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Further Development for Binder Quality Assurance Program

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The current TxDOT binder QC/QA system uses two asphalt binder supplier categories; suppliers who have an approved quality control plan (QCP) on file with TxDOT and those who do not. Suppliers who maintain a current QCP can obtain approval to supply binders either on a monthly- or a quantity-basis, while for others, each load of asphalt must be tested for specification compliance. Recently, a few binder supplier-grade combinations have experienced higher failure rates than in the past. Many TxDOT practitioners indicate an approved binder source does not always provide acceptable quality binders, and that a more robust QC/QA system is needed to ensure the supply of binders that both meet specifications and maintain a consistent level of quality. This research project was launched to develop a quality management system that utilizes the latest QC/QA principles by sharing the quality management burden between the supplier and the client (TxDOT). First, TechMRT researchers undertook a constructability review of binder quality for TxDOT operations. TxDOT districts, along with binder suppliers, and several contractors were interviewed to solicit their viewpoints on the existing binder quality management program, binder usage, quality problems and possible solutions. The Researchers also performed a comprehensive statistical analysis of binder test data. Three years of TxDOT test results (QA data) and several years of supplier (QC) data were analyzed using several statistical quality control methodologies. A sound binder supply quality management scheme requires the cooperation between binder suppliers and TxDOT. The burden of producing an asphalt binder that both meets specifications and maintains a consistent level of quality lies primarily with the supplier. TxDOT has the responsibility to provide clear and specific guidelines for suppliers to follow, and to conduct random quality assurance tests. Based on this premise, the research product titled A Framework for TxDOT Binder Quality Management has been developed.</td></tr>
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FURTHER DEVELOPMENT OF BINDER QUALITY ASSURANCE PROGRAM

by

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and Wickrama Galagoda

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Acknowledgement

A research project of this magnitude cannot be successfully completed without the help and cooperation of a large number of individuals. The authors wish to acknowledge the cooperation extended by many TxDOT personnel (both at the district and division level), binder suppliers and contractors who volunteered their time and wisdom towards the successful completion of this research. Special thanks go to Michael Leaverton, Albert Ayenu-Prah and Aldo Romero, three members of this research team whose work provided valuable data and other information for this report.

Implementation Statement

The primary objective of this research project was to develop a new testing and evaluation protocol for aggregate-binder compatibility in seal coats that can be easily implemented. The researchers believe this objective has been met. A performance-based testing protocol was developed to evaluate various aggregate-binder combinations used in seal coats and surface treatments. The testing protocol has been verified using limited field performance data, and it has been demonstrated that the test method is capable of distinguishing between 'good' and 'poor' performing aggregate-binder combinations based on past experience in TxDOT. Furthermore, the effects of established construction and performance factors on aggregate-binder bonding have been demonstrated in the limited number of tests conducted in this research project. Further tests and field observations of seal coat test sections may be needed to fine-tune the test method and its evaluation protocol. The researchers feel good about the test method that has been developed, and strongly believe that TxDOT is getting a product (the testing protocol) that is effective, practical and economically suitable for seal coat and surface treatment applications. It is also ready for implementation.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate

(Revised September 1993)

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CHAPTER I

Introduction

Every customer wants to be assured the product they are buying will meet their needs. The Texas Department of Transportation (TxDOT) wants the same assurance for the hundreds of millions of dollars it spends for asphalt binder used in road construction and resurfacing. Currently, TxDOT uses a two-approach quality assurance strategy for its asphalt binders. The first approach is a monthly certification program for established suppliers where binder samples for each asphalt binder grade are randomly taken by either a TxDOT sampler or a sampling contractor. These binder samples are typically taken towards the end of a particular calendar month, and they are tested by the AASHTO-certified TxDOT materials laboratory for specification compliance. If the binder grades meet the corresponding specification criteria, that supplier is approved to supply that grade of asphalt for the subsequent month. In the other approach, binder quality is monitored for either each tank produced or each load supplied to a TxDOT construction project. This approach is typically adopted for "non-established" asphalt suppliers who typically supply smaller quantities of asphalt, and do not possess comprehensive plan testing capabilities. This research project is aimed at developing a more comprehensive quality management strategy for asphalt binders where binder supplier certification is done based on both supplier (QC) and TxDOT (QA) testing.

Road construction quality assurance and control practices vary across the country. Chapter 2 reviews the many aspects of asphalt binder quality. Construction specifications vary from method specifications, which specify every aspect of the construction project, to end result specifications, which allow contractors to innovate to reduce costs and improve quality. Asphalt binder performance is measured using a number of standard tests. Chapter 2 contains a review of these measures and some of the recent research relating these measures to binder performance in the field. The AASHTO guidelines and specifications for asphalt binder quality assurance and control are also reviewed. Acceptance sampling and estimation techniques are introduced as well.

Chapter 3 of this report reviews the quality assurance practices of TxDOT districts and other state DOTs. Each of the 25 TxDOT districts was consulted to get their viewpoints on binder QC/QA issues. Particular attention was also given to the quality control and quality assurance practices of some state DOTs including the Combined States Binder Group (CSBG), which is a consortium of seven states that have developed and adopted a unified binder QC/QA program. Industry groups including binder suppliers, contractors and trade groups were also consulted to get their views on this subject.

Results from a comprehensive analysis of quality data for TxDOT suppliers to determine the effectiveness of the current TxDOT quality assurance program is presented in Chapter 4. TxDOT test results from a three-year period (2002 to 2005) as well as a limited number of supplier test results from 2000 to 2004 were analyzed. A limited round-robin test program was conducted as a part of the project to investigate its suitability for TxDOT. A description of the program and the test results are presented.

Based on the review and analysis of binder QC/QA practices described in Chapter 2-4, conclusions and recommendations are offered. In addition, a comprehensive binder QC/QA scheme based on a binder supplier certification program is proposed. This proposed “TxDOT Binder Quality Management Framework” is included in Appendix A of this report.

Chapter II
Literature Review

2.1 BACKGROUND

2.1.1 Definitions on Quality Control and Quality Assurance

Quality control (QC) is generally defined as a system used to maintain a desired level of quality in a product or service (Gryna 2001). This may be achieved by various measures such as planning, design, use of proper procedures and equipment, inspection, and corrective action when a deviation is observed between the product, service, or process output and a specified standard. Quality assurance (QA) is generally defined as all planned and systematic actions necessary to provide confidence that a product or service will satisfy some given needs. QA answers five owner/agency questions: what do we want? (planning and design), how do we order it? (construction plans and specifications), did we get what we ordered? (inspection, sampling and testing), what do we do if it is not what was ordered? (acceptance/rejection), and what do we do if it is "better" than was ordered? (bonus and value engineering). (Emery 1995) Consistency in producing materials that meet specifications require that process control charts in QC are used to determine when a change in the process is required to maintain production of materials that meet specifications. Confidence intervals are used in QA for material sampling, testing variability, and to determine when a material fails a single property or multiple properties required in a specification. Traditional specifications are used to determine if material or workmanship is acceptable or unacceptable, and so are very rigid. QA takes guesswork out of specification interpretation and communicates it to the contractor before bidding a project.

2.1.2 Overview of Construction Quality

2.1.2.1 QC/QA in Construction

The International Organization for Standardization (ISO) states that "quality is the totality of characteristics of an entity that bear on its ability to satisfy stated or implied needs". Quality of construction is more difficult to define. The first reason is that the product is usually a unique piece of work instead of a repetitive unit. Secondly, the term "client" has a broader sense that not only includes those contracting the project, but also the community of people who will use it. "A quality product of building construction is one that meets all contractual requirements (including statutory regulations) at optimum cost and time" (Chung, 1999).

The development of quality assurance in the construction industry has been mainly client-led. Poor management and communication are the main reasons for defects. Preventive measures must be carried out to minimize the risk of managerial and communication problems (Chung, 1999).

The goal of quality assurance is to prevent quality deficiencies. To practice quality assurance, a quality management system (usually called quality system) is necessary for an organization in its daily operation. A quality system, sometimes referred to as a QC/QA program, ensures the type and amount of verification to be performed on the quality control functions. A well-established quality system results in higher productivity and more customer satisfaction (Chung, 1999).

Organizations make significant investments to implement and maintain a quality system. However, these investments pay dividends in later phases due to fewer incidents of reworking or rejection. "Quality does not cost – it pays" (Roberts, 1991). A well-structured quality system is also a powerful marketing tool.

In the construction industry, quality control covers the whole period of material manufacturing, from inspecting the incoming materials and monitoring production processes, to testing of the finished product. There are two choices when combining production control and acceptance control: rigid production control with lenient criteria of acceptance, and greater freedom in production control with stringent criteria of acceptance. The producer should balance these two aspects and find an economical optimum (Chung, 1999).

In the building industry, a common characteristic of inspection systems of quality control is that they identify mistakes after the event. This makes defective building work very difficult to rectify or replace, which increases costs. Therefore, regular supervision by the contractor is the key to quality. The commitment to quality by senior management is also critical to preventing poor workmanship (Chung, 1999).

2.1.2.2 Quality System

A quality system can be considered a framework for quality management. It embraces the "organizational structure, procedures, processes and resources needed to implement quality management" (ISO, 1994a). A quality system covers all the activities leading to the finished product.

The quality system should be fully documented. In a top-down sequence, the quality system documentation can be divided into quality policy statement, quality manual, quality procedures, work instructions, and quality records. On the project level, a quality plan is usually used as the supplement to those documents (Chung, 1999).

A quality system standard is a reference base used to evaluate a quality system. There are many quality system standards, and the most widely used is the ISO 9000 family of standards. ISO 9001 and ISO 9002 are suitable for the construction industry. Third-party certification largely relies on these international quality system standards (Chung, 1999).

The elements of quality system requirements based on ISO 9001 / ISO 9002 in the context of the construction industry are listed as follows (Chung, 1999):

- Management responsibility
    - Define, document and publicize quality policy.
    - Define and document responsibility, authority and interrelation of staff.
    - Identify and provide adequate resources.
    - Appoint quality manager.
    - Review the quality system at regular intervals.
- Quality system
    - Establish, document and maintain a quality system.
    - Prepare and effectively implement documented procedures.
    - Define and document how quality planning is conducted for a project or contract including preparation of a quality plan.
- Contract review

- Review tender before submission.
  - Review contract before signing.
  - Review variation order before acceptance and transfer of amended requirements to functions concerned.
- Design control
  - Plan design activities.
  - Identify and review design input.
  - Review, verify and validate design output.
- Document and data control
  - Review and approve documents prior to issue.
  - Review and approve document changes prior to issue.
  - Control distribution and updating of documents.
- Purchasing
  - Evaluate and select subcontractors on the basis of capabilities for quality.
  - Exercise appropriate control over subcontractors.
  - Review and approve purchasing documents (including subcontracts) prior to release.
  - Specify arrangements for verification and product release of subcontracted product or work at subcontractor's premises if required.
  - Allow the client or his representative to verify subcontracted product or work at the contractor's / subcontractor's premises where specified in contract.
- Control of customer-supplied product
  - Control verification, storage and maintenance of customer-supplied product.
- Product identification and traceability
  - Identify material and semi-finished product from receipt and during all stages of production, delivery and installation where appropriate.
  - Provide unique identification of individual product or batches where specifically required.
- Process control
  - Identify, plan and control production, installation and servicing processes, including provision of documented procedures and suitable equipment.
  - Assign qualified operators to carry out special processes.

- Inspection and testing
  - Conduct receiving inspection and testing of incoming materials and components.
  - Conduct in-process inspection and testing of semi-finished work in accordance with quality plan.
  - Conduct final inspection and testing of finished work in accordance with quality plan.
  - Maintain signed-off records of inspections and tests.
- Control of inspection, measuring and test equipment
  - Use inspection, measuring and testing equipment capable of necessary accuracy and precision.
  - Calibrate the equipment at prescribed intervals, or prior to use, and indicate its calibration status.
  - Review previous results when the equipment is found to be out of calibration.
- Inspection and test status
  - Indicate by suitable means the conformance or nonconformance of product or work with regard to inspection and tests performed.
- Control of nonconforming product
  - Identify, and segregate when practical, any nonconforming product or work.
  - Review and dispose of the nonconforming product or work by an authorized person.
  - Inspect and/or test the product or work again after repair.
- Corrective and preventive action
  - Investigate cause of nonconformities, including client complaints.
  - Take corrective / preventive action to eliminate cause / potential cause of nonconformities.
  - Implement and record changes to documented procedures resulting from corrective / preventive action.
  - Ensure that corrective / preventive action is taken and that it is effective.
- Handling, storage, packaging, preservation and delivery
  - Establish methods of handling product that prevent damage or deterioration.
  - Use designated storage areas to prevent damage or deterioration.
  - Assess condition of product in stock at appropriate intervals.
  - Protect product during delivery.

- Control of quality records
  - Retain quality records for prescribed period.
  - Maintain quality records in such a way that they are identifiable, retrievable and secured against damage, deterioration or loss.
- Internal quality audits
  - Plan and schedule internal quality audits.
  - Assign independent personnel to carry out internal quality audits.
  - Conduct follow-up audits if necessary.
- Training
  - Identify training needs of staff.
  - Provide training required.
- Servicing
  - Verify that servicing meets specified requirements.
- Statistical techniques
  - Identify the need for statistical techniques in quality control.
  - Implement and control the application of statistical techniques.

2.1.3 Quality Audits and Quality Assessments

A quality audit is an independent review conducted to compare some aspect of quality performance with a standard for that performance. (Gryna 2001) Quality assessment has a broader sense than quality audit because it includes managerial matters such as quality cost, staying in business, and quality culture. The components and elements of quality systems evaluation are:

A. Organizational design
B. Customer management practices
C. Organizational and individual development practices
D. Product development practices
E. Product and process control practices
F. Procurement practices
G. Warehousing and distribution practices
H. Quality assurance practices

I. Information analysis practices

J. Document management practices

2.1.4 Quality Monitoring

Quality monitoring procedures require a database of good materials and construction quality be maintained. When the database contains individual test results rather than averages, a wider range of analyses can be performed. If more supplemental construction information resides in the database (e.g., weather conditions, and distance from the plant), there is an increasing chance that causes of specifications effectiveness inconsistencies can be found and appropriately corrected (Pathomvanich, et al., 2002).

2.1.5 Recent TxDOT Research on Pavement Construction Quality

The biggest requirement of a structure is to perform satisfactorily throughout its design life. When it comes to pavements, however, distresses are developed in different sections of the roadway and one reason behind this is the variability of construction quality. Hence, quality of construction plays a very important role and a performance based construction quality management program will ensure that the quality of construction is maintained and thus the structure performs as expected. This report discusses a method of optimizing construction quality management of pavements using mechanistic performance analysis methods based on statistical techniques. One requirement is a method to identify and minimize the variability of material properties. A statistical algorithm which relates impact of construction parameters to the performance has been developed. The technique developed will assists the users in identifying what parameters impact the performance and the amount of impact.

The main focus of this research was on finding current practices and software packages that relate quality of construction to the performance of the pavement, developing an algorithm to identify the impact of construction parameters on the performance of the pavement, and determining the important parameters based on the developed algorithm.

Performance models, their primary design parameters and construction parameters that impact the primary design parameters were identified in the process. The feasibility of measuring these parameters had to be determined. A way to quantify variability of the construction parameters and its sources was established and finally, a method was developed to assess the variability of construction parameters that affects the expected life cycle performance. Fatigue cracking, subgrade rutting and rutting of AC layer are the performance indicators selected for the flexible pavement.

Fatigue cracking model is

$$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$$

Subgrade rutting model is

$$N_d = f_4(\varepsilon_c)^{-f_5}$$

Where:

N_f - allowable number of load repetitions to prevent fatigue cracking,

N_d - allowable number of load repetitions to prevent rutting,

E_1 - elastic modulus of asphalt-concrete layer,

ε_t - tensile strain at the bottom of asphalt-concrete layer,

ε_c - compressive strain at the top of the subgrade,

f_1-f_5 - parameters asphalt institute (AI) model.

AC rutting model when HMA less than 6 inches

$$\log RR = -5.617 + 4.343 \log w_0 - 0.167 \log N_{18} - 1.118 \log \sigma_c .$$

AC rutting model when HMA greater than 6 inches

$$\log RR = -1.173 + 0.717 ogw_0 - 0.658 \log N_{18} - 0.666 \log \sigma_c .$$

Where:

RR - rate of rutting in micro inches per axle load repetition,

w_0 - surface deflection in mil,

σ_c - vertical compressive stress under HMA in psi,

N_{18} - equivalent 18 kip single axle load in 10^5 ESALS.

In the report, the equivalent linear program, WESLEA developed by Ke et al. (2000) was adapted as the structural model in order to determine ε_t ,ε_c and σ_c.

The next step was the selection of material models in order to connect construction parameters to performance models. "Witczak" was selected for the material model for AC layer and it is

$$\log E_{AC} = 5.553833 + 0.028829\frac{P_{200}}{f^{0.17033}} - 0.03476V_v + 0.070377\eta + 0.000005t_p^{(1.3+0.49825\log f)}P_{ac}^{0.5} -$$
$$0.00189t_p^{(1.3+0.49825\log f)}\frac{P_{ac}^{0.5}}{f^{1.1}} + 0.931757f^{-0.02774} + \varepsilon$$

Where:

$E_{AC} =$ dynamic modulus of AC mix (in 10^5 psi),

$\eta =$ viscosity in bitumen (in 10^6 poise),

$f =$ load frequency (in Hz),

$V_v =$ % air voids in the mix by volume,

$P_{ac} =$ % bitumen content by volume,

$P_{200} =$ % passing #200 sieve.

As the material model for the base and for the subgrade layers, universal model was selected and the form is

$$M_R = k_1 \theta^{k_2} \sigma_d^{\ k_3}$$

Where:

$\theta = \sigma_1 + \sigma_2 + \sigma_3 =$ bulk stress (σ_1, σ_2 and σ_3 are principal stress),

$\sigma_d = \sigma_1 - \sigma_3 =$ deviator stress,

$k_1, k_2, k_3 =$ material regression constants and statistically obtained from laboratory tests.

The equation above is the general form and for coarse grained materials k_3 is set to zero and for fine grained material k_2 is set to zero.

It's stated that a probabilistic approach with mechanistic based algorithms would identify the impact of construction parameters on pavement performance. A structural model, a material model and a statistical algorithm are required in order to determine the impact due to the variability of parameters on the performance of the pavement using laboratory tests and field tests. A probabilistic approach was adopted here in order to account the variability of parameters whereas in a deterministic approach one value is considered for each parameter.

The algorithm developed to assess the importance of construction parameters combines the performance, structural and material models. The relevant construction parameters such as viscosity, asphalt content for AC layer and dry density, moisture content for subgrade layers are defined as the initial step. Simulated parameters using Monte Carlo simulation and two point mass methods were put into the system and got the relevant performance indicators. The size of the sample to be generated by the Monte Carlo technique was selected as 500 based on repeatability. Coefficient of Variation was compared to determine which of the considered construction parameters is affecting performance the most. Impact value (I_i) was considered in order to prioritize the construction parameters and determined as

$$I_i = \frac{COV_i}{COV_{ALL}}$$

Where

COV_i = COV of performance indicator based on perturbing parameter,

COV_{ALL} = COV of the same performance indicator when all input parameters are varied Simultaneously,

Normalized impact value (NIV_i) is considered in order to assess the relative significance of parameters and determined as

$$NIV_i = \frac{I_i}{\sum_{i=1}^{n}(I_i)}.$$

An impact pie chart was obtained using all NIV^s. If the NIV is large for a particular parameter, the impact from that parameter to the pavement is considered large. If the variability of the performance indicator is not acceptable, the variability of the construction parameters with the greatest effect is adjusted and the program rerun until variability of the performance indicator is acceptable. This way, one can clearly identify which construction parameters are truly affecting the performance of the pavement and its remaining life.

2.1.6 Quality Issues in HMAC Construction

2.1.6.1 Pay Factors

The major concern of developing a pay schedule is to determine the pay factors and practical pay levels based on quality. An appropriate pay schedule is based on quality-performance relationships. It aims to cover future costs for repairs and replacement. Pay adjustment can be positive or negative based on the economic impact of a departure from the predefined quality level. The construction with early completion or superior quality will receive a bonus. (Afferton et al., 1992)

R.M. Weed provided an equation for pay factors of highway pavement as following (Afferton et al., 1992):

$$PF = 100[1 + C_0(R^{Ld} - R^{Le})/C_p(1 - R^{Lo})]$$

where

PF = appropriate pay factor (percent),

C_p = present unit cost of pavement (bid item only),

C_o = present unit cost of overlay (total in-place cost),

L_d = design life of pavement,

L_e = expected life of pavement,

L_o = expected life of overlay,

, $R = (1 + R_{\inf} / 100) / (1 + R_{\mathrm{int}} / 100)$

$R_{\inf}$ = annual inflation rate (percent),

R_{int} = annual interest rate (percent).

It is necessary to develop an appropriate relationship between quality and performance to construct a pay schedule. Engineering judgment and experience may be used to estimate the expected service life as a function of the quality parameters. A continuous pay schedule has an important advantage of providing a smooth progression of payment as quality varies, avoiding a substantial change in payment due to sampling errors when the true quality level lies close to the specification. (Afferton et al., 1992)

Afferton et al. (1992) suggest that zero pay factors are justified by the fact that it is possible that the expenses of repairs exceed the initial cost of an inferior construction item. Some less critical items in a project can be treated as non-pay-adjustment items that are subject to a pass-or-fail decision.

Echeverry et al. (1988) developed graduated unit price payment schedules that provide effective tools for the contractors to estimate the cost of achieving a specific quality level and corresponding payments. Elliott and Herrin (1986) developed a pay schedule based on the value concept. Hultman-Hall et al. (2004) concluded that the international roughness index (IRI) is appropriate as a quality measure of smoothness. Lin et al. (2001) employed statistical methods such as principal component analysis to develop a general approach to payment adjustments for flexible pavements. They concluded that “pay factors based on multiple distress indicators are usually lower than those based on one single indicator when the variation in influencing factor such as asphalt concrete thickness is large”. Choi and Bahia (2004) proposed an embedded

Monte Carlo simulation incorporating the life-cycle cost analysis. It was concluded that the method can effectively model an overall pay adjustment. Scholz et al. (2001) conducted a sensitivity analysis of the pay factors to the variation of certain key materials and construction factors. The results showed a considerable sensitivity to variations in thickness, air void content, and asphalt content. Monismith et al. (2004) proposed an approach to determine appropriate pay factors using performance models.

With regard to specifications based on multiple quality characteristics, the pay adjustment is usually a function of the combined effects of all quality characteristics which contains a separate term for each of the quality characteristics. The pavement performance is better characterized by an additive function rather than by the average of the individual quality measures (Weed, 2001). An alternative is to generate a single quality measure that is a composite of all the quality characteristics. This approach is most suitable when several quality characteristics jointly affect performance and higher quality in one offsets inferior in the others (Weed, 2000).

The New Jersey Department of Transportation (NJDOT) employs air voids, thickness, and smoothness as pay factors in the performance-related specifications (Weed, 2000). The Illinois Department of Transportation (IDOT) uses mix composition and pavement density to develop the pay schedule (Echeverry et al., 1988). The Arizona Department of Transportation (ADOT) implements an incentive/disincentive asphalt concrete smoothness specification in 1990 (Delton et al., 2003), as did Kansas state (Hossain and Parcells, 1995), Florida state (Ksaibati et al., 1999), and Maryland state (Stephanos et al., 2003)

Alberta DOT applied design of experiment (DOE) to determine the sample size for each of the quality characteristics: asphalt content, percent compaction, and aggregate gradation. The results of one way ANOVA and independent T-test demonstrated that the sample size could be reduced to maintain the same level of mean values and degree of confidence, and it did not significantly affect the price adjustments to the contractor. (McCabe, 1999).

2.2 ASPHALT BINDER TESTING

2.2.1 Binder Properties and Performance

2.2.1.1 Superpave Asphalt Binder Tests and Objectives

The Strategic Highway Research Program (SHRP) published binder testing methods and specifications for Performance Grade (PG) binders. Many states have adopted these testing methods and specifications. In the performance grade system, asphalt binders are tested at the expected service temperatures in order to guarantee the ability of asphalt binders to perform satisfactorily. Rutting, fatigue cracking and thermal cracking are the three main distresses encountered in flexible pavements (Haddock et al. 2002). PG binder testing is conducted on original, short-term aged, and long-term aged asphalt binders. Oxidation and loss of volatiles during construction is considered to be short-term aging and is simulated by the Rolling Thin Film Oven test in an ordinary laboratory testing. Oxidation that occurs after five to ten years in service is considered to be long-term aging and is simulated by aging the asphalt in the Pressure Aging Vessel in a laboratory (Prowell 1999).

In order to categorize the asphalt binder based on the Superpave method, several tests are performed. These tests include the Rotational Viscosity and Dynamic Shear Rheometer (DSR) tests on original binder, the DSR on Rotational Thin Film Oven (RTFO) aged binder, the DSR on Pressure Aging Vessel (PAV) aged binder, the Bending Beam Rheometer (BBR) test (stiffness and m-value) on PAV-aged binder, the Direct Tension Test (DTT) on PAV-aged binder, and the mass loss in RTFO (Haddock et al. 2002). Rotational Viscosity measures binder properties at high construction temperatures to ensure handling and pumping. Dynamic Shear Rheometer measures binder properties at high and intermediate service temperatures to insure the binder’s resistance to permanent deformation (rutting) and fatigue cracking. Bending Beam Rheometer measures binder properties at low service temperature to insure resistance to thermal cracking and the Direct Tension Test measures the binder properties at low service temperature to insure resistance to thermal cracking.

Binder properties are directly related to the performance of flexible pavements. Viscosity is considered one of the main properties although it is not directly related to the performance of the asphalt binder once it is laid on the pavements. The Rotational Viscometer and Capillary Viscometer are used to conduct the viscosity tests. The Rotational Viscometer is widely used for testing many modified binders since there is a tendency to get blocked Capillary Viscometers, disturbing the smooth flow. Viscosity tests are performed to determine the capability of the material for pumping and mixing. The viscosity is determined at high temperatures since the mixing is carried out at high temperatures (Roberts et al. 1996).

The Dynamic Shear Rheometer (DSR) test is the most important test to characterize the elastic and viscous behavior of asphalt binder. DSR provides a complete picture of the behavior of asphalt binder at pavement service temperature by measuring the complex modulus G* and phase angle δ. Most asphalt binders behave like viscoelastic materials at usual service temperatures (Roberts et al. 1996). In the DSR test, unaged binder and RTFO-aged binders are tested at the maximum design temperature in order to ensure the binder's ability to withstand permanent deformation. In order to determine the binder's ability to resist fatigue cracking, PAV-aged asphalt binders are tested at an intermediate design temperature.

2.2.1.2 Asphalt Binder Properties and Pavement Performance

There are four major temperature ranges that relate to the asphalt binder's life and its performance. From the production of asphalt until it is laid down in the intended pavement, asphalt binder goes through different temperature levels.

Mixing and construction usually take place at high temperatures such as above 100^0 C. Therefore, the binder consistency needs to be controlled. Most binders behave like Newtonian fluids at high temperatures and therefore act like viscous fluid. Hence, it is sufficient to determine the viscosity at high temperatures in order to determine the workability of asphalt during mixing and construction of hot mix asphalt (Bahia and Anderson 1995).

In pavement service temperatures, one of the main distresses encountered is rutting. Complex modulus and phase angle predict the ability of the selected asphalt binder grade to resist rutting. Since complex modulus represents resistance of the binder to deformation when sheared, higher complex modulus is favorable when considering rutting. Also, a lower phase angle indicates that the binder has a more elastic component when deformed and thus helps resist rutting.

Unlike at high temperatures where asphalt is generally viscous, at intermediate temperatures asphalt binders are harder and more elastic. Therefore, in these temperatures, one of the main distresses is fatigue cracking which is a result of repeated cycles of loading at levels lower than the static strength of the material (Bahia and Anderson 1995). Here also, complex modulus and phase angle play a role in damage caused by fatigue. These two parameters are important since the damage to the material is assessed by how much stress and strain develop within the material and how much of it is recovered or lost. Usually softer and more elastic materials are more favorable for resisting fatigue cracking since the stress developed is low and the ability to recover to its original position is high (Bahia and Anderson 1995).

At low temperatures thermal stresses develop due to the shrinkage of the pavement. Eventually this leads to thermal cracking. During thermal cooling, asphalt stiffness increases continuously and leads to higher stresses for a particular strain. Due to the viscoelastic nature of the asphalt binder, these stresses relax at the same time. Therefore, stiffness and the rate of relaxation need to be determined in order to predict the binder's behavior to thermal cracking (Bahia and Anderson 1995).

It is understood that binder properties have to be capable of resisting three major pavement distresses namely rutting, fatigue cracking and thermal cracking.

Permanent deformation known as rutting is described as the progressive movement of the material under repeated loads. This is an accumulation of permanent deformation caused by repeated applications of traffic loading. The movement is mainly lateral and the concerned area is along the wheel path. Excessive asphalt binder usage in a mix is the main reason for the permanent lateral movement of the hot mix asphalt, although the use of soft asphalt in hot desert climates can also contribute to permanent rutting. The load on a pavement is primarily carried by the aggregate. Once there is more than the required amount of asphalt binder there is a tendency by the asphalt binder to carry some load, which eventually leads to deformation. Some resistance to permanent deformation can be achieved using binders with high complex modulus (G*) and low phase angle (δ). When the complex modulus is high the material exhibits high stiffness. Stiffer material is more resistant to permanent deformation. Similarly if the phase angle is low, the material exhibits high elastic properties. The higher the elastic property the more deformation is recovered. Since the rutting occurs at high temperatures, parameters are determined at high temperatures in order to determine if the binder is suitable for use. Therefore, original and RTFO binders are tested at high temperatures. Long-term aging continues to increase the stiffness of the binder, and resistant to rutting increases. Therefore, it is important to test the binder before hardening (Roberts et al. 1996). In order to mitigate the rutting problems, more emphasis is also given to polymer modified asphalt, although the cost of this is high.

Another significant distress in flexible pavements is fatigue cracking. Fatigue cracking is most common in thin pavement sections, but it can also be a problem in thick pavement sections. Fatigue is a controlled-stress phenomenon in thick pavements and controlled-strain in thin pavements (Bahia and Anderson 1995). RTFO-aged binder samples after PAV-aged are tested in the DSR to determine the binder's ability to resist fatigue cracking. It is important to note that asphalt binder ages throughout its service life. Therefore, it is more susceptible to cracking with time (Roberts et al. 1996).

The next typical distress is low temperature cracking. Thermal cracking results when the temperature drops rapidly. Since the pavement shrinks, stresses begin to develop. If the stresses exceed the stress relaxation ability of the flexible pavement, cracks develop. The Bending Beam Rheometer is used to test the asphalt binders at low service temperatures to determine the ability to resist thermal cracking. Creep stiffness and m-value are determined by this test method. Creep stiffness indicates how the asphalt binders resist creep-loading. It measures how the thermal stresses develop in the hot mix asphalt pavement as a result of thermal contraction. The m-value gives an indication of the rate that creep stiffness changes with time. Alternatively, it is a measure of the rate of stress relaxation in asphalt binder. As the creep stiffness increases the tendency to develop stresses in the pavement structure increases. Therefore, more thermal cracking develops with high creep stiffness. Similarly, if the m-value decreases the rate of stress relaxation decreases, which indicates a reduced ability to relieve stresses. The laboratory experiment should be carried out at the lowest temperature, but due to the time involved, the time-temperature superposition principle is adopted to shorten the duration of the test. Due to the use of time-temperature superposition, the original two hour testing duration can be reduced to 60 seconds. Here the test is done at elevated temperature (by 10) instead it is done at lowest pavement temperature. There is a reasonable relationship between the stiffness of the binder and the amount of stretching. The creep stiffness of the material measured by BBR does not always characterize the low temperature behavior of the asphalt binder related to thermal cracking. There are some modified binders that do not meet the specifications limits. This means they may have higher stiffness values and stretch further before cracking occurs. The Direct Tensile Test (DTT) was developed to address these kinds of behaviors. DTT is used for binders with creep stiffness between 300 – 600 MPa (Roberts et al. 1996).

2.2.2 Recent TxDOT Research on Binder Quality

The study by Epps, et al. (2001) considered binder properties related to performance and models relating binder properties to performance; factors affecting binder properties prior to construction; and binder QA programs in Texas and other states. Binder properties must be such that they are able to resist the three main pavement distresses: Rutting, fatigue cracking, and temperature (thermal) cracking. The properties specified in the PG system are consistent for all binders, only the temperatures requirements vary. A characterization test is used to measure each property. References cited by Epps et al. (2001) indicate that the Rolling Thin Film Oven (RTFO) test (ASTM D 2872) is used to simulate the critical state of a binder during construction regarding rutting performance; the binder is short-termed aged. Binder that has been short-term aged in the RTFO and long-term aged in the Pressure Aging Vessel (PAV) (AASHTO PP1) is used to measure performance against fatigue and thermal cracking. The Dynamic Shear Test (AASHTO TP5) is used to measure performance against rutting and fatigue cracking, which is used to determine the time-dependent and temperature-dependent behavior of binders at intermediate and high temperatures. The Dynamic Shear Rheometer test (DSR) is used to measure the viscoelastic property of the material in terms of a complex shear modulus and a phase angle. The complex shear modulus gives a measurement of the total resistance of the material to repeated shear, including the elastic deformation and the viscous deformation. The phase angle gives a measure of the relative amount of elastic response as compared to viscous response. The Bending Beam Rheometer (BBR) and the Direct Tension Tester (DTT) are used to measure the low-temperature behavior of binders (Epps, et al. 2001). Epps et al. (2001) discussed the changes made to the original PG specification system by the NCHRP 9-10 study. The NCHRP 9-10 study addressed various issues that were deficient in the original PG system. Epps et al. (2001) indicated that the current TxDOT binder QA would be continuously improved as the field validation of the NCHRP 9-10 study proceeds.

Table 2.1 Factors That May Affect Binder Properties Prior to Construction (After Epps et al. 2001)

Category	Factors
Supplier Location	Storage Time
	Storage Temperature (Overheating)
	Blending
	Changing Crude Source
	Refinery Process (Temperature and/or Pressure
	Contamination in Tanks
Transportation	Contamination in Tanks
	Overheating
Contractor Location	Storage Time
	Storage Temperature (Overheating)
	Contamination/Mixing Different Binders
	Separation
	Dilution
	Presence of Modifier

Factors that could affect binder properties were outlined by Epps et al. (2001) Table 2-1. These factors affect binder properties during transit from refinery to construction site.

<u>Volumetric Properties</u>

Good QC/QA may depend on the volumetric properties of an HMA mix. Hauling and storage of asphalt binders may affect the properties of the binder and consequently affect the properties of the mix. Asphalt cement has minimal effect on the overall volumetric properties of an HMA mix. During storage, asphalt cement aging and temperature would have minimal effect on volumetric properties as well as aging during hauling. Absorption of asphalt cement has quite some effect on the volumetric properties, though, and storage and hauling may adversely affect it (Tuggle, 1994).

2.2.3 Precision and Bias of Asphalt Binder Testing

Most highway agencies use testing laboratories that are certified either at the national level through a program such as AASHTO Material Reference Laboratory (AMRL) or at the state level. Although the laboratories may be certified, their technicians well qualified and the equipment well maintained, differences in test results can still occur. Therefore, in order to distinguish between differences that occur due to random variation and those occurring due to laboratory specific causes, precision and bias criteria – which include values to assess repeatability and reproducibility – have been developed for commonly used binder test methods and included at the end of each test method specification (AASHTO 2002). These criteria are developed based on analysis of data from the AASHTO (AMRL) proficiency sample program.

Repeatability is referred to as single-laboratory or single-operator precision. This indicates the allowable difference between two test results obtained from the same sample by the same operator using the same equipment in the same laboratory. These test conditions are referred to as repeatability conditions. The difference between the results of two tests conducted under repeatability conditions is expressed as a percentage of the average of the results, referred to as repeatability D2S%, and is checked against the repeatability criterion for the test in question.

Reproducibility is referred to as multi-laboratory precision. This indicates the allowable difference between two test results obtained from the same sample by different laboratories using the same standard test procedure. Here also, the difference between the results of two tests conducted at different laboratories is expressed as a percentage of the average of the results, referred to as reproducibility D2S%, and is checked against the reproducibility criterion for the test in question. Repeatability and reproducibility criteria for selected key binder tests are listed in Table 2.2 below.

Table 2.2 AASHTO Precision and Bias Criteria for Selected Binder Test Methods (AASHTO 2002)

Type	Test	Repeatability (D2S%)	Reproducibility (D2S%)
PG	**DSR, G*/Sinδ (kPa)**		
	Original Binder	9.5	29.1
	RTFO/TFO Residue	11	31.3
	PAV Residue	22.4	56.1
	BBR		
	Creep Stiffness (MPa)	9.1	26.9
	Slope	4	13
AC	**Absolute Viscosity**	7.0	10.0
	Penetration		
	Below 50 penetration	1	4
	Above 50 penetration	3	8
Emulsion	**Demulsibility** for RS Weight % 30 to 100 (not applied when used DSS)	5	30
	Saybolt Viscosity	1	2
	Distillation Residue weight % 50 to 70	1	2
Cutbacks	**Distillation**		
	Distillation volume % of the original sample upto 347°F	% differ by less than 1.0 volume % of the original sample	3.5
	Distillation volume % of the original sample above 347°F		2.0
	Residue, vol. % by difference from original sample		2.0
	Kinematics viscosity		
	Asphalt cements @ 135°C	1.8	8.8
	Liquid asphalt @ 60°C		
	Below 3000 cSt	1.5	3.0
	3000 to 6000 cSt	2.0	9.0
	above 6000 cSt	8.9	10.0

2.2.3.1 Construction Material Variability:

When developing acceptance specifications and tolerances, production, sampling and testing variability should be considered. Difference two-sigma (d2s) is used as the test tolerance for the test. "The d2s limit refers to the maximum acceptable difference between two results with 95% confidence". The d2s limits were set through round robin testing. Tolerances from round robin testing data indicate mainly testing errors. When split samples test results are compared the AMRL-established tolerances (round robin test tolerances) are suitable. However, this is not applicable for QC/QA since QC/QA test results contain production and sampling variability for supplier and department. Therefore, different tolerances are required in different situations when test results are compared (Haddock et al. 2002)

2.2.3.2 Data Analysis Results

In a VDOT funded project, test result data from 1997 to 2000 were analyzed and discussed to determine the quality of binder and testing capabilities. Analysis of the VTRC tested samples indicates that producers are becoming more comfortable with the level of modification necessary to produce new grades. With the confidence they gain over time, producers use less modifiers to achieve the required grade thus reducing the cost. There is a clear indication of decreasing standard deviation for test results. The reason may be producers are comfortable with the new specification and test methods. From the data analyses of both the VTRC and producer tested samples, the standard deviation and mean appear to be consistent within the supplier's results. This demonstrates that it is not necessary to test each and every terminal for a same supplier. Therefore, it is suggested that instead of testing each terminal of the supplier, samples from the HMA producer's tanks should be tested to look for contamination. It's shown that both the VTRC and the supplier produce similar results for the tests. Also, it has been found that standard deviation is decreasing in both VTRC and producers. If both have the same standard deviation it is easier to establish testing tolerances for both the industry and the user agency. It is recommended that participating in a round robin setting will be useful for identifying and solving problems with testing equipments and procedures. Also it states that each DOT should maintain a database of binder data in order to set allowable testing tolerances (Haddock et al. 2002).

2.3 PAVEMENT MATERIALS SPECIFICATIONS

2.3.1 Overview of Specifications for Highway Construction

There are several different specifications currently adopted by different states: Method Specification, End Result Specification, Performance-Related Specification, Performance-Based Specification, Warranty Specification, and QC/QA Specification.

In Method Specification, the owner or the agency makes all the decisions. They specify the materials, design, and type and method of construction. The advantages of Method Specification are reduced job delays, contract claims, and escalation in future bid prices. The shortcomings are that the contractors do not have incentive to be innovative to improve the product quality, and this method requires the personnel of the owner/agency to inspect production at all times.

The End Result Specification is superior to the Method Specification. It uses parameters that serve as indicators of long-term pavement performance as criteria to judge the quality of the product and to decide the pay factors. It allows the contractors to control the quality of production and products on their own. The owner/agency's responsibilities are to ensure the quality control by contractors is effective, to make the decision to accept or reject the final product, and to determine the payment. In many states, statistical data analysis for the real projects shows the product quality in End Result Specification is better than in Method Specification in most product parameters.

The End Result Specification is divided into four levels. The first level is described in the previous paragraph. The second level corresponds to the Performance-Related Specification, which requires measurement of properties that are not direct measures of pavement performance, but related to performance measures. The third level is called Performance-Based Specification. The fourth level is the Warranty Specification. The responsibility of the owner/agency for quality of the end product decreases and that of the contractor increases as the End Result Specification moves from Level One to Level Four.

A statistical QC/QA specification can be applied to any specification if the owner/agency and the contractor use statistical concepts and methods in quality assurance and quality control. The important elements of a QC/QA Specification (Tuggle, 1994 (AAPT journal)) are as follows:

- It recognizes variability in the highway materials, construction process, sampling and testing procedures.
- A statistical lot size is described. It defines the total population that the samples will represent.
- Random sampling and number of samples are described.
- The test method used is described.
- The required level of quality is specified with no ambiguities.
- A decision must be made on acceptability by the highway agency after the contractor has produced the specified material.

2.3.2 Review of Asphalt Binder Quality Control/Quality Assurance

State highway agency (SHA) involvement in the design and construction phases of a hot-mix asphalt (HMA) project has decreased and varied considerably due to movement away from method-based specifications toward QC/QA and warranty specifications (Schmitt et al. 1998). Figure 2-1 indicates the trend.

The agency and contractor surveys conducted by Schmitt et al. (1998) reflect the three basic attributes: contractor requirements, project resources, and acceptance testing. Of the 42 states surveyed, 36 require contractor technician certification, and 33 states use various programs for technician training. Most states are requiring the contractor to perform mix designs and provide QC plans. The QC plan provides the agency and contractor with a document that outlines those tests or production processes that will be tested and monitored during construction (Schmitt et al. 1998). Testing levels are not affected by cost in most states, but to some degree affected by agency staffing levels. Costs range from 0.5% to 10% in terms of contractor cost to total project cost.

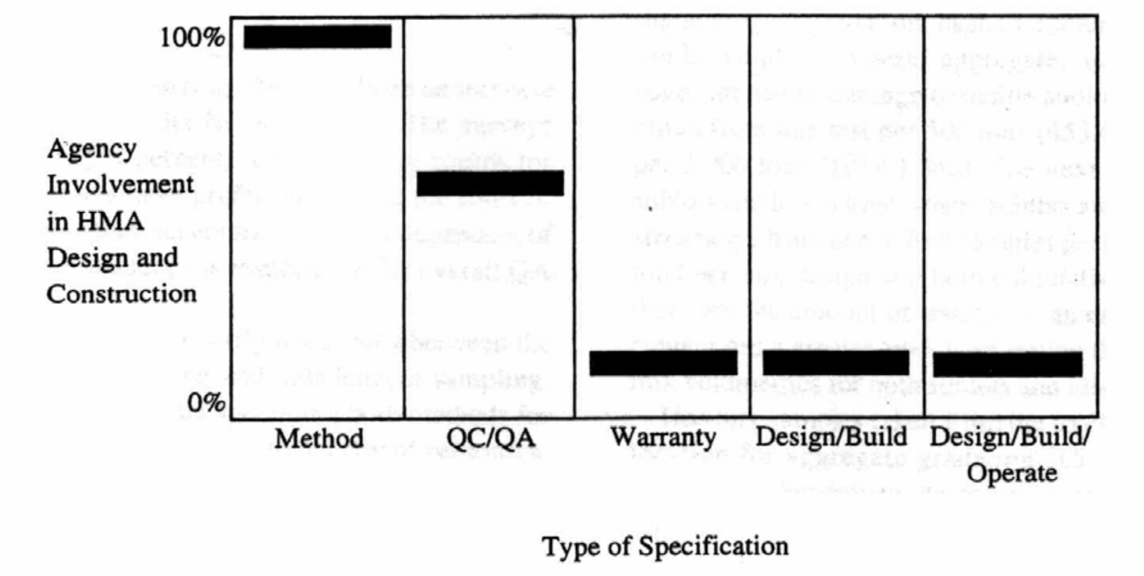

Figure 2.1 Agency Involvement for HMA Specification Type (After Schmitt et al. 1998).

Current staffing levels for a typical QC/QA project are two field personnel for agencies, with one at the mix plant and the other at laydown operations; two to four field personnel on the average QC/QA project, with a minimum of one person assigned to the mix plant (QC lab), one person at laydown operations to measure pavement density, and most contractors also have a QC manager who supports the plant and laydown personnel; personnel work from 6 to 8 hours per day, whereas contractor personnel work about 10 hours per day (Schmitt et al. 1998). The authors found three fundamental measures for acceptance testing. These measures describe overall pavement quality by measuring the HMA material composition (mix properties), the density, and the ride quality (smoothness). Five different measures were used to determine specification compliance: Average, quality level analysis, average absolute deviation, moving average, and range.

A fundamental decision to consider when determining testing levels is whether to use time or quantity to define a lot. Table 3 presents the relative advantages and disadvantages for such a decision. According to the authors, when using a quantity-based measure (such as metric tons), a given quantity of material can be tracked through plant mixing and laydown operations, allowing for an evaluation of the material at discrete points. Minimum testing times for HMA tests are given in Table 2.3, applied to assumed 10-hr production data (Schmitt et al. 1998).

Table 2.3 Minimum Time Requirements for HMA Tests (After Schmitt et al. 1998)

Test (1)	Time, hours (2)	Number of tests per 10-hour workday (3)
(a) Input Aggregate Gradation		
Coldfeeds	1.75	5
Hot Bins	2.00	5
(b) Plant Mixing		
Asphalt Content - Extraction	1.25	10
Asphalt Content - Ignition Oven	1.00	8
Aggregate Gradation	2.50	4
Volumetrics	2.25	4
(c) Density		
Cores	0.50	20
Nuclear Density Gauge	0.20	50

In their concluding remarks, Schmitt et al. (1998) indicated that from a resource availability point of view, minimizing the cumulative number of contractor and agency tests requires using contractor data for acceptance. Further, agencies should either collect their own samples or watch the contractor collect, split the sample and have the agency field representative immediately take possession of their portion of the split sample, which should be tested again for verification by the agency.

The California Department of Transportation, Caltrans, has QC/QA specifications that were written to be less prescriptive and to more clearly define the responsibilities of the engineer and contractor (Dobrowolski and Bressette, 1998).

Minimum QC test frequency required for acceptance in California is also presented in Table 2.4. Quality is encouraged by paying a bonus to the contractor and a disincentive is used to discourage poor quality work (Dobrowolski and Bressette, 1998).

According to Dobrowolski and Bressette (1998), a statistical quality analysis is used to determine a pay factor for each quality characteristic and then a composite pay factor is calculated by using weighted individual pay factors. Decisions regarding acceptance or rejection of the AC, stopping production, or terminating the lot as well as paying the contractor depend on the individual and composite pay factors. The authors discuss the current Caltrans QC/QA specifications and recommend some future changes, which include:

- Analyzing pay factors and using pay factor research to bring them in line with plant and street operating characteristics and making them consistent with the life-cycle cost impact of deviations from the desired level of quality;
- Establishing more joint Caltrans/industry training and prejob training;
- Extending QC/QA to all AC types;
- Extending QC/QA to bases and subbases so that roadway projects will be completely QC/QA;
- Extending the principles of QC, including QC plans and QC managers, to all projects;
- Evaluating test methods to determine whether it is possible to develop uniform test methods for the western states; and
- Establishing a uniform western states inspection and testing program.

Table 2.4 Minimum QC Test Frequency Required for Acceptance (After Dobrowolski and Bressette, 1998)

Quality Characteristic	*Specification Limits*	*Weighting Factor for Pay*	*Test Method*	*Minimum Sampling and Testing Frequency*	*Point of Sampling*
Asphalt Content [1]	**TV ± 0.5%** [2]	**0.30**	Extraction CT310 Nuclear gauge CT379 or Ignition Oven CT382	One sample per 450 tonnes (Not less than 1 sample per day)	Mat behind paver
Gradation			Washed sieve analysis, CT 202	One sample per 450 tonnes (Not less than 1 sample per day)	Batch Plant- from hot bins Drum Plant - from cold feed
3/4" or 1/2" [3]	**TV ± 5%** [2]	**0.01**			
3/8"	**TV ± 6%**	**0.01**			
No. 4	**TV ± 7%**	**0.05**			
No. 8	**TV ± 5%**	**0.05**			
No. 30 [1]	**TV ± 4%**	**0.08**			
No. 200 [1]	**TV ± 2%**	**0.10**			
Relative Compaction [1]	**96% (Minimum)**	**0.40**	CT375	Per Test Method	Finished mat after rolling
Test Max. Density			CT375	Per Test Method	Mat behind paver
Mix Moisture Content	**<1%**	**Non-pay item**	CT310 or CT370	One sample per 450 tonnes (Not less than 1 sample per day)	Mat behind paver
Asphalt & Mix Temperature	**120° to 190°C (Asphalt) ≤165°C (Mix)**	**Non-pay item**		Continuous	Plant

1. Defined as critical quality characteristics
2. TV = Target Value from contractor's proposed mix design
3. Depending on aggregate gradation specified for AC

Note: **1 in. = 25.4 mm; 1 tonne (metric ton) = 1 Mg.**

Statistically reviewing 50 jobs recently completed by California's new QC/QA specification for AC, Benson (1998) indicates that QC/QA will result in achieving better quality products by allowing the contractor more direct control over their operation; control of work quality should be more efficient when the control function is fully integrated into the contractor's operation, which will significantly improve feedback and enhance the contractor or supplier's product knowledge. Benson (1998) states further that integrated control can also free the contractor to innovate, creating more opportunities for efficiencies. The end result is that either work quality continues to meet expected specifications at a lower cost, or the work quality improves at the same or increased cost. This increase, should it occur, should be more than offset by the cost of savings realized through extended project life.

After analyzing the California QC/QA specification, Benson (1998) concludes there is potential for the specification to work as intended, but only when it is combined with a vigilant verification program. Verification is important due to the considerable lack of agreement between QC and QA test results. The author further concludes that the cost-effectiveness of California's QC/QA specification is still an open question. This was due to the fact that cost analysis revealed that QC/QA jobs were costing, on average, 3 percent more than method and end-result jobs (2.3 percent if savings from reduced agency testing are considered).

Douglas et al. (1999) evaluated QC/QA implementation for asphalt concrete (AC) specifications in California. The project objectives included

- Provision of an independent evaluation of the effectiveness of Caltrans' and the contractor's implementation of a quality management program using statistical quality assurance and performance standards;
- Provision of the expertise to review, analyze, and make recommendations relative to Caltrans' implementation of the new AC specifications;
- Revision and analysis of the technical, operational, and human factors associated with the implementation; and
- Provision of a synthesis of the interrelationships among Caltrans, the contractors, the specifications, the resulting products, and the performance of all participants.

Interviews, documentation, and direct observation were used as the sources of evidence for the study. Interviews were conducted prejob, on site, and postjob with three levels of personnel both in Caltrans and contractor organizations. Recommendations were made regarding training and testing, among others. Some useful recommendations are outlined below.

- Training: All levels of personnel (management, engineers, technicians) in both Caltrans and the contractor organizations were recommended to receive some form of training regarding the QC/QA specification. Information included in the training needed to be personnel-friendly, that is, different levels of personnel needed to be trained in different concepts.
- Testing: It was recommended that all testers and inspectors be certified; test methods

must be well documented and consistent between Caltrans and contractors to avoid variations in interpretation of testing procedures, which could lead to differences in test results. It was recommended that Caltrans furnish sampling locations to the contractor on a daily basis, either on the morning of the day's production or the night before. According to the authors, split sample testing should continue to be conducted during placement of the test strip to permit a sampling rate higher than 10 percent during the first few sublots to increase the degrees of freedom for verification, and also permit measuring the variance in the test method, which can be compared with precision statements for the test methods. It was essential that turnaround times be improved for test results for both QC and QA so that effective decisions can be made. The study did not recommend the use of a t-test; it favored split sampling.

Special procedures for multiple plants were recommended by Douglas et al. (1999) including:

- Materials from the different plants should not be intermingled at the point of delivery on grade. This will require some type of visual identification of trucks from the different plants.
- Random sampling plans will need to be adjusted to ensure that density tests are not taken in transition zones, where materials from both plants are intermixed.
- The test strip at project start-up can be used to determine if the same roller pattern is applicable to each of the materials. Perhaps the test strip also can be used to determine the length of transition zones.
- The specifications should be modified to require separate control charts for each plant.
- The pay factors, particularly for relative density, need to be calculated separately for each plant. The pay factor program should be enhanced to handle this situation.

These procedures were recommended since material from more than one plant is permitted to be delivered to the jobsite.

The Arkansas State Highway and Transportation Department (AHTD) made a transition from a primarily method-based HMA construction specification to a QC/QA system in the mid-1990s (Hall and Williams, 2002). In the study by Hall and Williams (2002) to establish variability for hot-mix asphalt (HMA) construction in Arkansas, the authors indicate that whereas the state does

QA, QC is primarily the contractor's responsibility. The specification was quasi-statistics-based and was initially developed with data and experience gained with Marshall mix-design mixes. When AHTD implemented the Superpave mix design from 1996 to 1998, the applicability of testing plans and acceptance criteria developed for Marshall mixes to Superpave mixes was in doubt. Therefore, the objective of the study by Hall and Williams (2002) was to develop a new QC/QA system for Arkansas if necessary. Primary pay factors used to control HMA quality were air voids, voids in the mineral aggregate (VMA), binder content (P_b), and field density, expressed as percent compaction [maximum theoretical specific gravity of the mixture (G_{mm})].

According to the authors and references cited therein, many QC/QA specifications make the contractor primarily responsible for QC and the highway agency the QA. These specifications are typically statistics-based, state the authors, in which methods such as stratified random sampling and lot-by-lot testing are used to allow the contractors to ensure their operations are producing an acceptable product. A 1992 survey cited by the authors indicated that all 50 states except 8 either used or had made plans to use QC/QA specifications. End-result specifications require finished products by the contractor to have already defined attributes and properties; many current QA specifications were likely developed from end-result specifications, according to the authors. The study cited by the authors revealed that fewer problems with acceptance and rejection were identified with end-result specifications. The major criticism of the end-result approach is that it did not necessarily measure characteristics related to the performance of the pavement. There are no definitive criteria for identification of pavement performance characteristics. Therefore, the specifications are unable to quantify substantial compliance or to determine price adjustment factors that relate to reduced or enhanced quality (Hall and Williams, 2002, and references cited therein).

Another QA/QC method is the performance-related specification (PRS) in which the agency is mainly concerned with the performance of the final product, whereas it gives less emphasis to methods of construction and the materials used. Determination of the acceptability of the product and possibility of determination of pay level is by test methods that are based on estimation of the actual performance of the in-service pavement (Hall and Williams, 2002). The authors cite from other references that one goal of PRS is to identify the level of quality providing the best balance between cost and performance.

2.3.3 NECEPT Study

The Northeast Center of Excellence for Pavement Technology (NECEPT), the Northeast Regional Superpave center, was tasked to develop a draft QA specification for the Northeast region of the United States. It was realized that many questions were unanswered in AASHTO PP26-97 regarding acceptance of PG binders, questions that apply to testing methods as well as to specification properties and their relationships to performance (Marasteanu et al., 1999). These unanswered questions covered the accuracy, precision, and repeatability of test procedures; effect of differences in test equipment, testing environment, and/or operator variability on accuracy and repeatability; tolerance range for specification limits; frequency of sampling for QA, where samples are to be taken, and who does the testing; and procedures regarding re-testing for non-conforming materials. According to the NECEPT study, PP-26 is very general in nature and does not address several important questions regarding QC and acceptance. The standard assigns responsibility for QC essentially to the hot-mix contractor; it does not have specifications on testing needs once the material is in transit from the supplier to the contractor, which could cause variability in material properties before getting to the contractor; and the standard does not address issues regarding laboratory testing variability that could balance the acceptance-rejection risk for the buyer and seller, and to develop pay adjustment factors. The NECEPT study, thus, covered two issues: The current state of SHRP PG grade binder QA practice based on interviews with state agencies, and a framework for a statistically-based QA plan for SHRP PG-grade binders that can be universally applied throughout the region. It would supplement PP-26 as a guideline for QC as the binder is in transit from the supplier to the consumer, and a guideline that includes recommendations for the frequency of testing and criteria for material acceptance and rejection by the consumer.

Price Adjustment Schedules

Price adjustments should be related to performance in order to be equitable to all parties. If there is loss of performance of the product or loss in service life, negative adjustments should be applied. The FHWA has endorsed the use of incentives for improved quality provided they are based on readily measured characteristics that reflect improved performance. States, however, disagree on factors to be used, the pay schedules, and how multiple factors are treated (Tuggle, 1994 (AAPT journal)).

2.3.4 State DOT Binder QC/QA Practices

2.3.4.1 Texas DOT

Epps et al. (2001) and references cited therein indicate that as part of the current TxDOT QA program, TxDOT samples and approves asphalt materials at the source based on procedures set forth in October 1998. The source is either the production site (refinery) or supplier (producer) terminal. The supplier must provide test results that prove compliance to specifications before TxDOT approves the material. Further, TxDOT uses Test Method Tex-500-C to sample materials in the presence of the producer for QA testing. Sampling is done in various ways: If batched, TxDOT samples from tanks or, if blended, as transports are being loaded. TxDOT may also sample randomly at the producer terminal prior to transporting to the consumer. As many tests as necessary are performed on the samples by the TxDOT laboratory in Austin to ascertain the compliance of the materials. These verification tests comprise the current QA program of TxDOT. For failing samples, TxDOT cancels the shipment rights of the originating tank. TxDOT approves up to 60 days and 30 days for asphalt cements and for liquid asphalts (emulsions and cutbacks) respectively. In addition to the QA program at the supplier terminal, suggestions have been made for TxDOT district offices to randomly sample in the field, though TxDOT does not require field sampling at this time (Epps et al. 2001 and references cited therein). Three proposals have been made to TxDOT regarding field testing QA programs, and are summarized in Figure 2-2.

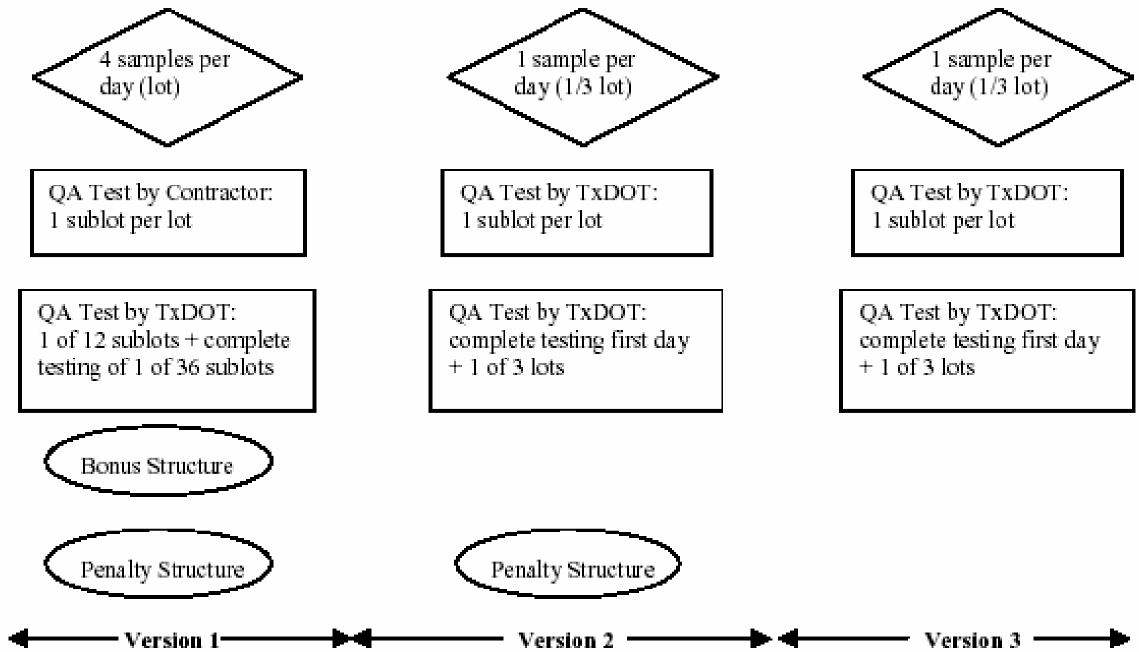

Figure 2.2 Previously Proposed Binder QC/QA for TxDOT (After Epps et al. 2001).

According to Epps et al. (2001), the specification requires samples be taken and labeled as specific lots and sublots during construction. A lot is defined as the amount of binder used during one day's production of HMA for a specific project. Each lot contains four sublots. In Arkansas, a lot is equal to 3,000 tons of HMA mix, which is subdivided into four equal sublots containing 750 tons each. Arkansas' specification requires that the contractor randomly sample each of the four sublots within a given lot, and the Arkansas State Highway and Transportation Department (AHTD) inspector randomly samples the lot. The contractor's results represent QC, whereas the agency's results represent QA (Hall and Williams, 2002).

Some recommendations were made by Epps et al. (2001).

- There existed a definite need to conduct a comprehensive evaluation of the current TxDOT binder QA program.
- Following a comprehensive evaluation, implementation of revisions was expected. The researchers recommended the appointment of a binder QA program manager. In addition, they recommended education of all employees on all aspects of the revised binder QA program to ensure maximum benefit at the least cost.
- It was recommended that the binder QA program established by TxDOT be only one tool in a system aimed at improving quality of the materials used during pavement

construction and thus prolonging pavement life. Other recommended tools included required QC plans for both binder suppliers and asphalt paving contractors. They also suggested training programs for all binder technicians and personnel responsible for taking samples. A round-robin program to establish the testing variability for selected binder QA parameters across multiple laboratories as another tool in the system was also recommended.

- Data collected in the binder QA program should be stored in a user-friendly database that can be accessed by TxDOT district personnel. In addition, the number of labels for data records should be reduced to three, if possible, to facilitate the production of meaningful statistical results.
- It was also strongly recommended that data be organized and analyzed frequently to detect problems or show historical specification compliance for different binders and suppliers. TxDOT may use historical data to set field sampling rates by binder and supplier on an annual basis. Implementation of this recommendation will require time to educate suppliers, contractors, and TxDOT personnel.
- When field samples are taken, contractors or TxDOT personnel must label them with the corresponding acceptance laboratory number based on the supplier sample. With this information and a readily accessible database, statistical analysis can be used to gather further evidence of the potential problem of binder properties changing subsequent to acceptance.
- Based on the partial results from the laboratory experiment, preliminary analysis indicated that modifier, time, and contamination produce a significant change in the selected binder property (RTFO-DSR). Therefore, it was recommended that it should include special handling requirements in QC plans for both suppliers and contractors. Contractors may also need to check for specification compliance of supplier and/or field samples and total storage time at elevated temperatures.
- Data for a particular binder shipment should include storage times and storage temperatures for both the supplier and contractor locations. It was recommended that this information, along with specification compliance of supplier and/or field samples, be stored in the same database as pavement performance data throughout the life of the pavement. This may help in forensic investigations and allow future research projects to

examine the effect of binder noncompliance on pavement performance. They state that development of these types of models was urgently needed.

2.3.4.2 Other States

In Alberta, Canada, QA measures are based upon test results of samples collected on a lot-by-lot basis. For the Alberta Transportation and Utilities (ATU), a lot is generally defined as representing a full day of hot-mix production and placement. Core samples are collected for each lot as it is completed and tested in a laboratory for each QA measure. McCabe et al. (2002) did a study to learn if statistically significant differences existed between mean test values of post-construction samples compared to during-construction samples for three QA measures: asphalt content, pavement compaction, and aggregate gradation. Highway sections undergoing pavement construction were sampled during construction and then again after construction. Sources that could cause variance between results from during-construction samples and post-construction samples were included in different sampling locations, testing equipment and procedures, testing personnel, and changes in material properties with time. It was found that there was no statistically significant difference between post-construction samples and during-construction samples.

2.3.5 Other Relevant Pavement Quality-Related Information

2.3.5.1 TxDOT Aggregate Quality Monitoring Program (AQMP):

This program was created to improve efficiency in TxDOT operations. It provides the requirements and procedures for CST/M&P to accept aggregate products that have demonstrated continuing quality and uniformity. Through this program districts have the opportunity to use aggregate from certified sources without project specific testing. They only have to carry out the job control and independent assurance tests for final acceptance. AQMP includes quality monitoring of aggregate products, statistical evaluation of aggregate quality test, expediency in aggregate quality acceptance, and optimized resource utilization by reducing aggregate acceptance based on a test prior to use test (TxDOT 2004).

