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Effective Supplier Quality Practices in the Construction Industry

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Effective Supplier Quality Practices in the Construction Industry

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Abstract

The dynamic and irregular nature of projects in the construction industry causes the complexity of supplier quality management (SQM). The Construction Industry Institute (CII) Research Team (RT) 308 is focused on achieving zero rework through effective supplier quality practices.

This honors thesis is an extension of RT 308's project work. Its purpose is to look at current supplier evaluation practices within the construction industry, confirm arecommended supplier cutoff rating through data analysis, and determine if outliers in the data set could be normalized. A survey was developed in Qualtrics (an online survey software tool) and sent to CII members for data collection. Once the data was collected and tested for normality, various analysis techniques were used to analyze the data. These techniques include looking at average supplier rating, assigning 0 (poor) or 1 (good) from the average rating, supplier category ratings, average supplier ratings versus the number of non-conformances (NCs)/Purchase Order (P.O.) dollar, and additional category analysis. It was concluded that the recommended cutoff rating of 4 chosen initially was the correct cutoff rating to choose to ensure suppliers with a high number of NCs do not receive a good supplier rating. Category variations were minimal. The effort to eliminate the outliers by looking at the P.O. size was inconclusive. However, the research team could determine causation of the outliers by tracing the responses back to the respondents. Also, if more data was collected, the outliers could potentially be removed with more data points. A larger data set would get a larger sample of the population and may cause some of the data to become normally distributed.

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Introduction

Supplier quality management (SQM), particularly in the construction industry, is complex due to the dynamic and irregular nature of the projects (AlMaian et al., May 2015). There is no standard on how organizations should evaluate suppliers or on which criteria they should evaluate the suppliers. However, there are some common practices regarding supplier evaluations discussed in the literature.

The Construction Industry Institute (CII) Research Team (RT) 308 is focused on achieving zero rework through effective supplier quality practices. The two-year research project initially wrapped up in July 2014, but some questions were raised during the report out presentation that could be responded to with an extension of the project. This honors thesis was performed during this project extension to assist RT 308 with further examination of effective supplier quality practices specifically through the study of Purchase Orders (P.O.s) for shop fabricated piping materials.

This project was a joint effort between Dr. Kim Needy at the University of Arkansas and Dr. Thais Alves at San Diego State University as part of the RT 308 extension. Panthil Desai, a graduate student working under Dr. Alves at San Diego State University, had previously run normality tests on seven of the survey questions. The normality tests were run twice using two different software: Minitab and Statistical Package for the Social Science (SPSS).

Literature Review

There is a vast amount of scholarly literature on supplier quality management, evaluation, and performance. The purpose of this literature review was to gain an overall understanding of current supplier quality practices, particularly in the construction industry. Articles, journal papers, and book chapters were collected and reviewed and were broken into four common themes: supplier quality management, supplier quality surveillance, supplier evaluation and performance, and quality communication. Table 1 shows each article and the category assigned to it.

Table 1: Literature Review Categories

Category	Articles
Supplier Quality Management	AlMaian, Needy, Walsh, Alves – Supplier Quality Management Inside and Outside the Construction Industry (May 2015)
	AlMaian, Needy, Alves, Walsh – Analyzing Effective Supplier-Quality-Management Practices Using Simple Multiattribute Rating Technique and Value-Focused Thinking (Jun 2015)
	Theodorakioglou, Gotzamani, Tsiolvas – Supplier Management and its Relationship to Buyers' Quality Management (2006)
	Monczka, Handfield, Giunipero, Patterson – Chapter 8: Supplier Quality Management (2016)
Supplier Quality Surveillance	Alves, Walsh, Neuman, Needy, AlMaian – Supplier Quality Surveillance Practices in Construction (2013)
	Neuman, Alves, Walsh, Needy – Quantitative Analysis of Supplier Quality Surveillance Practices in EPC Projects (2015)
Supplier Evaluation and Performance	Kannan, Tan – Supplier Selection and Assessment: Their Impact on Business Performance (2002)
	Simpson, Siguaw, White – Measuring the Performance of Suppliers: An Analysis of the Evaluation Process (2002)
	Drury – Inspection Performance (1992)
	Monczka, Handfield, Giunipero, Patterson – Chapter 7: Supplier Evaluation and Selection (2011)
	Alves, Ravaghi, Needy – Supplier Selection in EPC Projects: An Overview of the Process and Its Main Activities (2016)
Quality Communication	Prahinski, Fan – Supplier Evaluations: The Role of Communication Quality (2007)
	Roethlein, Ackerson – Quality Communication Within a Connected Manufacturing Supply Chain (2004)

Supplier Quality Management

"Supplier quality management (SQM) is a system of processes and practices applied by the organization to ensure that the quality of fabricated materials and equipment meets the project's requirements and specifications" (AlMaian et al., Mar 2015, p. 11). SQM in the construction industry is difficult and complex due to projects being dynamic and irregular. No project is the exact same, so SQM practices that were effective for one project may not be effective for another. Unlike manufacturing environments, quality in the construction industry must be implemented throughout the system since departments tend to overlap. "Construction projects are expensive, take a long time to be completed, interfere with the surrounding environment and neighborhoods, and are built by dispersed teams and suppliers in a project-based fashion where participants might never have worked with each other before and might never work together again" (AlMaian et al., Mar 2015, p. 11). Continuous improvement is difficult in construction projects unless a partnership exists between the organization and supplier; even with a partnership, project variability may still restrict this.

Regardless, the relationship between the construction organization and its suppliers is crucial. The relationship should be collaborative and trusting; partnerships can be considered if the organization and supplier will be working together on multiple projects (Monczka et al., 2016). However, there is no consistent system to aid in the decisions for supplier selection in the construction industry (AlMaian et al., Mar 2015). It is recommended (regardless of industry) for cross-functional teams to visit potential suppliers to assist with supplier selection decisions (Monczka et al., 2016). Once suppliers are selected, frequent quality meetings with both the organization and the supplier in attendance will help keep project quality on track as well as enable the teams to determine any improvements that can be made. SQM practices should be internally reviewed frequently to ensure communication between the organization and the suppliers is consistent (AlMaian et al., Jun 2015).

Theodorakioglou et al. (2006) performed a study regarding the correlation between supply chain management practices and quality management practices. The study concludes that "proper process management provides an infrastructure to the firm that helps the firm to achieve a better relationship quality with its suppliers, a more solid relationship handling and a better information sharing with its suppliers" (Theodorakioglou et al., 2006, p. 154). Therefore, if an organization utilizes effective supply chain management practices when evaluating, choosing, and working with suppliers, the organization is more likely to also have effective quality management practices. One of the most common practices used in the construction industry is supplier quality surveillance.

Supplier Quality Surveillance

Inspection processes are typically non-value added; inspection alone does not ensure quality (Alves et al., 2013). In the construction industry, supplier quality surveillance (SQS) practices are required to be capable of spanning over multiple suppliers with various criticality requirements due to the nature of the industry. Typical issues with current SQS practices include "feedback between organizations, multiple audits, traditional construction practices of the industry rooted in inspection, and multiplicity of requirements and standards" as well as lack of collaboration, lack of trust, and various standards being adopted by certain industries (Alves et al., 2013, p. 835).

Regardless of what organizations observe through SQS, many suppliers in the construction industry have no incentives to change their current ways due to the lack of partnerships because of the variable nature of the construction industry (Alves et al., 2013). If a supplier is only working with an organization once for a short amount of time, they may not believe there is any reason why they should change their current quality expectations.

SQS practices typically include inspection at the shop, inspection at the site, and mechanical completion. Inspection at the shop is the initial inspection following production. The product will either be approved for delivery to the site, conditionally approved, or corrections need to be made. Conditionally approved items will be sent and corrected at the site, approved in its current condition, or corrected at the shop and then sent to the site. Once items are sent to the site, another inspection is performed to ensure the initial inspection was correct and shipping damage did not occur. This inspection is where overages, shortages, and damages are assessed. These products will be approved for installation, corrected on site, or sent back to the shop for corrections. Ultimately, the number of products sent back to the shop for corrections should be minimal. A product has reached mechanical completion once it is installed and ready for use; another quality inspection is performed at this stage (Alves et al., 2013).

SQS could improve through communication, transparency, and learning from both the organization and suppliers. Increasing collaboration between the organization and the suppliers would ensure projects are completed with less cost and the best quality. SQS is a broad process and will vary from project to project depending on the specific scope, size, and timeline. Supply chain management allows for an organization to control "the multiple factors that constitute the delivery of material, equipment, resources, and information in order to achieve project completion" (Neuman et al., 2015, p. 2). Quality control or inspection and testing plans were reported in 100% of the responses received by a survey created for a previous research project performed by RT 308 concerning supplier quality surveillance practices; however, it was noted that this plan is not always followed for various reasons. This same study also found that as communication with suppliers both before and during execution increases, the supplier quality increases (Neuman et al., 2015).

Supplier Evaluation and Performance

There are many examples in literature today that have studied supplier evaluation and performance metrics. Kannan and Tan (2002) created a survey to see what elements of a supplier assessment are most important to firms. Each firm was asked to rate the level of importance of each criteria on a scale of 1 to 5, with 1 being low importance and 5 being high importance. The results are shown in Table 2 (Kannan & Tan, 2002).

Table 2: Elements of Supplier Assessment (Kannan & Tan, 2002)

Assessment Criteria	Mean Score
Quality level	4.73
Service level	4.62
On-time delivery	4.57
Quick response time in case of emergency, problem, or special request	4.44
The flexibility to respond to unexpected demand changes	4.27
Correct quantity	4.15
Price/cost of product	4.10
Willingness to change their products and services to meet your changing needs	3.88
Communication skills/systems (phone, fax, email, internet)	3.79
Willingness to participate in your firm's new product development and value analysis	3.57
Presence of certification or other documentation	3.50
Willingness to share sensitive information	3.10
Use of electronic data interchange (EDI)	2.69

Table 2 shows quality and service levels were most important to firms. Use of EDI and willingness to share sensitive information were least important to firms. Simpson, Siguaw, and White (2002) analyzed the evaluation process itself, noting that certifications and awards may not distinguish suppliers from each other as they keep achieving the same quality levels. It was discovered that 35.7% of the respondents have a pre-selection evaluation in place. 59.5% of the respondents stated the buyer performs the evaluation, with 41.7% of the evaluation processes being extensive. If a weighting system is in place (meaning weights are put on each category on the evaluation form), the weight is usually placed on quality. The criteria that were included most often on the form were quality and process control, continuous improvement, facility environment, customer relationship, delivery, inventory and warehousing, ordering, and financial conditions (Simpson, Siguaw, & White, 2002).

Colin Drury (1992) dug deeper into quality inspection by studying inspection performance. He broke down inspection into four characteristics: accuracy, speed, flexibility, and stability. An inspection function must involve these characteristics to be successful in minimizing quality errors. Once an inspection error has occurred, it can be solved in three ways: ignoring it, reducing it, or compensating for it. Drury notes that ignoring an inspection error can be dangerous and costly; this is especially true for the construction industry. He continues by explaining hits, misses, correct accepts, and false alarms. Inspection functions will have four tasks: present, search, decision, and action. Drury also discusses the possibility of automating inspection. However, these automating systems are still reliant on human inspectors. There is also a storage and handling problem that comes with inspection, especially with larger products. By including a reliable inspection system in the process design, errors can be faced and measured to ensure quality products (Drury, 1992).

The 5th edition of *Purchasing and Supply Chain Management* states that many supplier evaluations have three criteria: price/cost, quality, and delivery. A buyer will also evaluate a supplier's management capability, employee capability, cost structure, total quality performance, systems, philosophy, process and technological capability, sustainability and environmental compliance, financial stability, production scheduling, control systems, e-commerce capability, sourcing strategies/policies/techniques, and longer-term relationship potential. Supplier evaluations are typically performed using comprehensive, objective surveys (Monczka et al., 2011).

"The main goal of the supplier selection and evaluation process is to reduce the purchase risk and increase value to the purchaser" (Alves et al., 2016, p. 210). RT 308 performed research regarding critical procurement quality practices to assist with developing the supplier evaluation criteria for the survey used with this thesis. The results found that quality, scheduling, experience, cost, and capabilities were the top five characteristics suppliers are evaluated on (Alves et al., 2016). The results of this research assisted in the development of the nine criteria used in the Qualtrics survey.

Quality Communication

Communication between a buyer and its suppliers seems intuitively crucial to the success of the project at hand. Prahinski and Fan (2007) studied automotive suppliers due to the industry's long-standing supplier evaluation programs. After gaining survey responses from 138 suppliers, it was found that communication quality and supplier performance does not have a direct relationship. However, "when the supplier believes that the evaluation content is important, the level of communication quality, in terms of usefulness, timeliness, clarity and thoroughness, is considered to be high" (Prahinski & Fan, 2007, p. 22).

Roethlein and Ackerson (2004) studied communication in a connected supply chain through interviewing a distributor, manufacturer, supplier, and sub-supplier. It was discovered that the best communication of quality goals occurred between the manufacturer and supplier. Communication of quality goals was good between the manufacturer and distributor, and poor throughout the rest of the chain. This supply chain had “no integrated management or goal alignment” and “true partnerships did not exist in this connected supply chain” (Roethlein & Ackerson, 2004, p. 328).

Results of the Literature Review

After performing this literature review, RT 308 used this information to develop a survey to collect supplier quality data on P.O.s of shop fabricated piping materials. The research performed by Alves, Ravaghi, and Needy assisted with the development of the nine supplier criteria included in the survey (Alves et al., 2016). Survey questions were placed into Qualtrics (an online survey software tool), tested for errors, and sent to CII members for data collection. The analyses performed and discussed throughout the duration of this thesis used data collected from this survey. A copy of the survey distributed can be found in Appendix A.

Approach and Methodology

A visual timeline of the research team’s approach is shown in Figure 1.

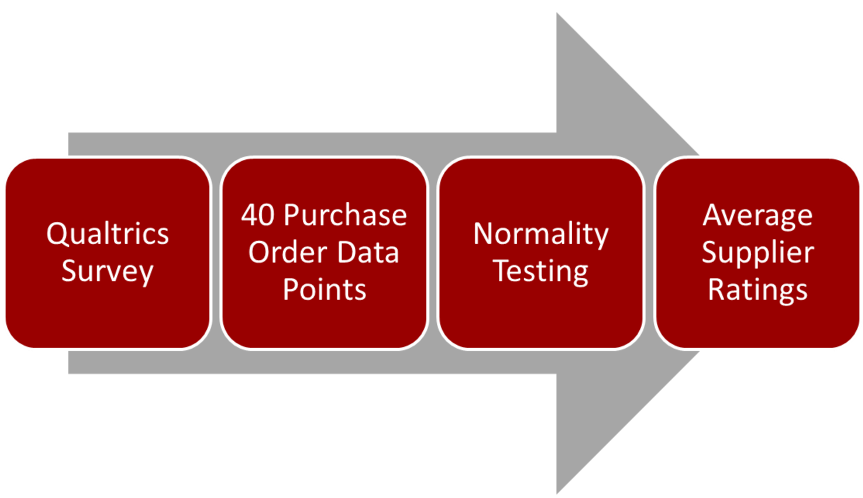

Figure 1: Approach Steps

Shortly after the normality tests were run on the existing survey data, more Purchase Order (PO) data was entered into Qualtrics. This caused the need for the normality tests to be re-run on both Minitab and SPSS. Working in collaboration with Panthil Desai ensured the tests were run with the same rules for each of the questions.

Two hypotheses posed for this research project extension involved supplier ratings; one of these hypotheses focused on the relationship between supplier ratings and the number of non-conformances (NCs) at the shop. In this approach, an average supplier rating was calculated by taking the simple average of the nine supplier criterion from the Qualtrics survey which included plant operations/building infrastructure, manufacturing capability, experience and qualifications, workforce, engineering capability, material control, adherence to procedures and standards, safety adherence and record, and handling of subcontractors and suppliers. It was initially decided an average supplier rating of 4 (on a 5-point Likert scale with 5 as the highest rating) or above meant the supplier received a high rating, and an average rating below 4 (with 1 as the lowest rating) meant the supplier received a low rating. However, this cutoff value of 4 was really selected arbitrarily. The team desired a structured method for determining the cutoff value for whether suppliers received high or low average ratings. The hypothesis used for this analysis stated that higher supplier ratings should result in a lower number of NCs in the shop.

Five methods for analyzing the survey data were used. These methods are displayed in Figure 2.

Figure 2: Five Data Analysis Methods

One method to determining the cutoff value was to graph a scatter plot of the average supplier quality rating against the number of NCs at the shop and fit a linear regression line to the data. This line would indicate the data's overall trend and help solidify that the higher the number of NCs at the shop, the lower the supplier rating and vice versa. By fitting a linear regression to the model, the R-squared value could be used to determine goodness of fit. Next, a horizontal line would be used on the same graph to determine the cutoff between a high rating and a low rating; by moving the placement of this horizontal line, the cutoff rating would be adjusted and give more suppliers high or low ratings depending on the direction the line moves.

The second method to determining the best cutoff value was to test several cutoff ratings using a binary approach. This method gave suppliers a score of 1 for a good rating or 0 for a poor rating; several cutoff values were taken into consideration. By graphing the ratings of 0 or 1 against the number of NCs at the shop, the number of suppliers for each rating would be counted. The accuracy of the cutoff rating would be determined by looking at the number of outliers, meaning the number of suppliers given a score of 0 (poor rating) with a low number of NCs (high quality) at the shop as well as the number of suppliers given a score of 1 (high rating) with a high number of NCs (low quality) at the shop.

The third method was to graph each category (criterion) rating, rather than the average rating, against the number of NCs at the shop. This approach gives visibility to the supplier ratings in each category to see if one category is skewing the average supplier rating.

After the results of the first three methods, it was decided that a fourth method should be used in an effort to further study two major outliers in the data set. The two major outliers had a much higher number of NCs in comparison to the other data points; it was decided that P.O. size (in terms of dollars) should be considered as well to account for the belief that the size of the P.O. could influence the number of NCs in the shop. Therefore, the fourth method graphed the number of NCs in the shop per P.O. dollar against the average supplier quality rating in order to normalize the data. The number of NCs in the shop per P.O. dollar was factored by 10,000,000 to make the values larger and easier to graphically depict.

A fifth method was added for additional category data analysis. This approach counted the number of each rating for each category. This method also used a binary approach and counted the number of suppliers receiving a good rating versus a poor rating depending on the cutoff used.

Results

Normality Testing

The results of the re-run normality tests with the full data set on both Minitab and SPSS were the same as Panthil Desai's results. All normality tests resulted in the data not being normally distributed with p-values of less than 0.01. Since many statistical tests assume the data is normally distributed, traditional statistical tests cannot be run with this data set.

Therefore, when looking into the hypothesis regarding supplier ratings and number of NCs at the shop, statistical testing was not the preferred method of analysis. Instead, the focus was on data trends and graphs rather than statistical tests.

Method 1: Average Supplier Rating

The first method evaluated the average supplier ratings against the number of NCs in the shop. A scatter plot was generated with the data, and a linear trend line was fit to the data to determine the equation for the data overall as well as the R^2 value. To test the cutoff ratings, a horizontal line was added and shifted up and down (higher and lower) to show each cutoff value.

One main issue that was consistent throughout the analysis was outliers. Two survey responses had a supplier with NC values of 351 and 750; in comparison, the rest of the survey responses had NCs equal to or less than 55. To allow for visibility of the other data points, additional graphs were created with the two major outliers removed.

The first cutoff value evaluated was a value of 4.5; suppliers with an average rating of 4.5 or above were considered good while suppliers with an average rating below 4.5 were considered poor. A linear regression trend line was added to the graph to confirm that as the number of NCs increases, the supplier quality rating should decrease. Figure 3 displays the results of this initial cutoff value.

