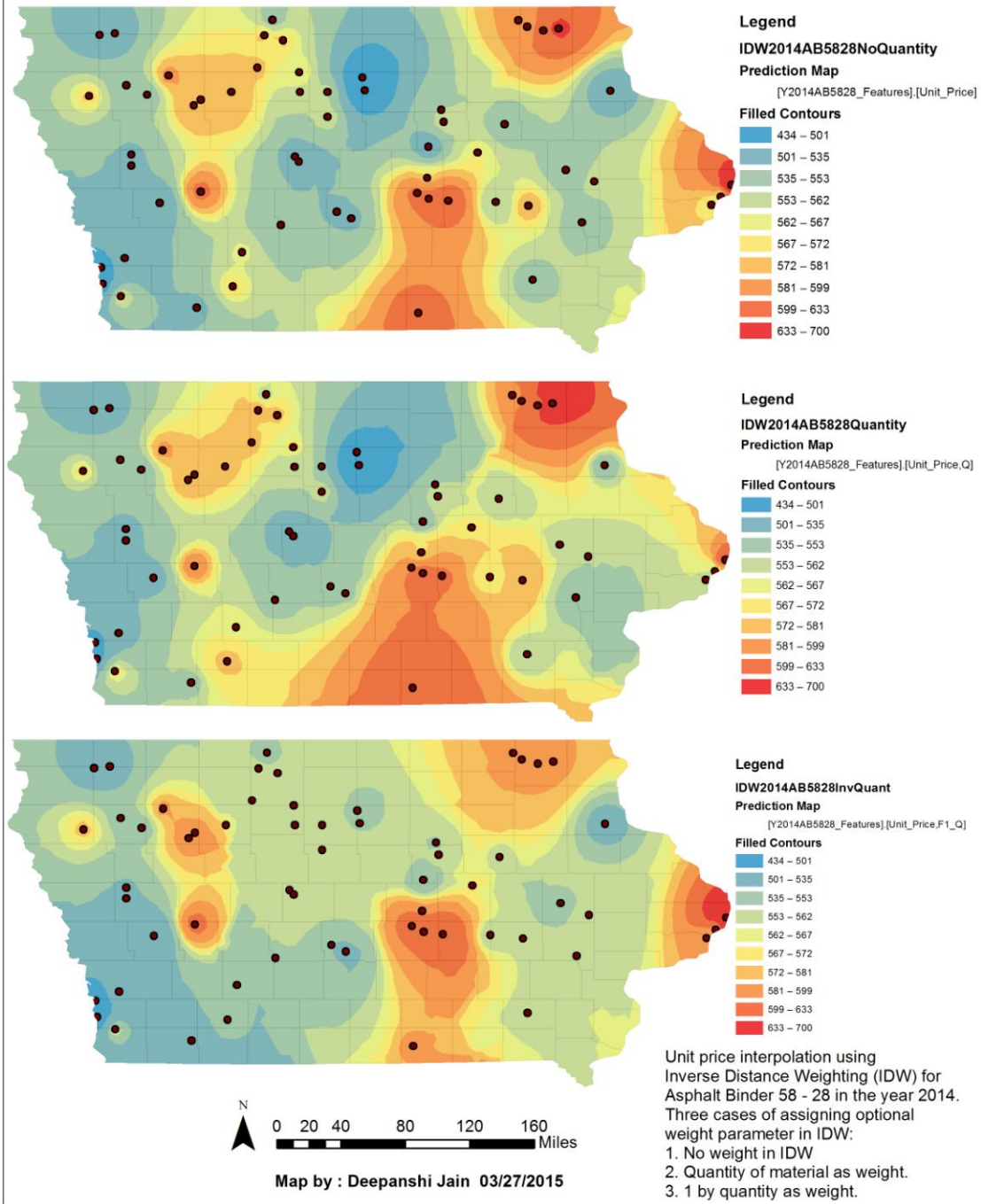


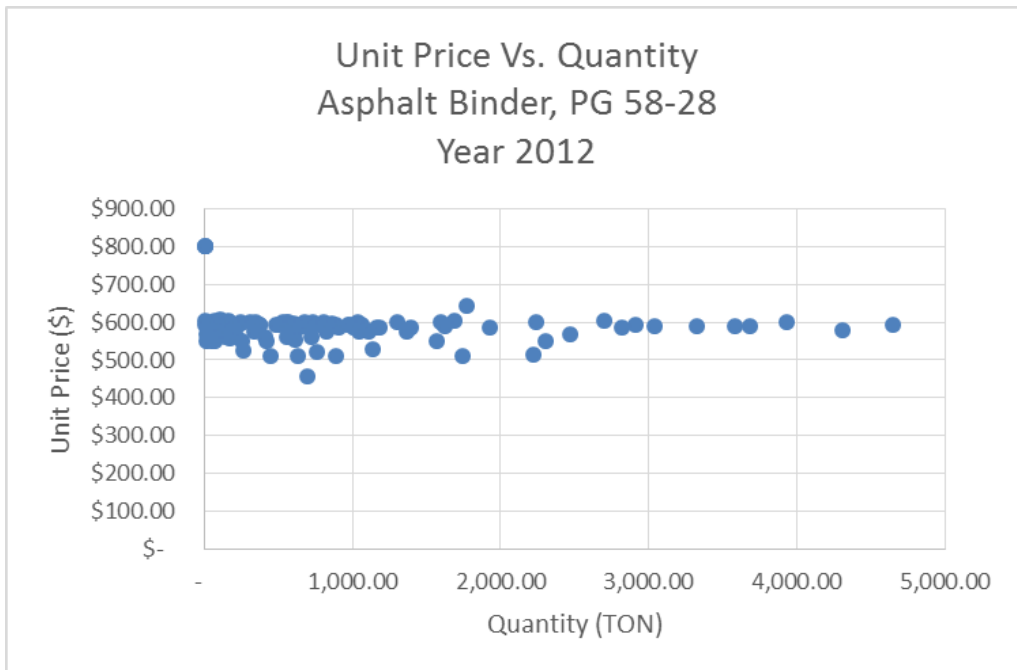
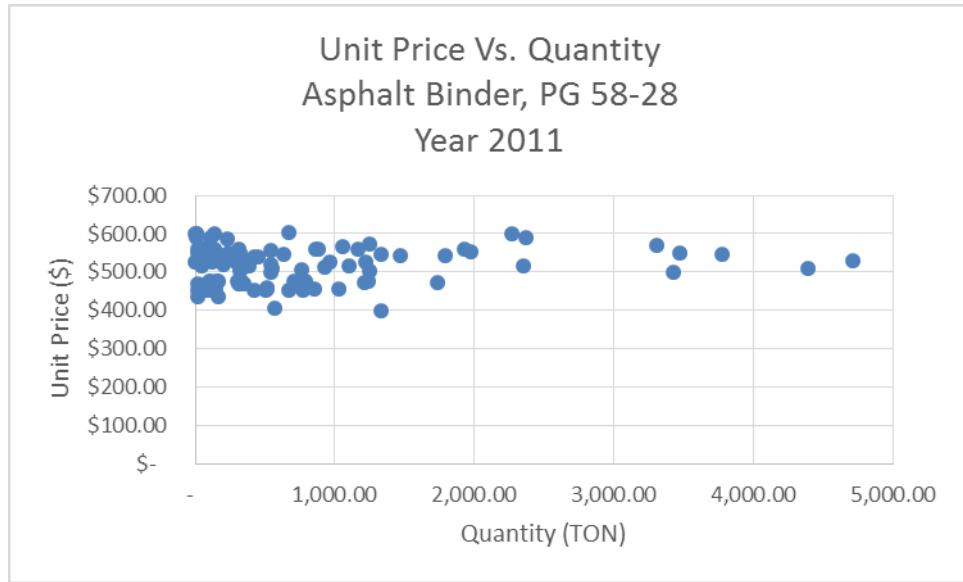


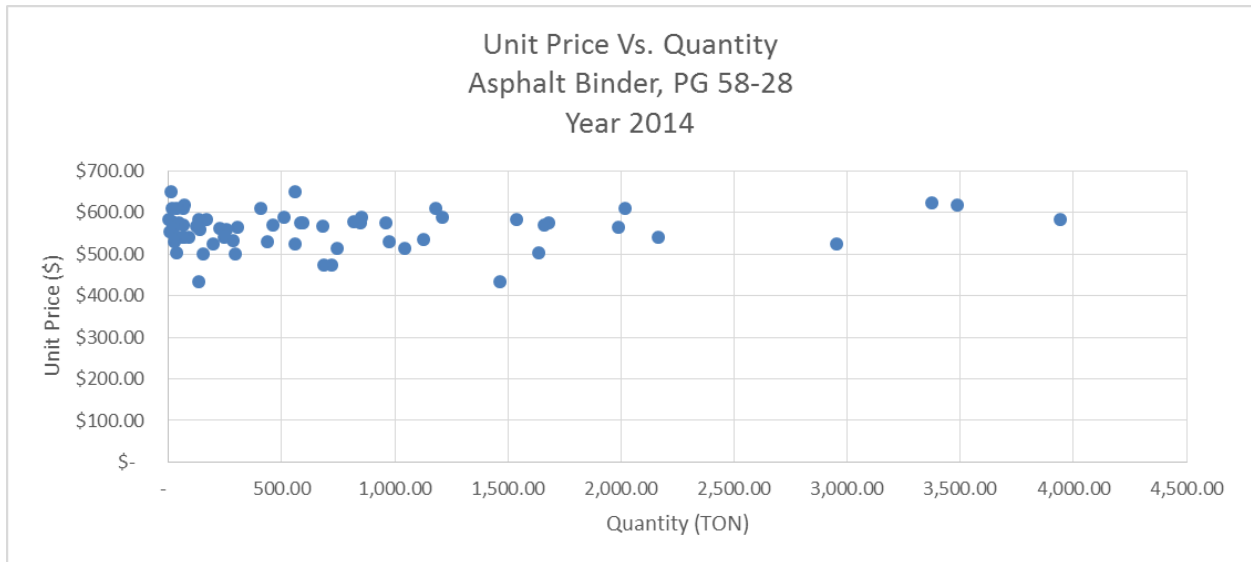
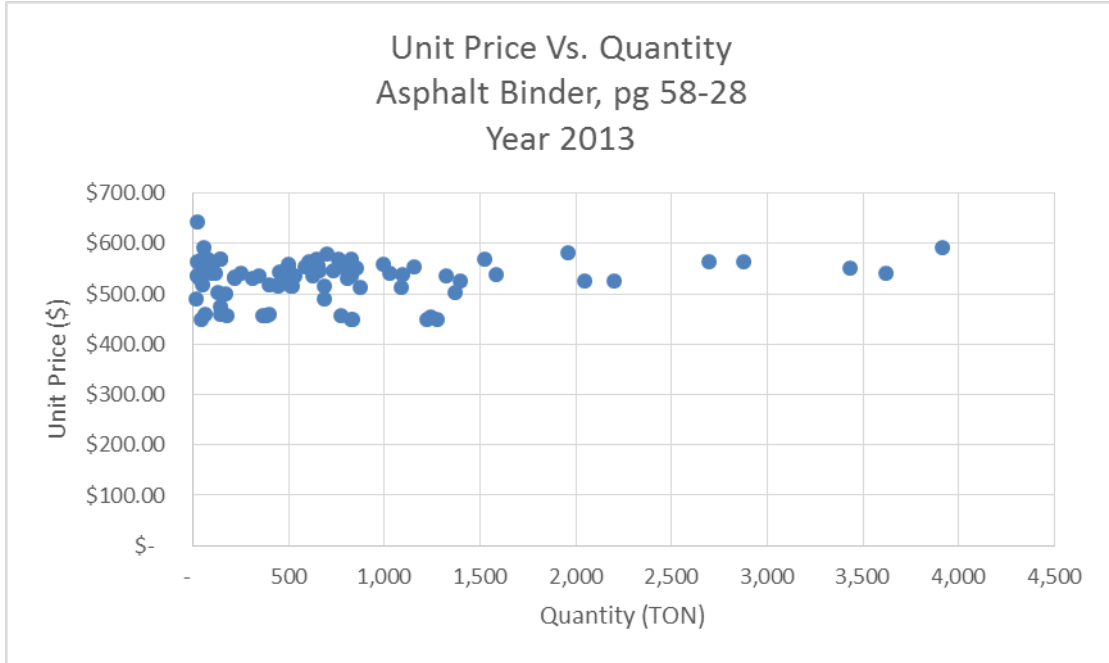
## Asphalt Binder 58-28: Effect of Quantity 2013



## Asphalt Binder 58 - 28 : Effect of Quantity 2014

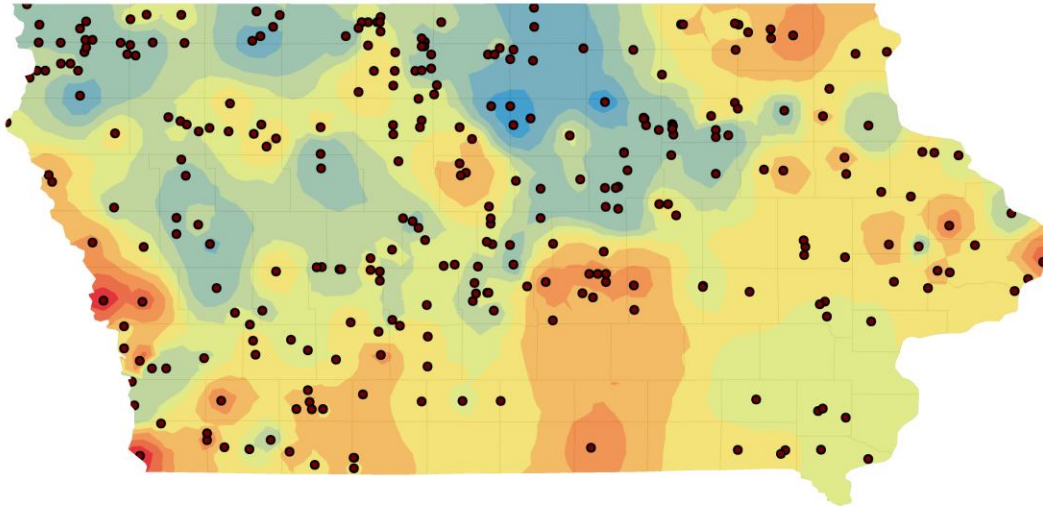






**Phase 3 Results**

**Average Unit Prices for Asphalt Binder, PG 58-28  
Year 2014**



**Legend**

**Inverse Distance Weighting**

**Prediction Map**

[Avg2014AB5828\_Features].[UnitPrice]

**Filled Contours**

Blue	429 – 479
Light Blue	479 – 514
Light Green	514 – 538
Light Yellow	538 – 555
Yellow	555 – 566
Light Orange	566 – 583
Orange	583 – 608
Dark Orange	608 – 642
Red-Orange	642 – 692
Red	692 – 763

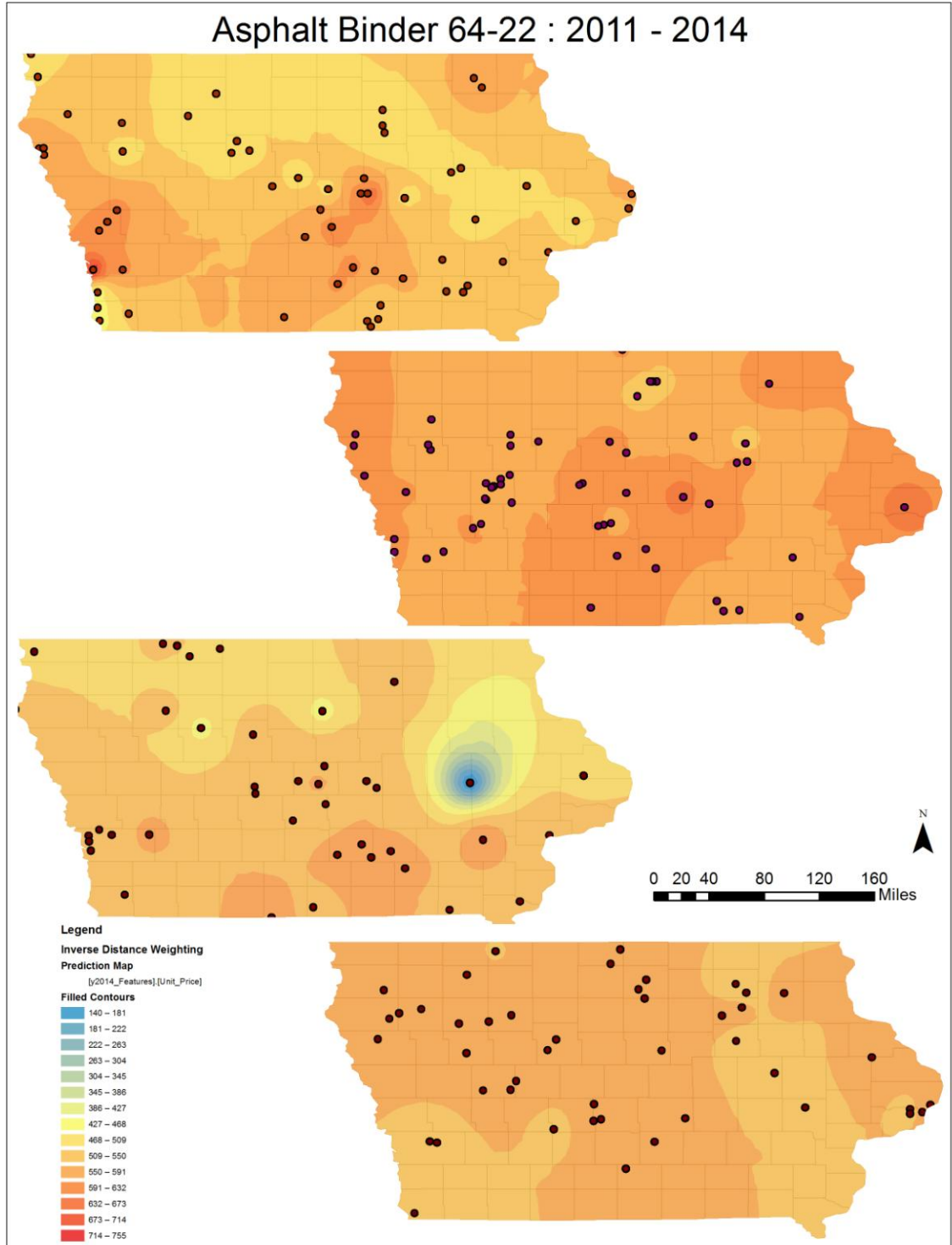
Bid data was obtained from Iowa Department of Transportation and average unit prices for year 2011 to 2014 were calculated. Inflation index was developed using this average unit price keeping 2014 as base year. Unit price data for 2011, 2012, and 2013 were multiplied by index developed to obtain prices in 2014. Thus more number of data points with better distribution were obtained.