Responsibilities of CST/M&P, districts and producers are outlined in the report. CST/M&P is responsible for requesting samples, testing, reporting, and qualifying aggregates for coarse and fine aggregate for Portland cement concrete, natural aggregate or lightweight aggregate for asphaltic concrete or surface treatment and natural aggregate for micro surfacing. Districts have the responsibilities of taking AQMP samples from sources and splitting them with the producers. They also have the responsibility of job control testing and final acceptance. They notify the contractor if any status changes occur. Producers are responsible for maintaining the sources on the AQMP (TxDOT 2004).

The producers' quality control plans should mainly describe

- The point and method of sampling
- The type, frequency and method of quality control testing
- Records review and monitoring
- Qualification and responsibilities of quality control personnel
- Plans for communication and reporting

AQMP acceptance criteria for individual aggregate products are outlined in the report. They should have a test history of at least five TxDOT project samples within the past two years while sampling dates are at least one month apart. Test results of five recent samples must satisfy the standard specification quality requirement. Also, statistical ratings of the five sample test history should meet all the applicable project specification quality requirements (TxDOT 2006).

AQMP acceptance and maintenance are based on the statistical evaluation. If the statistical rating of the five most recent project samples' test results or AQMP sample test results satisfy the aggregate quality tests, the product will stay in AQMP. If a rated source statistical value (excluding RSPV) for a particular aggregate product is within 10% of TxDOT standard specification limits, that product is placed on a probational status for more frequent sampling and testing. If any of the statistical rating of a product fails to meet the specification, the following action will be taken.

- Review the recent quality control test history and determine if the condition warrants a check sample.
- If a condition does not warrants a check sample or the check sample does not produce a statistical value that satisfies the specification requirement, the supplier and the district

will be notified about the situation and the product is removed from the AQMP.

AQMP status can be reinstated by re-establishing a satisfactory project sample test history and meeting the AQMP criteria (TxDOT 2006).

Sampling is done by an authorized TxDOT representative according to method Tex 400-A and all the samples are split with the producer. The sampling rate for bituminous (also for concrete) is once in six months. This rate may vary if quality has been fallen and the product is on probational status. Sampling rate may vary for polish value of bituminous aggregates (once in every three months if the spread is equal to or greater that 6 of the recent five test results) and light weight aggregate (monthly). If monthly quality control test results are consistent with CST/M&P test results, the rate will be reduced to one sample per two to three months for light weight aggregate. Reliability of producers' quality control test data will be evaluated through the split sample test results (TxDOT 2004).

Updating and Reporting of Rated Source Statistical Values:

Statistical values for the quality tests covered by AQMP will be published every six months through the "Rated Source Quality Catalog" (RSQC). RSQC will be given to districts, producers of the sources on the AQMP and pre-qualified contractors. Test data gathered for the six month period ending three months prior to the catalog effective date is analyzed to provide the revised rated source statistical values. If the AQMP or check sample produces a statistical value that fails to meet the specification, the aggregate product and its rating will be removed from the AQMP in 60 days (TxDOT 2004).

2.4 National Guidelines for Binder QC/QA

2.4.1 AASHTO Guidelines and Specifications on Binder QC/QA

2.4.1.1 Quality Assurance Program Implementation

Quality Assurance (QA) concepts include quality control (QC), acceptance and independent assurance (IA). Agency management support and industry support are important in developing and implementing a QA program. Agency management support is critical in providing necessary personnel, equipment, and technical training. Industry support is equally essential because it can contribute much in technical aspects as well as concept promotion.

An effective QA program should achieve quality improvement as well as effective usage of existing personnel. The agency and the supplier/contractor should cooperate as a partnership when approaching a QA program, with well-defined and separate responsibilities. Specification design is one of the keys leading to a successful QA program. A gradual approach with critical mileposts is a practical way to improve specifications. Begin with a pivot investigation, consisting of a few projects, evaluate the results and adjust some policies, such as procedures or pay adjustment provisions. Comprehensive presentation to make the program concepts and significances clear to all is desired. Training is the most important issue to be addressed prior to the QA program implementation. The program should integrate the joint training sessions for all contractors, supplier, and agency personnel.

With an effective QA program, the engineering personnel no longer determine the proper amount of pay adjustment based on their subjective judgment, but on the specification. They can improve the communication with the supplier/contractor personnel regarding performance and adjustments due to the program. The supplier/contractor should fully understand the mechanics of the new QA program. They must understand that QC is their responsibility, and “Acceptance” is the agency’s responsibility. The agency must realize that the test results will not be identical, and address this in their specifications.

When designing specifications, the agency should investigate the supplier/contractor’s capabilities, state-of-the-art recommendations, and actual product performance history, and set tolerances in the beginning close to what will be the ultimate specification. Appropriate specification limits should consider the normal variation inherent within most production processes, and minimize both the agency’s and supplier/contractor’s risks. Pay factors and incentives are set for encouraging quality. Pay factors are should be set based on a curvilinear relationship rather than a straight-line relationship, so that it will affect the pay adjustments more significantly as quality level severely deviates from the specification. By making QC testing a separate pay item, the agency provides the supplier/contractor a way to quantify the costs related to QC. It is suggested that all test records be kept permanently. These results should be statistically analyzed on a periodic basis to ensure the appropriateness of the specification limits and the fairness of the pay factors. A reliable and effective feedback system is equally important.

Combining “method type” specification requirements with QA concepts is not recommended. The specifications need to be kept as “method specifications” until a reliable “end-result” test can be developed.

2.4.1.2 Agency, Contractor, and Supplier Responsibilities (AASHTO)

Contractors and suppliers are responsible for maintaining their own QC regarding binder quality. The owner, usually a DOT, defines and maintains the QA system to ensure that a binder has all the properties required by the specification to prevent premature failure (Epps, et al, 2001). In describing what is covered and what is not covered in AASHTO PP26 (Standard Practice for Certifying Suppliers of PG Asphalt Binders), Epps, et al. (2001) state that the standard provides guidance for minimum QC plan components that include transport inspection guidelines and initial, reduced, and minimum testing frequencies. The standard also provides a standard form for reporting data, and sampling and laboratory accreditation requirements. To minimize disruptions in construction projects, a demonstrated historical compliance by the supplier provides them with an approved supplier certification. This program is described in the AASHTO PP26 to be used by agencies. According to Epps, et al. (2001), agency responsibilities outlined in the standard include acceptance of the QC plan, administration of the certification program, and inspection of supplier facilities. Though the standard does not specify guidelines for sampling and testing frequencies or any specific acceptable tolerances for specification parameters, it gives provisions for split samples, and QA sampling and testing (Epps, et al. 2001).

2.4.1.3 Laboratory Accreditation

The AASHTO Accreditation Program (AAP) provides a mechanism for formally recognizing the competency of a testing laboratory. The minimum requirements are specified for the testing qualifications and personnel qualifications. All the laboratories involved in the QA program, including agency laboratories, contractor, consultant, or supplier-owned facilities, shall be accredited by the agency or the AAP.

2.4.1.4 Sampling and Testing Personnel

The individuals performing any sampling and testing in QA program require a certain amount of training. The training includes:

- A basic knowledge of related mathematics
- A basic knowledge of the concepts of QA
- An understanding of the items to be sampled and tested and the importance of the appropriate procedure of sampling and testing
- Formal training of basic knowledge of principles of sampling and training

The individuals involved in the QA program are also required to be certified by the particular institutes to ensure the quality of sampling and testing.

2.4.1.5 Quality Control

Quality is "built in," not tested in or inspected in, and is done by the suppliers/contractors. A quality assurance specification should contain minimum requirements for the contractor's QC system. It is the contractor's responsibility to ensure that all materials and work submitted for acceptance conform to the contract. Each QC plan should include: a) documentation of the contractor's QC plan; b) statistically valid sampling, testing and analysis plan with frequencies, locations, and methods; c) provisions for disposal or rework of materials or work that is off specification; d) the qualified labs, equipment and personnel; e) provisions for control charts.

The contractor QC plan is for both production facilities and field operations. The typical elements of a contractor's QC plan are: descriptive information, personnel, mix design, testing frequency, notification of production operations, control charts, test result reporting, inspection, nonconforming material and construction, and sample storage. For mix design, the contractor should perform testing during the mix design development to ensure the material is in accordance with the contract. Only materials from a qualified source can be used in the mix design. It is critical that the mix produced in the plant is the same as in the lab. QC test frequency may be derived in terms of time, quantity, or a combination of the two.

2.4.1.6 Acceptance Program

The objective of the acceptance program is to determine the degree of compliance with contract requirements and value of a product. The core of the program is the results of the agency's acceptance tests and its timely inspection. Only qualified laboratories and personnel can perform the required tests.

The agency has a choice of whether or not to incorporate results of the supplier/contractor's QC testing into the program. If the agency decides not to use the supplier/contractor's results, the frequency of sampling and testing is relatively high; if it chooses to use their results, the agency needs to develop a basis for validating the supplier/contractor's results. When the agency decides to use the contractor's testing data, it should follow validation procedures to determine the validity of the data. If the contractor QC tests are different from those of the agency, the contractor test results should not be used for an acceptance decision.

The agency should first determine a testing frequency and lot size. Lot size can be defined on either a quantity or time basis. A quantity basis assures the same lot size and same number of tests, but the lot may be comprised when daily production is limited, or there may be more than one lot per day. For a time basis, the amount of material in each lot would be different. Considering the percentage of the samples in the whole production quantity, a frequency schedule based on quantity may yield more samples when production rates are high and fewer when production rates are low. Schedules based on time tend to yield fewer samples for high production and more samples for low production. In many cases, it is best to select the time based frequency schedule because keeping a process in control is usually more difficult under a low production rate than under a high production rate.

For validation procedures, the agency can either get split samples or independent samples. The test results are influenced by the variability due to: a) material, b) sampling, c) testing, and d) equipment. Independently obtained samples contain all four sources of variability. Split samples contain components (a) and (d). If independent samples are used, the agency test results and the contractor's results can be combined to make the acceptance decision; if split samples are used, the agency test results are only for verification. The two tests should not be combined for an acceptance decision because of their dependence. If the agency aims to identify discrepancies in testing procedures or equipment, split samples should be used for initial validation; if the agency wants to validate the entire sampling and testing process, independent samples should be used. Test results should not be combined from independently obtained samples with those from split samples.

Split sample validation results are used to determine whether the contractor and agency tests are consistent. Consistency does not necessarily mean they are both correct. When the test results are not similar, further investigation should be carried out to determine whether the agency's or the contractor's results are wrong.

Normally, the agency will use a larger amount of testing in an early phase of a project. Once the initial validation is successfully completed, the agency can reduce its testing frequency.

2.4.1.7 Independent Assurance Program

The IA program is an independent verification of sampling and testing procedures and is designed to assure the continuity to the quality assurance program. Compared with the agency acceptance program which is built to verify the contractor QC program, the IA program is a check on the verification system for the agency's sampling, testing, personnel and equipment. The IA program should contain different qualified sampling and testing personnel, and different equipment from those in the acceptance and QC program. Similar to the Acceptance Program, either independent samples or split samples can be used in IA program with different objectives. The purpose of IA is not to compare the IA test results to the specification requirements, but to ensure continuous reliability of agency results.

A typical IA program includes: 1) IA sampling and testing frequencies; 2) A reasonable portion of the IA program to be accomplished by observation; 3) Tolerances for comparison of IA test results with agency test results; 4) Procedures to address tolerance deviations; 5) periodic evaluation; 6) Documentation and reporting; 7) Provisions to monitor equipment.

There are 2 methods to establish the frequency for sampling and testing for IA. One is based on project testing frequencies. That is, the IA sampling rate should be 10 percent of the agency verification sampling rate. The rate can be changed based on the history of a material. The other is based on source. In this case, the personnel and equipment would be systematically verified several times per year.

2.4.1.8 Dispute Resolution

Dispute resolution is the procedure used to resolve conflicts resulting from discrepancies between the agency's and contractor's results of sufficient magnitude to impact payment. A formal monitoring program is required to ensure the reliability of all data, and will detect items with the potential to lead to discrepancies between contractor and agency. Typical elements of a monitoring program are:

- All sampling and testing performed by qualified personnel and labs
- Pre-production correlation testing
- All testing labs participating in a round robin program
- An approved random scheduling sampling method
- Agency observation of contractor sampling and testing methods
- Partnering concepts first, formal dispute second
- Using IA sampling as an initial third party check
- Timely communication between parties
- Both parties fully understanding the QA program
- Clarifying the confusion about QA program during the pre-placement conference
- Clear QA specification

A time schedule should be established for dispute resolution based on criticality of the item in dispute and the degree of difference of the dispute. The primary objectives of the resolution process are correction of problems and performance of the final product.

<u>2.4.2 Round-Robin Testing</u>

2.4.2.1 Precision Estimates – ASTM

Almost all the binder suppliers carry out binder testing of their material in order to assure themselves as well as other agencies that their products meet the required specifications. In general, AASHTO and ASTM provide the standard test specification for highway material used in the pavement construction. Testing is to be carried out by qualified, experienced lab personnel using timely calibrated testing apparatus. Although the testing is performed by qualified technicians using well calibrated testing equipment according to the said specification, there may be differences in test results for the same sample. Moreover, the test results may vary for the same sample if conducted by the same qualified technicians with the same testing apparatus. Therefore, it is advisable to carry out round robin testing (interlaboratory studies) with the participation of many laboratories and perform the relevant data analysis to determine the precision of test results. ASTM provides guidelines to plan, conduct and analyze the results of inter-laboratory studies of test methods.

The guidelines mainly suggest that before any such studies take place, a well-written procedure and a well-designed and calibrated apparatus should be available. Also, an adequate number of labs, material and operators should be available. The labs should be well qualified, meaning proper laboratory facilities and testing equipment, a reputation for reliable testing work and sufficient time and interest to do the testing. The guidelines also recommend that at least ten laboratories should be included in the study. The lab personnel should be well trained and qualified to perform the expected tests. Also recommended is that the entire interlaboratory test program be developed with the help and advice of persons who are familiar with statistical procedures, as well as with the material involved.

Collection of data is an important part of a sound round robin testing program. A specific form and instructions for obtaining and recording data should be made available for all participating laboratories in order to minimize confusion when analyzing the data. Also, care should be taken when rounding off the test results since this may lead to errors. In general, a minimum of three materials should be studied. Another important factor to be considered is the number of replicates to be made on each material in each of the laboratories. An increase in the number of replicates improves the estimates of the within-laboratory precision, but has no effect on between-laboratory precision. It is recommended that at least three replicates be required if the number of participating laboratories is between 10 and 15. If the number of laboratories is less than 10, the number of replicates should be equal to or greater than $30/p+1$ where p is the number of participating laboratories. Care must be taken when removing suspicious data from the analysis.

Single-operator precision and multilaboratory precision are the two basic elements to be determined in a study like this. Single-operator precision provides an estimate of the difference that may take place between two measurements made on the same material sample by a single person using the same testing apparatus in a same lab over a relatively short period of time. Multilaboratory precision provides an estimate of the difference that may take place between measurements made on the same material in two different laboratories.

ASTM suggests the first step in the analysis of data is to obtain estimates of within- laboratory and between-laboratory variances for each material. For a given material (material A) with *n* replicates test results for each of the *p* laboratories, the within-laboratory averages ($\bar{x}_i$) and the within laboratory variances (s_i^2) are determined as

$$\bar{x}_i = \frac{\sum x_i}{n}$$

$$s_i^2 = \left(\sum x_i^2 - n\bar{x}_i^2\right)/(n-1)\ .$$

Using the above calculated within-laboratory averages and variances for individual labs, the following quantities are determined.

Overall average, $\bar{x}_A = \dfrac{\sum \bar{x}_i}{p}$,

Pooled within-laboratory variance, $s_A^2(pooled) = \sum s_i^2 \,/\, p$,

Variance of laboratory averages, $S_{\bar{x}_A}{}^2 = \left[\sum \bar{x}_i^2 - p(\bar{x}_A)^2\right]/(p-1)$,

Between-laboratory component of variance, $S_{L_A}^2 = S_{\bar{x}_A}^2 - \left[S_A^2(pooled)/n\right]$.

A similar procedure is carried out for other materials (material A, material B, etc).

At this stage it is necessary to check if the variances are the same in different laboratories (homogeneity of variance) and whether the results show the same pattern of change from one material to another in the different laboratories (lack of interaction). It is easier to assemble all the quantities calculated so far according to Table 2.5.

Table 2.5 Summary of Test Result Variability both Within and Between Laboratories

Material	Average	Components of Variance		Variance	
		Within laboratory	Between laboratory	Within laboratory	Between laboratory
A B C D					

Column 2 shows the overall average for each of the materials. The component of variance in Columns 3 and 4 are the pooled within-laboratory variance and the component of between-laboratory variance, respectively. The variance in Columns 5 and 6 are the pooled within-laboratory variance and the sum of the two components of variances (Column 3 and 4), respectively.

The next step is to determine the standard deviation and coefficient of variation for within-laboratory and between-laboratory. Within-laboratory standard deviation is obtained by taking the square root of Column 5 and the between-laboratory standard deviation is obtained by taking the square root of Column 6. Within-laboratory and between-laboratory coefficients of variation are determined by dividing the standard deviations with their corresponding averages and multiplying by 100.

According to ASTM specification there are three main forms of relationships. The first form is where the standard deviation is somewhat constant. The second form is where the coefficient of variation is somewhat constant and the standard deviation has an approximate linear relationship. The third form is where the material falls into two or more distinct groups above forms one or two. In the first form where the standard deviation is somewhat constant, single-operator standard deviation (1s) is the within-laboratory standard deviation over all the materials and is determined by adding the values in Column 5 and dividing the sum by the number of material, then taking the square root. Similarly, multilaboratory standard deviation (1s) of the first form is the between-laboratory standard deviation and is determined by adding the values in Column 6 and dividing by the number of materials and taking the square root. In the second form where the coefficient of variation is somewhat constant, single-operator one sigma limit in percent (1s%) is the average within-laboratory coefficient of variation and is determined by simply taking the average of within-laboratory coefficient of variation of all the materials. Similarly, multilaboratory one sigma limit in percent (1s%) is the average of between-laboratory coefficient of variation and is determined by taking the average of between-laboratory coefficient of variations of all the materials. In the third form where there are separate groups of constant standard deviation or constant coefficient of variation, one sigma limit (1s) or one sigma limit in percent (1s%) for within-laboratory or between-laboratory is determined separately for each group as described above for the first or second methods.

2.4.2.2 Precision Estimates - AASHTO

The AASHTO Materials Reference Laboratory (AMRL) has conducted a multi-phase research project to improve estimates of precision in AASHTO test methods for asphalt binder and hot mix asphalt. The report of phase 3 of NCHRP 9-26 includes the results of the analysis and the updated precision estimates for AASHTO T308, AASHTO T48, AASHTO T228, AASHTO T240, AASHTO T313, AASHTO T314, AASHTO T315, and AASHTO T316. The report states that some precision estimates have become outdated since some of the test methods have been improved and others need to be verified to make sure they are still accurate. The data from the AMRL Proficiency Sample Program (PSP) were used to update the precision estimates for different test methods.

Paired binder samples to be tested according to AASHTO test methods were sent to laboratories participating in the AMRL proficiency sample program. AMRL has developed a four-step technique to analyze the proficiency sample data. It consists of removing the extraneous results and analyzing only the core data of the paired samples to determine repeatability and reproducibility precision estimates. The program is based on testing two samples of the same material. The same test is carried out for the two samples, thus getting two independent test results for two identical samples. The first step of the four-step procedure involves removing null responses and unpaired data, the second step removes invalid data, the third step removes outliers and the fourth steps consists of doing a standard deviation type analysis for the remaining data.

Step 1: Remove unpaired and null data

Unpaired results are results that contain only one of the two identical samples and null data means that no results were received for either of the samples.

Step 2: Remove Invalid data

Data falling outside the values of I_U and I_L are invalid and are removed. In this step, data beyond the equivalent of 4.725 standard deviations from the median value is considered to be invalid. The values of I_U and I_L are

$$I_U = RI_{75U} + (1.555(RI_{75}))$$
$$I_L = RI_{75L} - (1.555(RI_{75}))$$

where

$RI_{75} = RI_{75U} - RI_{75L}$ = the range of inner 75% of data,

$RI_{75U} = 87.5^{th}$ percentile point of data,

$RI_{75L} = 12.5^{th}$ percentile point of data.

Step 3: Remove outliers

Data falling outside the values of O_u and O_L are outliers and are removed. In this step, data beyond the equivalent of 2.7 standard deviations from the median value are considered to be outliers. The values of O_U and O_L are

$$O_U = RI_{75U}{}^* + (0.674(RI_{75}{}^*))$$
$$O_L = RI_{75L}{}^* - (0.674(RI_{75}{}^*))$$

where

$RI_{75}{}^* = RI_{75U}{}^* - RI_{75L}{}^*$ = The range of inner 75% of data without invalid data,

$RI_{75U}{}^* = 87.5^{th}$ revised percentile point of data after removal of invalid data,

$RI_{75L}{}^* = 12.5^{th}$ revised percentile point of data after removal of invalid data.

Step 4: Analyze the data

The traditional standard deviation type analyses are performed on the remaining data. Repeatability (S_r) estimates have been obtained using

$$S_r = \sqrt{\frac{\sum\left[(x_i - y_i) - (\bar{x} - \bar{y})\right]^2}{2(n-1)}} .$$

Reproducibility estimates (S_{Rx} *and* S_{Ry}) are obtained using

$$S_{Rx} = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}} ,$$

$$S_{Ry} = \sqrt{\frac{\sum(y_i - \bar{y})^2}{(n-1)}}$$

where:

S_r = repeatability estimate,

S_{Rx} = reproducibility estimate for odd number sample pair,

S_{Ry} = reproducibility estimate for even number sample pair,

x_i = laboratory test results from the odd number sample of a pair,

y_i = laboratory test results from the even number sample of a pair,

$\bar{x}$ = average of all x_i,

$\bar{y}$ = average of all y_i ,

n = number of laboratories.

2.5 Statistical Aspects of Quality

2.5.1 Acceptance Sampling

Acceptance sampling is one of the major components of statistical quality control. It is used primarily for incoming inspection by customers, and it has become a typical tool to work with suppliers to improve their quality performance recently. Acceptance sampling is an elementary tool of statistical quality control. As an organization matures it relies less on acceptance sampling and more on statistical process control (SPC) and design of experiment (DOE). The purpose of acceptance sampling is to sentence lots, not to estimate the lot quality, and there exists some random errors affecting the decision making. Acceptance sampling plans have nothing to do with direct quality control. It simply provides the decision on accepting or rejecting lots. However, it is a useful auditing approach for process control and accumulates the quality history. It is also a method of providing protection for both producers and consumers. (Montgomery 2005)

According to Montgomery (2005), an acceptance sampling plan is “a statement of the sample size to be used and the associated acceptance or rejection criteria for sentencing individual lots”. A sampling scheme can be defined as “a set of procedures consisting of acceptance sampling plans in which lot sizes, sample sizes, and acceptance or rejection criteria along with the amount of 100% inspection and sampling are related”. “A sampling system is a unified collection of one or more acceptance sampling schemes”.

There are three methods for lot sentencing: (1) accept with no inspection; (2) 100% inspection; and (3) acceptance sampling. Acceptance sampling is most likely to be useful in the following situation: (Montgomery 2005)

1. When testing is destructive.
2. When 100% inspection is economically impractical.
3. When 100% inspection is not technologically feasible or would require so much time that production schedule would be seriously impacted.
4. When the number of inspection items is large and the inspection error rate is very high.
5. When the supplier has an excellent quality history while a low process capability
6. When there are potentially serious product liability risks.

Compared with 100% inspection, acceptance sampling has following advantages: (Montgomery 2005)

1. It is less expensive.
2. It reduces damage due to less handling of materials or products.
3. It is fit for destructive testing.
4. It saves human resources.
5. It reduces the amount of inspection error.

6. It stimulates quality improvements made by suppliers because it employs the rejection of entire lots instead of defectives.

The disadvantages of acceptance sampling are: (Montgomery 2005)

1. It involves risks of accepting “bad” lots (Type II error) and rejecting “good” lots (Type I error).
2. It provides less information about the products and the processes.
3. It takes time to plan and document the acceptance sampling procedures.

Acceptance sampling plans can be classified by attributes and variables. “Attributes are quality characteristics that are expressed on a ‘go, no-go’ basis.” Variables are defined as quality characteristics that are measured on a continuously numerical scale. Random sampling is extremely important for forming an unbiased acceptance sampling plan (Montgomery 2005).

For acceptance sampling by attributes, there are single-sampling plan, double-sampling plan, multiple-sampling plan and sequential sampling plan. These plans can be designed to generate equivalent results in terms of probability of acceptance for a specific level of quality. (Montgomery 2005)

Acceptance sampling by variables has several advantages over attributes acceptance sampling. The first one is that a variables sampling plan has the same protection as attributes sampling plan with smaller sample size, which saves the sampling cost and inspection cost for destructive testing. The second advantage is that a variables acceptance sampling plan provides more information about the lots and the manufacturing processes than an attributes sampling plan. Finally, the sample size required by an attributes sampling plan is tremendously large when acceptable quality level is very small. Switching to a variables sampling plan provides significant benefits in this situation. (Montgomery 2005)

One of the disadvantages of an acceptance sampling plan by variables is that the distribution of the quality characteristic must be known; otherwise it would generate a serious departure in decision making. The second disadvantage is that a separate sampling plan must be used for each quality characteristic, which increases the costs. The third disadvantage is that it may cause a dispute between the supplier and customer, since with a variables sampling plan, the customer may reject a lot even though the actual sample does not contain any defectives. (Montgomery 2005)

There are two general types of variables acceptance sampling procedures. One is based on the lot or process fraction defective (or nonconforming) and the other is based on the lot or process parameter (usually the mean). (Montgomery 2005)

The way to define a lot affects the effectiveness of acceptance sampling plans. Considerations in forming lots are: (Montgomery 2005)

1. Lots should be homogeneous, such as produced by the same machines, the same operators, from common raw materials, and at nearly the same time.
2. Larger lots are preferred over smaller ones due to economical efficiency.
3. Lots should be conformable to the materials-handling systems used in both the supplier and consumer facilities.

Generally speaking, the selection of an acceptance sampling procedure is based on the objective of the organization and the quality history of the products. The major types of acceptance sampling procedures and corresponding applications are shown in Table 2-5 (Montgomery 2005).

The AASHTO R-9 (2005), "Acceptance Sampling Plans for Highway Construction," contains the Type I and Type II errors in different situations in construction industry, as shown in Table 2.6.

Table 2.6 Acceptance Sampling Procedures

Objective	**Attributes Procedure**	**Variables Procedure**
Assure quality levels for consumer/producer	Select plan for specific OC curve	Select plan for specific OC curve
Maintain quality at a target	AQL system; MIL STD 105E, ANSI/ASQC Z1.4	AQL system; MIL STD 414, ANSI/ASQC Z1.9
Assure average outgoing quality level	AOQL system; Dodge-Romig plans	AOQL system
Reduce inspection, with small sample size, good-quality history	Chain sampling	Narrow-limit gauging
Reduce inspection after good-quality history	Skip-lot sampling; double sampling	Skip-lot sampling; double sampling
Assure quality no worse than target	LTPD plan; Dodge-Romig plans	LTPD plan; hypothesis testing

Table 2.7 AASHTO R 9 - Suggested Risk Levels

Criticality	α	ß
Critical	0.050 (5.0%)	0.005 (0.5%)
Major	0.010 (1.0%)	0.050 (5.0%)
Minor	0.005 (0.5%)	0.100 (10.0%)
Contractual	0.001 (0.1%)	0.200 (20.0%)

For classification purposes, the following ranges of criticality are suggested:

- *Critical* --- when the requirement is essential to preservation of life
- *Major* --- when the requirement is necessary for the prevention of substantial

financial loss

- ♦ *Minor* --- when the requirement does not materially affect performance
- ♦ *Contractual* --- when the requirement is established only to provide uniform standards for bidding

2.5.2 Military Standard 414

Military Standard 414 (MIL-STD-414) is a mature acceptance sampling standard by variables. MIL-STD-414 corresponds to ISO/DIS 3951, which is the international standard. The U.S. commercial version of MIL-STD-414 is ANSI/ASQC Z1.9.

Procedures and tables in MIL-STD-414 are based on the concept of AQL (Acceptable Quality Level). AQL is defined by military standard as "the maximum percent defective (or the maximum number of defects per hundred units) that, for purposes of sampling inspection, can be considered satisfactory as a process average." MIL-STD-414 assumes lot-by-lot acceptance inspection. Lot size greatly determines the sample size. There are several inspection levels based on the lot size. MIL-STD-414 includes normal, tightened, or reduced inspection plan, with switching rules. Under the normal inspection plans, the producer’s risk is relatively small. Tightened inspection makes the consumer’s risk small. All plans are identified by sample size code letter. MIL-STD-414 assumes variables are normally distributed. (E.L. Grant 1996)

The procedures in MIL-STD-414 can be divided into a single or two specification limits, and known or unknown sigma. For the situation of unknown sigma, the standard provides two methods: standard deviation method and range method. The following is the procedure for a single specification limit and unknown variability with the standard deviation method:

- Step 1 Sample size: n
- Step 2 Sum of measurements: $\sum X$
- Step 3 Sum of squared measurements: $\sum(X^2)$
- Step 4 Correction factor (CF): $(\sum X)^2 / n$
- Step 5 Corrected Sum of square (SS): $\sum(X^2)$-CF
- Step 6 Variance (V): SS/(n-1)
- Step 7 Estimate of lot standard deviation s: $V^{1/2}$

- Step 8 Sample mean X: ∑X /n
- Step 9 Specification limit (lower): L
- Step 10 The quantity: (X - L)/s
- Step 11 Acceptability constant: k
- Step 12 Acceptability criterion: Compare (X – L)/s with k

Tightened inspection is required when both condition 1 and 2 are satisfied:

1) The estimated process average is greater than the AQL.
2) More than a designated number of the lots used to compute the process average has a percentage defective exceeding the AQL.

The estimated process average is "the arithmetic mean of the estimated lot percent defective computed from the sampling inspection results of the preceding 10 lots or as may be otherwise designated." T depends on the number of lots used to compute the process average, sample size code letter and the AQL. (E.L. Grant 1996)

Once the process meets the two conditions, tightened inspection is initiated. Once the estimated process average of all lots under tightened inspection is equal to or less than the AQL, normal inspection is reinstated.

"To initiate reduced inspection, all the preceding 10 lots (or other designated number) must have been accepted and the estimated percentage nonconforming for each of these preceding lots must have been less than a stated limit." The stated limits are tabulated in MIL-STD-414 based on the number of lots and AQL. (E.L. Grant 1996)

Reduced inspection must be discontinued and normal inspection reinstated whenever:

1) A lot is rejected
2) The estimated process average exceeds the AQL
3) Production becomes irregular or delayed
4) Other conditions exist that may warrant normal inspection should be reinstated.

2.5.3 Military Standard 1235

MIL-STD-1235 addresses continuous production. Continuous sampling plans have characteristics similar to lot-by-lot sampling schemes in that: (E.L. Grant 1996)

- In lot-by-lot schemes, an unfavorable sample from a lot results in the screening inspection of that particular lot.
- In continuous sampling, a bad sample calls for the screening of subsequent production.

Multilevel continuous sampling plans have some important advantages: (E.L. Grant 1996)

- It is not necessary to accumulate a lot before making a decision for adjusting sampling frequency or acceptance/rejection. This is highly advantageous for large and expensive items.
- The enterprise can deliver products more rapidly.
- Less storage space is required.
- Both producers and consumers save the inspection cost as long as the quality meets requirements.
- It is quicker to detect the causes of defects.

MIL-STD-1235 contains many different sampling plans CSP-1, CSP-2, CSP-A (U.S. Navy), CSP-M, CSP-T, and some other modifications. The application of MIL-STD-1235 is restricted to these conditions:

- product flowing in assembly-line fashion
- very stringent homogeneity of the production system
- the overall product quality should meet requirements

Dogde's AOQL plan for continuous production (CSP-1) is the earliest continuous acceptance sampling plan. The procedures can be explained as follows: (E.L. Grant 1996)

a) At the outset, inspect 100% of the units consecutively as produced and continue such inspection until *i* units in succession are found clear of defects.
b) When *i* units in succession are found clear of defects, discontinue 100% inspection, and inspect only a fraction *f* of the units, selecting individual sample units one at a time from the flow of product, in such a manner as to assure an unbiased sample.

c) If a sample unit is found defective, revert immediately to a 100% inspection of succeeding units and continue until again *i* units in succession are found clear of defects, as in procedure (a).
d) Correct or replace, with good units, all defective units found.

There are two similar sampling plans, CSP-2 and CSP-3, which are the modification of CSP-1. CSP-2 differs from CSP-1 in that, "once sampling inspection is started, 100% inspection is not invoked when each defect is found but is invoked only if a second defect occurs in the next *k* or less sample units". Here $k = i$. CSP-3 is a refinement of CSP-2 in that it offers greater protection against a sudden run of bad quality. "When one sample defective is found, the next four units from the production line are inspected. If none of these are defective, the sampling procedure is continued as in CSP-2. If one of the four units is defective, 100% inspection is resumed at once and continued under the rules of CSP-2". (E.L. Grant 1996)

The switching rules of multilevel continuous sampling plans (CSP-M) are based on the fraction of defects in a certain run length rather than the number of defects in the different run lengths. CSP-M is fit for sampling inspection with a relatively large fraction sampled, such as the sampling fraction *f* is equal to 2/3, 1/2, or 1/3.

Lieberman-Solomon plans are a typical kind of CSP-M. They "start with 100% inspection that continues until *i* acceptable units have been found in succession. Then sampling inspection is initiated with a fraction *f* inspected. If *i* acceptable units in succession are found under this sampling inspection, subsequent inspection is at the fraction *f^2*. Another *i* acceptable units in a row qualify for inspection at *f^3*, and so on. When a unit is rejected, inspection is shifted back to the next lower level". (E.L. Grant 1996)

CSP-T differs from CSP-M in:

1) Sampling rate *f* progresses from *f* to *f/2* to *f/4*.
2) When an item is rejected on sampling inspection, inspection reverts immediately back to 100% inspection on the rejection of an item at any level.

Skip-lot sampling is a variation on continuous sampling wherein the inspection unit is a lot or batch rather than an individual item. It is most useful when conducting a quality audit procedure of a supplier's material where Just-in-time (JIT) inventory management is employed and lots received are small or inspection costs are high. The assumption of applying skip-lot sampling is the homogeneity among lots and a good quality history. (E.L. Grant 1996)

2.5.4 Process Capability

Process capability quantifies how capable the processes are of satisfying the customer. Only when the process is in control, which means the assignable variation is eliminated and the common cause is the only source of the process variation, the concept of process capability is meaningful. Process capability index (PCI) was widely used as a single number instead of graphs to quantify the process capability. (Kotz and Lovelace, 1998)

Deleryd (1996) illustrated 13 most common ways of employing process capability analysis:

1. As a basis in the improvement process.
2. As an alarm clock.
3. As specifications for investments.
4. As a certificate for customers.
5. As a basis for defining specifications in new construction.
6. For control of maintenance efforts.
7. As specifications for introducing new products.
8. For assessing the reasonableness of customer demands.
9. For motivation of co-workers.
10. For deciding priorities in the improvement process.
11. As a basis for inspection activities.
12. As a receipt for improvements.
13. For formulating quality improvement programs.

The process capability analysis should be addressed at the beginning of the life cycle of a product (Kotz and Lovelace, 1998). Finley (1992) recommended the following procedure for implementing process capability analysis:

1. The customer defines the nominal or target value specifications of the product.
2. The customer's engineers develop specification limits which allow for process variability

without sacrificing the function.

3. The manufacturer analyzes the possible processes to determine if they can achieve the customer's required specifications.
4. An approved drawing or blueprint is formed based on the agreement between the customer and the manufacturer on the specification limits.
5. After the production starts, the manufacturer conducts process capability studies to compare its manufacturing output to the required specification. Process capability indices are used at the point to numerically quantify or rate its capability to produce acceptable products.

"The general idea behind a process capability index is to compare what the process 'should do' with what the process is 'actually doing'." The general form of PCIs equals 'specification interval' divided by 'process spread'. The current PCIs assume that the underlying distribution of data is normal, the data are independent, and the processes are in statistical control. There are three basic PCIs: C_p, C_{PK}, and C_{pm}. "C_p judges a process to be capable by comparing the spread of the process to the specification interval; C_{PK} compares the location of the outer tails of the distribution to the individual specification limits, then uses the minimum of the two measures of comparison as a measure of process capability; C_{pm} adds an additional penalty for being off-target." (Kotz and Lovelace, 1998)

1. $C_p = \dfrac{USL - LSL}{6\sigma}$

   where,

   USL: upper specification limit

   LSL: lower specification limit

   σ: process standard deviation

The criteria for C_p are different for different industries and situations. Mizuno (1988) suggest the criteria for C_p:

If $1.33 \le C_p$, it passes;

If $1 \le C_p \le 1.33$, it needs watching;

If $C_p < 1$, it fails.

The relationship between percentage non-conforming (NC) and C_p is given by:

$p \geq 2\Phi(-3C_p)$

where $\Phi(\bullet)$ is the cumulative distribution function of the standard normal distribution $N(0,1)$.

The major weakness of C_p is that it does not consider the mean of the process, which means C_p can not measure how close the process mean to the target value.

2. $C_{pk} = \min(C_{pu}, C_{pl}) = \dfrac{d - |\mu - M|}{3\sigma}$

where,

$C_{pu} = \dfrac{USL - \mu}{3\sigma}$,

$C_{pl} = \dfrac{\mu - LSL}{3\sigma}$,

$d = \dfrac{(USL - LSL)}{2}$ is the half-interval length,

$M = \dfrac{(USL + LSL)}{2}$ is the midpoint of the specification interval,

μ is the process mean.

C_{pk} is only standard for the worst-tail to specification limit relationship. Gunter (1989) described C_{pk} as "a way to measure the ratio of the amount of room needed to the amount of room available to produce product within specifications".

The relationship between percentage non-conforming and both C_{pk} and C_p is given by:

$\Phi(-3C_{pk}) \leq p \leq 2\Phi(-3C_{pk})$, and

$p = \Phi[-3(2C_p - C_{pk})] + \Phi(-3C_{pk})$

C_{pk} has the similar weakness as C_p: process location and process spread are confounded in a single index. C_{pk} does not indicate a process is on-target of off-target. What's more, C_{pk} provides no information about the direction in which the process is off-target.

3. $C_{pm} = \frac{USL - LSL}{6\tau} = \frac{d}{3\sqrt{\sigma^2 + (\mu - T)^2}}$

   where,

   τ is the standard deviation about the target,

   T is the target value,

C_{pm} is a modification of C_p and C_{pk}. It is able to indicate whether the process mean is on target, and whether the process variation is within specification limits. The relationship among C_p, C_{pk}, C_{pm} is listed here:

$$C_{pm} = \frac{C_p}{\sqrt{1 + 9(C_p - C_{pk})^2}}$$

The relationship between percentage non-conforming and C_{pm} is given by:

$$p = \Phi(\frac{-d-\mu}{\sqrt{\lambda^2 - \mu^2}}) + 1 - \Phi(\frac{d-\mu}{\sqrt{\lambda^2 - \mu^2}})$$

$$\lambda = \frac{d}{3C_{pm}}$$

C_{pm} is assumed that the target lies at the midpoint of the specification range. If this is not the case, C_{pm} should be not used casually.

For non-normal data, there are seven methods to compute the PCIs: probability plot, distribution-free tolerance intervals, weighted variance method, Clements' method, Box-Cox power transformation, Johnson transformation, and Wright's process capability index C_s. (Tang and

Than, 1999).

Divinsky et al. (2003) employed basic PCIs and control charts to develop a quality system for asphalt mixing plants. The quality mark (QM) characteristic has been used to evaluate the quality of interested characteristics.

Chapter III
Constructability Review

A constructability review was undertaken to assess the state asphalt binder quality management at the state and national levels. Several groups, including TxDOT districts, state DOTs, binder suppliers and contractors were contacted. One industry group, the Texas Asphalt Paving Association (TxAPA), was also contacted.

Every year, TxDOT purchases a large quantity of asphaltic binders from its suppliers. TxDOT billing records indicate that in 2004, this quantity was in excess of 330 million gallons for all types and grades of binder (Figure 3.1). A major portion of this quantity consist of hot asphalts (PG and AC binders), but the quantities of emulsified and cutback asphalts are also significant. Figure 3.2 shows the TxDOT asphalt usage by binder type and grade. A significant majority of it was PG64-22, with other types and grades in varying quantities.

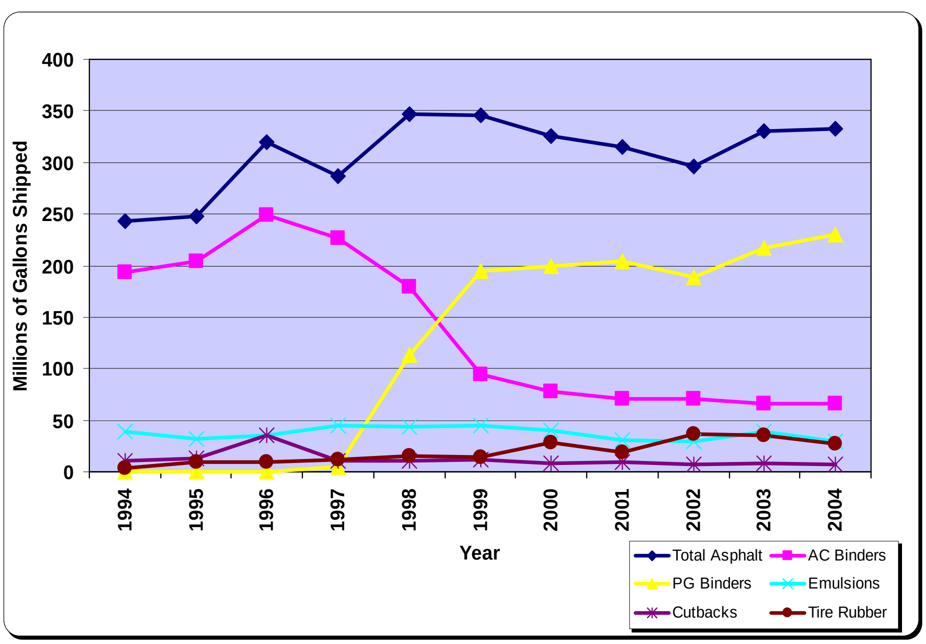

Figure 3.1 TxDOT Asphalt Use from 1994 to 2004

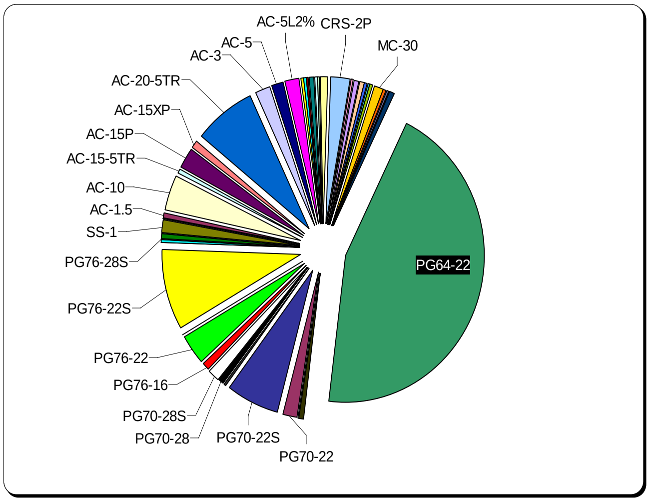

Figure 3.2 TxDOT 2004 Asphalt Binder Grade Use

The supply of asphalt to TxDOT is dominated by a few suppliers, and the companies and their plants change hands quite frequently. Several such events occurred during the course of this research project, and the information that we provide on specific companies and plants may not be current as a result. Figure 3.3 shows the breakdown of binder quantities supplied to TxDOT projects by different companies.

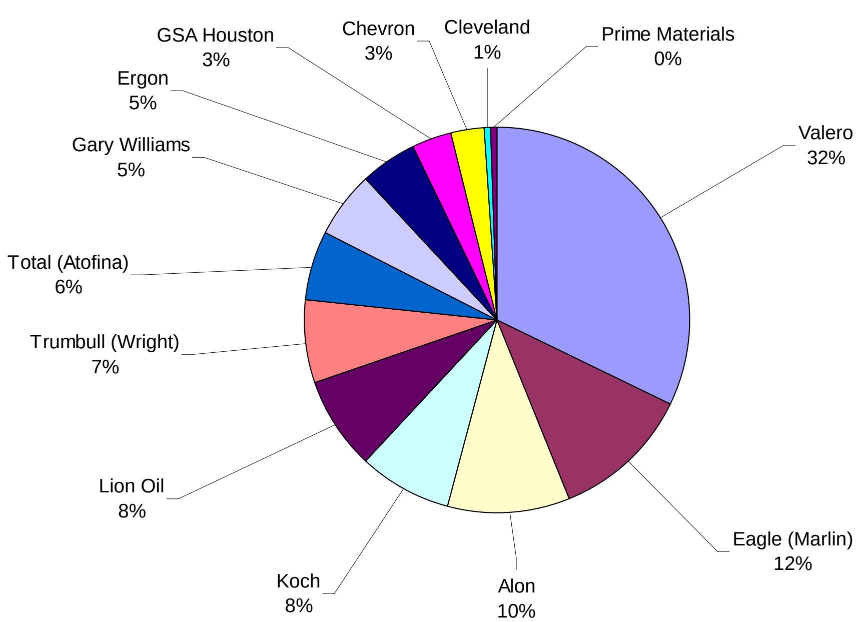

Figure 3.3 Major TxDOT Asphalt Supply Companies for 2004

The quantities of binder supplied by individual plants are also dominated by a few, and that breakdown is shown in Figure 3.4. These breakdowns were considered in selecting binder supply plants for detailed data analysis, the results from which are presented in Chapter IV.

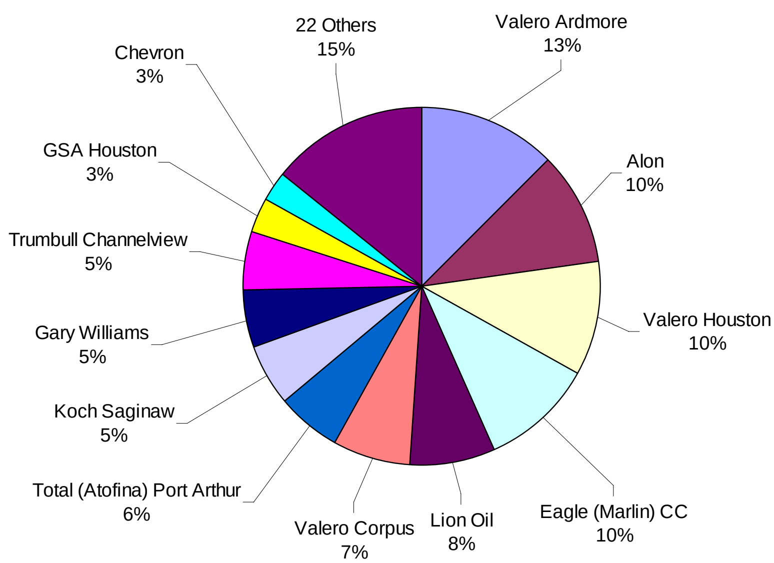

Figure 3.4 Major TxDOT Asphalt Supply Plants for 2004

3.1 TxDOT Districts

First, all TxDOT districts were contacted to get their viewpoints on the existing state of binder quality. Fifteen districts were contacted by visiting them, and the remaining districts were contacted either by e-mail or phone. The fifteen districts that were visited by the researchers were selected based on reported asphalt binder quality issues. A questionnaire was used to guide the district interview process, and it is presented in Appendix B of this report. Table 3.1 shows a summary of the key binder quality-related information provided by the fifteen districts that were visited.

A quick glance at Table 3.1 indicates some key observations. Most districts appear to have binder quality problems. Some have problems that are due to quality issues at a particular plant, and others have problems that are more random in nature. Some districts encounter binder quality problems mostly with seal coat or surface treatment binders. Others encounter problems with certain types of modified binders. There appears to be a consensus that the unique contractual nature of the binder supply process creates a situation that does not allow TxDOT to directly intervene in binder quality matters relating to a particular construction or maintenance project. Figure 3.5 shows a schematic of this relationship.

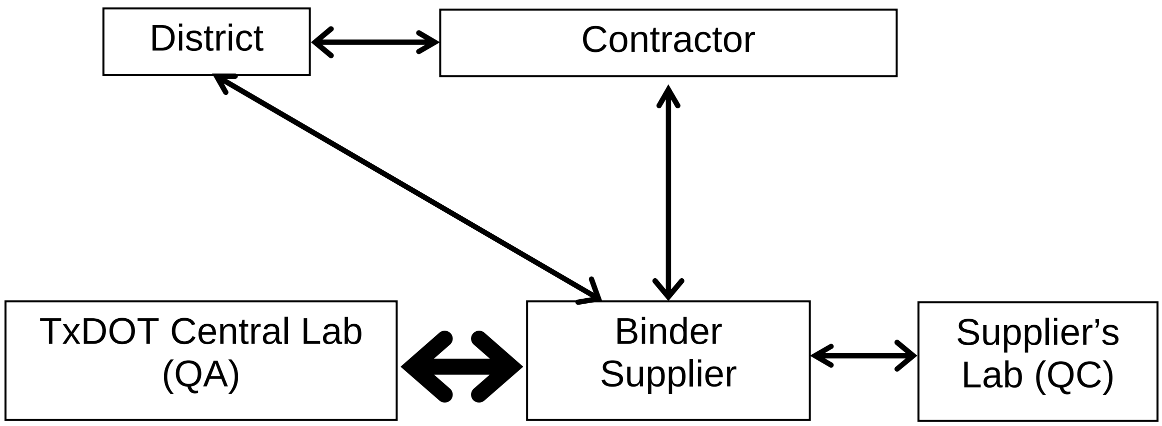

Figure 3.5 TxDOT Binder QC/QA Entity Relationship Diagram

As shown in Figure 3.5, TxDOT's contractual obligation is with the prime contractor of a project, and it is the prime contractor who in turn enters into an agreement with a binder supplier. TxDOT is able to control the quality of a key construction material such as asphalt binder by approving binder suppliers. Under the current system, binder suppliers are approved for a particular binder grade and the approval could be for a particular year or a quantity. There is concern among many districts that once approved, there is no avenue for TxDOT to control binder quality for the remainder of the approval duration or quantity. In fact, districts indicate of evidence that binder from an approved supplier may fail when tested using field samples. Some districts have gone to the extent of sampling each transport of asphalt and send the samples to Cedar Park lab for testing. If more districts take this route, the central asphalt laboratory will be burdened with an extremely high testing load. Therefore, a system has to be implemented to ensure the supply of asphalt binder, both to meet specifications and to maintain consistency of quality. That is the objective of this research project.

Table 3.1 Summary of Responses from Selected Districts

District	Binder Information	QC/QA Information	Data Disputes/Conflicts	CI/Implementation
Abilene	Mostly ALON, Also Koch **Evidence of variability in quality;**	Began sampling each transport (samples kept for 1 year in case of a dispute)	District collects and tests a sample, and if failed, contact supplier to compare results and sends sample to Austin for tests;	<u>Research</u>: The use of binders (reduce the # of binder types used) <u>Tests</u>: **Pen and Visc**.
Amarillo	HMAC: Valero(Sunray), Alon ST: Koch (Lubbock)	Modified asphalt should be tested when made; There are problems with separation. Get a material testing person from TxDOT in refineries.		
Atlanta	HMAC: Lion, Wright (Ch) ST: Koch, Ergon SC: Numerous sources No problems.	HMAC: 1/wk/course, increasing up to 1/day if problems arise ST: 1 /2 wks/source US: 1 / 2wks/travel way SC: 1 /ref./source Favors daily testing for RAP	Won't know results until later. Action may be taken if performance or polymer is lacking In case of problems – contractor choice of monetary hickey or remove (Item 6, 1993 spec)	<u>Suggestions</u>: Do not favor bonus incentives for binders. **DSR helps screen PG** **New CSTM procedure to screen for polymers (hope it will work)**
Beaumont	HMAC: Atofina ST: Koch (PN) SC: Gulf States No problems reported.	Monthly sampling per QC/QA Spec for HMAC – results back in 1 week	Action depends on amount of material, sometime holds money until problem is resolved. Uses an escalation procedure (Lab-Dir of Op-Austin)	<u>To be Addressed:</u> **Storage life of a binder** <u>Suggestions</u>: **Tie quality to approval process, Monthly sampling not sufficient** <u>Tests</u>: **DSR**

Table 3.1 (continued)

District	Binder Information	QC/QA Information	Data Disputes/Conflicts	CI/Implementation
Brownwood	HMAC: Koch, ALON, Gulf States, Eagle ST: Wright, Ergon, Koch SC: Koch Run-off problem for emulsion, flushing for AC20-5TR; Some PG 64-22 failures; Quality of Wright Asphalt products varies for different plants	Monthly sampling sent to Austin (Daily sampling if problems arise), checks tank temp charts daily. Does Saybolt Viscosity for Emulsions in district	**Emulsion problems easy to detect,** but AC is difficult. Negotiation used to resolve disputes. No set procedure	To be Addressed: **Improve reporting system (use e-mail) Contractor has no accountability now. Needs a problem resolution method** Suggestions: Sample at Transporter-Distributor or Transporter-Tank Tests: **Saybolt or Demuls for Emulsion, AC- Penetration**
Bryan	Section not filled out General comment: **Seem to have more problems with SC binders than AC binders**	AC: Tests each sublot; for maint. Work, sample per 200 or 1000 tons ST: Bryan samples each transport; Huntsville samples micro binder and sends to Austin, Hearne samples each transport, but sends for tests only if problems arise SC: Samples each transport, may or may not	Each transport sampled, and sent for testing if problems arise. Meet with supplier and contractor to review results, remove/replace or reduction in pay if warranted Disputes handled per AE; Bryan-chain of escalation, Huntsville- no prescribed procedure, Hearne – negotiation/partnering	Research: **Ratings for PG binders, Could binder classification specs be reviewed?** Suggestions: **Need a quick SC binder test to determine construction related properties** (Demulsibility, Viscosity) Tests: **Viscosity/Pen for SC**

		send for testing (depends on AE)		
Childress	HMAC: Koch, ALON; **24% failure rate**; primary failures in m-value and DSR ST: Koch, ALON; **25% failure rate**; Pen/Vis usually low SC: Total; **90% failure rate on AC 15P**; **Pen/Vis usually low**	Sample 1 qt per transport and sent to Austin for tests; District does DSR w/results in 4 hrs; Austin results in 10 days	Transport loads may be rejected based on "visual" test; Otherwise, would not know for 10 days until Austin results arrive; Disputes are resolved through partnering (No claims)	Suggestions: **Make suppliers more directly responsible to their product** Tests: No specific binder tests; mix tests like Hamburg better
Fort Worth	HMAC: Valero (Ard), Koch (Sag), ALON ST: Eagle/Wright, Koch SC: Eagle, Koch(Sag)	Only pull samples when problems arise	Will only know after the fact, but if work is continuing, samples will be pulled for more tests that may lead to shut downs. No specific procedure for resolution of disputes. Partnering is used to alleviate problems and resolve issues.	To be Addressed: **Changes at refineries (crude sources) affect consistency – need to modify QA procedures** Suggestions: **Run viscosity for consistency – both at the HM plant/road and at supplier** Tests: **Viscosity and DSR** (both done at district if requested by AE

Table 3.1 (continued)

District	**Binder Information**	**QC/QA Information**	**Data Disputes/Conflicts**	**CI/Implementation**
Laredo	HMAC: Eagle ST: Eagle SC: Eagle, Ergon No binder problems Ergon – **CPME Excellent emulsion!**	District binder quality program implemented in July 99. One sample per lot of HMAC tested for DSR (Virgin and RTFO). One split sample submitted to Austin and other kept for referee testing ST: One sample per transport sent to Austin	**4 occurrences of failed asphalts (mostly due to contamination in contractor having only one binder tank)**	<u>To be Addressed</u>: Suppliers say PG 76-22 can be supplied without modifiers – need to check this for validity. <u>Suggestions</u>: **Implement a binder QC/QA program.** <u>Tests</u>: **DSR and viscosity**

Table 3.1 (continued)

Lubbock	HMAC: Alon, Koch (Saginaw), Coastal	Same manufacturing processes for asphalt with different crude oils causes problems on the job. Sample random transports daily.		To be Researched: TxDOT has not specified the needed "quality" for a job. Contracting Industry has asked TxDOT to "tighten up" viscosity requirements. Consider paying contractor extra for better quality control of binder/asphalt. TxDOT can consider buying material.
Pharr	HMAC: Eagle, Trigeant, Valero ST: Koch, Eagle SC: Eagle	HMAC: Used to collect weekly samples, but now only collects occasionally to be sent to Austin. ST: None. SC: Samples binder once at the beginning of job. Now will do sublot testing as per spec.	No problems, but if it were to happen, would sample and test the next lot before taking action. No formal procedure to resolve disputes.	To be Researched: **Contamination in single tank, restrictions on how long binder should be stored, how often to be heated, etc.** Suggestions: **QC/QA program for binders such as for Hot Mix**. Tests: **DSR** (Virgin and RTFO)

Table 3.1 (continued)

District	**Binder Information**	**QC/QA Information**	**Data Disputes/Conflicts**	**CI/Implementation**
San Angelo	HMAC: ALON, Valero SC: ALON, Eagle No problems.	HMAC: Random spot checks, samples every day's production, inspector observes.	Visual evaluation to determine quality (for emulsions in particular) No prescribed procedure to resolve conflicts, but treated on a case-by-case basis.	To be Addressed: **Consistency in quality**
San Antonio	HMAC: Valero, Eagle ST: Valero, Koch SC: Valero Valero submitted out-of-date lab number once. Need to recode the number (Related to problem binder)	New specs for sampling may be overkill. Samples should be pulled constantly to keep contractor honest	Handled on a case-by-case basis (hold money, remove-replace)	To be Addressed: **Lab # need triggered responses, need to reflect modified binders** Suggestions: **Publish results in the same format as TxDOT standard test procedures,** Tests: **DSR**
Tyler	HMAC: Moore Asphalt, Longview Asphalt SC: Wright, Gulf States, Cleveland, Ergon No problems.	HMAC and SC: Weekly samples since 2004 but results are not received from Austin in a timely manner.	No failed tests occurred. No established procedure.	

Table 3.1 Summary of Responses from Selected Districts (continued)

Waco	HMAC: Eagle, Valero, Koch, Wright ST: Wright, Koch, Ergon SC: Wright, Koch (Sag), ALON, Ergon	HMAC: Sample every sublot for PG76-22. PG 64-22 tested if needed. ST and SC: Sample every transport	No failed tests experiences. Will negotiate a reduced price if happened. No specific dispute resolution procedure	
Wichita Falls	HMAC: Gary Williams, Valero, Koch, ALON ST: Valero (Ard) SC: ALON, Koch (Sag) Problems with seal coat hot asphalt (low pen, lack of qc)	HMAC & ST: Daily samples, and randomly test 1 out of 5. SC: Will begin daily sampling	No failed tests experienced. May resort to remove-replace if needed. No specific procedure to resolve disputes.	Suggestions: **Need guidelines to hold binder supplier responsible instead of contractor**
Yoakum	HMAC: Valero, Eagle, Wright (Ch) SC: Eagle, Ergon, Gulf States No problems.	Existing procedures have worked well.		

3.2 Other Industry Groups

As a part of the constructability review, seven binder suppliers, four prime contractors, two hot mix asphalt concrete contractors and one trade association (TxAPA) were contacted. The idea was to get their viewpoints on the quality management aspects of asphalt concrete. The responses that were received varied widely. However, these discussions allowed the researchers to get a broad industry overview of binder quality issues. Table 3.2 presents a summary of responses received from the binder suppliers. The researchers also generated process flowcharts for hot asphalt (Figure 3.6) and asphalt emulsion (Figure 3.7) from the refinery to end-use point.

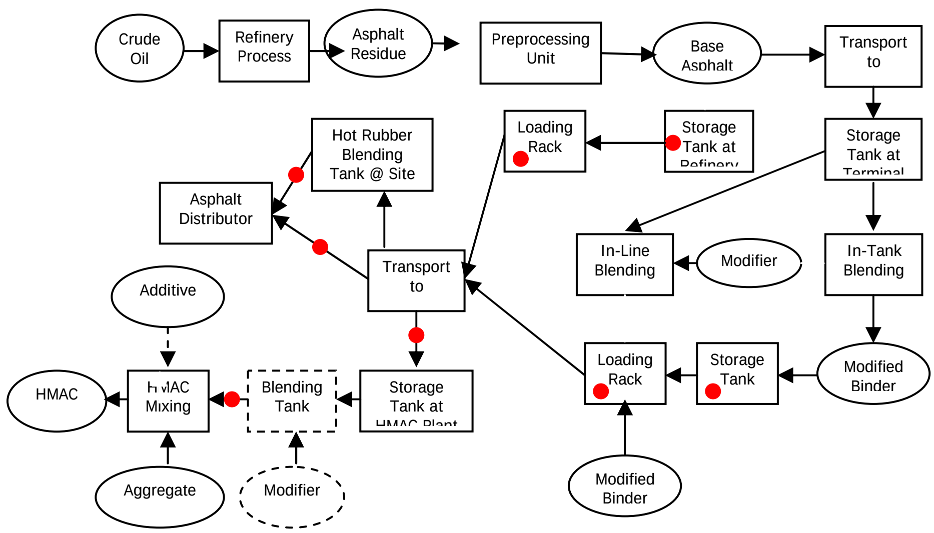

Figure 3.6 Process Flowchart Depicting Hot Asphalt Production Scenarios

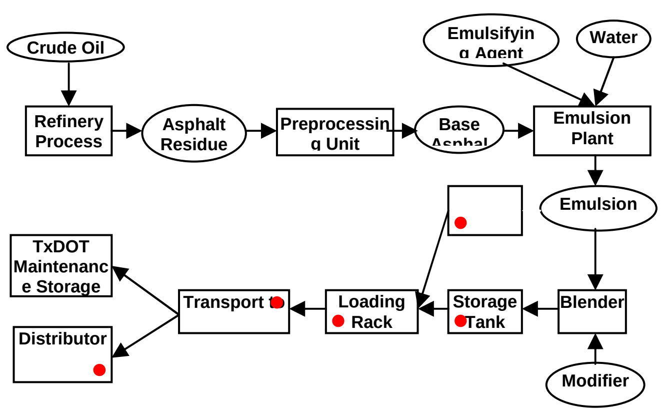

Figure 3.7 Process Flowchart Depicting Emulsified Asphalt Production Scenarios

Table 3.2 Summary of Responses from Selected TxDOT Binder Suppliers

Company	Responsible Personnel	Approval	Sampling	QC Test Frequency		Response to Off-Spec Test Results
				Spec compliance (complete set of tests)	Manufacturing Guidance	
Valero	Rene Correa Cleve Forward	for next month's shipment	AASHTO T40	Weekly	AC-15P-1st load of each day PG - 3times/week	Stop loading; Re-test; Inform PM & contractor; Follow up
Marlin	John M. Chipy	for next month's shipment		PG: for all new batches & weekly HSTA: all new batches and daily. Cutback: all new batch and weekly.	twice a day twice a day	Stop loading; Re-test; Inform PM & contractor; Follow up
Chevron		for next month's shipment		on all split samples		Stop loading; Re-test; Inform PM & contractor; Follow up

Table 3.2 (continued)

KOCH	Austin: Jim Catron Lbk: Smallwood Corpus Christy: Frank Saginaw: Dooley	for next month's shipment	KOCH guidelines	PG: bi-monthly Emulsion: monthly Inventory Maint. Tests bi-monthly	PG:Live tank: weekly & bi-weekly Blending: 1st truck of the day Emulsion: per production run Inventory Maint. Test	Stop loading; Re-test; Inform PM & contractor; Follow up
Gulf States	Navarrete	for next month's shipment				Stop loading; Re-test; Inform PM & contractor; Follow up
FINA	Matthew Byrd	for next month's shipment	AASHTO T40	Whenever tanks refilled		Stop loading; Re-test; Inform PM & contractor; Follow up
Alon	Kevin Armstrong Bill Atchley	for next month's shipment	AASHTO T40	AC-15P/AC15-5TR twice a day	PG: part of Manufacturing guidance tests - twice a day	Stop loading; Re-test; Inform PM & contractor; Follow up

3.3 State DOTs

3.3.1 Background

This section evaluates Quality Assurance programs for asphalt binders that are used in state departments of transportation within the United States and compares the different approaches to determine efficient procedures and guidelines that can be incorporated into further development of the Texas Department of Transportation Quality Assurance Program for asphalt binders. Improvement of TxDOT's quality assurance program could assist in reducing discrepancies within the material's properties at a construction project and at a manufacturer's plant. By having a more efficient system, TxDOT can then be able to minimize sampling and testing done at the suppliers' end, or on site, thus being able to address dispute resolutions more easily.