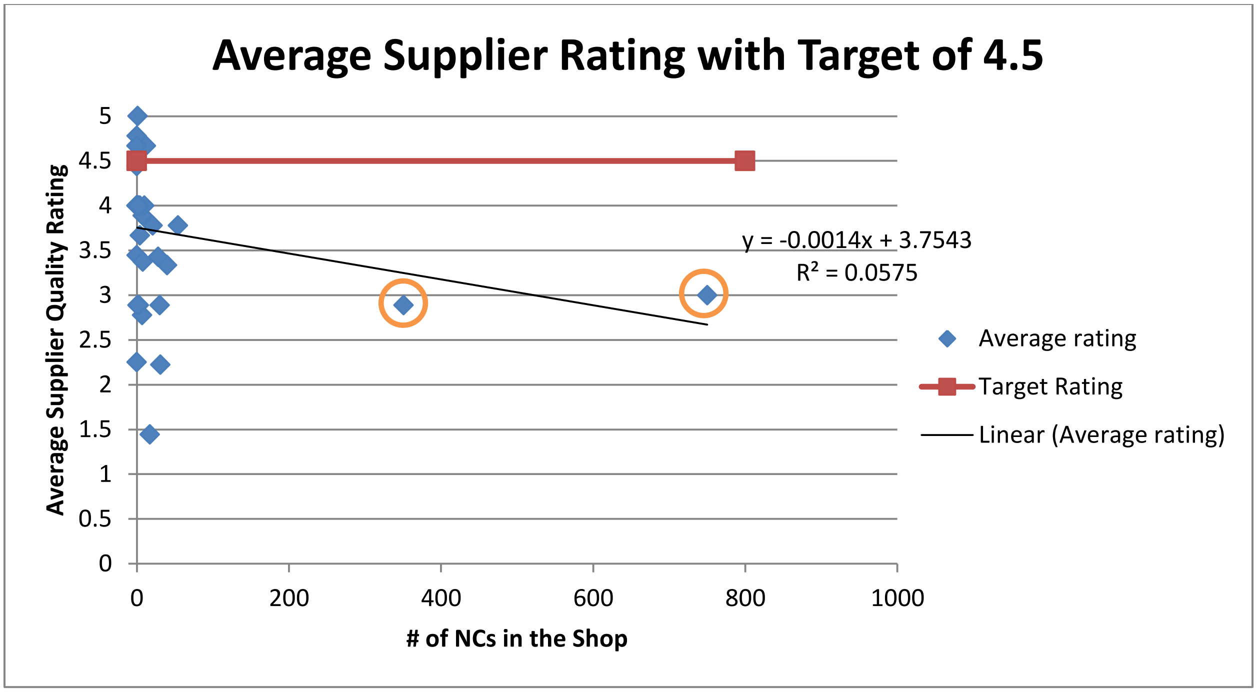

Figure 3: Average Supplier Rating with Target of 4.5

As shown in Figure 3, the two outliers (circled in orange) make it difficult for one to see the other data points. Figure 4 below displays the same information as Figure 3 but with the two major outliers removed.

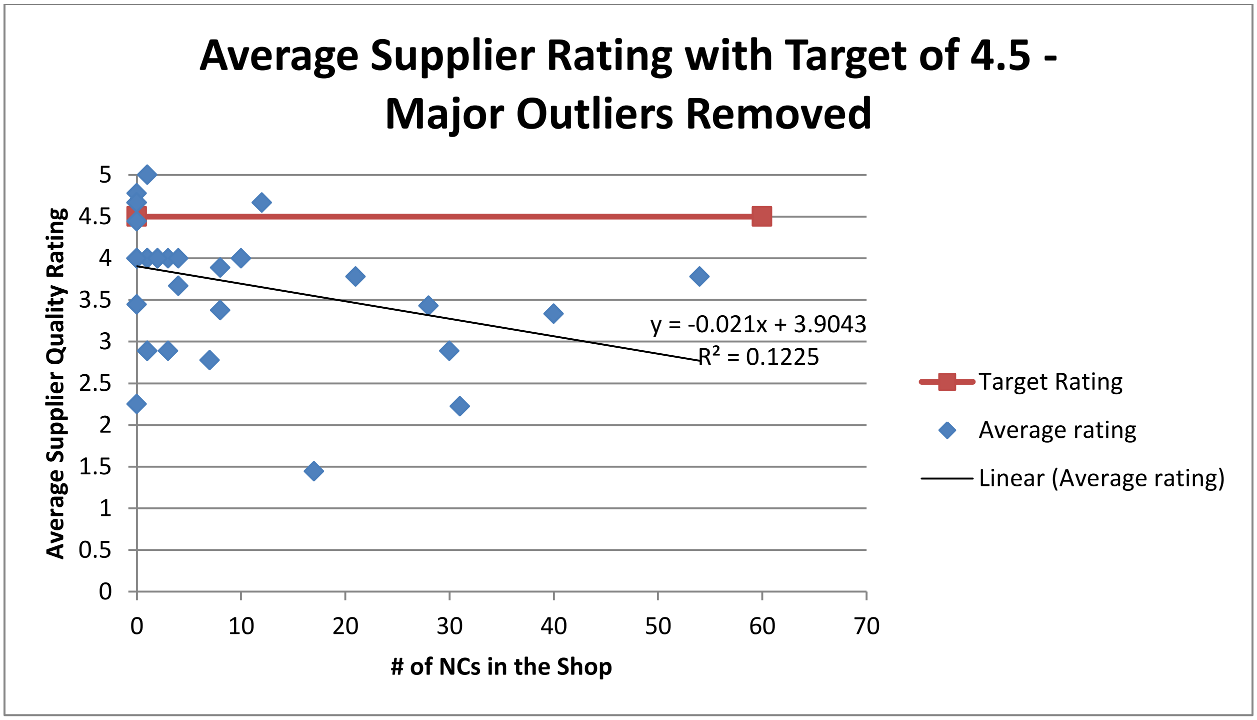

Figure 4: Average Supplier Rating with Target of 4.5 - Major Outliers Removed

With the removal of the two outliers, Figure 4 allows for better visibility of the data. The regression line confirms what the overall trend of the data should be. Next, a cutoff value of 4 was evaluated. Recall that the value of 4 was the value that had been previously selected arbitrarily. The results of this cutoff value are displayed in Figure 5 and Figure 6. Figure 6 uses the same principle as Figure 4: the outliers were removed to allow for better visibility of the data.

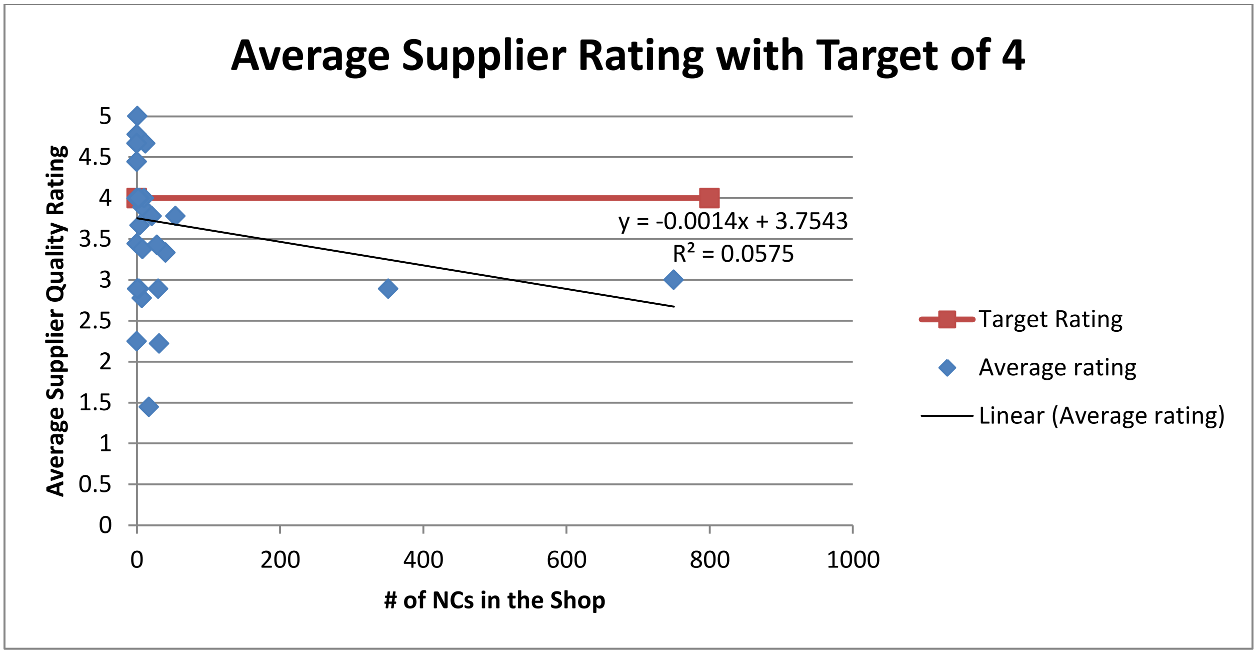

Figure 5: Average Supplier Rating with Target of 4

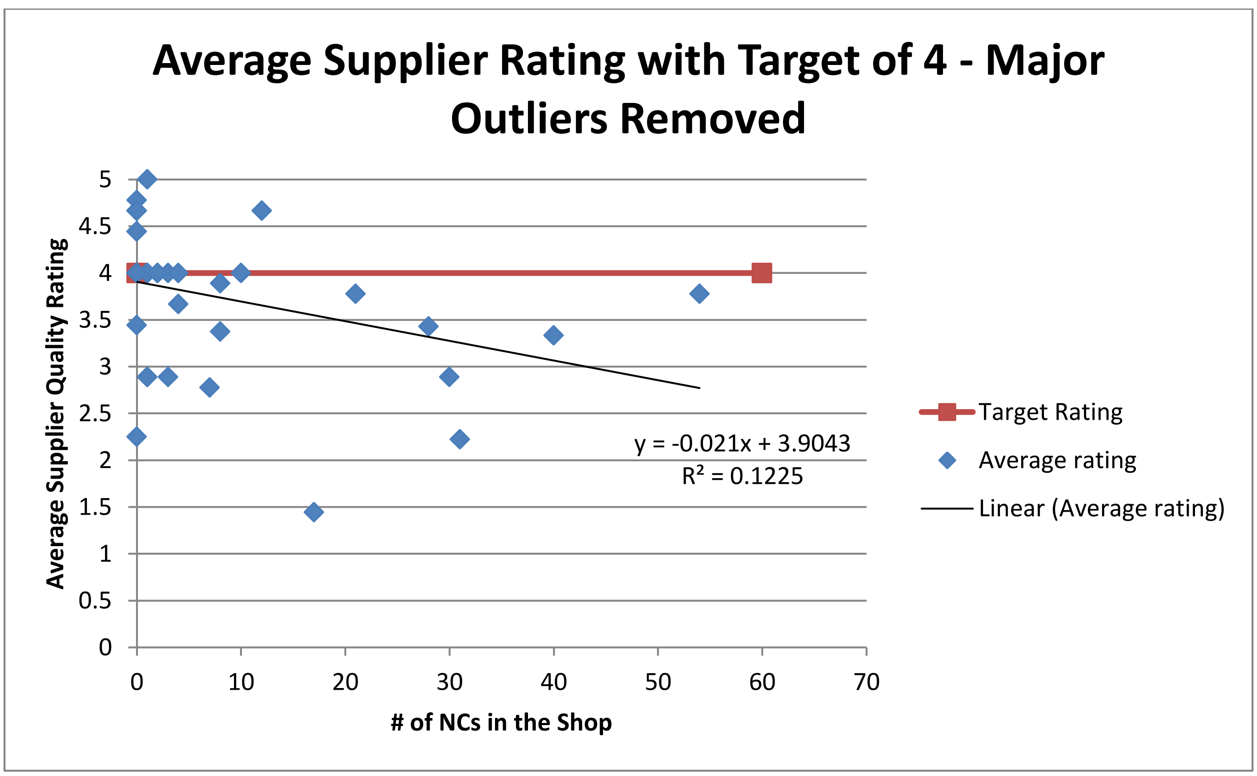

Figure 6: Average Supplier Rating with Target of 4 - Major Outliers Removed

Figure 6 shows that all of the suppliers with an average rating greater than or equal to 4 have a low number of NCs in the shop in comparison to the other data points. All of the suppliers with an average rating less than 4 are still being given a poor rating based on the cutoff value of 4. The next cutoff rating evaluated was a cutoff of 3.5. Figures 7 and 8 illustrate the results of the analysis for this cutoff rating using the same principles and methods applied in Figures 3-6 above.

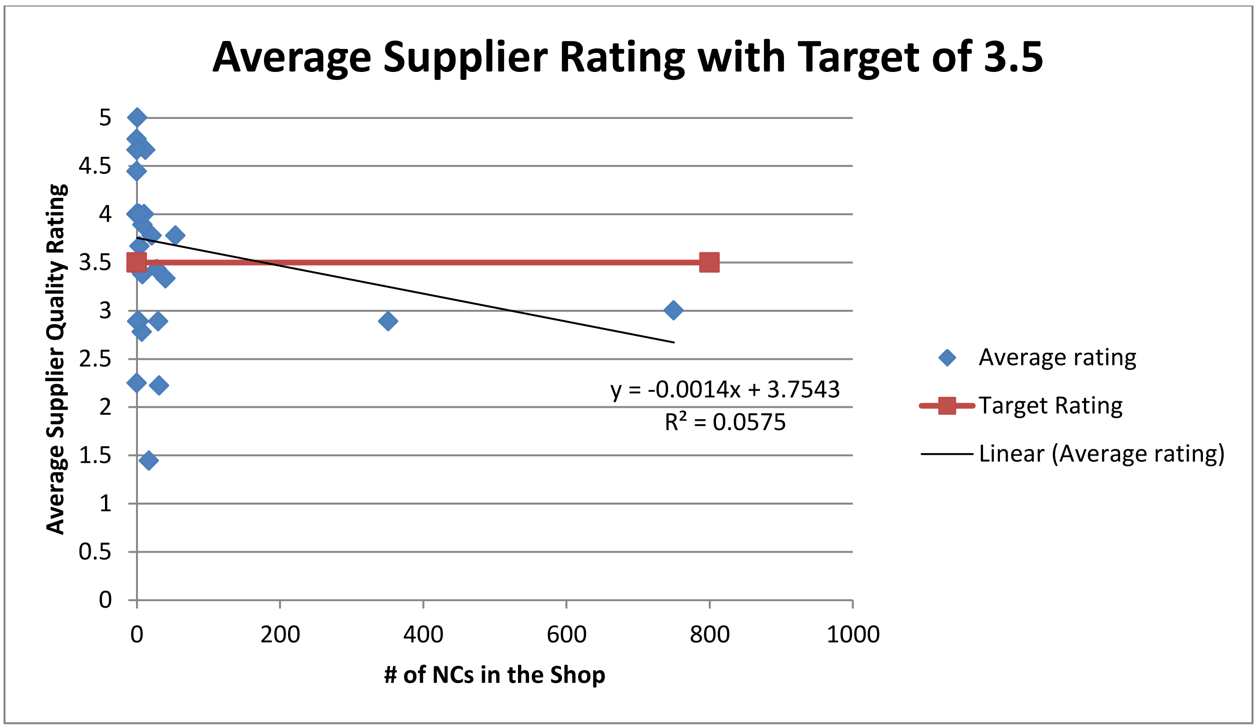

Figure 7: Average Supplier Rating with Target of 3.5

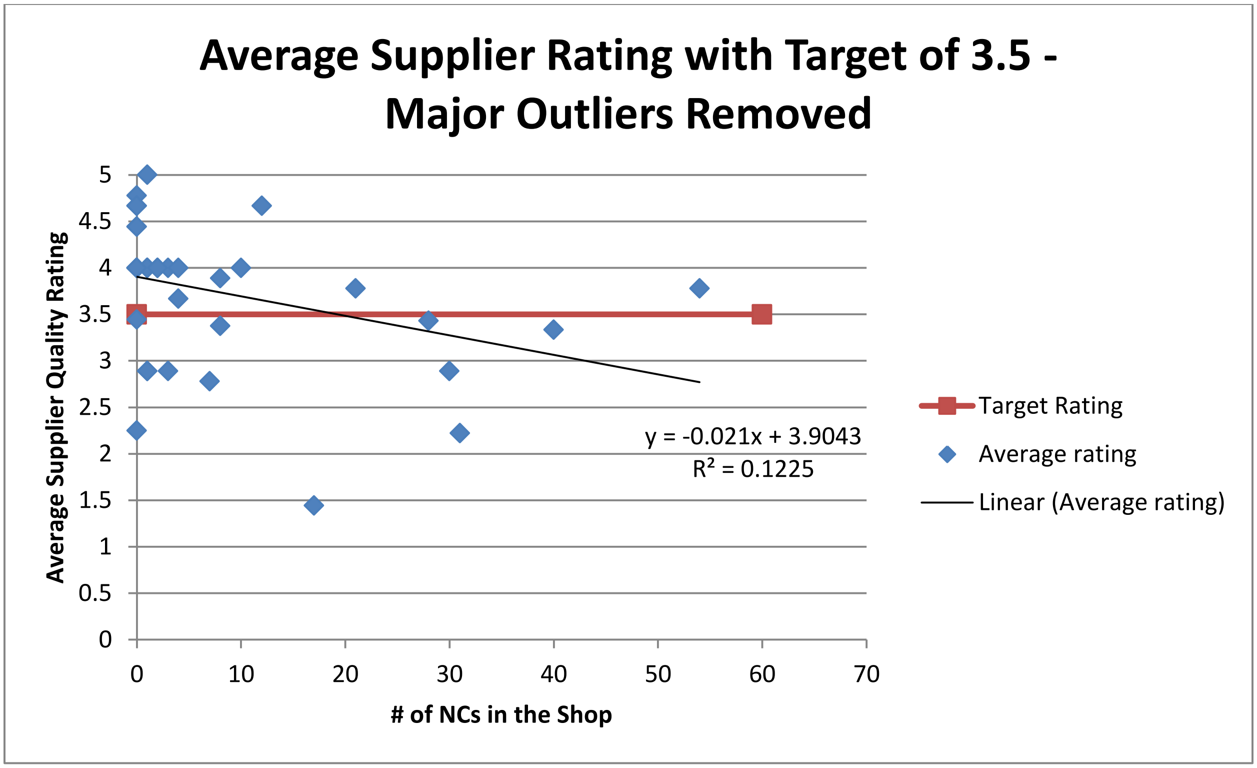

Figure 8: Average Supplier Rating with Target of 3.5 - Major Outliers Removed

In Figure 8, one can see that some data points are now appearing above the target rating line even though they have a high number of NCs in comparison to the other data points. This means that these suppliers are receiving good ratings with a high number of NCs, which is counterintuitive. Suppliers with a high number of NCs should be receiving poor ratings. The line between good and poor becomes even more blurred with a target cutoff rating of 3. The analysis for the cutoff rating of 3 is shown in Figures 9 and 10.