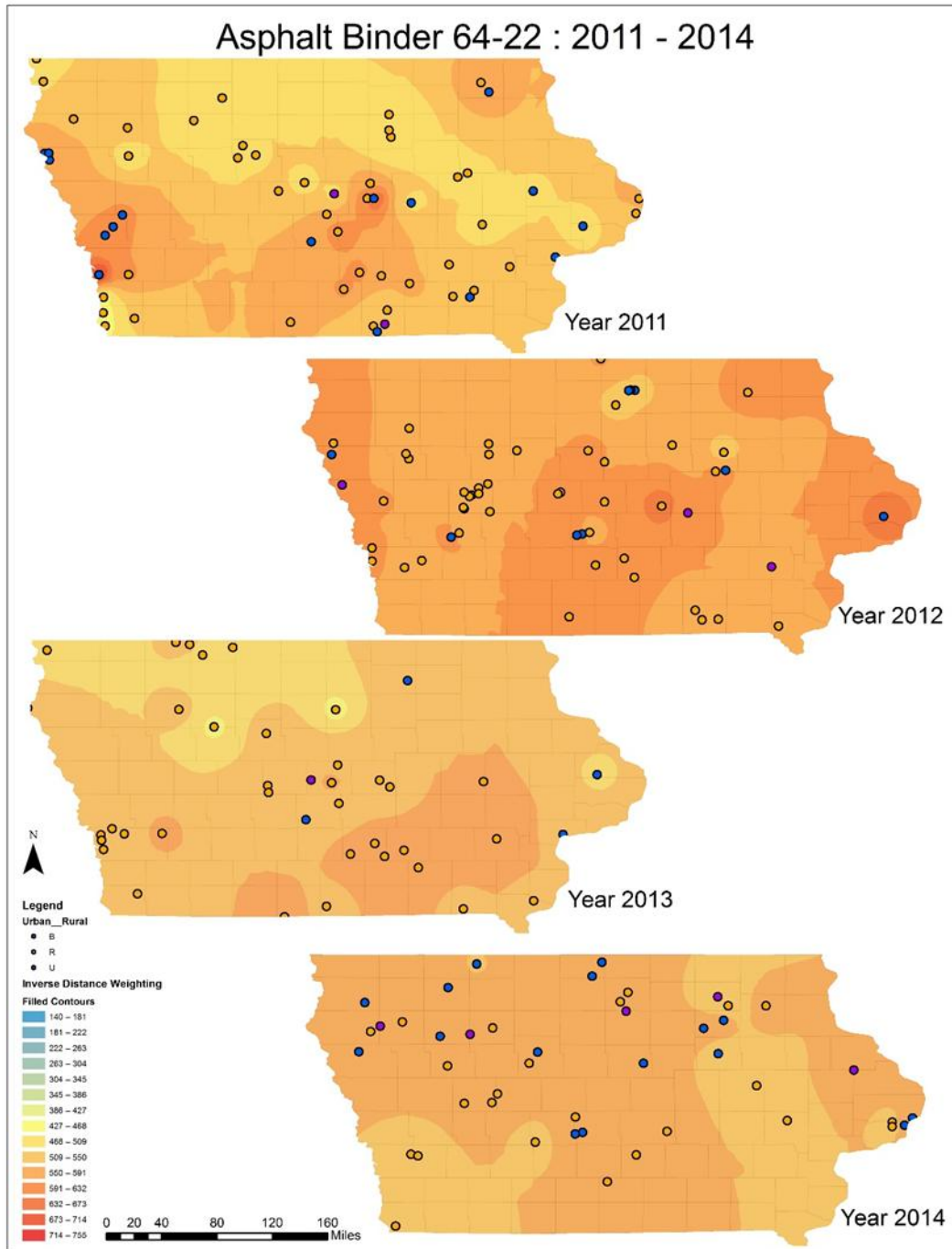


Map by: Deepanshi Jain  
Date: 04/01/2015

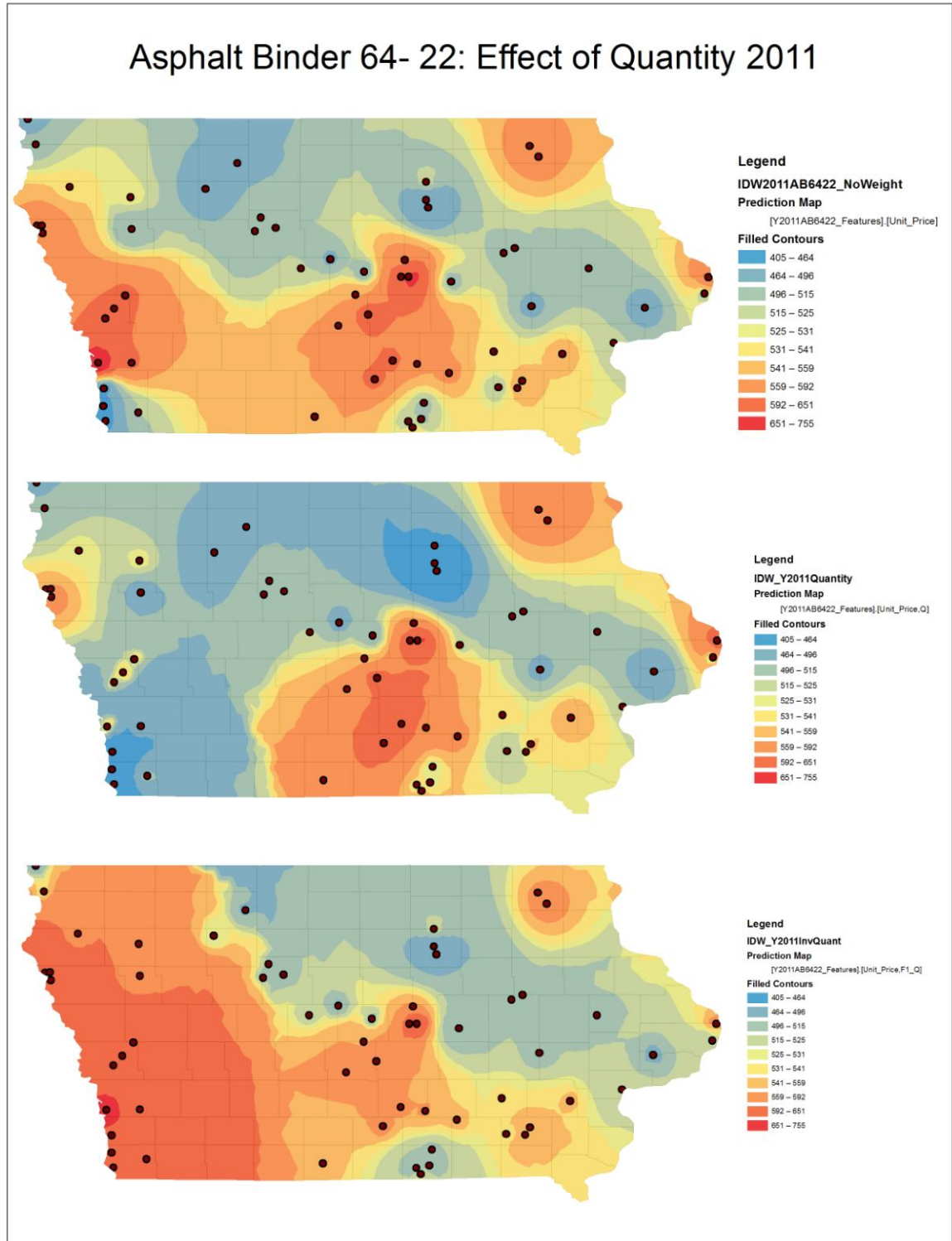
# ASPHALT BINDER 64 22

## Phase 1 Results



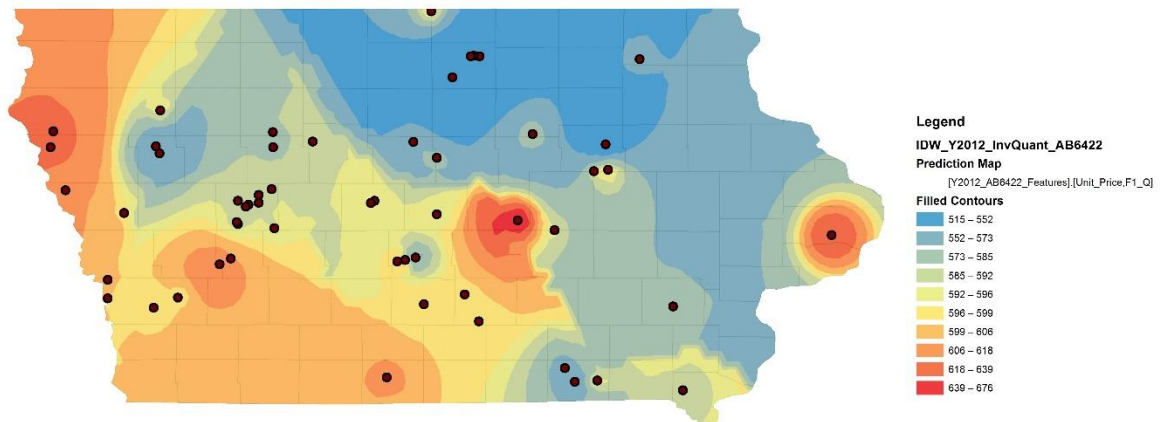
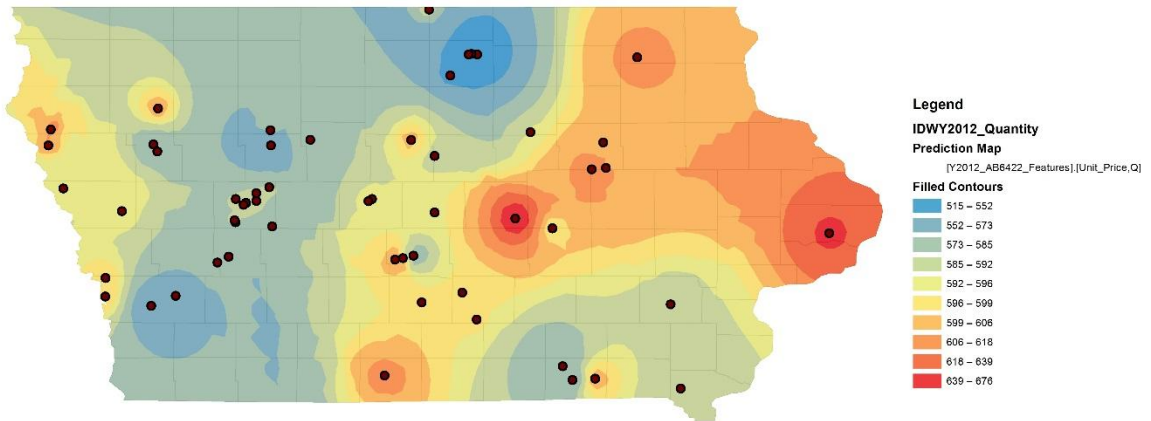
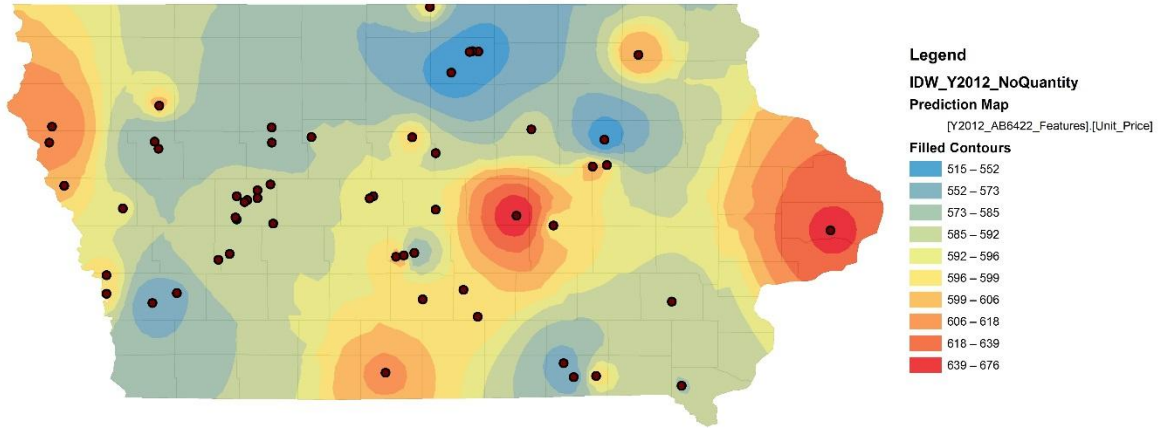


Phase 2 Results

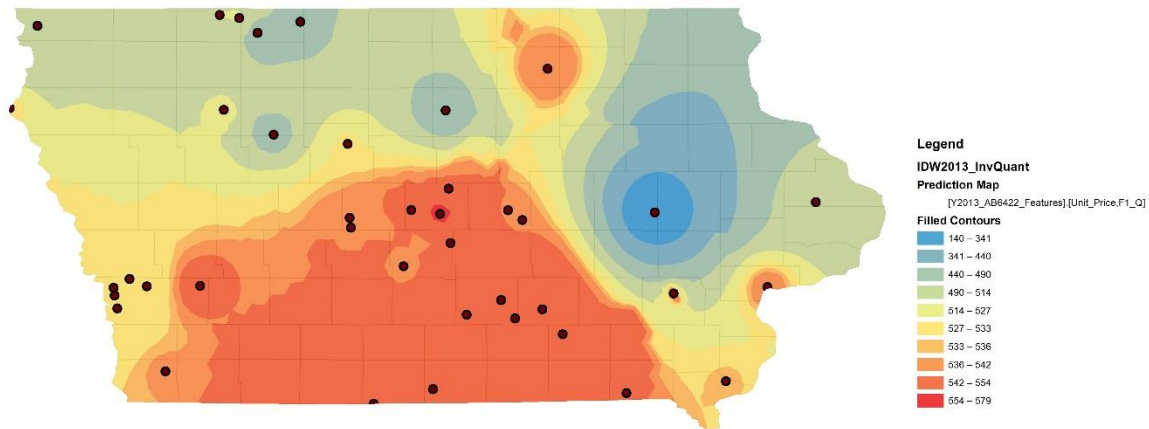
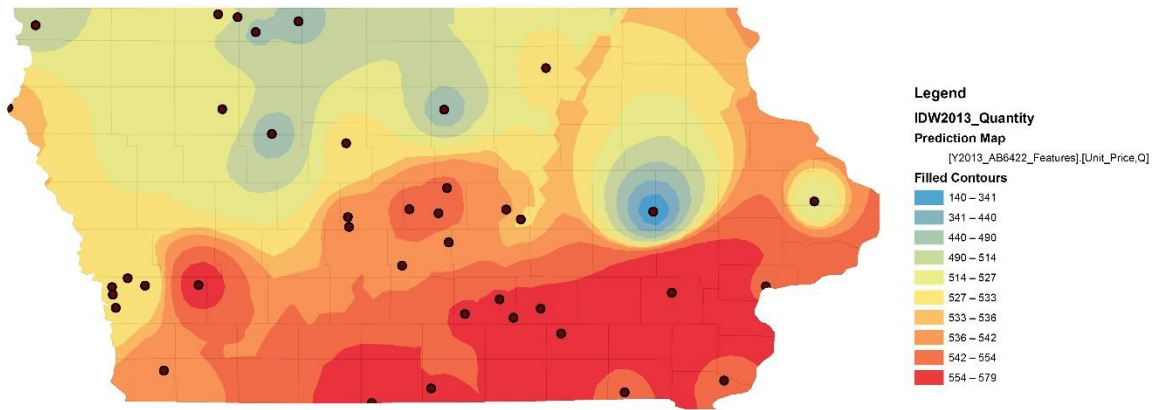
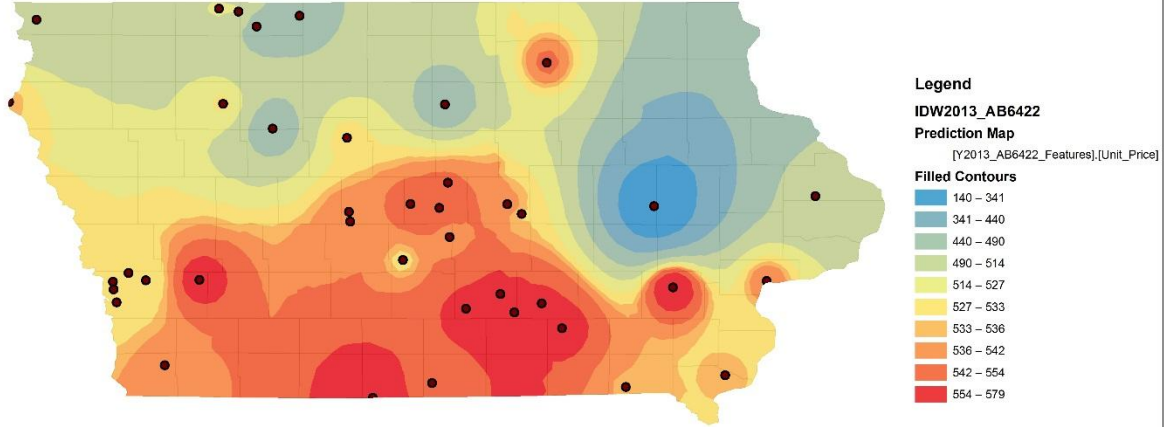




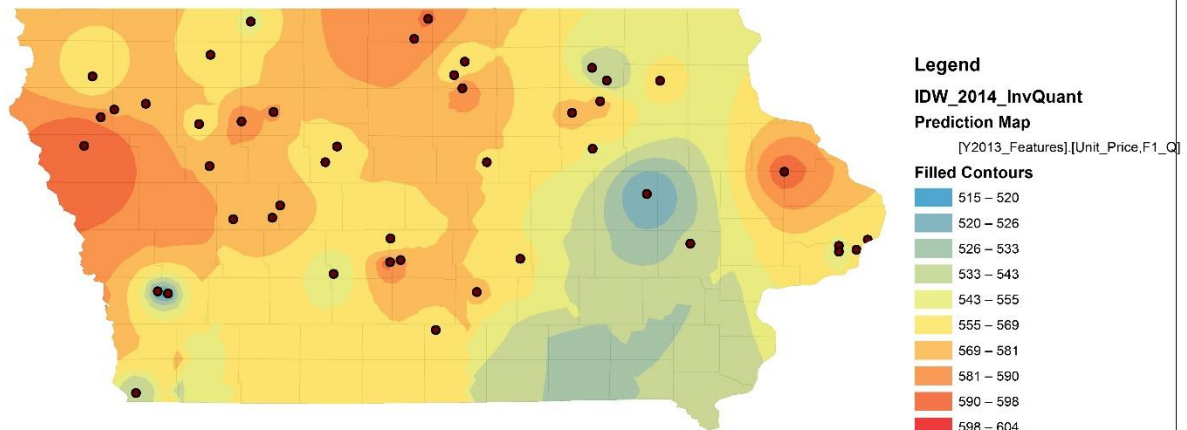
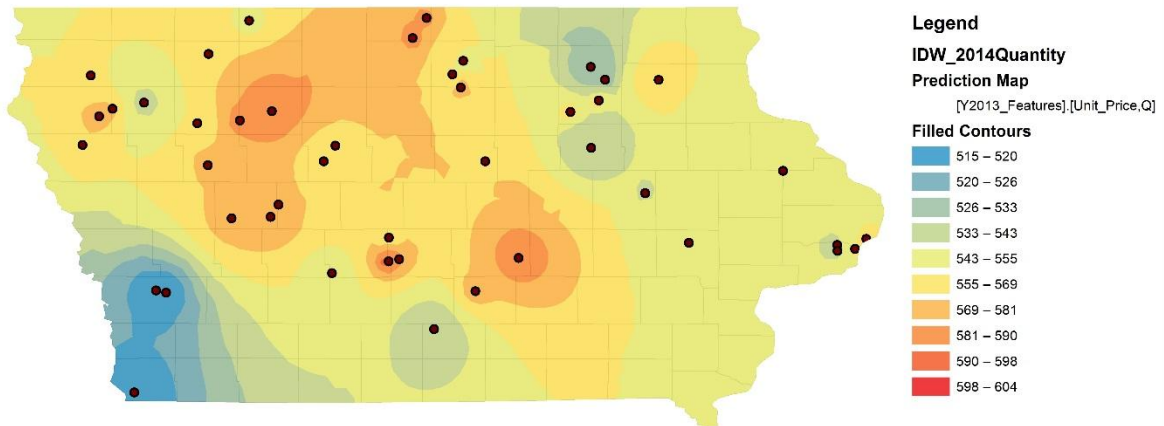
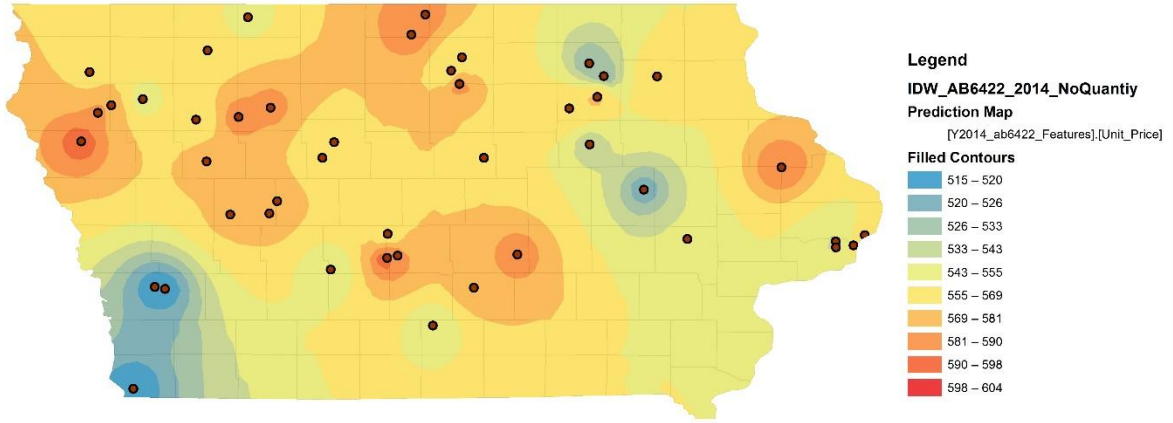
## Asphalt Binder 64-22 : Effect of Quantity 2012