Much of the information presented was gathered through phone interviews with representatives of state DOT's. The representatives were given a brief survey with questions regarding their individual DOT's QA program for asphalt binders. All information gathered was recorded and transferred to Microsoft Word documents and Microsoft Excel spreadsheets. For those states that were not contacted through phone interviews, a blank copy of the survey was emailed to a knowledgeable representative of the department. Most states were very helpful in taking time to answer all the questions and were very interested in being part of the research.

All except eight departments responded by answering questions from the survey. The departments that did not respond, or were not contacted during this phase of research were California, District of Columbia, Illinois, Mississippi, New Jersey, Oregon, Utah, and Washington. However, binder quality management information was collected from literature available for California and Mississippi.

3.2.1.1 Basis of Approval

Basis of approval differed between departments and can be divided into the five categories listed below. Figure 3.8 breaks down the amount of each category by number of states and percentage.

1. Time
2. Project

3. Load
4. Tanks
5. Quantity

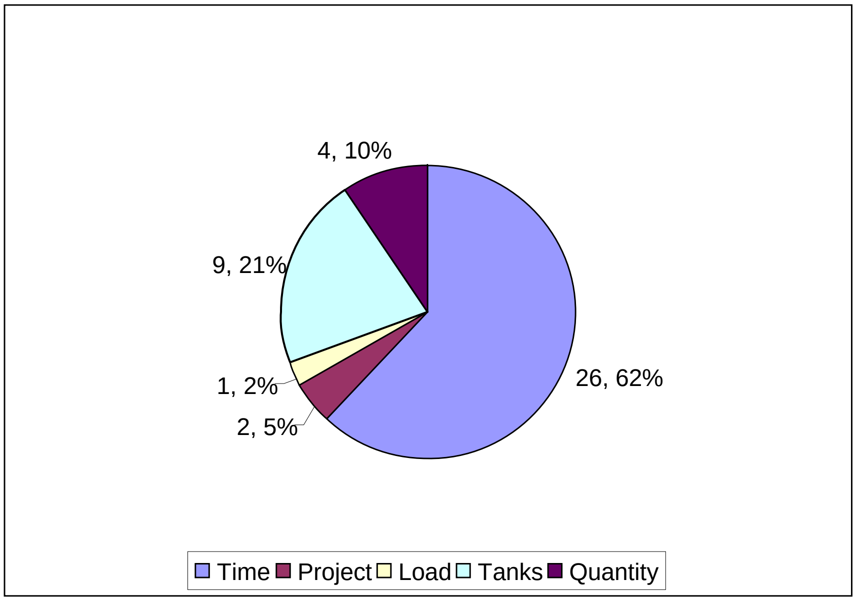

Figure 3.8 Basis of Approval by Category in Numbers and Percentages

Most departments of transportation approve binder material based on time. Most of these states do so through a certification program that tests supplier material for compliance in material properties and standards. In most cases, the certification lasts for a complete year, normally beginning in January. The states with certification programs were typically "larger" states. It would seem to be more beneficial for larger states to use certification programs because much time spent would be spent on sampling and testing due to the large number of suppliers within those states. In comparison, smaller states such as Hawaii and Rhode Island based their approval on projects. Since these projects tend to be smaller, more time could be spent on sampling and testing of material. Approximately 20% of the survey respondents use tank approval with loads and quantities being used as a basis for approval for just over 10%.

3.3.1.2 Sampling

Figures 3.9, 3.10 and 3.11, present information that pertain to binder sample size, sample splitting and sampling location. Some departments did not specify all fields used in the survey; therefore the sum of some results is not equal to the number of departments contacted.

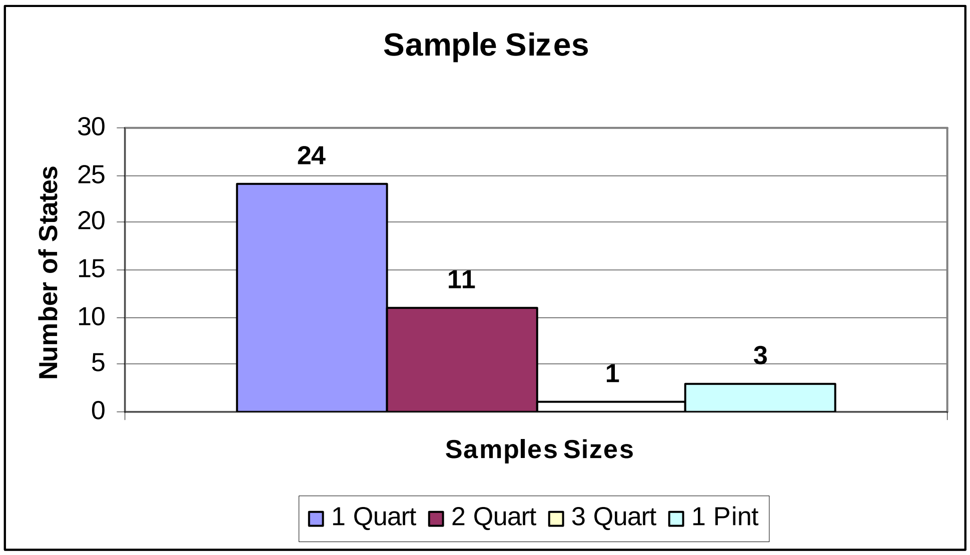

Figure 3.9 Sample Sizes Used By States

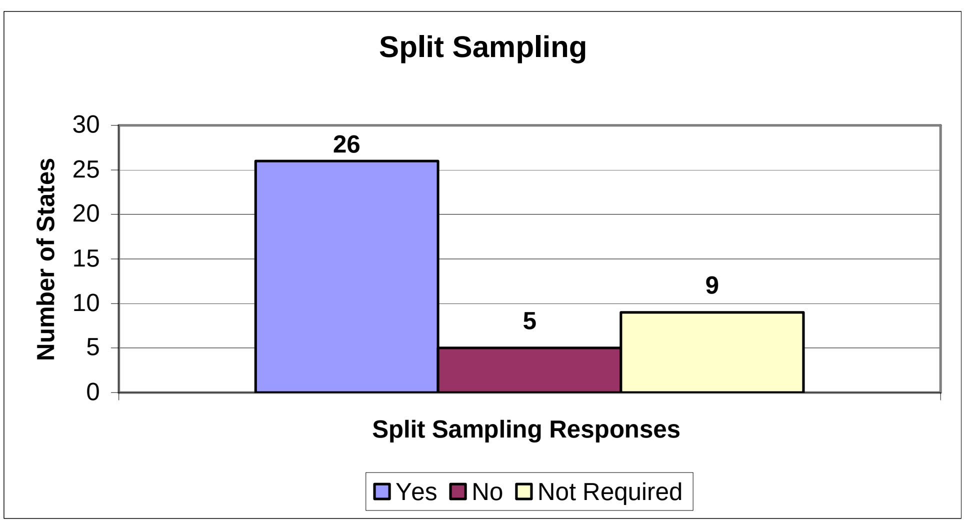

Figure 3.10 Split Sampling Responses

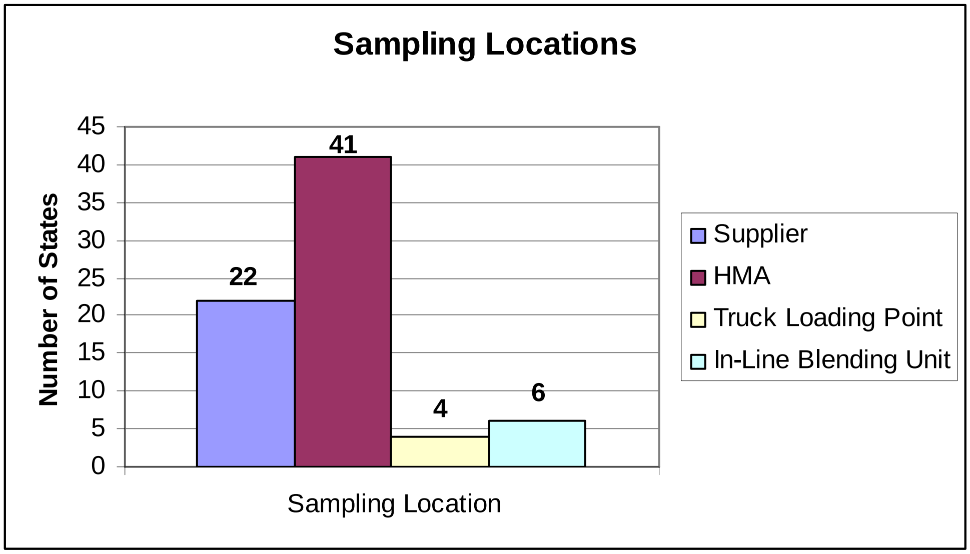

Figure 3.11 Sampling Location Responses

3.3.1.3 Failures, Resolutions, and Incentives

All state departments will encounter failures within projects based upon noncompliance from materials. Departments handle these situations in different ways, but all have the same intention of resolving the problem with both the contractor and the agency in the least complex manner. A formal monitoring program is a very effective way to minimize discrepancies related to material properties. Raising disputes within a timely manner can be helpful in resolving situations between the agency and contractor in order to come to an agreement on whether or not material is within compliance. Some departments rely on independent third parties (private, certified laboratories) to run tests on the failed material. Both contractor and department agree that the results from the third party will be the governing decision in the matter. This is referred to as *referee testing*. However, not all departments rely on referee testing. In these cases the decision depends solely on the results of the department.

Few departments reward contractors for having consistency of material properties for certain quantities or time frames. A reduction in the number of disputes is beneficial for departments since time and resources are not spent resolving issues. Certain departments offer incentives, but not all do. Research showed that some departments are actually thinking about integrating an incentive program into their quality assurance programs.

3.3.2 Combined State Binder Group

The Combined State Binder Group (CSBG) *Method of Acceptance for Asphalt Binders* was an important part of this research. The Departments of Transportation in seven states – Iowa, Michigan, Minnesota, Nebraska, North Dakota, South Dakota, and Wisconsin – developed this Certification Method of Acceptance for asphalt binders. These seven states collaborate to form one single system for binder acceptance. The benefit to using this system is that it reduces the amount of disputes within different suppliers within the region of the seven states and gives a sense of trust to all involved. The method defines general requirements, qualification for certification, loss of certification, qualifying for recertification, sampling and testing by suppliers, which include a Combined State Binder Group Quarterly Round Robin Program, test reports, certification of shipments and documentation, acceptance of asphalt binder not on the approved list, samples obtained by the state, and samples tested by the state with non-complying results.

Suppliers are required to have good laboratory facilities with qualified personnel who are capable of performing all required tests. Suppliers are responsible for maintaining an updated quality control program. Also, all test records shall be maintained for five years and department personnel have access to these records whenever they are needed. Suppliers who seek certified status under this program must furnish a quality control program which should include quality control tests, testing frequencies, laboratory facilities, etc. According to the program, department personnel inspect the refinery or supplier locations every spring in order to assure that the refineries or suppliers are maintaining the required lab facilities, testing procedures, storage facilities etc. If a supplier is certified by one state the other states in the combined state binder group will accept that supplier as certified for their projects as well (CSBG 2004).

The certification will be cancelled if a supplier

- Fails to supply consistent material for three consecutive jobs,
- Fails to participate in four combined state binder group round robin testing,
- Fails to respond to notification of outlying labs in writing,
- Fails to maintain required records,

- Documents shipments improperly,
- Fails to maintain an acceptable quality control program.

If the certification is cancelled, the supplier is given a three-month period to prove that his products are up to the standard. He must also furnish the details regarding what went wrong and what actions were taken to correct the problem (CSBG, 2004). Sampling and testing are done in three different settings.

Minimum annual requirement: In order to identify the characteristic of material prior to the start of the shipping season, sample testing is done. Then, bi-weekly sample testing is done on minimum of one sample for each grade to be shipped. Reports are sent when testing is completed.

Daily Requirement**:** One sample for each grade is tested for penetration and viscosity or dynamic shear (dynamic shear is for modified binder). Reports are sent generally on a weekly basis.

Bi-weekly Requirement**:** One sample for each grade is tested for solubility, flash point, Brookfield viscosity, dynamic shear (original binder, RTFO aged binder, PAV aged binder), mass loss, creep stiffness and direct tension. Reports are sent when testing is completed (CSBG, 2004).

One of the unique aspects of the CSBG is their “Quarterly Round Robin” system. The Round Robin system functions in the following manner:

1. **General:** WisDOT will send a Combined State Binder Group “Round Robin” PG-Binder sample to each supplier, approximately every three (3) months, with a maximum of four (4) samples annually.
2. **Purpose:** To provide repeatability and reproducibility test data between the Department and suppliers.
3. **Report:** Send a report of test results to the designated WisDOT Representative when completed.
4. **Summary:** WisDOT will compile a summary report and distribute to all participants.

Each supplier's data will remain confidential.

5. **<u>Notification of Outliers:</u>** WisDOT will notify "Round-Robin" participants of any tests for which their data was determined to be a statistical outlier. An outlier is defined as that data which is outside of three standard deviations from the average. The determination of outliers is an iterative process. The notification will be contained in a letter attached to the summary report. The participant shall have 30 days to provide WisDOT with a response as to the apparent cause of the outlier. This information will be shared with the other Departments.
6. **<u>Equipment Failures:</u>** Labs will be required to respond to WisDOT in writing with resolution to equipment failures. This information will be shared with the other Departments.

The CSBG's Quarterly Round Robin system is a very effective way to keep the supplier accountable for his equipment and testing methods to assure that all testing equipment is working properly and that compliant material is being supplied. The seven states all share the system thus reduce the necessity for individual testing and QC/QA necessities in doing this by themselves as opposed to running the system within the group.

They are maintaining an acceptable shipping and documentation method for material shipped to job sites. For each and every truck, a shipping ticket is prepared that contains all the details of the material such as supplier, grade, additives used, supplier tank number, truck number etc. One important thing is that if a material is shipped and unloaded in a secondary place and the secondary facility is not certified then the material will not be accepted for state work as a certified material (CSBG, 2004).

If a department-tested sample shows non-compliance results with the specifications, investigations will be made to identify the failure.

Refinery/Terminal Samples**:** If a sample taken at a supplier plant shows any test results out of specification then,

- The supplier is notified and the quantity and the location of the material will be determined by the department and the supplier together.

- The department will retest the sample.
- The districts/regions will be notified if applicable.
- The sampling rate is increased.
- The department will prepare a report including all information with instructions to resolve the sample problem.
- The supplier needs to take the corrective action and submit and explanation.

Field Samples**:** If a sample taken at a project site shows any test results out of specification then,

- The district/region is notified and the district/region notifies the contractor. The quantity and the location of the material will be determined.
- The department will retest the sample.
- The department will notify the supplier who will arrange to investigate the material in question.
- The supplier will report the findings to the department.
- The sampling rate is increased.
- The department will prepare a report including all information with instructions to resolve the sample problem.
- The department will issue a standard test report.
- The district/region will make the final decision with the help of the department report (Sometimes decisions involve reduced payment for the material in question).
- The supplier needs to take the corrective action and notifies the department (CSBG, 2004).

Even though the seven states share the same acceptance program each individual state has their own distinct Certification of Shipments and Documentation procedures based on verification for field samples. The verification for field samples for each state differs from sampling rate, sampling location and sampling size, aside from other factors. All other procedures outlined within the CSBG document applies for the current seven states

3.3.3 Binder Quality Control Programs for Selected DOTs

After having completed the survey of all the states' DOTs, a few states were selected for further examination of their quality control program. Close attention is given to the California, Mississippi, New Mexico, Arkansas, Oklahoma and Louisiana DOTs.

3.3.3.1 California

In order to incorporate quality asphalt binders in its construction and maintenance projects, California DOT is maintaining a certification program for binder suppliers. This program specifies requirements and procedures to be followed by all the suppliers who intend to supply asphalt binder to Department projects. Based on this program, asphalt can be supplied to the Department by either certified or non-certified suppliers.

Each supplier is required to identify one laboratory for each of the four lab categories, namely, primary, satellite, back-up and dispute resolution, to conduct its laboratory testing depending on its testing objectives. Caltrans requires that all supplier laboratories that intend to conduct testing for suppliers be AASHTO accredited.

A certified supplier is required to maintain an updated quality control (QC) plan that describes all the important and relevant information related to binder quality. This QC plan primarily includes information such as the facility type, facility location, contact information of its quality personnel, information on all its laboratories, and relevant laboratory accreditation documents. It should also describe the type(s) and frequency of each quality control test, their methods and location of sampling, the procedure to handle "out of specification" material, methods of checking binder transport vehicles, and the relevant reporting procedure. Sampling is typically done according to the AASHTO T-40 procedures and the containers are labeled with the appropriate identification information.

Different testing protocols are also described in the certification program. They are identified as Initial, Quality Control, Specification Compliance, Quality Assurance, and Verification testing. Supplier's laboratory test results can be entered into a standard reporting format and submitted to the department electronically. The requirements that should be followed by certified suppliers when supplying asphalt, is also indicated in the document. These include a certificate of compliance that has to accompany the shipment, along with the supplier's loading and shipping log. Suppliers will lose their certified status for 12 months if they do not adhere to their quality control plan. The suppliers that are not certified can still provide asphalt binder to the California DOT projects. Binders from these non-certified suppliers are typically subjected to more frequent sampling and testing.

3.3.3.2 Mississippi

Mississippi DOT also uses a certification program for its asphalt binder suppliers. The DOT maintains an inspection, testing and certification manual in which one section describes the basic measures to be taken by a supplier when shipping binders to Department projects, and a separate section describes the steps to be taken for bituminous material and performance graded binders.

For performance-graded binders, suppliers should maintain an updated quality control plan. In addition to the typical standard information in the QC plan, it also describes procedures to deal with non-compliance material that are identified as such after being shipped. It is required to conduct at least one weekly test after the initial refinery test. Shipping binders from a pretested storage tank to a project site or HMA producer, and shipping binder from intermediate storage to a project site or HMA producer, have slight differences in the procedures to be followed by the suppliers. Sampling is done by a Department representative according to the AASHTO T-40 or ASTM D3665. Sampling is done either at the refinery, terminal, or in the field. A Department representative will compare the temperature – viscosity curves of the asphalt binder shipped to the HMA plant and the one received with the mix design to the HMA plant. If the two curves are found to be significantly different, specific corrective measures are taken.

3.3.3.3 Arkansas

In Arkansas DOT, material is accepted for its projects based on a certification provided by the suppliers. Suppliers must maintain a quality control plan and the laboratory thus used must be AASHTO accredited and must participate in the AMRL reference sample program. Sampling and testing frequencies should be included to the QC plan which is approved by the department. Also, the department takes into account the supplier quality history when evaluating suppliers historical data of particular suppliers when the suppliers intend to supply the material to the department through the certification method. The Department publishes a list of suppliers who have adopted the department procedure to supply material under certified method. Material from these certified suppliers will be accepted if a certified shipping ticket accompanies the shipment. If suppliers fail to comply with the quality control, their certificat0n will be revoked. then the certified status will be revoked. In this case material is sampled at the jobsite and tested before being incorporated into projects.

3.3.3.4 New Mexico

New Mexico DOT also maintains a certification program for performance-graded asphalt binder suppliers, and the intent of this is to minimize delays due to testing requirements. This certification system together with quality control and specification compliance tests is designed to the Department quality requirements. The suppliers have to maintain an approved quality control plan. Sampling will have to be in accordance with AASHTO T40 or ASTM D3665 requirements.

Quality control tests to be performed should be chosen from AASHTO M320. However, non-AASHTO M320 tests can be chosen if approved by the Department. The frequency of testing should be included in the quality control plan. At least two tests must be used in order to monitor high and low temperature properties. Also, the method of testing and frequency of initial, quality control and specification compliance testing should be indicated in the quality control plan. Prior to the first shipment of performance-graded asphalt binder, the supplier must submit the test results to the Department for each grade of asphalt.

At least three (3) consecutive production lots need to be tested for specification compliance initially. The minimum frequency for specification compliance tests is twice per month, and for small quantities (< 500 tons), it is once per month. The frequency of specification compliance tests will be reduced if the supplier's initial test results meet some performance criteria such as $G^*/\sin(\delta) \geq 1.10$ kPa for original binder, $G^*/\sin(\delta) \geq 2.42$ kPa for RTFO binder etc. All the laboratories that intend to conduct testing for the suppliers should be accredited by the AASHTO accreditation program. This requirement can be waived for a maximum of one year if acceptable documentation is provided to the department showing the efforts being taken to obtain accreditation. These labs are also required to participate in the AMRL proficiency sample testing program. The suppliers should take corrective action regarding non-compliant material, and such action must be stated in the quality control plan. An accepted format for the QC plan is maintained by the Department for supplier reporting purposes.

3.3.3.5 Louisiana

Louisiana DOT maintains a qualified product list as a part of its quality assurance program. This qualified product list is developed especially for materials that require more than usual sampling and testing. According to this method, a thorough one time evaluation is given to the material. After the initial evaluation of a material grade and placing in the qualified product list, short-term identification tests or certifications are required to assure that the material continues to meet the specifications. The qualification procedure requires the submission of a "qualified product evaluation form", information listed in the qualification procedure and a material sample. All the information relevant to the product such as manufacturer's specifications, type and percentage polymer used, etc. should be provided. Plant inspections are done by the Department materials laboratory prior to granting the approval to supply the asphaltic material. The asphalt cement temperature–viscosity curve should also be submitted. Each shipment of asphalt material must be accompanied by the Certificate of Asphalt Delivery, and the material must be sampled according to the Department specifications.

3.3.3.6 Oklahoma

Oklahoma DOT obtains bituminous material from approved sources and this material must be manufactured and certified under a quality control agreement. The supplier must submit the quality control agreement and the certification for bituminous material. The quality control agreement should also include agreement by the supplier to maintain quality of material, allowing access to quality records and quality history data, and allowing access to inspect test procedure and equipment. A supplier certification stating that the material being shipped to a job site is manufactured under the quality control agreement, should also be submitted to the department. The department has also outlined requirements for handling and storage of material. The laboratories that intend to test asphalt materials for the supplier must maintain a laboratory quality manual. These laboratories must also be Department qualified, and requirements for such a qualification are also outlined. The laboratories that are AASHTO accredited are also required to submit relevant documentation in order to get the Department approval status.

The details of the binder quality management programs of the State DOTs described above are presented in Appendix C.

3.4 Discussion

This chapter has shown how different DOTs maintain successful quality assurance programs for asphalt binders based on support from both the supplier/contractor and the agency. A well-managed quality assurance program needs both parties to work together efficiently to have a well-balanced system.

The Combined State Binder Group demonstrates a very effective and useful way for different departments to collaborate while creating a bond of trust within the seven departments and the suppliers. The system the CSBG has created suggests that making the supplier accountable for keeping all equipment, staff and material certified can minimize discrepancies within the supplied material and, in turn, create the opportunity for suppliers to have trust in the agencies. The system also benefits suppliers and the agencies because a certified supplier from a neighboring state can supply to any state within the CSBG without further sampling and testing.

CHAPTER IV

Data Analysis and Discussion Of Results

4.1 Data Used In The Analysis

Three types of data were available for the data analysis. The first type of data is obtained from the TxDOT LIMS database. These data are related to the testing done by the TxDOT central laboratory in Austin in order to certify the binder to be used in its projects. The other important type of data are the test results the binder suppliers send to TxDOT from the quality control tests at their laboratories. The next type of data is obtained by conducting a round-robin testing program. Researchers obtained binder samples from selected suppliers and sent them to selected laboratories. The main purpose of the program is to initiate a round-robin procedure and to check the reproducibility and repeatability among the testing laboratories.

4.1.1 LIMS Data Base

The Laboratory Information Management System (LIMS) database consists of information related to construction material used by the Texas Department of Transportation for its highway projects. Information related to laboratory test results for asphalt binder is the main interest for this project. Initially PG, AC, Emulsion and Cutback data information were extracted and sorted. The database consists of two types of results. One type is for samples taken for quality assurance testing from the supplier locations and the other type is for verification purposes from the field locations before the material is incorporated into the project. Laboratory test results during the period from May 2002 to March 2005 were selected for analysis. For this purpose, only the laboratory results from the tests conducted for quality assurance purposes were chosen. First, the data was sorted into four main binder types (PG, AC, Emulsion, & Cutbacks). Then each binder type was further sorted based on binder grades and the binder supplier. All the tests performed for each grade and the number of each test performed for every grade were determined. Based on the number of tests performed and the consistency of the available data, the suppliers, grades and tests were selected for further analysis. DSR for original binder, elastic recovery and BBR were selected for performance graded binder. Penetration and Absolute Viscosity were selected for AC binders. Demulsibility, Saybolt Viscosity, Distillation, and Penetration for residue were selected for Emulsions while Distillation, Kinematic Viscosity and Penetration were selected for the Cutbacks.

4.1.2 Supplier (QC) Data

Suppliers conduct testing of their product for quality control purposes. A considerable amount of this data was available from the suppliers. But these test results are in hard copy format; typically fax copies. Some of them are not readable due to poor fax quality. The readable information was entered into an Excel file. Data were available from January 2000 to October 2004. An approach similar to that of the LIMS database analysis was used to narrow down the information. Every effort was taken to match suppliers, grades and test types from both the LIMS database and the quality control test results. Based on the availability and the time frame, only seven suppliers were chosen. Based on the number of tests performed with respect to the length of the time frame, the following tests were selected for further analysis. DSR for original binder, BBR and ER was selected for performance graded binder. Penetration and Absolute Viscosity were selected for AC binders. Demulsibility, Saybolt Viscosity, Distillation and Penetration were selected for Emulsions and Distillation, Kinematic Viscosity and Penetration were selected for the Cutbacks. Clustered data was available for some of the grades and these were analyzed as a whole and separately after breaking into periods.

4.1.3 Round Robin Data

A round-robin testing program was conducted as part of this research. PG binder, AC binder, Emulsion, and Cutbacks samples were obtained from a selected supplier and distributed among the selected laboratories. DSR for original binder and ER were selected for PG binders, Penetration and Absolute Viscosity were selected for AC binders, Saybolt Viscosity, Distillation and Demulsibility were selected for Emulsions and Distillation and Kinematic Viscosity were selected for Cutbacks. Binder samples were sent to the participating laboratories who conducted the above mentioned tests for the relevant samples. Test results obtained from these laboratories were used to carry out the data analysis.

4.2 Data Analysis Methods

The objectives of the statistical data analysis are to determine the overall quality level of asphalt binders in Texas, and quality level of asphalt binders supplied by each main supplier. The methodology can be divided into the following five steps:

1. Construct specification charts
2. Check outliers
3. Check normality
4. Construct QC charts
5. Determine process capability

Minitab 14.20 and Excel 2003 were employed to perform data analysis are. Minitab is used in Step 3, 4, and 5. Excel is used to build the specification charts.

Step 1: Construct Specification Charts

A specification chart plots the test results of a specific supplier-grade-test combination with the specification limits, across the entire time frame. The abscissa of the specification chart is the date and the ordinate is the testing value. One modified specification chart combines charts from different suppliers with the same test and same grade. From this type of specification chart, we can compare the quality levels among different suppliers. We constructed specification charts for both raw data and data without outliers.

In Step 1, we also calculated the percentage outside the specifications for each specification chart. If the percentage outside the specifications is greater than 5%, the asphalt binders are considered to be nonconforming.

Step 2: Check Outliers

We define an outlier as a test value that lies more than three standard deviations away from the mean of all samples for a specific supplier-grade-test combination. In general, the objective of checking for outliers is to trace back to the production process and find out their causes. After eliminating the causes, the quality of product improves. Due to the scope of the project and the limitation of information, we were unable to conduct this analysis. Our methodology is to delete the outliers arbitrarily and compare the quality of asphalt binders with and without outliers. With the information given in Step 1, we can also determine whether the outliers are meeting the specifications or not.

After deleting an outlier, the mean and the standard deviation will change, and new outliers may appear. Therefore, checking for outliers is an iterative process. The process stops when there are no more outliers. We use the term “original number of outliers” to represent the total number of outliers before deleting any from the raw data. The term “final number of outliers” stands for the total number of outliers when the iteration process stops.

Step 3: Check Normality

Each set of data is checked for normality to justify the definition of an “outlier” and the methodology used in calculating process capability in Step 5. If the underlying distribution is non-normal, we probably cannot consider “outlier” as the testing results lay more than three standard deviations away from the mean. Similarly, the common methodology for process capability requires the data are normally distributed.

Four different tests for normality were used: Ryan-Joiner, Shapiro-Wilk, Anderson-Darling, Kolmogorov-Smirnov, and Chi-Square test. The results showed that the Ryan-Joiner test has the least number of non-normality indications for all the supplier-grade-test combinations. Therefore, the Ryan-Joiner test was for checking normality to provide the most lenient test.

The Ryan-Joiner test is similar to the Shapiro-Wilk test. It is based on the correlation coefficient between the empirical distribution and the standard normal distribution. The Ryan-Joiner test statistic is the correlation between the data and the normal scores. The greater the value of the Ryan-Joiner test statistic, the more likely the sample data are from a normal distribution. The smaller the p-value, the less likely that the sample data are from a normal distribution. Each supplier-grade-test combination, for both raw data and data without outliers, was checked for normality. The p-value criterion was 0.05. If the p-value of the Ryan-Joiner test statistic was less than 0.05, the distribution was considered non-normal.

<u>Step 4: Construct QC Charts</u>

Statistical Quality Control (SQC), also called Statistical Process Control (SPC), is a classical tool for quality control and improvement. A control chart is able to monitor whether a process is stable (in control). Variation in a stable process is caused by factors inherent to the process. If a signal appears on a control chart, it is likely the process is out of control. A stable process leads to superior quality and cost saving. A process that is out of control is being affected by external causes of variation.

X and R charts were used to examine test results to determine if production processes were in control. As is common in industrial applications, three standard deviations were used as the distance from the center line (CL) to the upper/lower control limits (UCL/LCL). QC charts were constructed for each supplier-grade-test combination, with and without outliers, using the following procedure:

- Subgroups are roughly based on data over a calendar quarter (3 months).
- Subgroup size remains the same for all subgroups.
- Subgroup size is determined by the quarter with the least number of samples for a supplier-grade-test combination.
- If possible, pick t*he same sample size in each month??* in one subgroup.
- If subgroup size = 2, pick the first sample of the first and second month, if available.
- If subgroup size $\geq$ 3, pick at least one sample in each month, if available.
- Pick the samples in one month by the following order:
    1. The first sample
    2. The last sample

3. The (1 + $\left\lceil \frac{a}{b} \right\rceil$) th sample

4. The (a - $\left\lceil \frac{a}{b} \right\rceil$) th sample

5. The (1 + 2$\left\lceil \frac{a}{b} \right\rceil$) th sample and the (a - 2$\left\lceil \frac{a}{b} \right\rceil$) th sample, and so on.

   a: Number of samples in the month

   b: Number of samples to pick in the month

Eight types of tests were performed for detecting signals in the QA and QC data analysis:

a. 1 point > 3 standard deviations from center line
b. 2 out of 3 points > 2 standard deviations from center line (same side)
c. 4 out of 5 points > 1 standard deviation from center line (same side)
d. 6 points in a row, all increasing or decreasing
e. 9 points in a row on same side of center line
f. 14 points in a row, alternating up and down
g. 8 points in a row > 1 standard deviation from center line (either side)
h. 15 points in a row within 1 standard deviation from center line (either side)

Signal type (a), (b), (c), and (d) appear in control charts of QA data. Signal type (a), (b), (c), (d), and (g) appear in control charts of QC data.

Step 5: Determine Process Capability

The approaches for calculating process capability assume that the data are normally distributed and the process is in statistical control. If these requirements are not satisfied, the results are not valid.

Process capability analysis was conducted for each supplier-grade-test combination, with and without outliers. Up to 5% nonconforming material was used as a criterion. If the process capability analysis showed the possibility of more than five percent of the material outside the specifications, the process was considered incapable of meeting the desired quality.

4.3 QA Data Analysis

This section provides a discussion of results obtained from the analysis of three years of QA data obtained from TxDOT testing of binder samples. A detailed summary of this data, separated by binder supplier and by binder grade, is presented in Appendix D. A graphical representation of detailed results for each plant-grade combination is presented in Appendix E.

4.3.1 Grouped by Suppliers

Of the 145 supplier-grade-test combinations analyzed, 30 did not meet the specification requirement that less than 5% of the test results be outside specifications. Details are summarized in Table 4.1. The first column in Table 4.1 presents the twenty suppliers using codes. The second column is the total number of grade-test combinations for the specific supplier in column one. The third column represents the number of combinations where the supplier does not meet the specification requirement that less than 5% of the test results are outside specifications. Column four represents the percentage of the total grade-test combinations for each supplier that failed to meet the criteria. All the combinations of the following suppliers meet the specification: 0201, 0601, 0801, 0802, 1101, 1102, 1201, and 1402.

Table 4.1 Summary of Raw Data Outside Specifications

Supplier	Total number of grade-test combinations	Number of combinations outside spec.	% of combinations outside spec.
0101	21	5	23.81
0201	1	0	0.00
0301	6	3	50.00
0401	4	3	75.00
0402	11	3	27.27
0501	17	1	5.88
0601	7	0	0.00
0702	11	5	45.45
0703	10	1	0.10
0801	1	0	0.00
0802	8	0	0.00
0901	4	2	50.00
1001	4	2	50.00
1101	2	0	0.00
1102	2	0	0.00
1201	3	0	0.00
1301	6	1	16.67
1302	10	1	10.00
1401	16	3	18.75
1402	1	0	0.00
Total	**145**	**30**	**20.69**

Similarly, Table 4.2 presents the details of outliers for all the grade-test combinations for each supplier. Of 145 supplier-grade-test combinations, outliers occur in 56 cases. Only 1 outlier occurs in almost 60% of the cases containing outliers.

Table 4.2 Summary of Number of Outliers

Supplier	Total number of grade-test combinations	Number of combinations containing 1 outliers	Number of combinations containing at least 2 outliers
0101	21	2	4
0201	1	0	0
0301	6	2	0
0401	4	1	0
0402	11	4	3
0501	17	6	2
0601	7	1	0
0702	11	4	1
0703	10	2	0
0801	1	0	0
0802	8	3	2
0901	4	0	3
1001	4	2	1
1101	2	0	2
1102	2	0	0
1201	3	0	2
1301	6	2	0
1302	10	3	0
1401	16	1	3
1402	1	0	0
Total	**145**	**33**	**23**

Table 4.3 presents the total number of grade-test combinations, with and without outliers, with non-normal data based on the Ryan-Joiner test. In case of raw data, out of the 145 supplier-grade-test combinations, 78 cases were non-normal. In case of raw data without outliers, 47 cases were non-normal out of 145. The normality of the data significantly improves when outliers were eliminated.

Table 4.3 Summary of Normality With and Without Outliers

Supplier	Total number of grade-test combinations	Number of combinations non-normal (with outliers)	Number of combinations non-normal (w/o outliers)
0101	21	9	4
0201	1	0	0
0301	6	3	2
0401	4	4	3
0402	11	8	7
0501	17	8	3
0601	7	1	0
0702	11	8	5
0703	10	5	5
0801	1	0	0
0802	8	7	2
0901	4	4	4
1001	4	3	2
1101	2	2	1
1102	2	1	1
1201	3	2	0
1301	6	2	0
1302	10	3	1
1401	16	8	7
1402	1	0	0
Total	**145**	**78**	**47**

Table 4.4 Summary of Signals in Control Charts

Supplier	Total number of grade-test combinations	Total number of combinations containing signals		Total number of signals in X bar chart		Total number of signals in R chart		Total number of signals for each type in X bar chart								Total number of signals for each type in R chart							
		with outliers	w/o outliers	with outliers	w/o outliers	with outliers	w/o outliers	with outliers				w/o outliers				with outliers				w/o outliers			
								I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
0101	21	10	9	13	16	3	3	9	3	1		11	4	1		3				3			
0201	1	0	0	0	0	0	0																
0301	6	4	3	7	6	1	0	5	2			4	2			1				0			
0401	4	1	0	0	0	1	0									1				0			
0402	11	6	3	9	7	4	0	8	1			6	1			4				0			
0501	17	13	11	27	31	10	6	20	6	1		23	7	1		9			1	5			1
0601	7	3	3	3	6	1	1	3	0			5	1			1				1			
0702	11	5	2	2	2	4	0	1		1		1		1		4							
0703	10	7	6	17	16	2	0	7	10			6	10			2							
0801	1	1	1	3	3	1	1	2	1			2	1			1				1			
0802	8	8	7	23	25	5	2	11	8	4		11	9	5		5				2			
0901	4	3	2	4	3	1	1	4				3				1				1			
1001	4	1	1	2	2	0	0	2				2											
1101	2	1	0	0	0	1	0									1				0			
1102	2	1	1	2	2	0	0	1	1			1	1										
1201	3	3	3	6	5	2	1	5	1			4	1			2				1			
1301	6	5	3	9	8	3	1	7	2			6	2			3				1			
1302	10	3	2	2	2	1	0	1		1		1		1		1				0			
1401	16	5	3	3	4	4	1	2		1		3		1		4				1			
1402	1	0	0	0	0	0	0																

The information regarding the signals identified in the control charts is summarized in Table 4.4. The total number of grade-test combinations containing signals and total number of signals for each supplier are indicated. Two situations, with and without outliers, are presented for both X-bar and R charts. By eliminating the outliers, the process control improves, although not significantly.

Table 4.5 summarizes the information of the process capability. Based on raw data, of the 145 supplier-grade-test combinations, the process capabilities of 58 cases were greater than 5%. Based on data without outliers, the estimated proportion of material that is nonconforming was greater than 5% in 53 out of 145 cases. The outliers did not affect the process capability significantly.

Table 4.5 Summary of Process Capability

Supplier	Total number of grade-test combinations	Number of combinations > 5% (with outliers)	Number of combinations > 5% (w/o outliers)
0101	21	9	9
0201	1	0	0
0301	6	2	2
0401	4	3	3
0402	11	7	7
0501	17	5	4
0601	7	1	1
0702	11	8	8
0703	10	2	1
0801	1	0	0
0802	8	2	1
0901	4	2	2
1001	4	1	1
1101	2	2	0
1102	2	0	0
1201	3	0	0
1301	6	0	0
1302	10	6	6
1401	16	8	8
1402	1	0	0
Total	**145**	**58**	**53**

4.3.2 Grouped by Binder Grade

PG binders have the best performance in terms of meeting the specifications. Only in 1 out of 25 combinations was the percentage of test results outside the specifications using raw data greater than 5%. The quality of emulsions is the worst among the four types of grades. In 40% of combinations for emulsions, the percentage of test results outside the specifications for raw data is greater than 5%. Table 4.6 summarizes the detailed information. The first column in Table 4.6 lists the grades which were selected for data analysis. The second column is the total number of all the supplier-test combinations for the specific grade in column one. The third column represents the number of cases where the grade does not meet the specification requirement that less than 5% of the test results be outside specifications. The percentage of the total supplier-test combinations for each grade which failed is presented in column four. All the tests of the following grades meet the specification: PG 64-22, PG 70-22, PG 76-22S, AC-15-5TR, AC-5L2%, CSS-1H, and MC-30.

Table 4.6 Summary of Raw Data Outside Specifications

Grade	Total number of supplier-test combinations	Number of combinations outside spec.	% of combinations outside spec.
PG (All)	**25**	**1**	**4.00**
PG 64-22	9	0	0.00
PG 70-22	4	0	0.00
PG 76-22	6	1	16.67
PG 76-22S	6	0	0.00
AC (All)	**38**	**7**	**18.42**
AC-10	8	2	25.00
AC-15-5TR	8	0	0.00
AC-15P	8	1	12.50
AC-5	10	4	40.00
AC-5L2%	4	0	0.00
Emulsion (All)	**40**	**16**	**40.00**
CRS-1P	8	5	62.50
CRS-2	8	4	50.00
CRS-2P	12	6	50.00
CSS-1H	6	0	0.00
SS-1	6	1	16.67
Cutback (All)	**42**	**6**	**14.29**
MC-30	18	0	0.00
RC-250	24	6	25.00
Grand Total	**145**	**30**	**20.68**

Similarly, Table 4.7 presents results of the analysis of outliers for all the supplier-test combinations of each grade. PG and AC binders have better performance in terms of the percentage of cases containing outliers. Outliers occur in 7 out of 25 cases for PG binders and in 11 out of 38 cases for AC binders. In nearly 50% of the cases, the outliers occur in both emulsions and cutbacks. Only 1 outlier occurs in almost 60% of the cases containing outliers.

Table 4.7 Summary of Number of Outliers

Grade	Total number of supplier-test combinations	Number of combinations containing 1 outliers	Number of combinations containing at least 2 outliers
PG (All)	**25**	**2**	**5**
PG 64-22	9	0	1
PG 70-22	4	1	0
PG 76-22	6	1	2
PG 76-22S	6	0	2
AC (All)	**38**	**6**	**5**
AC-10	8	2	0
AC-15-5TR	8	1	3
AC-15P	8	1	2
AC-5	10	2	0
AC-5L2%	4	0	0
Emulsion (All)	**40**	**12**	**8**
CRS-1P	8	2	1
CRS-2	8	4	0
CRS-2P	12	4	4
CSS-1H	6	1	3
SS-1	6	1	0
Cutback (All)	**42**	**13**	**5**
MC-30	18	4	3
RC-250	24	9	2
Grand Total	**145**	**33**	**23**

Table 4.8 presents the number of combinations with non-normal distributions based on the Ryan-Joiner test, with and without outliers, for all the supplier-test combinations for each grade. PG and AC binders have better performance than emulsions and cutbacks in terms of the normality test. Normality was significantly improved by eliminating the outliers.

Table 4.8 Summary of Normality With and Without Outliers

Grade	Total number of supplier-test combinations	Number of combinations non-normal (with outliers)	Number of combinations non-normal (w/o outliers)
PG (All)	**25**	**11**	**4**
PG 64-22	9	2	1
PG 70-22	4	2	1
PG 76-22	6	4	1
PG 76-22S	6	3	1
AC (All)	**38**	**15**	**8**
AC-10	8	3	1
AC-15-5TR	8	6	3
AC-15P	8	4	3
AC-5	10	2	1
AC-5L2%	4	0	0
Emulsion (All)	**40**	**29**	**23**
CRS-1P	8	8	5
CRS-2	8	6	5
CRS-2P	12	9	7
CSS-1H	6	4	4
SS-1	6	2	2
Cutback (All)	**42**	**23**	**12**
MC-30	18	10	5
RC-250	24	13	7
Grand Total	**145**	**78**	**47**

Table 4.9 Summary of Signals in Control Charts

Grade	Total number of supplier-test combinations	Total number of combinations containing signals		Total number of signals in X bar chart		Total number of signals in R chart		Total number of signals for each type in X bar chart								Total number of signals for each type in R chart							
		with outliers	w/o outliers	with outliers	w/o outliers	with outliers	w/o outliers	with outliers				w/o outliers				with outliers				w/o outliers			
								I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
PG																							
PG 64-22	9	6	5	11	10	1	1	8	3			7	3			1				1			
PG 70-22	4	3	2	6	6	2	1	4	1	1		4	1	1		2				1			
PG 76-22	6	5	4	5	6	3	0	1	4			2	4			3				0			
PG 76-22S	6	3	3	4	3	2	1	3	1			2	1			2				1			
AC																							
AC-10	8	5	4	12	12	4	2	9	2	1		9	2	1		4				2			
AC-15-5TR	8	2	0	0	0	2	0									2				0			
AC-15P	4	4	6	4	6	2	1	4				5	1			2				1			
AC-5	10	6	6	12	12	0	0	5	5	2		5	5	2									
AC-5L2%	4	1	1	2	2	0	0	1	1			1	1										
Emulsion																							
CRS-1P	8	3	0	0	0	3	0									3				0			
CRS-2	8	4	2	7	6	2	0	7				6				2				0			
CRS-2P	12	5	4	7	6	1	1	7				6				1				1			
CSS-1H	6	4	2	3	2	4	0	1	1	1		0	1	1		4				0			
SS-1	6	4	3	12	11	2	1	8	4			7	4			2				1			
Cutback																							
MC-30	18	12	12	29	37	6	6	17	8	4		21	11	5		6				6			
RC-250	24	13	8	18	19	10	3	13	5			14	5			9			1	2			1

Information about the signals in the control charts is summarized in Table 4.4.9. The total number of supplier-test combinations containing signals and total number of signals for each grade are indicated. The table contains the numbers of combinations and signals both with and without outliers, for both X-bar and R charts. Eliminating the outliers improved the process, although not significantly.

Table 4.10 summarizes the information for process capability. PG binders have the best performance in terms of the estimated percentage outside the specifications. In only 3 (2) out of 25 cases was the estimated proportion of nonconforming material computed based on raw data with (without) outliers greater than 5%. The quality of emulsions is the worst among the four types of grades. In more than 50% of the considerations for emulsions, the estimated percentage outside the specifications is greater than 5%. The outliers do not significantly affect the process capability.

Table 4.10 Summary of Process Capability

Grade	Total number of supplier-test combinations	Number of combinations > 5% (with outliers)	Number of combinations > 5% (w/o outliers)
PG (All)	**25**	**3**	**2**
PG 64-22	9	0	0
PG 70-22	4	1	1
PG 76-22	6	1	0
PG 76-22S	6	1	1
AC (All)	**38**	**19**	**15**
AC-10	8	4	4
AC-15-5TR	8	6	4
AC-15P	8	4	2
AC-5	10	4	4
AC-5L2%	4	1	1
Emulsion (All)	**40**	**23**	**23**
CRS-1P	8	7	7
CRS-2	8	5	5
CRS-2P	12	5	5
CSS-1H	6	4	4
SS-1	6	2	2
Cutback (All)	**42**	**13**	**13**
MC-30	18	3	3
RC-250	24	10	10
Grand Total	**145**	**58**	**53**

4.4 QC Data Analysis

This section provides a discussion of results obtained from the analysis of several years of QC data provided by suppliers from their testing of binder samples. A detailed summary of this data, separated by binder supplier and by binder grade, is presented in Appendix F. A graphical representation of detailed results for each plant-grade combination is presented in Appendix G.

4.4.1 Grouped by Suppliers

Of the 81 supplier-grade-test combinations, 13 do not meet the specification requirement that less than 5% of the test results be outside specifications. Details are summarized in Table 4.11. The first column in Table 4.11 lists the six suppliers using codes. The second column shows the total number of all the grade-test combinations for the specific supplier in column one. The third column represents the number of cases where the supplier does not meet the specification requirement that less than 5% of the test results be outside the specifications. Column four represents the percentage of the total grade-test combinations that failed for each supplier. All the tests of supplier 0802 meet the specification.

Table 4.11 Summary of Raw Data Outside Specifications

Supplier	Total number of grade-test combinations	Number of combinations outside spec.	% of combinations outside spec.
0101	21	4	19.05
0701	15	3	20.00
0702	9	1	11.11
0703	28	4	21.43
0802	3	0	0.00
1201	5	1	20.00
Total	**81**	**13**	**16.05**

Similarly, Table 4.12 presents the details of outliers for all the grade-test combinations for each supplier. Out of 81 supplier-grade-test combinations, outliers occur in 30 cases. Only 1 outlier occurs in 50% of the cases containing outliers.

Table 4.13 presents the total number of non-normal distributions based on the Ryan-Joiner test for all grade-test combinations for each supplier, with and without outliers. In the case of raw data, out of 81 supplier-grade-test combinations, 54 cases are non-normal. In the case of raw data without outliers, 36 out of 81 cases are non-normal. The normality significantly improves by eliminating the outliers.

Information about signals in the control charts is summarized in Table 4.14. The total number of grade-test combinations containing signals and the total number of signals for each supplier are indicated. Two situations, with and without outliers, are presented for both X-bar and R charts. By eliminating the outliers, the process improves, although not significantly.

Table 4.12 Summary of Number of Outliers

Supplier	Total number of grade-test combinations	Number of combinations containing 1 outliers	Number of combinations containing at least 2 outliers
0101	21	6	1
0701	15	2	5
0702	9	1	3
0703	28	5	6
0802	3	1	0
1201	5	0	0
Total	**81**	**15**	**15**

Table 4.13 Summary of Normality With and Without Outliers

Supplier	Total number of grade-test combinations	Number of combinations non-normal (with outliers)	Number of combinations non-normal (w/o outliers)
0101	21	12	6
0701	15	13	10
0702	9	7	4
0703	28	18	13
0802	3	2	1
1201	5	2	2
Total	**81**	**54**	**36**

Table 4.15 summarizes the information for process capability. Based on raw data, out of the 81 supplier-grade-test combinations, 22 cases represented processes that were not capable of

meeting requirements. Based on data without outliers, 16 out of 81 cases have processes that are not capable of meeting requirements are greater than 5%. The outliers do not significantly affect the process capability.

Table 4.14 Summary of Signals in Control Charts

Supplier	Total number of grade-test combinations	Total number of combinations containing signals		Total number of signals in X bar chart		Total number of signals in R chart		Total number of signals for each type in X bar chart								Total number of signals for each type in R chart							
		with outliers	w/o outliers	with outliers	w/o outliers	with outliers	w/o outliers	with outliers				w/o outliers				with outliers				w/o outliers			
								I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
0101	21	11	9	22	22	6	3	16	4	2		16	4	2		6				3			
0701	15	11	9	24	16	10	3	13	3	5	3	10	4	2	0	8			2	3			0
0702	9	5	4	11	6	6	3	9	1	1		3	2	1		6				3			
0703	28	15	13	32	32	10	4	21	8	3		21	8	3		10				4			
0802	3	3	3	7	7	0	0	4		3		4		3									
1201	5	3	3	9	9	0	0	3	4	2		3	4	2									

Table 4.15 Summary of Process Capability

Supplier	Total number of grade-test combinations	Number of combinations with estimated proportion nonconforming > 5% (with outliers)	Number of combinations with estimated proportion nonconforming > 5% (w/o outliers)
0101	21	6	4
0701	15	1	0
0702	9	5	4
0703	28	9	7
0802	3	0	0
1201	5	1	1
Total	**81**	**22**	**16**

4.4.2 Grouped by Binder Grade

Table 4.16 summarizes the detailed information of raw data meeting the specifications. The first column lists the grades which were selected for analysis. The second column contains the total number of supplier-test combinations for the specific grade in column one. The third column represents the number of cases where the grade does not meet the specification requirement that less than 5% of test results be outside specifications. The percentage of the total supplier-test combinations that fail for each grade is presented in column four. PG binders have the best performance in terms of meeting the specifications. None of 20 cases had a percentage of raw data outside the specifications greater than 5%. The quality of AC binders is the worst among the four types of grades. In 45% of combinations in AC binders, the percentage outside the specifications of raw data was greater than 5%.

Similarly, Table 4.17 presents the details for outliers for all the supplier-test combinations of each grade. Emulsions have the best performance in terms of the percentage of cases containing outliers. Outliers occur in 12 out of 39 cases for emulsions. Outliers occur in cutbacks in more than 50% of cases. In 50% of all cases containing outliers only 1 outlier occurs.

Table 4.18 presents the number of non-normal distributions based on the Ryan-Joiner test, with and without outliers, for all the supplier-test combinations for each grade. More than 50% of the combinations for each type of binder are non-normal. Normality is significantly improved by eliminating the outliers.

Information about the signals in the control charts is summarized in Table 4.19. The total number of supplier-test combinations containing signals and the total number of signals for each grade are indicated. The table contains the numbers of combinations and signals both with and without outliers, for both X-bar and R charts. Eliminating the outliers improves process stability, although not significantly.

Table 4.20 summarizes the information for process capability. PG binders have the best performance in terms of the estimated percentage outside the specifications. In only 2 (0) out of

20 cases was the process incapable of meeting requirements. The quality of cutbacks is the worst among the four types of grades. In nearly 50% of cases in cutbacks, the estimated percentage outside the specifications is greater than 5%. The outliers do not significantly affect the process capability.

Table 4.16 Summary of Raw Data Outside Specifications

Grade	Total number of supplier-test combinations	Number of combinations with more than 5% outside spec.	% of combinations with more than 5% outside spec.
PG (All)	**20**	**0**	**0.00**
PG 64-22	2	0	0.00
PG 64-22S	3	0	0.00
PG 64-28S	3	0	0.00
PG 70-22	1	0	0.00
PG 70-22S	1	0	0.00
PG 70-28	1	0	0.00
PG 76-22	7	0	0.00
PG 76-22S	1	0	0.00
PG 76-28	1	0	0.00
AC (All)	**11**	**5**	**45.45**
AC-10	4	1	25.00
AC-15P	2	2	100.00
AC-15XP	2	0	0.00
AC-5	3	2	66.67
Emulsion (All)	**39**	**5**	**12.82**
AE-P	5	0	0.00
CRS-2	12	2	16.67
CRS-2H	2	0	0.00
CRS-2P	2	1	50.00
CSS-1H	1	0	0.00
HFRS-2	4	1	25.00
HFRS-2P	4	1	25.00
MS-2	6	0	0.00
SS-1	3	0	0.00
Cutback (All)	**11**	**3**	**27.27**
MC-30	5	0	0.00
RC-250	6	3	50.00
Grand Total	**81**	**13**	**16.05**

Table 4.17 Summary of Number of Outliers

Grade	Total number of supplier-test combinations	Number of combinations containing 1 outliers	Number of combinations containing at least 2 outliers
PG (All)	**20**	**4**	**4**
PG 64-22	2	0	0
PG 64-22S	3	0	0
PG 64-28S	3	1	0
PG 70-22	1	1	0
PG 70-22S	1	0	0
PG 70-28	1	1	0
PG 76-22	7	1	3
PG 76-22S	1	0	0
PG 76-28	1	0	1
AC (All)	**11**	**2**	**2**
AC-10	4	0	0
AC-15P	2	0	1
AC-15XP	2	1	1
AC-5	3	1	0
Emulsion (All)	**39**	**4**	**8**
AE-P	5	1	1
CRS-2	12	2	1
CRS-2H	2	0	0
CRS-2P	2	0	0
CSS-1H	1	0	1
HFRS-2	4	0	2
HFRS-2P	4	1	1
MS-2	6	0	1
SS-1	3	0	1
Cutback (All)	**11**	**5**	**1**
MC-30	5	2	1
RC-250	6	3	0
Grand Total	**81**	**15**	**15**

Table 4.18 Summary of Normality With and Without Outliers

Grade	Total number of supplier-test combinations	Number of combinations non-normal (with outliers)	Number of combinations non-normal (w/o outliers)
PG (All)	**20**	**11**	**7**
PG 64-22	2	1	1
PG 64-22S	3	0	0
PG 64-28S	3	1	0
PG 70-22	1	0	0
PG 70-22S	1	1	1
PG 70-28	1	1	1
PG 76-22	7	5	2
PG 76-22S	1	1	1
PG 76-28	1	1	1
AC (All)	**11**	**8**	**6**
AC-10	4	2	2
AC-15P	2	2	2
AC-15XP	2	2	0
AC-5	3	2	2
Emulsion (All)	**39**	**27**	**20**
AE-P	5	4	4
CRS-2	12	10	7
CRS-2H	2	1	1
CRS-2P	2	1	1
CSS-1H	1	1	0
HFRS-2	4	3	1
HFRS-2P	4	3	3
MS-2	6	2	1
SS-1	3	2	2

Table 4.18 (continued)

Cutback (All)	**11**	**8**	**3**
MC-30	5	5	3
RC-250	6	3	0
Grand Total	**81**	**54**	**36**

Table 4.19 Summary of Signals in Control Charts

Grade	Total number of supplier-test combinations	Total number of combinations containing signals		Total number of signals in X bar chart		Total number of signals in R chart		Total number of signals for each type in X bar chart								Total number of signals for each type in R chart							
		with outliers	w/o outliers	with outliers	w/o outliers	with outliers	w/o outliers	with outliers				w/o outliers				with outliers				w/o outliers			
								I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
PG																							
PG 64-22	2	2	2	3	3	2	2	1	1	1		1	1	1		2				2			
PG 64-22S	3	1	1	1	1	2	1	1				1											
PG 64-28S	3	2	2	4	4	0	0	3	1			3	1										
PG 70-22	1	0	0	0	0	0	0																
PG 70-22S	1	0	0	0	0	0	0																
PG 70-28	1	1	1	3	5	1	0	2	1			4	1			1				0			
PG 76-22	7	5	4	9	9	3	0	6		3		6		3		3				0			
PG 76-22S	1	1	1	1	1	0	0		1				1										
PG 76-28	1	0	0	0	0	0	0																
AC																							
AC-10	4	2	2	8	8	0	0	4	2	2		4	2	2									
AC-15P	2	2	2	2	2	1	0	1	1			1	1			1				0			
AC-15XP	2	2	1	1	0	1	1	1				0				1				1			
AC-5	3	1	1	1	1	1	0	1				1				1				0			

Table 4.19 (continued)

Emulsion																						
AE-P	5	4	3	6	6	5	1	4	1		1	4	2		0	3			2	1		0
CRS-2	12	8	6	16	15	6	4	10	3	3		8	4	3		6				4		
CRS-2H	2	0	0	0	0	0	0															
CRS-2P	2	1	1	4	4	0	0	1	2	1		1	2	1								
CSS-1H	1	1	1	0	1	2	0			0				1		2				0		
HFRS-2	4	3	3	9	3	2	1	3	1	3	2	2	1	0	0	2				1		
HFRS-2P	4	2	2	3	2	1	0	3				2				1				0		
MS-2	6	3	2	10	9	1	0	8	2			7	2			1				0		
SS-1	3	2	2	9	3	1	1	7	1	1		2	1	0		1				1		
Cutback																						
MC-30	5	3	3	12	12	3	2	7	3	2		7	3	2		3				2		
CR-250	6	3	1	3	3	3	0	3				3				3				0		

Table 4.20 Summary of Process Capability

Grade	Total number of supplier-test combinations	Number of combinations with estimated proportion non-conforming > 5% (with outliers)	Number of combinations with estimated proportion non-conforming > 5% (w/o outliers)
PG (All)	**20**	**2**	**0**
PG 64-22	2	0	0
PG 64-22S	3	0	0
PG 64-28S	3	0	0
PG 70-22	1	0	0
PG 70-22S	1	0	0
PG 70-28	1	0	0
PG 76-22	7	2	0
PG 76-22S	1	0	0
PG 76-28	1	0	0
AC (All)	**11**	**4**	**4**
AC-10	4	1	1
AC-15P	2	1	1
AC-15XP	2	0	0
AC-5	3	2	2
Emulsion (All)	**39**	**11**	**9**
AE-P	5	1	0
CRS-2	12	5	4
CRS-2H	2	0	0
CRS-2P	2	1	1

Table 4.20 (continued)

CSS-1H	1	1	1
HFRS-2	4	0	0
HFRS-2P	4	0	0
MS-2	6	2	2
SS-1	3	1	1
Cutback (All)	**11**	**5**	**3**
MC-30	5	1	1
RC-250	6	4	2
Grand Total	**81**	**22**	**16**

4.5 Discussion of Round Robin Results

As part of this research, a round robin program was carried out. Laboratories were selected based on the types of tests they wished to perform. A total of ten laboratories including the TxDOT laboratory and the Texas Tech asphalt laboratory participated in the program. Two samples of PG binder were sent to eight laboratories and seven responded with the results. Two samples of AC binder were sent to five laboratories and all of them responded with results. One emulsion sample was sent to five laboratories and three responded with the results. A second sample was sent to four laboratories and two responded with results. One cutbacks sample was sent to four laboratories and two responded with the results. Laboratories were not aware of the grades of binders they had received. Table 4.21 below summarizes the grades of asphalt used in the round robin program and the types of tests requested for the different binder grades.

Table 4.21 Grades of Asphalt and Types of Tests

PG		AC		Emulsion		Cutbacks
PG 64-22	PG 76-22	AC-5	AC-5L2%	CRS-1P	CSS-1H	MC-30
DSR OB @ 64°C DSR OB @ 70°C	DSR OB @ 70°C DSR OB @ 76°C Elastic Recovery	Penetration Absolute Viscosity	Penetration Absolute Viscosity	Saybolt Viscosity Distillation Demulsibility	Saybolt Viscosity Distillation	Distillation Kinematic Viscosity

The results were analyzed and used to check the participating laboratories. Some of the laboratories repeated their tests two or three times while other laboratories sent only one result for each sample. The results of DSR OB for PG 64-22 and for PG 76-22 tested at temperature 70°C were not considered for the analysis. The results were plotted together with the mean ± 3 standard deviations and the mean ± 2 standard deviations. When there are replicates, an average value was calculated and considered as the laboratory test result for that particular test and this value was used for the above plot. All the results fall between the mean ± 2 standard deviations. A sample graph is shown below for DSR original binder for PG64-22. The calculated average values together with other test results that do not have replicates were used to check the reproducibility condition. The repeatability condition was checked for the laboratory results that had replicates.

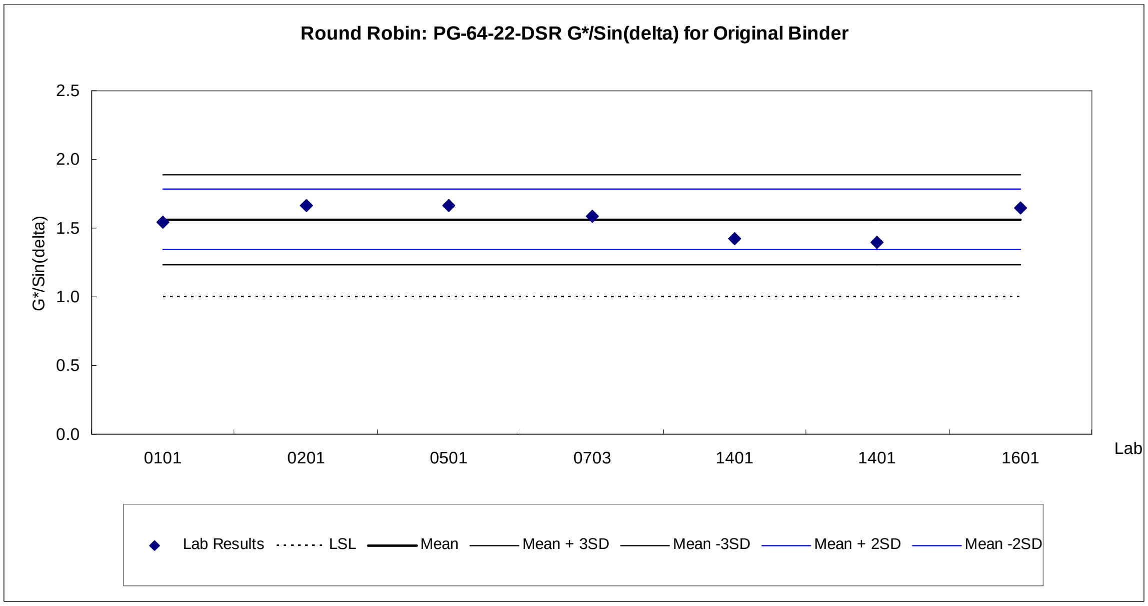

Figure 4.1 Test Results with “Mean ± 3SD” and “Mean ± 2SD”

4.5.1 Reproducibility Criteria

Between-laboratory precision was calculated and Table 4.22 below summarizes the results.

Table 4.22 Tabular Results of Reproducibility Analysis

Binder Type	Test	# of labs participated	# of combinations	# do not meet the criterion
PG64-22	DSR OB	7	21	0
PG76-22	DSR OB	7	21	2
	Elastic Recovery	6	not applicable	
AC-5	Absolute Viscosity	5	10	0
	Penetration	5	10	2
AC-5L2%	Absolute Viscosity	5	10	0
	Penetration	5	10	7
CRS-1P	Demulsibility	2	not applicable	
	Distillation	2	1	0
	Saybolt Viscosity	3	3	3
CSS-1H	Saybolt Viscosity	2	1	1
	Distillation	1	-	-
MC-30	Distillation @ 437°F	2	1	1
	Distillation @ 500°F	2	1	1
	Distillation @ 600°F	2	1	1
	Distillation Res. (%)	2	1	1
	Kinematic Viscosity	2	1	0

For between-laboratory accuracy, two out of 42 combinations of DSR OB test results do not meet the inter-laboratory precision criteria, while 2 out of 20 combinations of AC binder tests do not meet the same criteria. Therefore, the inter-laboratory precision is acceptable for PG and AC binders. Emulsion and cutbacks do not show good accuracy when between-laboratory precision is determined.

4.5.2 Repeatability Criteria

Within-laboratory precision was determined for laboratories if more than one replication of a test was performed for a sample. The four tables below summarize the results for each type of binder. The repeatability criterion is satisfied by all laboratories except for one case in one laboratory for PG binders. The repeatability criterion was usually satisfied for AC binders except in six occasions in three labs. Emulsion and cutbacks gave mixed accuracies. One laboratory (1601) did not meet the repeatability criterion for its emulsion tests.