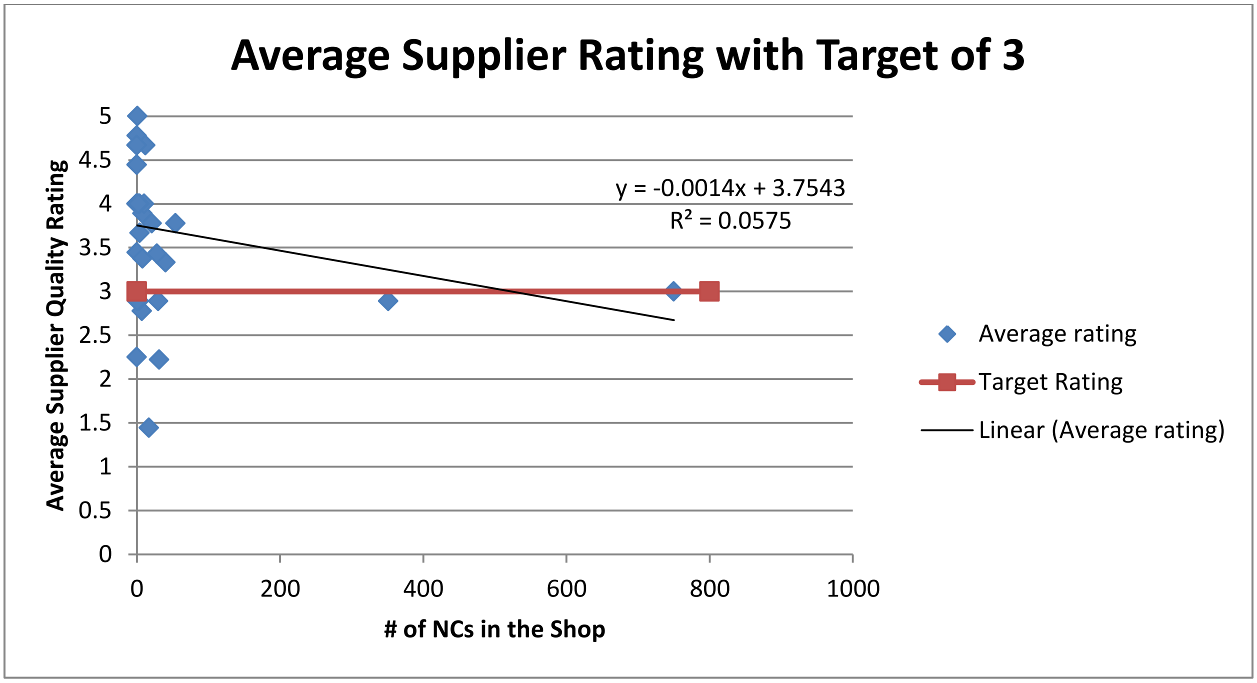

Figure 9: Average Supplier Rating with Target of 3

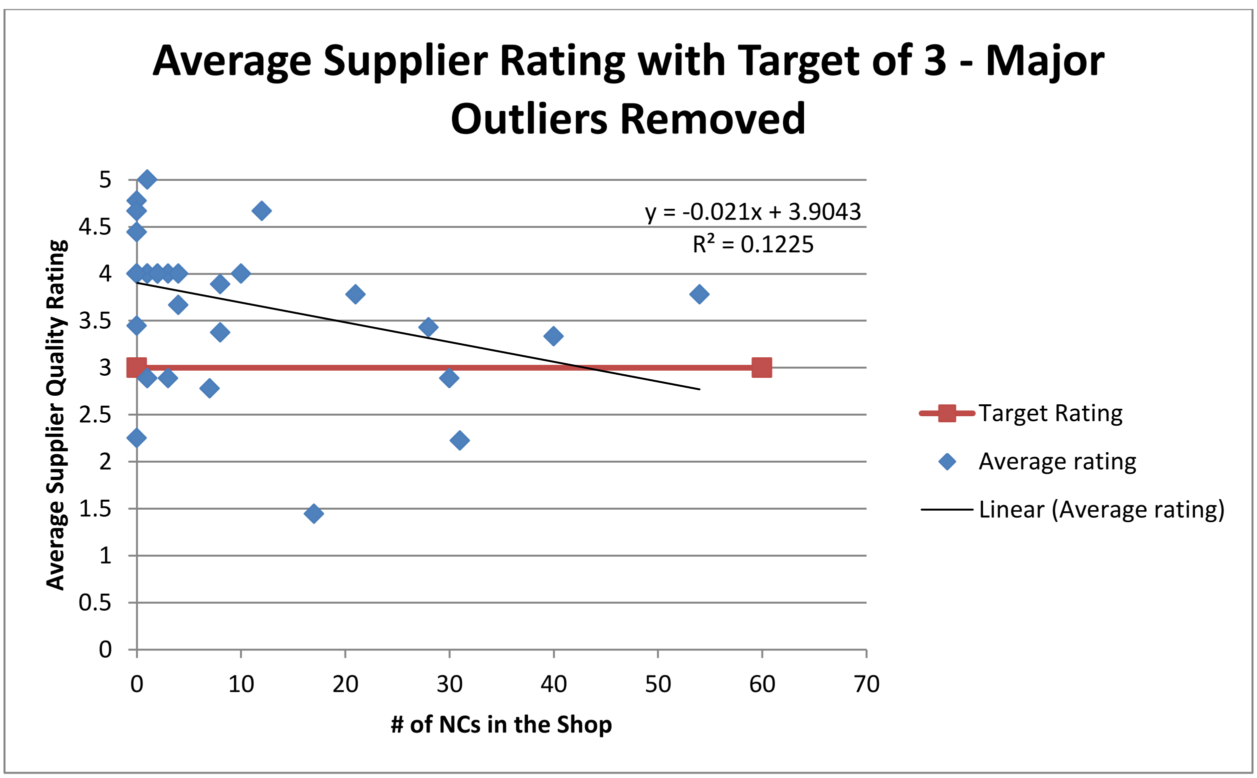

Figure 10: Average Supplier Rating with Target of 3 - Major Outliers Removed

Based on the results above, it was concluded that a cutoff rating of 3 is too relaxed, while a cutoff rating of 4.5 is too strict. A target rating of 3 has several suppliers receiving a good rating with a high number of NCs, and a target rating of 4.5 has too few suppliers with a low number of NCs receiving a good rating. Therefore, the two remaining target values are 3.5 and 4. The major outliers would both receive an overall poor rating with either of these target values. However, the best cutoff rating to choose would be a cutoff rating of 4. This cutoff value ensures there are no suppliers that receive a good rating with a high number of NCs. A cutoff value of 3.5 would have a few suppliers with a high number of NCs receiving a good rating; this is something the research team is trying to avoid. Table B – 1 in the Appendix shows the number of suppliers that would receive a good or poor rating based on the cutoff value. Overall, the intuition to choose a cutoff rating of 4 was validated through this method of analysis.

Method 2: Assigning 0 (Poor) or 1 (Good) from the Average Rating

The second method evaluated the average ratings at the same four cutoff values of 4.5, 4, 3.5, and 3. However, instead of plotting the average rating on the y-axis, suppliers were assigned a rating of 0 if they were a poor supplier or 1 if they were a good supplier based on each cutoff value.

The outliers for the second method are the same two outliers as those in the first method. The outliers were handled in the same way as the first method; they were removed to help see what the rest of the data points look like. Figure 11 shows the initial graph with a good rating (1) being given for average supplier ratings of 4.5 or above and the outliers circled in orange, while Figure 12 shows the same graph as Figure 11 but with the outliers removed.

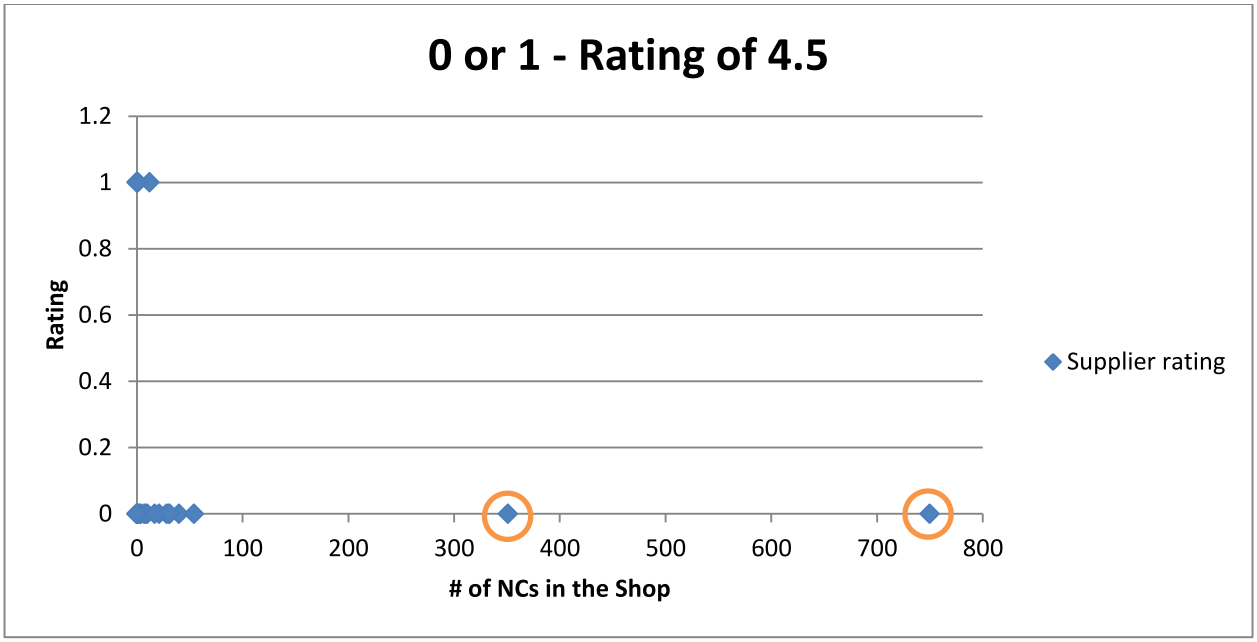

Figure 11: Average Rating, Good (1) = 4.5

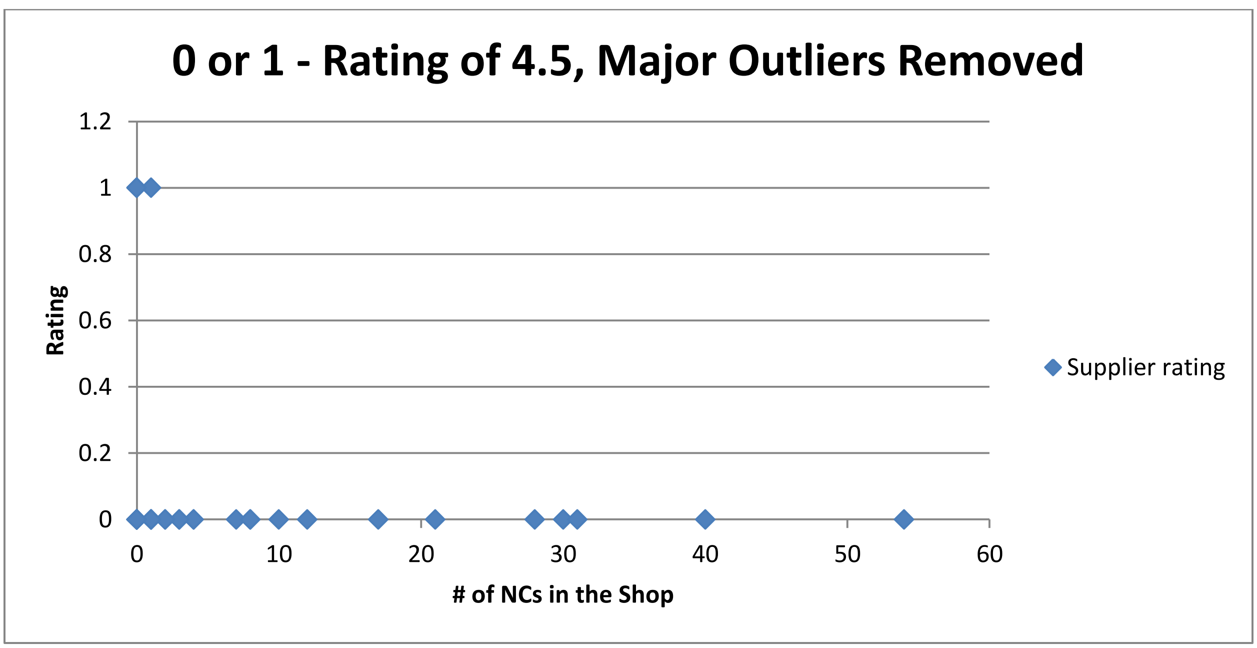

Figure 12: Average Rating, Good (1) = 4.5, Major Outliers Removed

With a cutoff rating of 4.5, no suppliers with a high number of NCs received a good supplier rating. Next, a cutoff rating of 4 was evaluated using the same procedure. Figures 13 and 14 illustrate this cutoff rating analysis.

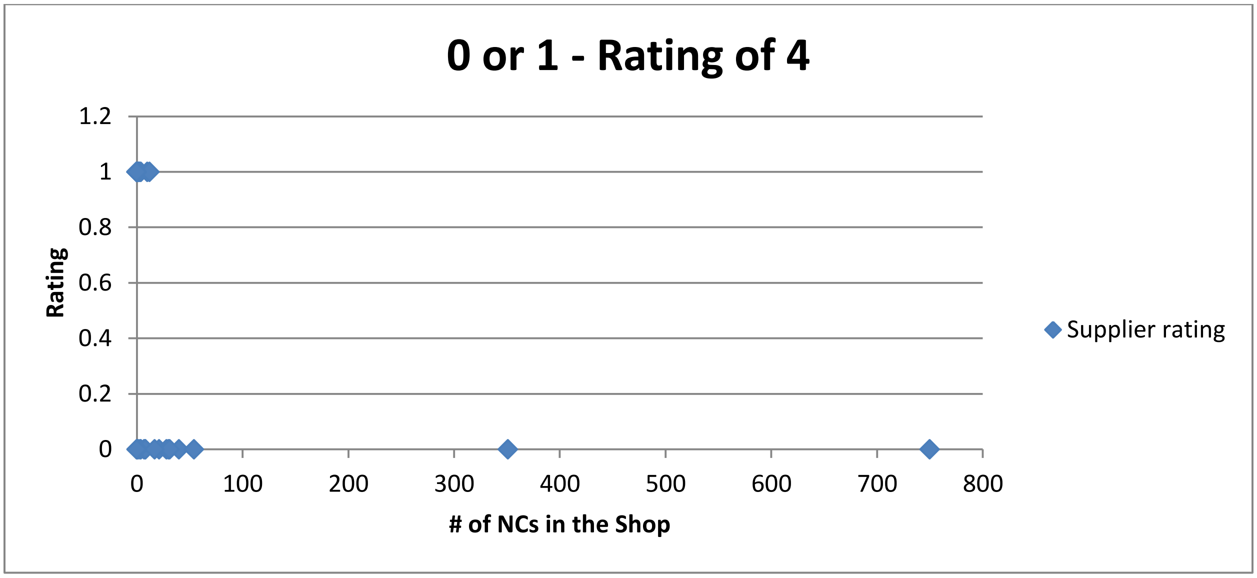

Figure 13: Average Rating, Good (1) = 4

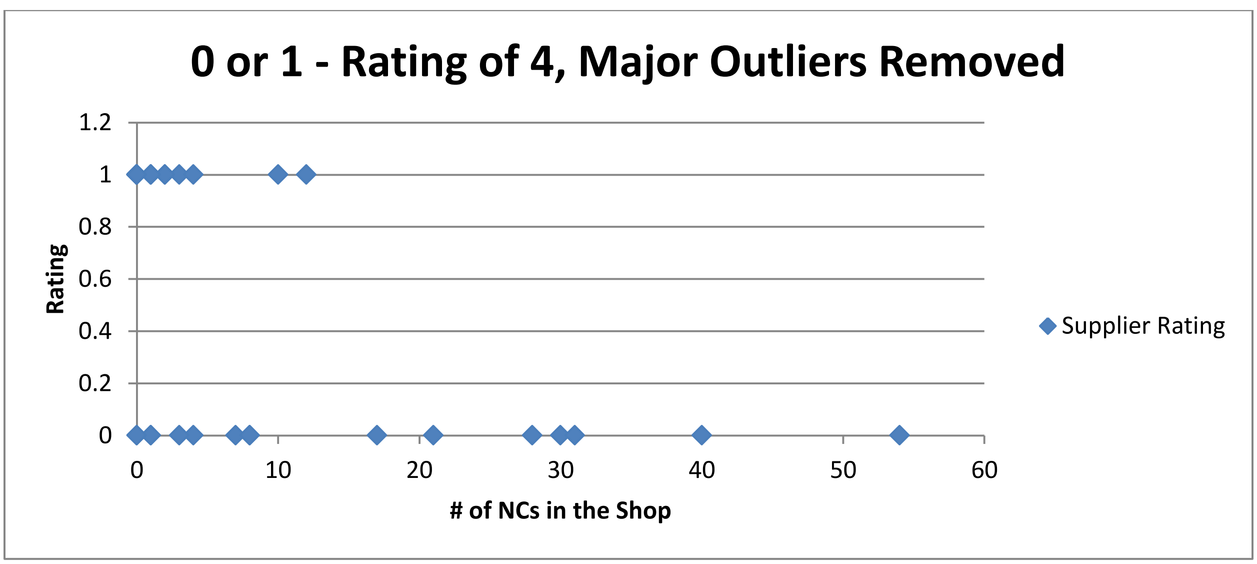

Figure 14: Average Rating, Good (1) = 4, Major Outliers Removed

With a cutoff rating of 4, all of the suppliers with a high number of NCs are still receiving a poor (0) rating. Next, a cutoff rating of 3 was evaluated; Figures 15 and 16 illustrate this analysis.

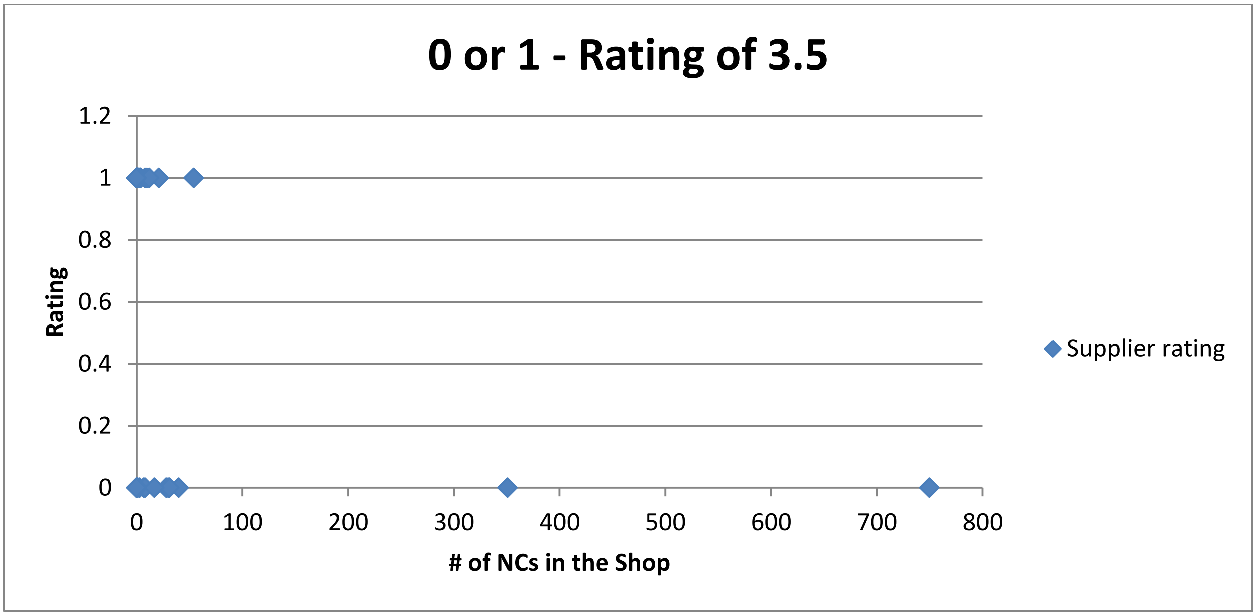

Figure 15: Average Rating, Good (1) = 3.5

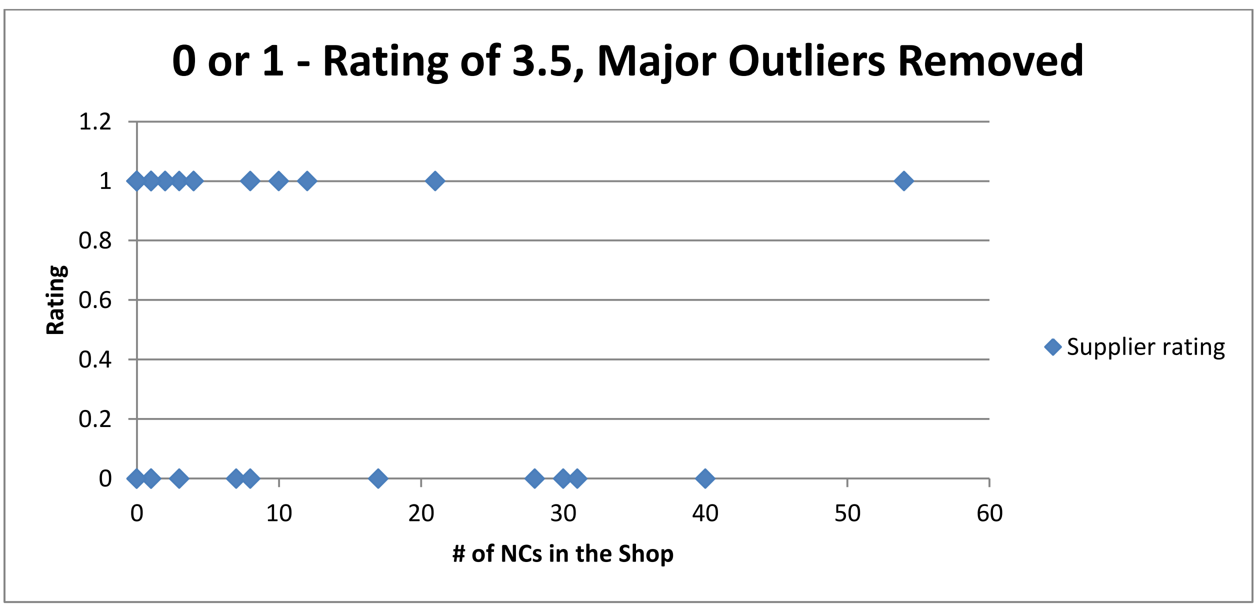

Figure 16: Average Rating, Good (1) = 3.5, Major Outliers Removed

With the major outliers removed and a cutoff rating of 3.5, the supplier with the highest number of NCs is receiving a good supplier rating. This shows that as the cutoff value decreases, there are more discrepancies in each supplier's overall rating. Finally, a cutoff value of 3 was evaluated as depicted in Figures 17 and 18.