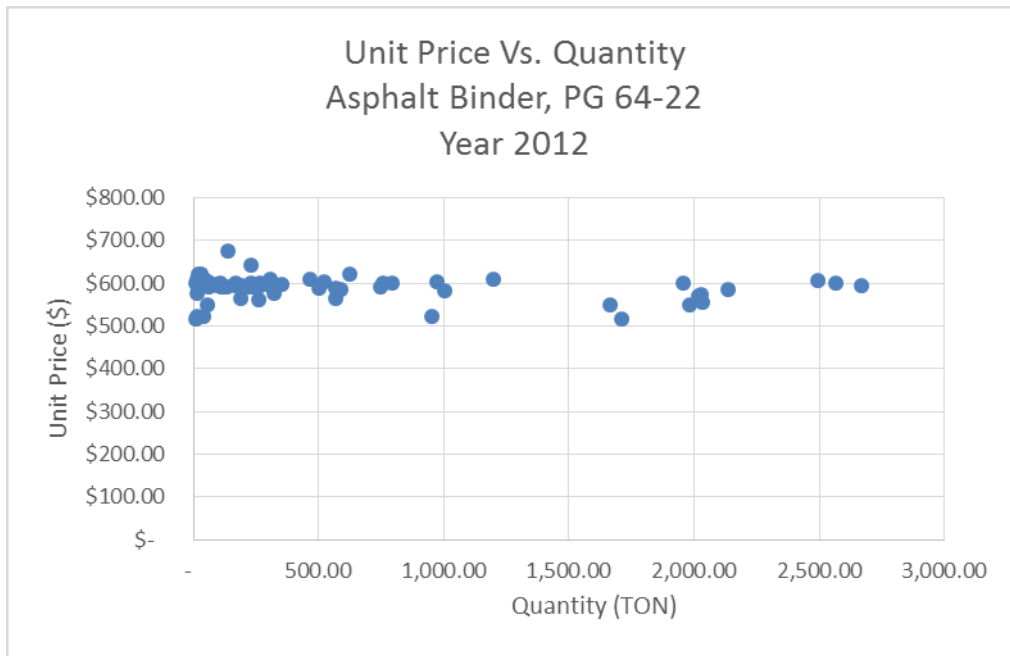
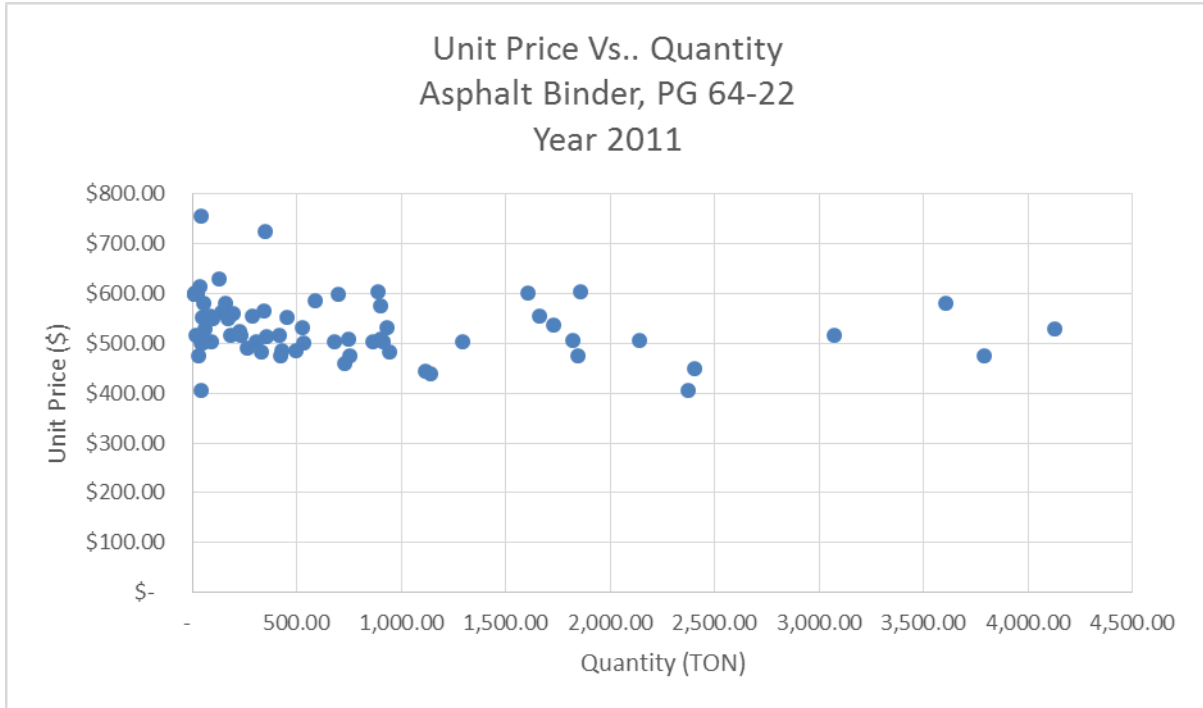


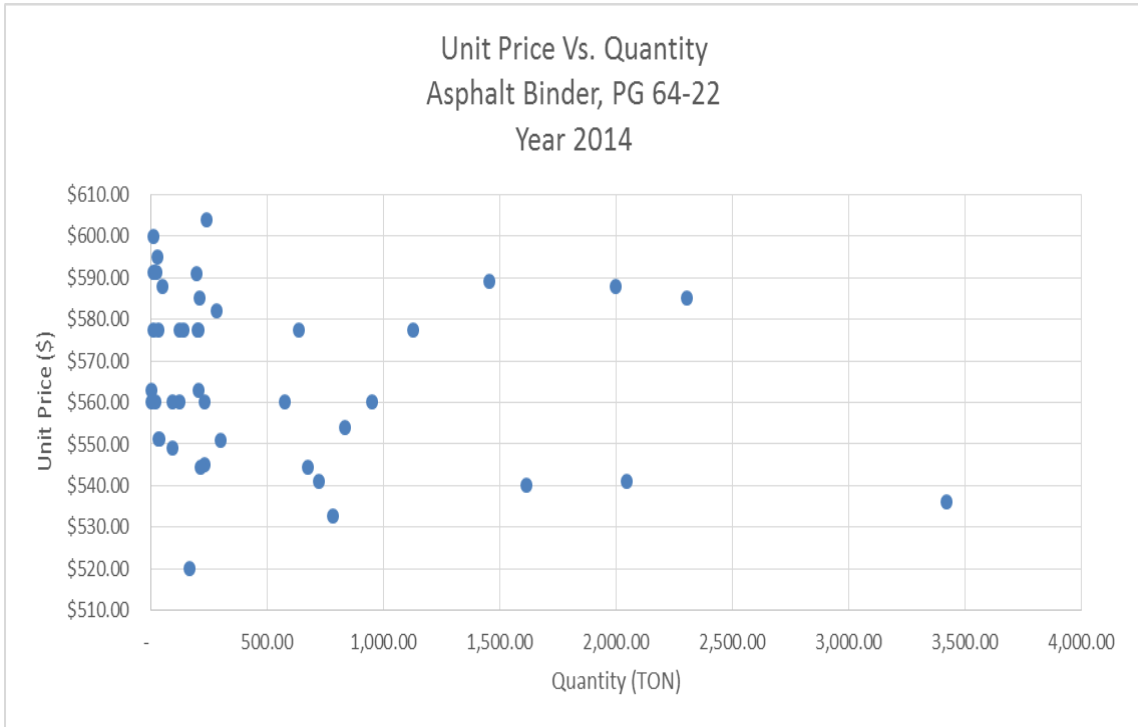
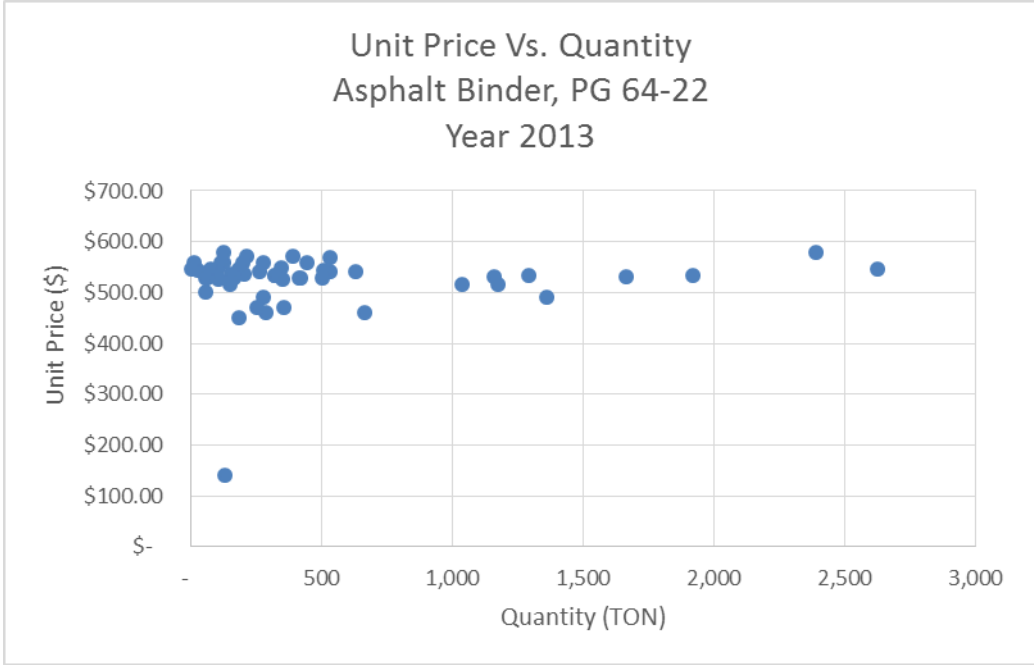
## Asphalt Binder 64 - 22 : Effect of Quantity 2013



## Asphalt Binder 64 - 22 : Effect of Quantity 2014

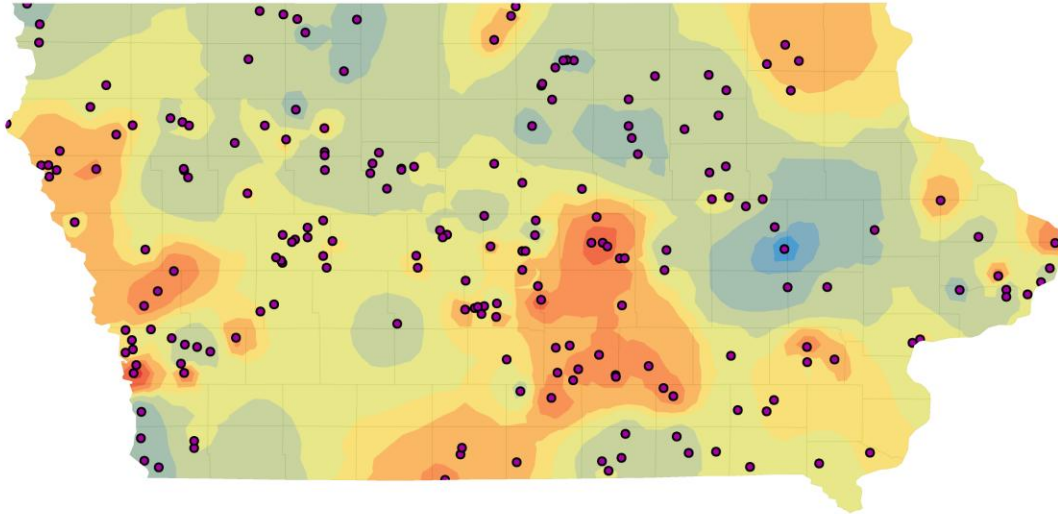






**Phase 3 Results**

**Average Unit Prices for Asphalt Binder, PG 64-22  
Year 2014**



**Legend**

**Inverse Distance Weighting**

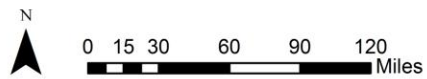
**Prediction Map**

[y2014avg\_Features].[Unit\_Price]

**Filled Contours**

- 149 – 357
- 357 – 466
- 466 – 524
- 524 – 554
- 554 – 570
- 570 – 579
- 579 – 595
- 595 – 625
- 625 – 683
- 683 – 792

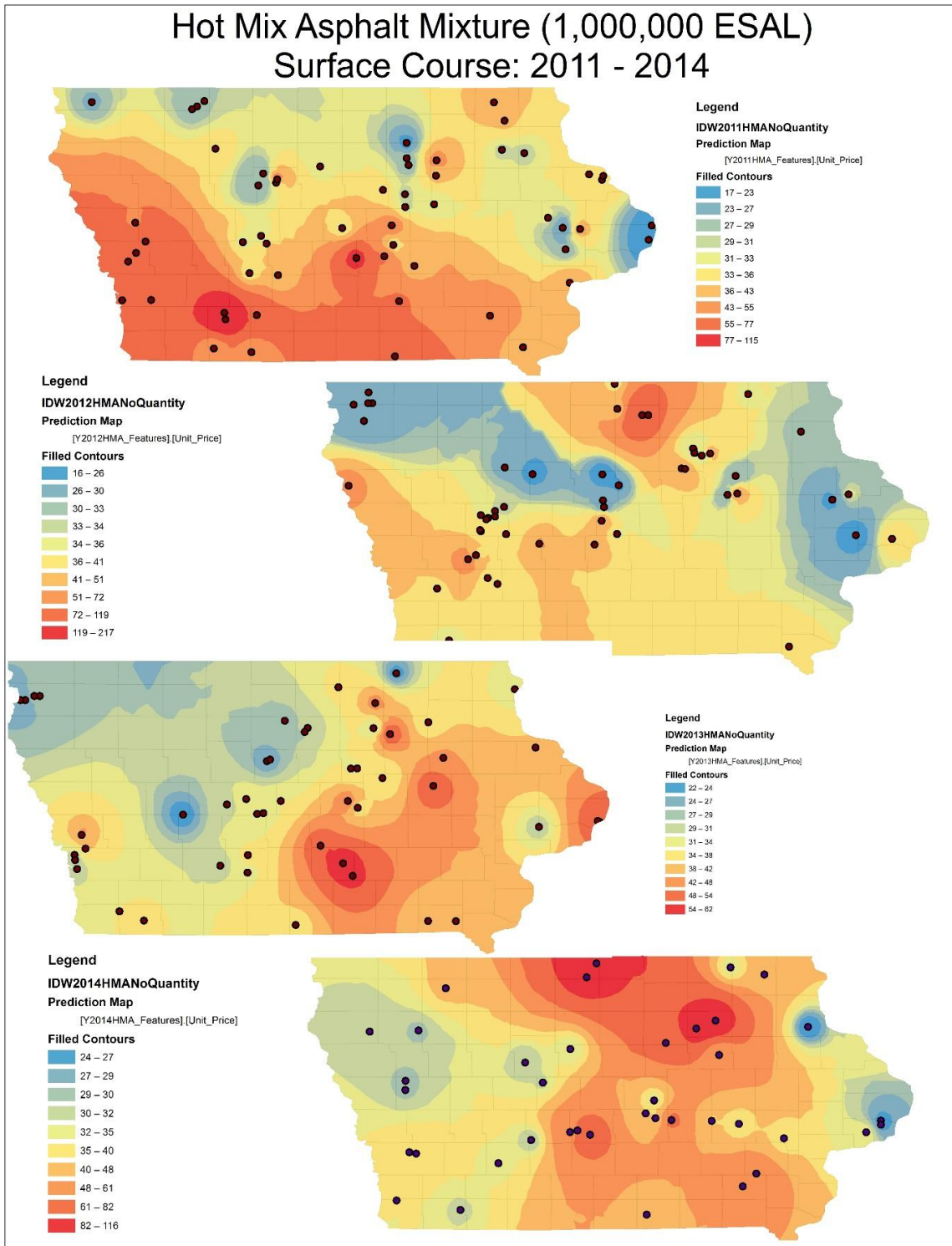
Bid data was obtained from Iowa Department of Transportation and average unit prices for year 2011 to 2014 were calculated. Cost index was developed using this average unit price keeping 2014 as base year. Unit price data for 2011, 2012, and 2013 were multiplied by index developed to obtain prices in 2014. Thus more number of data points with better distribution were obtained.