Table 4.23 Tabular Results of Repeatability Analysis for PG Binder

PG	PG64-22		PG76-22			
	DSR OB - G*/sin(delta)		DSR OB - G*/sin(delta)		Elastic Recovery (%)	
	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion
0101	3	0	3	0	3	not applicable
0201	1	-	1	-	1	
0501	1	-	1	-	-	
0703	3	0	3	0	2	
1401	3	0	3	0	3	
1101	3	0	3	1	3	
1601	3	0	3	0	-	

Table 4.24 Tabular Results of Repeatability Analysis for AC Binder

AC	AC-5				AC-5L2%			
	Absolute Viscosity		Penetration		Absolute Viscosity		Penetration	
	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion
1501	1	-	1	-	1	-	1	-
0101	3	0	3	0	3	0	3	2
0501	3	0	3	0	3	0	3	0
0703	3	0	3	2	3	0	3	0
1401	3	0	3	2	3	0	3	0

Table 4.25 Tabular Results of Repeatability Analysis for Emulsion

Emulsion	CRS-1P						CSS-1H			
	Demulsibility		Distillation		Saybolt Viscosity		Distillation		Saybolt Viscosity	
	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion
0402	3	not applicable	3	0	3	0	-	-	-	-
0703	3		3	0	3	0	3	0	3	0
1601	-	-	-	-	3	3	-	-	3	3

Table 4.26 Tabular Results of Repeatability Analysis for Cutbacks

Cutbacks	MC-30									
	Distillation @ 437°F		Distillation @ 500°F		Distillation @ 600°F		Distillation Res. (%)		Kinematic Viscosity	
	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion	# repeated	# do not meet the criterion
0101	3	3	3	1	3	2	3	1	3	0
0501	1	-	1	-	1	-	1	-	1	-

4.6 Summary

Ten laboratories participated in the round robin program. This program was conducted to ensure the feasibility of such a program and the availability of the laboratories. Laboratories were open to the idea and responded promptly to the request to participate. Although one laboratory agreed to participate in the program, they could not complete the testing because a change of ownership was taking place at that time. Other laboratories sent their results immediately upon completion of the tests. The level of precision of the testing of PG binders within the laboratory and between the laboratories was satisfactory. For AC binders, it was acceptable except for the reproducibility criterion for penetration for AC-5L2% and the repeatability criterion in six occasions for three labs. Emulsion and Cutbacks results were average. Overall, when taken into account the attitude of the participating laboratories toward a round robin program was satisfactory. But careful attention should be given to the accuracy of the testing and the equipment especially for tests related to Emulsion and Cutbacks.

QA data was obtained from roughly mid-2002 to early 2005. The data are from the TxDOT LIMS database and had a consistent format. QC data are from 2000 to 2004. They are collected from suppliers' own records and do not have a consistent format. QC data is frequently unreported. The periods of availability for QC data vary largely for different supplier-grade-test combinations.

The criteria of data selection for statistical analysis were based on the availability of data and the importance of suppliers, grades and tests. Twenty suppliers were selected for QA data analysis. Four grades of PG binders, five grades of AC binders, five grades of emulsions, and two grades of cutbacks were selected for analysis. There were a total of 145 supplier-grade-test combinations selected for QA data analysis.

Six suppliers were selected for QC data analysis and five of them were also selected for QA data analysis. Nine grades of PG binders, four grades of AC binders, nine grades of emulsions, and two grades of cutbacks were selected for analysis. A total of 81 supplier-grade-test combinations which are selected for QC data analysis.

The statistical analysis can be divided into five steps: analysis of specification charts for raw data, analysis of outliers for raw data, analysis of normality for raw data, analysis of control charts for averaged data, and analysis of process capabilities for estimated processes.

The results of data analysis are presented in three formats: individual charts containing the complete information Appendices E and G, the two summary tables in Appendices D and F describing the charts in Appendices E and G, and twenty summary tables in Sections 3 and 4 of this chapter.

Generally speaking, the binder quality of both QA and QC are not satisfactory in terms of meeting product specifications or having stable processes. With regard to the percentages of raw data outside the specifications, numbers of outliers, and signals in control charts, the binder quality of QA and QC are comparable. The QA data have fewer non-normal cases than the QC data. The QC data have better process capability performance than the QA data.

Chapter V
Conclusions and Recommendations

TxDOT uses a two-approach quality assurance strategy for its asphalt binders. The first approach is a monthly certification program for established suppliers where binder samples for each asphalt binder grade are randomly taken by either a TxDOT sampler or a sampling contractor. These binder samples are typically taken towards the end of a particular calendar month, and they are tested by the AASHTO-certified TxDOT materials laboratory for specification compliance. If the binder grades meet the corresponding specification criteria, that supplier is approved to supply that grade of asphalt for the subsequent month. In the other approach, binder quality is monitored for either each tank produced, or each load supplied to a TxDOT construction project. This approach is typically adopted for “non-established” asphalt suppliers who generally supply smaller quantities of asphalt, and do not possess comprehensive testing capabilities. This research project is aimed at developing a more comprehensive quality management strategy for asphalt binders where binder supplier certification is done based on both supplier (QC) and TxDOT (QA) testing.

Chapter 3 of this report reviewed the quality assurance practices of TxDOT districts and other state DOTs. Each of the 25 TxDOT districts were contacted to get their viewpoints on binder QC/QA issues. Particular attention was also given to the quality control and quality assurance practices of some state DOTs including the Combined States Binder Group (CSBG), which is a consortium of seven midwestern states that have developed and adopted a unified binder QC/QA program. Industry groups including binder suppliers, contractors and trade groups were also consulted to get their views on this subject. Information collected during the constructability review revealed wide variations in district and other states’ binder quality management practices. It also revealed problems faced by highway agency personnel that could be attributed to both poor quality and lack of consistency in the quality of binders. The CSBG and the State of California have adopted comprehensive binder quality management programs that rely on supplier QC results for binder quality management to a greater extent than before.

Results from a comprehensive analysis of quality-related data for TxDOT suppliers to determine the effectiveness of the current TxDOT quality assurance program was presented in Chapter 4. TxDOT test results from a three-year period (2002 to 2005) as well as a limited number of supplier test results from 2000 to 2004 were analyzed. A limited round-robin test program was conducted as a part of the project to investigate its suitability for TxDOT.

QA data were available from roughly mid-2002 to early 2005. The data were from the TxDOT LIMS database and were in one consistent format. QC data were available from 2000 to 2004 in the form of test results the suppliers submitted to TxDOT. However, reporting formats for this data were not uniform, and data were not reported to TxDOT on a regular basis. The periods for which QC data was available varied widely for different supplier-grade-test combinations.

The criteria for selecting data for statistical analysis were based on the availability of data and the importance of suppliers, grades and tests. Twenty suppliers were selected for QA data analysis. Four grades of PG binders, five grades of AC binders, five grades of emulsions, and two grades of cutbacks were selected for QA data analysis. This included a total of 145 supplier-grade-test combinations.

Six suppliers were selected for QC data analysis and five of them were also selected for QA data analysis. Nine grades of PG binders, four grades of AC binders, nine grades of emulsions, and two grades of cutbacks were selected for QC data analysis. This included a total of 81 supplier-grade-test combinations.

The statistical analysis consisted of five steps: analysis of specification charts for raw data, analysis of outliers for raw data, analysis of normality for raw data, analysis of control charts for averaged data, and analysis of process capabilities for estimated processes.

The results of data analysis were presented in two formats: a total of more than one thousand charts containing the complete information for QA and QC data analysis in Appendices B and C respectively. A summary of the same data was included in Chapter 4 of this report.

Generally speaking, the binder quality requirements for both QA and QC were not satisfied in terms of meeting product specifications and stable processes. With regard to the percentages of raw data outside the specifications, numbers of outliers, and signals in control charts, the binder quality of QA and QC were roughly comparable. The QA data had fewer non-normal cases than the QC data. The QC data had better process capability performance than the QA data. It is suggested that TxDOT use the factors affecting quality of binders that have been identified in this report and implement better approaches to manage quality of binders used in construction and maintenance projects.

A framework for an improved TxDOT Binder Quality Management is presented for TxDOT consideration in Appendix A of this report. The researchers hope that this framework will be a catalyst for a discussion regarding a future direction for TxDOT binder quality management. This framework was prepared by carefully looking at results from statistical data analysis of QA and QC data presented in Chapter 4, and also considering several other key factors; maintain a consistent quality binder supply from those who supply both larger and smaller quantities, reward suppliers who manage the quality of their products well and penalize those who do not, maximize the use of supplier production control tests for quality control purposes through streamlining of operations, streamlining sampling practices to keep them manageable, and keep TxDOT testing load at manageable levels.

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APPENDIX A
0-4681-P1

0-4681: Further Development of Binder Quality Assurance Program

Product P1: A Framework for TxDOT Binder Quality Management

Table of Contents

1. Overview of the Certification Program

This draft certification program has been developed based on research conducted by TxDOT on its asphalt binder quality control and quality assurance practices. Both the supplier quality control data as well as the TxDOT quality assurance data for the past several years were analyzed by the researchers, and criteria were developed for the purpose of rating the suppliers based on their quality history.

The objective of this certification program is to ensure that asphalt incorporated into TxDOT projects is of acceptable quality and consistency by using quality control plans, quality control testing, quality assurance testing, and statistical analysis of results. The two parties involved in the certification process are the supplier and the Department. The Department defines quality by specifying binder acceptance criteria that are related to performance. The suppliers control quality using a Supplier Quality Plan which is approved by the Department. The Department also monitors suppliers by conducting quality assurance testing and by evaluating supplier quality history. For those suppliers whose laboratories are not AASHTO certified, the Department requires participation in a quarterly round-robin test program. It is the supplier's responsibility to ensure the quality of asphalt by conducting daily and weekly or bi-weekly tests. This also includes the proper implementation and maintenance of a Department approved Supplier Quality Plan. It is the Department's responsibility to assure the quality of the asphalt being used for projects by taking appropriate quality assurance samples and conducting necessary tests.

This proposed program deviates significantly from the existing binder quality management system in which suppliers are certified either monthly or for a certain quantity. The proposed program allows a binder supplier to supply asphalt as either a "certified" or "non-certified" supplier. Separate quality control and quality assurance criteria are specified in this document for both these categories of suppliers. If a supplier is participating in the certification program, the Department will assign a "supplier certification rating" for the supplier based on their material quality history. This supplier certification rating, which will be based on a four-tiered rating system (Tiers 1-4) will be updated every month based on several criteria that will be outlined later in this document. The Department encourages all suppliers to be participants in the certification program. If a supplier opts not to participate in this program, its binders will be more frequently verified through split sample testing. This will not be a practical and viable option for suppliers who supply large quantities of materials to the Department.

2. Reference Documents

2.1 Relevant Department Manuals and Specifications

- Material Inspection Guide
- Quality Assurance Program
- Construction Specifications
- Tex-500-C: “Asphalt Test Procedures Manual”
- Construction Contract Administration Manual

2.2 AASHTO Specifications

- R-18: “Establishing and Implementing a Quality System for Construction Materials Testing Laboratories”
- R-26: “Certifying Suppliers of Performance-Graded Asphalts”
- T-40: “Sampling Bituminous Materials”

2.3 ASTM Specifications

- C 670: “Standard Practice for Preparing Precision and Bias Statement for Test Method for Construction Materials”
- D 3244: “Standard Practice for Utilization of Test Data to Determine Conformance with Specifications”
- D 3665: “Practice for Random Sampling of Construction Materials”

3. Terminology

AASHTO Accredited Laboratory:
A laboratory that is accredited by the AASHTO Materials Reference Laboratory (AMRL) program based on its testing proficiency, testing personnel and repeatability of results.

Asphalt:
In this document, Asphalt refers to products of refined crude petroleum or its derivatives that are used in highway construction. This includes performance graded (PG) binder, asphalt cement, emulsified asphalt and cutbacks. These products may or may not contain modifiers and shall conform to the appropriate Department specifications.

Certificate of Compliance:
A certified statement of the supplier indicating that the asphalt being supplied conforms to the specifications and complies with the Supplier's Quality Plan.

Certified Supplier:
An asphalt supplier who meets the requirements of the supplier certification program and has been approved by the Department.

Continued Supply:
Supply of asphalt either from an approved existing batch or from a continuous production process

Department:
Texas Department of Transportation (TxDOT).

Department Approved Laboratory:
A laboratory that is approved by the Department to conduct binder testing on behalf of a supplier.

Engineer:
The Engineer on record for the project for which asphalt is supplied.

Established Supplier:
An established supplier is a certified supplier who has submitted more than 40 specification compliance test results to the Department over the past 2 years.

Failed Test:
When the results of a test do not meet the required Department specification criteria.

Initial Production:
Production of a batch of asphalt

Initial Testing:
Testing conducted during the process of a supplier's application to be certified, and during the probationary period.

Laboratory:
Facility that tests asphalt which is intended for use in Department projects.

Non-Certified Supplier:
Suppliers approved by the Department to supply asphalt without a Certificate of Compliance.

Non-Established Supplier:
A non-established supplier is a certified supplier who has submitted less than 40 specification compliance test results to the Department over the past 2 years.

Production Processes:
The processes used to manufacture asphalt for construction projects.

Batch Production:
Production of asphalt one batch at a time

Continuous Production:
Production of asphalt using a continuous process such as in-line blending

Probationary Period:
Period following application for certification until the certification is granted.

Production Testing:
Testing performed by the supplier when each batch of asphalt is produced.

Quality Assurance (QA):
All those planned and systematic actions of the Department to provide adequate confidence that asphalt being supplied will satisfy given requirements for quality.

Quality Assurance Testing:
Tests performed by the Department to ensure the quality of asphalt being supplied.

Quality Audit:
A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives. (ISO 8402)

Quality Control (QC):
All activities performed by the supplier to ensure that asphalt being supplied meets all the specification requirements.

Quality Control Testing:
Set of tests performed by the supplier in order to monitor the quality of asphalt being supplied. Quality control tests to be conducted and their frequency shall be described in the Supplier Quality Plan.

Quality Incident:
An occurrence such as results from laboratory testing or observations in the field that indicate unacceptable quality of binder.

Round Robin Testing:
Testing performed by the laboratories of suppliers participating in the Round Robin Test Program conducted by the Department.

Specification Compliance Testing:
A suite of tests conducted to ensure that the asphalt being supplied meets the specification requirements.

Supplier:
A supplier carries out the final production or modification of the asphalt, and is responsible for its quality. A refinery, terminal, in-line blender or hot mix asphalt producer (who modifies asphalt at the hot mix production facility) may qualify as a supplier.

Supplier Certification Rating:
Quality rating assigned by the Department based on an assessment of supplier quality history.

Supplier Quality Plan:
The document that clearly describes the supplier's quality operations so that everyone involved in implementing them understands their responsibilities and how to accomplish them. A Department approved quality plan is required to become a certified asphalt supplier.

Supply Resumption Testing:
Testing performed by a certified supplier who discontinued supply for a period longer than 90 days, in order to resume supplying asphalt.

4. Safety

4.1 The safety requirements specified in the relevant Department and federal (OSHA) regulations shall be observed.

5. Testing Laboratories

All laboratories that conduct testing for binder suppliers must be either AASHTO accredited or Department approved.

5.1 Types of supplier laboratories

Each supplier must identify in its Supplier Quality Plan a laboratory for each of the following types.

- Primary
  - Coordinates the supplier's quality control and specification compliance testing.
  - Shall be equipped to conduct all required tests.
- Satellite
  - Provides limited testing when the primary laboratory is short of staff or equipment.
  - Shall be equipped to conduct all required tests.
- Backup
  - Provides testing when the supplier's primary or satellite laboratory is unable to perform testing.
  - Shall be equipped to conduct all required tests.
- Dispute resolution
  - Shall be chosen by the supplier from a list of laboratories provided by the Department.
  - Shall be AASHTO accredited and equipped to conduct all required tests.
  - Samples for dispute resolution shall be sent by the Department to the dispute resolution laboratory without identification of the supplier.

5.2 Laboratory Certification and Proficiency

- AASHTO Accredited
  - Participates in the Department round-robin test program at least once a year
  - Suppliers who supplied >2% of total Department binder usage in previous calendar year must use an AASHTO certified lab.
  - A current copy of the laboratory's AASHTO Certification Report shall be submitted to the Department.
- Department Approved
  - AASHTO accredited labs are Department approved by default.
  - Laboratories that are not AASHTO certified must participate in the Department's round-robin test program at least 4 times a year

5.3 Round-Robin Test Program

- Participation
  - All laboratories used by suppliers must participate in the round-robin program
  - AASHTO certified laboratories participate at least once each year. (Their participation is aimed at creating a representative database.)
  - Other laboratories participate at least four times each year
- Evaluation Criteria
  - Based on the AASHTO Accreditation Program Procedures Manual
  - Repeated occurrences of either non-participation or poor results will result in the revocation of *Department Approved Laboratory* status.
  - Proficiency sample results which are beyond 2 standard deviations from the grand average are considered to be poor results. The laboratory shall, within 30 calendar days of the date of issuance of the proficiency sample report,
    - investigate to determine the reason(s) for the poor results,
    - record and report to the Department, results of the investigation and any corrective actions taken
    - maintain records of the investigation and corrective actions taken.

6. Sampling

6.1 Standard Procedure

- All samples required for this specification program must meet the criteria specified in Section 11 of the Material Inspection Guide and other relevant specifications.
- The presence of a Department quality representative at the producer plant is required when taking split samples for specification compliance tests. Since the plants that use "continuous production" methods (i.e. in-line blending) are required to take daily split samples, the Department may need to station its quality representative at the plant during the supply period to monitor the taking of samples and other quality-related activities.

6.2 Split Sampling Procedure

- Split samples are obtained at the supplier's facility and split into three containers as required in the appropriate Department specifications. One sample is for testing by the supplier, one for verification testing by the Department (which is sent along with supplier's test results), and the third sample is saved by the supplier as a retained sample.
- Retained samples are kept by the supplier until the Department completes verification testing, until any disputes have been resolved or for 6 months from the date of the supplier's test results to the Department. In the case of a dispute in results, the supplier will send the retained sample to the Department for dispute-resolution testing.

6.3 Information to be included in container labeling:

- Supplier name and address
- Grade of asphalt
- Sample source (i.e. tank, blender, etc.)
- Sample date and time
- Sample purpose (initial testing, verification testing, problem resolution, retained sample, etc.)

7. Testing

- Testing shall be conducted in accordance with the Department Standard Test Procedure Tex-500-C and the binder specification criteria provided in Item 300 of the Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.
- The Precision and Bias Criteria specified in respective AASHTO/ASTM specifications will be used in the evaluation of split sample test results.
- If the supplier's lab is AASHTO certified, the split sample test results from the supplier and the Department will be compared using the AASHTO Precision and Bias Criteria.
    - If the Department test result falls within the precision/bias range, the supplier's test result is used to verify specification compliance.
    - If the Department test result falls outside the precision/bias range, the third split sample will be tested by the designated dispute resolution lab.
    - If the dispute resolution lab result is within precision/bias limits of the supplier's result only, the supplier's result shall be used to verify specification compliance. The Department will undertake a quality audit for the laboratory test under question.
    - If the dispute resolution lab result is within precision/bias limits of the Department's result only, the Department's result shall be used to verify specification compliance. The supplier's lab will undertake a quality audit for the laboratory test under question.
    - If the dispute resolution lab result is within precision/bias limits of both the supplier's and the Department's results, the dispute resolution lab result will be used to determine specification compliance.
    - If the dispute resolution lab result is outside precision/bias limits of both the supplier's and the Department's results, the average of the three results is used to determine specification compliance.
- If the supplier's lab is not AASHTO certified, the Department's test result for the split sample shall be used to verify specification compliance.
    - The Department will compare the supplier's and the Department's test results using the AASHTO Precision and Bias Criteria. If the supplier's test result falls outside the precision/bias range of the Department's result, the supplier's lab will undertake a quality audit for the laboratory test under question.

8. Requirements to be approved as a Certified Supplier of Asphalt

8.1 How to Become a Certified Supplier

- New supplier
  - Application for certification
    - Includes binder grade(s) and past supply histories (if any) including quantities, client, etc.
    - Supplier quality plan
    - Initial test results verifying specification compliance, along with a split sample

- A certified supplier who discontinued supply for a specific period (>90-Days)
  - Application for resumption of testing
    - Binder grade(s) to be supplied
    - Past quality history supplying to the Department, including binder grade, quantity, non-compliance incidents
    - Updated supplier quality plan
    - Supply resumption test results verifying specification compliance, along with a split sample

8.2 Supplier Quality Plan

The Supplier Quality Plan presents the supplier's quality goals and plans to achieve them. It presents the answers to questions *who, what, where, when, why and how* regarding supplier quality. The quality plan describes the procedures and tasks related to quality that are to be performed. It specifies where and when these activities are to be performed as well as how they are to be accomplished. The personnel responsible for managing and accomplishing these activities are identified and their duties and responsibilities are described. The plan details the data and measurements that are gathered, how they are recorded, and how they are analyzed. It describes the decisions that must be made, the alternative courses of action that are to be taken, and the criteria for taking these actions. The plan details records that must be kept and any reports required to document actions that are taken. The quality plan clearly describes the supplier's quality operations so that everyone involved in implementing them understands their responsibilities and how to accomplish them.

The following information must be included in the supplier quality plan.

- Quality Objectives
  - Quality objectives serve to focus improvement efforts. They should be specific, measurable and achievable.
- Facility information

    - Type (refinery, terminal, in-line blending, HMA plant, field blending plant)
    - Location (mailing and shipping address)
- Personnel
    - Organizational chart of quality personnel including identification of primary contact
    - Responsibilities & authority of quality personnel
    - Contact information for quality personnel (phone, fax, e-mail, webpage)
    - Training requirements
- Laboratories
    - Name, location and contact information for all laboratories designated (primary, satellite, backup, dispute-resolution)
- Sampling Plan
    - The sampling plan consolidates the information related to sampling. Specific procedures and requirements should be detailed in the document or referenced in appropriate supplier or Department documents that are readily accessible.
    - Method and location for sampling
    - Safety
- Inspection and Test Plan
    - The inspection and testing plan documents the activities taken to demonstrate conformance to Department specifications.
    - Personnel responsible for inspection or test
    - Inspections to be performed (For example, checking of transport vehicles before loading)
    - Types of inspection or test (visual tests, standard tests)
    - How inspections or tests are to be performed
        - Procedures
        - Checklists
    - Approval criteria
        - References to specifications
        - Guidelines
    - Records to be maintained
- Quality procedures and work instructions
    - Safety
    - Procedures following failed tests
        - Sequence of actions
        - Corrective action plan
        - Notification of affected parties (Engineer, contractor, etc.)
        - Provisions for disposal or rework of failed materials
    - Changes in blending stock
        - Notify the Department prior to any change in blending stock
    - Quality Audits

      Internal quality audits ensure adherence to the supplier quality plan. They are usually regularly scheduled events, but could also be triggered by quality incidents. These audits are internal, but should be performed by personnel who are not responsible for the system being audited in order to provide an independent assessment. They should be fact-driven and identify areas for improvement. The audit should evaluate whether the quality plan is capable of achieving its objectives, if the quality plan is being followed, and if the product conforms to Department specifications. The following information pertaining to quality audits should be included in the Supplier Quality Plan.

        - Responsible personnel
        - Frequency or dates of occurrence
        - Format for internal quality audits
    - Legal statements
- Optional quality procedures
    - Data analysis using quality management tools
        - Mean, standard deviation, specification charts, outliers
        - Use of control chart data for quality improvement
        - Process capability
- Quality records management

  The Supplier Quality Plan should contain a list of all the quality records collected and maintained. Formats for appropriate forms and sample documents should be included. Some of these records will demonstrate product conformance. Others will verify the completion of planned quality activities.
    - Types of records (testing, loading, shipment, Department submittals)
    - Format
    - Recording frequency
    - Storage (location, access)
- Updates to the quality plan
    - Frequency
    - Notify Department of significant changes

8.3 Testing Requirements

- Initial Testing for Specification Compliance
    - Must be conducted at a Department approved laboratory
    - Preliminary testing tied to application to be certified
        - The supplier must submit specification compliance test results along with a split sample as a part of the application for certification
    - Testing during probationary period which is tied to at least the first 3 lots of production
        - Results along with a split sample must be submitted to the Department
- Quality Control Testing
    - The quality control tests are conducted by the supplier to ensure consistency of quality. The tests to be conducted shall be determined by

the supplier as outlined in the Supplier Quality Plan and approved by the Department.

- Types of QC Tests
  - Daily tests
    - At least one of the daily QC tests shall be from the list of specification compliance tests.
  - Specification compliance tests
- Batch Production
  - Production testing
    - For each batch produced, supplier conducts specification compliance tests for initial production quality, and sends results with split sample to the Department.
  - Continued supply testing
    - Conduct daily tests and send results weekly to the Department
    - Conduct bi-weekly specification compliance tests and send results to the Department along with a split sample
- Continuous Production
  - Continued supply testing
    - Conduct daily tests and send results weekly to the Department with daily split samples
    - Conduct weekly specification compliance tests and send results to the Department along with a split sample
- If a supplier's QC test fails, production and supply must be stopped and the contractor and Engineer must be notified by phone. The supplier must repeat the test. If the repeat test passes, the supplier can resume shipment after notifying the contractor and Engineer.
- If the repeat test also fails, the supplier must rectify the quality problem.
  - Supply shall not be resumed until passing test results are obtained for the full set of specification compliance tests, and the contractor and Engineer are notified.
  - The supplier shall record the quality ***incident.*** This Quality Incident Report, and the test results must be sent to the Department within 24 hours of resumption of shipping. A split sample from the specification compliance test must also be shipped to the Department.

- Failed Quality Assurance Test Result(s)
  - If a Department's QA test fails, and the dispute resolution procedure results in a failed test:
    - The supplier and the Department must repeat the specification compliance test on a new split sample. If the repeat test passes, the supplier is cleared to continue normal operations.
    - During the re-test period, the Department shall allow the supplier to continue production if the supplier's daily QC tests show passing results. If they do not, production and supply of the material must be

stopped until a passing specification compliance test result is obtained, both by the supplier and the Department.

  - If the repeat test also fails,
    - Production and supply of the material must be stopped and the contractor and Engineer must be notified. Production can resume when a passing specification compliance test result is obtained, both by the supplier and the Department.
    - The supplier shall record the quality ***incident.*** This Quality Incident Report and the test results must be sent to the Department within 24 hours of resumption of shipping.

- Supply Resumption Testing
  - The supplier must have been a certified supplier within the past 12 months
  - The supplier must have demonstrated conformance to the specifications with no more than two non-compliant specification compliance test results or two non-compliant quality assurance test results in the previous 12 months for the grade of asphalt being shipped
  - Before shipping the asphalt, the supplier shall sample and test the binder for specification compliance as follows:
    - For batch operations, the first batch shall be tested for specification compliance and its results along with a split sample must be submitted to and received by the Department within three days of sampling.
    - For continuous (in-line blending) operation, at the time of first shipment, a sample must be taken downstream of the blending operation and tested for specification compliance. Its results along with a split sample must be submitted to and received by the Department within three days of sampling.
    - After the first batch or first shipment, the sampling and testing frequency shall be in accordance with the supplier quality plan.

8.4 Documentation Needed to Accept Asphalt Binders from a Certified Supplier

- Supplier Certification Document (Standardized Department form available)
  - Name and location of supplier
  - Grade of asphalt
  - Date and time of shipment
  - Transport vehicle inspection statement
  - Certification statement
  - Signature of an authorized company quality representative
- Loading and Shipping Log

    - Asphalt grade, quantity, purchaser, contract/project ID, date and time of transport vehicle inspection, bill of lading number, supplier shipping source
  - Bill of Lading

8.5 Requirements for Maintaining Certified Supplier Status

- Satisfy requirements for shipping documentation
- Compliance with certification requirements
- Provide access to authorized Department personnel to
  - Observe the supplier's quality control procedures by inspecting production, shipping and laboratory facilities
  - Verify adherence to supplier quality plan
  - Obtain samples for QA testing.

8.6 Reporting

- Reporting by Supplier (by E-mail)
  - (Bi-)Weekly test report
  - Quality Incident Report
    - To be submitted to the Department within 24 hours of such incident
    - Type(s) of incident
      - Failed daily test (failed initial and repeated test)
      - Failed specification compliance test (failed initial and repeated test)
      - Contamination in supplier tanks/transports
      - Other
    - Date of the incident
    - Description of the incident
    - Description of the action taken
  - Quality System Update Report
    - To be submitted to the Department within 72 hours of the availability of information on quality data or planned quality-related activities
    - Type(s) of update
      - Change in blending stock
      - Change in production process
      - Control chart signal
      - Outliers in raw data (beyond 3 standard deviations from the mean)
      - Changes in quality personnel/organization
      - Quality-related issues identified during internal quality audits
      - Other
    - Date of update
    - Description of the update
    - Description of the action taken, when applicable

- Reporting of Quality Incident by Department Representative
    - Quality Incident Report
        - Type(s) of incident
            - Contamination in tanks/transports
            - Quality system deficiencies identified during plant visits
            - Other
        - Date of incident
        - Description of the incident
        - Recommended action

8.7 Revoking TxDOT Certified Supplier Status

- Supplier certification may be revoked if the Department determines the supplier failed to meet stipulated program requirements
- The supplier shall be notified in writing regarding the revocation and the reasons for the action
- The effective period of revocation is 12 months
- The supplier may apply for certification after the period of revocation

9. Requirements for Suppliers Supplying Asphalt without a Certificate of Compliance

9.1 Application of Intent to Supply

- Facility information
  - Type of plant (refinery/terminal/in-line blending/HMA plant/field blending plant)
  - Location (mailing and shipping address)
- Personnel
  - Organizational chart of quality personnel including identification of primary contact
  - Responsibilities & authority of quality personnel
  - Contact information for quality personnel (phone, fax, e-mail, webpage)
  - Training requirements
- Laboratories
  - The supplier must designate a primary, a satellite and a backup laboratory as applicable, and provide the name, location and contact information for each laboratory designated.

9.2 Sampling and Testing Requirements

- Each shipment shall be accompanied by the most recent specification compliance test results to certify compliance.
- Initial Testing
  - Supply the Department with specification compliance test results from an accredited laboratory, along with a split sample and the request to supply asphalt
  - For batch production, the initial batch shall be tested for specification compliance and the results plus a split sample shall be submitted to the Department. Following the Department's verification of the test results, the Engineer will notify the supplier to supply asphalt to the project.
  - For continuous operation, a split sample will be taken downstream of the in-line blending operation and tested for specification compliance. Test results and a split sample shall be submitted to the Department prior to using the binder in the project.
    - Following the Department's verification of the test results, the Engineer will notify the supplier to supply asphalt to the project. Once production has begun, each truckload shall be sampled downstream from the in-line blending operation and tested using two tests specified by the Department for each type and grade of asphalt. Each split sample must be submitted to the Department along with the supplier test results. This initial testing continues until the Department has verified the results of the first three truckloads.

- Testing for Continued Supply
  - After initial testing of the first batch (for batch production) or first 3 truckloads (for continuous production) has been verified and the Department has approved use of the binder in the project, the supplier begins testing for continued supply, and the asphalt shall be sampled and tested as follows for quality control:
    - For batch production operations, each batch shall be tested for specification compliance, or, if no new batch is made, the contents of the shipping tank shall be tested for specification compliance at the beginning of each day. In addition, a minimum of one of the specification compliance tests shall be done for each load shipped.
    - For continuous production operations, a full specification compliance test must be done at the beginning of the day using a sample from the first truckload. In addition, every second truckload shall be sampled downstream from the in-line blending operation and tested for one of the specification compliance tests.
    - One split sample from the specification compliance testing (one per day) and the supplier's test results shall be delivered to the Department within 48 hours of sampling for unmodified asphalt, and within 72 hours for modified asphalt.
  - Failed Quality Control (QC) Test Results
    - If a supplier's QC test fails, production and supply must be stopped and the contractor and Engineer must be notified by phone. The supplier must repeat the test. If the repeat test passes, the supplier can resume shipment after notifying the contractor and Engineer.
    - If the repeat test also fails, the supplier must rectify the quality problem. Supply shall not be resumed until passing test results are obtained for the full set of specification compliance tests by both the supplier and the Department. At this point, the supply can be resumed after the contractor and Engineer are notified.
  - Failed Quality Assurance Test Results
    - If a supplier's QC specification compliance test passes, but the Department's QA test fails, the production and supply of the material must be stopped and the contractor and Engineer are notified. Production can resume when a passing specification compliance test result is obtained, both by the supplier and the Department.

10. Department Responsibilities

10.1 Department Quality Management Plan

The Department Quality Management Plan:

- Sets materials specifications
- Specifies supplier quality system requirements
- Reviews and accepts quality system documentation specified for suppliers
- Monitors implementation and operation of supplier quality plans
  - Observes sampling of binder
  - Reviews supplier quality audits/plant inspections
- Collects, reviews, and controls quality records provided by supplier
- Evaluates the suppliers' ability to meet requirements

10.2 Supplier Certification Program

The following sources of data are available for the Department to use to assess binder supplier quality.

- Supplier QC Test Results
  - Results from Daily Tests Submitted Weekly
  - SPC Charts plotted for Daily Tests Using Weekly Averages
  - Results from Weekly Specification Compliance Tests Submitted Weekly
  - SPC Charts plotted for Weekly Specification Compliance Tests using Monthly Averages
- Department QA Test Results
  - From supplier split samples
  - From field samples triggered by failed district lab tests or field binder quality incidents
- Data on "As-Received" Quality in the Field

The Department will assign each certified supplier a supplier certification rating based on assessments of the following criteria. Each criterion will be assessed and given an assessment level based on the supplier's performance. The supplier certification rating will be determined based on the criterion with the lowest assessment level.

- "Percent Outside Specification" for raw QC data
- "Percent Outside Specification" for raw QA data
- "Percent Failed Tests/Incidents"
- Timeliness and Completeness of Reporting QC Data
- Use of Quality Management Tools by the Supplier

10.3 Assessment of *QC Test Results* for Supplier Certification Rating Purposes

- Established Suppliers
  - An established supplier has more than 40 specification compliance test results submitted to the Department over the past 2 years.
  - Assessment levels based on "Percent Outside Specification" for Raw Data from weekly specification compliance test results over the past 2 years
    - "Level 1" if less than 3%
    - "Level 2" if between 3-6%
    - "Level 3" if between 6-10%
    - "Level 4" if greater than 10%
- Non-Established Suppliers
  - A non-established supplier has less than 40 specification compliance test results submitted to the Department over the past 2 years
  - To be assessed, a non-established supplier must have at least 40 days of the single daily specification compliance QC test data submitted to the Department
  - Assessment levels based on "Percent Outside Specification" for raw data from the daily specification compliance QC test(s) based on last 40 days of supply
    - "Level 1" if less than 3%
    - "Level 2" if between 3-6%
    - "Level 3" if between 6-10%
    - "Level 4" if greater than 10%

10.4 Assessment of *QA Test Results* for Supplier Certification Rating Purposes

The following samples received by the Department will be evaluated for QA test results. The actual testing by the Department on these samples will vary from one supplier to another and from one period to the next depending on the need for such testing.

- Certified Suppliers
  - Split samples from initial testing
    - With application for certification
    - During probationary period
  - Split samples from continued supply
    - Batch production
      - Split sample from each new batch produced
      - Split samples with bi-weekly specification compliance results
    - Continuous production
      - Daily split sample with QC results

        - Weekly split samples with specification compliance results
    - Split samples from supply resumption testing
    - Split samples from ad-hoc incidents
- Non-Certified Suppliers
    - Batch Production
        - Split sample from each new batch produced
        - Daily split samples from continued supply testing
    - Continuous production
        - Daily split samples from continued supply testing
    - Split samples from ad-hoc incidents
- Assessment levels based on the number of failed (outside specification) samples from random specification compliance tests over the past 12 months of supply
    - "Level 1" for zero failed tests
    - "Level 2" for one failed test
    - "Level 3" for two failed tests
    - "Level 4" for more than two failed tests
    - Failed tests are classified after the dispute resolution is completed

10.5 Assessment of *"As-Received" Quality* for Supplier Certification Rating Purposes

These assessments will be done based on the following information.

- Results from Department lab tests on field samples taken from transports
- Results from District lab tests on field samples taken from transports (Classified as an "incident" by District Lab Supervisor)
    - Visual inspection (Classified as a "field incident" by Department field representative)
    - Contamination in transports and supplier tanks
    - Problems with first few loads due to non-perfected recipe, blending process, etc.
- Binder temperature at the time of delivery (Classified as a field "incident" by the Department field representative)
- Assessment levels based on "Percent Failed Tests/Incidents" in the past 12 months of supply
    - "Level 1" if less than 3%
    - "Level 2" if between 3-6%
    - "Level 3" if between 6-10%
    - "Level 4" if greater than 10%

10.6 Assessment of *Timeliness and Completeness of Reporting QC Data* for Supplier Certification Rating Purposes

The assessment levels for this criterion are based on the following:

- "Level 1" if less than 3% of data is not turned in within one day after the due date
- "Level 2" if between 3-6%
- "Level 3" if between 6-10%
- "Level 4" if greater than 10%

10.7 Assessment of the *Use of Quality Management Tools by the Supplier* for Supplier Certification Rating Purposes

The assessment levels for this criterion are based on the following:

- "Level 1" if the supplier uses the following quality management tools
  - Mean, standard deviation, specification charts, outliers
  - Use of control chart data for quality improvement
  - Process capability Consistency/Improvement of Quality
- "Level 2" if the supplier uses the following quality management tools
  - Mean, standard deviation, specification charts, outliers
- "Level 3" if the supplier has submitted an updated quality plan that is approved by the Department
- There is no "Level 4" for this category.

10.8 Overall Asphalt Supplier Certification Rating

The following Table (Table 1) summarizes the levels for the assessed criteria indicated above.

Table 1 Assessment Criteria Levels

Assessment Level	QC Data (% failed tests)	QA Data (# of failed tests)	As-Received Quality (% failed Tests/ Incidents)	Timeliness/ Completeness of Documentation (% occurrences)	Use of Quality Management Tools
Level 1	<3%	0	<3%	<3%	Level 1 QM Tools
Level 2	3-6%	1	3-6%	3-6%	Level 2 QM Tools
Level 3	6-10%	2	6-10%	6-10%	Level 3 QM Tools
Level 4	>10%	>2	>10%	>10%	

The supplier certification rating will be based on the five criteria stipulated. The supplier certification rating will be based on the lowest level received by the supplier across all the assessment criteria. This overall rating is identified by “Tier” levels as shown in Table 2 below. This certification scheme could easily be converted to a quantitative rating scheme that incorporates weighting factors for each assessment criterion.

Table 2 Overall Supplier Certification Ratings

Supplier Certification Rating	Lowest Level Across All Assessment Criteria
1st Tier	Level 1
2nd Tier	Level 2
3rd Tier	Level 3
4th Tier	Level 4

11. Summary of Draft Proposed Department Binder QM Program

- No more monthly certification based on the Department's QA tests
- Ongoing Supplier Certification Program
  - Based on supplier QC data and other criteria
  - Rating levels
    - Tiers 1 through 4
    - 4th Tier suppliers lose certification for 12 months
- Requirements for suppliers who are not on the certification program

APPENDIX B
0-4681

Appendix B = Section 1

TxDOT District Interview Questionnaire for Project 0-4681
Further Development of Binder Quality Assurance Program

Asphalt Binder Material Information

Construction/ Maintenance Application where Asphalt is Used	Asphalt Binder(s) Typically used in Application (Type & Grade)	Binder Suppliers (Company/ Plant)	Approx. Quantity of each Binder Supplied	Any Problems Encountered with Binder Types/Sources [1]	Additional Comments
Hot-Mix Asphalt Concrete					
Construction Surface Treatments					
Seal Coats					
Applications using RAP					
Patching mixes					
Cold mixes					
Crack Seals/ Joint Seals					

[1] Select from: consistency of binder quality, quality control/sampling issues, construction issues, other (please specify)

Quality Control and Quality Assurance (QA)

Briefly describe the QC/QA activities related to asphalt binders in your district for each application identified in the Table below. You may include the following aspects of QC/QA in your description of the procedure:

- Sampling procedure
- Field inspector job functions
- Testing responsibility
- Test methods and timing of the availability of test results

Construction/ Maintenance Application	**QC/QA Procedure**
HMAC	
Construction Surface Treatments	
Seal Coats	
Applications using RAP	
Patching mixes	
Cold mixes	
Crack Seals/ Joint Seals	

Disputes and Data Conflicts

1. If an asphalt binder does not meet quality requirements on a particular day or for a specific transport truck load, how is it handled?
2. If the deficiency in quality was made aware after the asphalt is placed, what action, if any, are taken by TxDOT?
3. Are there any prescribed procedures to handle quality-related disputes between TxDOT, contractors and suppliers?

Continuous Improvement Issues and Implementation

4. Is your district currently providing any incentives to binder suppliers or contractors to encourage them to provide a consistently good quality product?
5. What binder quality issues could be addressed in this research?
6. Do you have any comments, suggestions or recommendations that would help TxDOT improve its Binder QA Program?
7. What test (or tests) do you think best represent the quality of binders you use in your district?
8. Do you have any asphalt construction projects that we could visit this summer to sample materials, and also possibly talk to your field inspectors?

Appendix B = Section 2
Asphalt Supplier Interview Questionnaire

Materials

1. What TxDOT Districts do you typically supply asphalt binders to?
2. What contractors do you typically work with (company name, location and contact information)?
3. Which binder types and grades do you supply to TxDOT?
4. What quantities of each type and grade of binder do you supply within a given time period?

Quality Control (QC)/Quality Assurance (QA)

5. Do you have in-house testing facilities?
6. What types of tests can be performed?
7. What is your testing capacity for each test?
8. What is your cost for testing?
9. How long does it take to get results for each test?
10. Are your testing personnel certified? How many of your personnel are certified? What type of certification do they have?
11. Describe the quality control (QC) plan for your plant.
12. Do you have a written QC plan? If so, may we have a copy of that document?
13. Do you provide the results of your QC testing to TxDOT? How often?
14. What types of sampling methods are used at your plant?
15. When does TxDOT see the results of your QC testing for a particular transport truck load (how long after sampling)?

Inspection

16. What types of sampling procedures are performed by TxDOT? What is the frequency?
17. Do you have any concerns with regard to safety, liability, or insurance requirements as they relate to TxDOT inspection personnel at your plant?

Disputes and Data Conflicts

18. If an asphalt does not meet quality standards on a particular day or for a specific transport truck load, how is this deficiency handled?
19. How are disputes resolved with TxDOT or a contractor?
20. Are there prescribed procedures for handling disputes?

Continuous Improvement Issues and Implementation

21. What can TxDOT do to encourage production of a consistently good quality binder material from your plant?
22. Is TxDOT using any type of "incentive" to encourage the production of a consistent quality binder material?
23. Do the contractors that you do business with offer any incentives to encourage the production of a consistent quality binder material?
24. Do you have any issues, concerns or problems with TxDOT that could be addressed in this research?
25. Do you have any issues, concerns or problems with contractors that can be addressed in this research?
26. Do you have any comments, suggestions or recommendations that would help TxDOT improve their Binder QA Program?

Other Questions for Discussion

- How are your relations with TxDOT personnel?
- How are your relations with the contractors that you do business with?

Appendix B = Section 3
Contractor Interview Questionnaire

Work

1. What types of asphaltic work do you perform for TxDOT (i.e., overlays, seal coats, surface treatments, AC paving, etc.)?
2. Which Districts do you work for?
3. How much work of each type do you perform within a given year?

Materials

4. Who supplies your asphalt binder materials (companies/plants and locations)?
5. Which binder types and grades do you use?
6. What quantities of each type and grade of binder do you use within a given time period?

Quality Control (QC)/Quality Assurance (QA)

7. What is your approach to quality control?
8. Does your company have any written QA/QC documents? If so, may we have a copy of those documents?
9. Do you have in-house testing facilities for binder materials?
10. If so, what types of tests do you perform?
11. Do you use an outside testing lab to perform any QA/QC testing on the asphalt binder materials?
12. If so, which tests are performed?
13. Do you sample your own materials?

Inspection

14. Do you have any concerns with regard to safety, liability, or insurance requirements as they relate to TxDOT inspection personnel at your jobsites?
15. Are test results and inspector approvals provided in a timely fashion?

Continuous Improvement Issues and Implementation

16. Do you have any issues, concerns or problems with TxDOT that could be addressed in this research?
17. Do you have any issues, concerns or problems with asphalt binder suppliers (plants) that could be addressed in this research?
18. What types of quality-related problems need to be addressed as part of this research?
19. Do you have any comments, suggestions or recommendations that would help TxDOT improve their Binder QA Program?

Disputes and Data Conflicts

20. If an asphalt does not meet quality standards on a particular day or for a specific transport truck load, how is this deficiency handled?
21. How are disputes resolved with TxDOT or an asphalt binder material supplier?
22. How are laboratory testing data disagreements handled?
23. Does your company have prescribed procedures for handling these types of disputes?

Informal Questions for Discussion

24. How are you relations with TxDOT personnel?
25. How are your relations with the asphalt binder suppliers that you do business with?
26. How are your relations with TxDOT in-house and outside inspection personnel? Do you have any concerns or suggestions for improvement?

APPENDIX C

0-4681

Appendix C
State DOT's Quality Control Programs (Acceptance Programs / Certification)

Table C1: California DOT

QC	QC Plan	* **Complete information of QC Plan:** Facility type (refinery, terminal in-line bending or HMA plant, etc.)); location; contact details of responsible persons; name, location & certification of labs & tests they perform; back-up laboratory information * A copy of the AASHTO accreditation for each lab * **Contingency plan:** Identify the asphalt in question, cease shipment, take corrective action, notify the department and work with the department to resolve the problem * Methods & location of sampling for initial, QC & specification. compliance testing * Tests & frequency of tests of above tests for each asphalt grade * Checking transport vehicles before loading * Program or system for maintaining testing, loading & shipment records * Shall include statements stating they comply with the specifications * Prepare monthly summary reports in standard formats and supply before 15th of next month * Notify the department if any changes made to the QC plan
	Sampling	* AASHTO T-40 * If split samples required, split into three 1-litre samples * Split samples should be taken from the same point where supplier takes samples * Modified asphalt: use cylindrical shaped 1-liter cans w/ an open top friction lid * Unmodified asphalt: same above or rectangular 1-liter cans w/ a screw-on lid * Label: supplier name & address, grade, source, date, time & purpose (initial, verification, problem resolution testing etc.)
	Testing Information	* **Initial Testing:** At least 3 consecutive lots, split samples & test results to be submitted * **Quality Control Testing:** As outlined in the QC plan & approved by the department * **Specification Compliance Testing:** First day & Weekly except solubility& Ductility, Split samples & test results to be reported monthly in a standard format; if failed corrective actions to be taken as outlined
	Reporting	* In a standard format electronically * Split samples and their test results of specification compliance monthly (minimum) * Previous month summary of all spec. compliance tests on 15th of next month
QA	Testing	* **Quality Assurance Testing:** Samples taken from in-line at the HMA production facility * **Verification Testing:** on split samples submitted by the supplier

Table C1 (contd.): California DOT

Round Robin		* Labs that perform initial, specification compliance or dispute resolution tests should participate in AMRL Sample Proficiency Testing program
Laboratory Requirement		* Primary laboratory (Initial, QC & specification compliance testing; AASHTO accredited) * Satellite laboratory (Capable of doing all tests if required) * Back-up laboratory (Capable of doing all tests; AASHTO accredited) * Dispute-resolution laboratory (Independent from both parties; both agree)
Treatment of fail tests		If supplier's specification compliance testing identified asphalt doesn't meet the specification then * Cease the shipment, remove from the shipping queue, identify shipments that contain non-complaint asphalt, retrieve if possible * Inform the department; Sample and re-test the asphalt; should take corrective action and provide documentations regarding the corrective action * **1st incident of non-compliance in 12 months:** Suspend the shipment until the problem resolved and notify before the shipment resume * **2nd incident of non-compliance in 12 months:** Suspend the shipment, provide the split sample and test results after problem resolved and wait until department verify the results to resume shipments * **3rd incident of non-compliance in 12 months:** Suspend the shipment, notify the department, supplier's status will be revoked for 12 months if it is a qualify problem of the production process
		If QA tests identify that asphalt doesn't meet the specifications * Notify the supplier within 24 hours * Supplier needs to conduct an investigation with HMA producer; gather all available data, additional testing & sampling, inspect storage tank, review records, events etc. * supplier and the HMA producer will jointly identify and correct the problem and the supplier needs to notify the department * **Up to 5 times in 3 months:** Supplier & HMA producer will work jointly to resolve the problem * **Up to 10 times in 12 months:** suspend the shipment; department, supplier & HMA producer will work jointly to resolve the problem * **10 times in 12 months:** Suspend the shipment, if it is a quality issue status will be revoked for 12 months * If test results cannot be verified (but specification compliance & verification results are in compliance) * Notify the supplier within 24 hours; both parties work together to resolve the problem; If supplier's testing program is responsible * **1st & 2nd incident in 12 months:** supplier review the testing program (protocols , equipments, practices etc); sample and retest; split samples & results to the department; if still the problem remains use the back-up lab * **3rd incident in 12 months:** use the back-up lab to re-test; approval given after 3 sets of specification compliance tests have been verified * **4th incident in 12 months:** use the back-up lab to re-test until problem resolved; use for 3 months or 10 specification compliance tests

Table C1 (contd.): California DOT

Remarks		* Clearly defined terminology * Laboratory requirements are clearly defined * Requirements needed to get the certification as an approved supplier are outlined * Requirements needed to maintain approved supplier status are defined * Requirements for suppliers supplying asphalt w/o a certificate are outlined * If non-compliance asphalt has been released then corrective actions to be taken is defined * If department's QA tests identify non-compliance asphalt then corrective actions to be taken is defined

Table C2: Mississippi DOT

QC	QC Plan	**Performance Graded Asphalt Binders** * **Complete information of QC Plan:** Facility type (refinery or terminal); location; contact details of responsible persons for QC; QC tests to be performed, name, address & location of labs that perform QC tests * Statement indicating how to tackle non shipment of non compliance material * should describe method and frequency for QC and specification compliance testing * Statement indicating the quarterly summary reports for QC and specification compliance testing will be prepared * Shall provide the procedure to check transport vehicles to prevent contamination
	Sampling	**Bituminous Material** **At the refinery or terminal** * Asphalt emulsion: one/tank from middle of the tank if capacity less than 10,000 gallons: 2/tank from top and middle if capacity 10,000 - 50,000 gallons * Other than emulsions: one/tank from middle if the tank capacity is less than 50,000 gallons, 2/tank from top and bottom if the capacity is 50,000-150,000gallons and 3/tank from top, middle and bottom if the capacity is more than 150,000 gallons **After a tank is approved:** stock sampling is done bi-weekly if shipped more than 50,000 for two weeks or stock sampling is done every 50,000 shipped **Field Acceptance Sampling** * Asphalt cement & cutbacks : 1 quart metal cans * Emulsified asphalt: 1 gallon plastic containers * Bituminous material for HMA: QA sample every 200,000 gal. and no sample if project contains < 250 tons of HMA * Bituminous material for ST: 1 per 50,000 gal and no sample if project contains < 6000 gal * Cutbacks or emulsions for prime, curing or erosion control: 1 per 30,000 gal and no sample if project contains < 6000 gal * If emulsion stored during freezing temperature, it should be resampled and sent to the central laboratory **Performance Graded Asphalt Binders** * AASHTO T 40 and ASTM D 3665 * MDOT obtain **field samples** at a minimum frequency of one sample per 200,000 gal * If split samples are taken then 3 samples should be taken (one for referee)
	Testing Information	* **Bituminous Material: Specification Compliance Testing**: At least 1/week week **Performance Graded Asphalt Binders**

Table C2: Mississippi DOT

		* **Specification Compliance Testing:** Complete testing according to AASHTO M 320 and procedure for verification of PGAB as described in AASHTO R 29 must be followed * **Specification Compliance Testing: (a) Initial testing:** For at least 3 consecutive lots **(b) Reduced frequency of testing:** If the individual test results for every sample of the initial testing is within specifications by at least the tolerance of the test method for each of the required test methods then testing will be done for every other lot
		* **Quality Control Testing:** At least 2 AASHTO M 320 tests (for high and low temp. properties); Non M 320 can be used if approved;
	Reporting	**Performance Graded Asphalt Binders** * Quarterly summary reports for all QC and specification compliance tests
QA	Testing	**Performance Graded Asphalt Binders** * Test split samples at a minimum frequency of one per 90 days (if split sample results and supplier results are not within the test tolerance then need to investigate) * At HMA plant, temp-vis curves are developed from sample (1 per 100,000 gal) and if viscosity range is varied more than 10^0F at compaction or mixing temperatures then a sample will be sent to the material division to determine compliance to specifications
Round Robin		
Laboratory Requirement		**Performance Graded Asphalt Binders** * Need to be approved by Material Division of MDOT (basis: participation of AMRL or MDOT proficiency samples program) * Certifying technicians should participate in a bituminous technician certification program
Treatment of fail tests		**Bituminous Material** * If stock sample fails: cease the shipment; if stock check sample is obtained the material will be rejected and no further testing; deficiency need to be corrected and resampled and re tested * No shipment of material (same type and grade) after the failure of the stock sample and the stock check sample until the new material is sampled, tested and accepted by the central laboratory **Performance Graded Asphalt Binders** * If stock sample fails: cease the shipment; if stock check sample is obtained the material will be rejected and no further testing; deficiency need to be corrected and resampled and re tested * If field samples fails to comply with specification then HMA producer and supplier will be notified and suspend the operations; investigate the cause for the problem. If any asphalt containing non compliance binder is placed then it will be accepted to department's standard specification section 105.03

Table C2: Mississippi DOT

Remarks		* All bituminous materials should be shipped under department certification program * should certify by a letter stating the acceptance of the provisions in the Inspection, Testing and Certification manual and to follow applicable AASHTO and MT methods for sampling and testing
		* **Case1- Bituminous material delivered directly from a pretested storage tank to a project site or maintenance work order**: Certified refinery test reports must be submitted to the state material engineer; Statement indicating the compliance, for each shipment additional certificate (certificate A); each truck shall accompany certificate A
		* **Case 2 - Bituminous material delivered directly from a pretested storage tank to a commercial asphalt plant which produces for department work:** certified refinery test report with an temperature-viscosity curve and certificate A to the authorized personnel * **Case 3 - Bituminous material delivered directly from a pretested storage tank to an intermediate terminal for trans-shipment to projects, work orders or asphalt plant:** certified test reports, temperature-viscosity curve and certificate A to the authorized personnel * **Case 4 - Bituminous material delivered from an intermediate terminal to a project or work order:** certificate B and a statement describing the material * **Case 5 - Bituminous material delivered from an intermediate terminal to a commercial asphalt plant which produces for the department work:** certificate B and the temperature-viscosity curve * At HMA plant, temp-vis curve of the asphalt shipped will be compared to the temp-vis curve receive with the mix-design. If change by a factor of 2 or more then the design need to be changed * **HMA producer responsibilities:** Shall insure that all PGAB conforms to the "inspection, testing and certification manual", purchased from and approved supplier, not contaminated, provide vehicle inspection reports if own vehicles used

Table C3: Arkansas DOT

QC	QC Plan	* should provide a QC plan for each facility * should include the types and frequency of QC testing * Any changes to the plan must be approved by the department before it is incorporated
	Sampling	* As defined in the department approved QC plan
	Testing Information	
	Reporting	* Copy of all QC tests should be forwarded to material division immediately * Monthly summary report (tabular format preferably in a digital spreadsheet)
QA	Testing	
Round Robin		* AMRL
Laboratory Requirement		* Must have a qualified laboratory or employ a qualified laboratory * Must provide laboratory's accreditation program (AASHTO accreditation, participation on AMRL reference sample program, AMRL inspections or any other * Should be listed in the CTTP[1] website
Treatment of fail tests		* Notify the department and the purchases immediately * Provide steps taken to determine the extent of the problem * Provide actions taken to remedy the problem
Remarks		* Acceptance of material is based on supplier's certification & the certification statement must be included * Supplier is defined as the final entity who has the responsibility for the final asphalt material properties * A copy of the bill of lading for each shipment need to be sent with the driver to the department field personnel * Specific gravity at 60^0F is to be shown in the bill of lading in addition to normal information

1: Center for Training Transportation Professionals (at Mack Blackwell Rural Transportation Study Center of the University of Arkansas at Fayetteville

Table C4: New Mexico DOT

QC	QC Plan	* Must submit Complete QC Plan within 4 week prior to the first shipment of binder * Should include facility type (refinery, terminal, in-line), facility location, contact details of persons responsible for QC * Should include QC tests and testing frequency, name and location of laboratories * Shall describe method and frequency of initial, QC and specification compliance testing * Need a statement stating that reports of QC and Specification compliance tests will be prepared and will be submitted to the QC engineer on request * Should include a procedure to check vehicle to prevent contamination and maintain records
	Sampling	* AASHTO T 40 and ASTM D 3665 * Split samples are from the same locations as QC samples * Approx. bi-weekly split samples are sent to QC engineer on request for specification compliance. tests **Project Level:** * Contractor perform all QA sampling using TTCP certified sampling personnel * As directed by the project manager from the sampling valve on the transport truck * The sample identification form is signed by both contractor and project manager * Minimum frequency is one sample per 500 tons and 3 separate 1 quart samples
	Testing Information	**Specification Compliance Testing:** * **Initial testing:** Accordance with M320 and at least 3 consecutive production lots (lot: fixed batch of material or specified quantity); * At least twice/month and if the quantity is less than 500 tons then once/month * If Initial testing meets specific criteria (DSR, $G^*/\sin(\delta) \geq 1.10$ kPa etc.) then frequency can be reduced to every other lot if approved by the state material engineer (frequency can be further reduced if results continue to meet above specific criteria and if approval) **Quality Control Testing:** * At least two AASHTO M 320 tests (for high and low temperature properties) **Project Level:** Complete Specification Compliance Testing done by the independent laboratory (AASHTO accredited) if a result is in question

Table C4: New Mexico DOT

	Reporting	* A copy of AASHTO inspection report within 4 weeks after received by the supplier & Copies of AMRL proficiency sample reports within 2 weeks after their results is published. If not they will lose the certification * Must submit daily records of all tests monthly (before 10th of each month) * "Statement of Typical Test Results" for each PG must be submitted prior to the first shipment of each PG material **Project Level:** * Results will be furnished to Project manager w/i 5 working days by State Material Bureau
QA	Testing	* May take PGAB samples for department compliance verification testing w/o prior notice * Approximately bi-weekly specification compliance testing
		* State Material Bureau may test completely or partially
Round Robin		* AMRL
Laboratory Requirement		* Testing should be done by AASHTO accredited laboratory * If State Material Engineer can be convinced, above lab requirement can be waived for 1 year * Should participate in AMRL proficiency sample testing program
Treatment of fail tests		Immediately notify the QC engineer and respective project manager * Identify the PGAB in question * Cease shipment until material complies with the specifications and verifies by the QC engineer Notify the QC engineer and relevant other personnel before resume the shipment * Implement any agreed procedures to dispose the material * Provide complete AASHTO M 320 specification compliance testing for the first three PGAB lots after resuming the work **Project Level:** * Immediate verification testing will be done and still not satisfied then the entire lot will be subjected to price adjustment
Remarks		* It states that no PGAB will be produced or blended to specification at the HMA plant * **Project Level:** * Contractor can appeal (within 14 days) for the price adjustment

TTCP: The department's Technician Training and Certification Program

Table C5: Louisiana DOT

QC	QC Plan	
	Sampling	* Sampling should be done according to DOTD S201 * Each transport is sampled according to Department's Material Sampling Manual Material in plant storage is resampled if storage exceeds 72 hours
	Testing Information	
	Reporting	
QA	Testing	
Round Robin		
Laboratory Requirement		
Treatment of fail tests		
Remarks		* QPL is maintained as part of QA program (Qualification procedure: submit a Qualified Product Evaluation form, Product data sheet, Plant inspection, submit notarized certificate of analyzing reports & temp - vis curve, submit samples etc * A certificate of asphalt delivery is accompanied each shipment of asphaltic materials * A temperature versus viscosity curve shall be furnished with recommended mixing and compaction temperatures

Table C6: Oklahoma DOT

QC	QC Plan	
	Sampling	* Frequency for PG binders is 1 per 100,000 gallons * For bituminous surface treatment - 1 per 20,000 gallons * No field samples for tack coat or prime coat is required
	Testing Information	
	Reporting	* Report on averages, high & low values to be reported monthly
QA	Testing	
Round Robin		
Laboratory Requirement		* **To do acceptance & QC/QA tests on ODOT projects:** Qualified Laboratory Status by either "Qualified Laboratory Agreement" and approved Lab's Quality Manual OR through AAP (in any method technicians need to be certified by the OHCMTCB)
Treatment of fail tests		
Remarks		* Qualified Laboratory Agreement: Quality system must satisfy some sections of AASHTO R 18; participate in ODOT, AMRL/CCRL proficiency sample programs etc. * Requirements for Handling & Storage of Bituminous Materials are stated * Bituminous sources should be approved & material is to be manufactured and certified under a **Quality Control Agreement** * Certification for each shipment stating bituminous is manufactured under this agreement and tests are compliance with specifications etc.