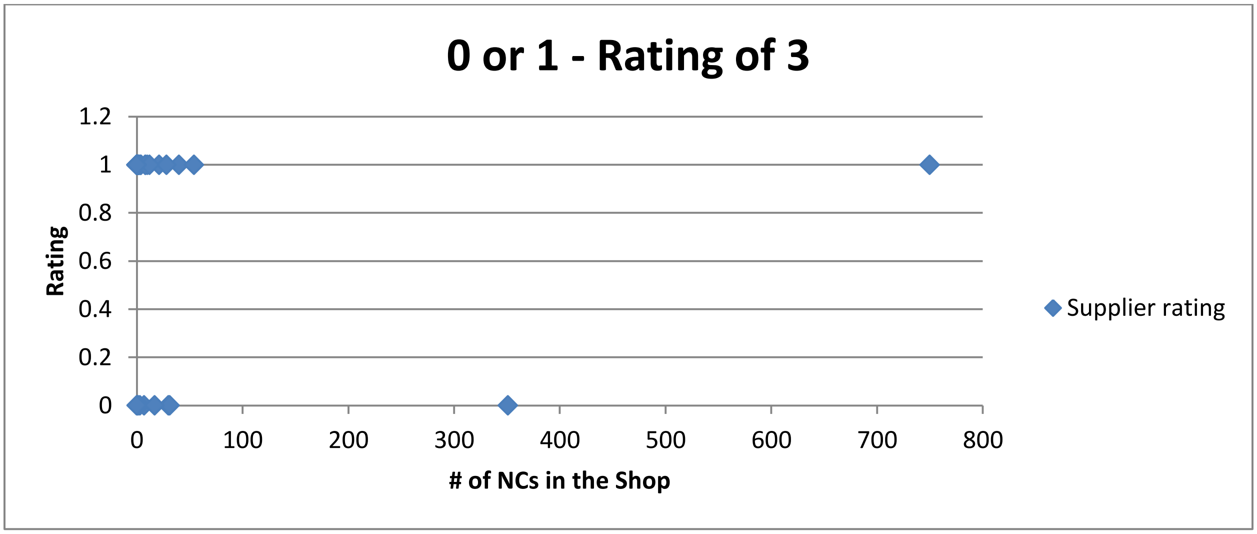

Figure 17: Average Rating, Good (1) = 3

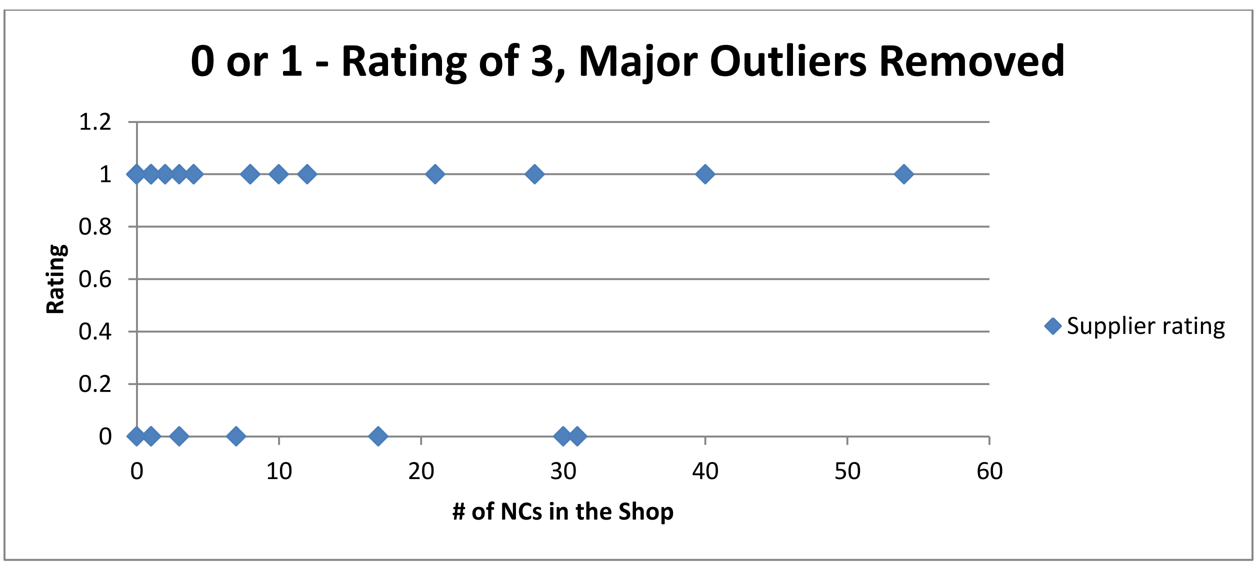

Figure 18: Average Rating, Good (1) = 3, Major Outliers Removed

Figure 18 supports the conclusion that a rating of 3 is too relaxed due to many suppliers with a high number of NCs receiving a good rating. Therefore, a cutoff rating of 4 is recommended.

Method 3: Supplier Category Ratings

The third method of analysis was to look at the category ratings for the suppliers to determine if there were one or two categories/criteria that skewed the average supplier rating. There are separate graphs for each category. The two outliers in the previous methods are still outliers in this method; they were removed for the same reasons as the previous methods. The list of categories is shown in Table 3 below.

Table 3: Survey Category Names

Category Number	Category Name
1	Plant Operations/Building and Infrastructure
2	Manufacturing Capability
3	Experience and Qualifications
4	Workforce
5	Engineering Capability
6	Material Control
7	Adherence to Procedures and Standards
8	Safety Adherence and Record
9	Handling of Subcontractors and Suppliers

Figures 19 and 20 represent category 1 with the major outliers in Figure 19 circled in orange. Figure 20 has the major outliers removed.

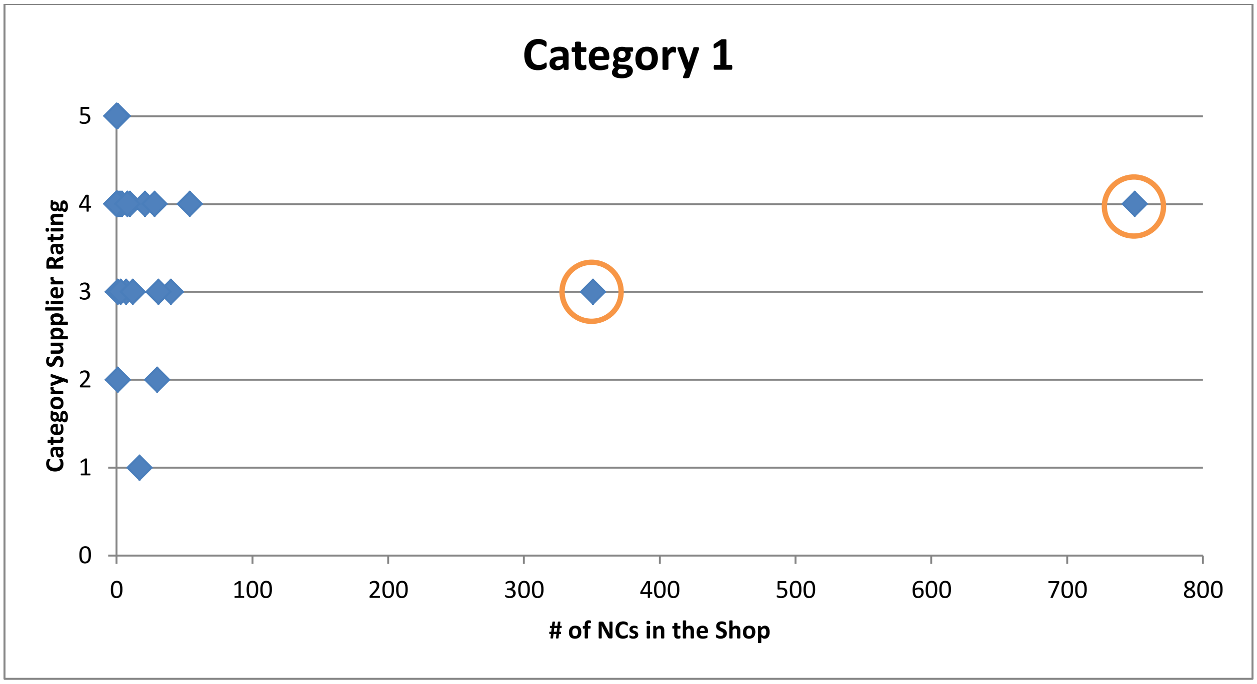

Figure 19: Category 1 - Plant Operations/Building Infrastructure

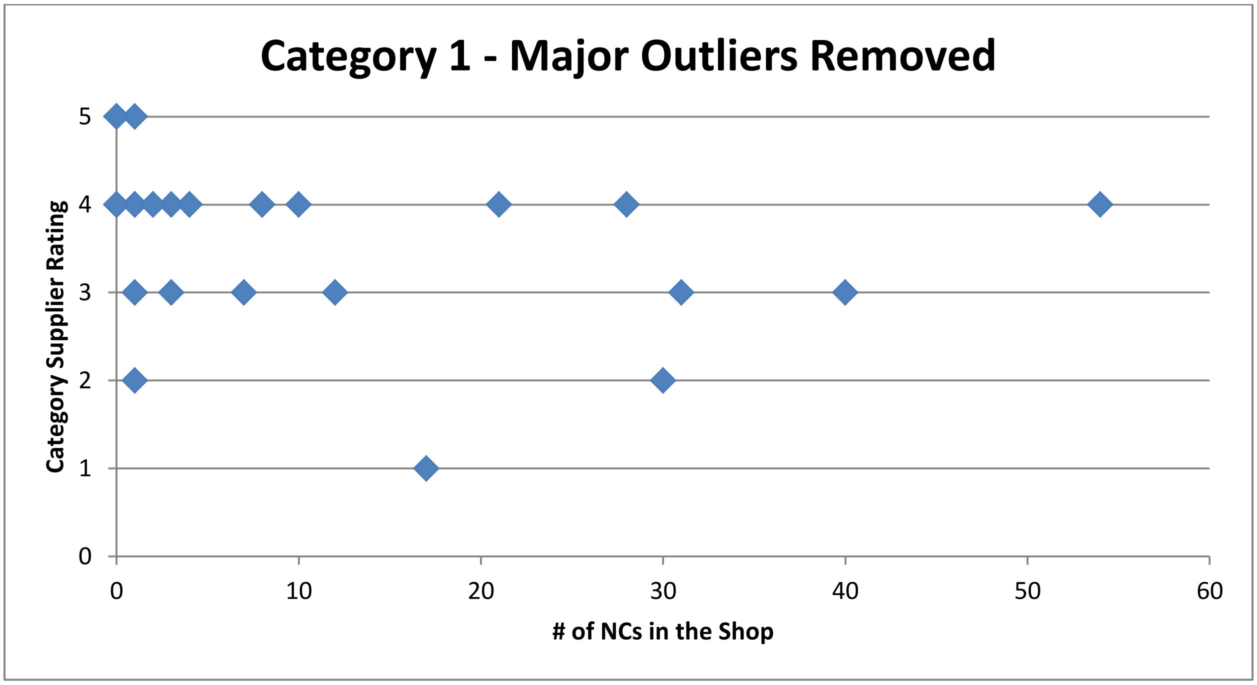

Figure 20: Category 1 - Plant Operations/Building Infrastructure, Major Outliers Removed

Figures 21 and 22 are for category 2 and use the same methods as category 1.

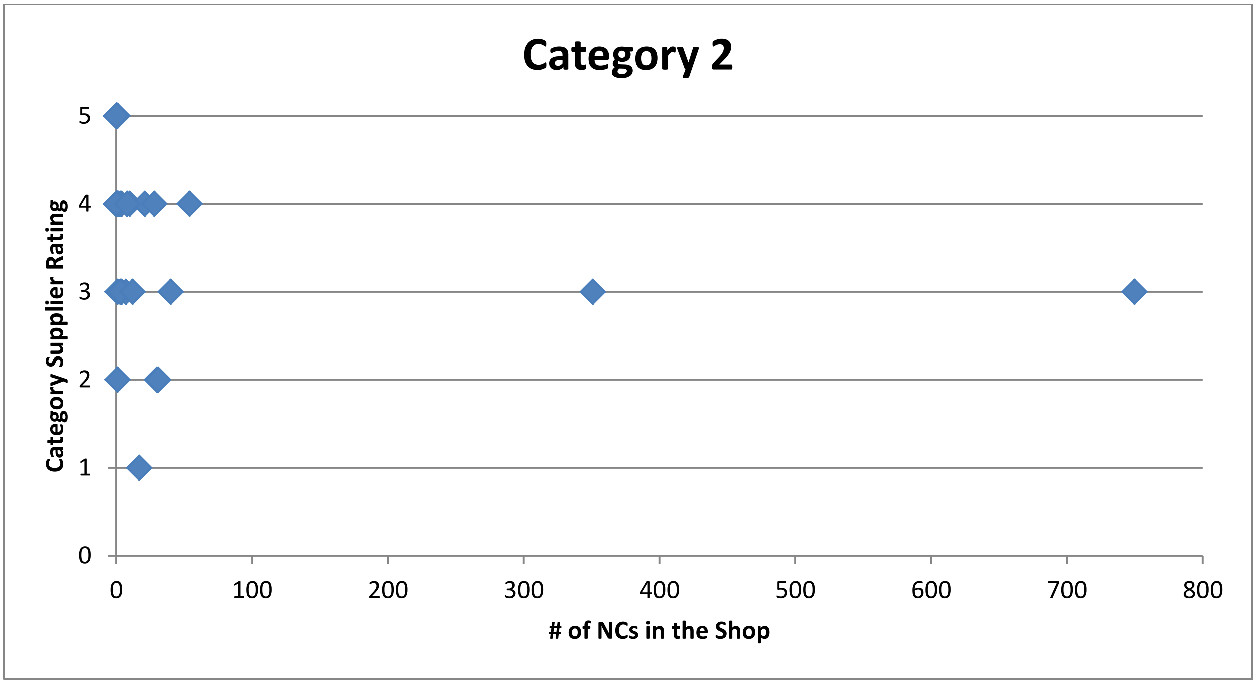

Figure 21: Category 2 - Manufacturing Capability

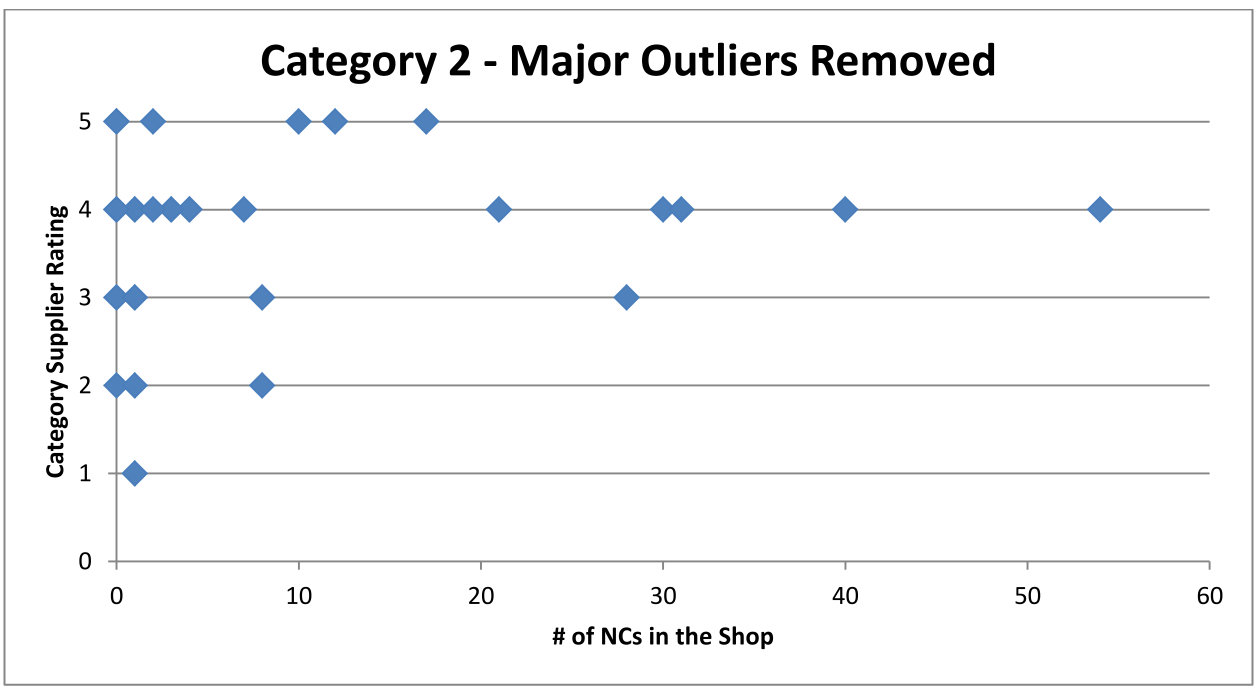

Figure 22: Category 2 - Manufacturing Capability, Major Outliers Removed

Figures 23 through 36 below represent categories 3 through 9 using the same methods as the first two categories, respectively.