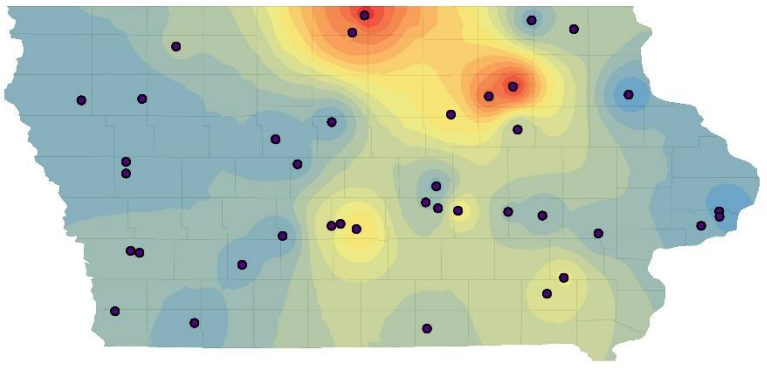
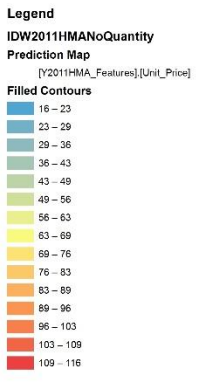
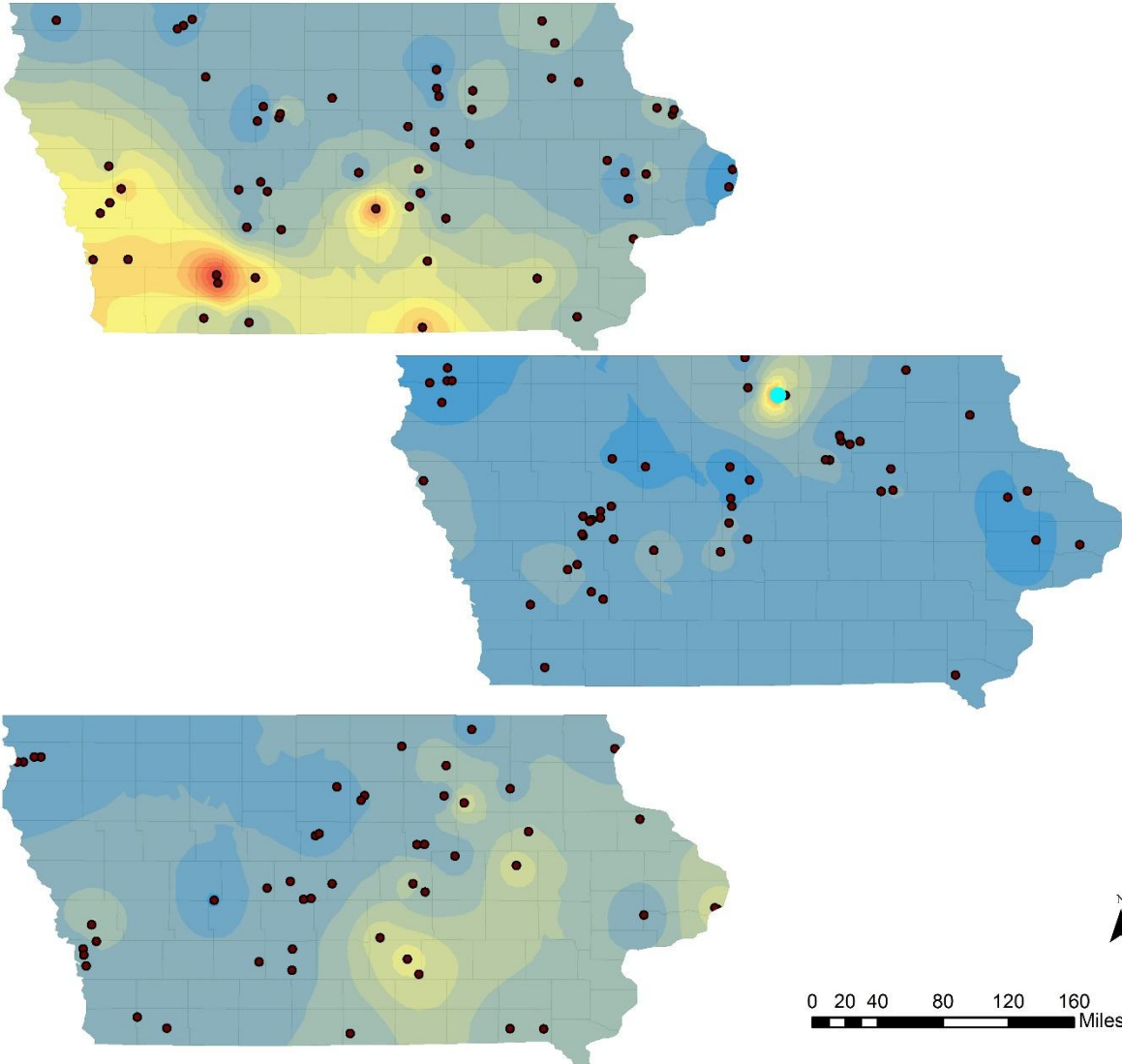
**Map by: Deepanshi Jain**  
**Date: 04/01/2015**

**HOT MIX ASPHALT MIXTURE (ESAL 1,000,000) SURFACE COURSE**

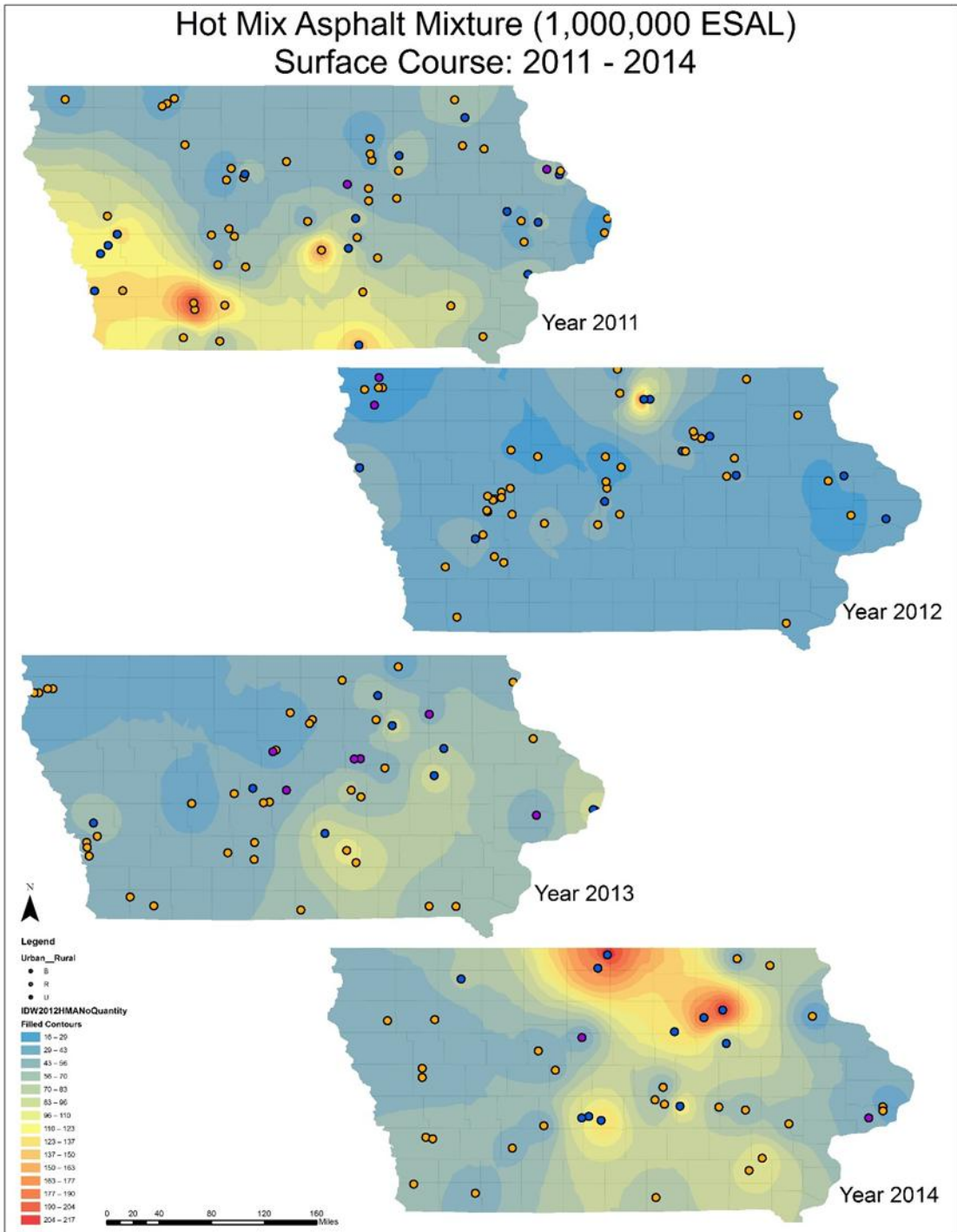
**Phase 1 Results**



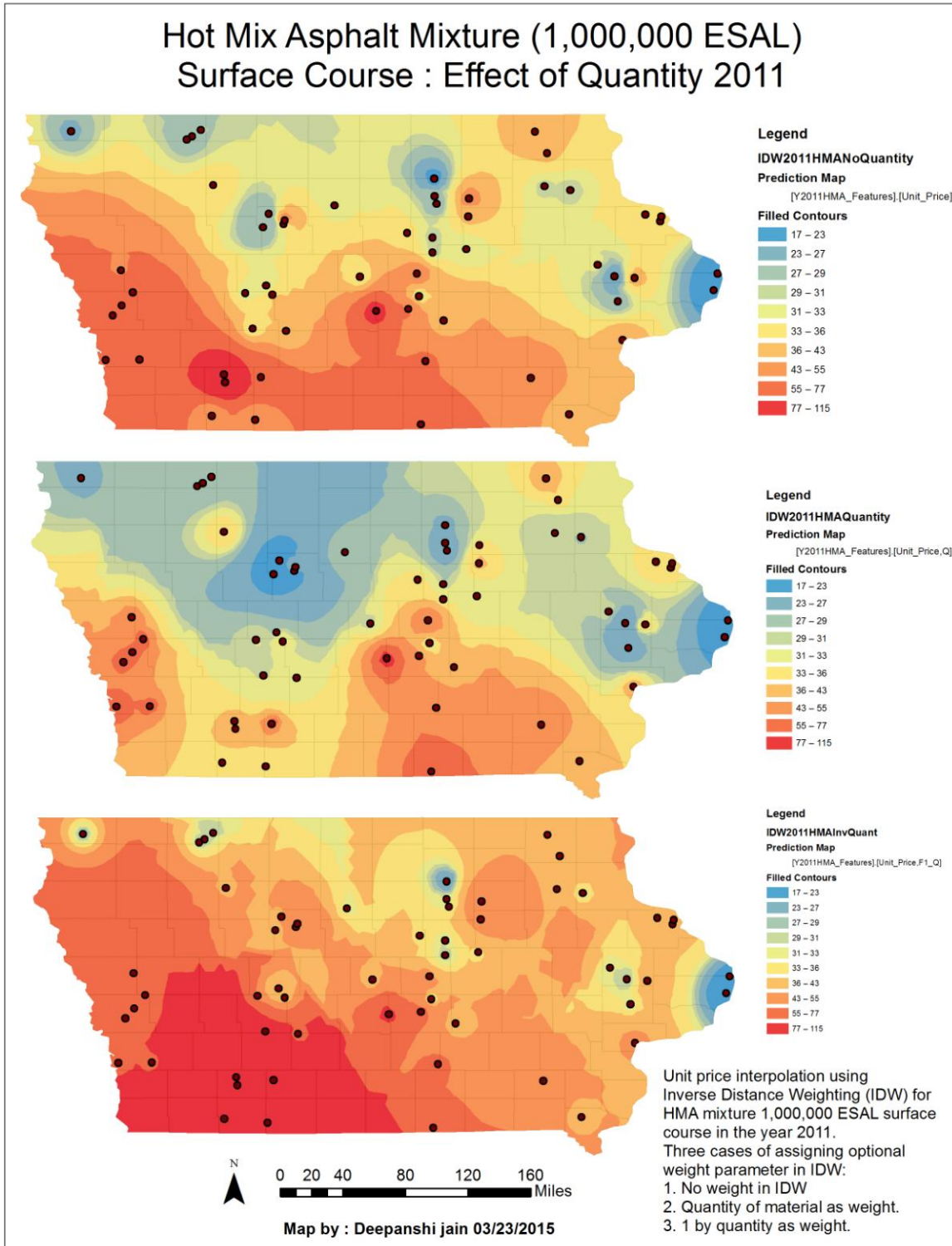
### Hot Mix Asphalt Mixture (1,000,000 ESAL) Surface Course: 2011 - 2014



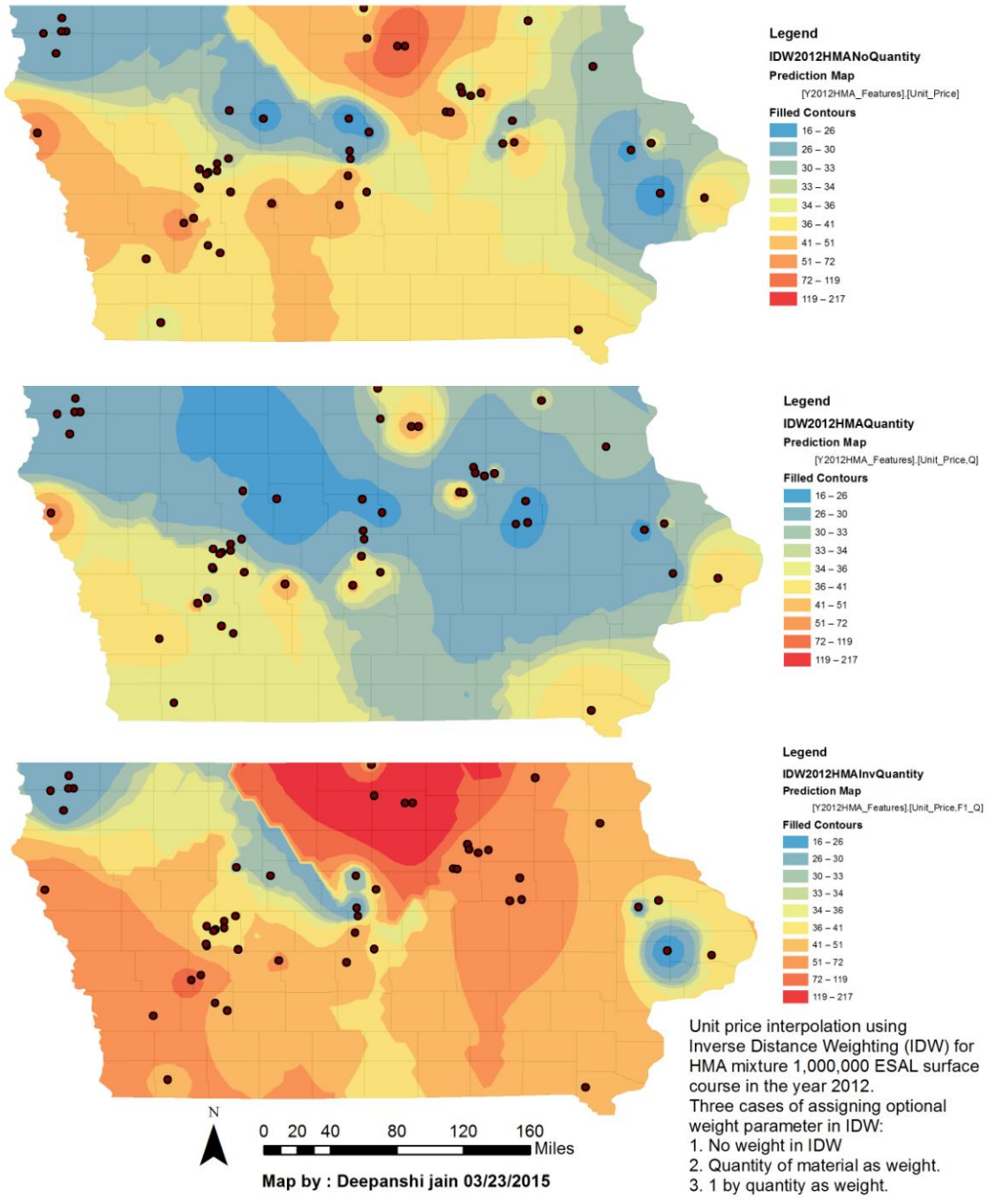




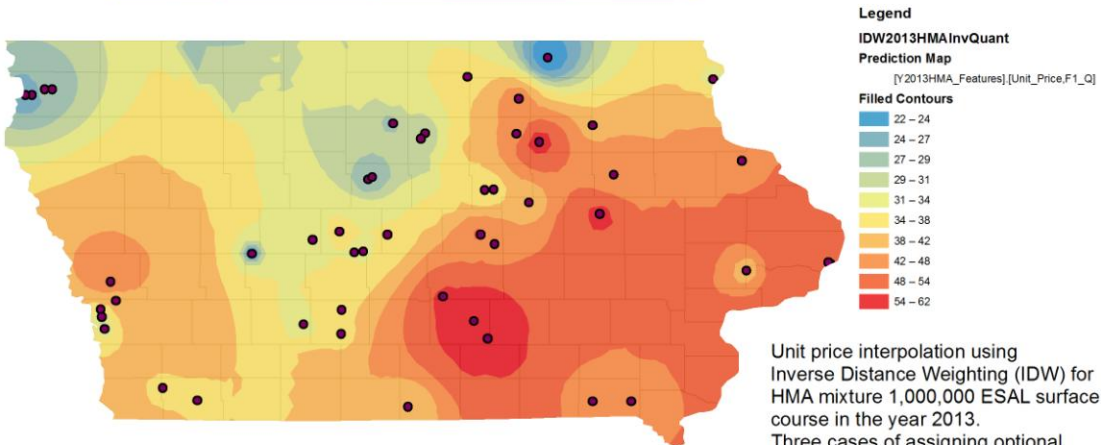
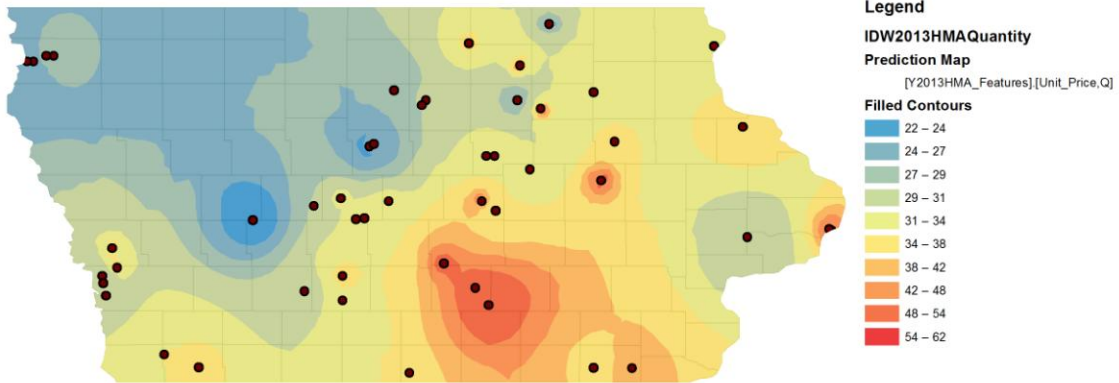
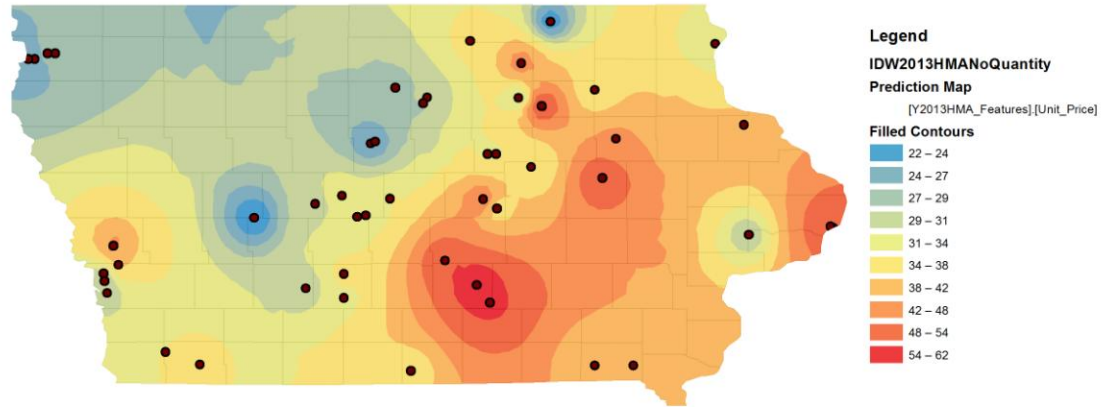
Phase 2 Results