AAP - AASHTO Accreditation Program
OHCMTCB - Oklahoma Highway Construction Materials Technician Certification Board

Table C7: Combined State Binder Group

QC	QC Plan	* (Do not talk about QC plan) * Shall maintain an acceptable quality control program (info. regarding control tests, testing frequencies, lab facilities, programs for maintaining test and shipment records etc.)
	Sampling	* Daily Requirement: One sample from the tank or blender representing each grade * Bi-Weekly Requirement: One sample from the tank or blender representing each grade Verification Field Samples: * IA - 1 per 45 tons (I.M. 323); MI - Daily Certification Verification samples; MN - first load & 1 per 1000 tons thereafter (T40); NE - 1 per 3750 tons (HMA) and minimum of 3 per project (NDR T40); ND - 1 per 250 tons; WI - 1 per 900 tons (T40)
	Testing Information	* Prior to start of shipping season, adequate testing to be performed. Before (or at the start) of shipping, bi-weekly testing should be completed for each grade * Daily Requirement: Penetration, any viscosity measurement or DSR (DSR is required if material is modified) * Bi-Weekly Requirement: Full suite of tests {Solubility (T44), Flash point (T48), Viscosity (T316), DSR for OB, RTFO, PAV (T315), Mass change (T240), Creep stiffness (T313), DTT (T314), ER for modified binders}
	Reporting	* Daily QC results to the department weekly basis * Bi-Weekly test results to the department when completed
QA	Testing	* Facility inspection in spring (include reviewing sampling, testing procedures, QC etc.)
Round Robin		* Quarterly
Laboratory Requirement		* Shall have laboratory facilities and qualified personnel to perform all specification tests

Table C7: Combined State Binder Group

Treatment of fail tests			If the department identified asphalt doesn't meet the specification then **Refinery/Terminal Samples**
		*	Department notify the supplier, next jointly determine the quantity and location of the material in question, if required department retest, if material is in transit then district/region will be notified, next increase the sampling frequency, department will investigate and review all pertinent test data, department prepares a report stating how to solve the problem, supplier should take corrective action and submit an explanation to the department, **Verification Field Samples**
		*	The department will notify the district/region and identify the quantity and location and necessary steps for retesting; supplier will notify the findings of loading, handling & delivery to the department; sampling frequency increase at site; department will investigate and review all pertinent test data, department prepares a report stating how to resolve the problem; supplier to implement corrective measures
Remarks		*	Certification given to a supplier by one DOT will be accepted by the other DOTs
		*	Acceptance of asphalt binder is based on a "Certification Method"
		*	If not certified, pretesting required before use, increasing sampling and testing and the increase sampling and testing cost to the supplier
		*	Test records must be available for 5 years after use on a project
		*	Supplier shall inspect each transport tank prior to loading (to avoid contamination)
		*	Departments records will be used to provide quality history of suppliers
		*	**Loss of Certification** (if 3 consecutive non-compliance job site samples, failure to participate in 4 round robins in one year, failure to respond to outliers within given time frame, lack of maintenance of required records, improper documentation of shipments, failure to maintain an acceptable QC program)
		*	To obtain the **recertification** 3 month period is allowed.(during this 3 month period asphalt may be accepted but require pre-testing and approval before use, increase the sampling and testing frequency at the job site and the department cost will be paid by the supplier). If recertification is not granted then material will not be accepted from that supplier after the 3 month period
		*	Statement certifying that material complies with CSBG requirement and the shipping ticket (indicating supplier, grade, additives, etc) have to be accompanied by each truck
		*	Material shipped to and unloaded into a secondary storage and subsequently shipped to state work will not be accepted if the secondary facility is not certified. Also modification at HMA plant will not be accepted unless plant is certified as a supplier

Appendix D
0-4681

Grade	Test (Specifications)	Supplier	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality Ryan-Joiner		SPC Chart (Type & No. of signals)																Proc. Cap. (% outside Spec.)	
										X-bar Chart								R Chart									
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Original	Without Outliers	Original				Without Outliers				Original				Without Outliers				Original	Without Outliers
										I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		
PG64-22	DSR-OB	0801	98	0%				p>0.1		2	1							1								0.00%	
	(LSL=1)	1201	75	0%				p>0.1		3	1															0.02%	
		1402	29	0%				p>0.1																		0.02%	
		0101	40	0%	1	2	3.416 2.045	p<0.01	p>0.1	1				0												0.43%	0.30%
		0601	34	0%				p>0.1																		0.11%	
		0201	33	0%				p>0.1																		0.11%	
		0703	33	0%				p=0.048			1															0.00%	
	BBR--S (USL=300)	0101	40	0%				p>0.1		1																0.00%	
	BBR--m (LSL=0.3)	0101	40	0%				p=0.055		1																0.14%	
PG70-22	DSR-OB	1301	39	0%	1	1	2.371	p<0.01	p>0.1									1				0				2.60%	1.49%
	(LSL=1)	1401	28	0%				p>0.1		1		1						1								0.03%	
	Elastic Recovery	1301	34	0%				p>0.1		3	1															0.00%	
	(LSL=30)	1401	26	0%				p=0.020																		5.28%	
PG76-22	DSR-OB	0802	93	0%	1	2	4.094 2.393	p<0.01	p>0.1	1				0				1				0				5.49%	2.59%
	(LSL=1)	0703	36	0%				p>0.1			1															0.08%	
		1401	33	0%				p>0.1																		0.90%	
	Elastic Recovery	0802	63	1.59%	1	1	**41**	p<0.01	p>0.1					1				1				0				0.10%	0.00%
	(LSL=50)	0703	32	0%				p<0.01			3															0.00%	
		1401	33	6.06%	1	2	**35.92 40**	p<0.01	p>0.1					1				1				0				0.21%	0.00%
PG76-22S	DSR-OB	1201	93	1.08%	2	2	**0.358** 2.297	p<0.01	p>0.1									1				1				0.54%	0.13%
	(LSL=1)	1102	56	0%				p>0.1		1	1															0.00%	
	Elastic Recovery	1201	80	1.25%	1	2	**37** 58	p<0.01	p>0.1	2				1				1				0				0.00%	0.00%
	(LSL=50)	1102	41	0%				p=0.043																		0.00%	
	BBR--S (USL=300)	0101	34	0%				p>0.1																		0.09%	
	BBR--m (LSL=0.3)	0101	34	0%				p>0.1																		13.61%	
AC-10	Penetration	0101	44	6.82%				p<0.01																		21.96%	
	(LSL=85)	1301	35	0%	1	1	148	p<0.01	p>0.1	1				0				1				0				4.11%	2.44%
		0501	34	0%				p>0.1		2	2	1														0.06%	
		1302	34	2.94%				p>0.1																		15.62%	
	Absolute Viscosity	0101	43	18.60%	1	1	**2106.27**	p<0.01	p>0.1					1				1				0				38.98%	24.19%
	(LSL=800 USL=1200)	1301	35	0%				p>0.1		3								1								0.00%	
		0501	34	0%				p>0.1		3								1								0.00%	
		1302	34	2.94%				p>0.1																		6.84%	

Grade	Test	Supplier	Sample	Raw Data	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																Proc. Cap.	
	(Specifications)		Size (N)	% outside	Original	Final	Testing Results	Ryan-Joiner		X-bar Chart								R Chart								(% outside Spec.)	
				Spec.	Number	Number	(Outside Spec.	Original	Without	Original				Without Outliers				Original				Without Outliers				Original	Without
							In Bold)		Outliers	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		Outliers
AC-15-5TR	Penetration	1101	67	2.99%	2	4	**44** **50** 77 79	p<0.01	p>0.1																	5.95%	0.05%
	(LSL=75 USL=125)	0101	39	0%				p=0.038																		10.02%	
		0501	31	0%				p>0.1																		0.38%	
		1401	21	0%				p=0.05																		0.58%	
	Absolute Viscosity	1101	67	0%	3	7	30868.31 25676.42 25081.91 21234.4 13676.07 12476.51 11469.44	p<0.01	p<0.01									1				0				16.39%	4.55%
	(LSL=1500)	0101	39	2.56%	1	3	12660.42 10047.71 7413.87	p<0.01	p>0.1																	16.25%	8.96%
		0501	31	0%	1	1	11423.9	p<0.01	p=0.089									1				0				12.82%	10.09%
		1401	21	0%				p<0.01																		17.09%	
AC-15P	Penetration	0501	34	0%				p>0.1		1																2.45%	
	(LSL=100 USL=150)	1401	27	0%				p=0.031		1																13.56%	
		0703	23	0%				p>0.1																		0.21%	
		0101	17	11.76%				p=0.05																		14.39%	
	Absolute Viscosity	0501	33	3.03%	1	3	118200 23853.17 21105	p<0.01	p<0.01	1				2	1			1				1				18.52%	3.05%
	(LSL=1500)	1401	27	0%	1	2	4788.13 4416.3	p<0.01	p>0.1																	2.52%	0.08%
		0703	23	0%	1	1	45765	p<0.01	p=0.037	1				1				1				0				35.79%	4.87%
		0101	17	0%				p=0.07																		0.67%	
AC-5	Penetration	0101	41	9.76%				p=0.086			2	1														12.59%	
	(LSL=135)	0501	35	0%	1	1	282	p<0.01	p<0.01	1	1			1	1											0.39%	0.39%
		1301	35	0%				p>0.1																		2.12%	
		0703	34	0%				p>0.1																		0.15%	
		1302	34	2.94%				p>0.1				1														10.47%	
	Absolute Viscosity	0101	41	21.95%				p=0.088		1																23.33%	
	(LSL=400 USL=600)	0501	35	2.86%	1	1	**354.69**	p=0.019	p>0.1																	1.54%	1.54%
		1301	35	5.71%				p>0.1			1															3.30%	
		0703	34	0%				p>0.1		3	1															0.11%	
		1302	34	5.88%				p>0.1																		7.60%	
AC-5L2%	Penetration	0101	41	0%				p=0.052		1	1															2.85%	
	(LSL=120)	1401	21	0%				p>0.1																		8.78%	
	Absolute Viscosity	0101	39	0%				p=0.061																		0.65%	
	(LSL=700)	1401	21	0%				p>0.1																		2.97%	

Grade	Test	Supplier	Sample	Raw Data	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																Proc. Cap.	
	(Specifications)		Size (N)	% outside	Original	Final	Testing Results	Ryan-Joiner		X-bar Chart								R Chart								(% outside Spec.)	
				Spec.	Number	Number	(Outside Spec.	Original	Without	Original				Without Outliers				Original				Without Outliers				Original	Without
							In Bold)		Outliers	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		Outliers
CRS-1P	Demulsibility	0401	37	29.73%				p<0.01																		21.26%	
	(LSL=60)	0702	33	12.12%				p=0.024																		16.90%	
	Saybolt Viscosity	0401	37	24.32%				p<0.01																		34.56%	
	(LSL=50 USL=150)	0702	33	12.12%	1	3	**799.9 265.1 248.5**	p<0.01	p>0.1									1				0				27.91%	15.51%
	Penetration	0401	37	35.14%				p=0.044																		58.49%	
	(LSL=225 USL=300)	0702	33	3.03%	1	1	**97**	p<0.01	p>0.1									1				0				38.46%	16.33%
	Distillation	0401	37	0%	1	1	86.85	p<0.01	p>0.1									1				0				2.39%	0.00%
	(LSL=65)	0702	33	0%				p<0.01																		5.54%	
CRS-2	Demulsibility	0702	43	16.28%	1	1	39.28	p<0.01	p>0.1									1				0				17.89%	14.95%
	(LSL=70)	0402	41	4.88%				p=0.088		5																0.41%	
	Saybolt Viscosity	0702	44	15.91%				p<0.01		1																16.84%	
	(LSL=150 USL=400)	0402	41	9.76%	1	1	**806.4**	p<0.01	p=0.020																	16.45%	16.45%
	Penetration	0702	44	11.36%	1	1	**225**	p<0.01	p=0.043																	25.89%	25.89%
	(LSL=120 USL=160)	0402	42	2.38%	1	1	**305**	p<0.01	p<0.01	1				0				1				0				37.91%	9.38%
	Distillation	0702	44	0%				p>0.1																		0.02%	
	(LSL=65)	0402	42	2.38%				p=0.049																		1.87%	
CRS-2P	Demulsibility	0901	285	17.19%	4	4	**38.72 40.56 41.9 42.4**	p<0.01	p<0.01	2				2												21.58%	20.02%
	(LSL=70)	0402	91	8.79%	1	1	**46.81**	p=0.047	p>0.1																	11.85%	11.85%
		1001	45	17.78%				p>0.1																		3.01%	
	Saybolt Viscosity	0901	285	18.60%	7	11	**999 976 973 896 768 725.8 710 615.9 604.8 603.6 577.6**	p<0.01	p<0.01	1				0												29.79%	19.15%
	(LSL=150 USL=400)	0402	93	7.53%				p<0.01		1																20.78%	
		1001	45	6.67%	1	1	**509**	p<0.01	p<0.01																	16.52%	16.52%
	Penetration	0901	284	0%				p<0.01																		1.42%	
	(LSL=90 USL=150)	0402	94	1.06%	1	1	**153**	p>0.1	p>0.1																	0.01%	0.01%
		1001	45	2.22%	2	2	**188** 90	p<0.01	p>0.1																	0.52%	0.09%
	Distillation	0901	285	0.35%	5	17	**61.9** 65.42 65.65 80.19 76.36 66.87 67.14 67.18 67.18 67.28 67.33 67.62 67.63 67.75 68 68.51 68.51	p<0.01	p=0.031	1				1				1				1				0.00%	0.00%
	(LSL=65)	0402	94	0%				p>0.1																		0.00%	
		1001	45	0%	1	1	78.92	p<0.01	p=0.046	2				2												0.11%	0.00%

Grade	Test	Supplier	Sample	Raw Data	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																Proc. Cap.	
	(Specifications)		Size (N)	% outside	Original	Final	Testing Results	Ryan-Joiner		X-bar Chart								R Chart								(% outside Spec.)	
				Spec.	Number	Number	(Outside Spec.	Original	Without	Original				Without Outliers				Original				Without Outliers				Original	Without
							In Bold)		Outliers	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		Outliers
CSS-1H	Saybolt Viscosity	0402	102	2.94%	2	4	100 81.1 45 43	p<0.01	p=0.039	1				0				2				0				15.07%	6.42%
	(LSL=20 USL=100)	0702	30	0%	1	1	94.1	p<0.01	p=0.030			1				1		1				0				2.65%	1.01%
	Penetration	0402	102	0.98%	1	3	**149** 110 110	p<0.01	p<0.01									1				0				8.15%	8.95%
	(LSL=70 USL=110)	0702	30	0%				p>0.1																		6.32%	
	Distillation	0402	102	2.94%	2	2	**55.48** 67.05	p<0.01	p<0.01		1				1											5.58%	5.58%
	(LSL=60)	0702	30	0%				p>0.1																		0.00%	
SS-1	Saybolt Viscosity	0501	20	0%				p=0.084		3																0.00%	
	(LSL=20 USL=100)	0703	45	2.22%	1	1	**109.9**	p<0.01	p<0.01	1				0				1				0				3.05%	1.32%
	Penetration	0501	20	15%				p=0.096		2								1								24.68%	
	(LSL=120 USL=160)	0703	45	22.22%				p=0.074																		34.81%	
	Distillation	0501	20	0%				p>0.1																		0.00%	
	(LSL=60)	0703	45	0%				p=0.049		2	4															0.06%	
MC-30	Distillation	0101	61	0%	1	1	80.06	p<0.01	p>0.1																	0.00%	0.00%
	(Residue)	0802	60	0%	1	4	78.46 50.38 50.98 51.08	p<0.01	p>0.1	1	1			1	2	1		1				0				0.25%	0.00%
	(LSL=50)	0601	33	0%	1	1	52.45	p<0.01	p>0.1					2	1			1				1				0.00%	0.00%
	Distillation	0101	51	1.96%	1	2	**28.28** 25	p=0.021	p>0.1	2				3				1				1				2.65%	0.91%
	(% to 437 |F)	0802	58	0%				p<0.01		5	2	1						1								1.01%	
	(LSL=0 USL=25)	0601	32	0%				p>0.1		1																0.05%	
	Distillation	0101	61	3.28%				p=0.083		2																0.29%	
	(% to 500 |F)	0802	60	0%	1	1	52	p=0.049	p>0.1	1		1		1		1										0.83%	0.86%
	(LSL=40 USL=70)	0601	33	0%				p>0.1																		0.27%	
	Distillation	0101	61	0%				p<0.01																		1.75%	
	(% to 600 |F)	0802	60	0%				p=0.01		2	2							1								2.01%	
	(LSL=75 USL=93)	0601	33	0%				p=0.088																		3.93%	
	Kinematic Viscosity	0101	61	0%				p>0.1																		1.74%	
	(LSL=30 USL=60)	0802	60	0%				p=0.074			3	1														0.27%	
		0601	33	0%				p>0.1		2																0.02%	
	Penetration	0101	61	1.64%	1	7	141 174 189 189 196 201 204	p<0.01	p<0.01					1	1			1				2				23.19%	21.50%
	(LSL=120 USL=250)	0802	60	0%	1	1	144	p<0.01	p<0.01	1		1		1		1										15.10%	15.10%
		0601	33	0%				p=0.073																		19.11%	

Grade	Test	Supplier	Sample	Raw Data	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																Proc. Cap.	
	(Specifications)		Size (N)	% outside	Original	Final	Testing Results	Ryan-Joiner		X-bar Chart								R Chart								(% outside Spec.)	
				Spec.	Number	Number	(Outside Spec.	Original	Without	Original				Without Outliers				Original				Without Outliers				Original	Without
							In Bold)		Outliers	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		Outliers
RC-250	Distillation	0501	38	0%	1	1	88.84	p<0.01	p>0.1	1	2			4	2			1				0				0.00%	0.00%
	(Residue)	1302	34	0%				p>0.1																		0.00%	
	(LSL=70)	0301	31	0%				p=0.031																		0.27%	
		1401	31	0%				p>0.1																		0.08%	
	Distillation	0501	38	0%				p>0.1		3	1										1					0.01%	
	(% to 437 |F)	1302	34	0%	1	1	48	p<0.01	p>0.1									1				0				0.43%	0.04%
	(LSL=40 USL=75)	0301	30	13.33%				p>0.1		2																1.34%	
		1401	31	6.45%	1	2	**31.48** 45	p<0.01	p=0.024									1				0				23.24%	21.27%
	Distillation	0501	38	2.63%	1	1	**60**	p<0.01	p=0.013	2				1				1				1				0.04%	0.03%
	(% to 500 |F)	1302	34	0%	1	1	70.21	p>0.1	p>0.1																	0.12%	0.02%
	(LSL=65 USL=90)	0301	31	6.45%				p>0.1		1	2															1.57%	
		1401	31	0%	1	1	66.67	p<0.01	p<0.01									1				0				8.23%	5.52%
	Distillation	0501	38	0%				p>0.1																		0.14%	
	(% to 600 |F)	1302	34	0%				p=0.048																		0.00%	
	(LSL=85)	0301	31	0%				p>0.1																		0.14%	
		1401	31	0%				p=0.035																		0.02%	
	Kinematic Viscosity	0501	38	10.53%	1	1	**564.92**	p<0.01	p=0.063									1				0				23.90%	14.82%
	(LSL=250 USL=400)	1302	34	2.94%	1	1	**574.26**	p<0.01	p=0.089																	25.99%	12.03%
		0301	31	19.35%	1	1	**1558.74**	p<0.01	p=0.039	1				0				1				0				68.32%	39.25%
		1401	31	6.45%				p=0.065																		13.10%	
	Penetration	0501	38	0%	1	2	90 94	p<0.01	p=0.084	1				1				2				1				17.90%	17.48%
	(LSL=80 USL=120)	1302	34	0%				p>0.1		1																7.51%	
		0301	31	0%	1	1	80	p=0.035	p>0.1	1				1												16.05%	13.60%
		1401	31	0%				p>0.1																		6.71%	

Remarks:

Types of Signals:
I. 1 point > 3 Std. Dev. from center line
II. 2 out of 3 points > 2 Std. Dev. from center line (same side)
III. 4 out of 5 points > 1 Std. Dev. from center line (same side)
IV. 6 points in a row, all increasing or decreasing

Pink	Specification Chart:	≥ 5% outside specification
Cells &	Normality:	$p < 0.05$
Purple	Control Chart:	Signals
Cells	Process Capability:	≥ 5% outside specification

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																Proc. Cap. (% outside Spec.)	
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Ryan-Joiner		X-bar Chart								R Chart									
								Original	Without Outliers	Original				Without Outliers				Original				Without Outliers				Original	Without Outliers
										I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		
0101	PG64-22	DSR-OB	40	0%	1	2	3.416 2.045	p<0.01	p>0.1	1				0												0.43%	0.30%
		BBR (stiffness)	40	0%				p>0.1		1																0.00%	
		BBR (m-value)	40	0%				p=0.055		1																0.14%	
	PG76-22S	BBR (stiffness)	34	0%				p>0.1																		0.09%	
		BBR (m-value)	34	0%				p>0.1																		13.61%	
	AC-10	Penetration	44	6.82%				p<0.01																		21.96%	
		Absolute Viscosity	43	18.60%	1	1	**2106.27**	p<0.01	p>0.1					1				1				0				38.98%	24.19%
	AC15-5TR	Penetration	39	0%				p=0.038																		10.02%	
		Absolute Viscosity	39	2.56%	1	3	12660.42 10047.71 7413.87	p<0.01	p>0.1																	16.25%	8.96%
	AC-15P	Penetration	17	11.76%				p=0.05																		14.39%	
		Absolute Viscosity	17	0%				p=0.07																		0.67%	
	AC-5	Penetration	41	9.76%				p=0.086			2	1														12.59%	
		Absolute Viscosity	41	21.95%				p=0.088		1																23.33%	
	AC-5L2%	Penetration	41	0%				p=0.052		1	1															2.85%	
		Absolute Viscosity	39	0%				p=0.061																		0.65%	
	MC-30	Distillation (Residue)	61	0%	1	1	80.06	p<0.01	p>0.1																	0.00%	0.00%
		Distillation (% to 437 |F)	51	1.96%	1	2	**28.28** 25	p=0.021	p>0.1	2				3				1				1				2.65%	0.91%
		Distillation (% to 500 |F)	61	3.28%				p=0.083		2																0.29%	
		Distillation (% to 600 |F)	61	0%				p<0.01																		1.75%	
		Kinematic Viscosity	61	0%				p>0.1																		1.74%	
		Penetration	61	1.64%	1	7	141 174 189 189 196 201 204	p<0.01	p<0.01					1	1			1				2				23.19%	21.50%
0201	PG64-22	DSR-OB	33	0%				p>0.1																		0.11%	
0301	RC-250	Distillation (Residue)	31	0%				p=0.031																		0.27%	
		Distillation (% to 437 |F)	30	13.33%				p>0.1		2																1.34%	
		Distillation (% to 500 |F)	31	6.45%				p>0.1		1	2															1.57%	
		Distillation (% to 600 |F)	31	0%				p>0.1																		0.14%	
		Kinematic Viscosity	31	19.35%	1	1	**1558.74**	p<0.01	p=0.039	1				0				1				0				68.32%	39.25%
		Penetration	31	0%	1	1	80	p=0.035	p>0.1	1				1												16.05%	13.60%
0401	CRS-1P	Demulsibility	37	29.73%				p<0.01																		21.26%	
		Saybolt Viscosity	37	24.32%				p<0.01																		34.56%	
		Penetration	37	35.14%				p=0.044																		58.49%	
		Distillation	37	0%	1	1	86.85	p<0.01	p>0.1									1				0				2.39%	0.00%

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality Ryan-Joiner		SPC Chart (Type & No. of signals)																Proc. Cap. (% outside Spec.)	
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Original	Without Outliers	X-bar Chart								R Chart								Original	Without Outliers
										Original				Without Outliers				Original				Without Outliers					
										I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		
0402	CRS-2	Demulsibility	41	4.88%				p=0.088		5																0.41%	
		Saybolt Viscosity	41	9.76%	1	1	**806.4**	p<0.01	p=0.020																	16.45%	16.45%
		Penetration	42	2.38%	1	1	**305**	p<0.01	p<0.01	1				0				1				0				37.91%	9.38%
		Distillation	42	2.38%				p=0.049																		1.87%	
	CRS-2P	Demulsibility	91	8.79%	1	1	**46.81**	p=0.047	p>0.1																	11.85%	11.85%
		Saybolt Viscosity	93	7.53%				p<0.01		1																20.78%	
		Penetration	94	1.06%	1	1	**153**	p>0.1	p>0.1																	0.01%	0.01%
		Distillation	94	0%				p>0.1																		0.00%	
	CSS-1H	Saybolt Viscosity	102	2.94%	2	4	100 81.1 45 43	p<0.01	p=0.039	1				0				2				0				15.07%	6.42%
		Penetration	102	0.98%	1	3	**149** 110 110	p<0.01	p<0.01									1				0				8.15%	8.95%
		Distillation	102	2.94%	2	2	**55.48** 67.05	p<0.01	p<0.01		1				1											5.58%	5.58%
0501	AC-10	Penetration	34	0%				p>0.1		2	2	1														0.06%	
		Absolute Viscosity	34	0%				p>0.1		3								1								0.00%	
	AC15-5TR	Penetration	31	0%				p>0.1																		0.38%	
		Absolute Viscosity	31	0%	1	1	11423.9	p<0.01	p=0.089									1				0				12.82%	10.09%
	AC-15P	Penetration	34	0%				p>0.1		1																2.45%	
		Absolute Viscosity	33	3.03%	1	3	118200 23853.17 21105	p<0.01	p<0.01	1				2	1			1				1				18.52%	3.05%
	AC-5	Penetration	35	0%	1	1	282	p<0.01	p<0.01	1	1			1	1											0.39%	0.39%
		Absolute Viscosity	35	2.86%	1	1	**354.69**	p=0.019	p>0.1																	1.54%	1.54%
	SS-1	Saybolt Viscosity	20	0%				p=0.084		3																0.00%	
		Penetration	20	15%				p=0.096		2								1								24.68%	
		Distillation	20	0%				p>0.1																		0.00%	
	RC-250	Distillation (Residue)	38	0%	1	1	88.84	p<0.01	p>0.1	1	2			4	2			1				0				0.00%	0.00%
		Distillation (% to 437 |F)	38	0%				p>0.1		3	1										1					0.01%	
		Distillation (% to 500 |F)	38	2.63%	1	1	**60**	p<0.01	p=0.013	2				1				1				1				0.04%	0.03%
		Distillation (% to 600 |F)	38	0%				p>0.1																		0.14%	
		Kinematic Viscosity	38	10.53%	1	1	**564.92**	p<0.01	p=0.063									1				0				23.90%	14.82%
		Penetration	38	0%	1	2	90 94	p<0.01	p=0.084	1				1				2				1				17.90%	17.48%
0601	PG64-22	DSR-OB	34	0%				p>0.1																		0.11%	
	MC-30	Distillation (Residue)	33	0%	1	1	52.45	p<0.01	p>0.1					2	1			1				1				0.00%	0.00%
		Distillation (% to 437 |F)	32	0%				p>0.1		1																0.05%	
		Distillation (% to 500 |F)	33	0%				p>0.1																		0.27%	
		Distillation (% to 600 |F)	33	0%				p=0.088																		3.93%	
		Kinematic Viscosity	33	0%				p>0.1		2																0.02%	
		Penetration	33	0%				p=0.073																		19.11%	

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality Ryan-Joiner		SPC Chart (Type & No. of signals) X-bar Chart								R Chart								Proc. Cap. (% outside Spec.)	
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Original	Without Outliers	Original I	Original II	Original III	Original IV	Without Outliers I	Without Outliers II	Without Outliers III	Without Outliers IV	Original I	Original II	Original III	Original IV	Without Outliers I	Without Outliers II	Without Outliers III	Without Outliers IV	Original	Without Outliers
0702	**CRS-1P**	Demulsibility	33	12.12%				p=0.024																		16.90%	
		Saybolt Viscosity	33	12.12%	1	3	**799.9 265.1 248.5**	p<0.01	p>0.1									1				0				27.91%	15.51%
		Penetration	33	3.03%	1	1	**97**	p<0.01	p>0.1									1				0				38.46%	16.33%
		Distillation	33	0%				p<0.01																		5.54%	
	CRS-2	Demulsibility	43	16.28%	1	1	39.28	p<0.01	p>0.1									1				0				17.89%	14.95%
		Saybolt Viscosity	44	15.91%				p<0.01		1																16.84%	
		Penetration	44	11.36%	1	1	**225**	p<0.01	p=0.043																	25.89%	25.89%
		Distillation	44	0%				p>0.1																		0.02%	
	CSS-1H	Saybolt Viscosity	30	0%	1	1	94.1	p<0.01	p=0.030			1				1		1				0				2.65%	1.01%
		Penetration	30	0%				p>0.1																		6.32%	
		Distillation	30	0%				p>0.1																		0.00%	
0703	**PG64-22**	DSR-OB	33	0%				p=0.048			1															0.00%	
	PG76-22	DSR-OB	36	0%				p>0.1			1															0.08%	
		Elastic Recovery	32	0%				p<0.01			3															0.00%	
	AC-15P	Penetration	23	0%				p>0.1																		0.21%	
		Absolute Viscosity	23	0%	1	1	45765	p<0.01	p=0.037	1				1				1				0				35.79%	4.87%
	AC-5	Penetration	34	0%				p>0.1																		0.15%	
		Absolute Viscosity	34	0%				p>0.1		3	1															0.11%	
	SS-1	Saybolt Viscosity	45	2.22%	1	1	**109.9**	p<0.01	p<0.01	1				0				1				0				3.05%	1.32%
		Penetration	45	22.22%				p=0.074																		34.81%	
		Distillation	45	0%				p=0.049		2	4															0.06%	
0801	**PG64-22**	DSR-OB	98	0%				p>0.1		2	1							1								0.00%	
0802	**PG76-22**	DSR-OB	93	0%	1	2	4.094 2.393	p<0.01	p>0.1	1				0				1				0				5.49%	2.59%
		Elastic Recovery	63	1.59%	1	1	**41**	p<0.01	p>0.1					1				1				0				0.10%	0.00%
	MC-30	Distillation (Residue)	60	0%	1	4	78.46 50.38 50.98 51.08	p<0.01	p>0.1	1	1			1	2	1		1				0				0.25%	0.00%
		Distillation (% to 437 |F)	58	0%				p<0.01		5	2	1						1								1.01%	
		Distillation (% to 500 |F)	60	0%	1	1	52	p=0.049	p>0.1	1		1		1		1										0.83%	0.86%
		Distillation (% to 600 |F)	60	0%				p=0.01		2	2							1								2.01%	
		Kinematic Viscosity	60	0%				p=0.074			3	1														0.27%	
		Penetration	60	0%	1	1	144	p<0.01	p<0.01	1		1		1		1										15.10%	15.10%

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality Ryan-Joiner		SPC Chart (Type & No. of signals)																Proc. Cap. (% outside Spec.)	
										X-bar Chart								R Chart									
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Original	Without Outliers	Original				Without Outliers				Original				Without Outliers				Original	Without Outliers
										I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		
0901	CRS-2P	Demulsibility	285	17.19%	4	4	**38.72 40.56 41.9 42.4**	p<0.01	p<0.01	2				2												21.58%	20.02%
		Saybolt Viscosity	285	18.60%	7	11	**999 976 973 896 768 725.8 710 615.9 604.8 603.6 577.6**	p<0.01	p<0.01	1				0												29.79%	19.15%
		Penetration	284	0%				p<0.01																		1.42%	
		Distillation	285	0.35%	5	17	**61.9** 65.42 65.65 80.19 76.36 66.87 67.14 67.18 67.18 67.28 67.33 67.62 67.63 67.75 68 68.51 68.51	p<0.01	p=0.031	1				1				1				1				0.00%	0.00%
1001	CRS_2P	Demulsibility	45	17.78%				p>0.1																		3.01%	
		Saybolt Viscosity	45	6.67%	1	1	**509**	p<0.01	p<0.01																	16.52%	16.52%
		Penetration	45	2.22%	2	2	**188** 90	p<0.01	p>0.1																	0.52%	0.09%
		Distillation	45	0%	1	1	78.92	p<0.01	p=0.046	2				2												0.11%	0.00%
1101	AC-15-5TR	Penetration	67	2.99%	2	4	**44 50** 77 79	p<0.01	p>0.1																	5.95%	0.05%
		Absolute Viscosity	67	0%	3	7	30868.31 25676.42 25081.91 21234.4 13676.07 12476.51 11469.44	p<0.01	p<0.01									1				0				16.39%	4.55%
1102	PG76-22S	DSR-OB	56	0%				p>0.1		1	1															0.00%	
		Elastic Recovery	41	0%				p=0.043																		0.00%	
1201	PG64-22	DSR-OB	75	0%				p>0.1		3	1															0.02%	
	PG76-22S	DSR-OB	93	1.08%	2	2	**0.358** 2.297	p<0.01	p>0.1									1				1				0.54%	0.13%
		Elastic Recovery	80	1.25%	1	2	**37** 58	p<0.01	p>0.1	2				1				1				0				0.00%	0.00%
1301	PG70-22	DSR-OB	39	0%	1	1	2.371	p<0.01	p>0.1									1				0				2.60%	1.49%
		Elastic Recovery	34	0%				p>0.1		3	1															0.00%	
	AC-10	Penetration	35	0%	1	1	148	p<0.01	p>0.1	1				0				1				0				4.11%	2.44%
		Absolute Viscosity	35	0%				p>0.1		3								1								0.00%	
	AC-5	Penetration	35	0%				p>0.1																		2.12%	
		Absolute Viscosity	35	5.71%				p>0.1			1															3.30%	

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality Ryan-Joiner		SPC Chart (Type & No. of signals)																Proc. Cap. (% outside Spec.)	
										X-bar Chart								R Chart									
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Original	Without Outliers	Original				Without Outliers				Original				Without Outliers				Original	Without Outliers
										I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		
1302	AC-10	Penetration	34	2.94%				p>0.1																		15.62%	
		Absolute Viscosity	34	2.94%				p>0.1																		6.84%	
	AC-5	Penetration	34	2.94%				p>0.1				1														10.47%	
		Absolute Viscosity	34	5.88%				p>0.1																		7.60%	
	RC-250	Distillation (Residue)	34	0%				p>0.1																		0.00%	
		Distillation (% to 437 |F)	34	0%	1	1	48	p<0.01	p>0.1									1				0				0.43%	0.04%
		Distillation (% to 500 |F)	34	0%	1	1	70.21	p>0.1	p>0.1																	0.12%	0.02%
		Distillation (% to 600 |F)	34	0%				p=0.048																		0.00%	
		Kinematic Viscosity	34	2.94%	1	1	**574.26**	p<0.01	p=0.089																	25.99%	12.03%
		Penetration	34	0%				p>0.1		1																7.51%	
1401	PG70-22	DSR-OB	28	0%				p>0.1		1		1						1								0.03%	
		Elastic Recovery	26	0%				p=0.020																		5.28%	
	PG76-22	DSR-OB	33	0%				p>0.1																		0.90%	
		Elastic Recovery	33	6.06%	1	2	**35.92 40**	p<0.01	p>0.1					1				1				0				0.21%	0.00%
	AC-15-5TR	Penetration	21	0%				p=0.05																		0.58%	
		Absolute Viscosity	21	0%				p<0.01																		17.09%	
	AC-15P	Penetration	27	0%				p=0.031		1																13.56%	
		Absolute Viscosity	27	0%	1	2	4788.13 4416.3	p<0.01	p>0.1																	2.52%	0.08%
	AC-5L2%	Penetration	21	0%				p>0.1																		8.78%	
		Absolute Viscosity	21	0%				p>0.1																		2.97%	
	RC-250	Distillation (Residue)	31	0%				p>0.1																		0.08%	
		Distillation (% to 437 |F)	31	6.45%	1	2	**31.48** 45	p<0.01	p=0.024									1				0				23.24%	21.27%
		Distillation (% to 500 |F)	31	0%	1	1	66.67	p<0.01	p<0.01									1				0				8.23%	5.52%
		Distillation (% to 600 |F)	31	0%				p=0.035																		0.02%	
		Kinematic Viscosity	31	6.45%				p=0.065																		13.10%	
		Penetration	31	0%				p>0.1																		6.71%	
1402	PG64-22	DSR-OB	29	0%				p>0.1																		0.02%	

Remarks:

Types of Signals:	
I.	1 point > 3 Std. Dev. from center line
II.	2 out of 3 points > 2 Std. Dev. from center line (same side)
III.	4 out of 5 points > 1 Std. Dev. from center line (same side)
IV.	6 points in a row, all increasing or decreasing

Pink Cells & Purple Cells		
	Specification Chart:	≥ 5% outside specification
	Normality:	$p < 0.05$
	Control Chart:	Signals
	Process Capability:	≥ 5% outside specification

APPENDIX E

0-4681

Appendix E
QA Data Analysis

This sections presents the graphical results of statistical analysis for each supplier-grade-test combination of QA data. The results are presented by the order of suppliers, then grades within each supplier, and tests within each grade. Due to the privacy of suppliers, codes are used in place of the suppliers' name.

For each supplier-grade-test combination, the following results of QA data analyis are presented:

- Specification Chart
- Probability Plot for Normality
- Control Charts
- Process Capability Plot

Actual testing values are illustrated in specification charts with the specification limits. The abscissa of specification chart is the date in which the test was conducted. The ordinate is the value of the specific test. The specification charts are presented for both raw data and data without outliers.

The abscissa of probability plot for normality is the value of the specific test. The ordinate is the rescaled percentile for normal distribution. If the data are perfect normal, they lie on the straight line as shown in the plot for reference. The more deviation the sample points are away from the line, the less likely the population is normally distributed. A box in the lower-right corner of the probability plot contains quantitative values of sample mean, sample standard deviation, sample size (N), Ryan-Joiner test statistic, and p-value. The probability plots for normality are presented for both raw data and data without outliers.

Control Charts include $\overline{X}$ chart and R chart. UCL/LCL and CL ($\overline{\overline{X}}$ for $\overline{X}$ chart and $\overline{R}$ for R chart) are presented as dash lines. The abscissa of control charts is the subgroup number. The ordinate of the $\overline{X}$ chart is the average value of testing values in a subgroup, while that of the R chart is the range of the testing values in a subgroup. The control charts are presented with and without outliers.

Normal distribution is assumed for the process capability plot. The estimated percentage outside the specifications are presented graphically and quantitatively. The abscissa of the process capability plot is the value of the specific test. The ordinate is the frequency of occurrence. The two boxes on the left side show the basic process data and simple process capability indices. The two boxes on the bottom present the observed and expected percentage outside the specifications. The process capability plots are presented with and without outliers.

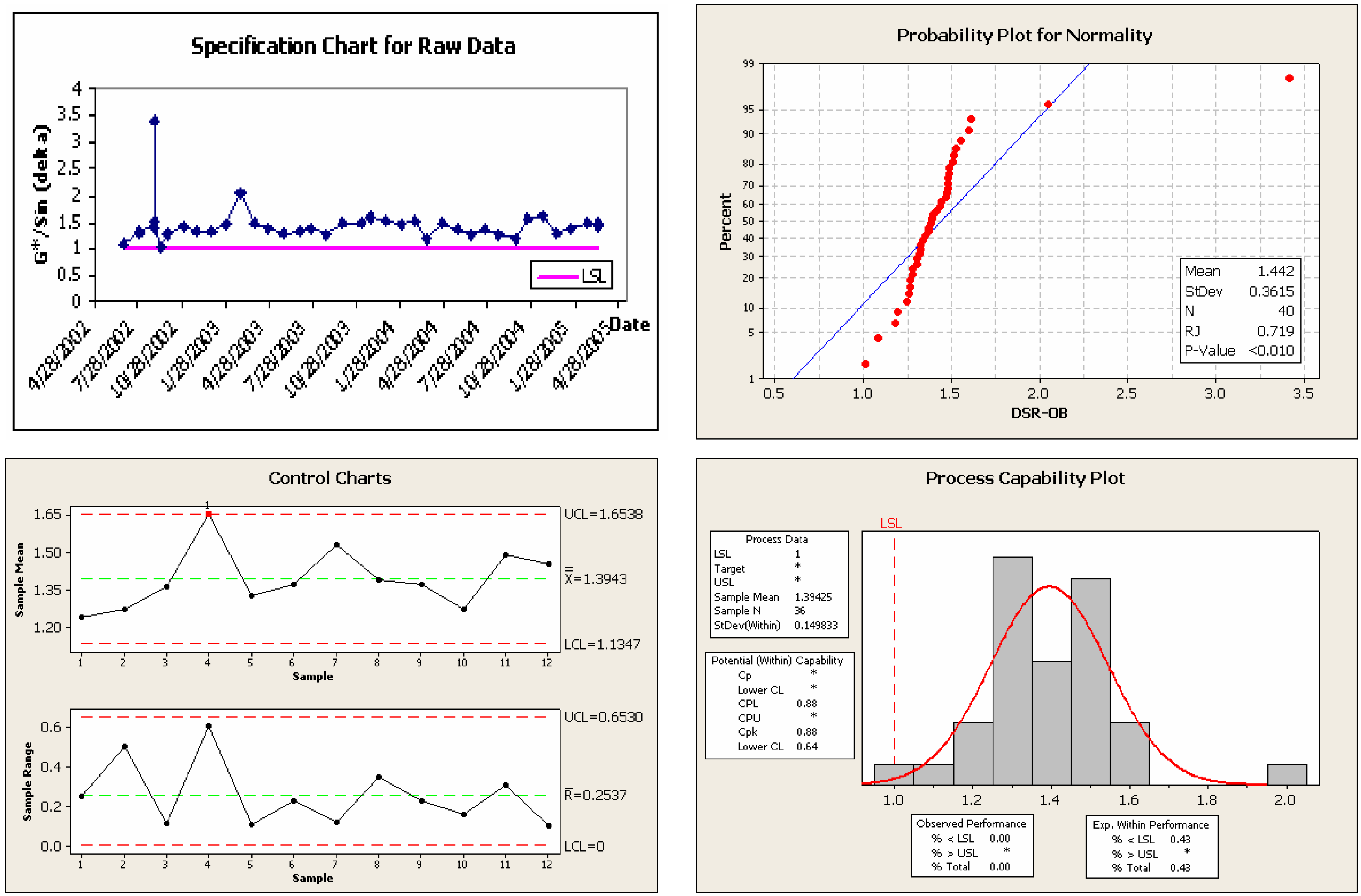


Figure E-1 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-22 Test: DSR-OB

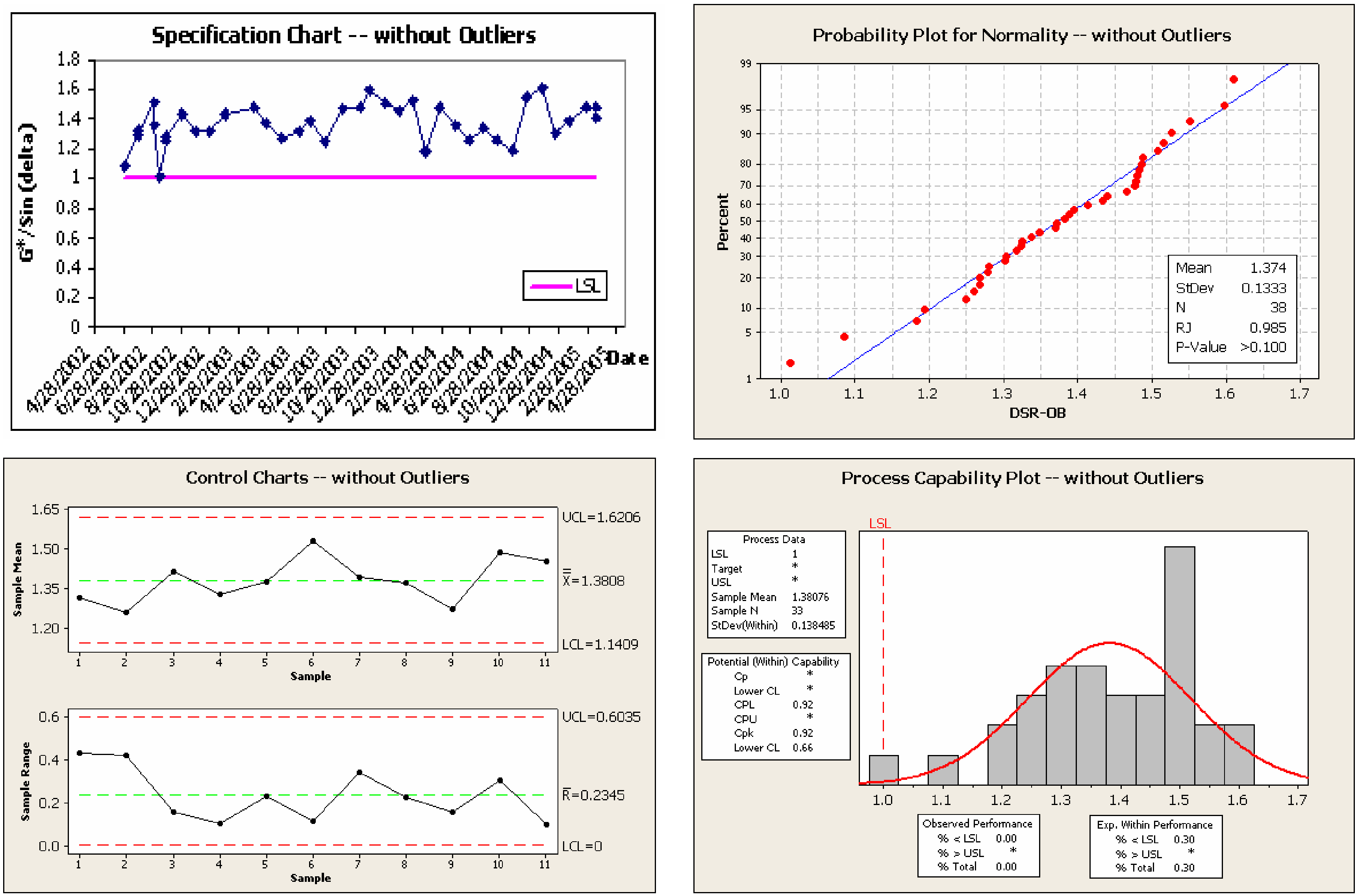


Figure E-2 Statistical Analysis Charts (without outliers) for Supplier: 0101 Grade: PG 64-22 Test: DSR-OB

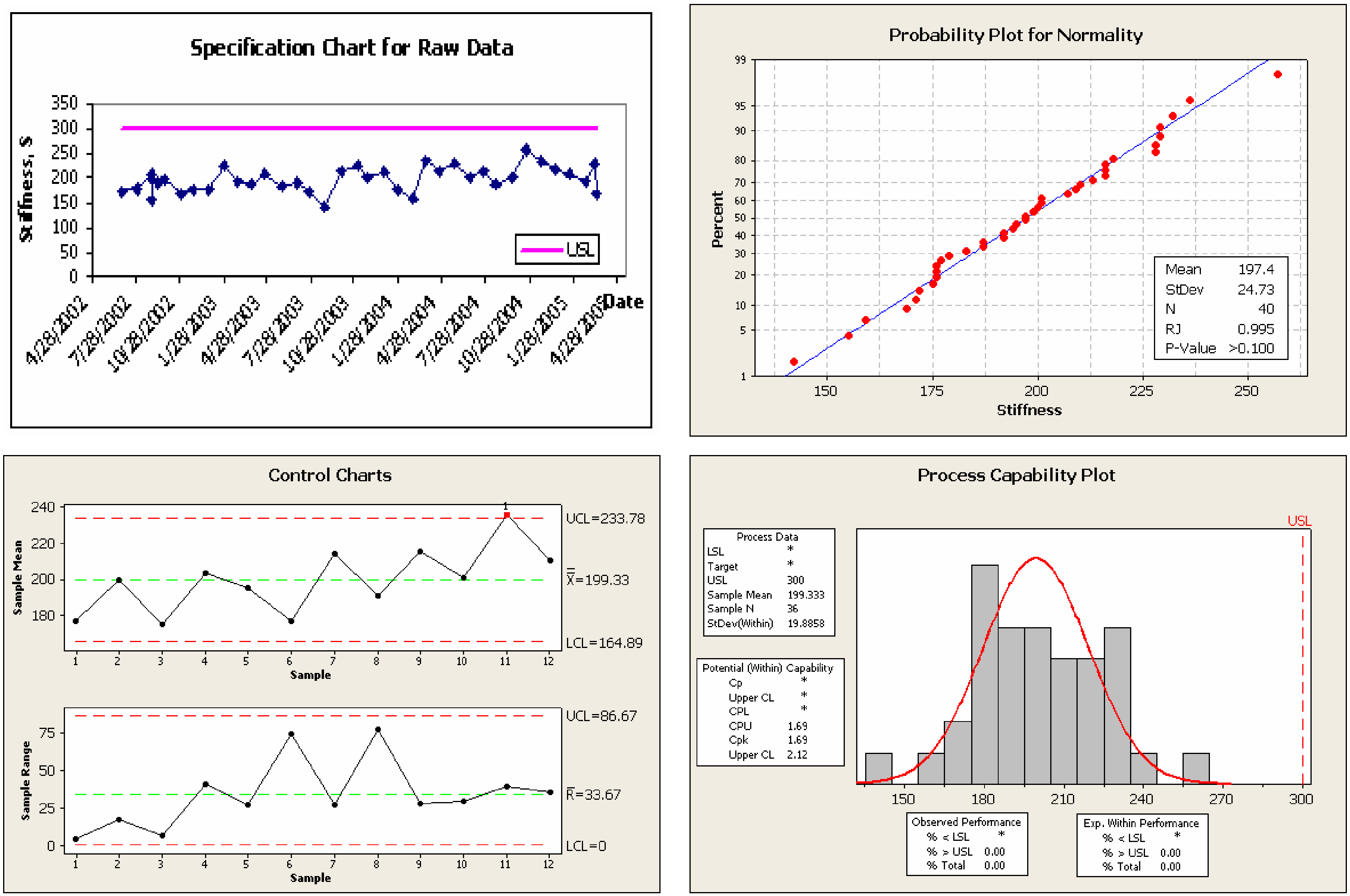


Figure E-3 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-22 Test: BBR-Stiffness

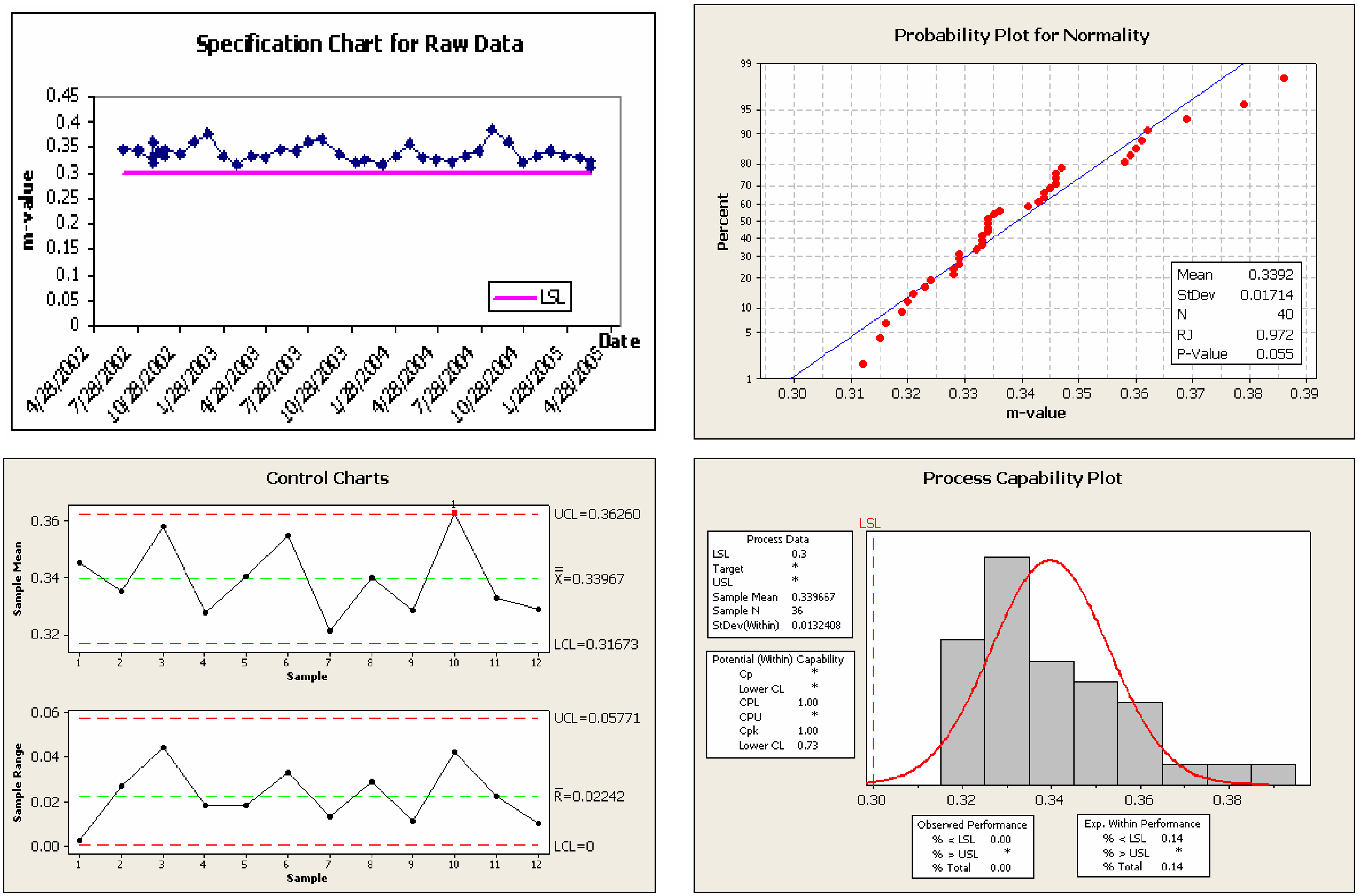


Figure E-4 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-22 Test: BBR-m-value

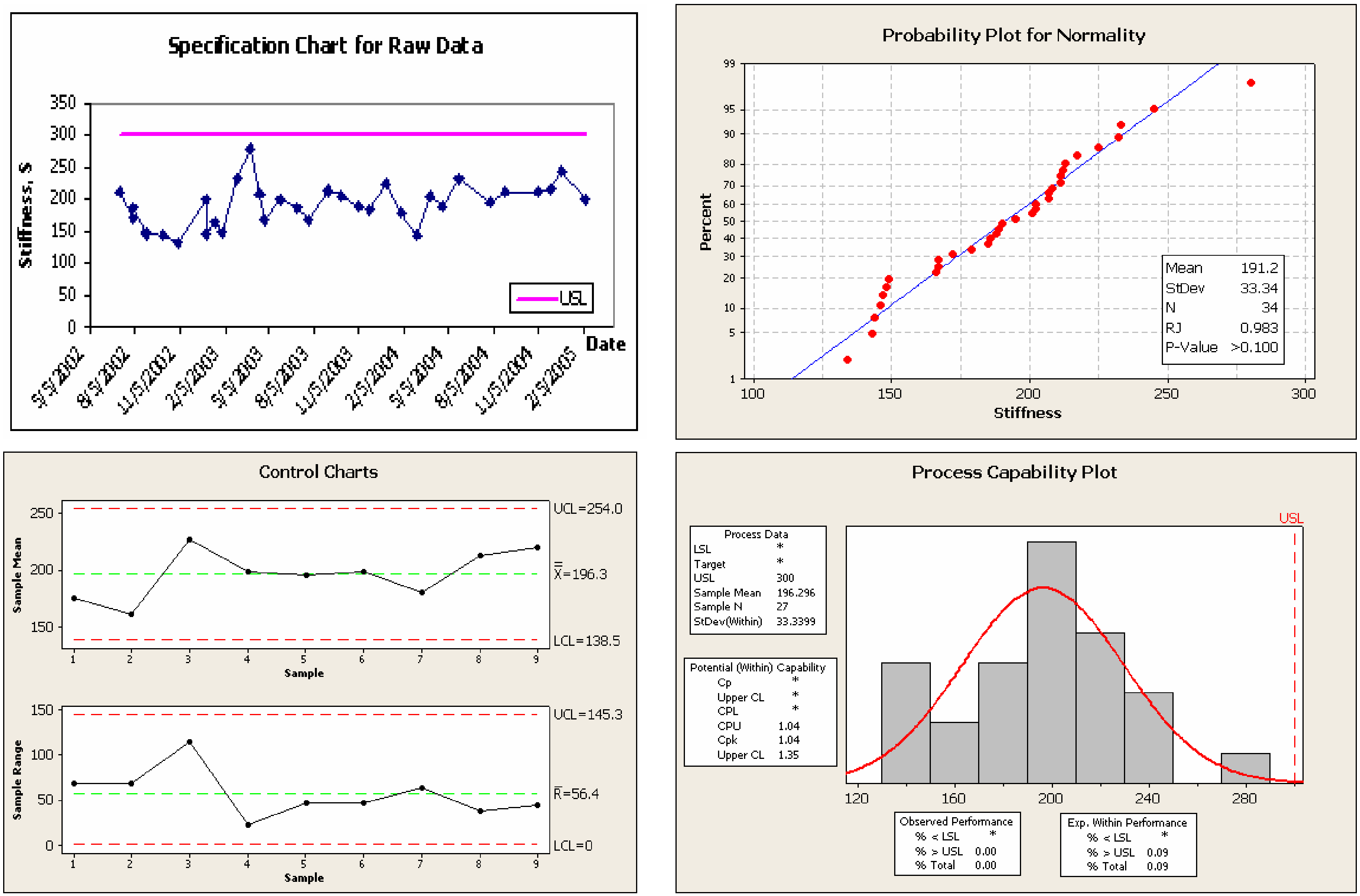


Figure E-5 Statistical Analysis Charts for Supplier: 0101 Grade: PG 76-22S Test: BBR-Stiffness

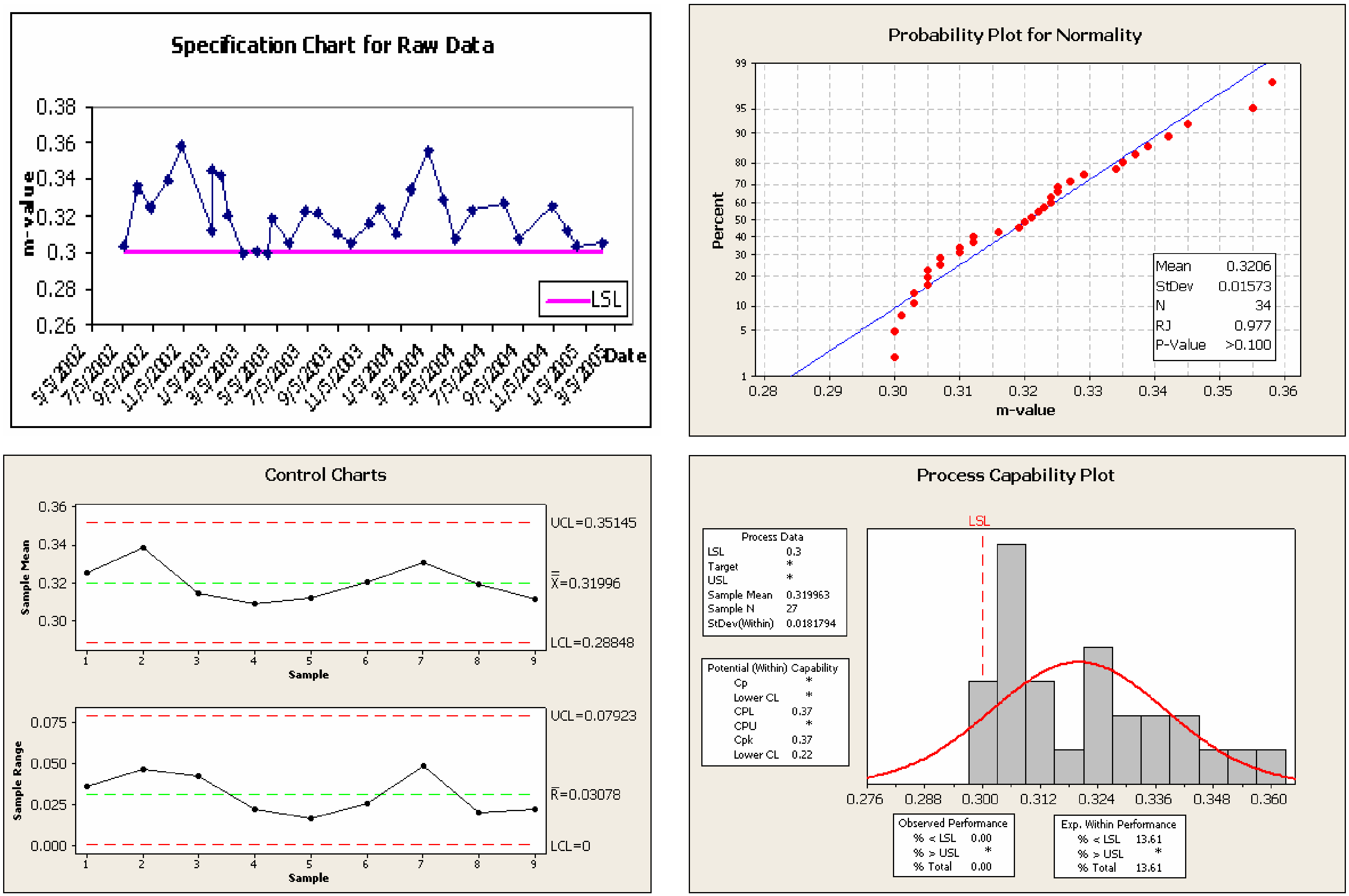
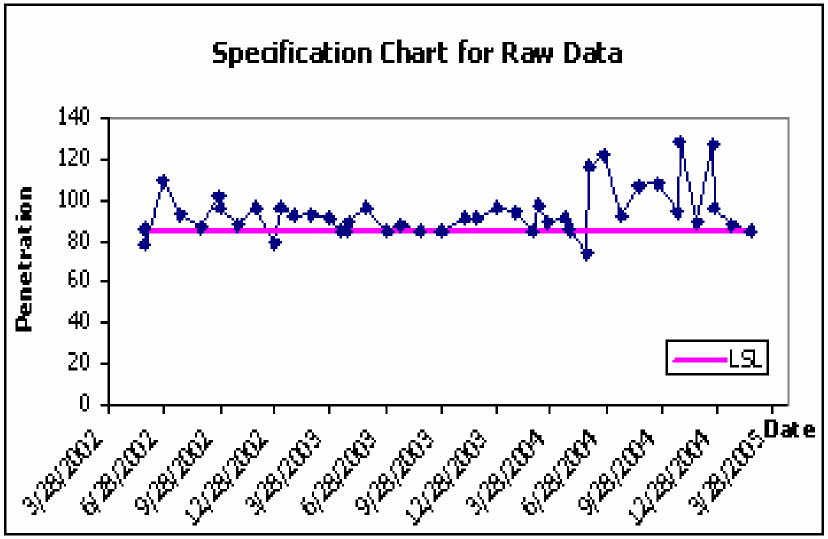
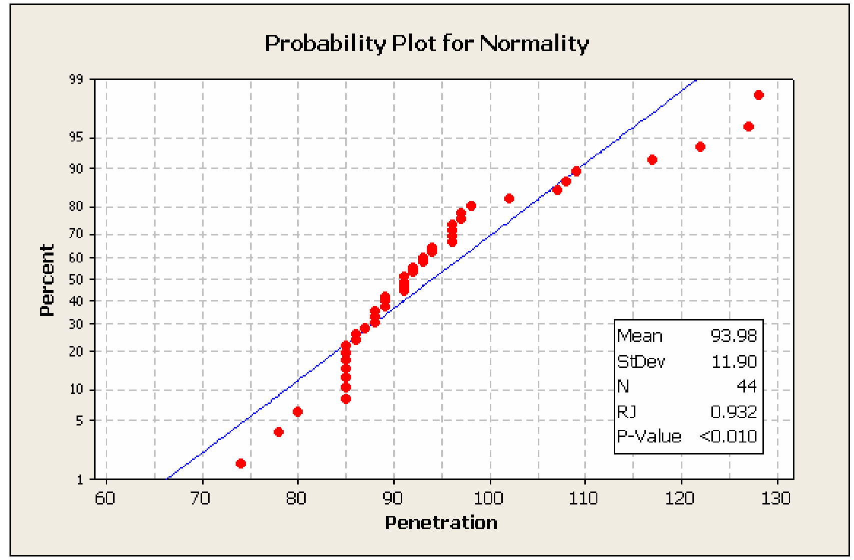
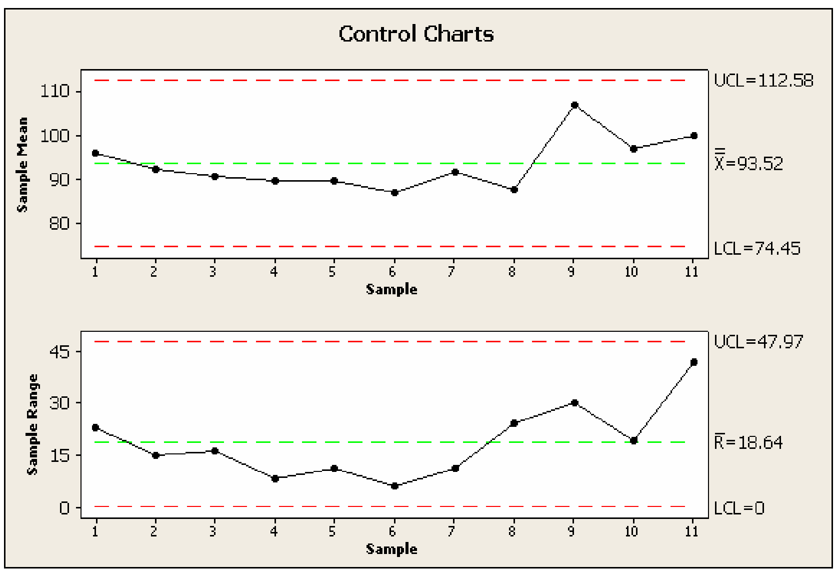


Figure E-6 Statistical Analysis Charts for Supplier: 0101 Grade: PG 76-22S Test: BBR-m-value







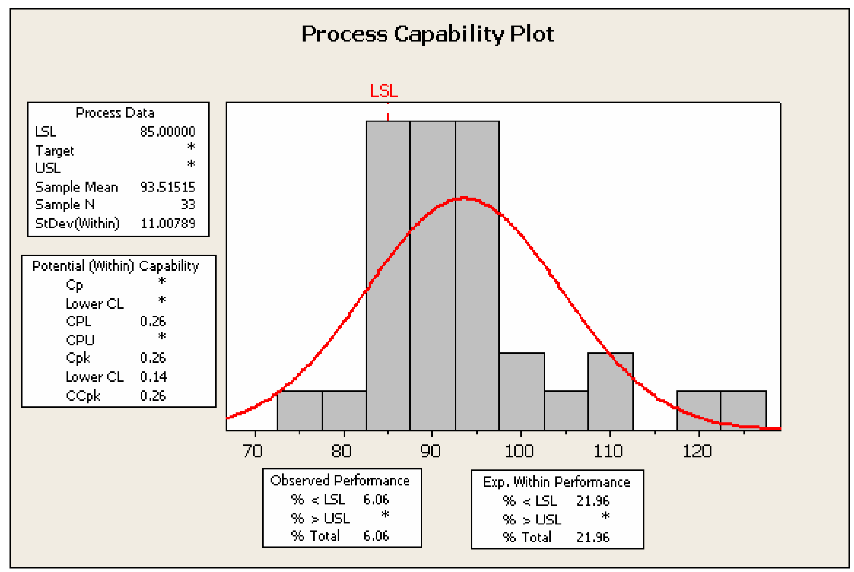


Figure E-7 Statistical Analysis Charts for Supplier: 0101 Grade: AC-10 Test: Penetration