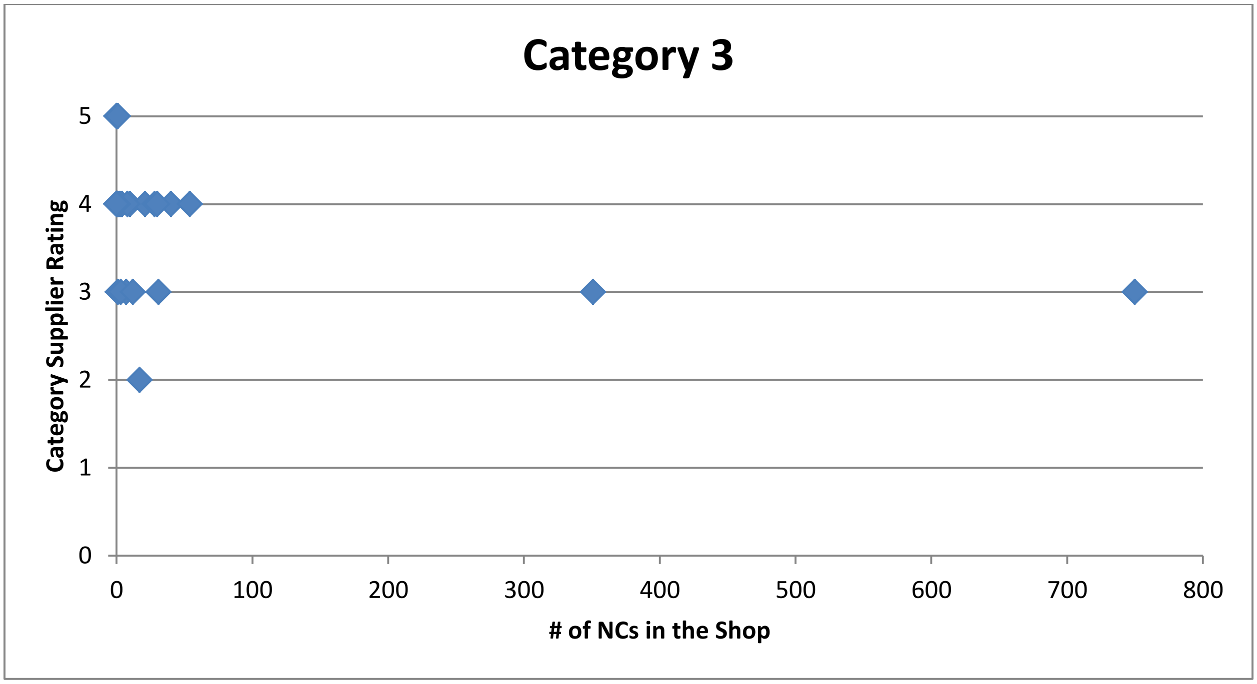

Figure 23: Category 3 - Experience and Qualifications

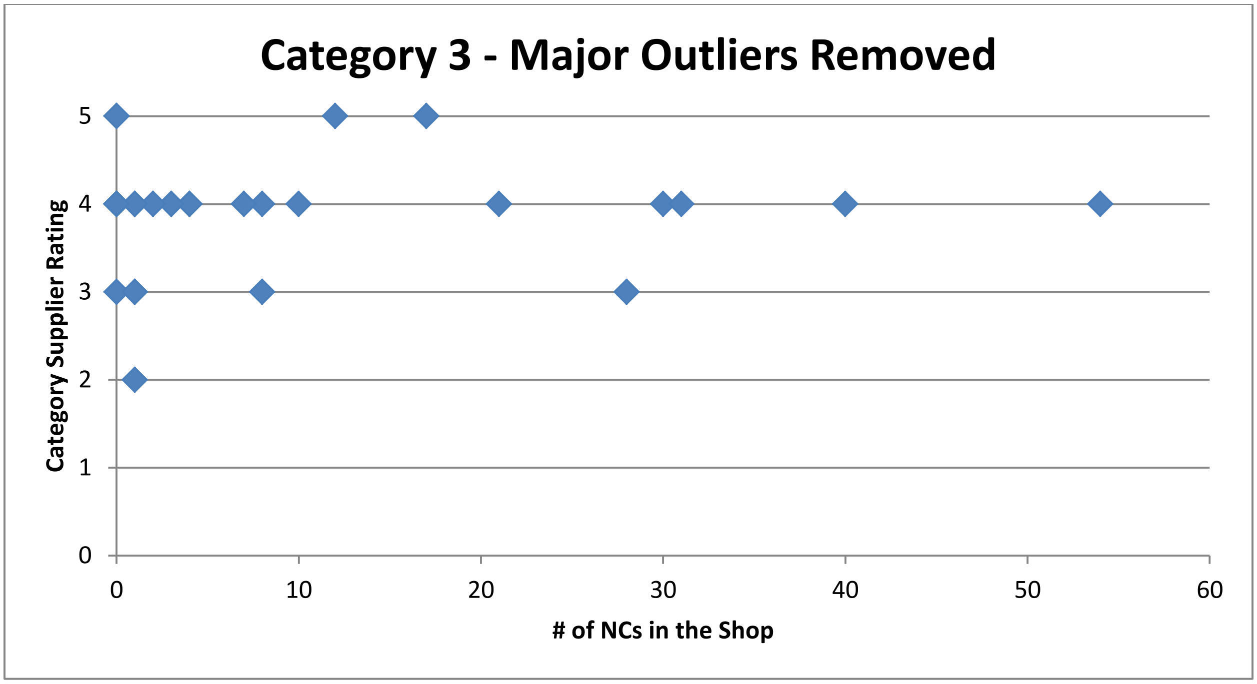

Figure 24: Category 3 - Experience and Qualifications, Major Outliers Removed

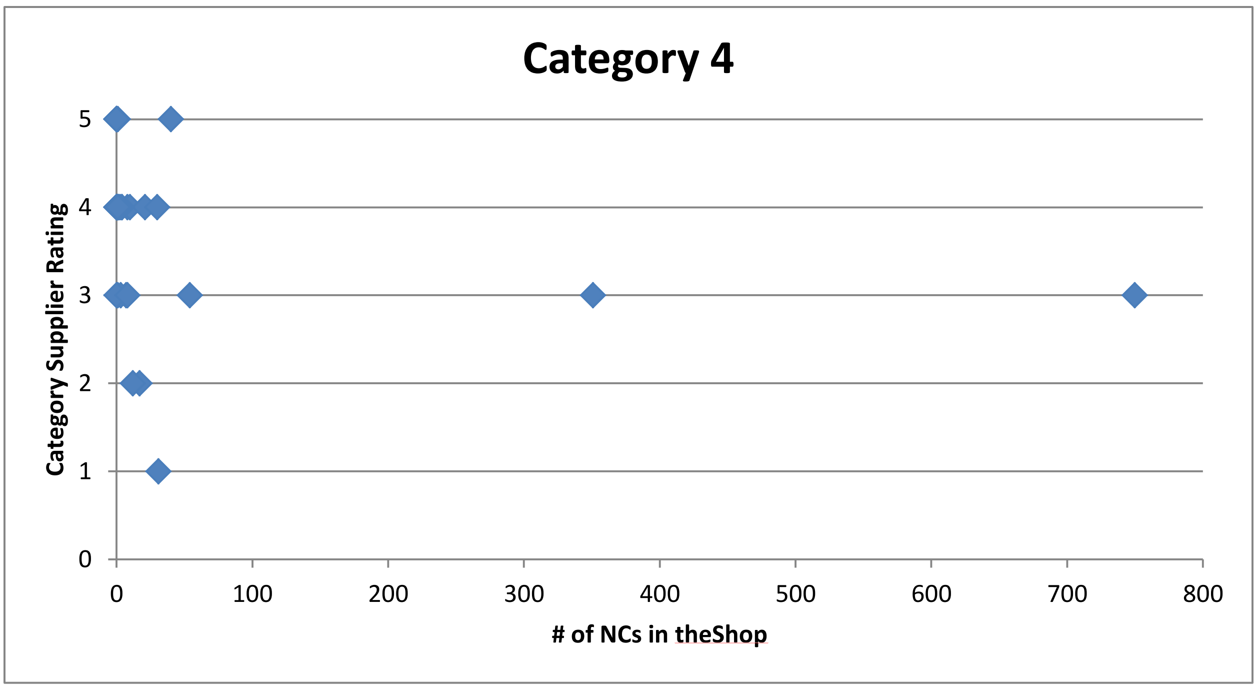

Figure 25: Category 4 - Workforce

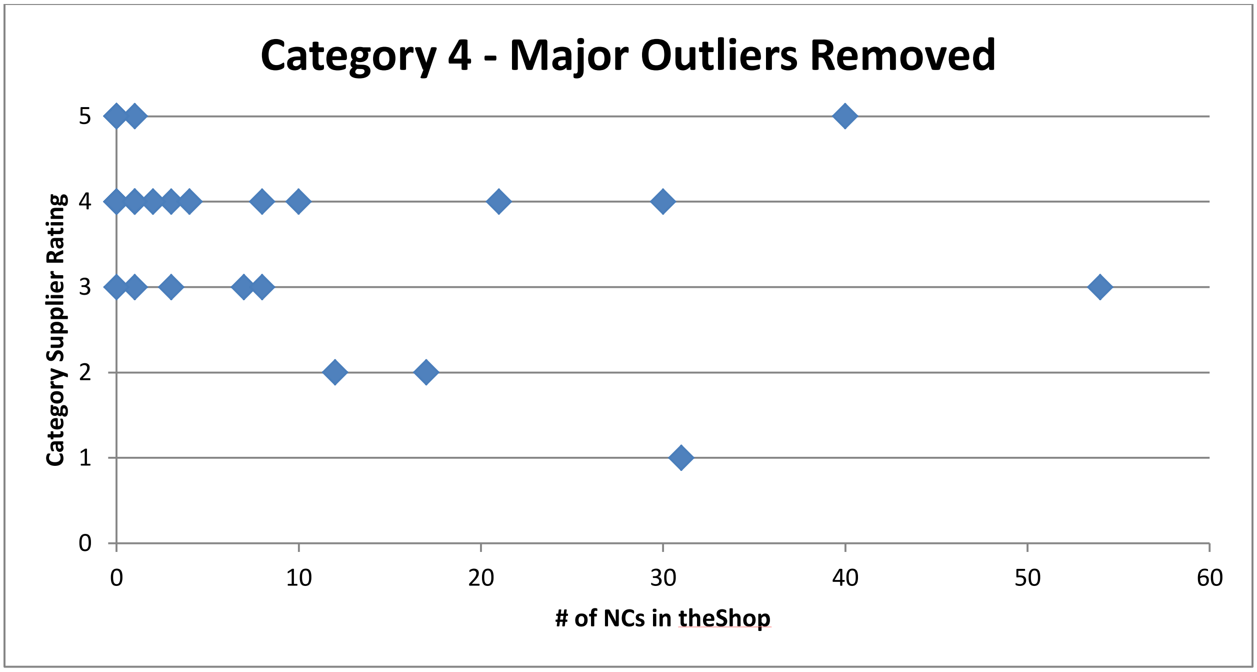

Figure 26: Category 4 - Workforce, Major Outliers Removed

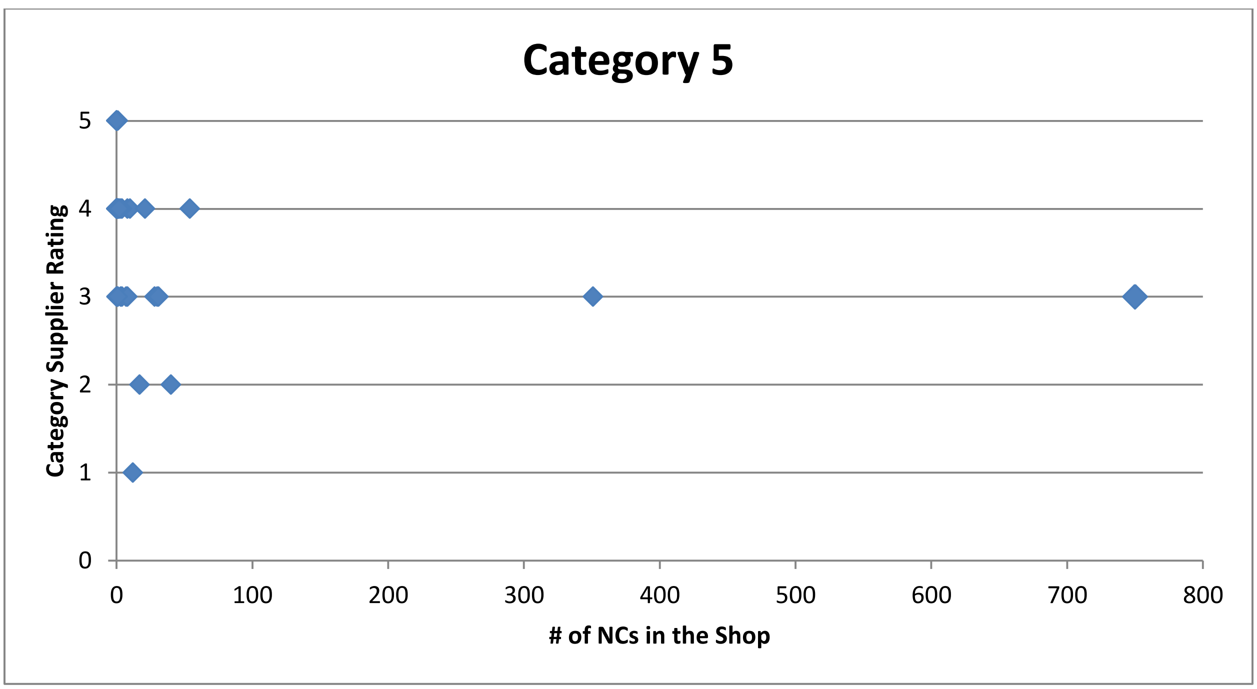

Figure 27: Category 5 - Engineering Capability

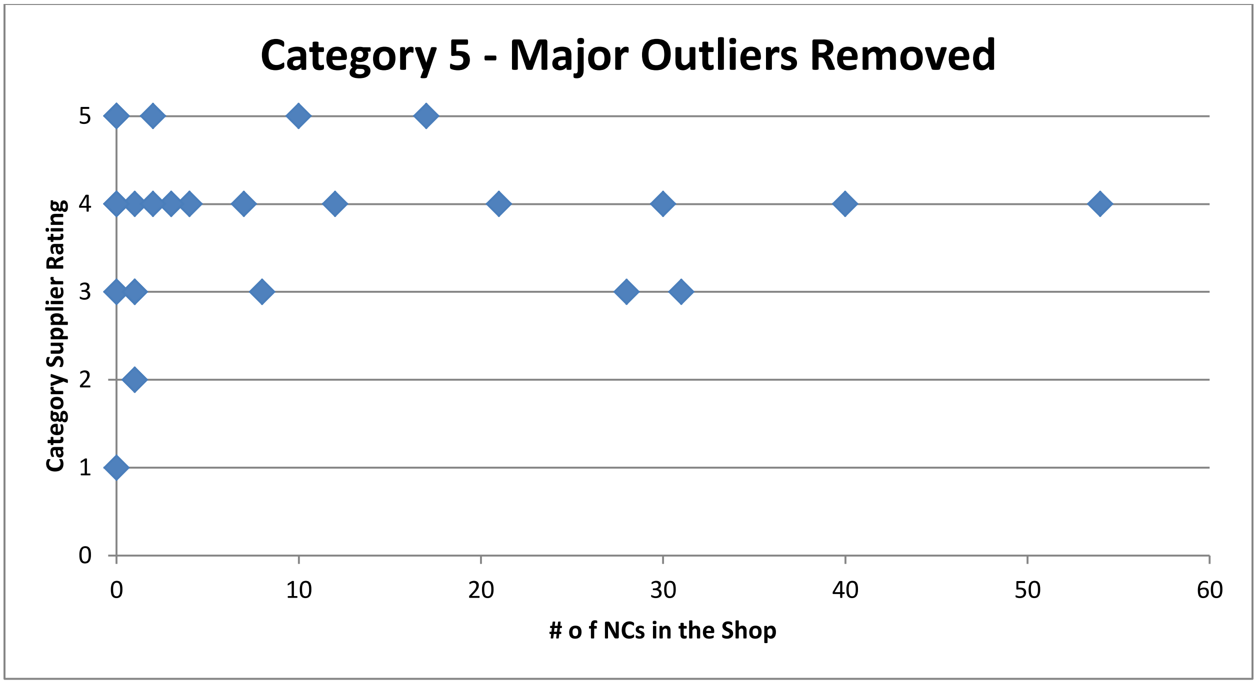

Figure 28: Category 5 - Engineering Capability, Major Outliers Removed

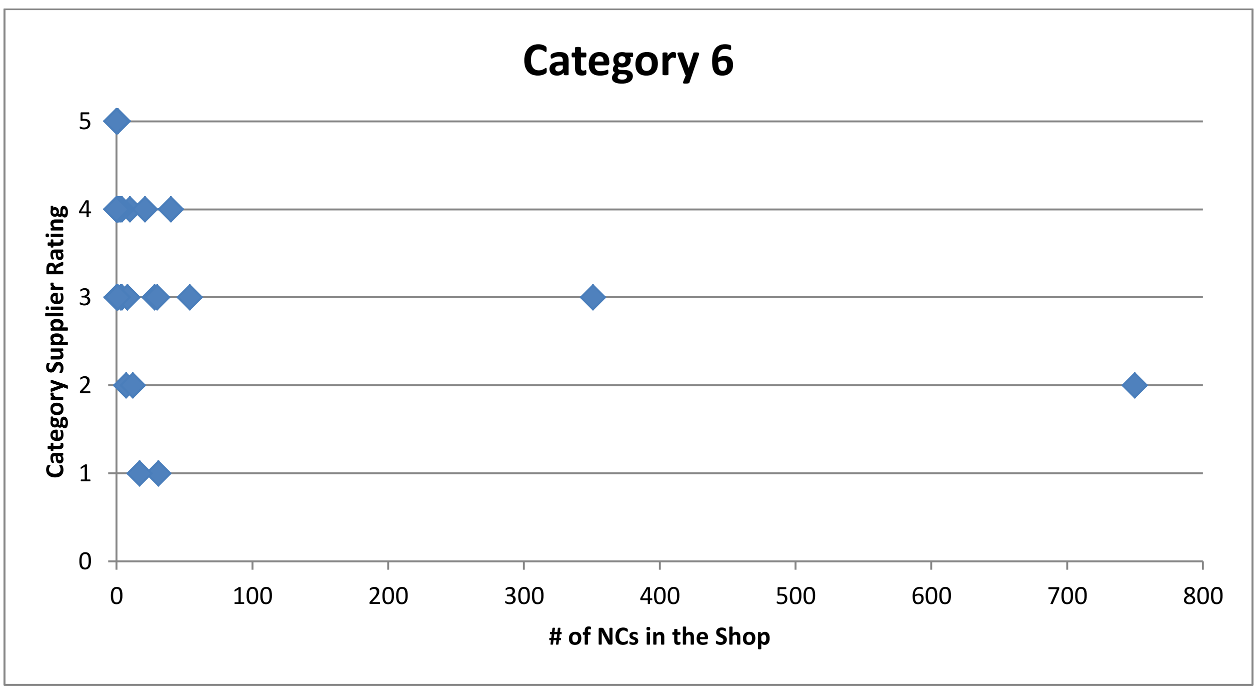

Figure 29: Category 6 - Material Control

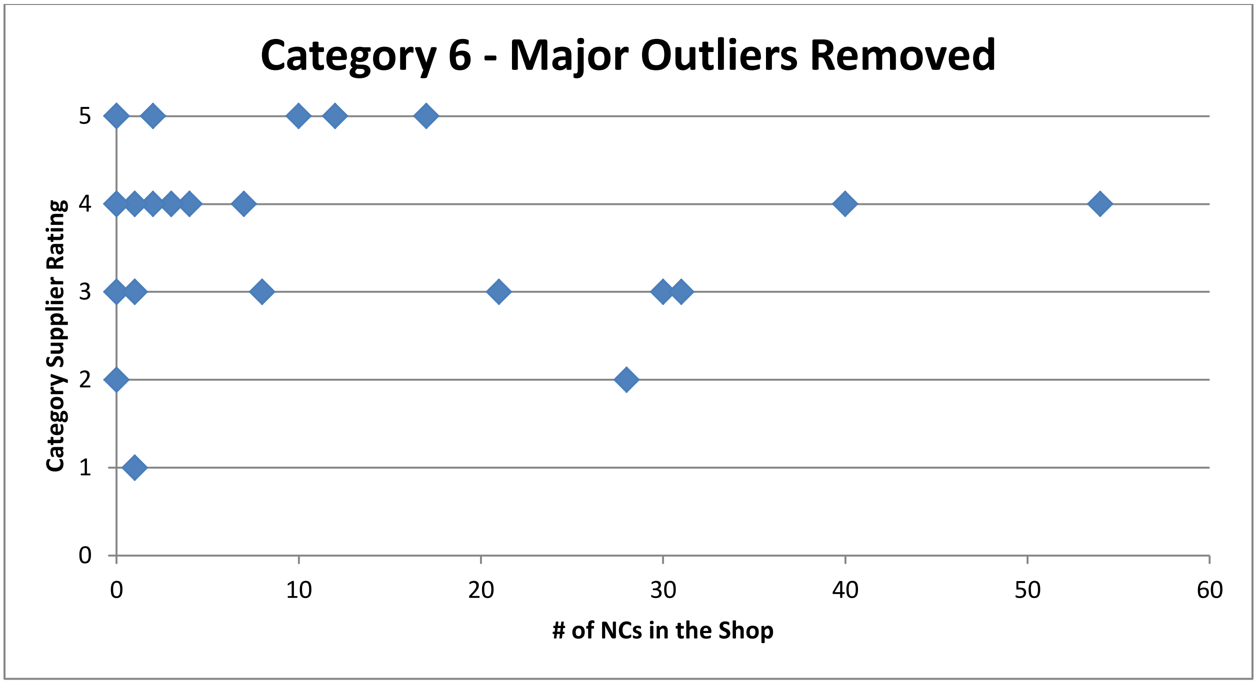

Figure 30: Category 6 - Material Control, Major Outliers Removed

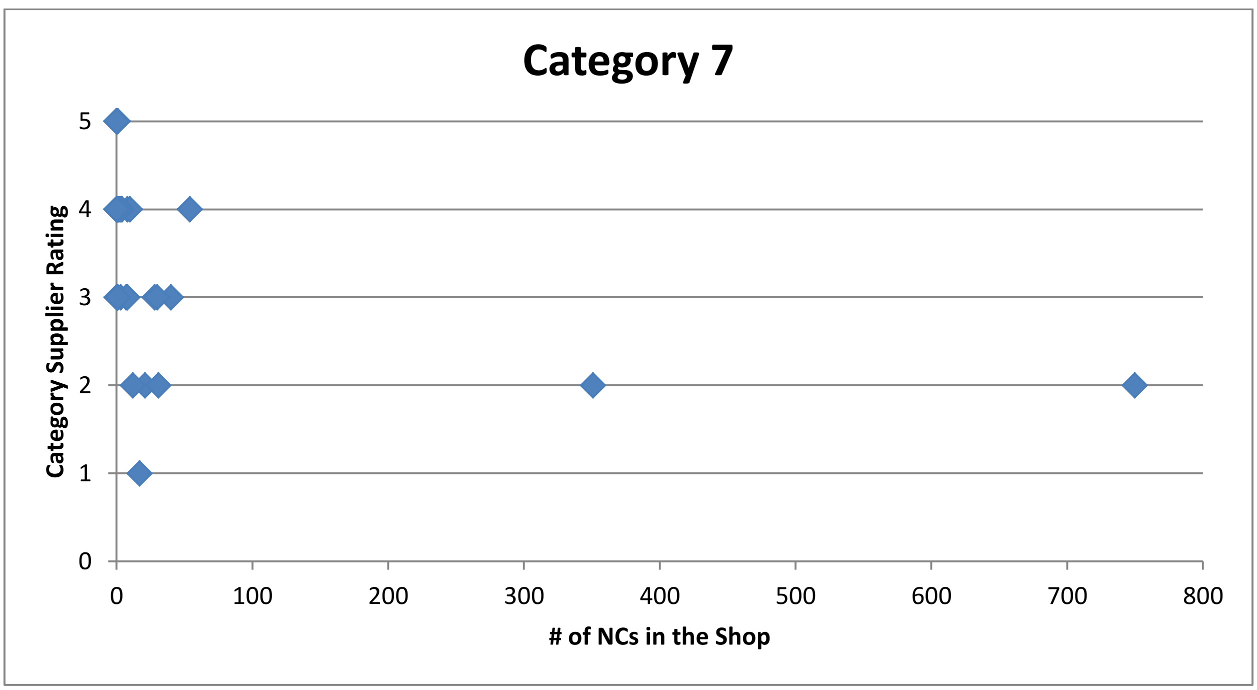

Figure 31: Category 7 - Adherence to Procedures and Standards

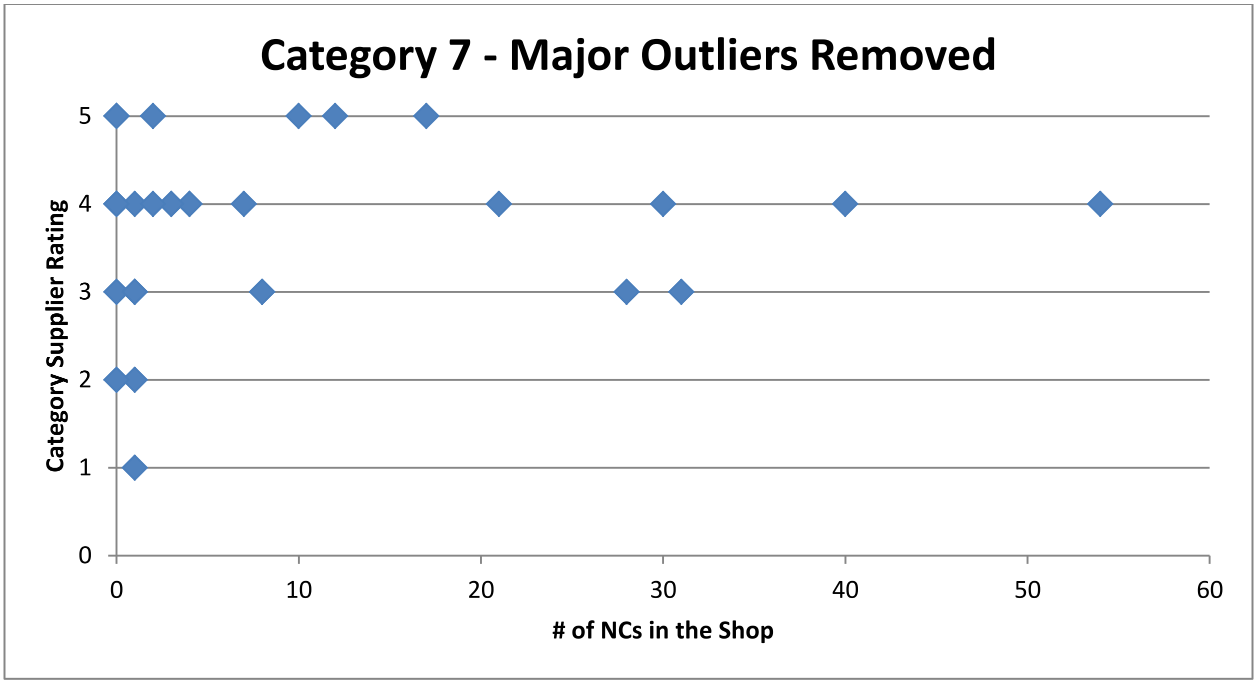

Figure 32: Category 7 - Adherence to Procedures and Standards, Major Outliers Removed

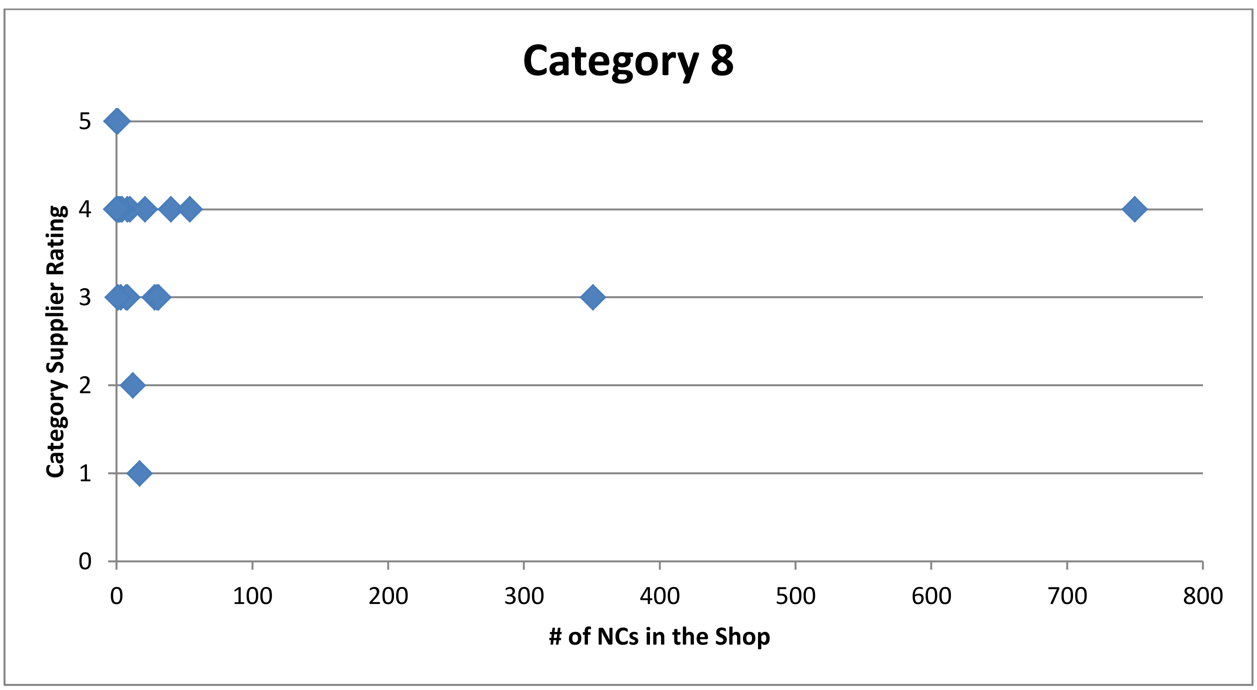

Figure 33: Category 8 - Safety Adherence and Record

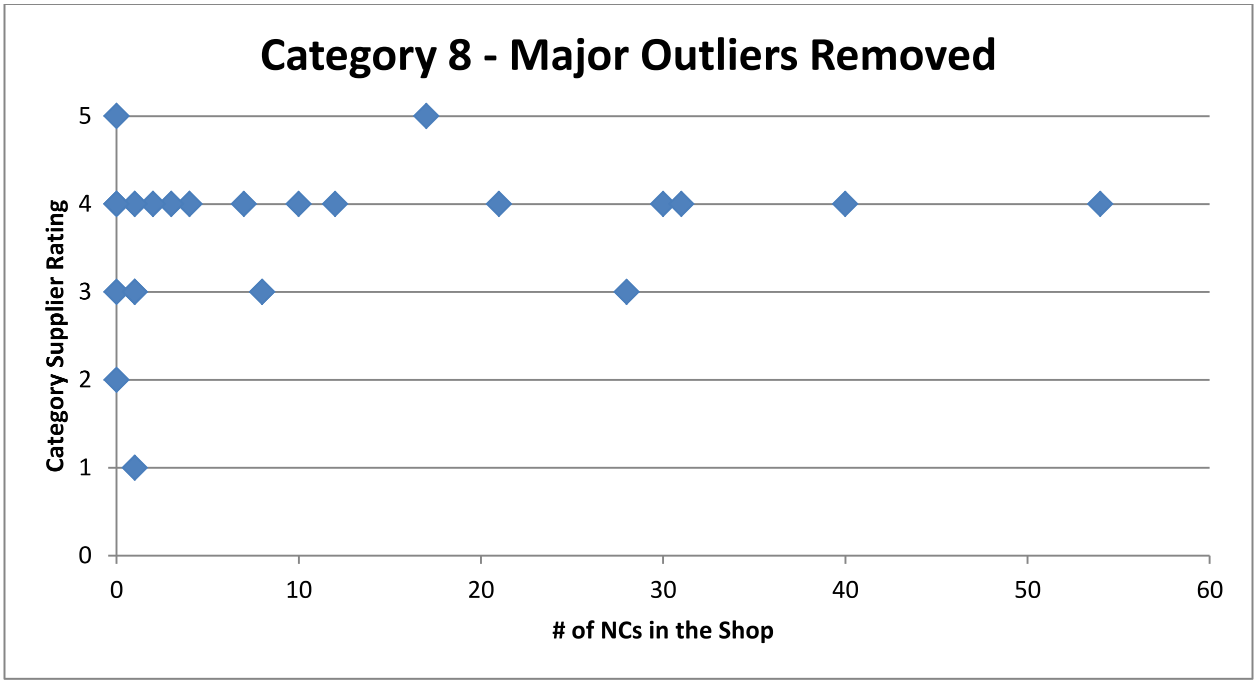

Figure 34: Category 8 - Safety Adherence and Record, Major Outliers Removed

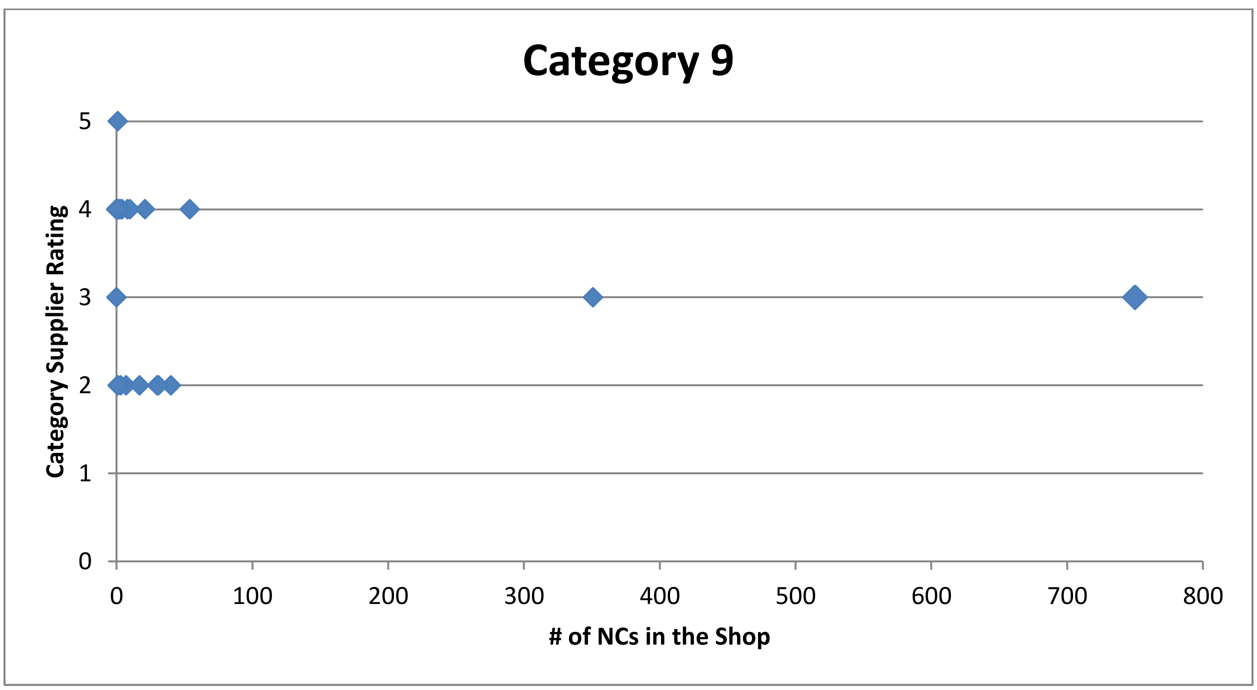

Figure 35: Category 9 - Handling of Subcontractors and Suppliers

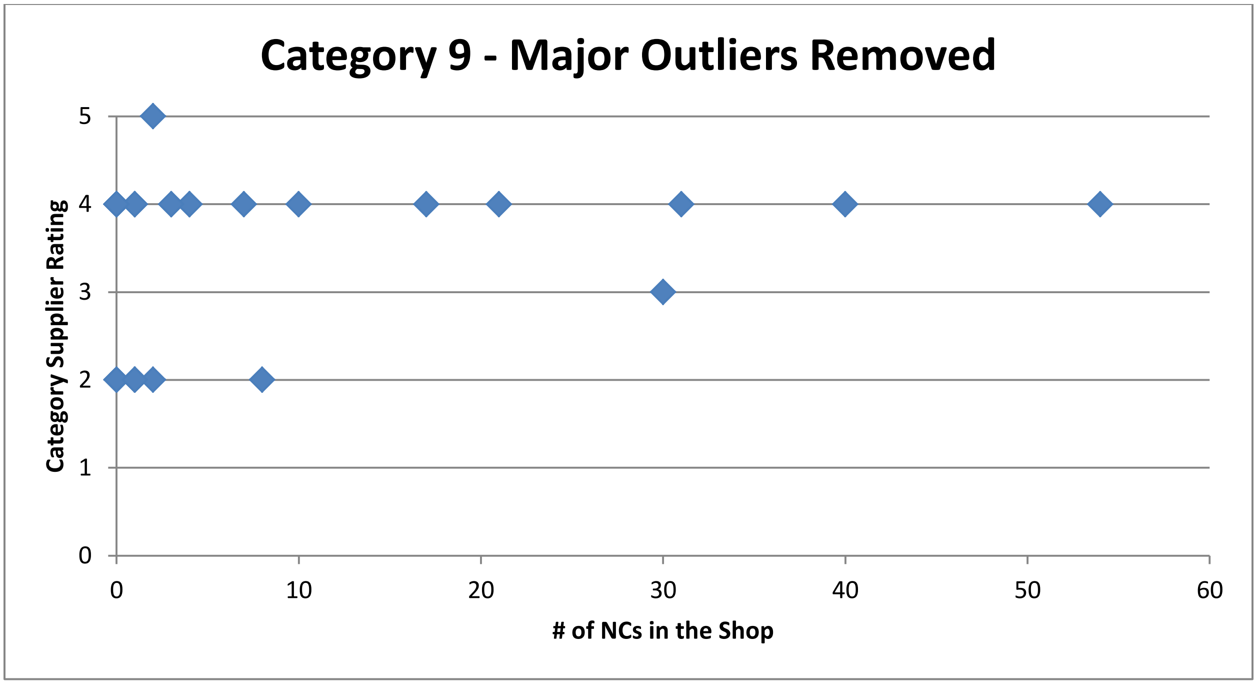

Figure 36: Category 9 - Handling of Subcontractors and Suppliers, Major Outliers Removed

Based on this method, category 4 (workforce) had ratings that were more scattered, and category 6 (material control) had fewer outliers in comparison to the rest of the categories. Each category had a fair amount of suppliers receiving ratings of 4 with a higher numbers of NCs than suppliers receiving ratings of 3. The two major outliers received poor ratings for categories 6 (material control) and 7 (adherence to procedures and standards). However, it was decided that additional analysis should be performed to try to normalize the data so the outliers would not have to be removed. The quantities of suppliers per rating per category can be found in Table B – 2 in the Appendix.

Method 4: Average Supplier Ratings vs # of NCs/$ P.O.

In an attempt to lessen the extremity of the two major outliers, Dr. Thais Alves suggested we look at the number of NCs per dollar of the P.O. for each data point. These values were factored by 10,000,000 to make the data easier to graph and understand. The entire data set was graphed for each of the four cutoff values (4.5, 4, 3.5, and 3). A regression line was included to validate the intuition that as the number of NCs/$ P.O. increases, the supplier quality rating should decrease. Figures 37 through 40 display the graphs for each cutoff value in descending order.