## Hot Mix Asphalt Mixture (1,000,000 ESAL) Surface Course : Effect of Quantity 2012



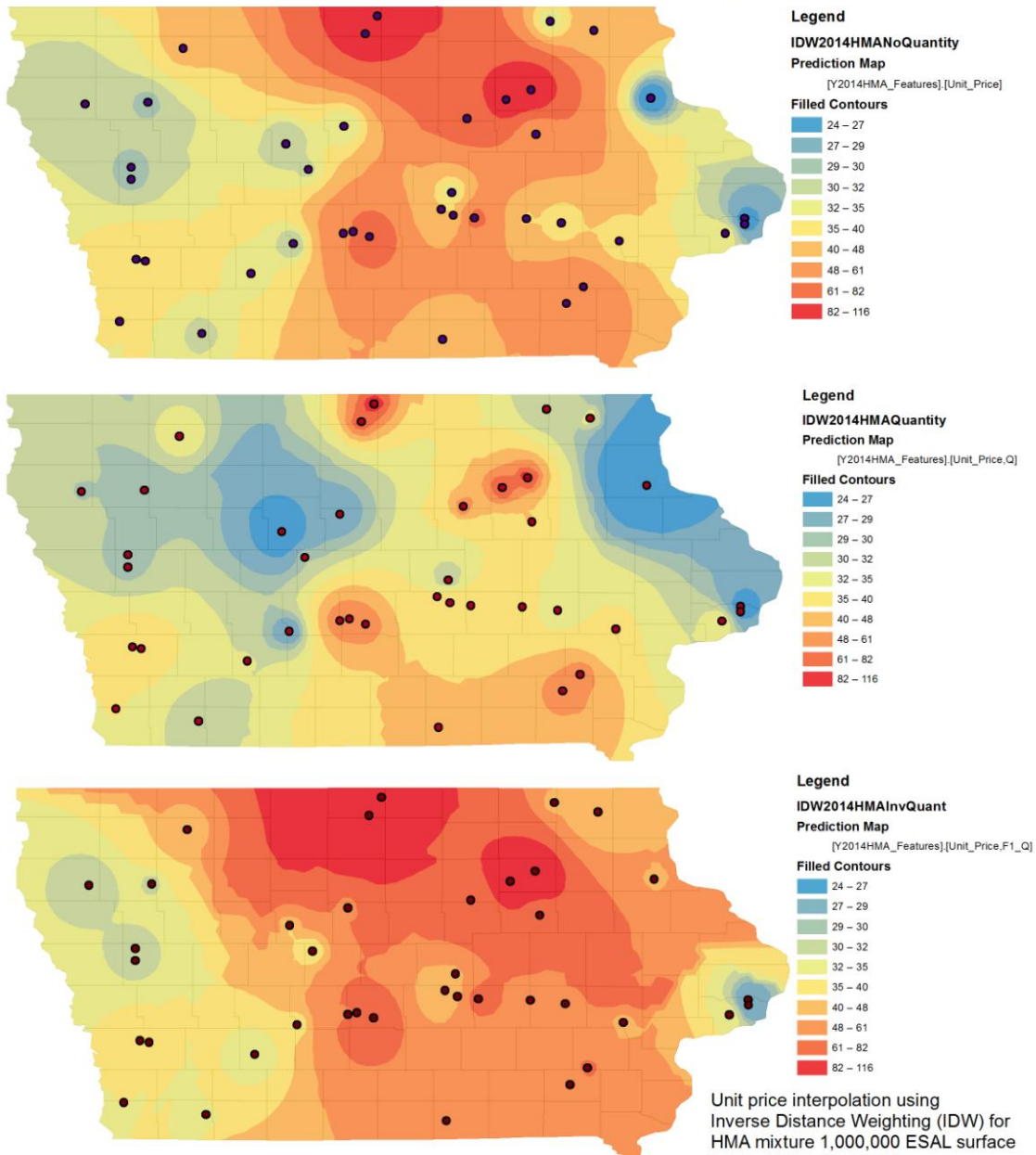
## Hot Mix Asphalt Mixture (1,000,000 ESAL), Surface Course: Effect of Quantity 2013



Map by : Deepanshi jain 03/23/2015

Unit price interpolation using Inverse Distance Weighting (IDW) for HMA mixture 1,000,000 ESAL surface course in the year 2013. Three cases of assigning optional weight parameter in IDW:  
1. No weight in IDW  
2. Quantity of material as weight.  
3. 1 by quantity as weight.

## Hot Mix Asphalt Mixture (1,000,000 ESAL) Surface Course: Effect of Quantity 2014

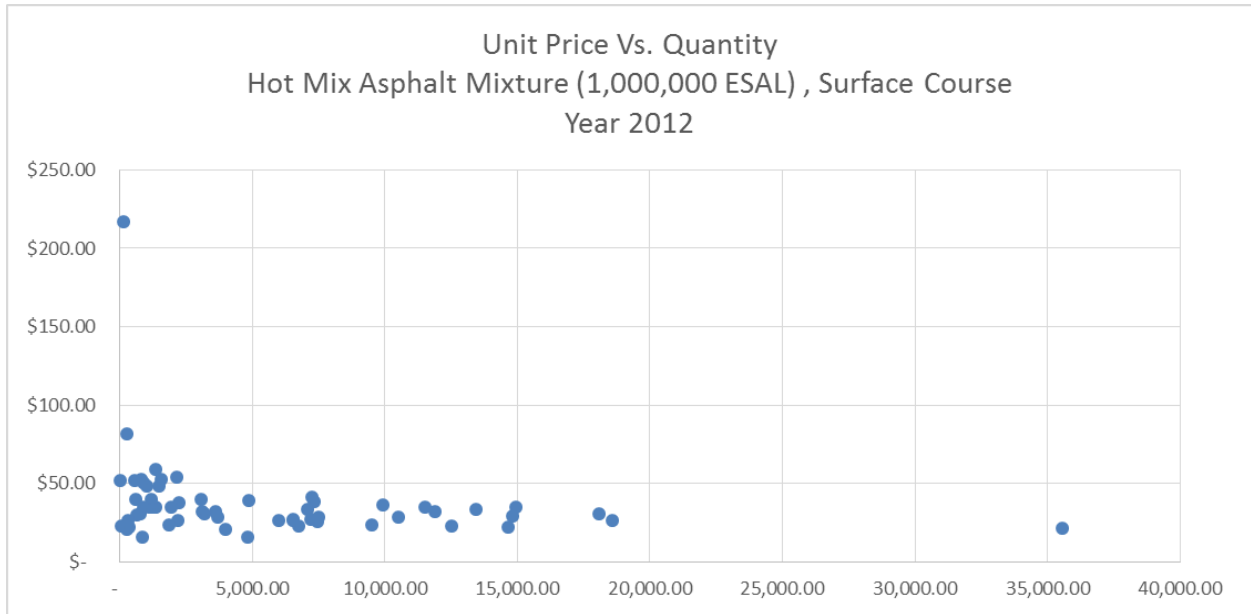
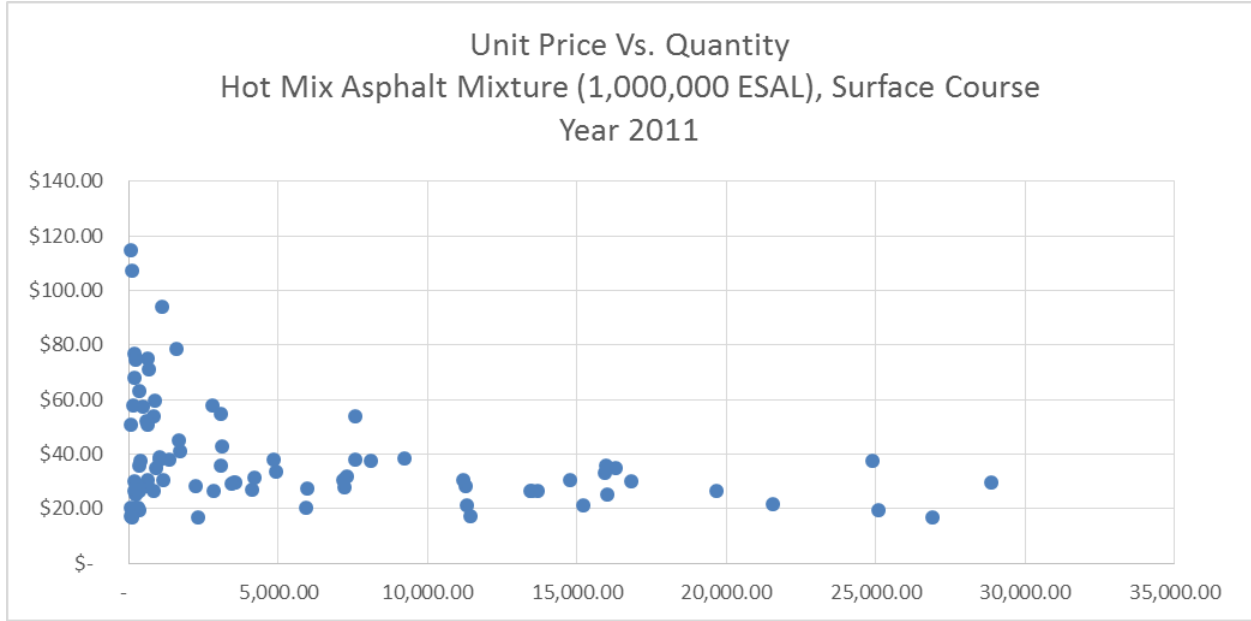


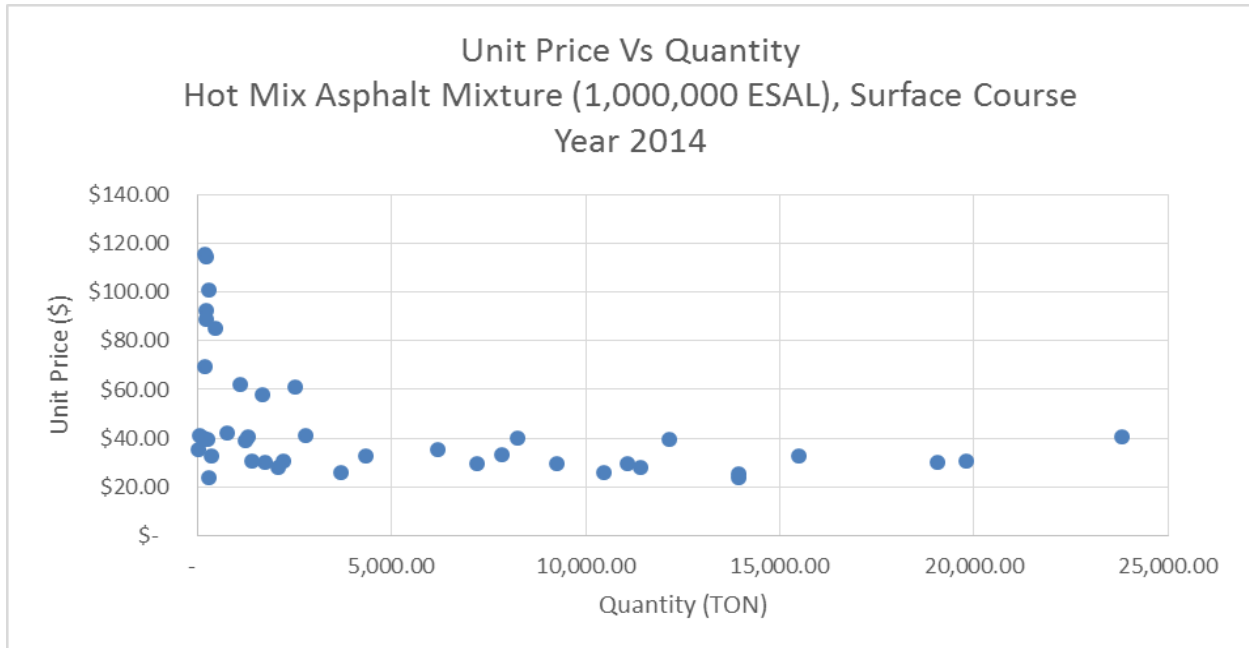
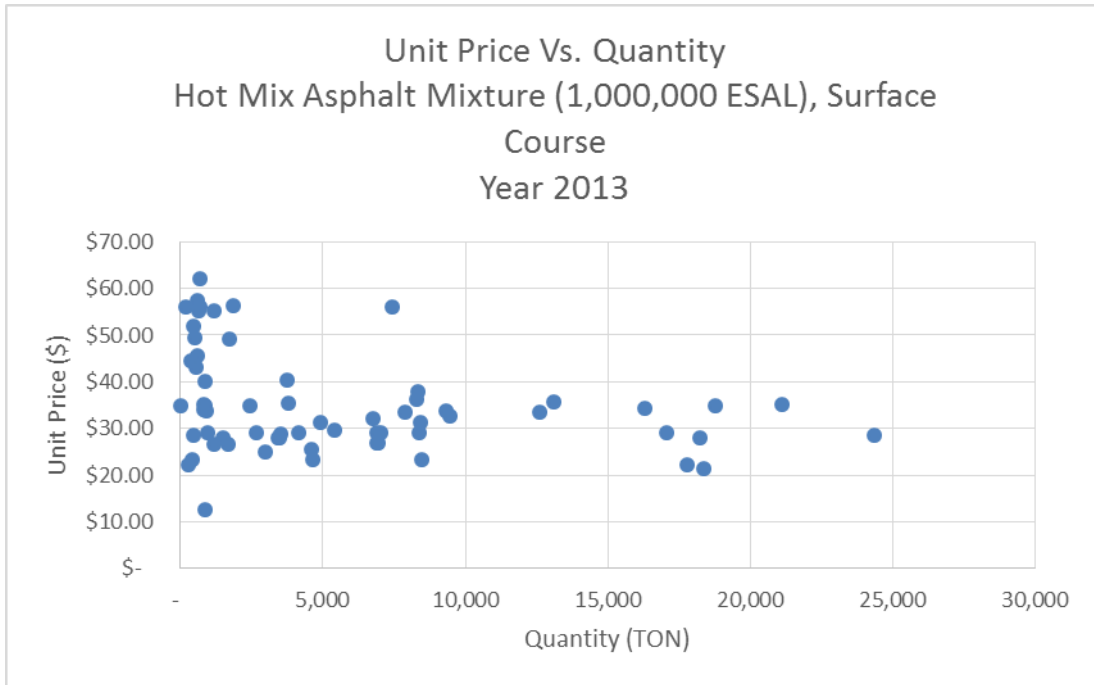
Map by : Deepanshi jain 03/23/2015

Unit price interpolation using Inverse Distance Weighting (IDW) for HMA mixture 1,000,000 ESAL surface course in the year 2014.

Three cases of assigning optional weight parameter in IDW:

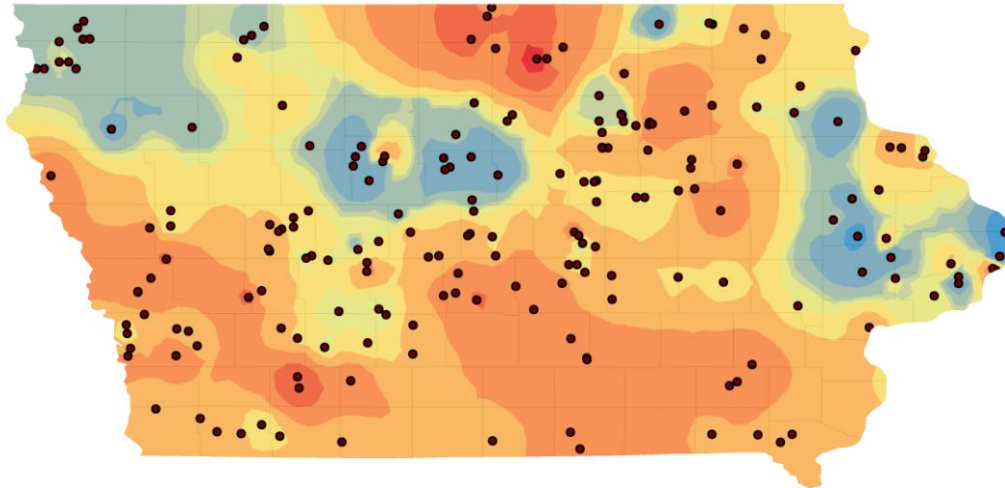
1. No weight in IDW
2. Quantity of material as weight.
3. 1 by quantity as weight.





**Phase 3 Results**

### Average Unit Prices for HotMix Asphalt Mixture (ESAL 100,000) Surface Course Year 2014



**Legend**

● cvrAverage2014

**Inverse Distance Weighting\_2**

**Prediction Map**

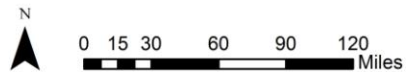
[HMA2014AVG\_Features].[UnitPrice]

**Filled Contours**

- 16 – 26
- 26 – 31
- 31 – 33
- 33 – 34
- 34 – 36
- 36 – 41
- 41 – 51
- 51 – 76
- 76 – 131
- 131 – 255

● HMA2014AVG Events

Bid data was obtained from Iowa Department of Transportation and average unit prices for year 2011 to 2014 were calculated. Cost index was developed using this average unit price keeping 2014 as base year. Unit price data for 2011, 2012, and 2013 were multiplied by index developed to obtain prices in 2014. Thus more number of data points with better distribution were obtained.