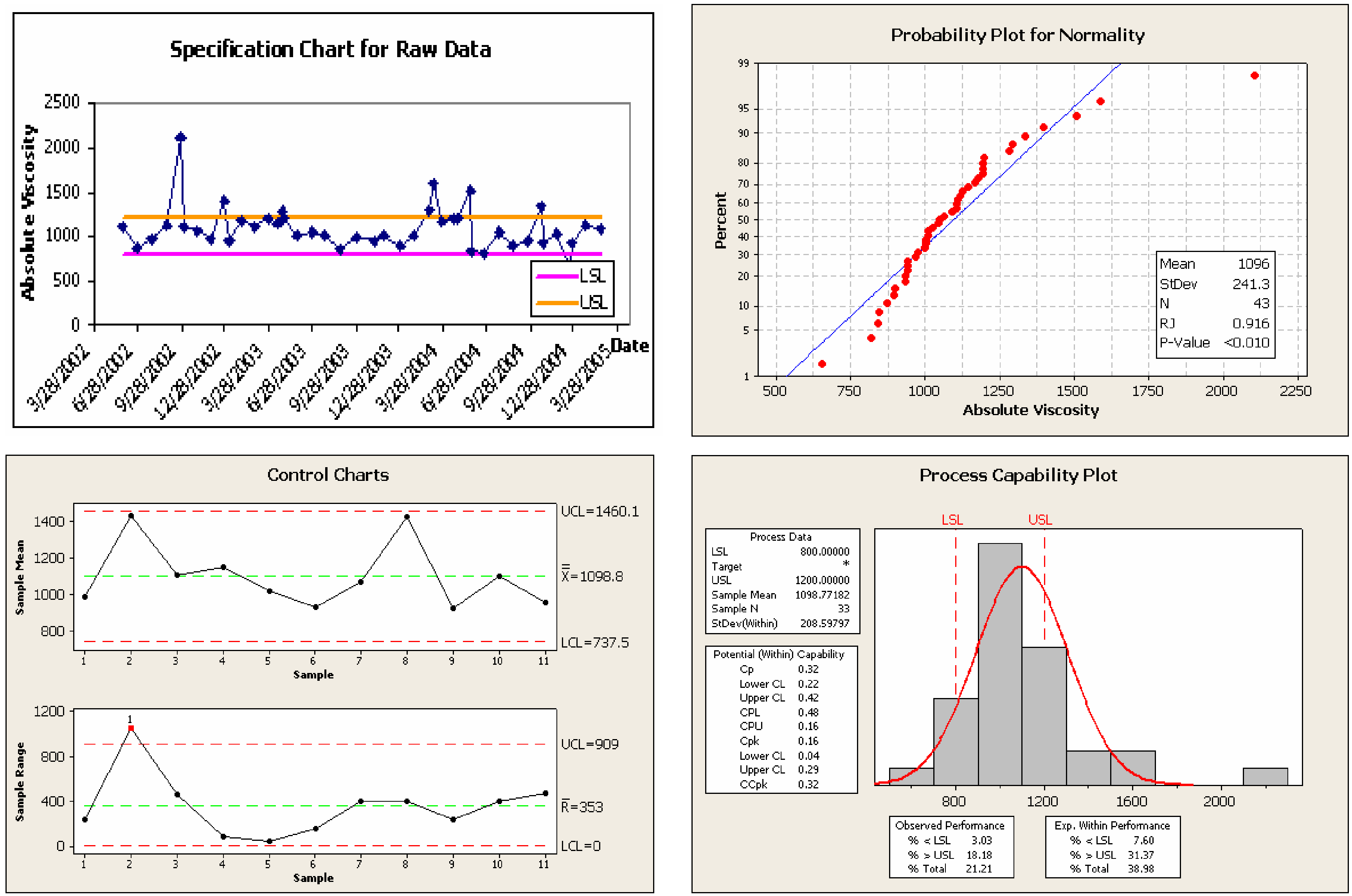


Figure E-8 Statistical Analysis Charts for Supplier: 0101 Grade: AC-10 Test: Absolute Viscosity

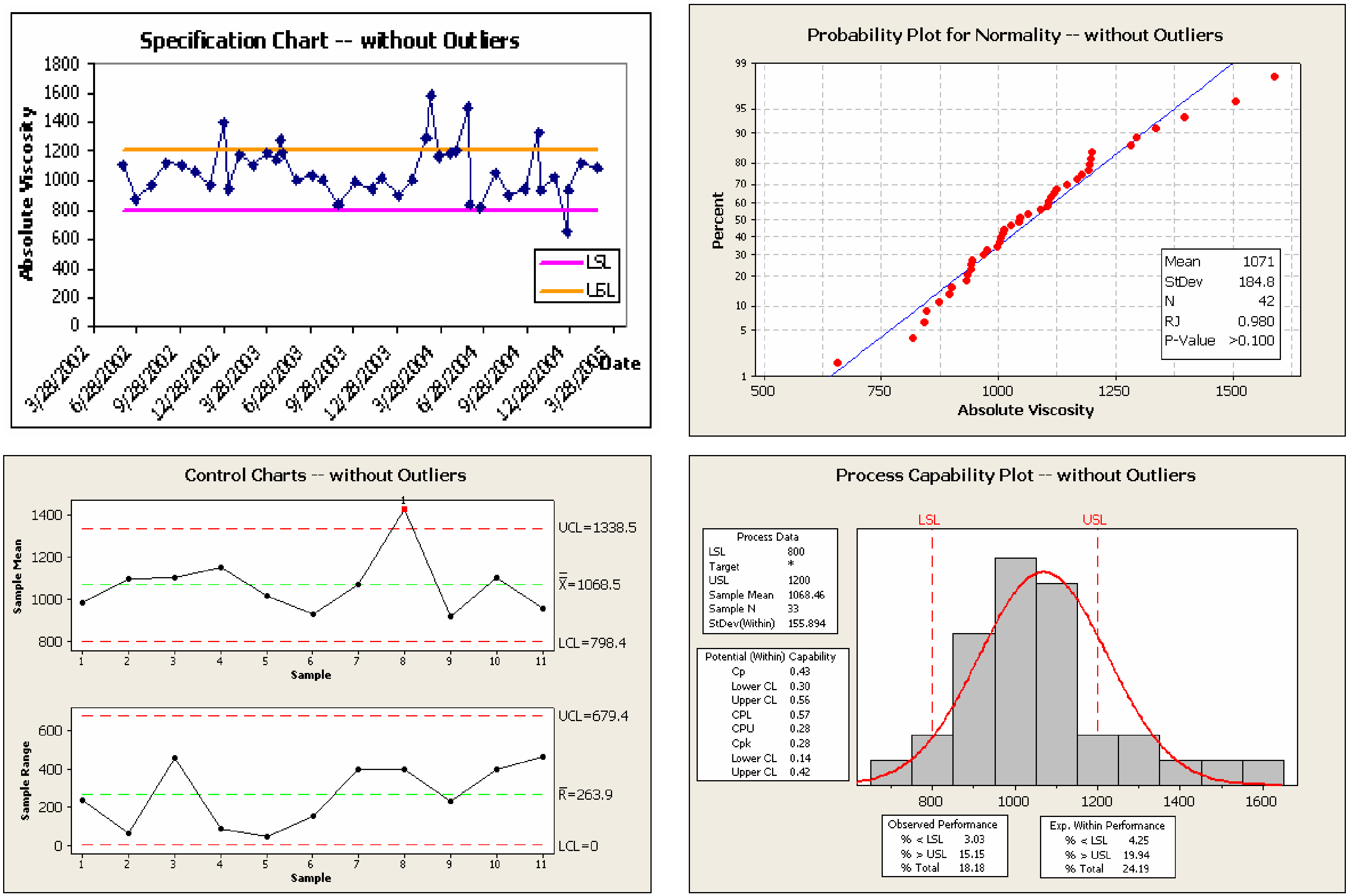


Figure E-9 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: AC-10 Test: Absolute Viscosity

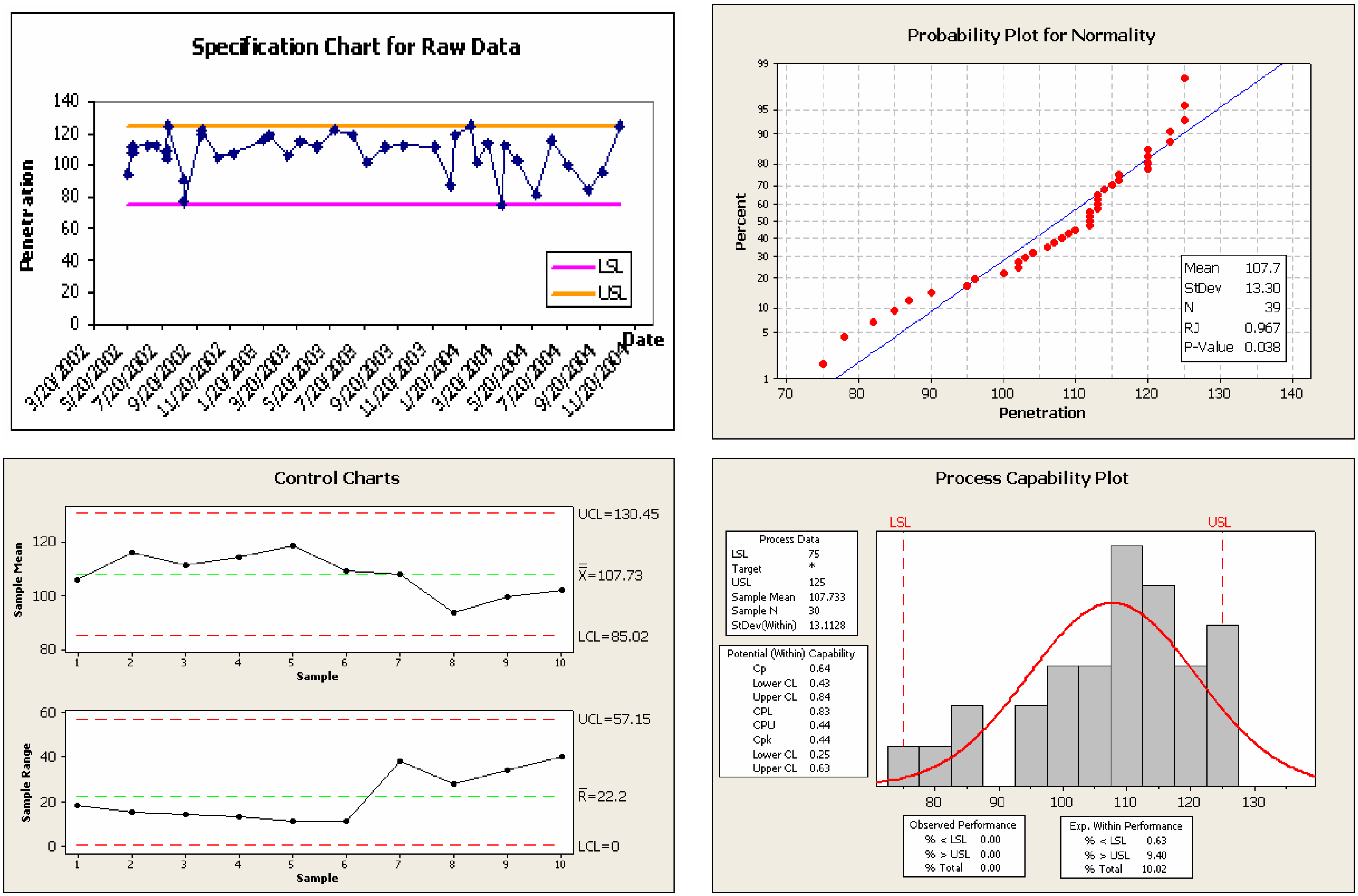


Figure E-10 Statistical Analysis Charts for Supplier: 0101 Grade: AC-15-5TR Test: Penetration

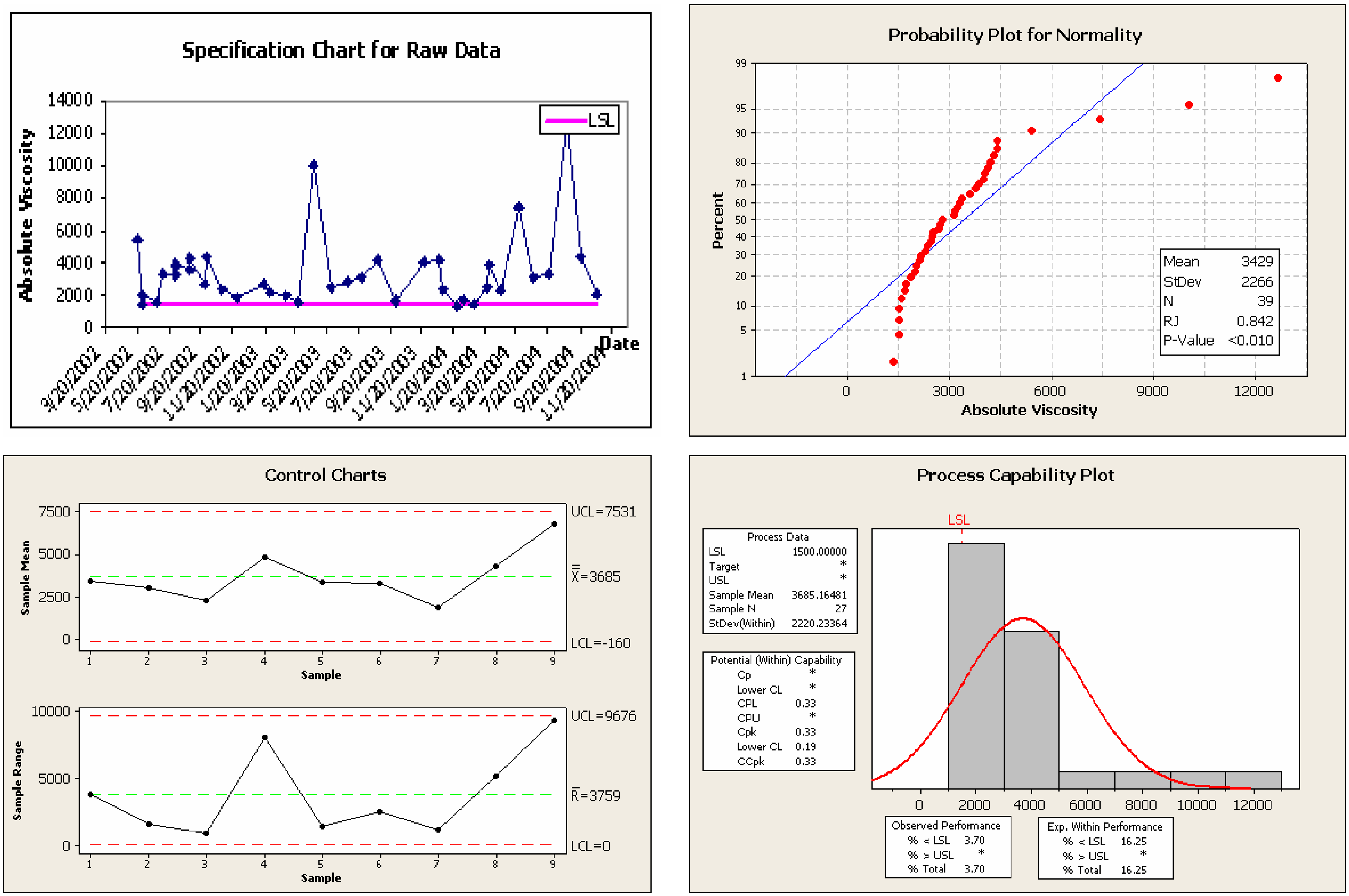


Figure E-11 Statistical Analysis Charts for Supplier: 0101 Grade: AC-15-5TR Test: Absolute Viscosity

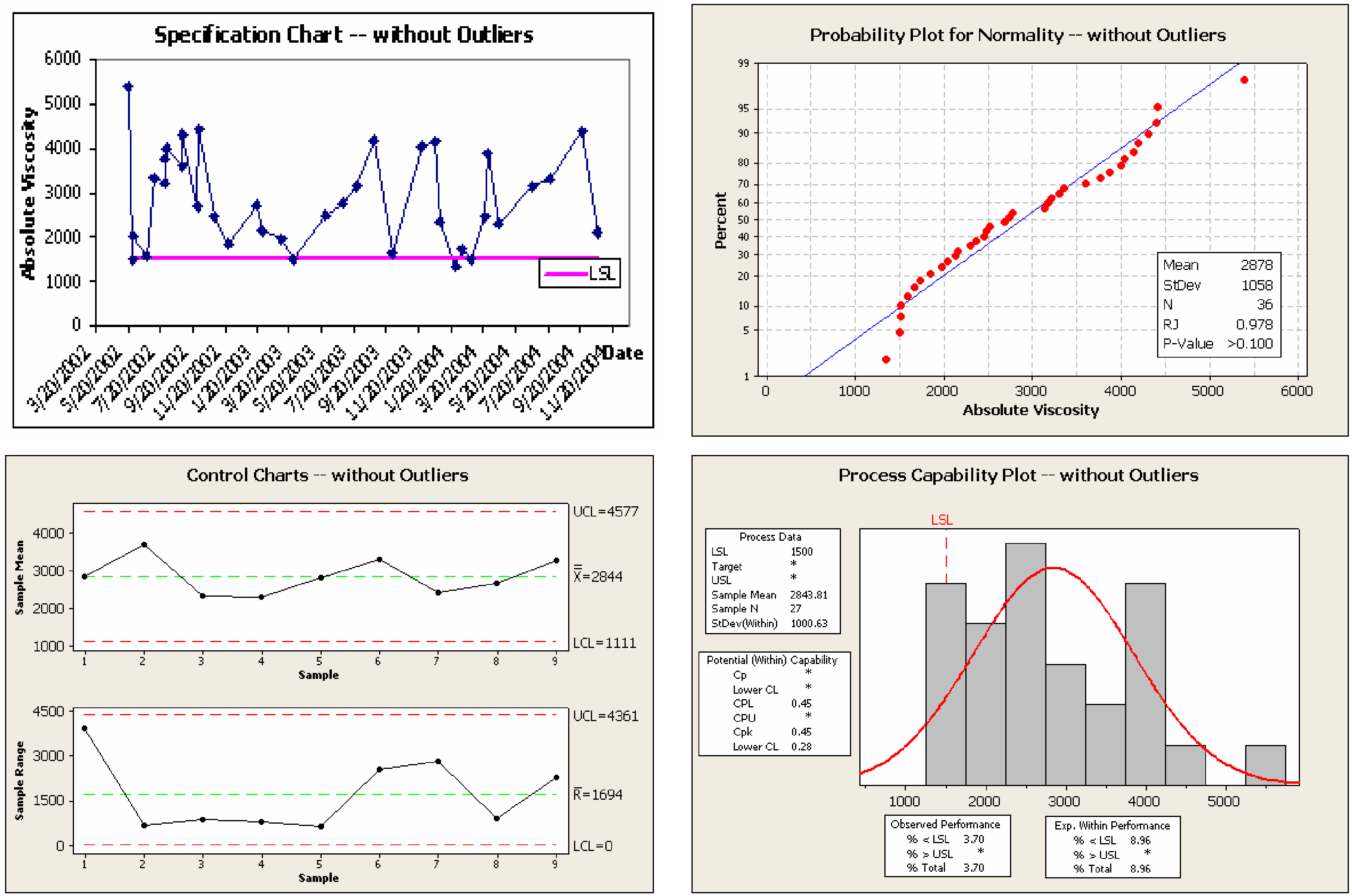


Figure E-12 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: AC-15-5TR Test: Absolute Viscosity

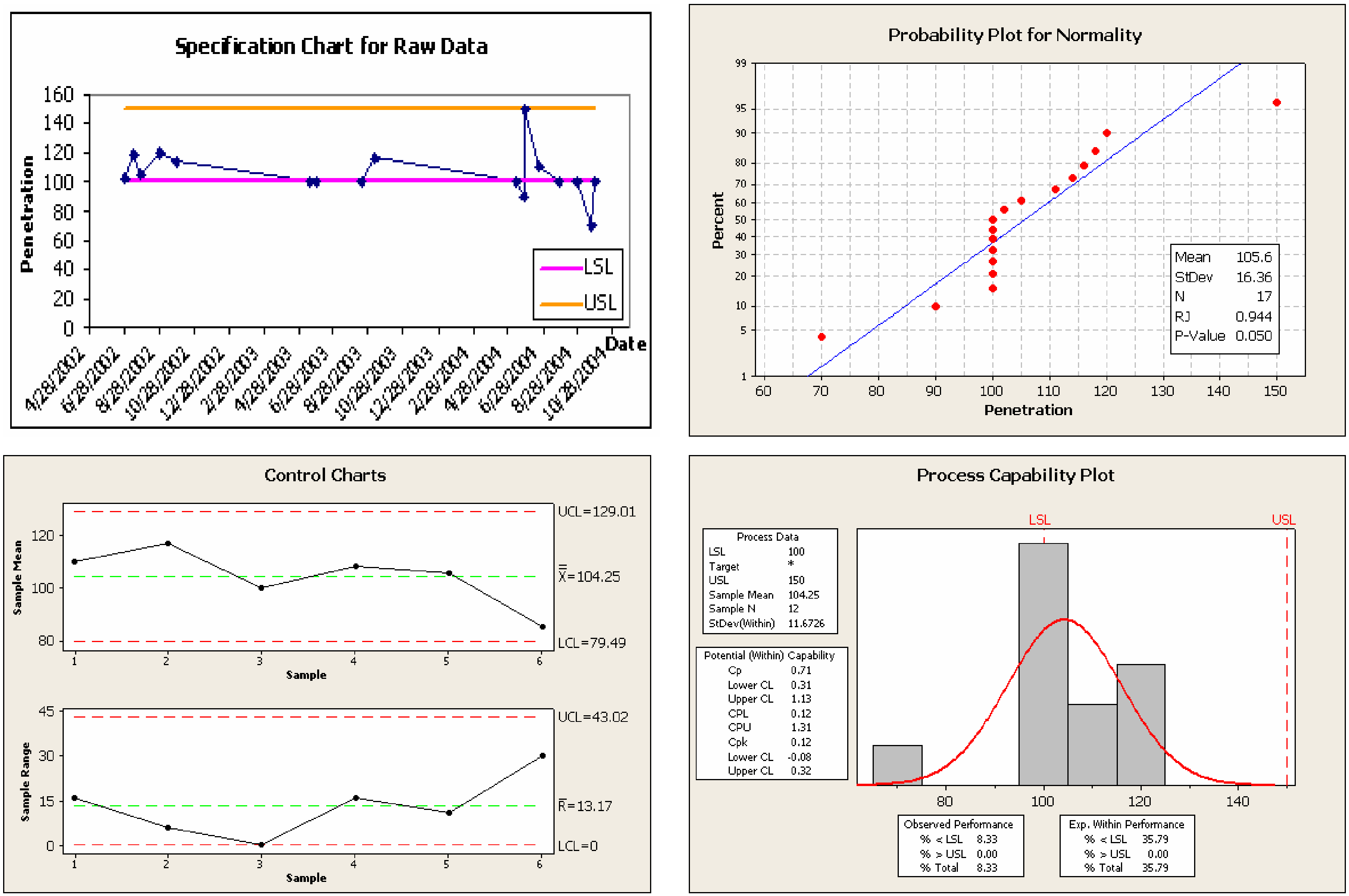


Figure E-13 Statistical Analysis Charts for Supplier: 0101 Grade: AC-15P Test: Penetration

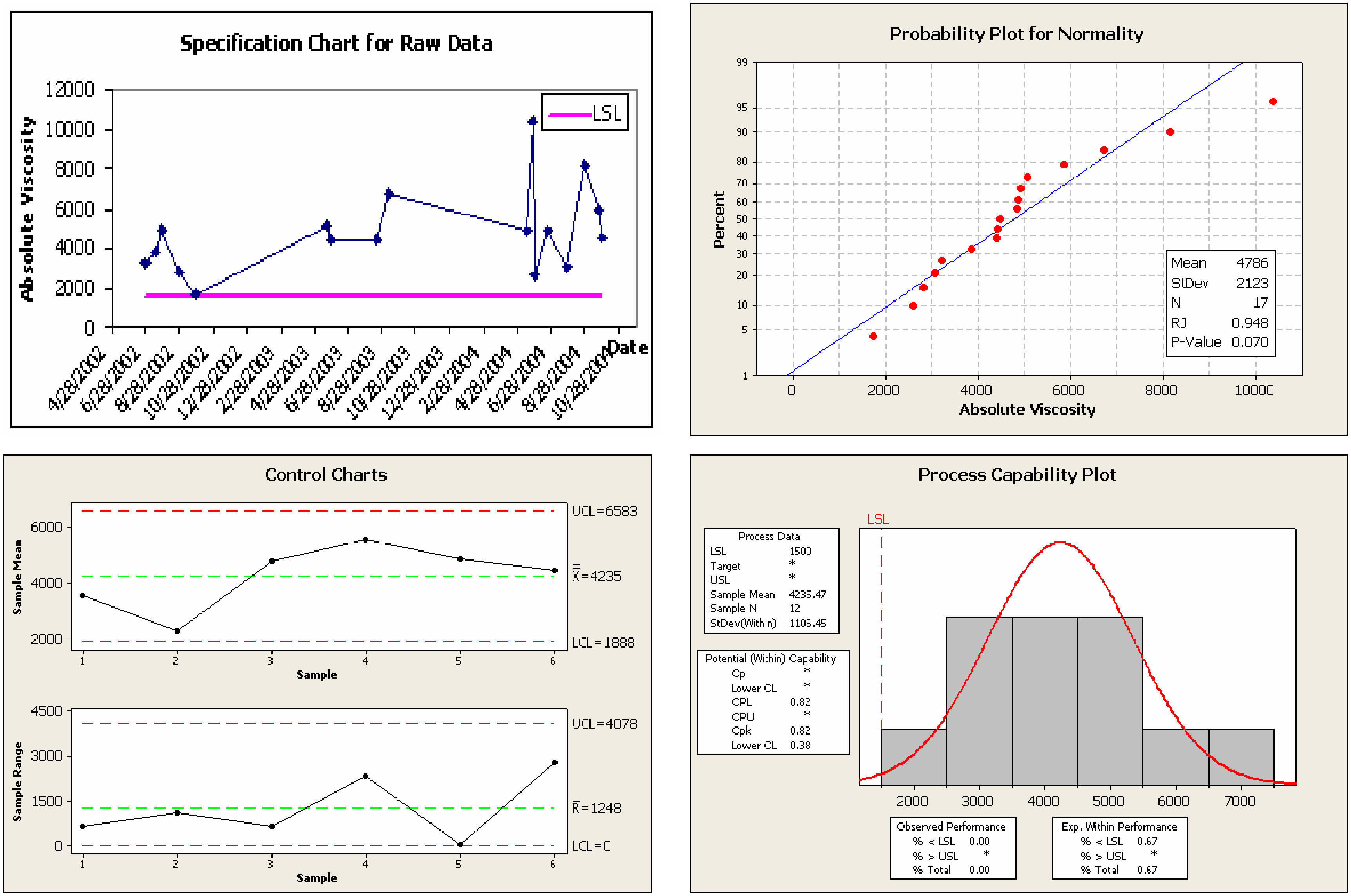


Figure E-14 Statistical Analysis Charts for Supplier: 0101 Grade: AC-15P Test: Absolute Viscosity

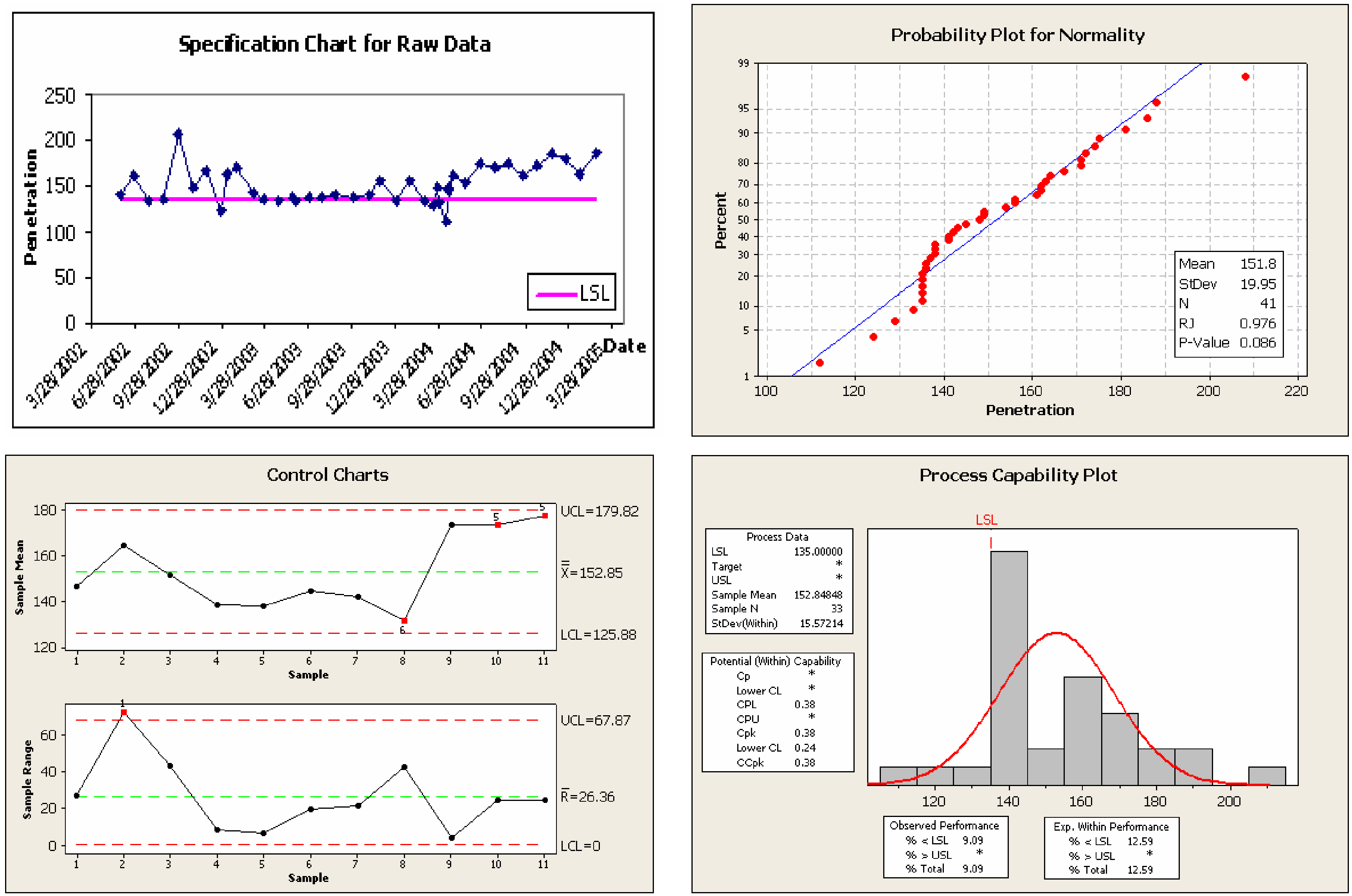


Figure E-15 Statistical Analysis Charts for Supplier: 0101 Grade: AC-5 Test: Penetration

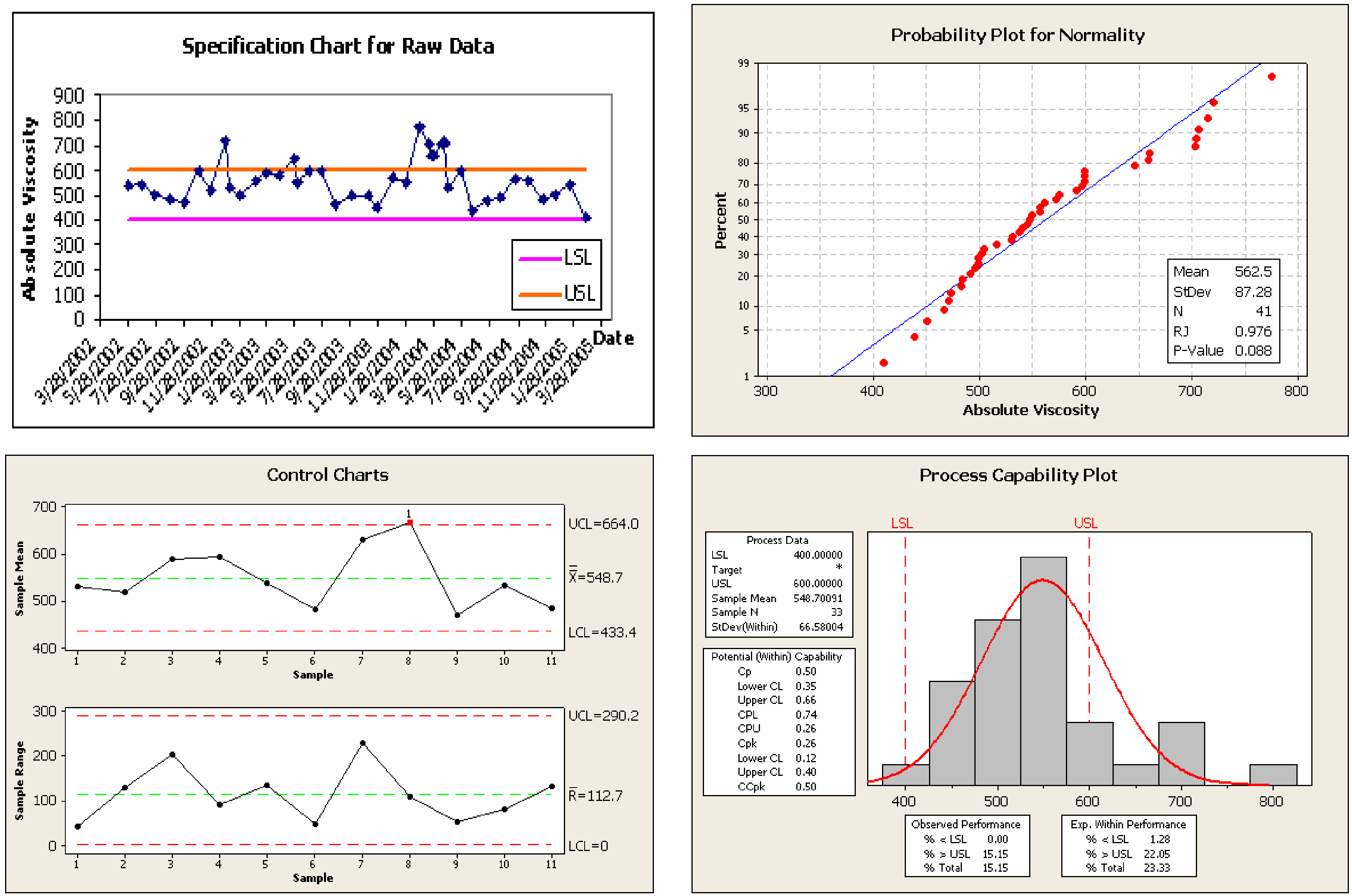


Figure E-16 Statistical Analysis Charts for Supplier: 0101 Grade: AC-5 Test: Absolute Viscosity

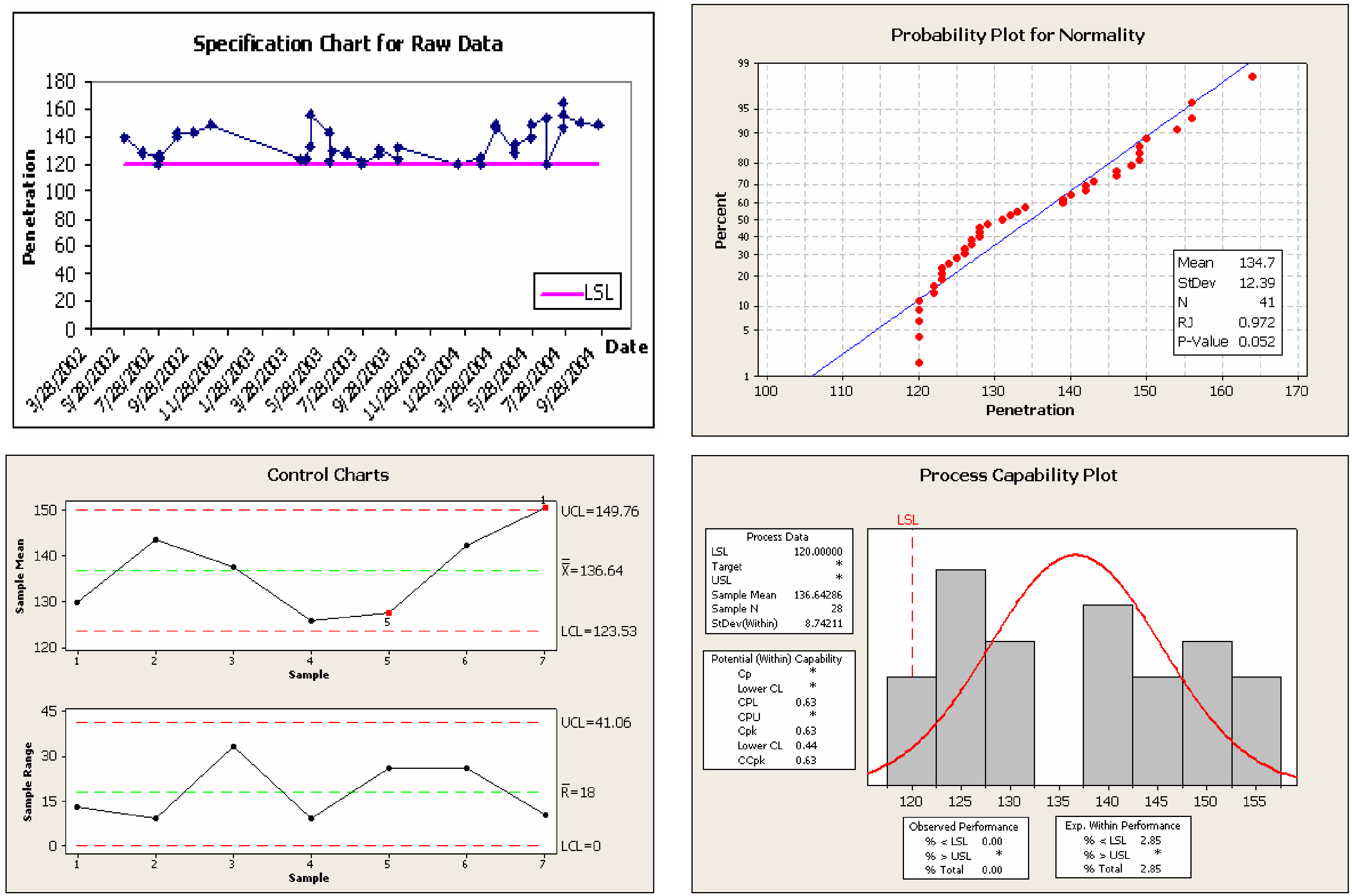


Figure E-17 Statistical Analysis Charts for Supplier: 0101 Grade: AC-5L2% Test: Penetration

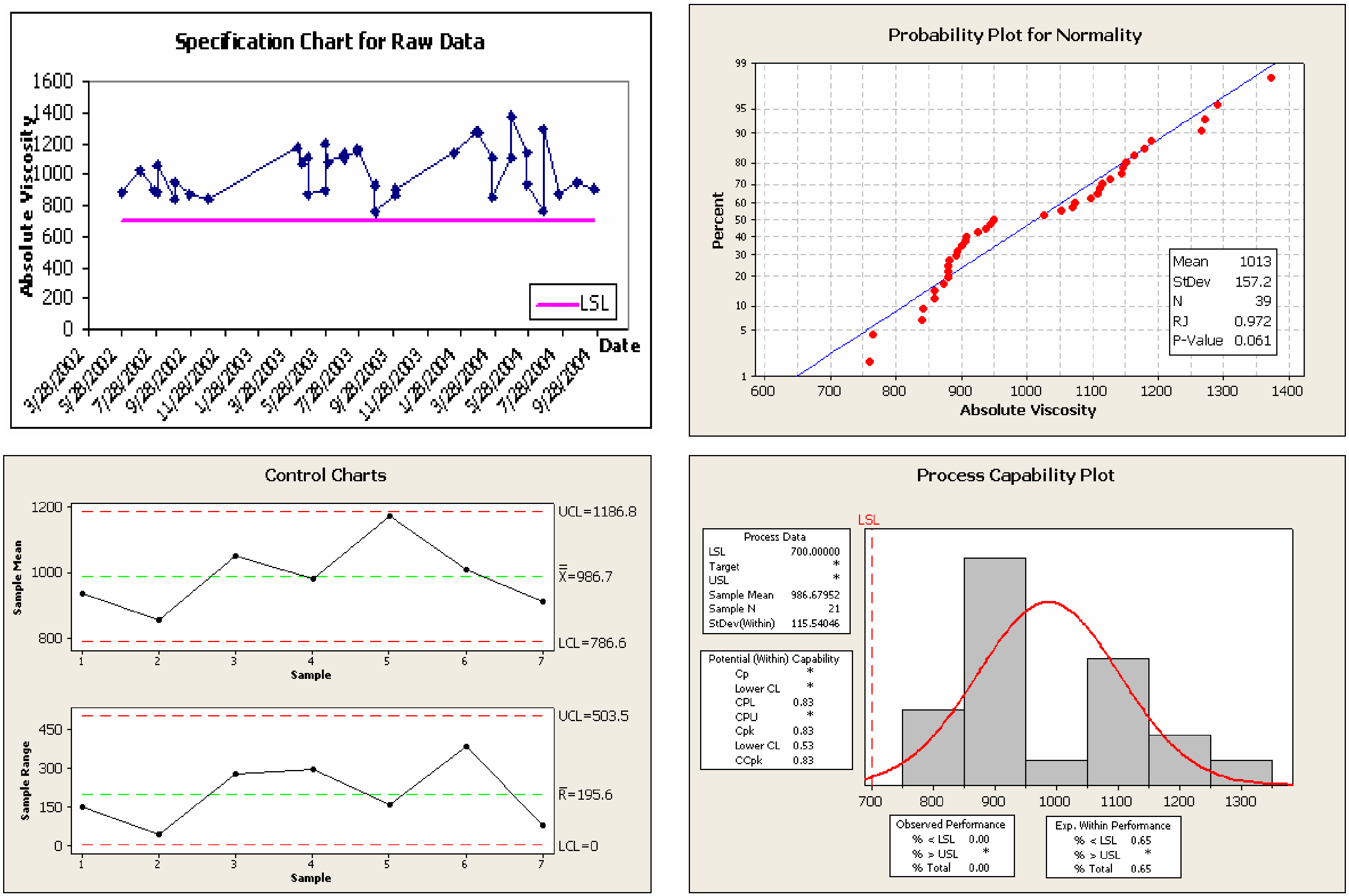


Figure E-18 Statistical Analysis Charts for Supplier: 0101 Grade: AC-5L2% Test: Absolute Viscosity

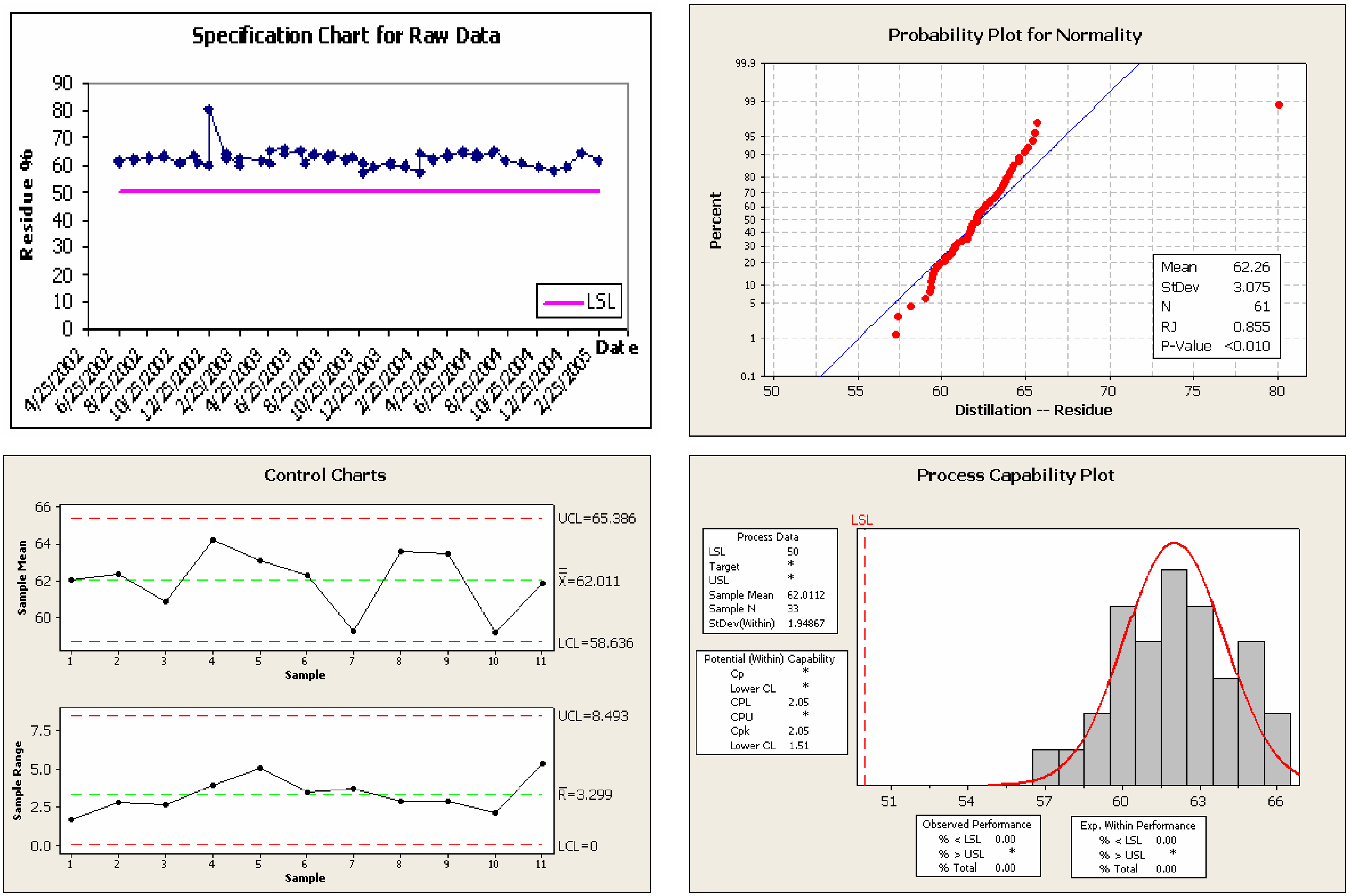


Figure E-19 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation-Residue

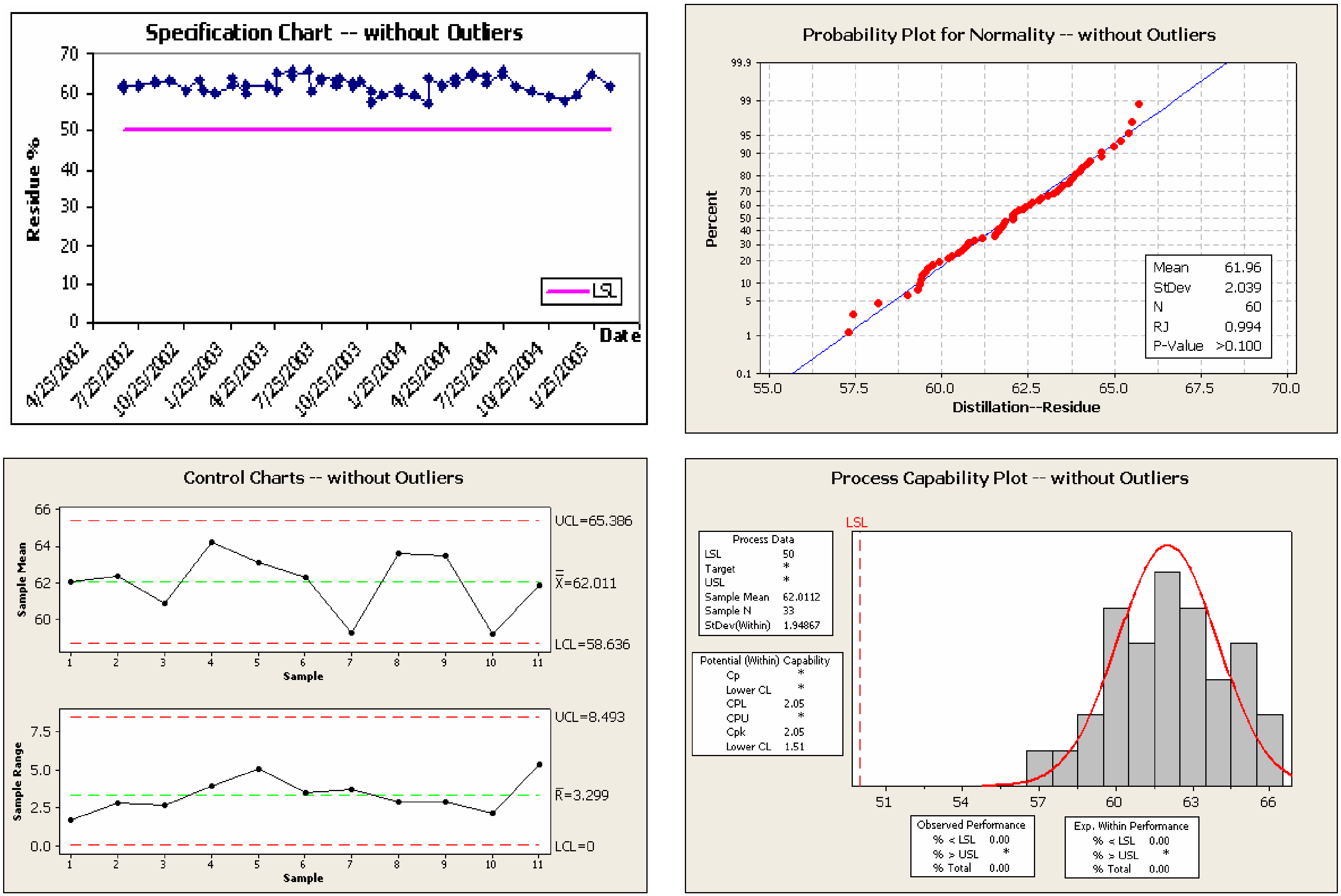


Figure E-20 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: MC-30 Test: Distillation-Residue

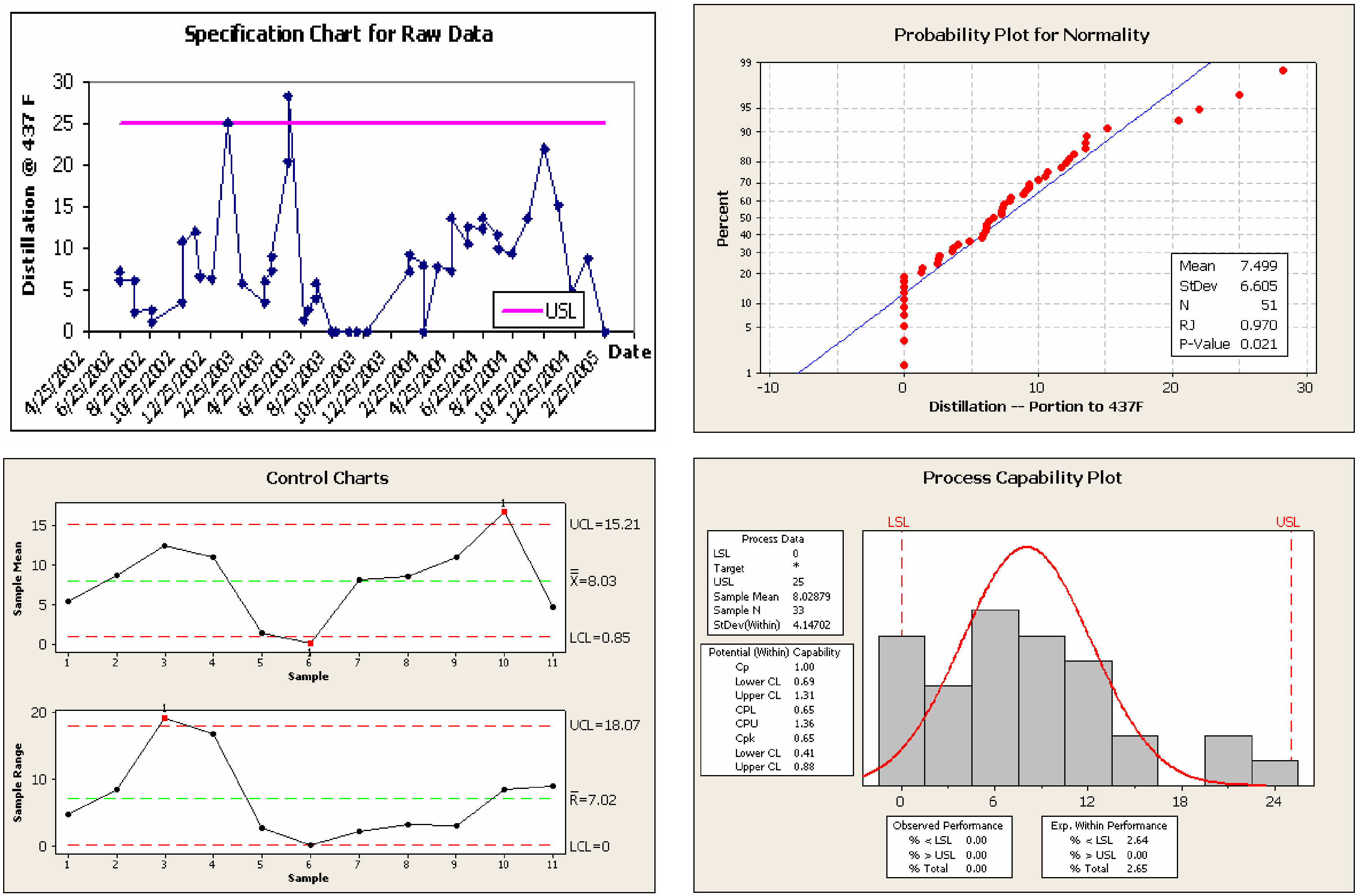


Figure E-21 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation @ 437|F

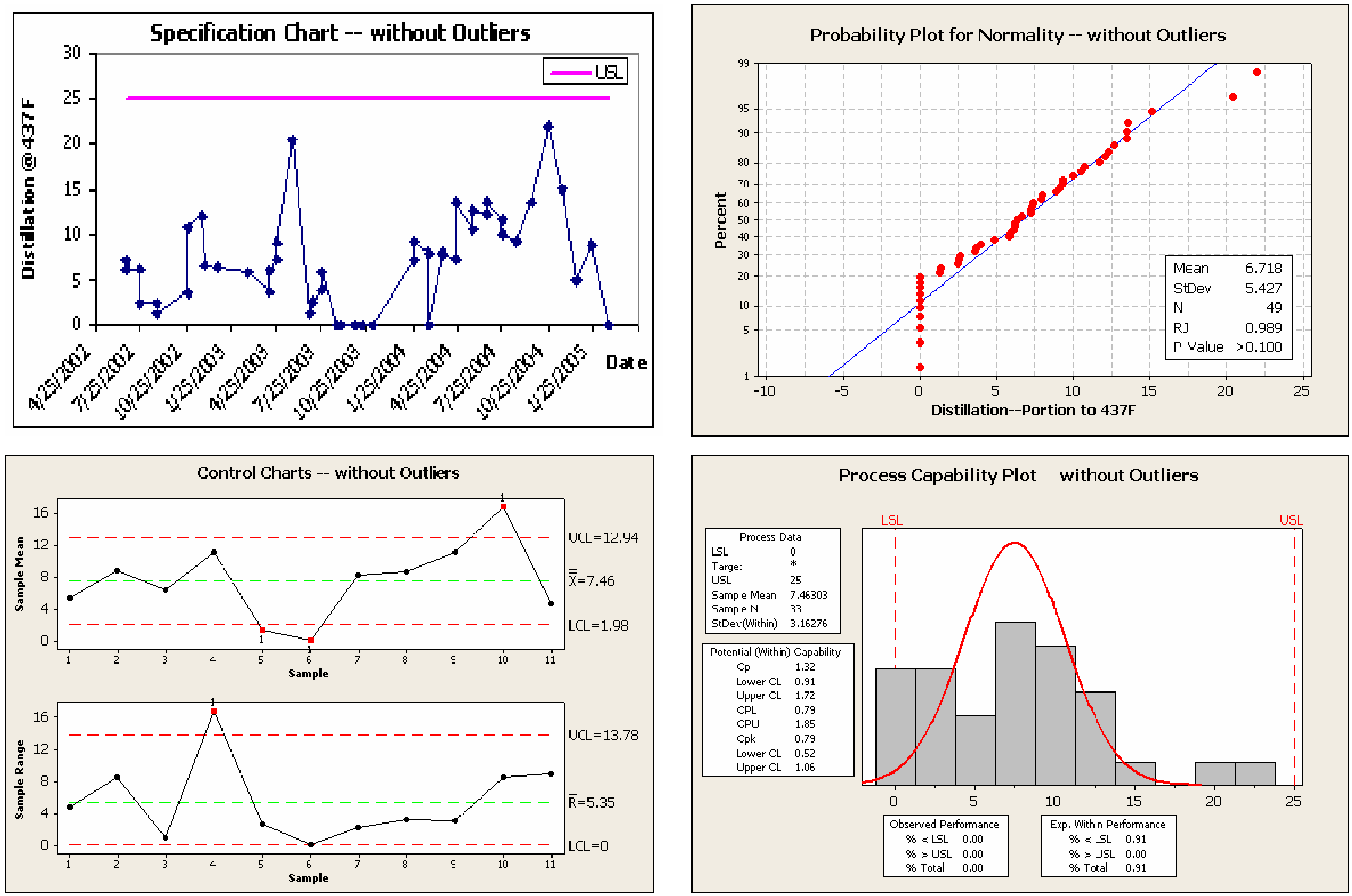


Figure E-22 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: MC-30 Test: Distillation @ 437|F

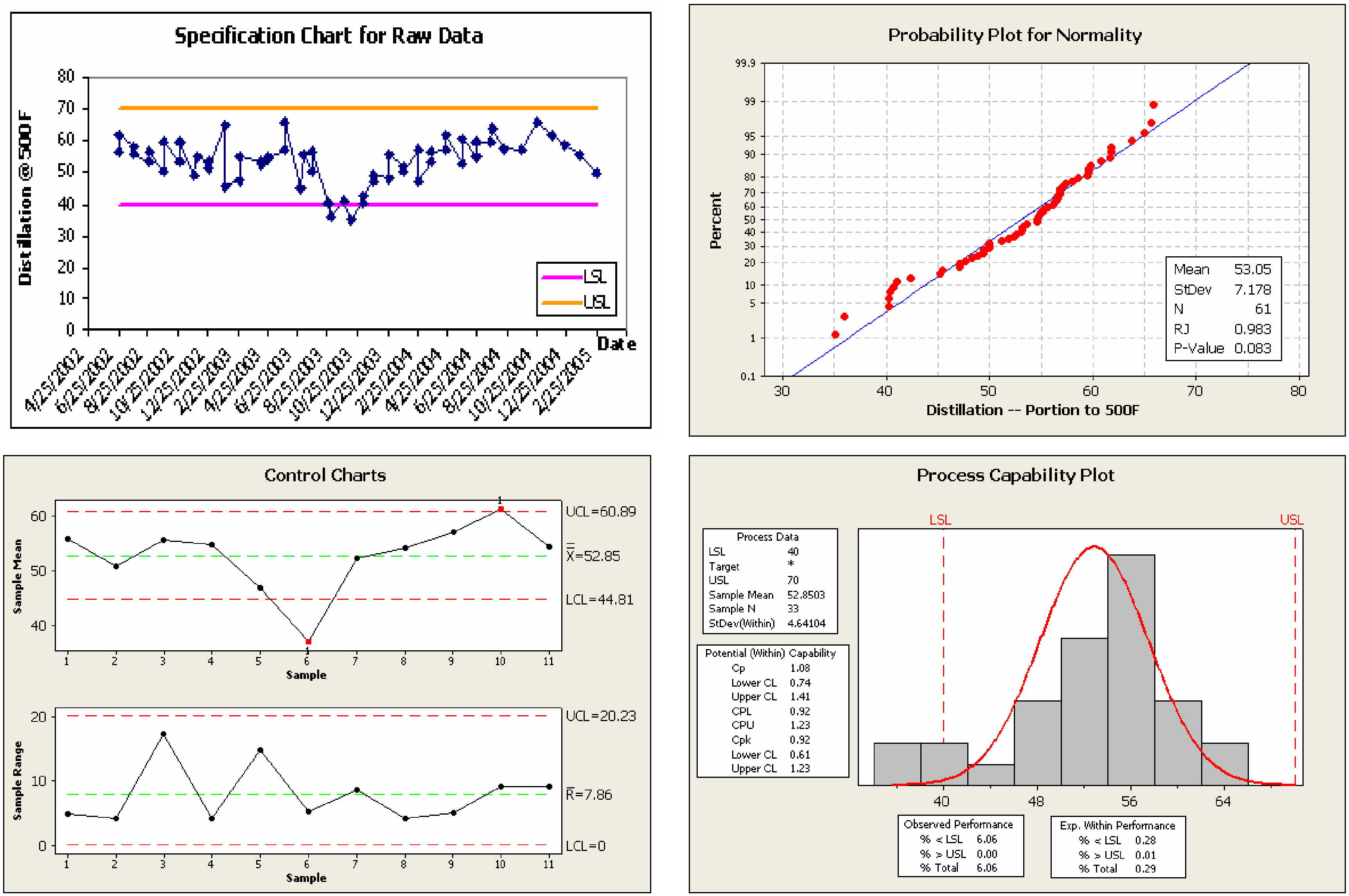


Figure E-23 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation @ 500|F

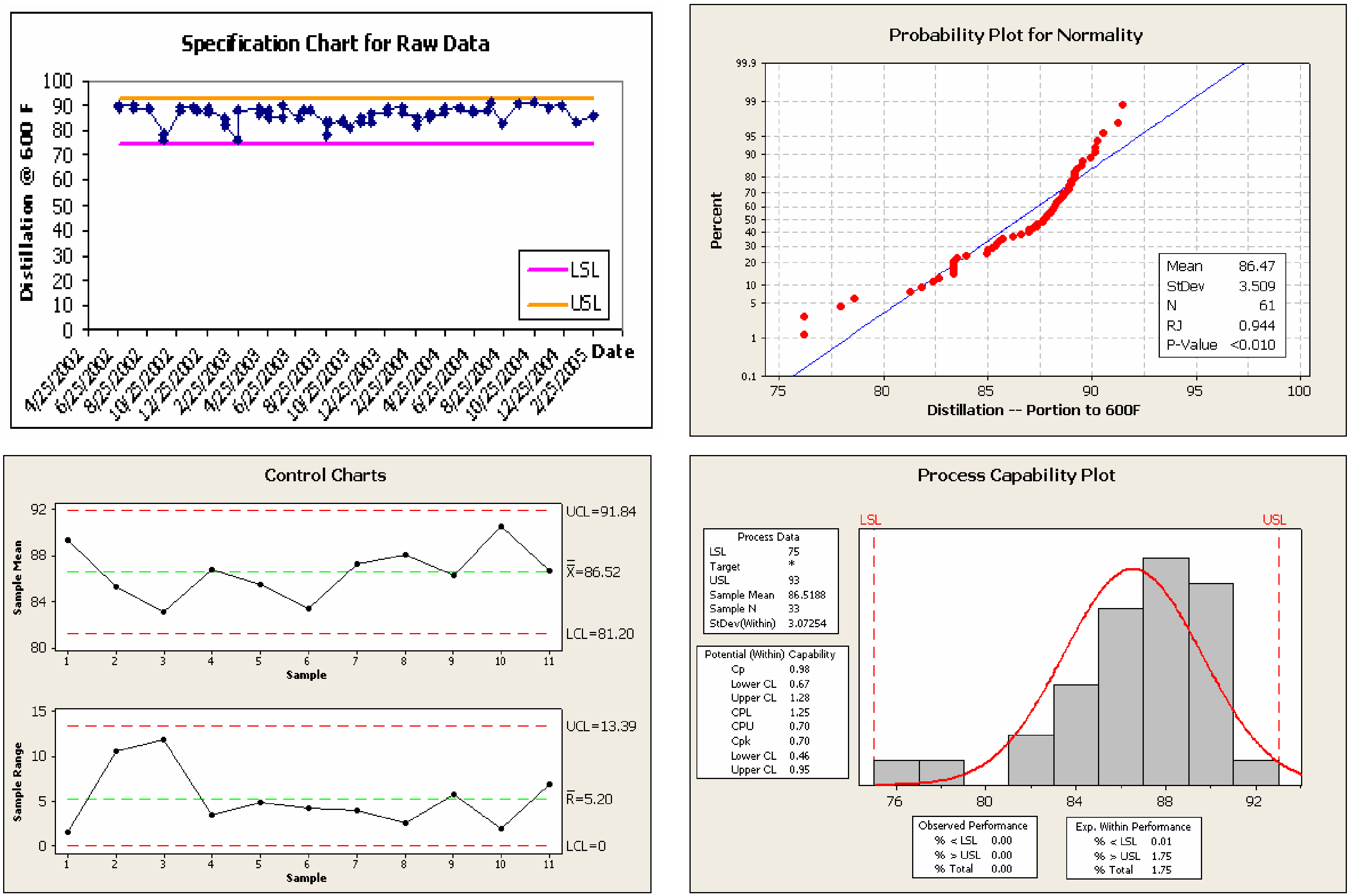


Figure E-24 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation @ 600|F

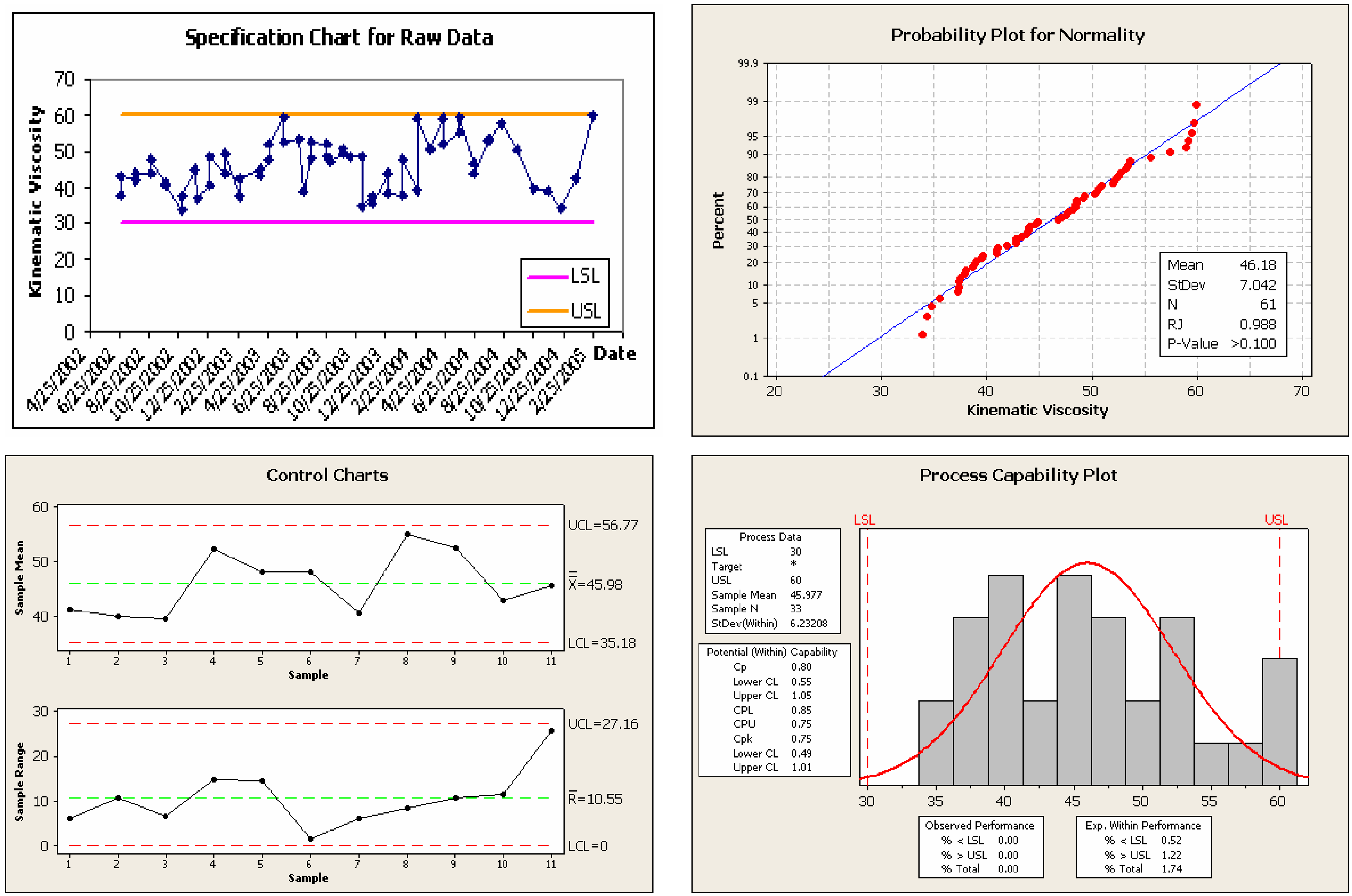


Figure E-25 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Kinematic Viscosity