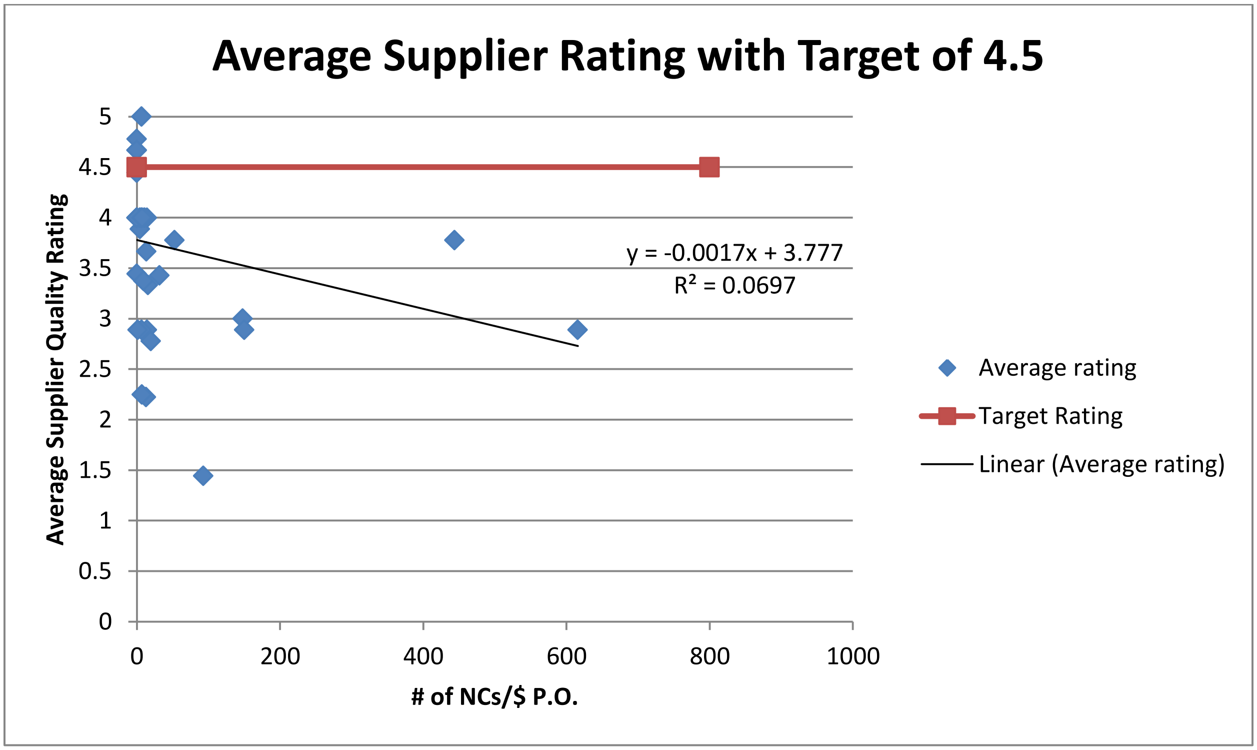

Figure 37: Average Supplier Rating with Target of 4.5, Based on P.O. Size

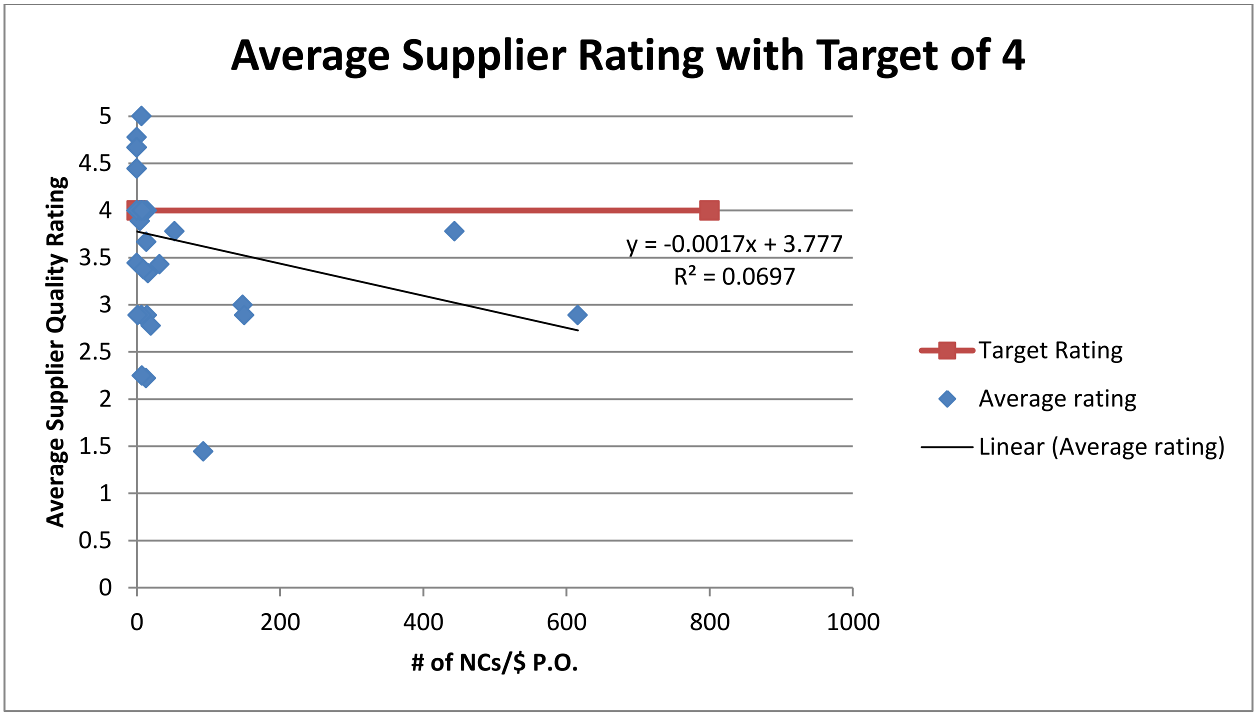

Figure 38: Average Supplier Rating with Target of 4, Based on P.O. Size

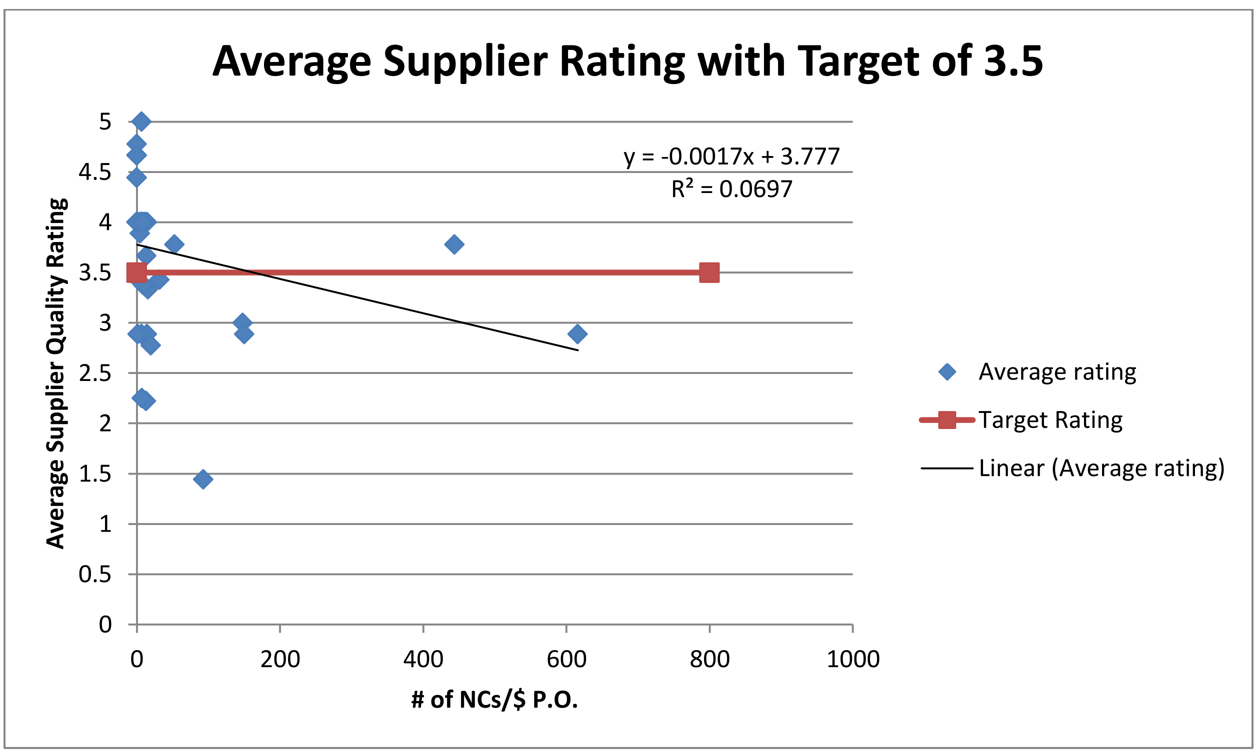

Figure 39: Average Supplier Rating with Target of 3.5, Based on P.O. Size

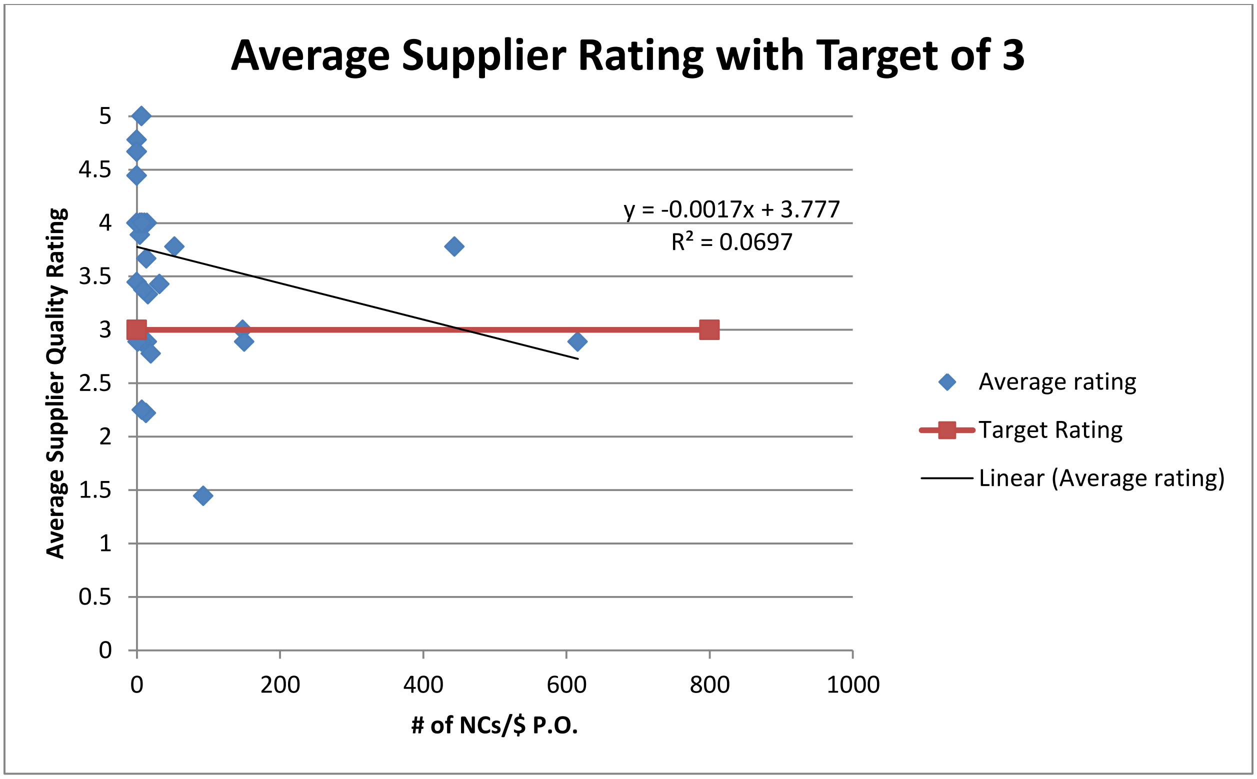

Figure 40: Average Supplier Rating with Target of 3, Based on P.O. Size

Instead of reducing the number of outliers, the number of outliers actually increased once P.O. size was taken into account. However, based on these new outliers, the results still show that a cutoff rating of 4 will cause the major outliers with a high value for # of NCs/$ P.O. to receive a poor supplier rating while a cutoff rating of 3.5 will cause some of the outliers to receive a good supplier rating. The regression line confirms our intuition that as the number of NCs/$ P.O. increases, the supplier quality rating decreases. Some simple statistics on this data can be found in Table B – 3 in the Appendix.

A larger data set may have caused the normalization of the outliers to be successful. Also, the research team could potentially confirm the accuracy of the outliers by tracing the responses back to the respondents to ensure the information was entered in correctly. Either collecting more data or tracing the responses could potentially cause this analysis to become conclusive rather than inconclusive.

Method 5: Additional Category Data Analysis

Some additional graphs were made to display the data differently for supplier ratings in each category. The first graph displays the number of suppliers grouped by their ratings for each category. This graph is shown in Figure 41 below.

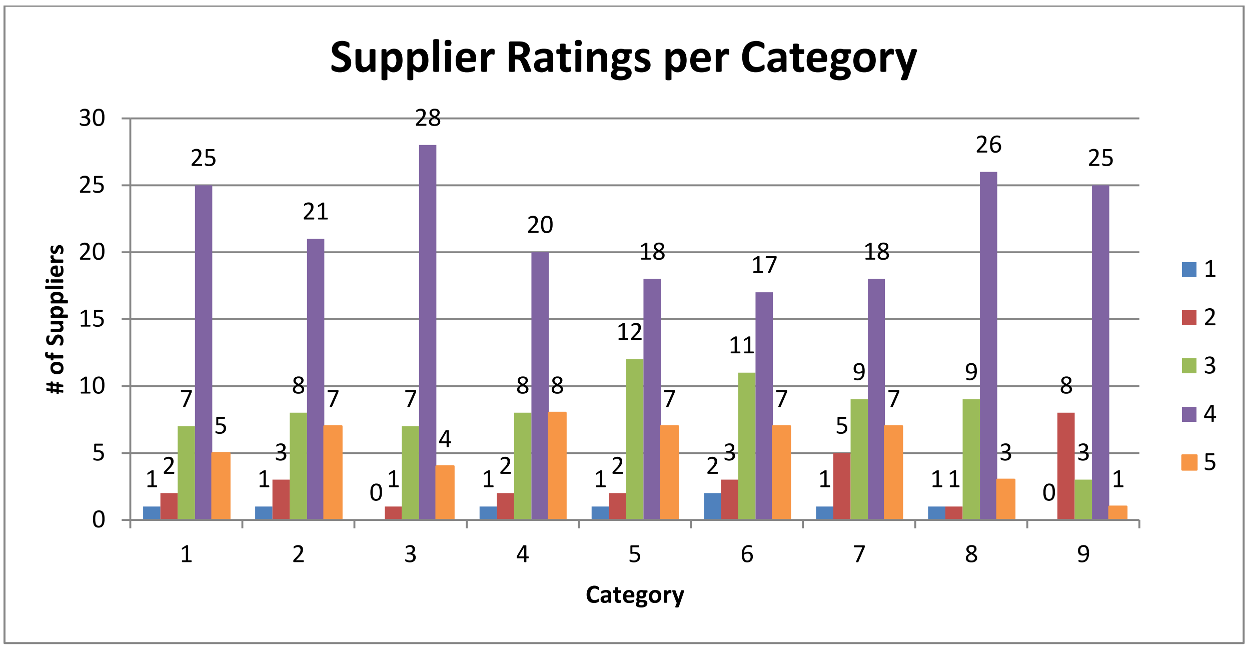

Figure 41: Supplier Ratings per Category

The legend shows the ratings the supplier receives, and the sum of each rating is graphed for each category. This graph shows the most common rating suppliers received was a rating of 4.

The next three graphs were created to display the number of suppliers that received a rating of 0 (poor) or 1 (good) based on various cutoff ranges for each of the categories. Due to the values being broken up by category, the cutoff ratings evaluated were ratings of 5, 4, and 3; these graphs are shown below in Figures 42 through 44, respectively.