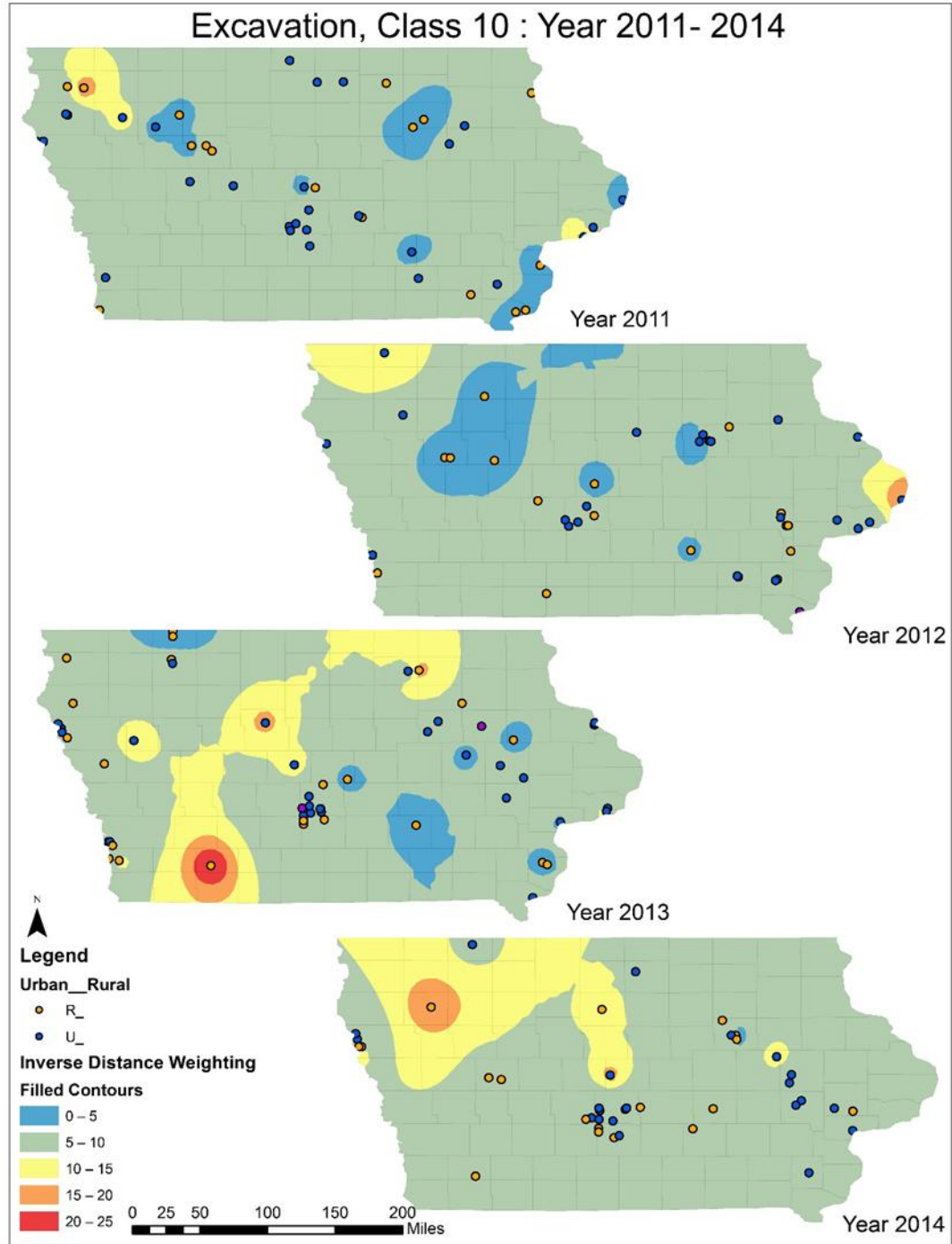


**Map by: Deepanshi Jain**  
**Date: 04/01/2015**

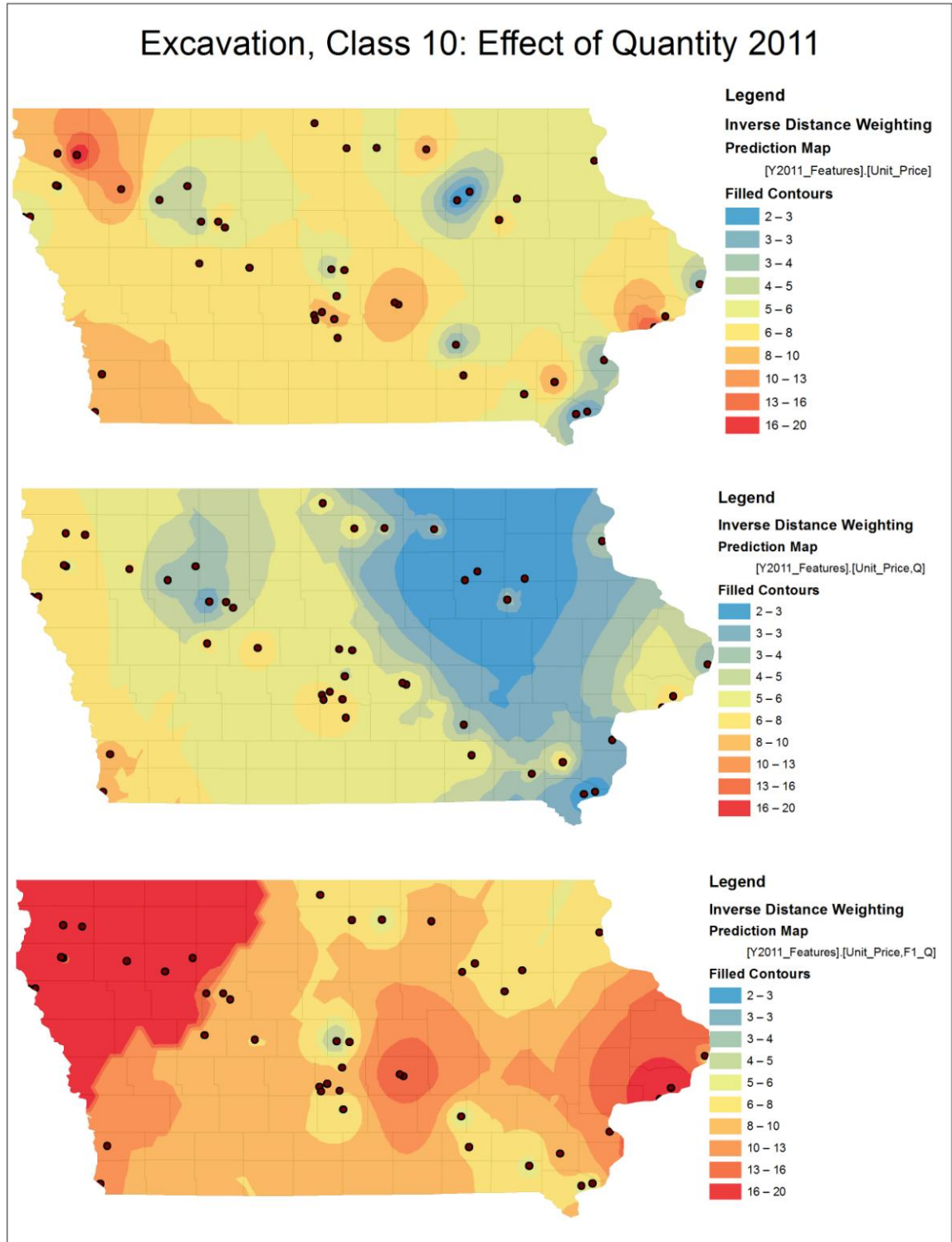


# EXCAVATION, CLASS 10

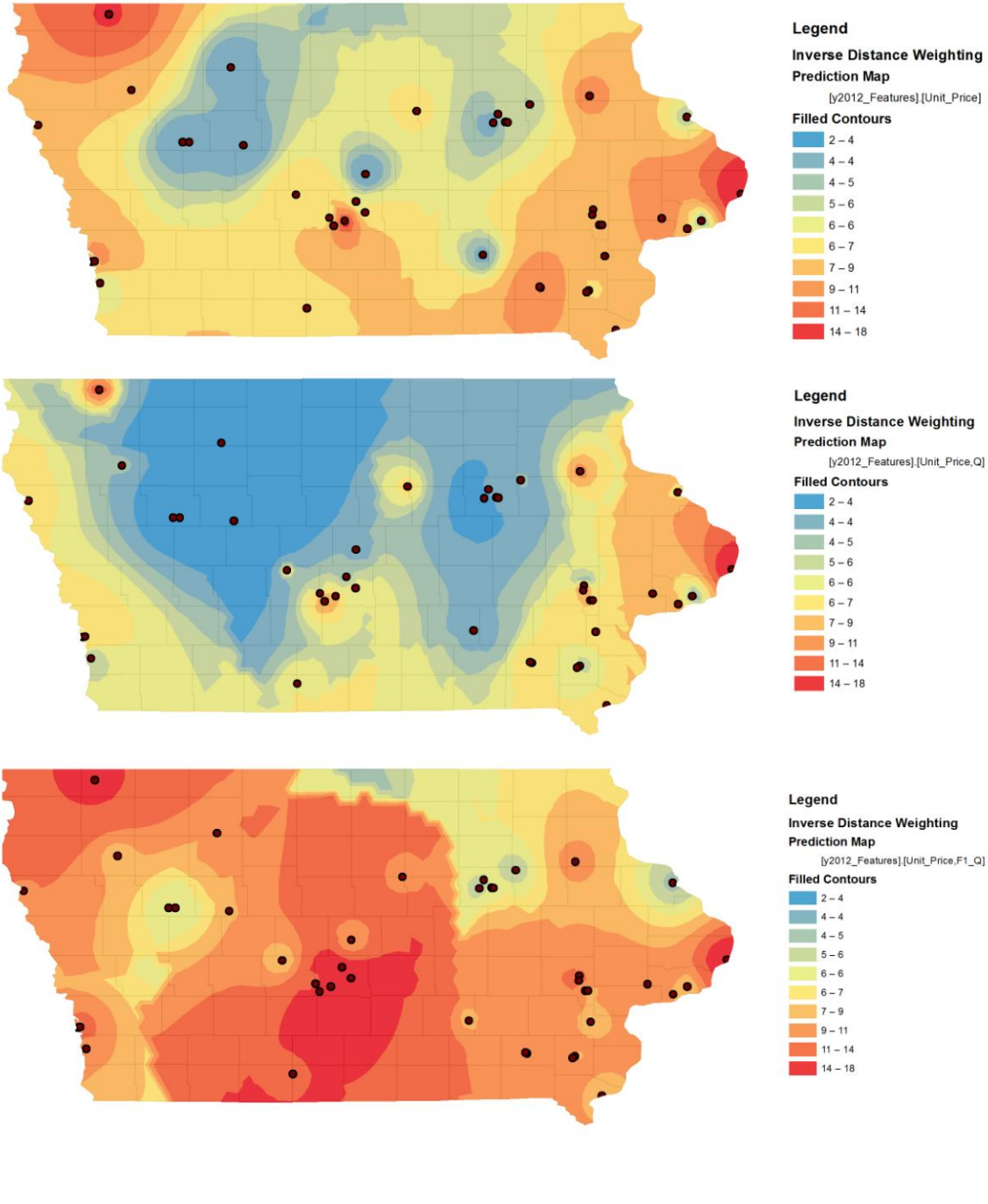
## Phase 1 Results



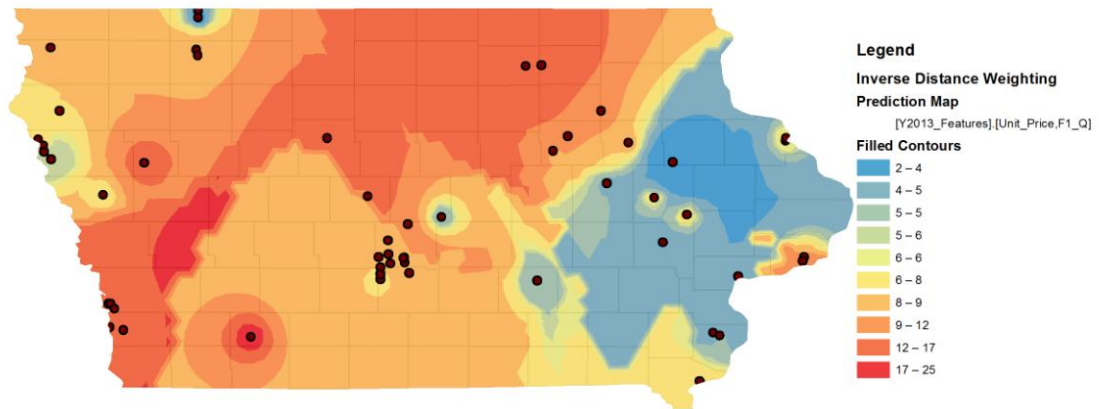
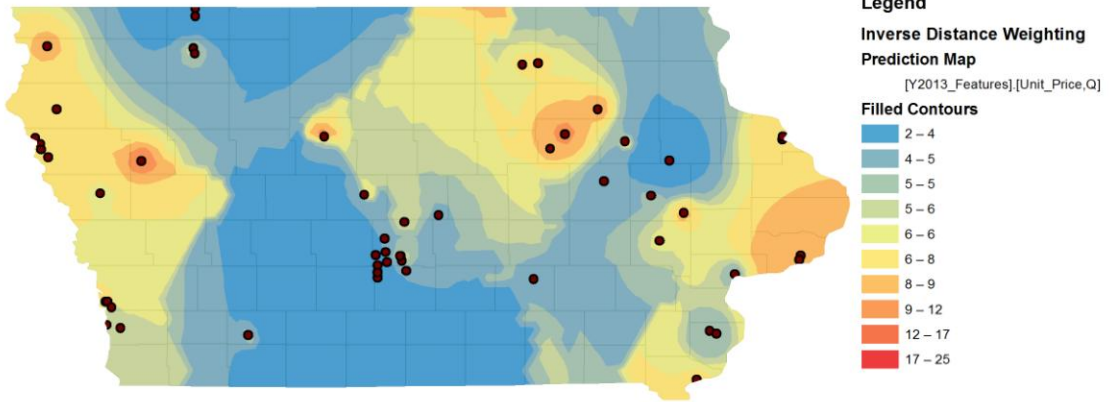
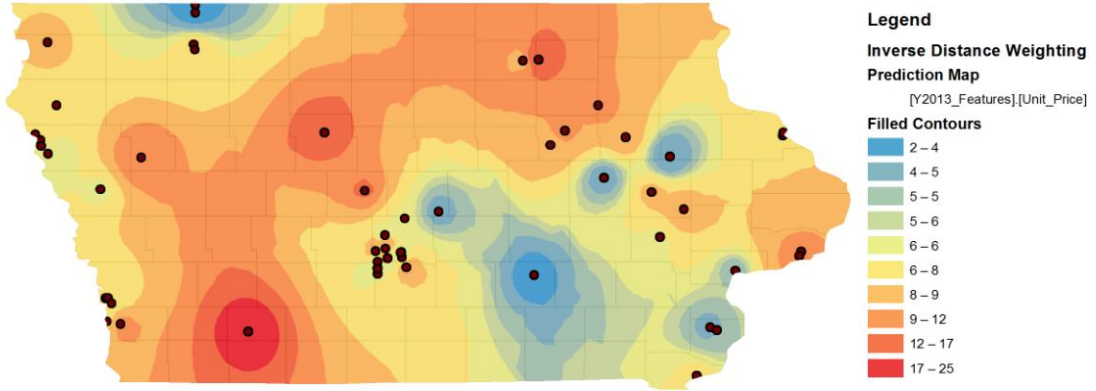
Phase 2 Results



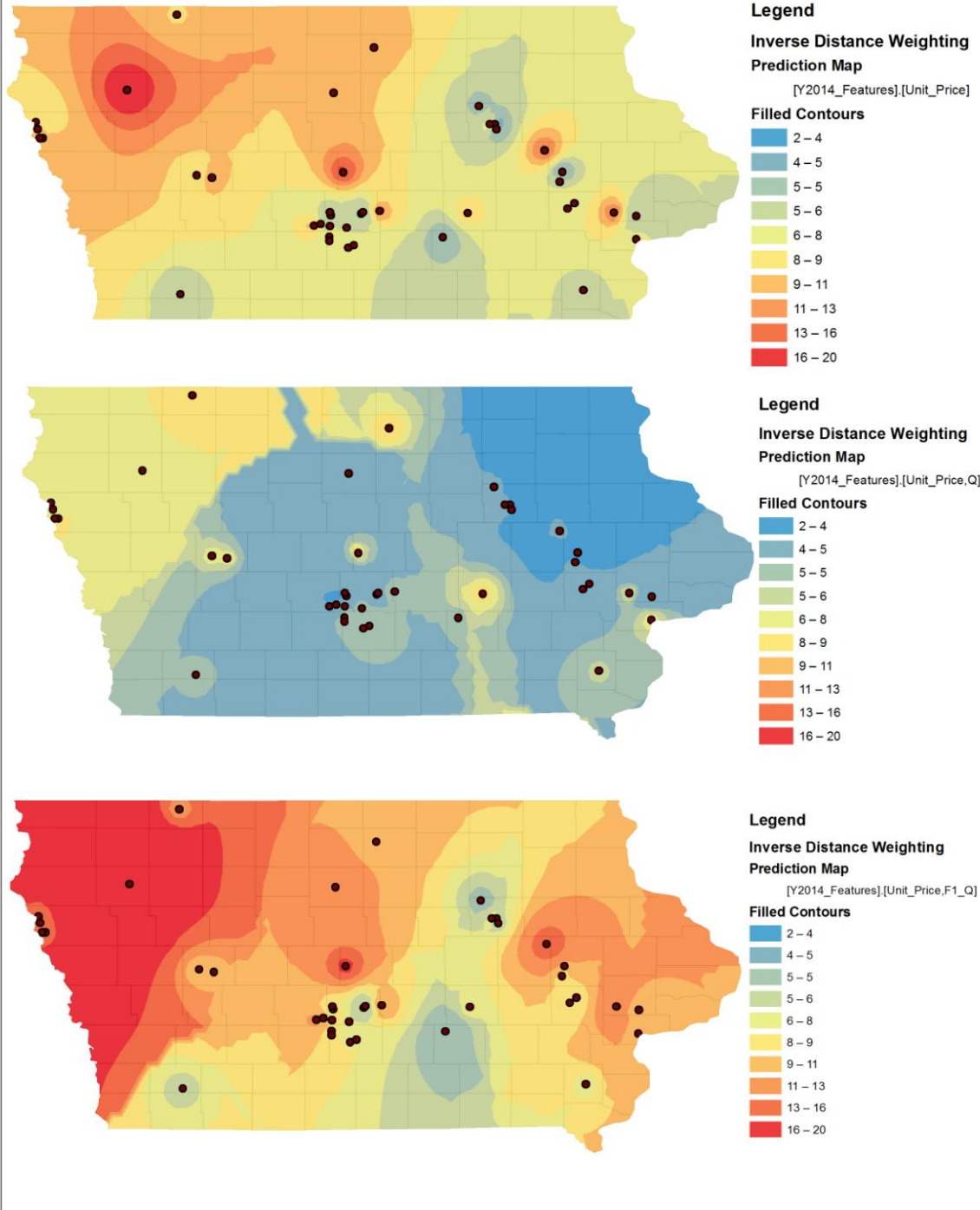
### Excavation, Class 10: Effect of Quantity 2012