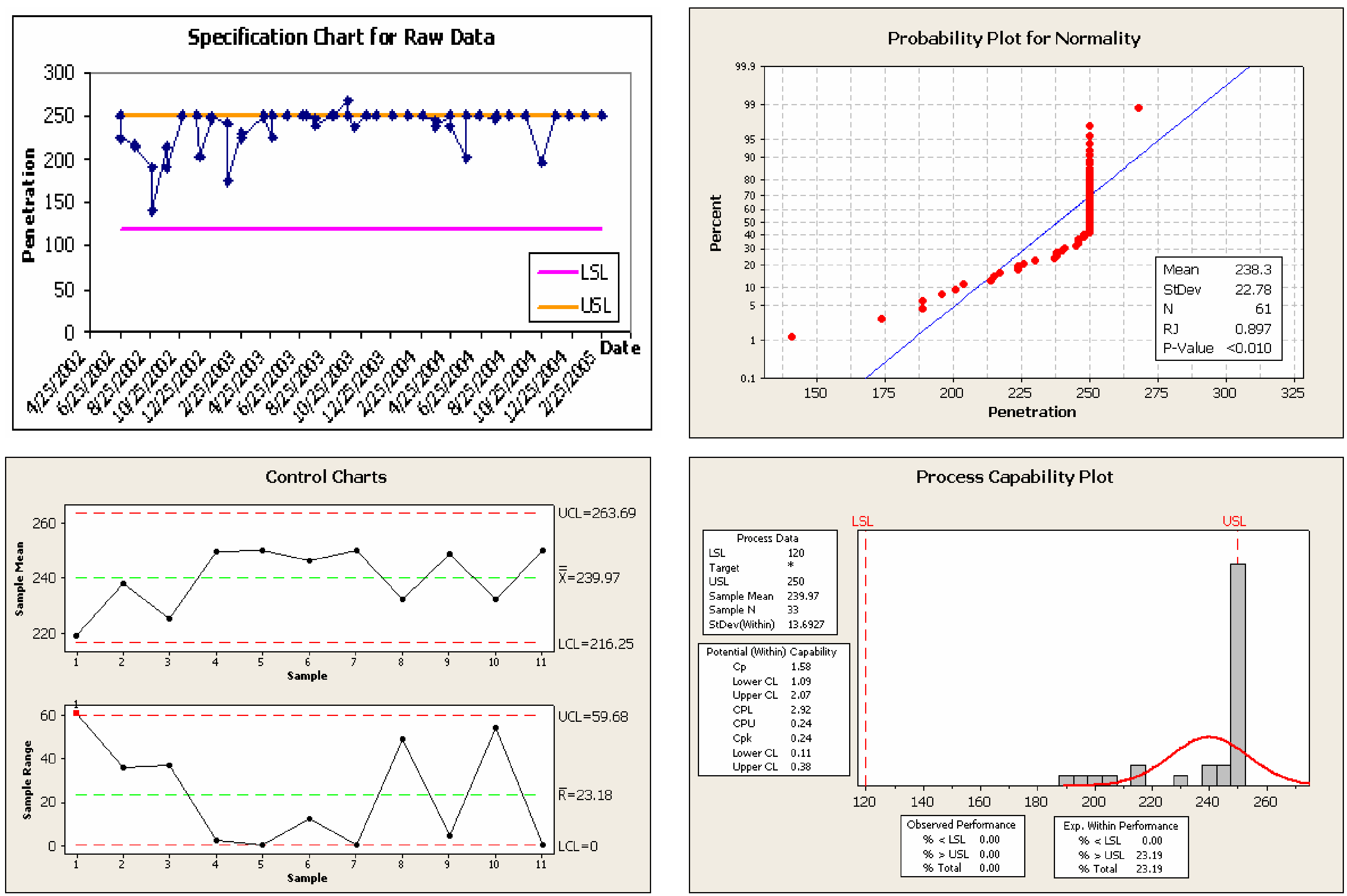


Figure E-26 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Penetration

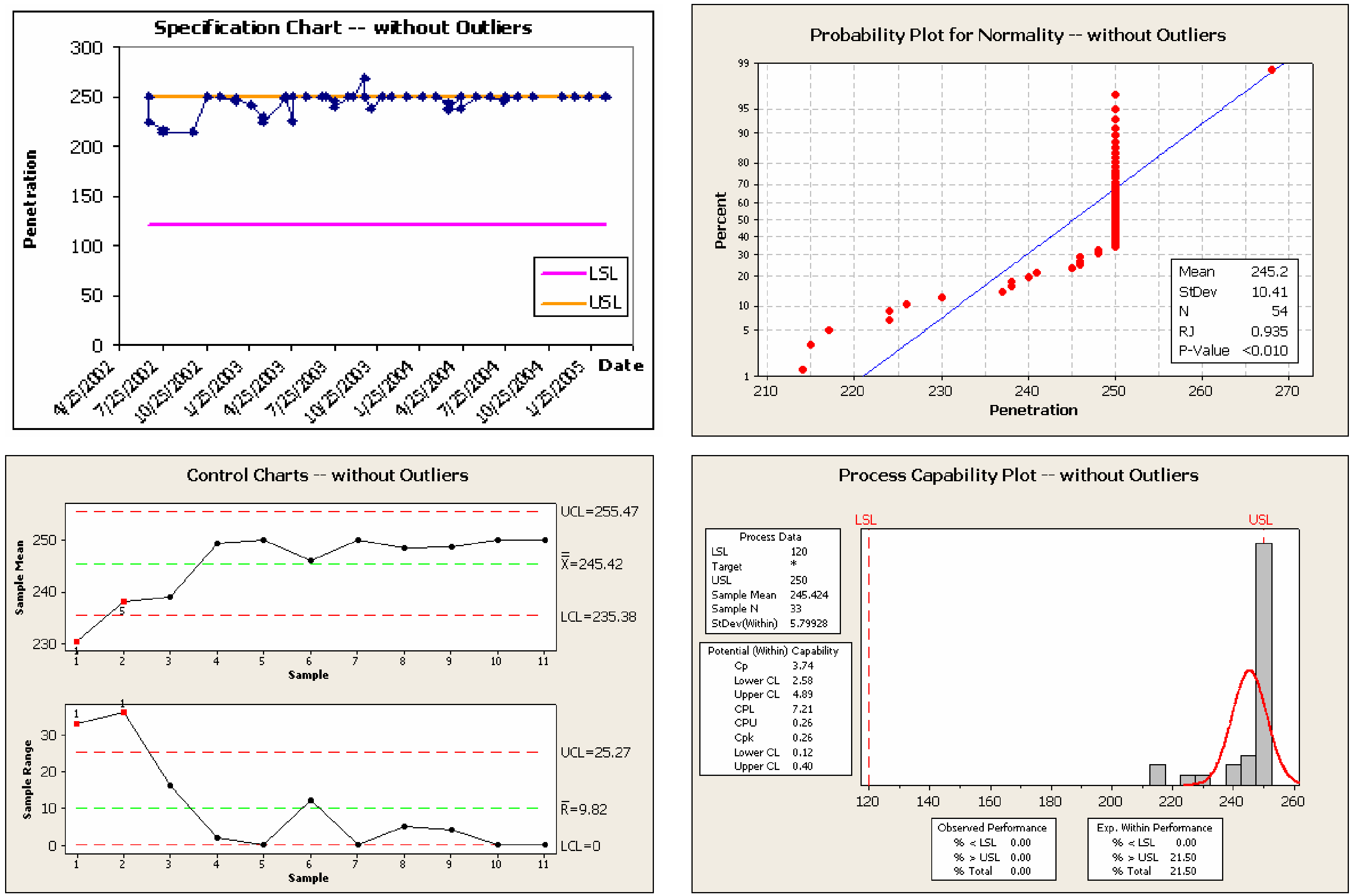


Figure E-27 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: MC-30 Test: Penetration

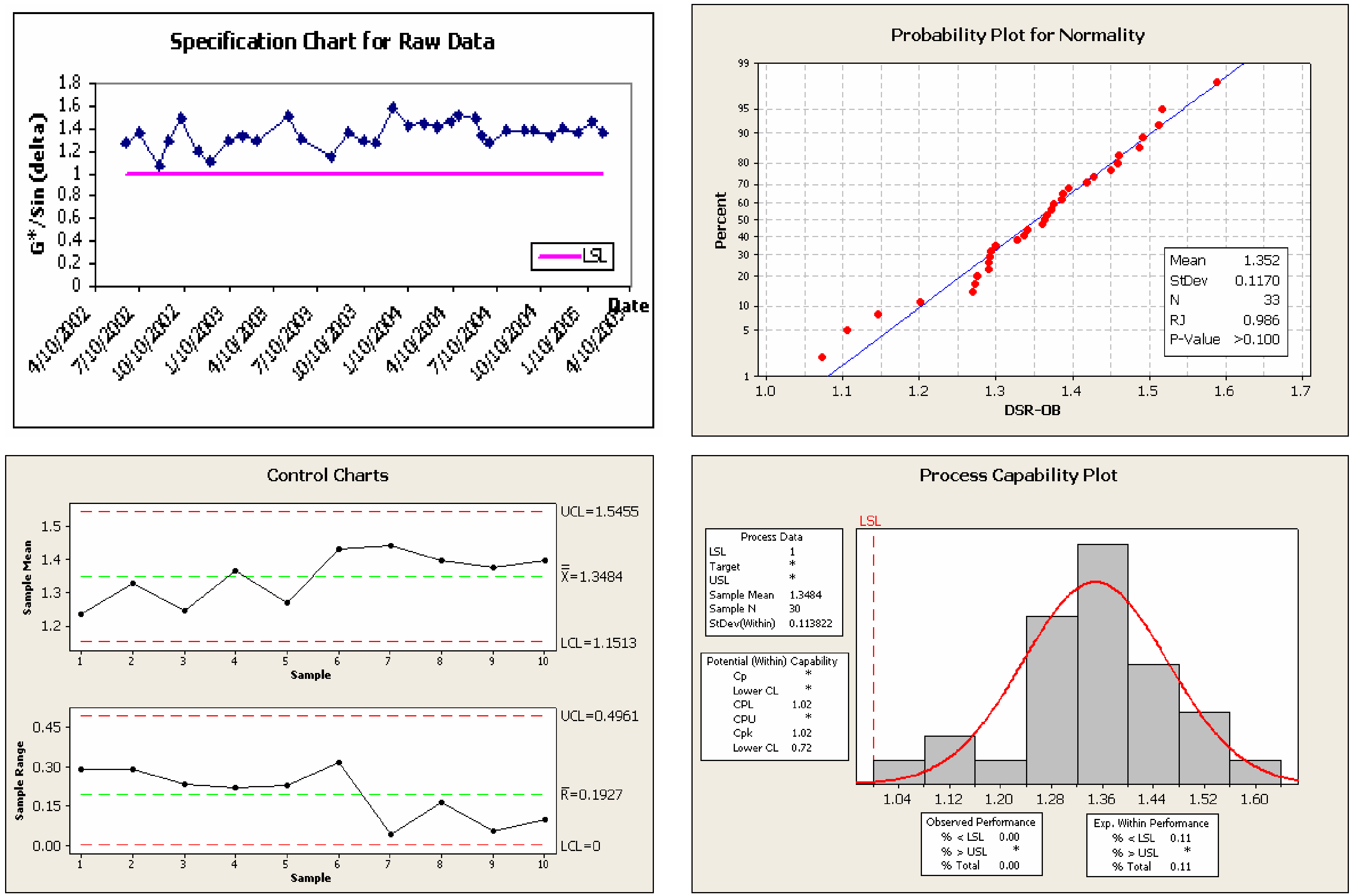


Figure E-28 Statistical Analysis Charts for Supplier: 0201 Grade: PG 64-22 Test: DSR-OB

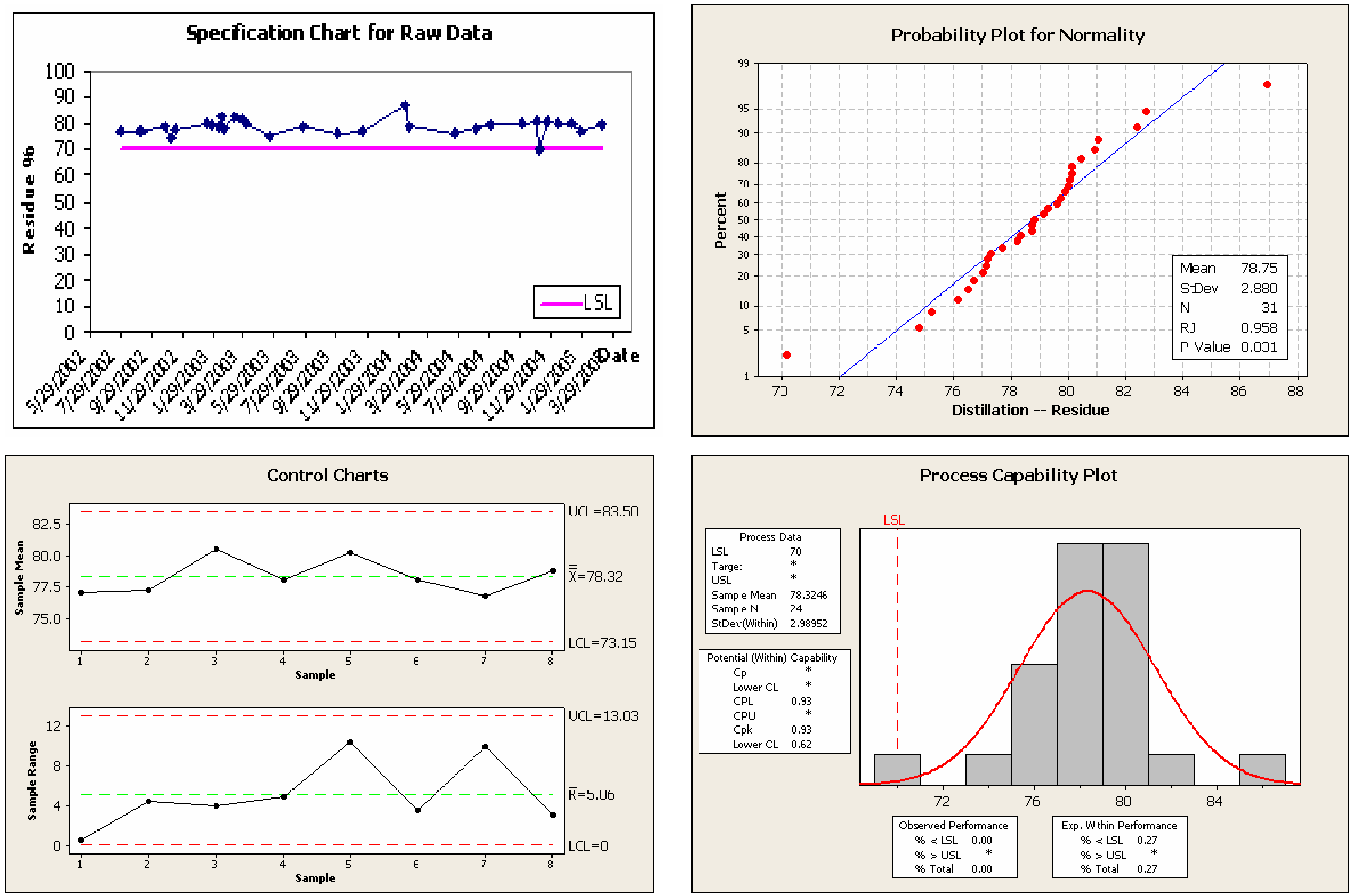


Figure E-29 Statistical Analysis Charts for Supplier: 0301 Grade: RC-250 Test: Distillation-Residue

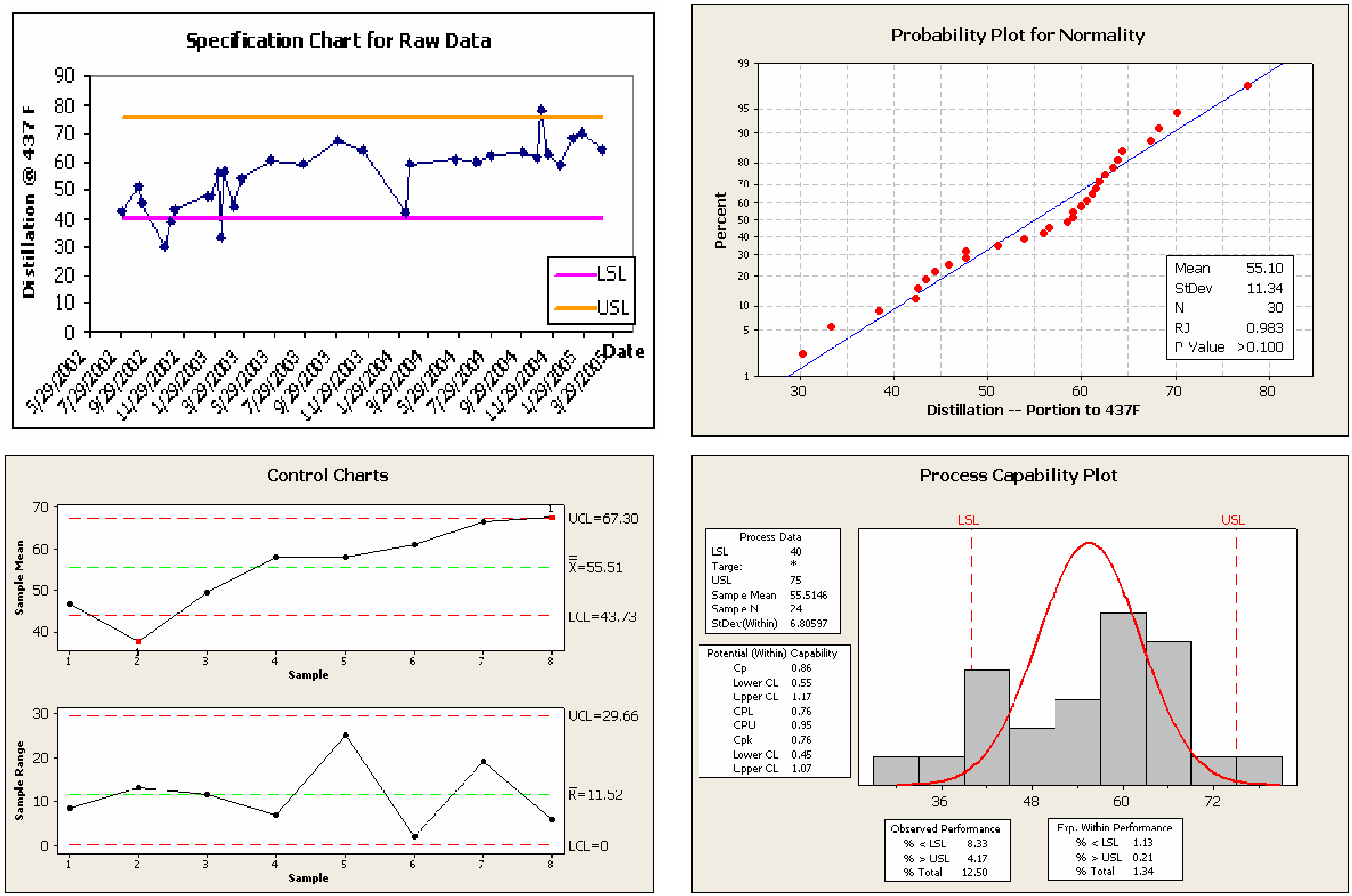


Figure E-30 Statistical Analysis Charts for Supplier: 0301 Grade: RC-250 Test: Distillation @ 437|F

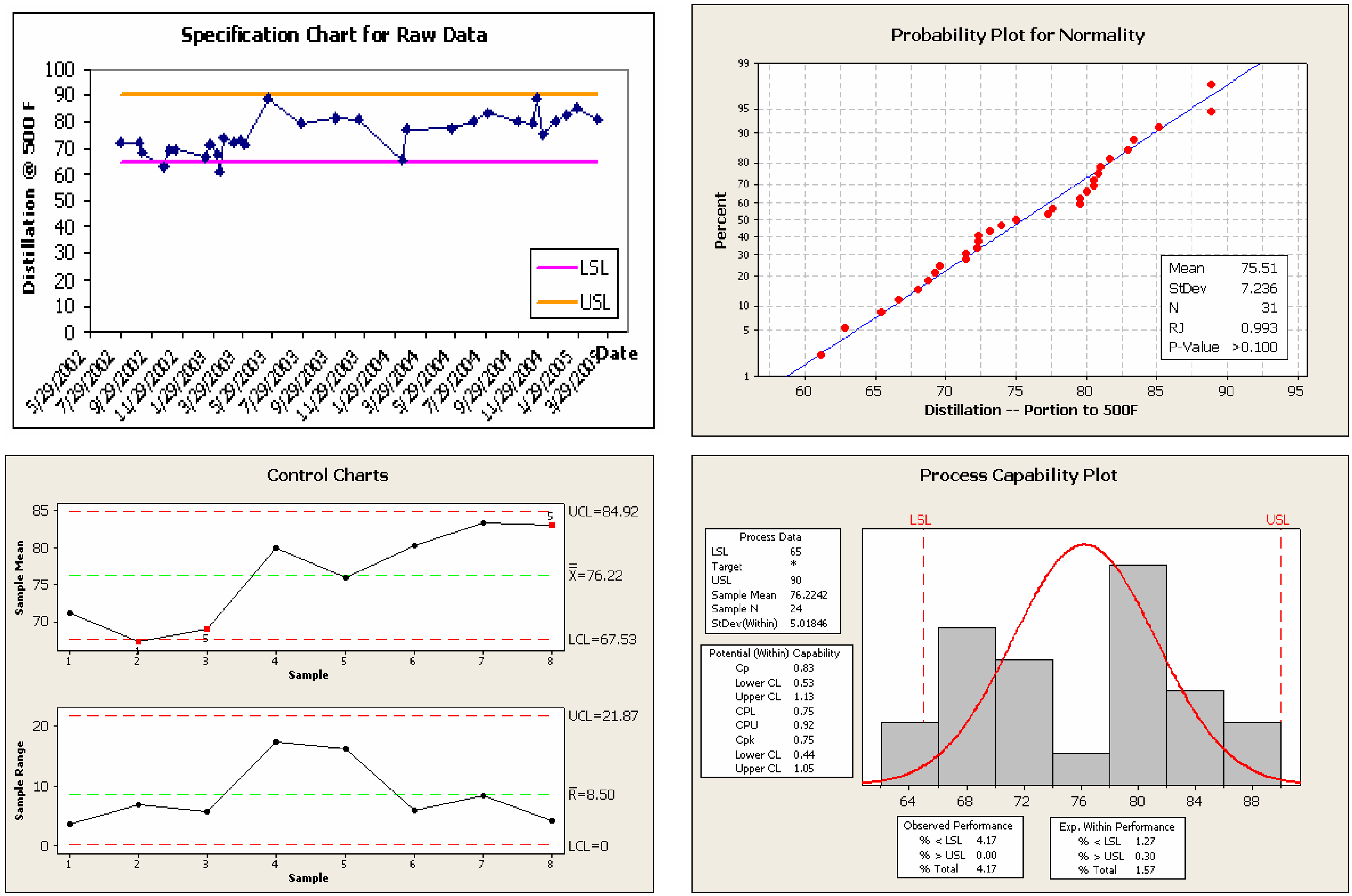


Figure E-31 Statistical Analysis Charts for Supplier: 0301 Grade: RC-250 Test: Distillation @ 500|F

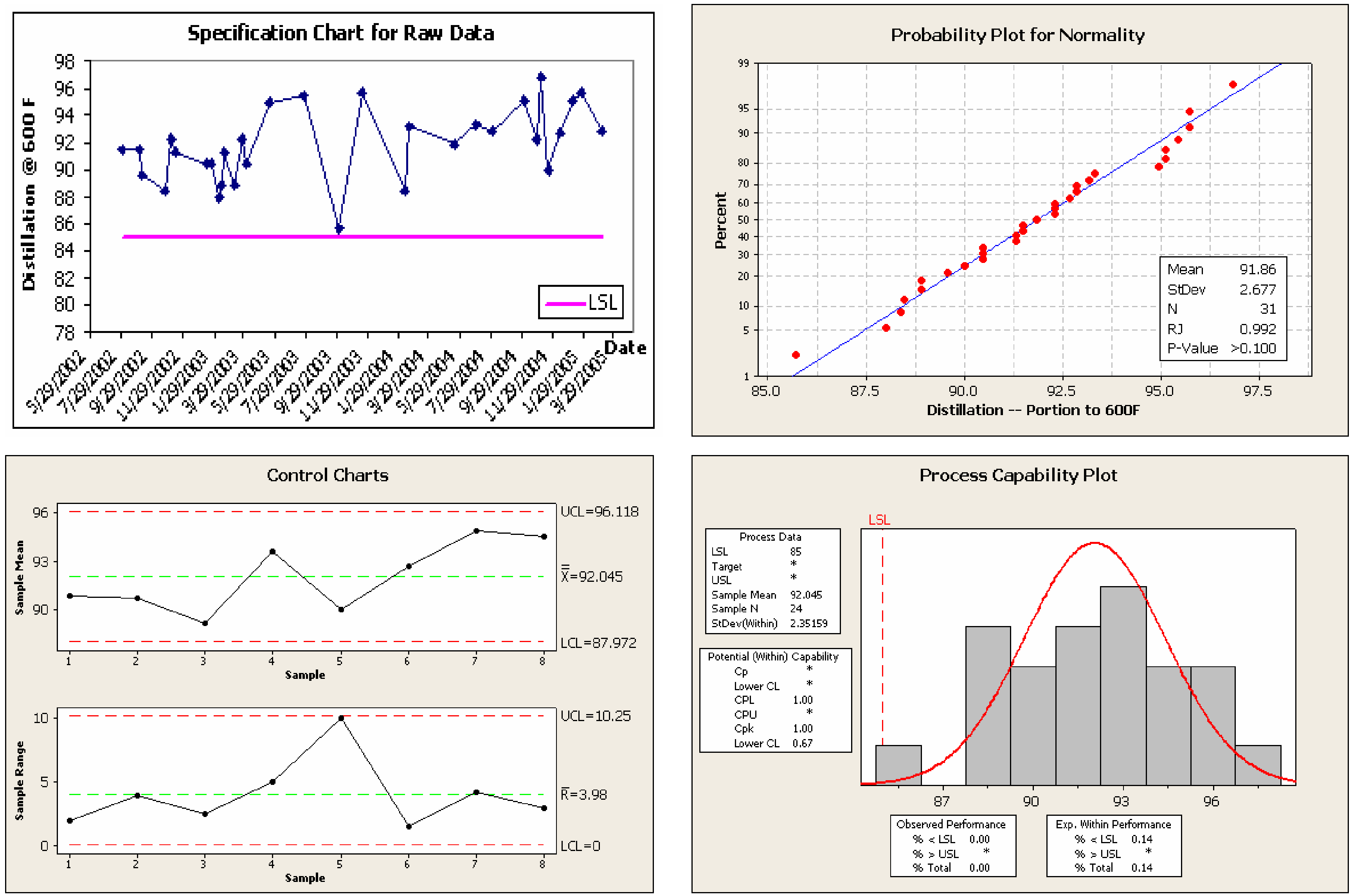
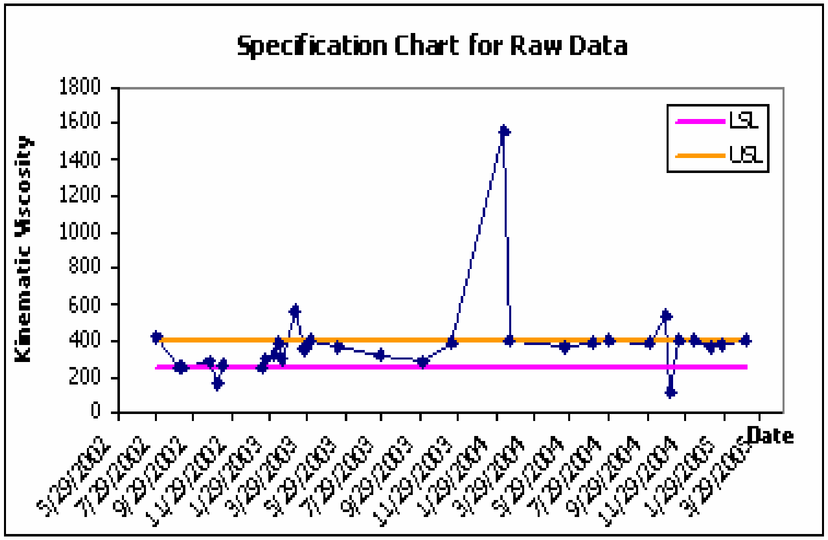
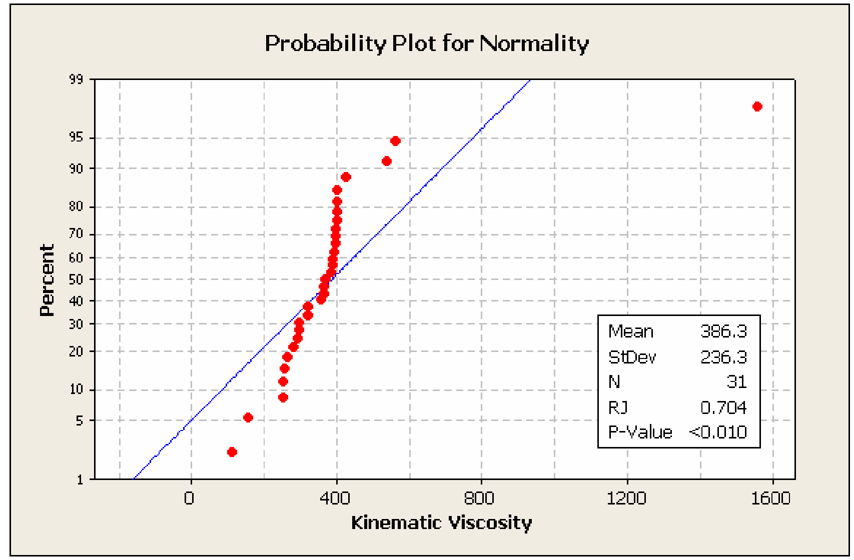
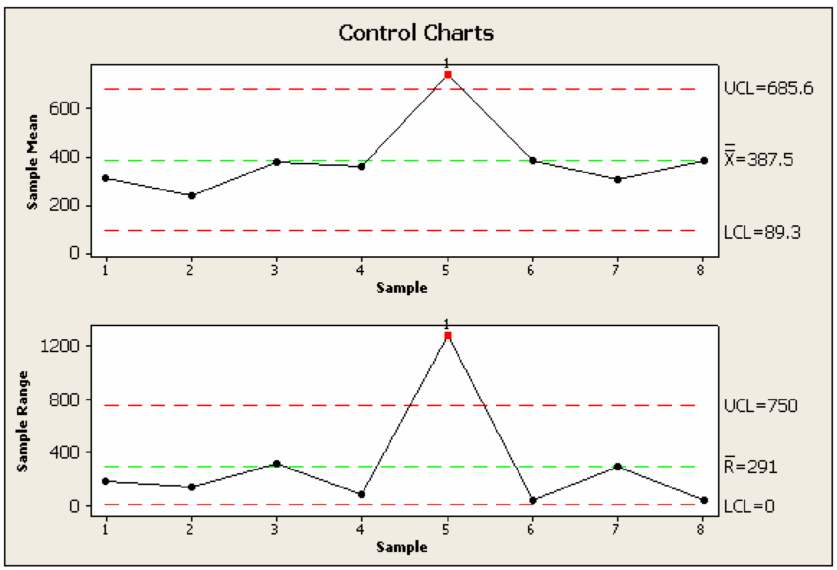


Figure E-32 Statistical Analysis Charts for Supplier: 0301 Grade: RC-250 Test: Distillation @ 600|F







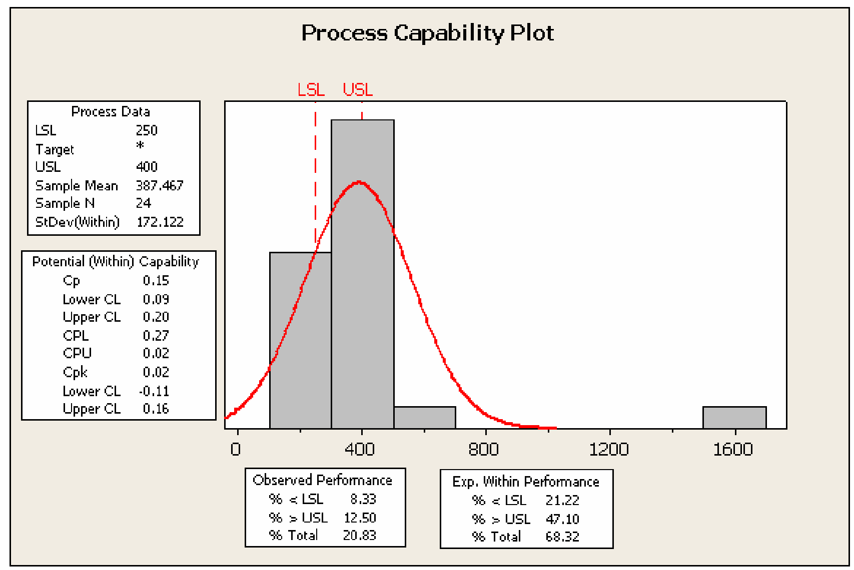


Figure E-33 Statistical Analysis Charts for Supplier: 0301 Grade: RC-250 Test: Kinematic Viscosity

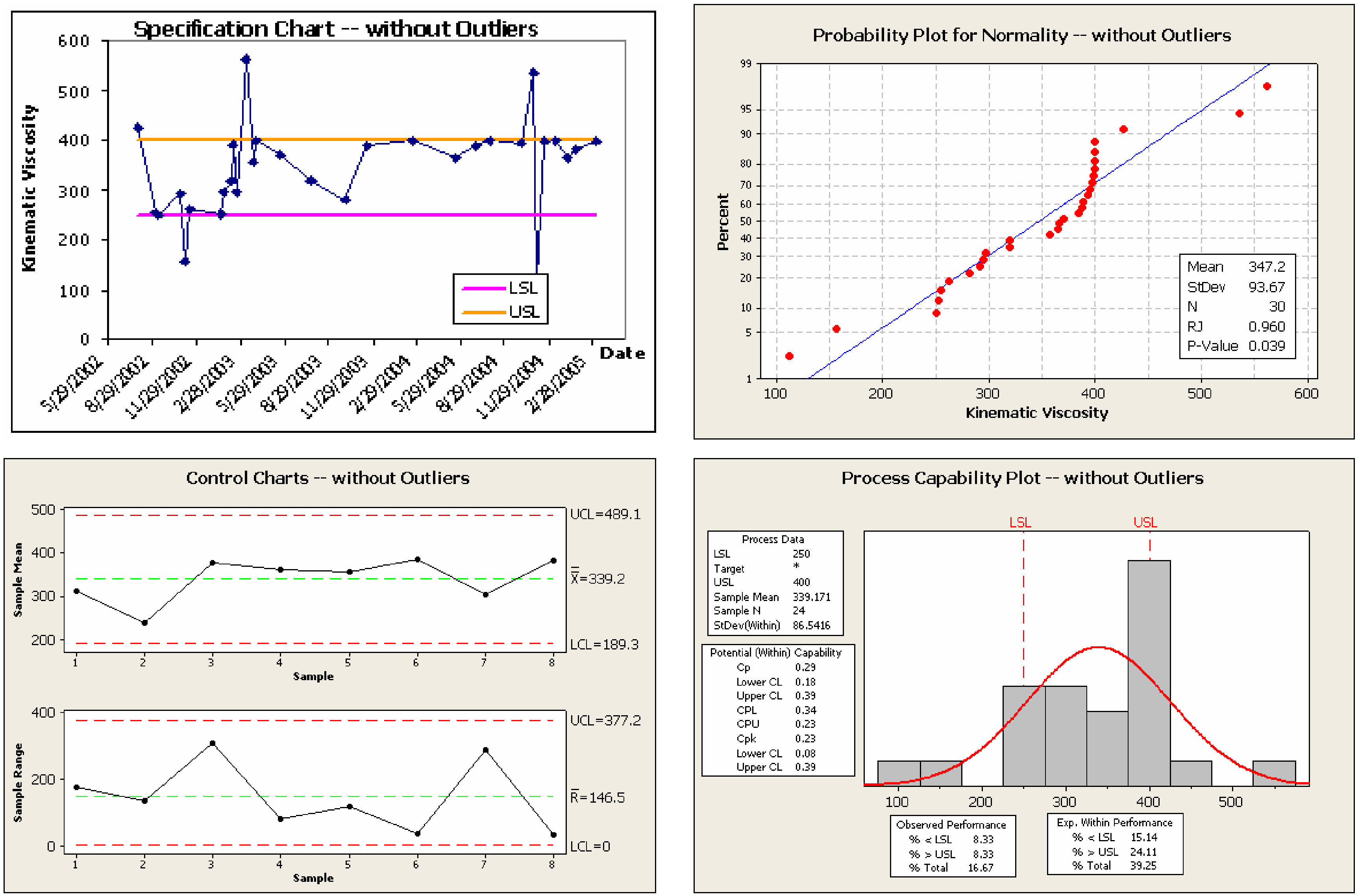


Figure E-34 Statistical Analysis Charts (without Outliers) for Supplier: 0301 Grade: RC-250 Test: Kinematic Viscosity

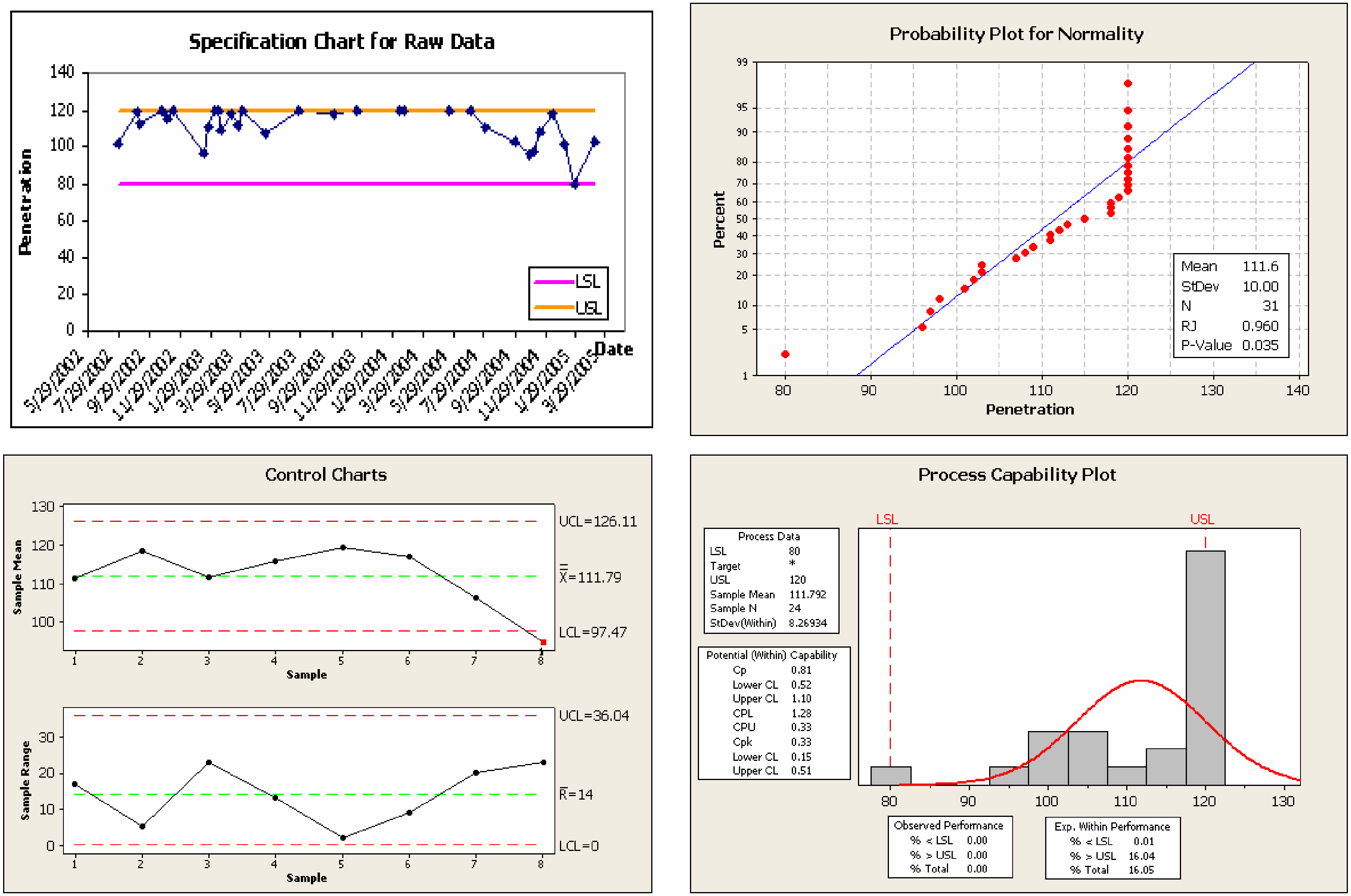


Figure E-35 Statistical Analysis Charts for Supplier: 0301 Grade: RC-250 Test: Penetration

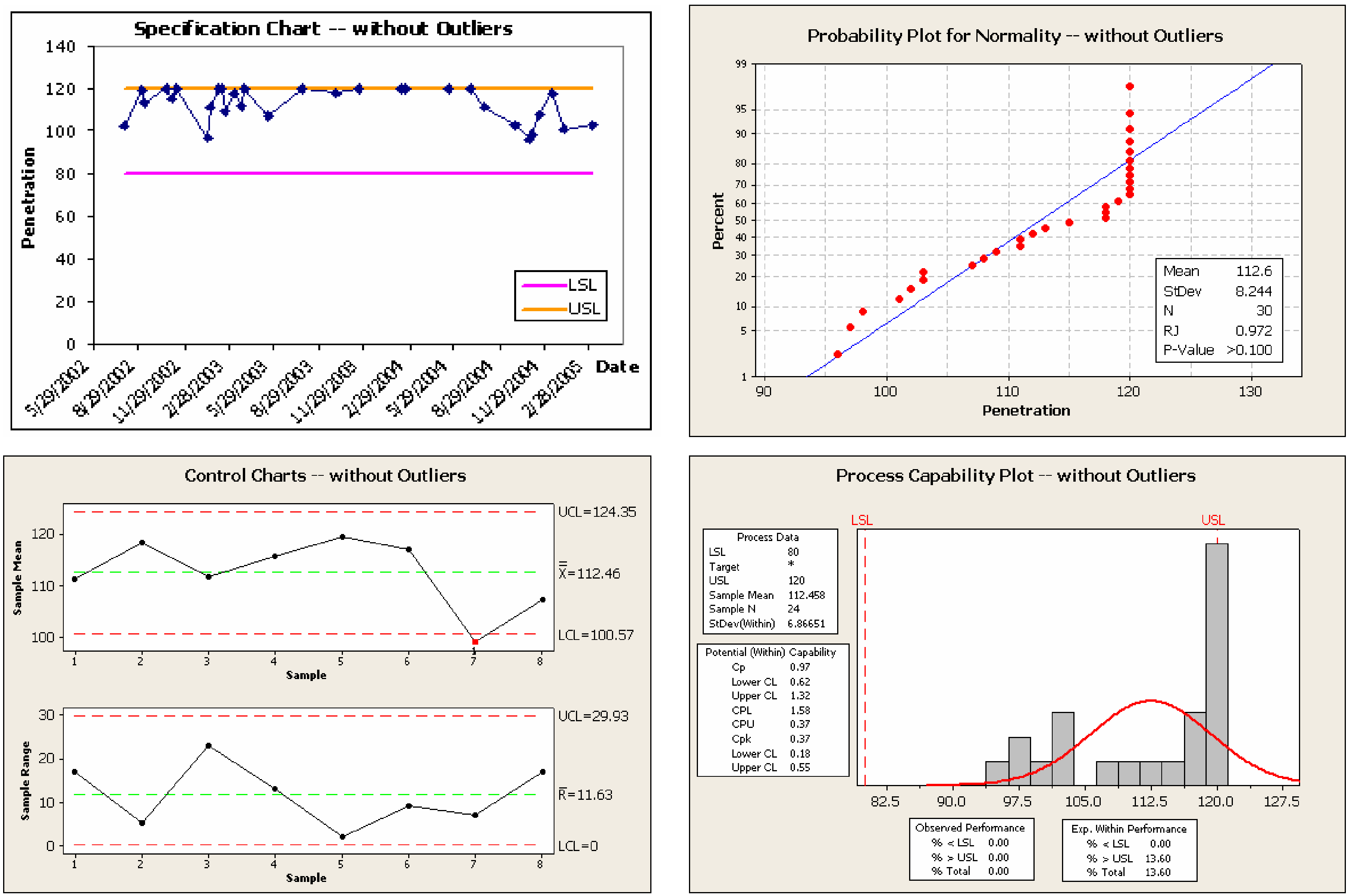


Figure E-36 Statistical Analysis Charts (without Outliers) for Supplier: 0301 Grade: RC-250 Test: Penetration

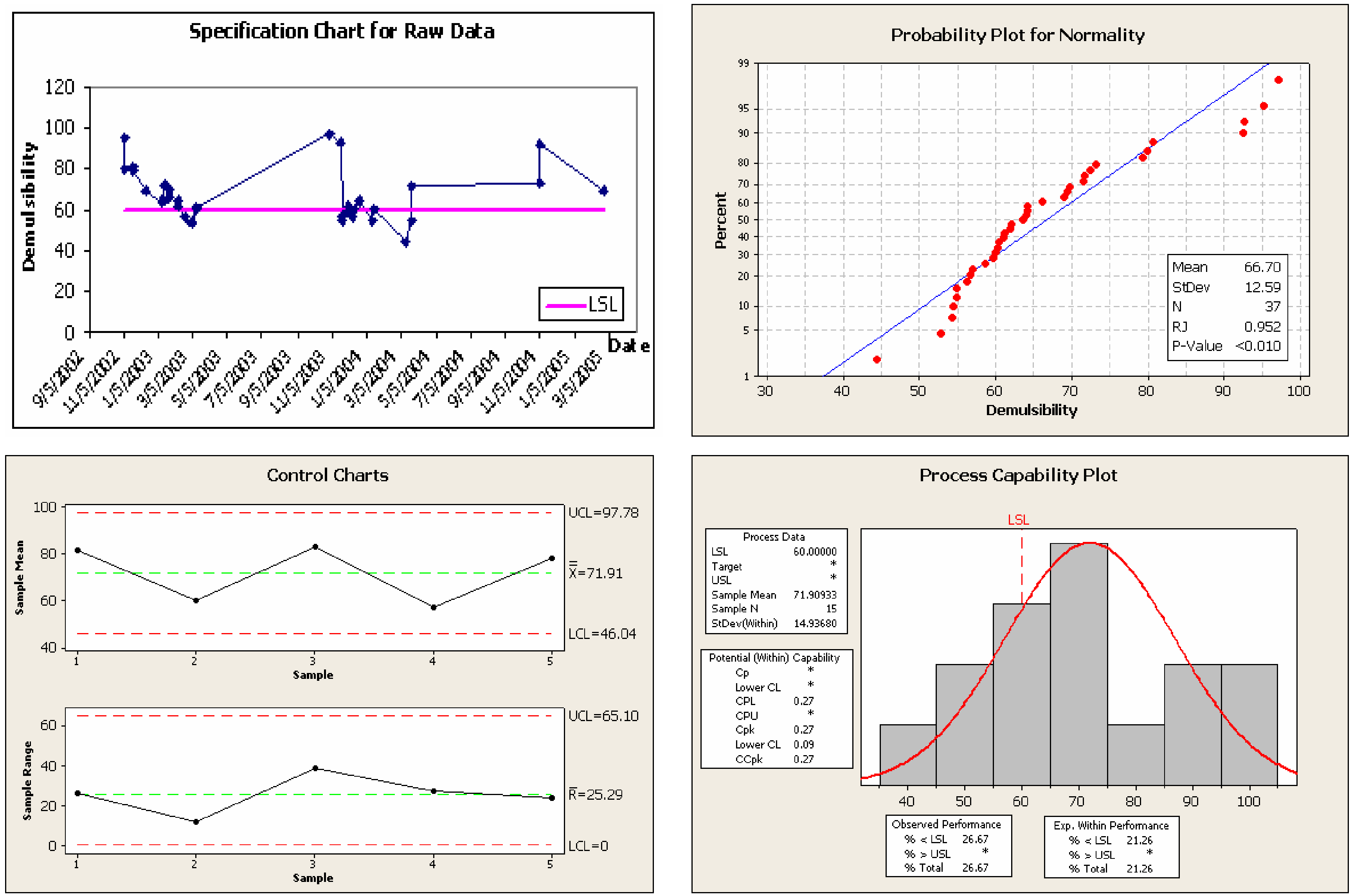
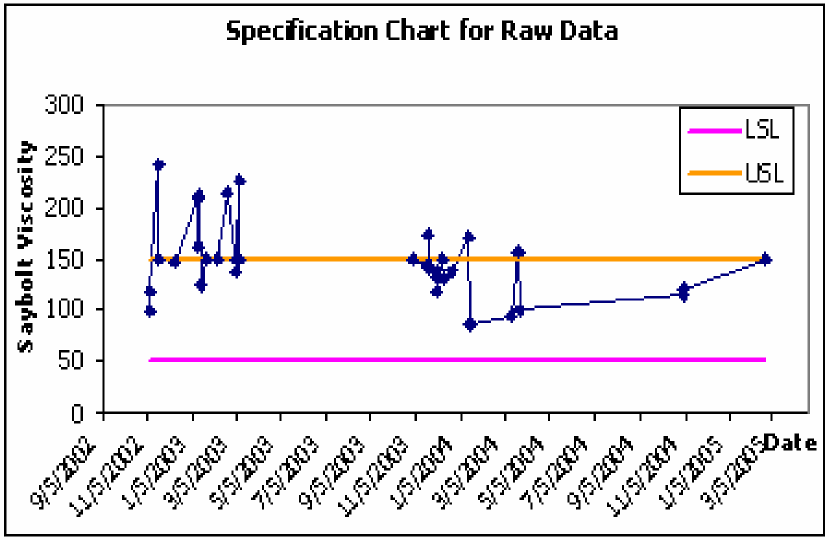
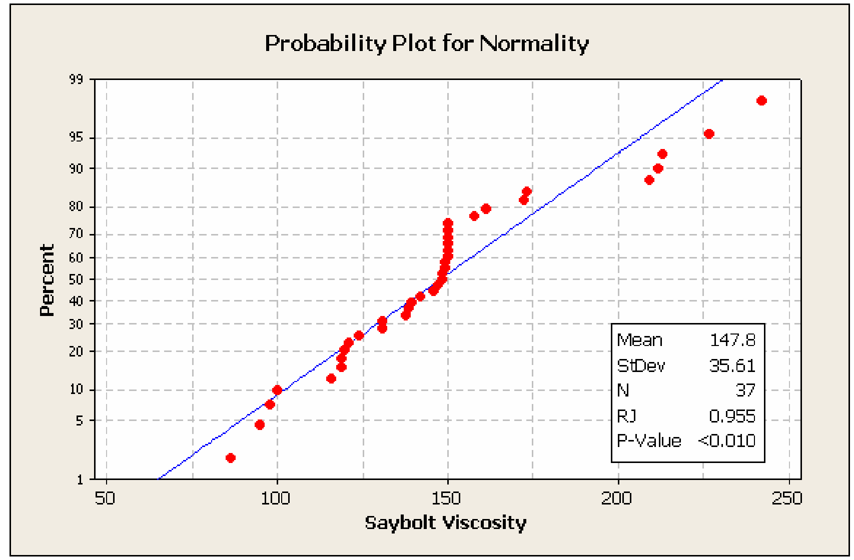
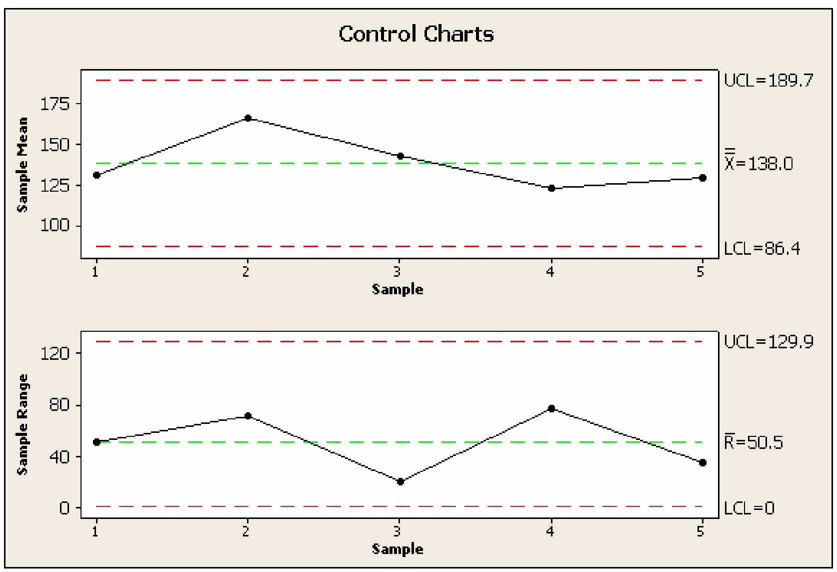


Figure E-37 Statistical Analysis Charts for Supplier: 0401 Grade: CRS-1P Test: Demulsibility







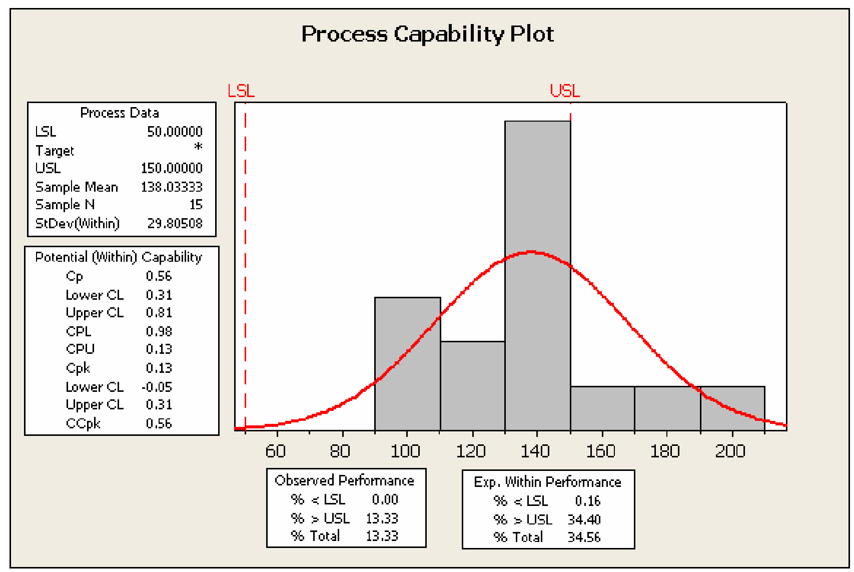


Figure E-38 Statistical Analysis Charts for Supplier: 0401 Grade: CRS-1P Test: Saybolt Viscosity

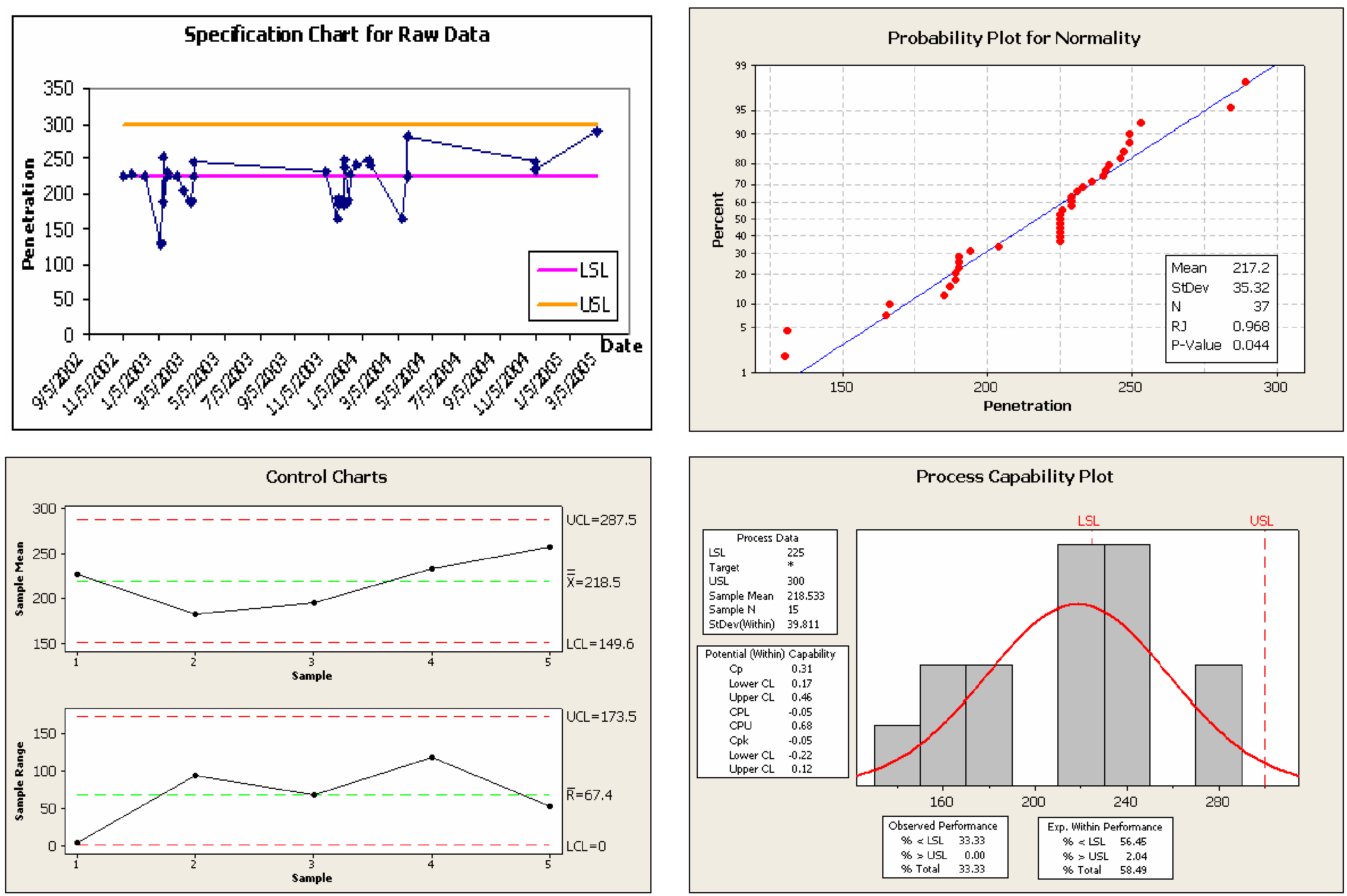


Figure E-39 Statistical Analysis Charts for Supplier: 0401 Grade: CRS-1P Test: Penetration

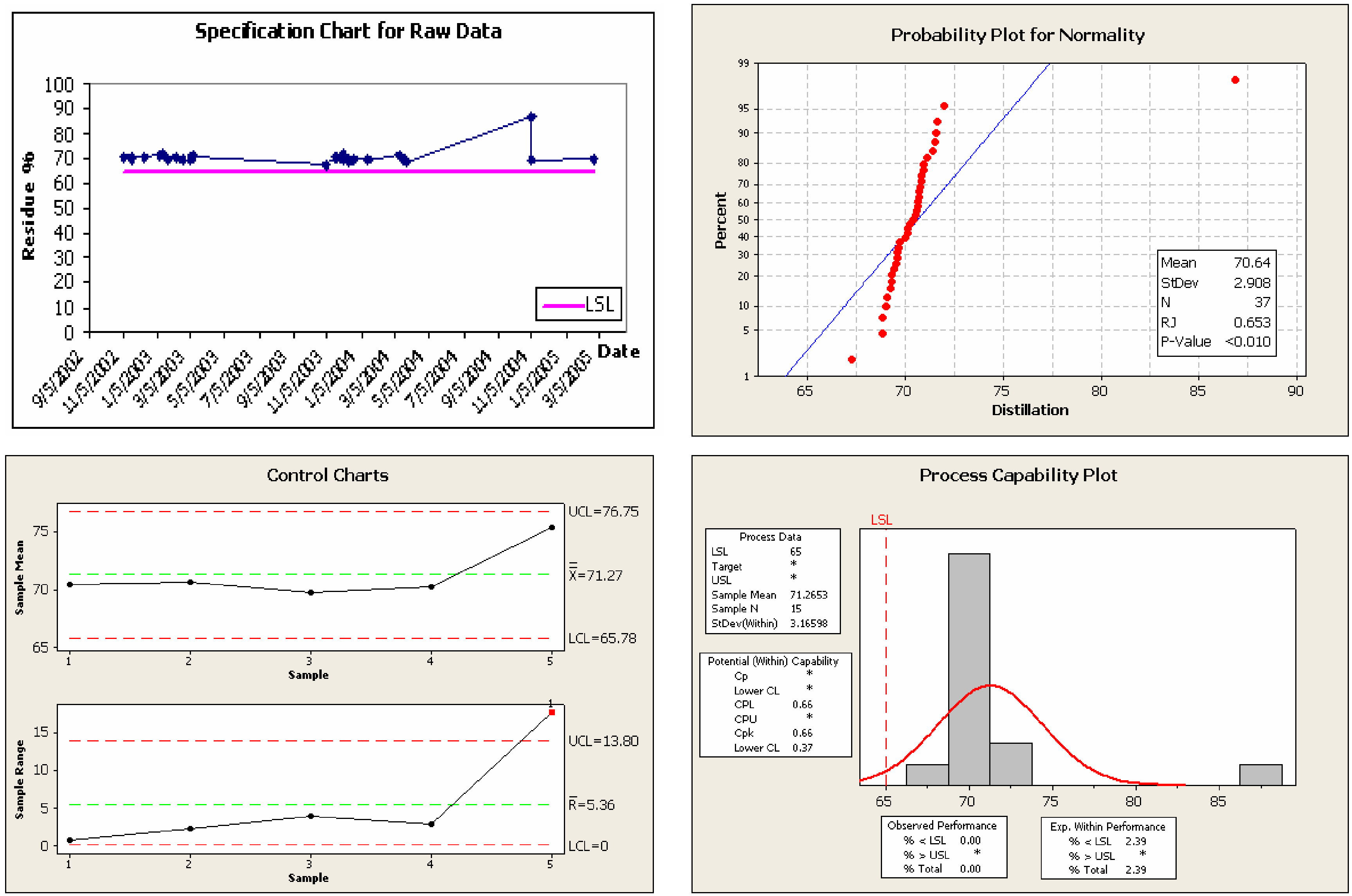


Figure E-40 Statistical Analysis Charts for Supplier: 0401 Grade: CRS-1P Test: Distillation