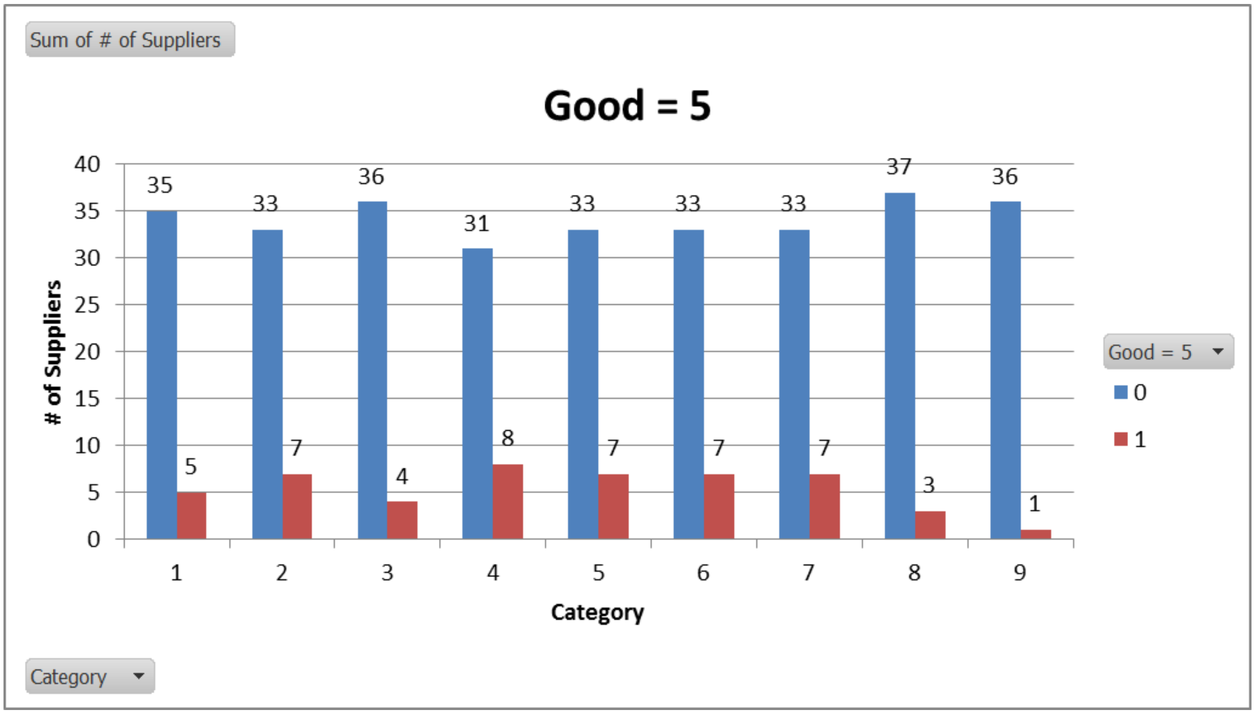

Figure 42: Category Ratings, Good = 5

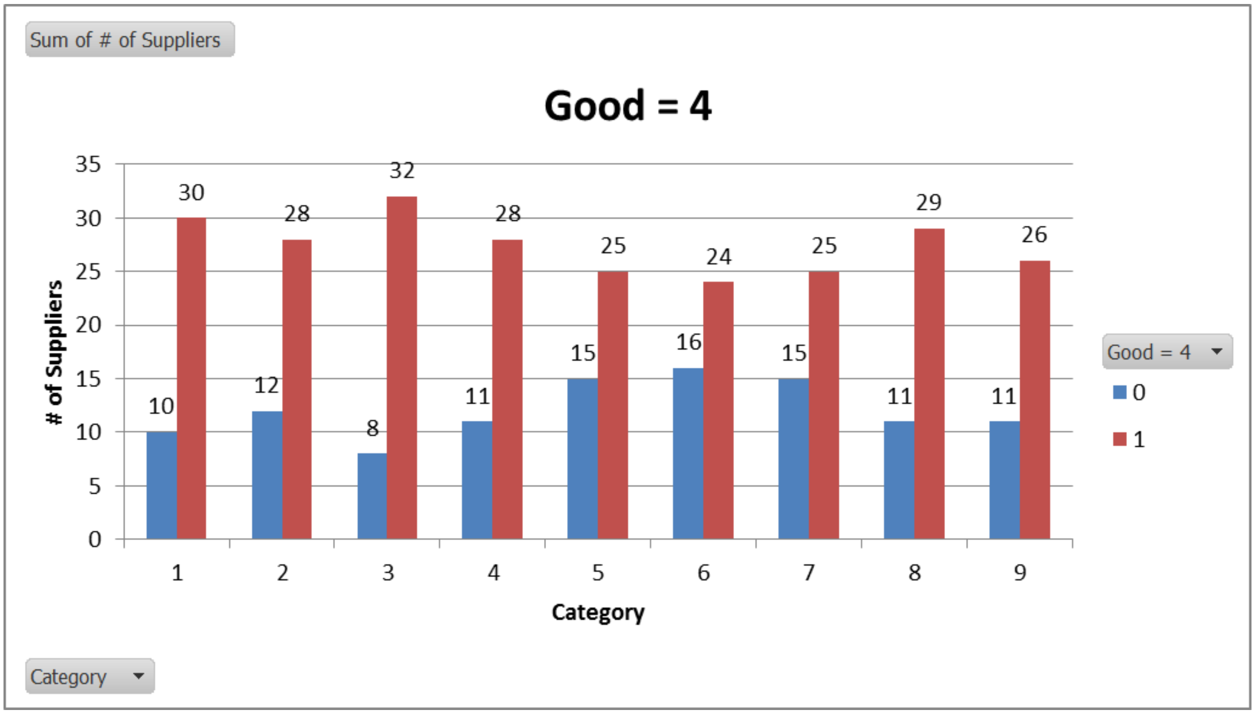

Figure 43: Category Ratings, Good = 4

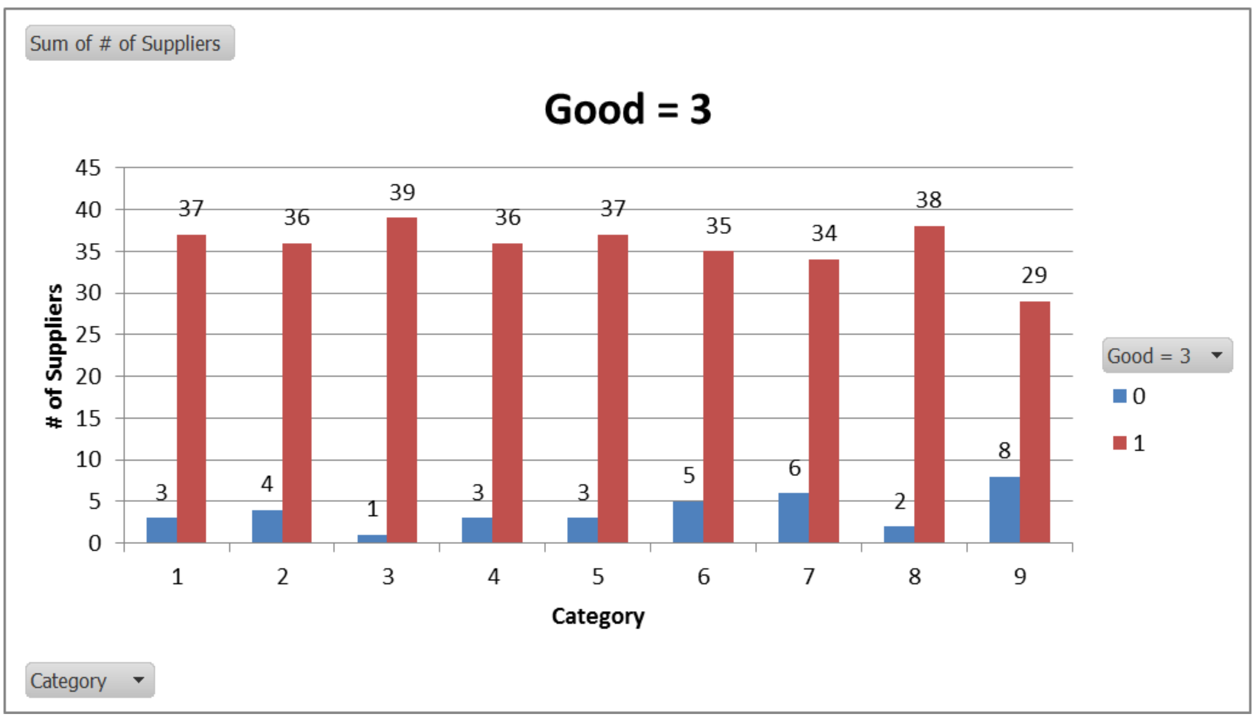

Figure 44: Category Ratings, Good = 3

For the cutoff rating of 4, this means that the supplier received a good score (1) if their rating for that category was a 4 or above. For the cutoff rating of 3, the supplier received a good score (1) if their rating for that category was a 3 or above. Displaying the data in this manner allows one to see how the number of good ratings increases as the cutoff value decreases.

Towards the end of the research project, an additional Qualtrics survey was sent out to CII members asking them to rate the supplier selection criteria from most important (1) to least important (9) when performing supplier selection. The responses were averaged together, and a rank was assigned to each category based on the averages. Table 3 shows the ranks for each category.

Table 4: Category Importance Rankings

Rank	Category
1	3: Experience and qualifications
2	2: Manufacturing capability
3	8: Safety adherence and record
4	7: Adherence to procedures and standards
5	5: Engineering capability
6	6: Material control
7	4: Workforce
8	9: Handling of subcontractors/sub-suppliers
9	1: Plant operations/building and infrastructure

Based on these results, we conclude that the supplier's experience and qualifications were found to be most important to organizations, while plant operations, building, and infrastructure were found to be least important to organizations. The survey can be found in Appendix C.

Conclusions and Future Work

Overall, choosing a cutoff rating of 4 was confirmed through these analyses. Even though it is the most common rating amongst the categories, it is the best cutoff to ensure that suppliers with a high number of NCs do not receive a good supplier rating. Categories 5 and 6 had more suppliers receiving 3s compared to the other categories; otherwise, none of the categories had variations in ratings that would cause many of the average ratings to be skewed. Additional analysis could be performed to determine if any of the nine supplier criteria predicts which suppliers have a high number of NCs. Based on the results of the second small Qualtrics survey, one could hypothesize that category 2 or category 3 should best predict a supplier's number of NCs. A logistics regression could also be fit to the categorical data to gain insight into which category influences the average supplier rating.

The effort to eliminate the outliers by looking at the size of the P.O. was inconclusive. More outliers were created, causing the initial judgment to remove the outliers to be the best judgment with this data set. However, more steps could be taken to determine the causation of these outliers. The research team could trace the two outlier responses back to the respondents; this would allow the team to contact the respondents to ensure the data was entered in correctly. Additionally, more data could be collected.

Other than the recommended supplier rating cutoff, the data analysis results were inconclusive. By collecting more data, the analysis could become more conclusive and more representative of the construction industry as a whole. Projects in the construction industry vary greatly in size and scope. Therefore, having a larger data set would get a larger sample of the population and could also cause some of the data to be normally distributed.

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Appendix A: Supplier Quality Survey

Survey – Defining P_{FAB} and P_{INSP}

The following questions are to be answered for a GIVEN PURCHASE ORDER for a project. It is helpful to obtain data from more than one P.O. for a given project, across a range of different types of purchases (levels of criticality, spend, etc.), and also to look for different projects. Please select P.O.s representative of all criticality levels, however, not by "cherry-picking" the best (or worst) P.O.s in recent experience. Select P.O.s were material was installed and not for storage. Ideally, P.O.s selected for this process should have been completed within the last THREE years.

The intent of this data collection effort is to identify practices and characteristics that influence the fabrication capability (P_{fab}) and inspection capability (P_{insp}) of suppliers, and how those affect the definition of the inspection effort by EPC firms and owners. In this instrument, P_{fab} is defined by the ability to fabricate according to specifications, whereas P_{insp} represents the capability of finding and correcting nonconformances.

Please assign a reference number for purposes of this instrument. This number should be different than your internal P.O. number, but please keep a record of which answers go with which of your internal P.O.s. That way, if there were to be any follow up questions, you could find the same P.O. easily.

IMPORTANT: PLEASE COMPLETE THIS INSTRUMENT BY extracting data from P.O.s and other archived data sources, and not by estimating or based on your impressions/memories about the project, unless otherwise noted in the question. You will likely need to confer with others to complete this instrument. The instrument is likely to take less than ½ hour to fill out, but it will likely take 1-3 hours to compile the data needed for each P.O. (including time to coordinate with others within your organization).

This instrument may be used for <u>only one P.O. at a time</u> for SHOP FABRICATED PIPING.

P.O.s for any other type of purchase should not be considered for this study.

This instrument is intended for anonymous data collection. Please make sure no individually identifying information is included among your answers. All data provided to CII in support of research activities by participating organizations are to be considered confidential information. The data have been provided by participating companies with the assurance that individual company data will not be communicated in any form to any party other than CII authorized academic researchers and designated CII staff members.

Any data or any analyses based on these data that are shared with others or published will represent summaries of data from multiple participating organizations that have been aggregated in a way that will preclude identification of proprietary data and the specific performance of individual organizations.

Reports, presentations, and proceedings containing statistical summaries of aggregated company data may be used to support team findings. To protect the confidentiality of companies submitting data, all data published and/or presented must reflect the aggregate of no less than 10 P.O.s, where project level data are collected, and must have been submitted by at least three (3) separate companies. In cases where a disproportionate amount of the data are provided by a single company, the research team will suppress publication of results until the data set is sufficiently large to mitigate confidentiality and bias concerns.

Should you have any questions about this request please contact any or all the project investigators: Dr. Thais Alves (talves@mail.sdsu.edu, +1 619-594-8289) and Dr. Kim Needy (kneedy@uark.edu, +1 479-575-4401). Alternatively you might contact the Institutional Review Board at San Diego State University at irb@mail.sdsu.edu or 619-594-6622 or at the University of Arkansas at irb@uark.edu or 479-575-2208 for any questions or concerns about this project (IRB# at UArk 15-08-066, approval date 8/28/2015 and expiration data 8/27/2016).

1. Contact information for follow up questions:
The following information will ONLY be used for follow up questions and will NOT be associated with the rest of the questions in the final database used for analysis.
Title:
Name:
Company:
Phone (Include area and country code if outside of USA or Canada):
Email:
Verify email:

PROJECT DATA

2. Project name:

3. Brief description of project for which this P.O. was initiated:

4. Project location (Country if outside USA, State if inside USA):

5. Project size (estimated total installed cost, should be an order of magnitude value, is it more like e.g. $1M, $10M, $100M). Include engineer, procure, and construct price to the owner:

6. Indicate your role on this project (contractor, owner, supplier):

P.O. BASIC DATA

7. P.O. number (note, this reference you should apply only to this response, that should be different from your internal P.O. number):

8. What was the estimated total number of spools for this P.O.?

9. Total value of P.O. (US $):

10. How many inspection hours were budgeted for this PO?

11. Primary location of supplier's facility (not headquarters, but rather where the bulk of the supplied material for this P.O. came from):

12. What was the criticality level assigned to this P.O. (low, medium, high)?

PRE-AWARD EVALUATION

Please answer the following questions in regards to the relationship with this particular supplier, for this particular P.O. at Pre-Award

13. What was the planned level of inspection assigned to this P.O.?
a. Full time (resident)
b. Occasionally, Randomly, or Periodically
c. Final only
d. Not at all

14. Did you perform a supplier evaluation before the P.O. was issued?
a) Yes
b) No
(If YES, please skip ahead and answer **Question 16,** if NO please answer **Question 15**)

15. If **NO**, please explain why. Then, skip ahead to **Question 19** (do NOT complete the Supplier Evaluation Scorecard shown in question 18).

16. If **YES**, is data available for this evaluation?
a) Yes
b) No
(If YES, please skip ahead to **Question 18,** if NO please answer **Question 17**)

17. If **NO**, please explain why. Then, skip ahead to **Question 19** (do not complete the Supplier Evaluation Scorecard).

18. Based on actual observation and existing documentation about this supplier's work, how was the supplier evaluated BEFORE the P.O. was issued using the following attributes? (Scale: 1 = poor, 2 = below average, 3 = average, 4 = above average, 5 = excellent)

Criterion	Attributes of the criterion	1	2	3	4	5
Plant operations/Building and infrastructure	Storage and shipping, Structure for QA/QC personnel and records, Examination and testing, Housekeeping, Security					
Manufacturing capability	Machining capability, Fabrication capability (including welding, coatings, etc.), Capability to manufacture per user requirements, Calibration records and procedures, Non-destructive testing and inspection capability and quality, Shop capacity					
Experience and qualifications	Geographical areas in which supplier is qualified to work, Familiarity with codes specific to certain geographic regions, Certifications (ASME, API, etc.), Work history					
Workforce	Documented training of the workforce, Craft types available at location, Qualifications of the workforce, Source of backup workers					
Engineering capability	Professional/technical specialties held in house, Compliance with documents and specifications, Cooperation, responsiveness of requests, and turnaround documents, Robust document management system					
Material control	QA/QC manual for material control, Process for material substitution, Material verification, Prevention of counterfeit materials, Material certification					
Adherence to procedures and standards	Adherence to codes and specifications, Quality, legibility and completeness of documentation, Nonconformance control, Proper notification of inspection and hold points, Identification of parts - traceability					
Safety adherence and record	Written safety, health and environmental program, Compliance to local/governmental safety and environmental requirements, Experience Modification Ratio (EMR), Total Recordable Incidence Rate (TRIR)					
Handling of subcontractors/sub-suppliers	Outsourced/subcontracted product/service control, Procedure to check subcontractor compliance with quality requirements, Documented evidence of compliance, Auditing subcontractors, Ability to schedule and expedite subcontractors/sub-suppliers					

POST- Execution

19. If available, how many inspection hours were utilized for this P.O.?

20. Was your inspection effort less, equal, or higher than BUDGETED?

21. Did the supplier subcontract a portion of the work for this P.O.?
a. Yes
b. No

22. If yes, by what percentage did it increase your inspection?

23. What was the final (actual) level of inspection executed for this P.O.?
a. Full time (resident)
b. Occasionally, Randomly, or Periodically
c. Final only
d. Not at all

24. Based on actual observation and existing documentation about this supplier's work, how was the supplier evaluated AFTER the P.O. was issued using the following attributes? (Scale: 1 = poor, 2 = below average, 3 = average, 4 = above average, 5 = excellent)

Criterion	Attributes of the criterion	1	2	3	4	5
Plant operations/Building and infrastructure	Storage and shipping, Structure for QA/QC personnel and records, Examination and testing, Housekeeping, Security					
Manufacturing capability	Machining capability, Fabrication capability (including welding, coatings, etc.), Capability to manufacture per user requirements, Calibration records and procedures, Non-destructive testing and inspection capability and quality, Shop capacity					
Experience and qualifications	Geographical areas in which supplier is qualified to work, Familiarity with codes specific to certain geographic regions, Certifications (ASME, API, etc.), Work history					
Workforce	Documented training of the workforce, Craft types available at location, Qualifications of the workforce, Source of backup workers					
Engineering capability	Professional/technical specialties held in house, Compliance with documents and specifications, Cooperation, responsiveness of requests, and turnaround documents, Robust document management system					

Material control	QA/QC manual for material control, Process for material substitution, Material verification, Prevention of counterfeit materials, Material certification					
Adherence to procedures and standards	Adherence to codes and specifications, Quality, legibility and completeness of documentation, Nonconformance control, Proper notification of inspection and hold points, Identification of parts - traceability					
Safety adherence and record	Written safety, health and environmental program, Compliance to local/governmental safety and environmental requirements, Experience Modification Ratio (EMR), Total Recordable Incidence Rate (TRIR)					
Handling of subcontractors/sub-suppliers	Outsourced/subcontracted product/service control, Procedure to check subcontractor compliance with quality requirements, Documented evidence of compliance, Auditing subcontractors, Ability to schedule and expedite subcontractors/sub-suppliers					

25. What was the total number of spools actually received for this P.O.?

26. Did you identify any unplanned quality events (i.e., non-conformances, such as variation, defect, failure,) during execution in the shop?
a. Yes
b. No

27. Indicate the total number of unplanned quality events noted **at the shop**.

28. Indicate the total number of unplanned quality events noted **at the site**. If no inspection was performed, answer N/A.

Appendix B: Survey Response Quantities and Statistics

Table B - 1: Quantities per Cutoff Category Using Method 1

Cutoff Value	N	Rating	# of Suppliers
3	38	Good	30
		Poor	8
3.5	38	Good	26
		Poor	12
4	38	Good	22
		Poor	16
4.5	38	Good	6
		Poor	32

Table B - 2: Quantities per Category

Category	N	Rating	# of Suppliers
1. Plant Operations /Building and Infrastructure	40	1	1
		2	2
		3	7
		4	25
		5	5
2. Manufacturing Capability	40	1	1
		2	3
		3	8
		4	21
		5	7
3. Experience and Qualifications	40	1	0
		2	1
		3	7
		4	28
		5	4
4. Workforce	39	1	1
		2	2
		3	8
		4	20
		5	8

Category	N	Rating	# of Suppliers
5. Engineering Capability	40	1	1
		2	2
		3	12
		4	18
		5	7
6. Material Control	40	1	2
		2	3
		3	11
		4	17
		5	7
7. Adherence to Procedures and Standards	40	1	1
		2	5
		3	9
		4	18
		5	7
8. Safety Adherence and Record	40	1	1
		2	1
		3	9
		4	26
		5	3
9. Handling of Subcontractors and Subsuppliers	37	1	0
		2	8
		3	3
		4	25
		5	1

Table B - 3: Simple Statistics on # NCs and # NCs/$ PO

	# NCs	# NCs/$ PO * 10,000,000
Min	0	0
Max	750	615.79
Median	1	6.67
Mode	0	0
Average	33.93	41.75
Range	0-750	0-615.79
Variance	16172.12	14087.8

Appendix C: Ranking Supplier Criteria Survey

Rank the following 9 supplier selection criteria from most important (1) to least important (9) when selecting a supplier to deliver a purchase order. For example, if the most important criterion is *manufacturing capability*, rank it as 1, if the second most important is *workforce*, rank it as 2, etc.

Criterion	**Attributes of the criterion** (factors considered in the analysis of each criterion)	**Ranking**
Plant operations / Building and infrastructure	Storage and shipping, Structure for QA/QC personnel and records, Examination and testing, Housekeeping, Security	
Manufacturing capability	Machining capability, Fabrication capability (including welding, coatings, etc.), Capability to manufacture per user requirements, Calibration records and procedures, Non-destructive testing and inspection capability and quality, Shop capacity	
Experience and qualifications	Geographical areas in which supplier is qualified to work, Familiarity with codes specific to certain geographic regions, Certifications (ASME, API, etc.), Work history	
Workforce	Documented training of the workforce, Craft types available at location, Qualifications of the workforce, Source of backup workers	
Engineering capability	Professional/technical specialties held in house, Compliance with documents and specifications, Cooperation, responsiveness of requests, and turnaround documents, Robust document management system	
Material control	QA/QC manual for material control, Process for material substitution, Material verification, Prevention of counterfeit materials, Material certification	
Adherence to procedures and standards	Adherence to codes and specifications, Quality, legibility and completeness of documentation, Non-conformance control, Proper notification of inspection and hold points, Identification of parts - traceability	
Safety adherence and record	Written safety, health and environmental program, Compliance to local/governmental safety and environmental requirements, Experience Modification Ratio (EMR), Total Recordable Incidence Rate (TRIR)	
Handling of subcontractors/sub-suppliers	Outsourced/subcontracted product/service control, Procedure to check subcontractor compliance with quality requirements, Documented evidence of compliance, Auditing subcontractors, Ability to schedule and expedite subcontractors/sub-suppliers	