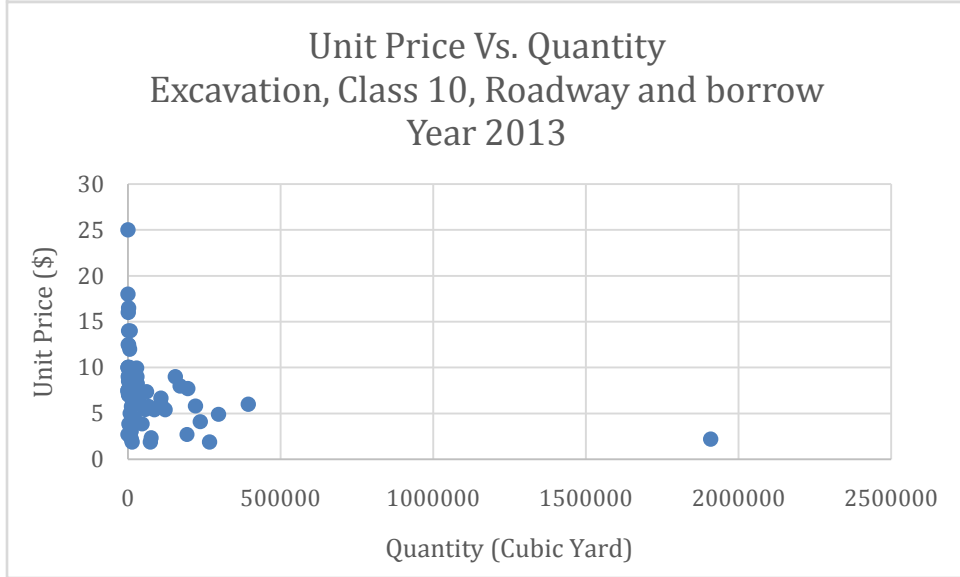
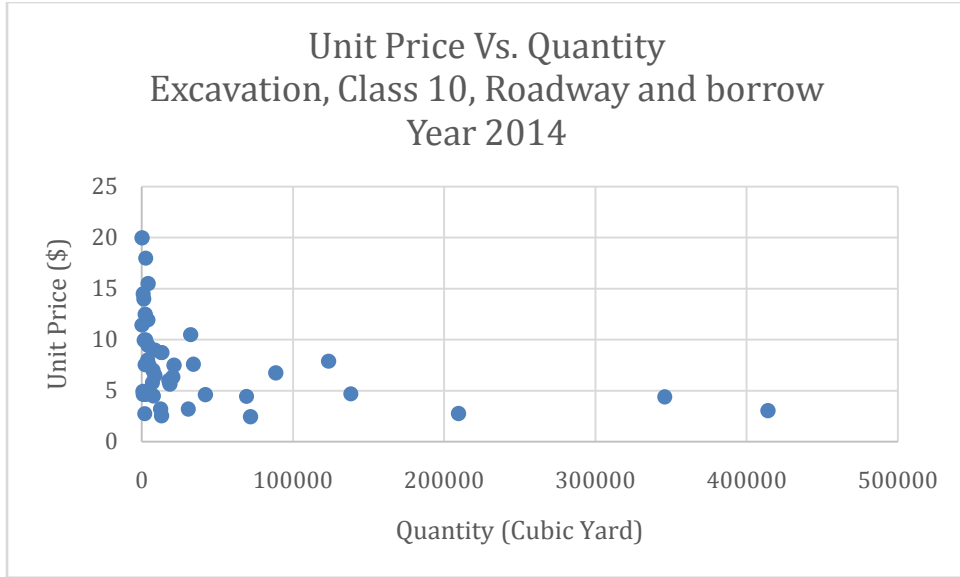


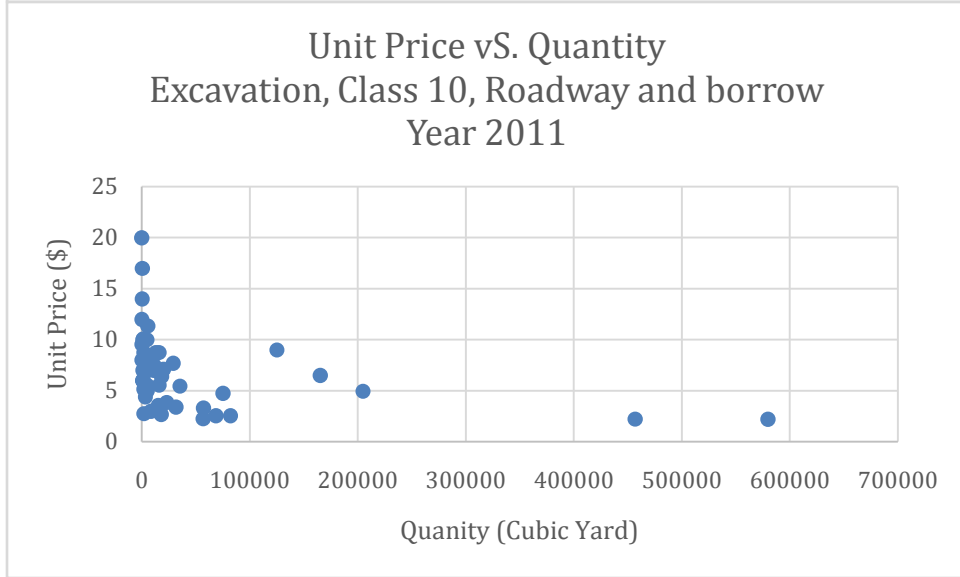
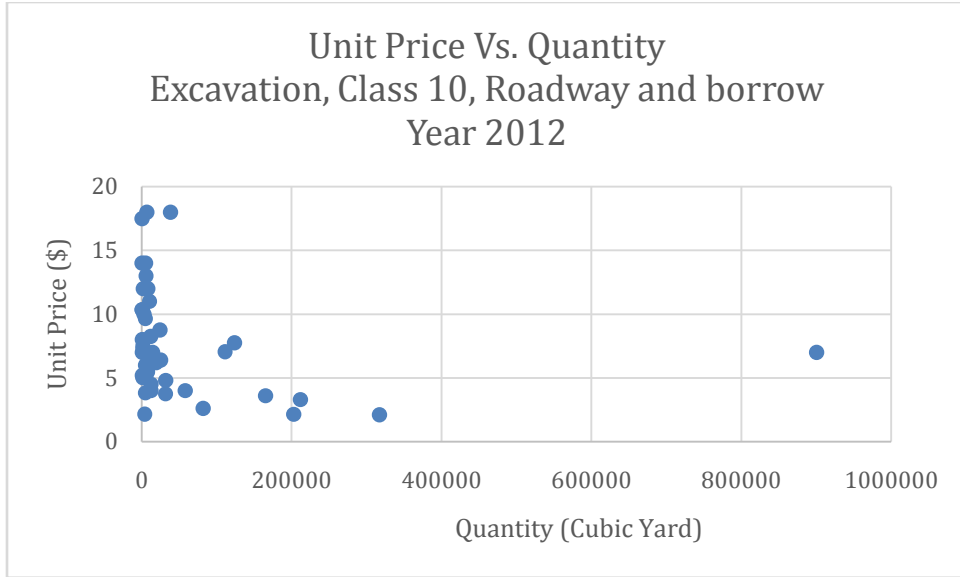
## Excavation, Class 10: Effect of Quantity 2013



### Excavation, Class 10: Effect of Quantity 2014

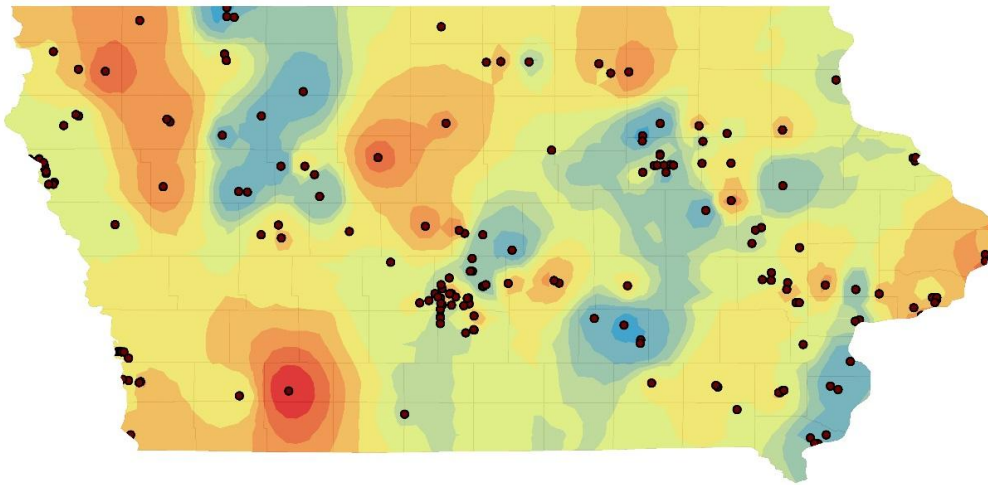






Phase 3 Results

Average Unit Price for Excavation Class 10 Year 2014



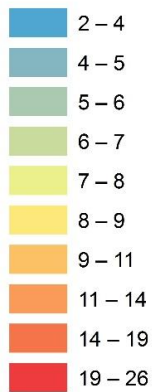
Legend

Inverse Distance Weighting

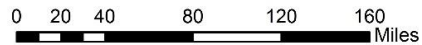
Prediction Map

[avg2014\_Features].[UnitPrice]

Filled Contours



Bid data was obtained from Iowa Department of Transportation and average unit prices for year 2011 to 2014 were calculated. Cost index was developed using this average unit price keeping 2014 as base year. Unit price data for 2011, 2012, and 2013 were multiplied by index developed to obtain prices in 2014. Thus, more number of data points with better distribution were obtained and the cross validation result proved that the average standard error reduced.

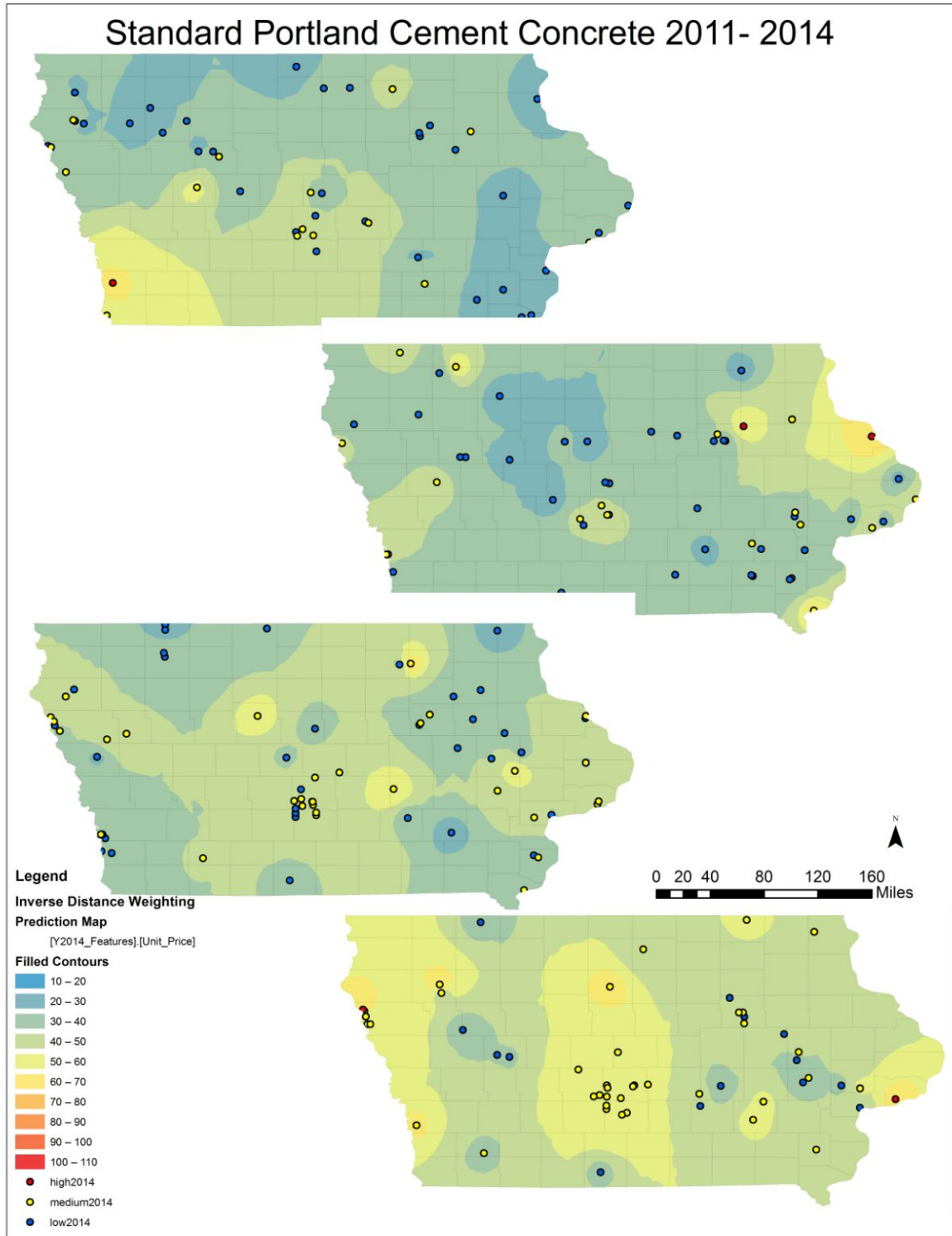


Map by: Deepanshi Jain  
Date: 04/01/2015

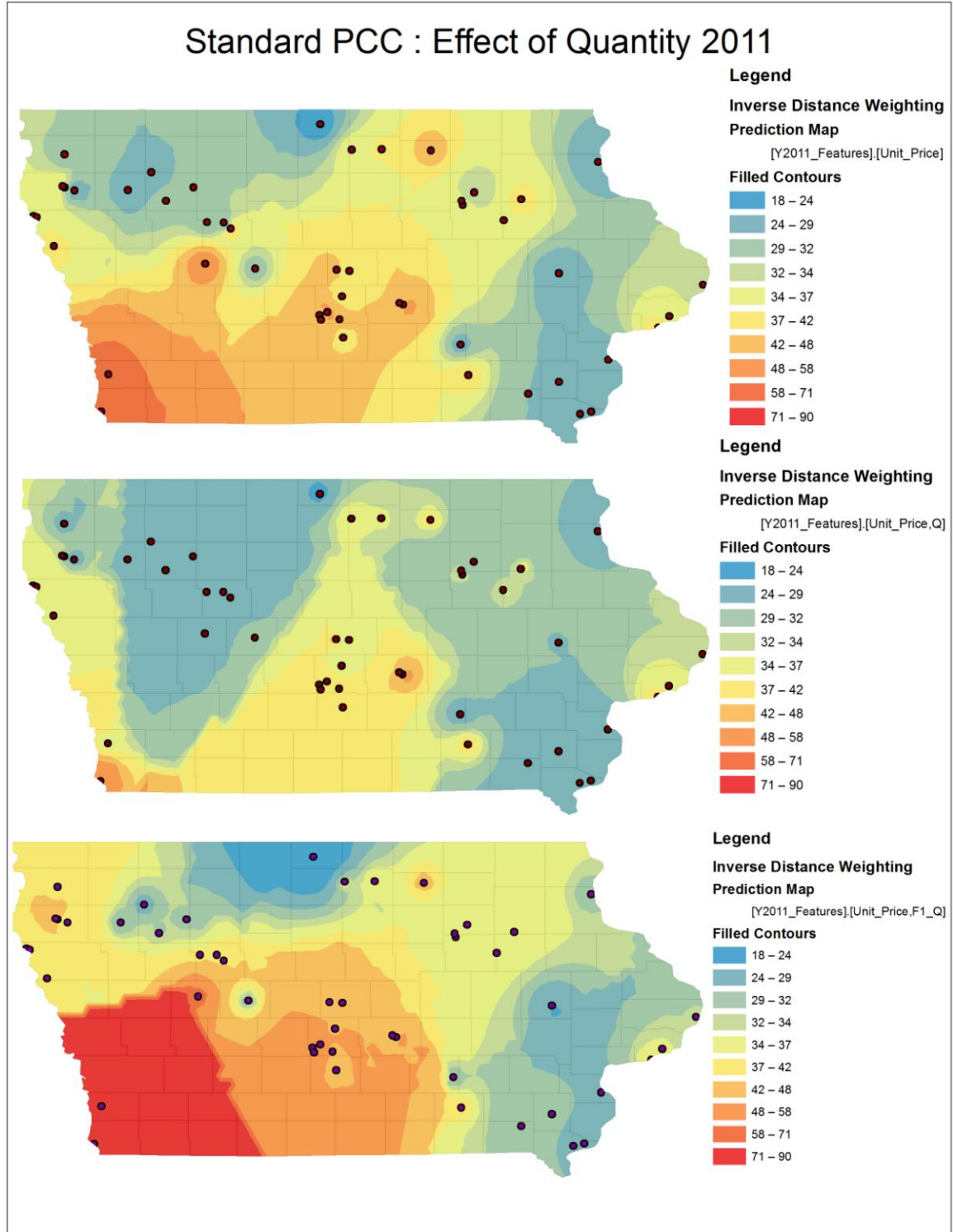


**STANDARD PORTLAND CEMENT CONCRETE**

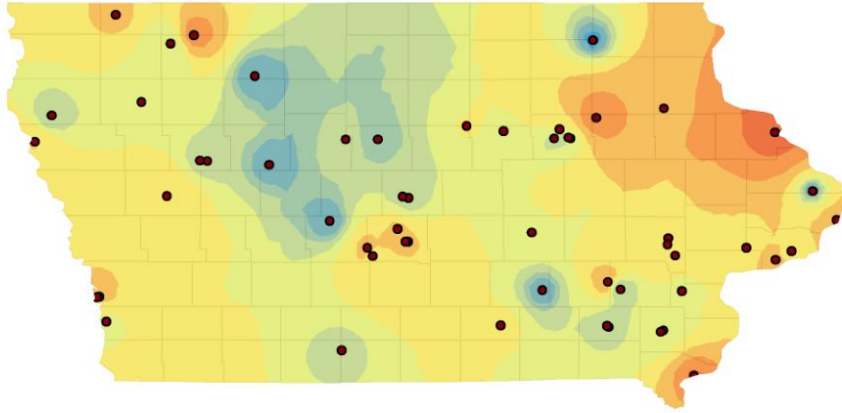
**Phase 1 Results**



Phase 2 Results



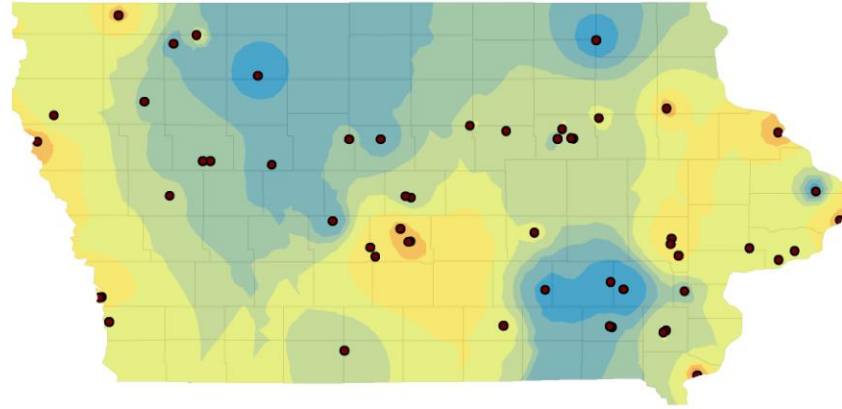
### Standard PCC: Effect of Quantity 2012



**Legend**  
Inverse Distance Weighting  
Prediction Map  
[Y2012\_Features],[Unit\_Price]

**Filled Contours**

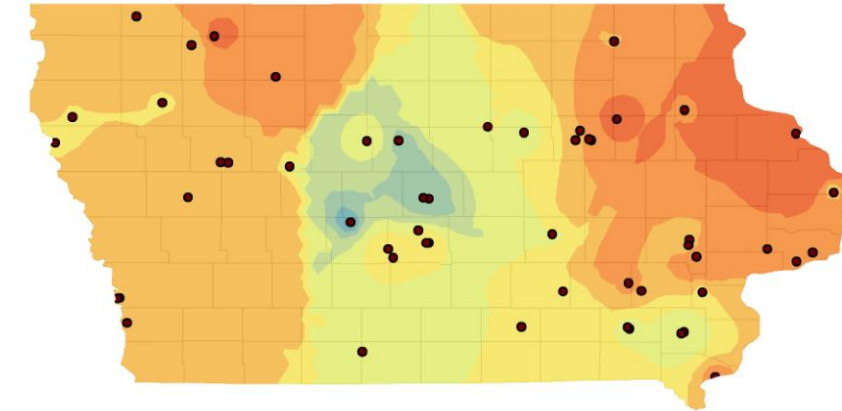
- 21 - 25
- 25 - 28
- 28 - 29
- 29 - 32
- 32 - 36
- 36 - 42
- 42 - 51
- 51 - 63
- 63 - 81
- 81 - 108



**Legend**  
Inverse Distance Weighting  
Prediction Map  
[Y2012\_Features],[Unit\_Price,Q]

**Filled Contours**

- 21 - 25
- 25 - 28
- 28 - 29
- 29 - 32
- 32 - 36
- 36 - 42
- 42 - 51
- 51 - 63
- 63 - 81
- 81 - 108

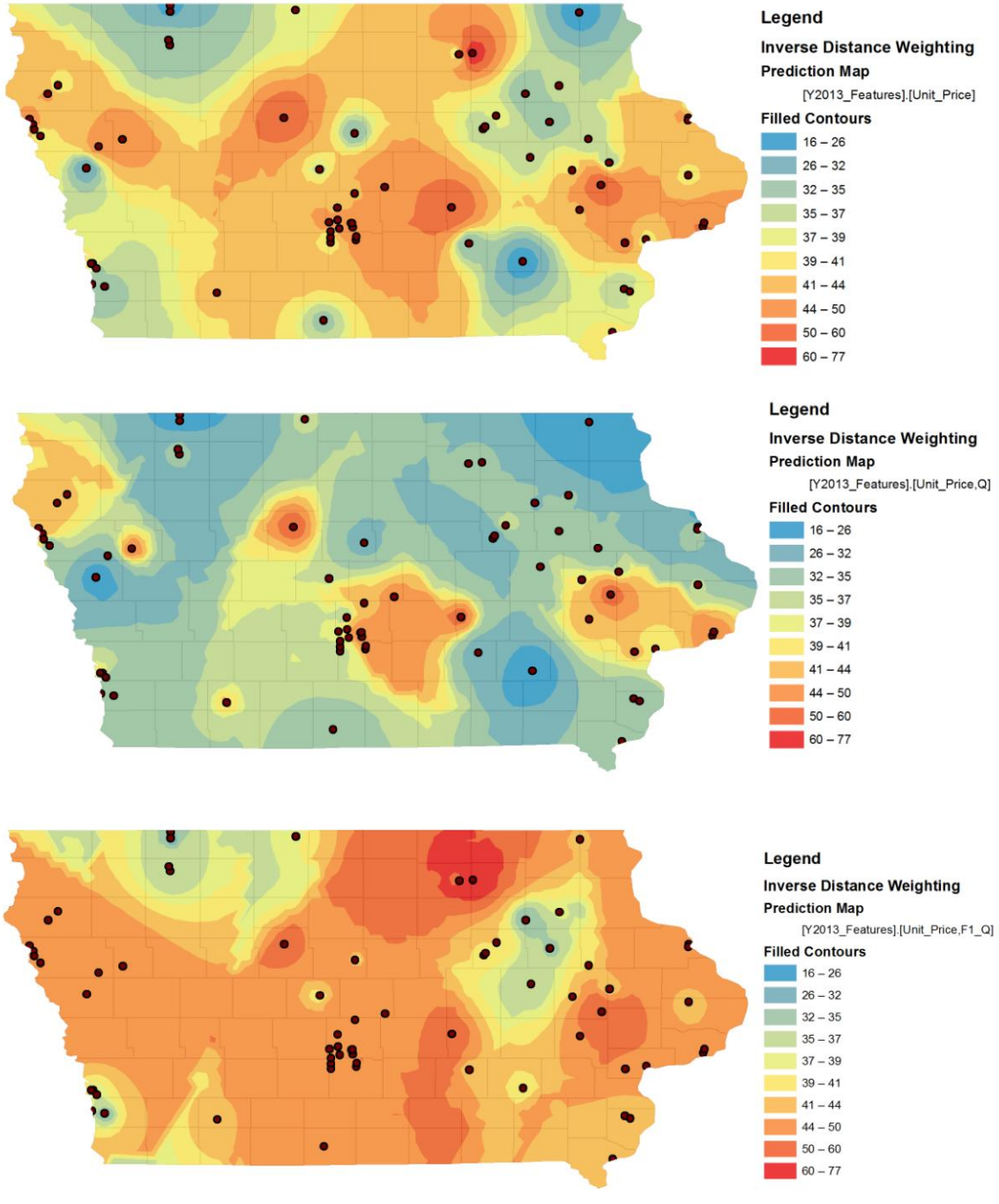


**Legend**  
Inverse Distance Weighting  
Prediction Map  
[Y2012\_Features],[Unit\_Price,F1,Q]

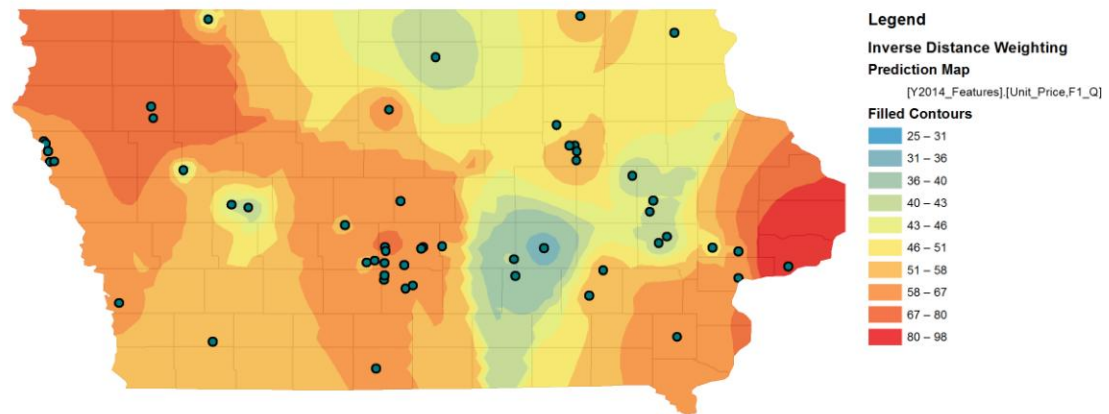
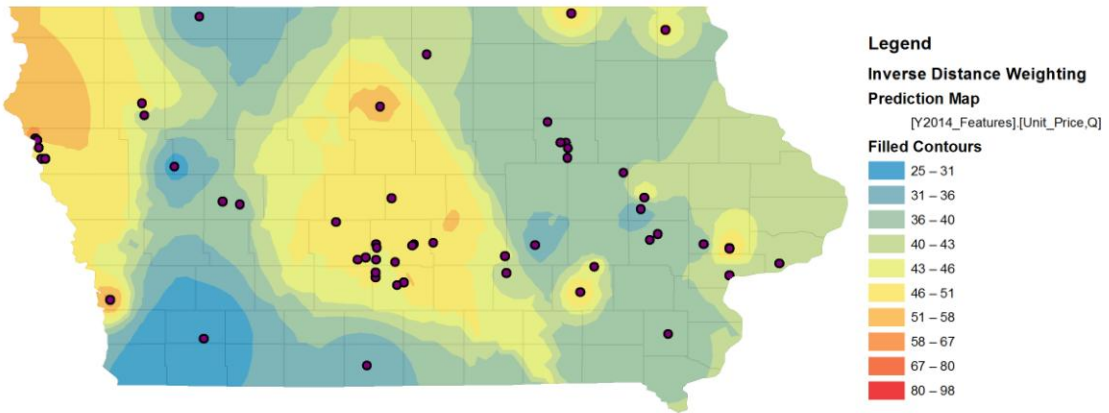
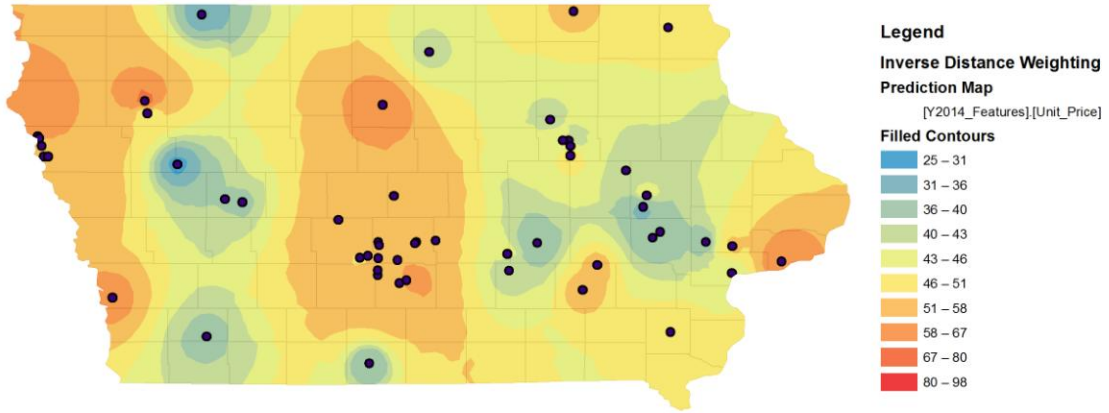
**Filled Contours**

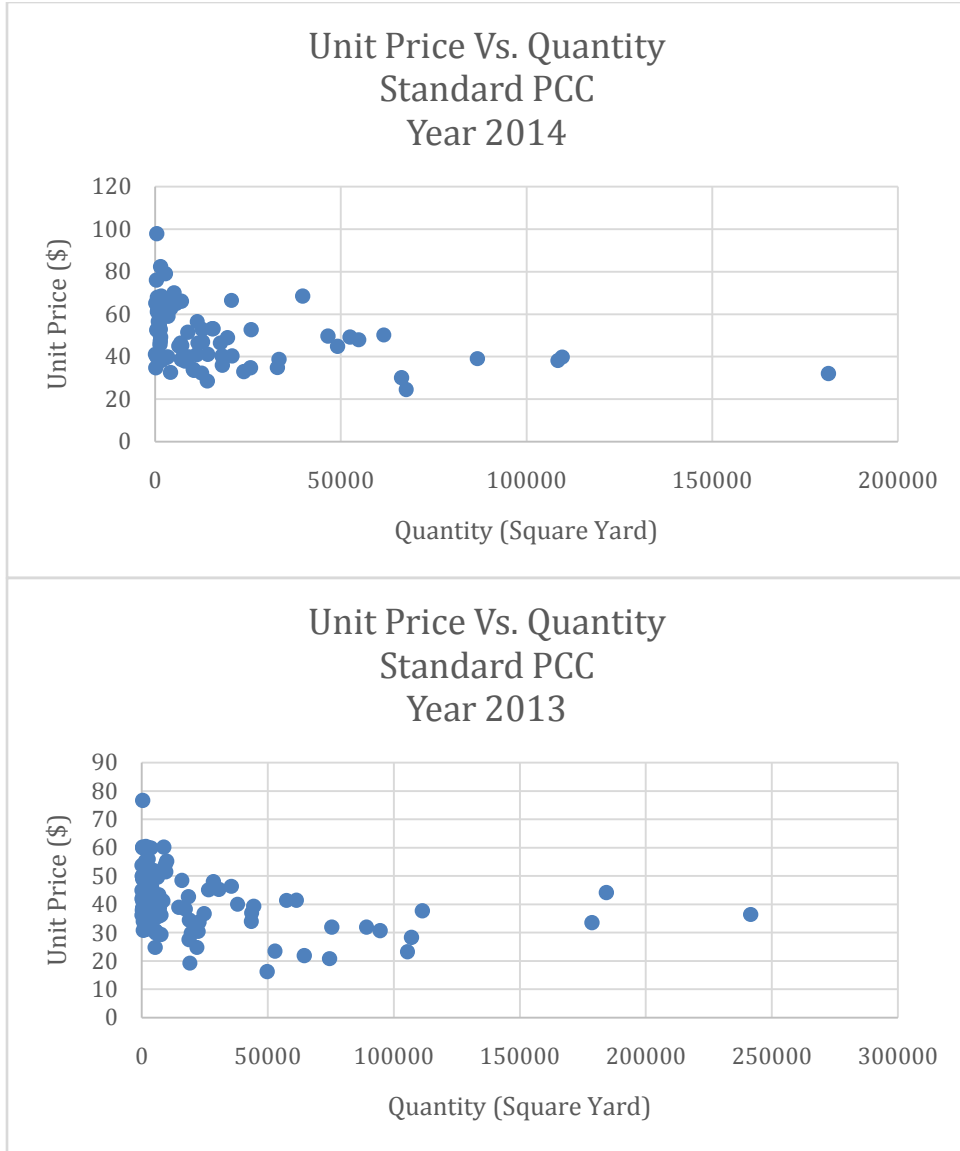
- 21 - 25
- 25 - 28
- 28 - 29
- 29 - 32
- 32 - 36
- 36 - 42
- 42 - 51
- 51 - 63
- 63 - 81
- 81 - 108

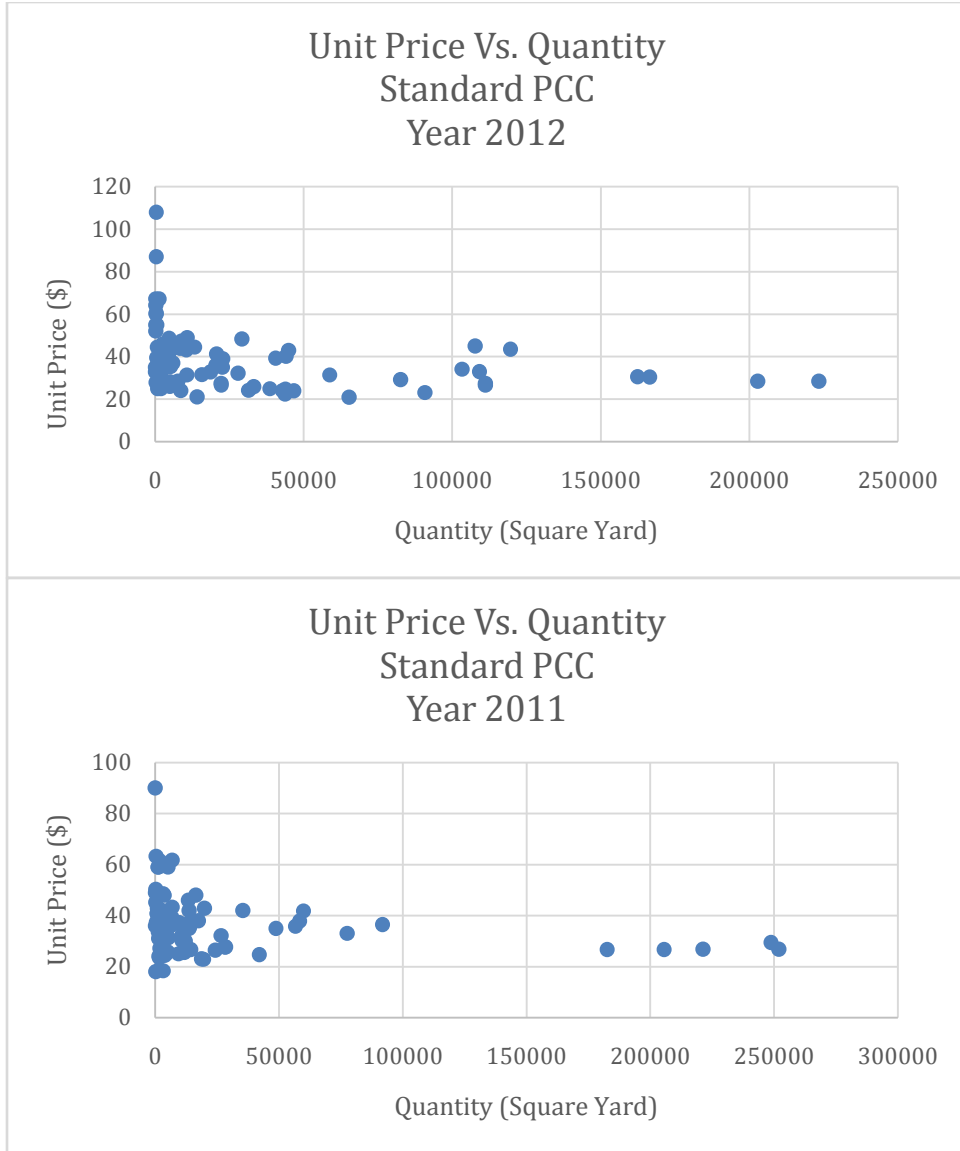
### Standard PCC: Effect of Quantity 2013



### Standard PCC: Effect of Quantity 2014

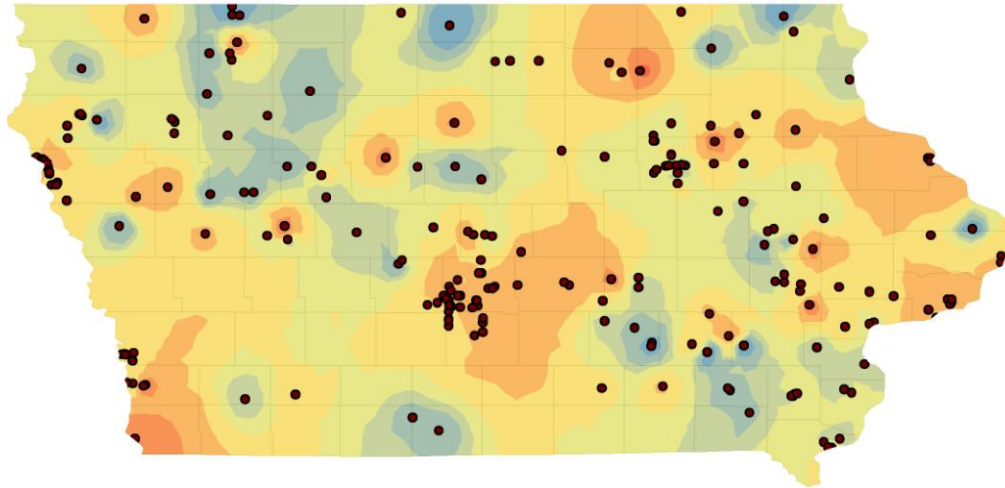






**Phase 3 Results**

**Average Unit Prices for Standard Portland Cement Concrete  
Year 2014**



**Legend**

**Inverse Distance Weighting**

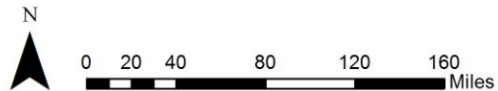
**Prediction Map**

[y2014average\_Features].[Unit\_Price]

**Filled Contours**

- 20 – 29
- 29 – 36
- 36 – 40
- 40 – 42
- 42 – 47
- 47 – 53
- 53 – 63
- 63 – 78
- 78 – 102
- 102 – 138

Bid data was obtained from Iowa Department of Transportation and average unit prices for year 2011 to 2014 were calculated. Cost index was developed using this average unit price keeping 2014 as base year. Unit price data for 2011, 2012, and 2013 were multiplied by index developed to obtain prices in 2014. Thus more number of data points with better distribution were obtained and the cross validation result proved that the average standard error is zero.



Map by: Deepanshi Jain  
Date: 04/01/2015