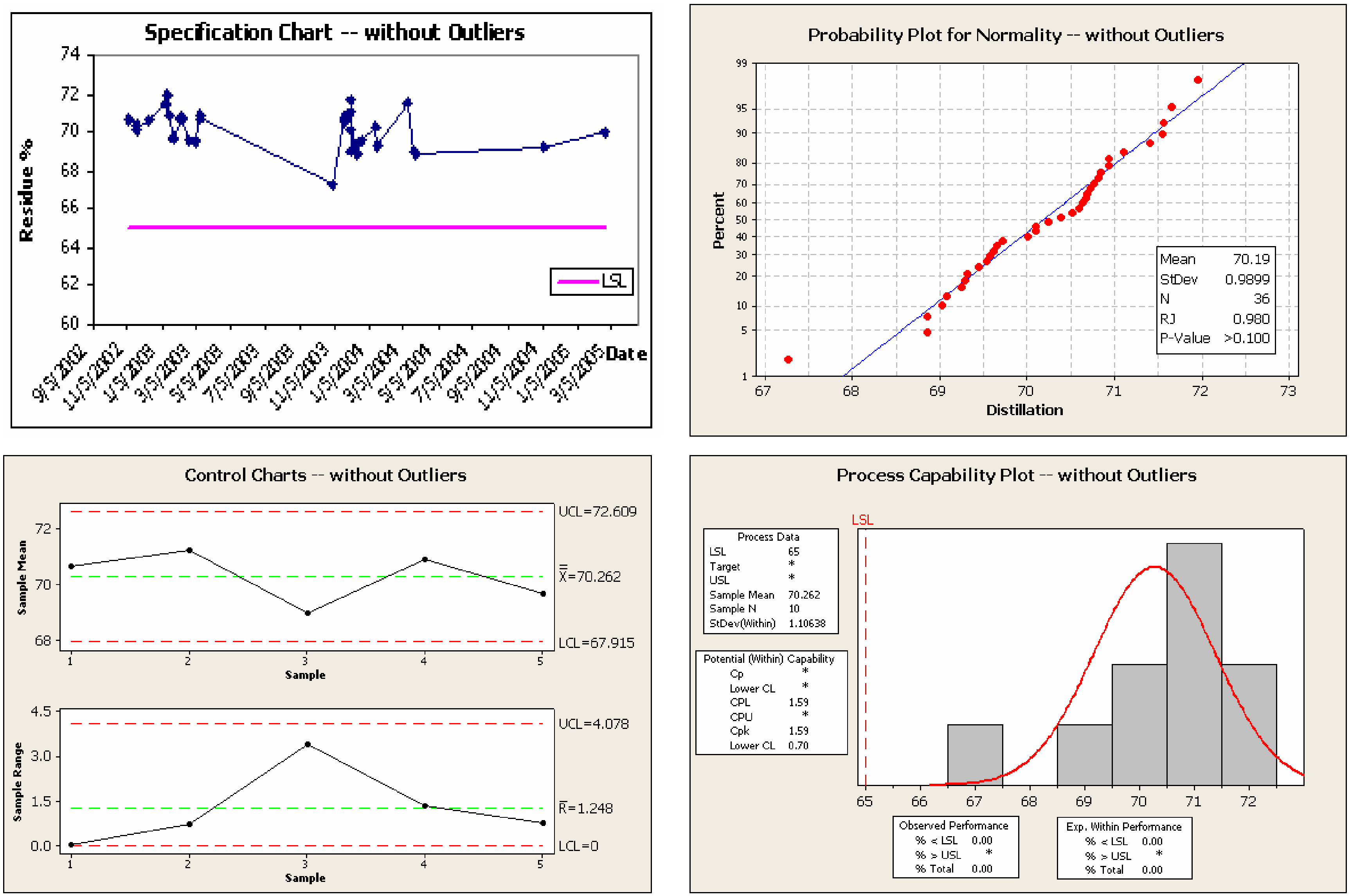


Figure E-41 Statistical Analysis Charts (without Outliers) for Supplier: 0401 Grade: CRS-1P Test: Distillation

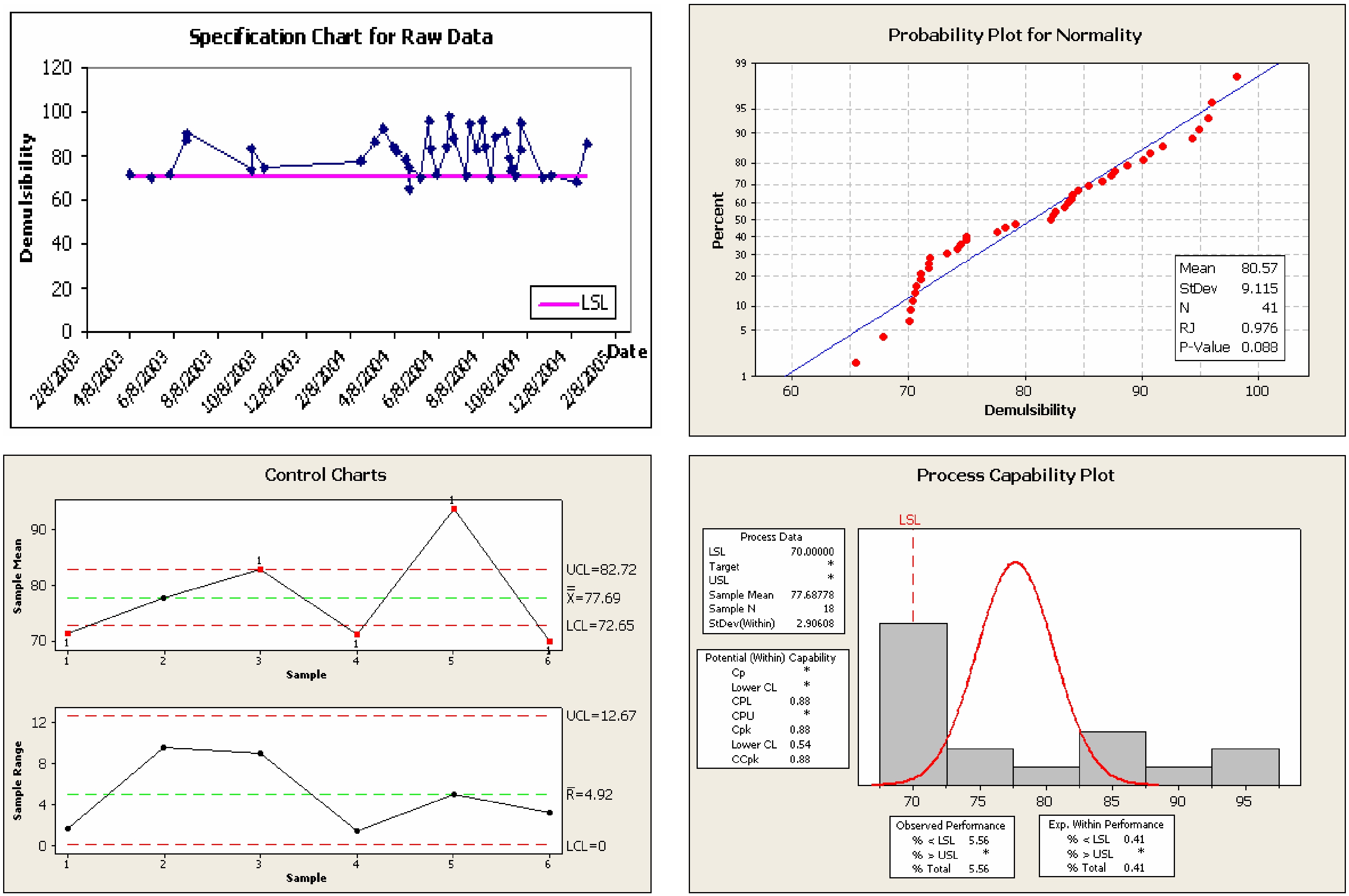


Figure E-42 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2 Test: Demulsibility

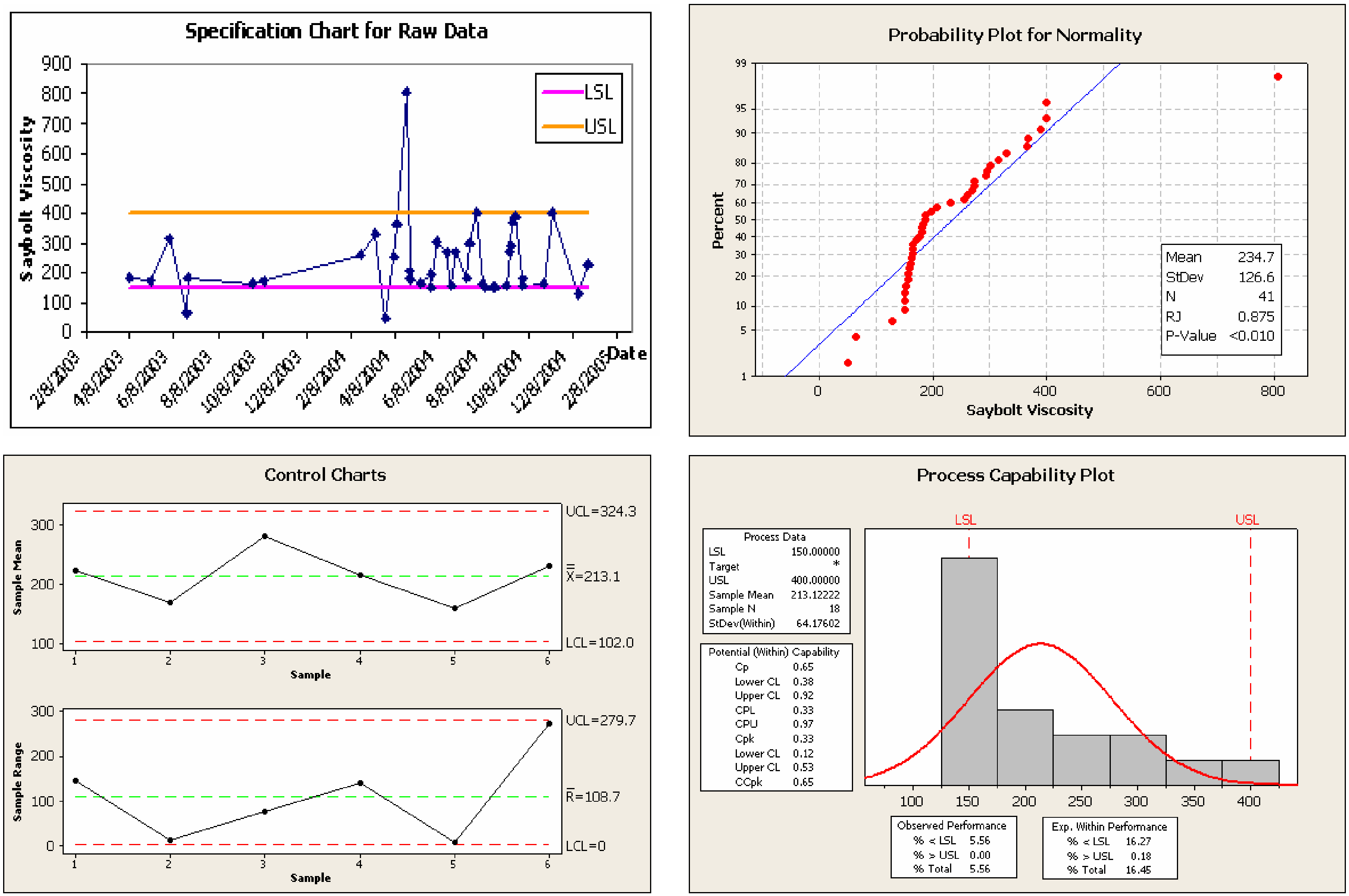
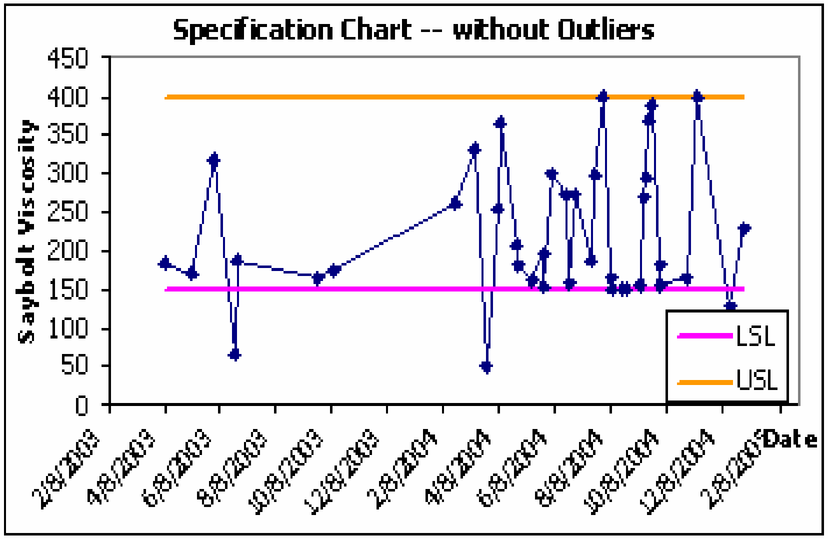
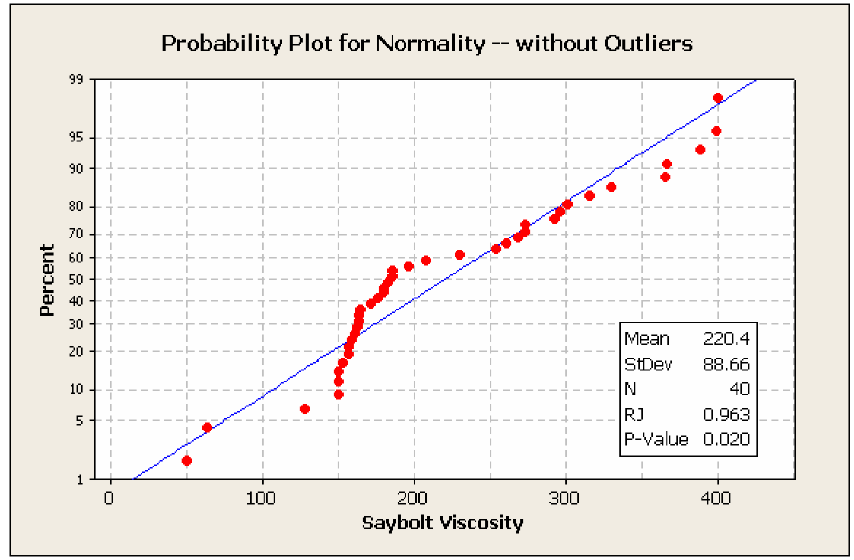
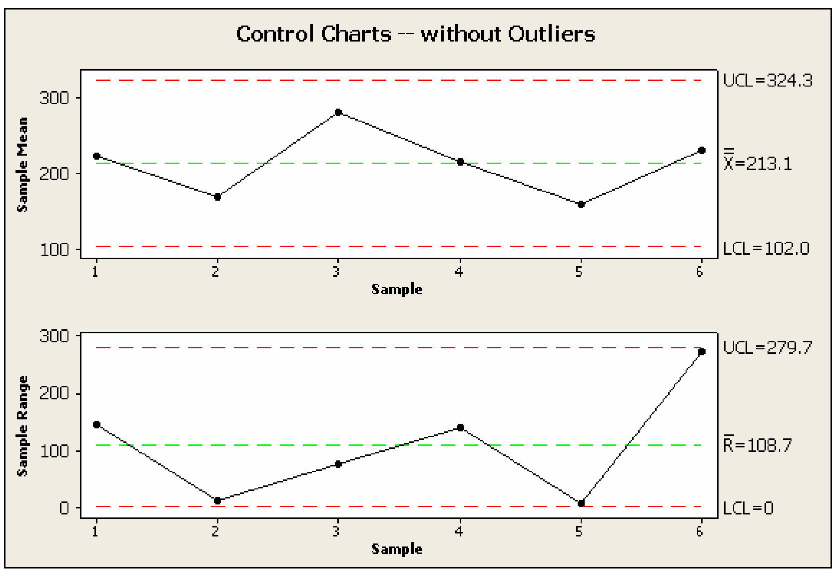


Figure E-43 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2 Test: Saybolt Viscosity







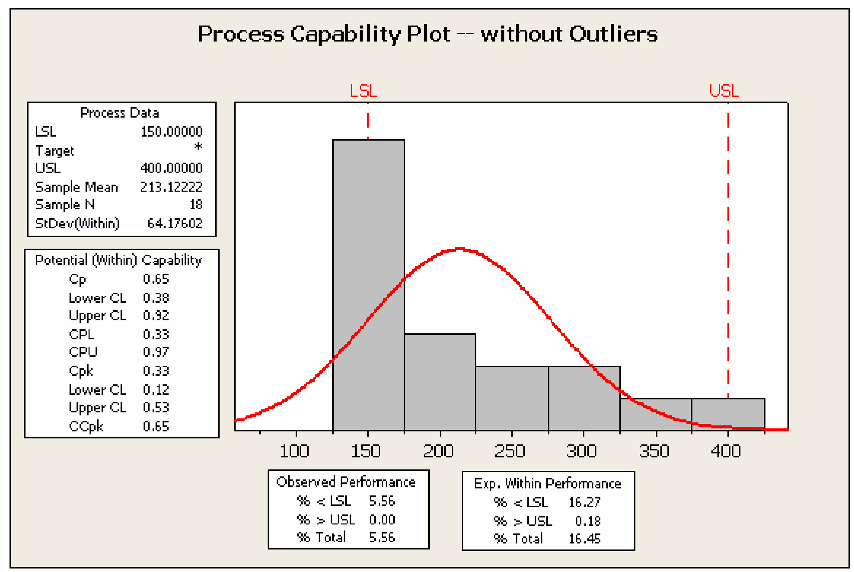


Figure E-44 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CRS-2 Test: Saybolt Viscosity

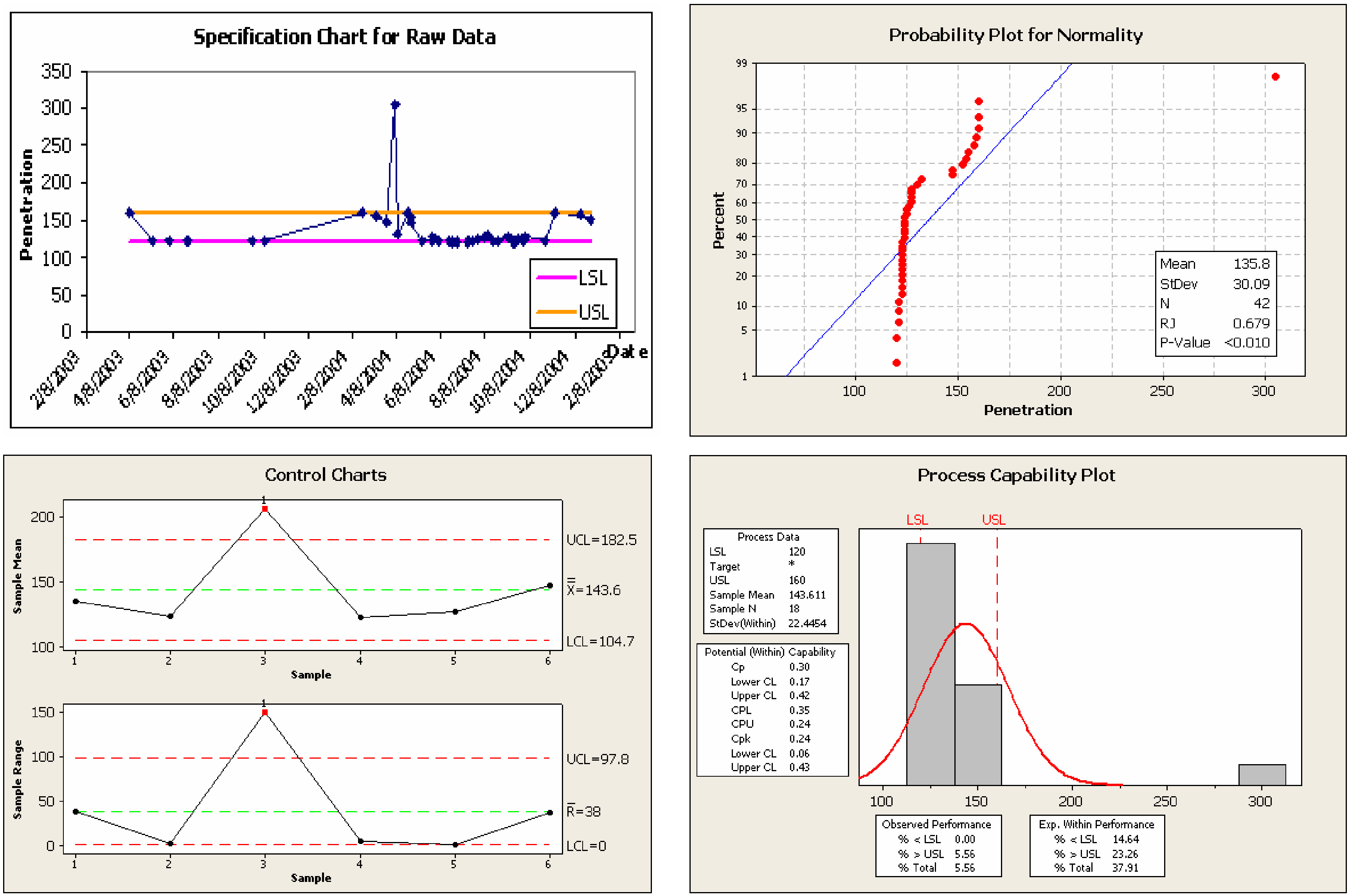


Figure E-45 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2 Test: Penetration

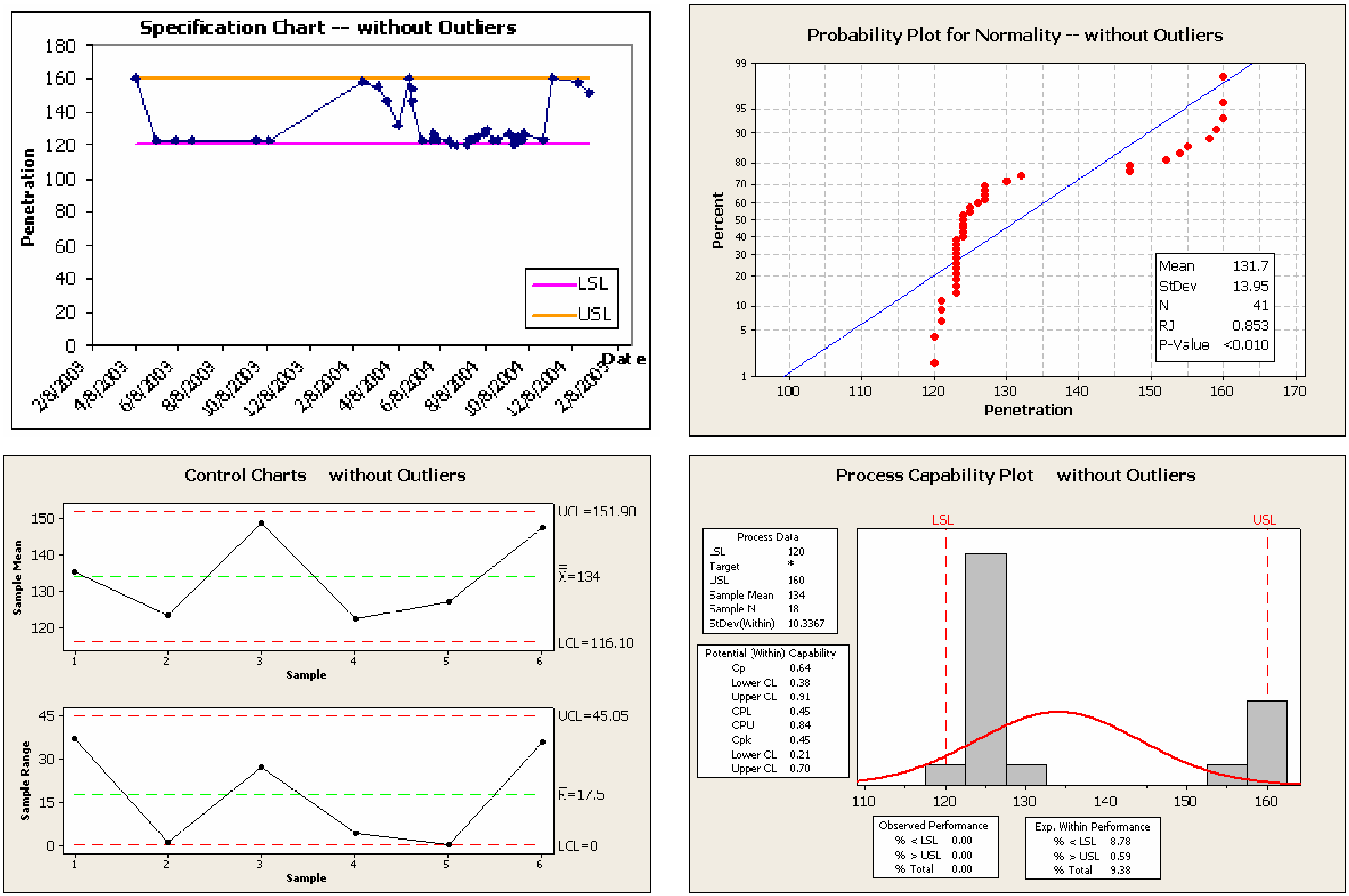


Figure E-46 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CRS-2 Test: Penetration

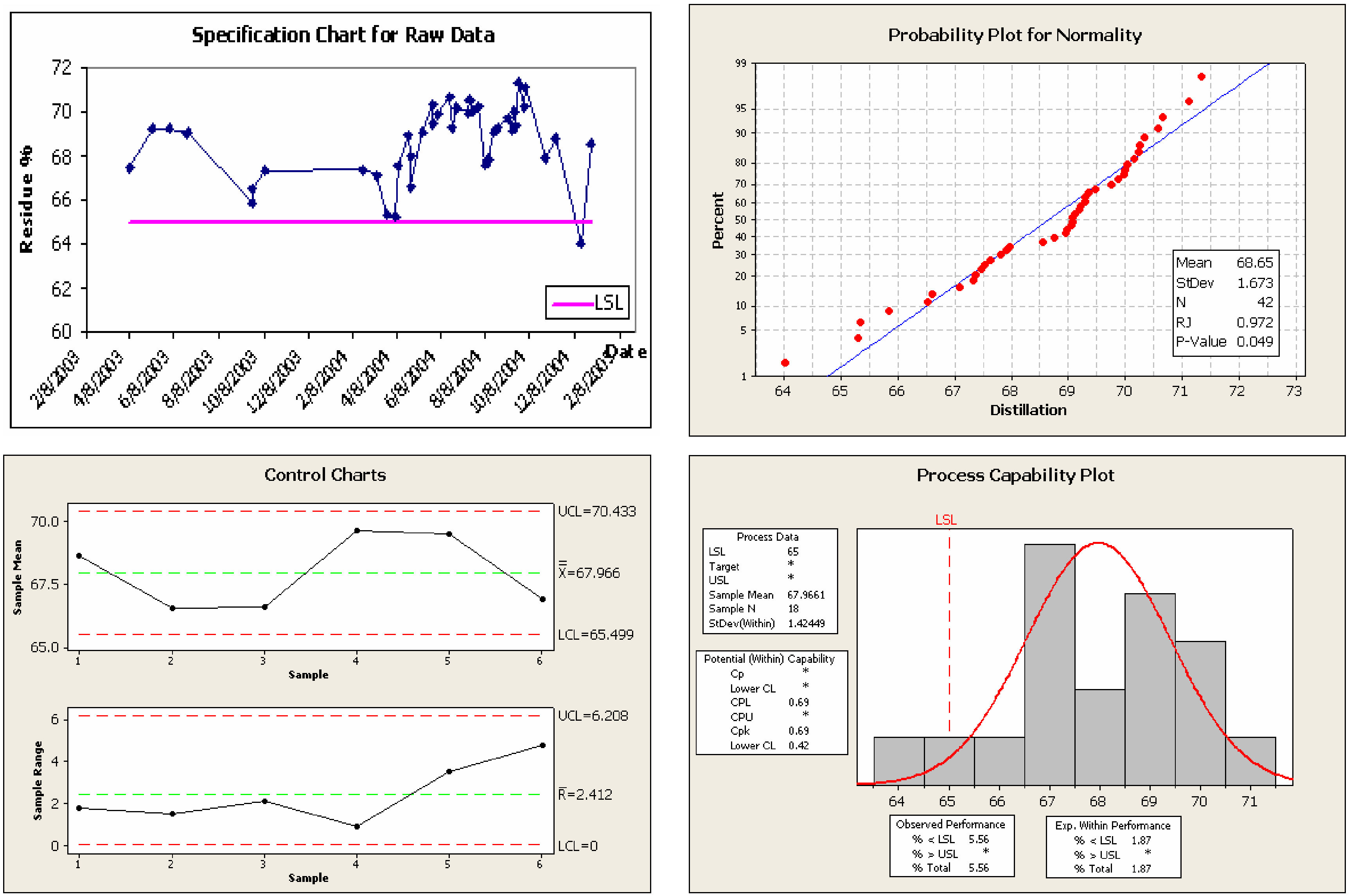


Figure E-47 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2 Test: Distillation

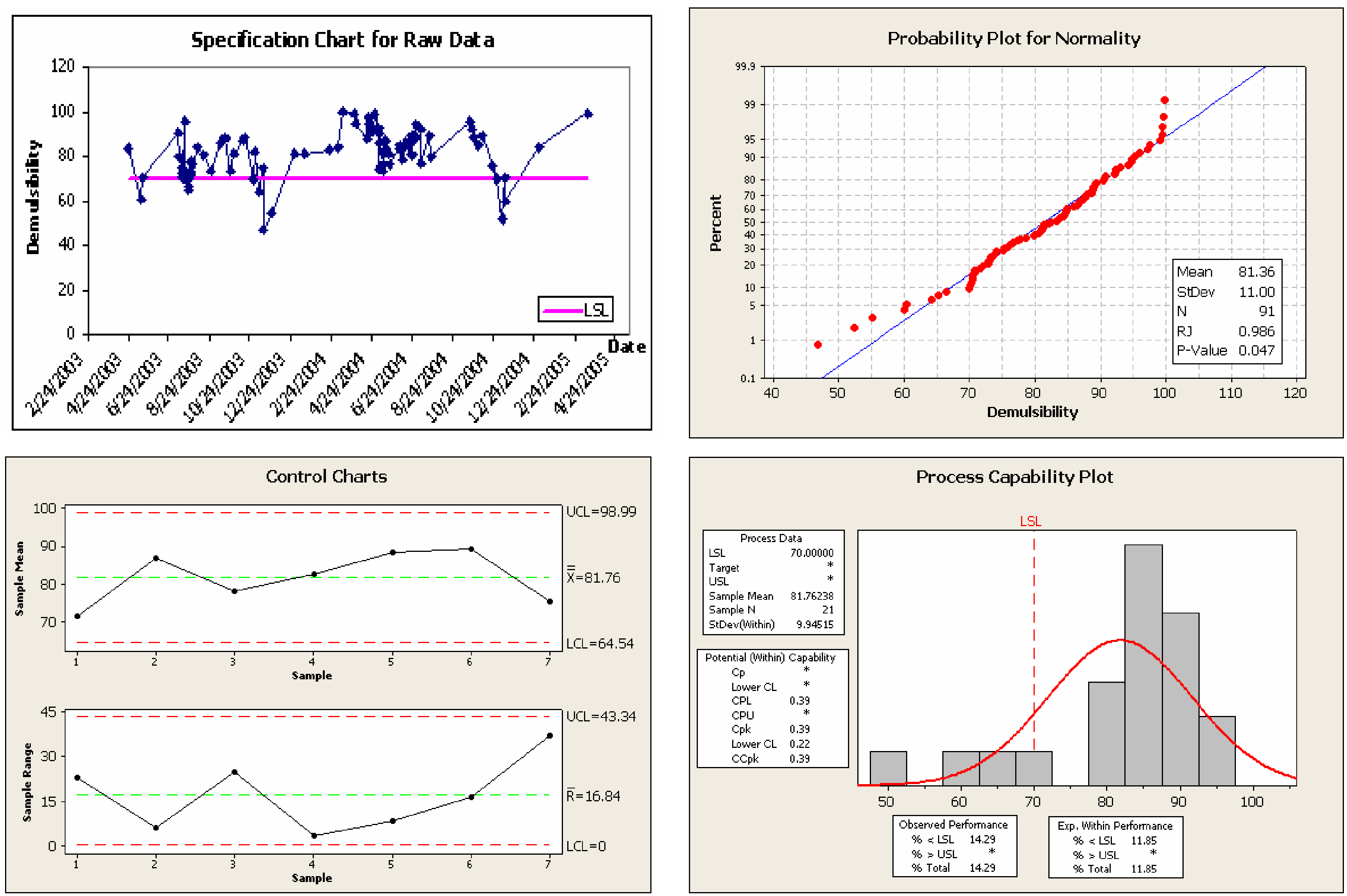


Figure E-48 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2P Test: Demulsibility

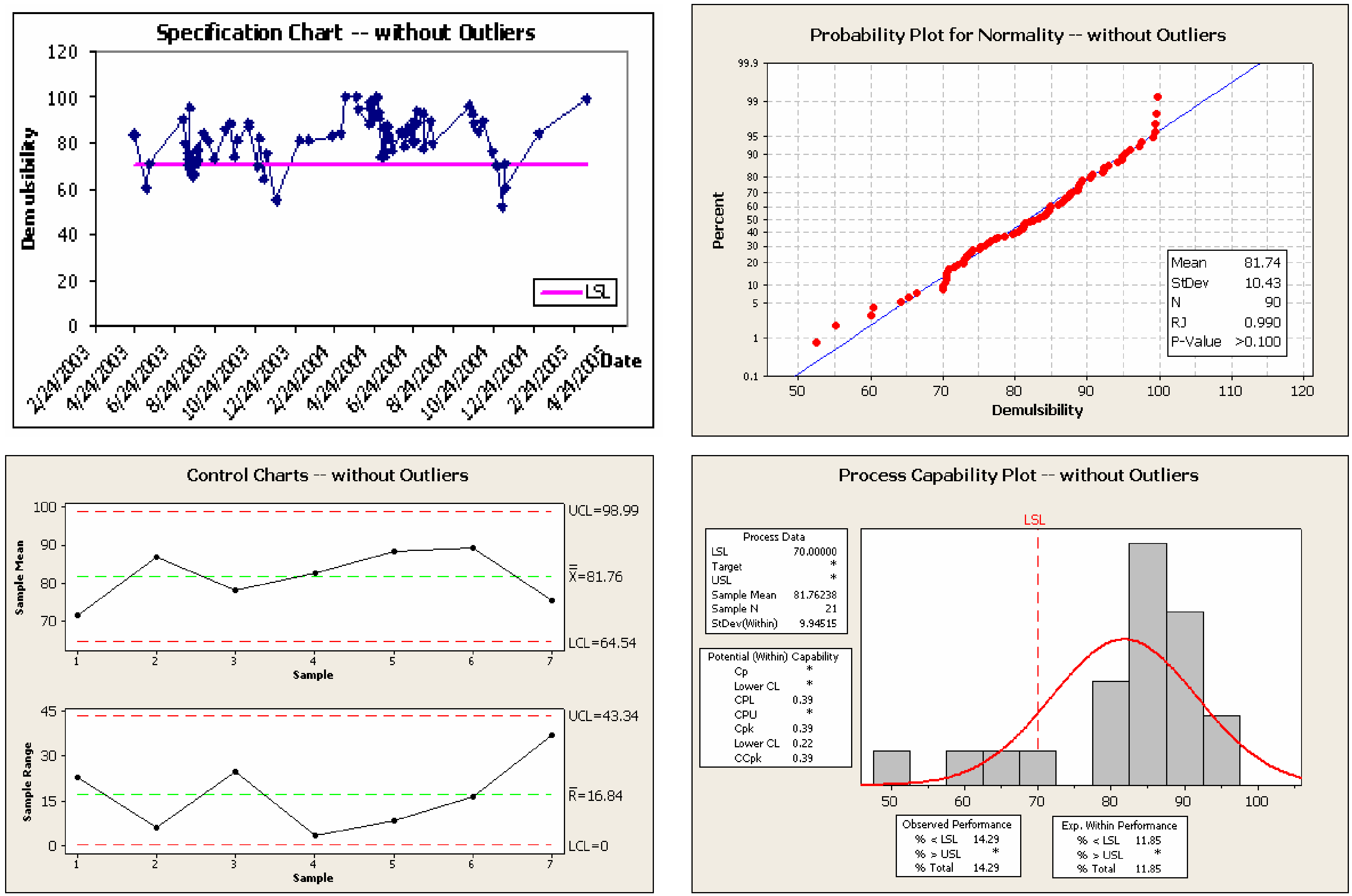


Figure E-49 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CRS-2P Test: Demulsibility

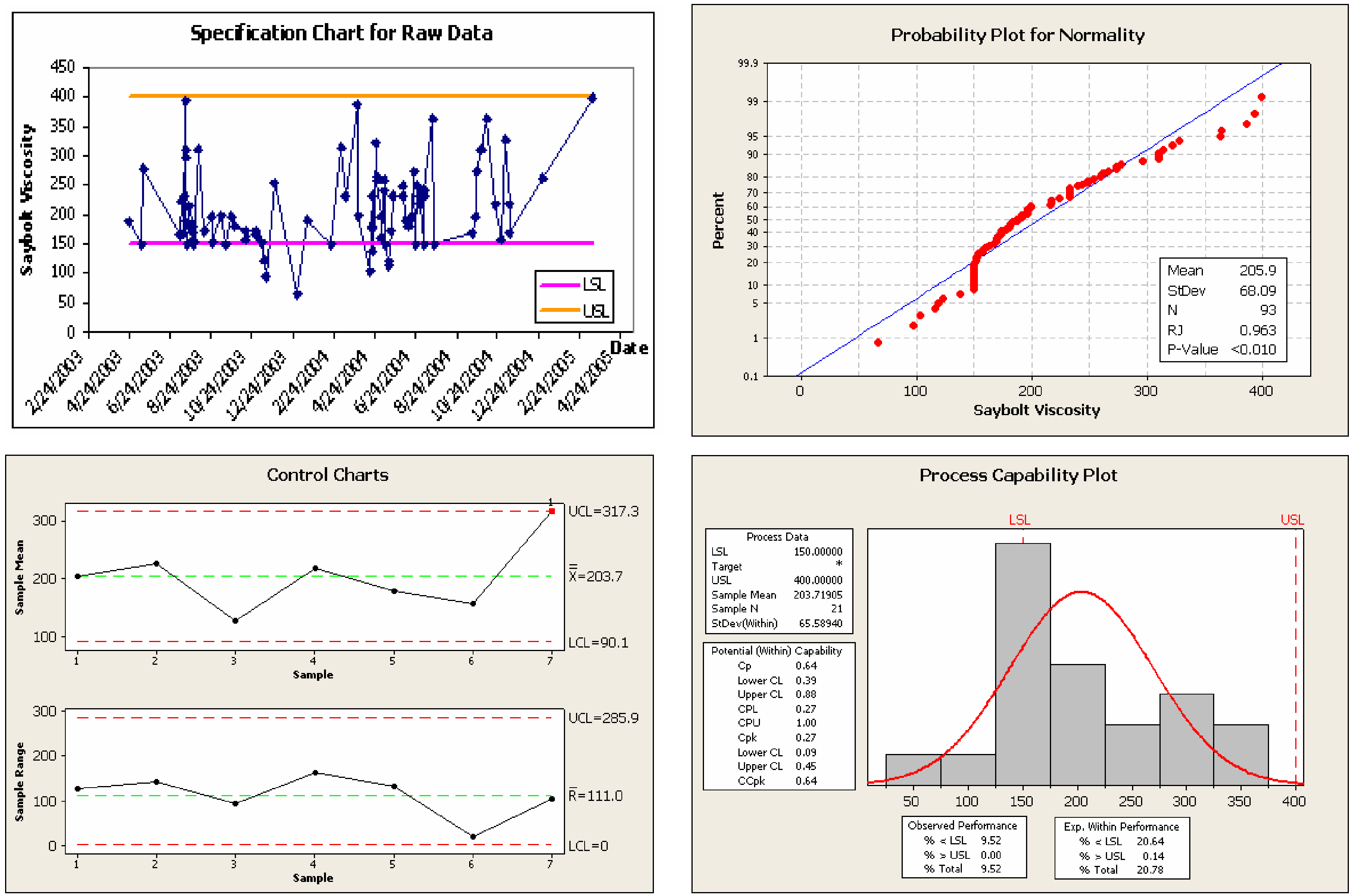


Figure E-50 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2P Test: Saybolt Viscosity

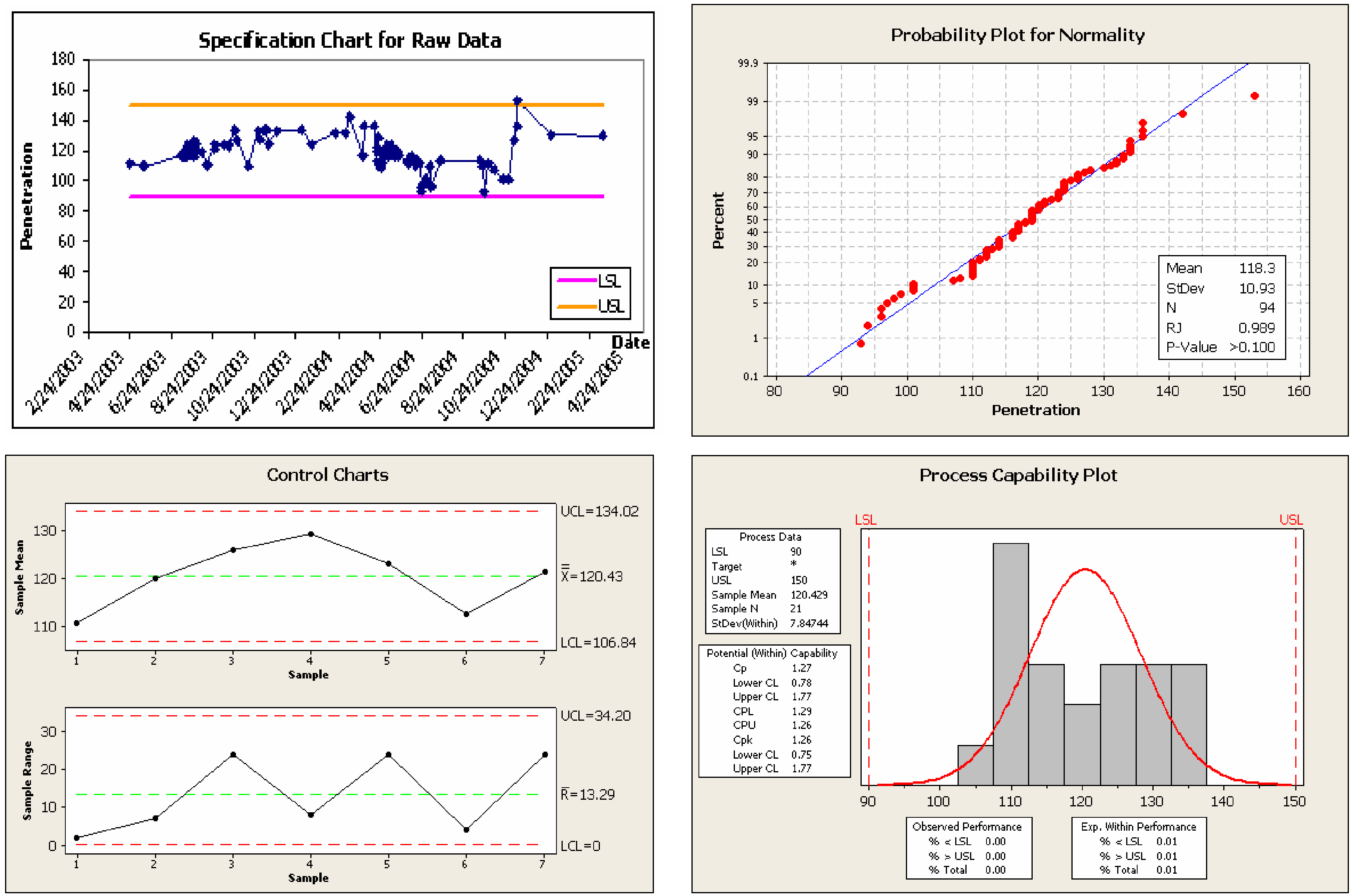


Figure E-51 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2P Test: Penetration

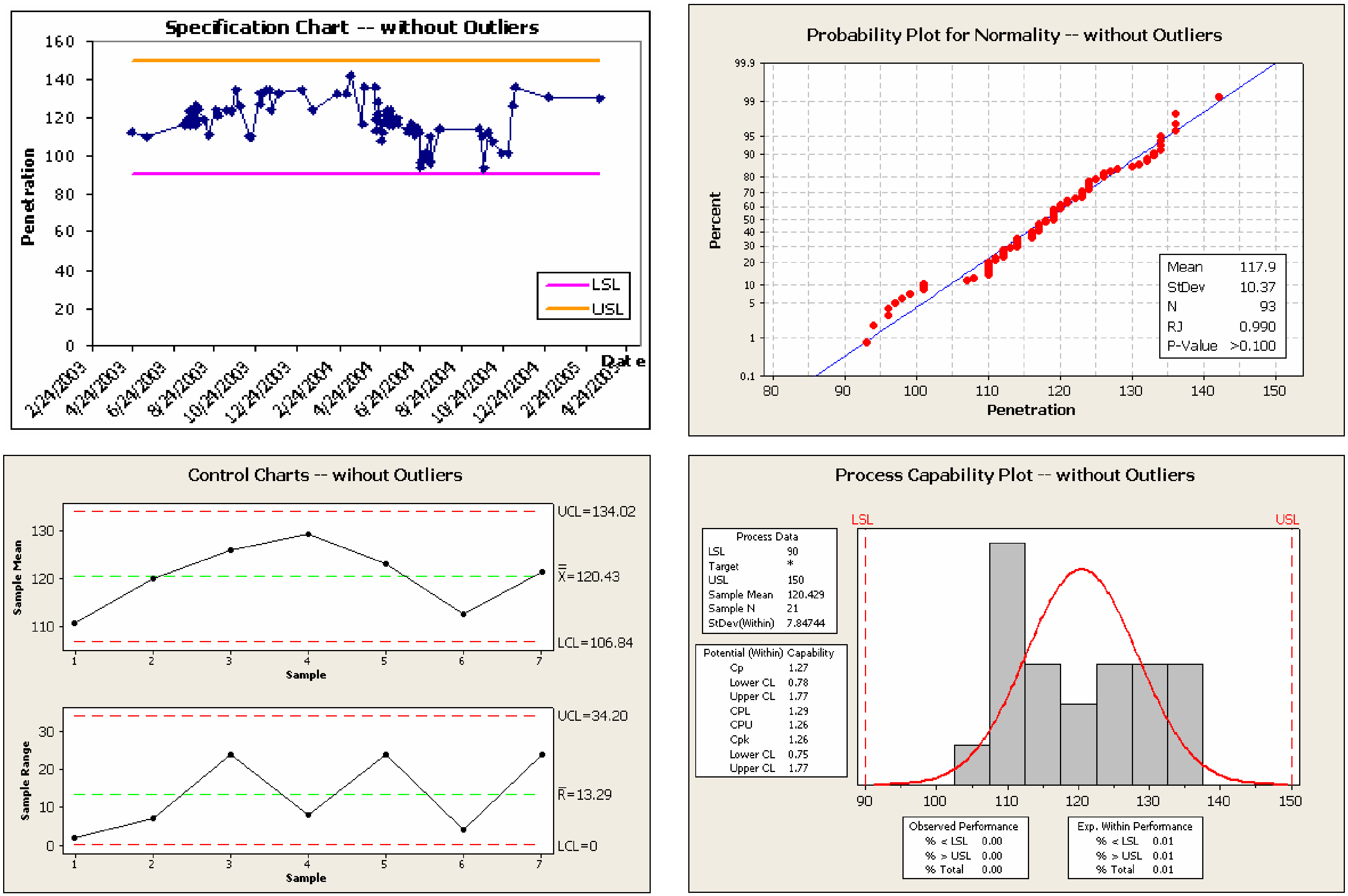


Figure E-52 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CRS-2P Test: Penetration

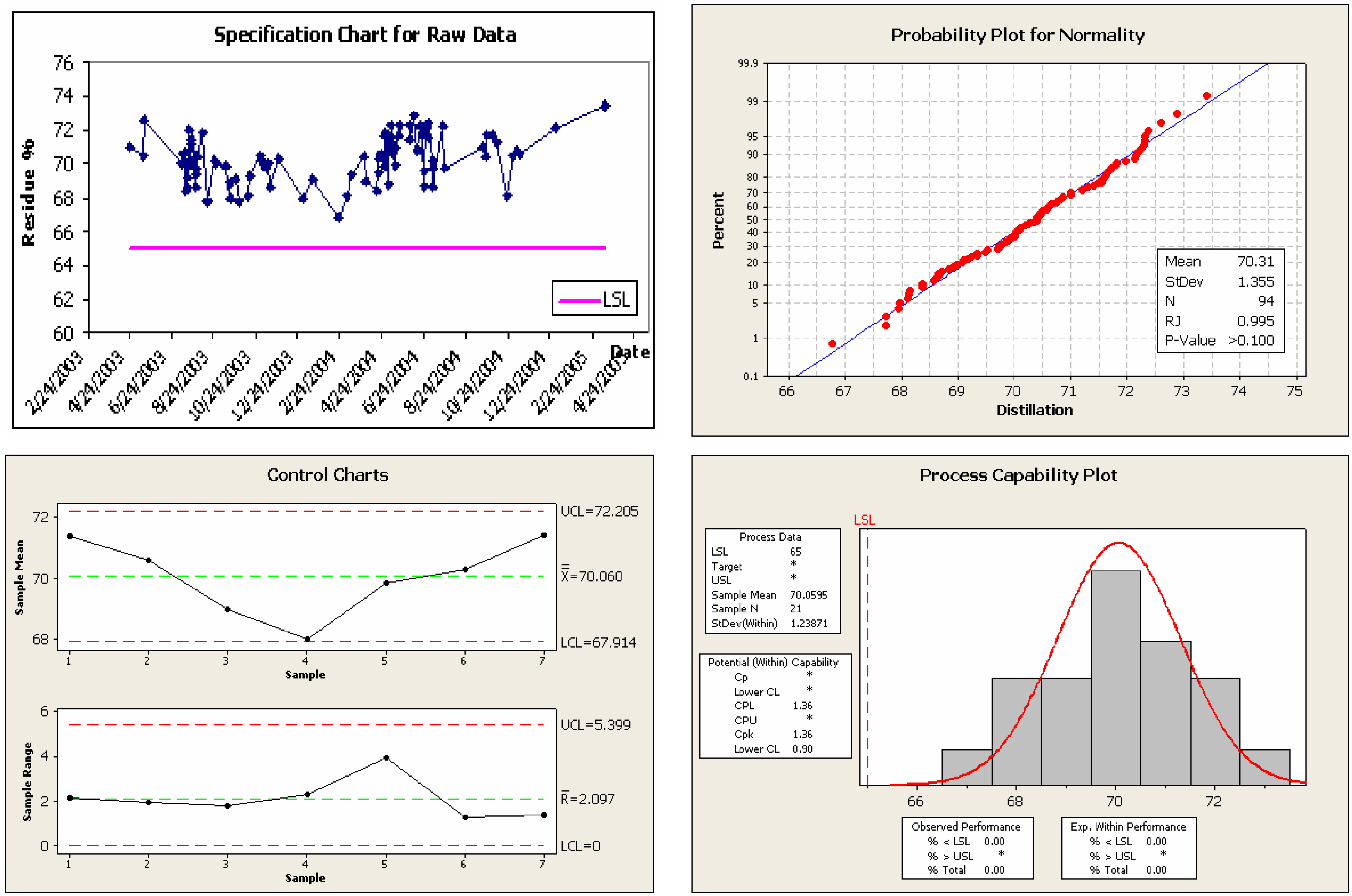


Figure E-53 Statistical Analysis Charts for Supplier: 0402 Grade: CRS-2P Test: Distillation

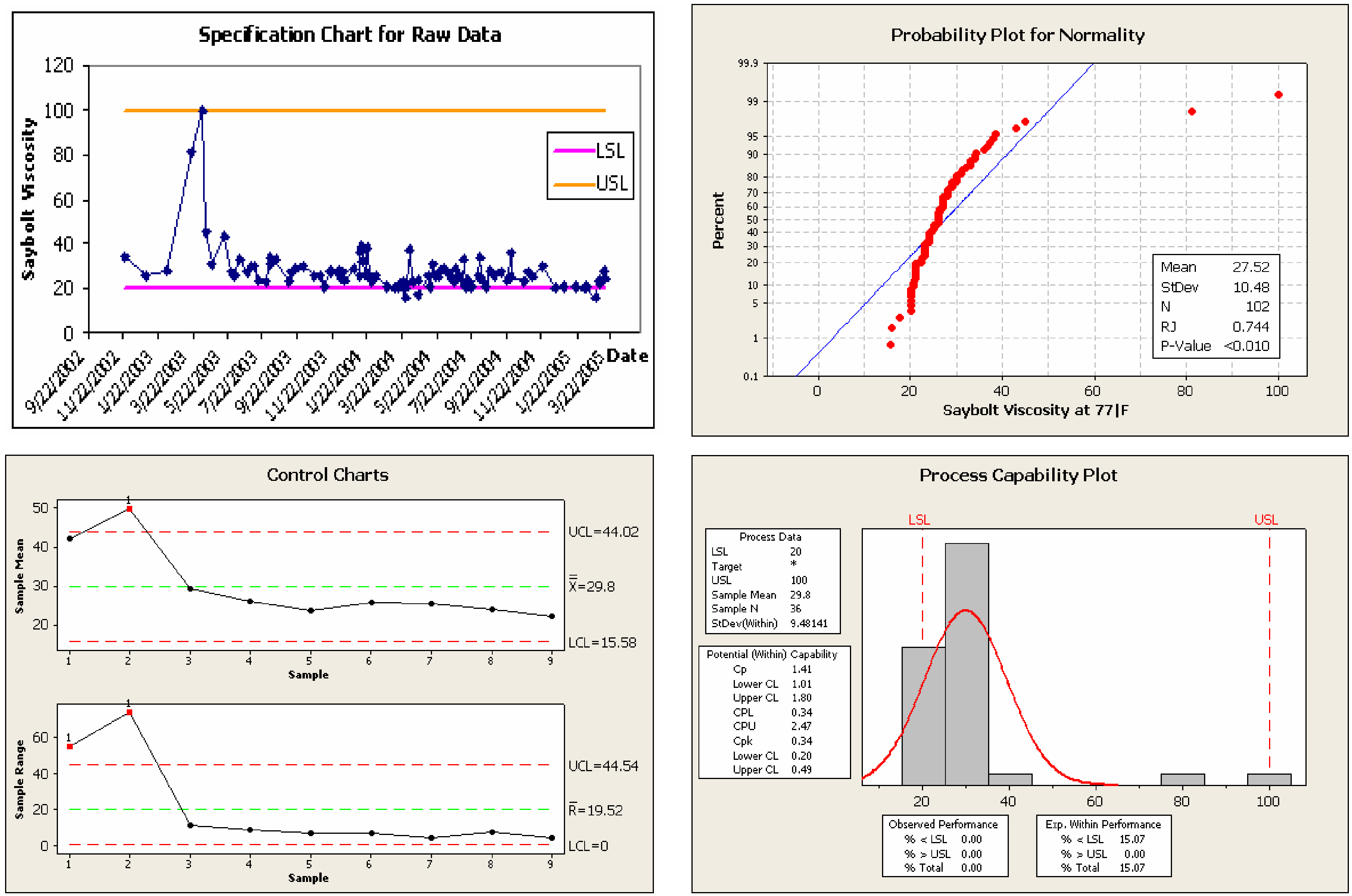


Figure E-54 Statistical Analysis Charts for Supplier: 0402 Grade: CSS-1H Test: Saybolt Viscosity

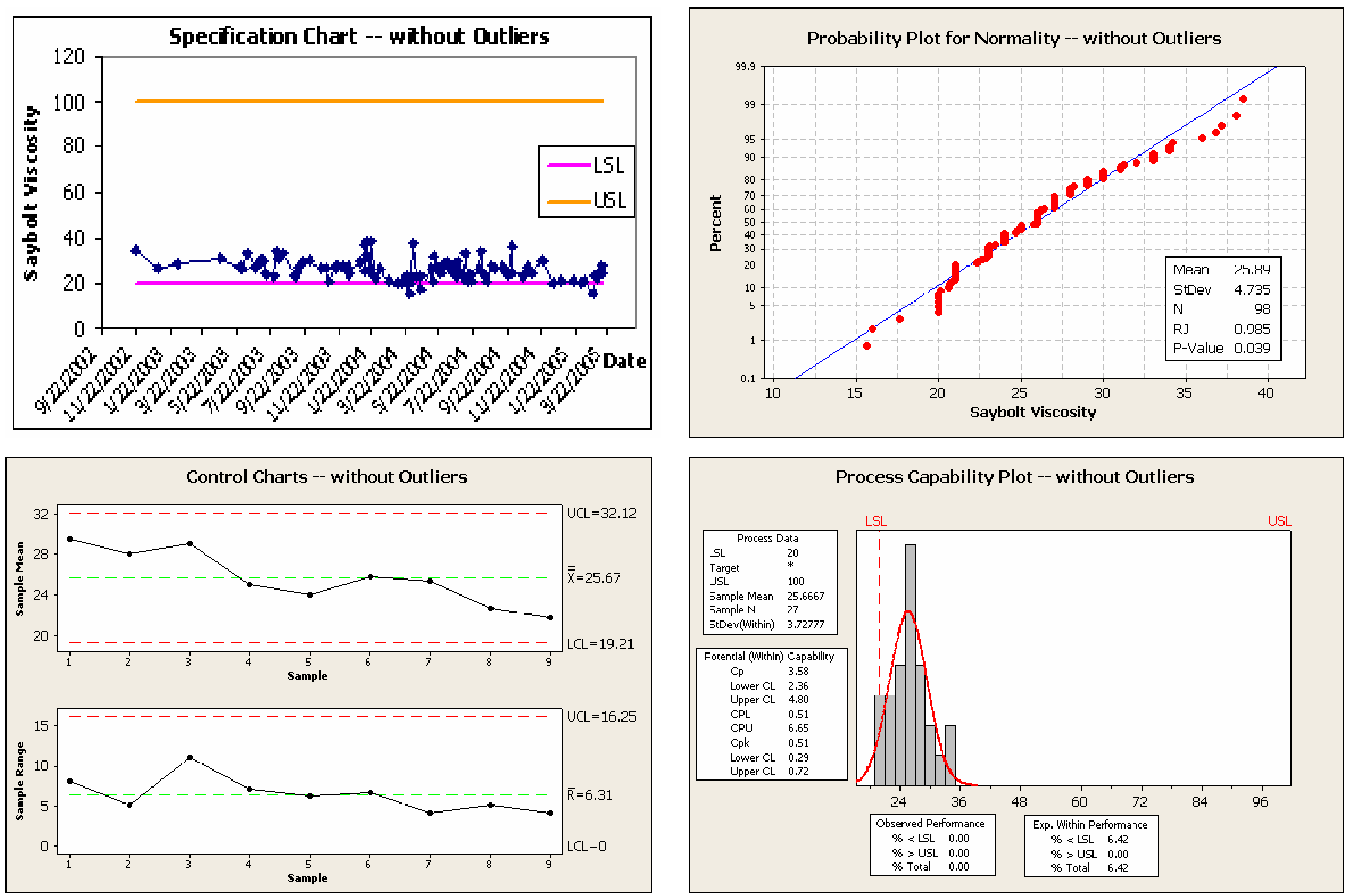


Figure E-55 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CSS-1H Test: Saybolt Viscosity

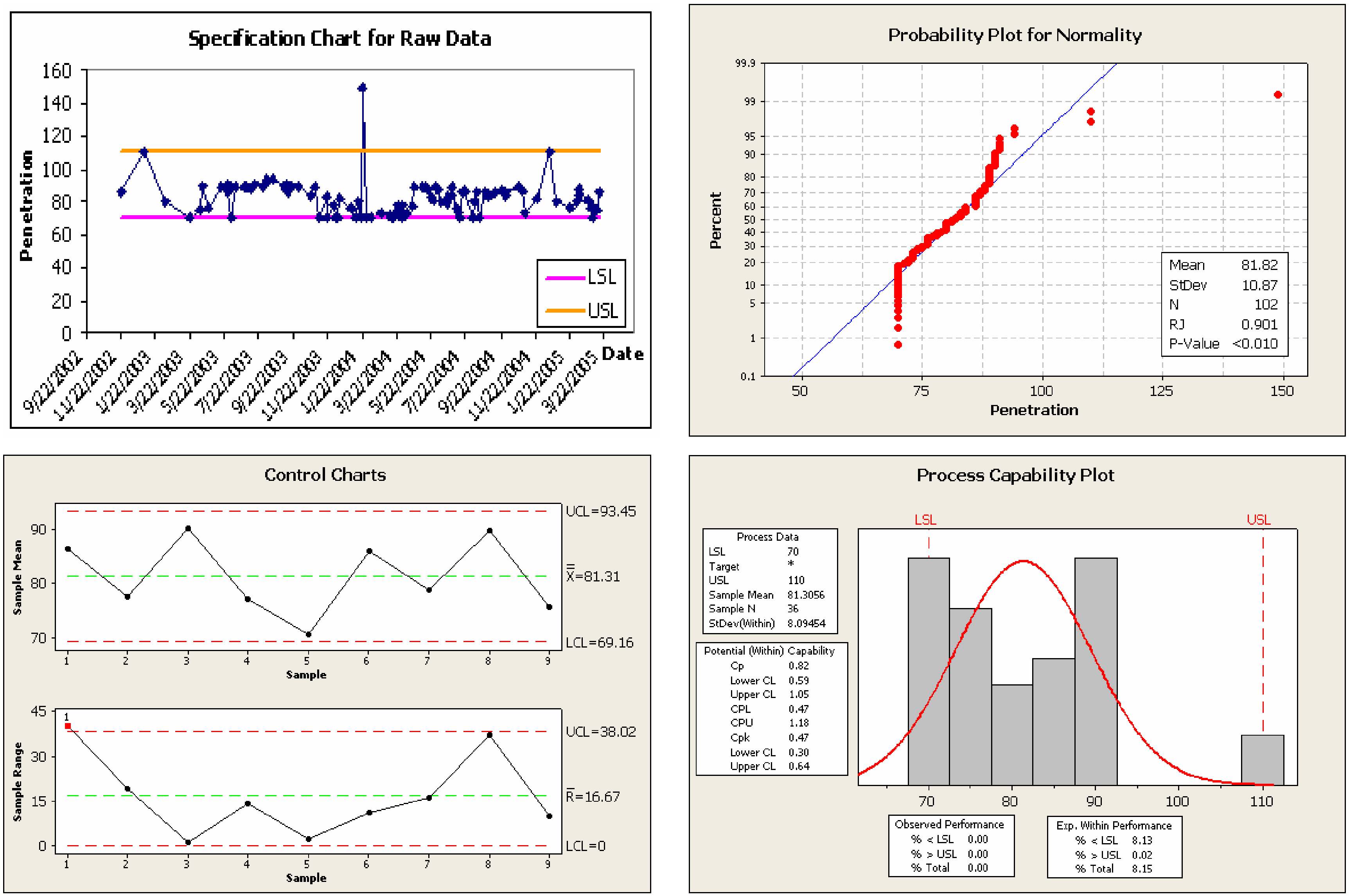


Figure E-56 Statistical Analysis Charts for Supplier: 0402 Grade: CSS-1H Test: Penetration

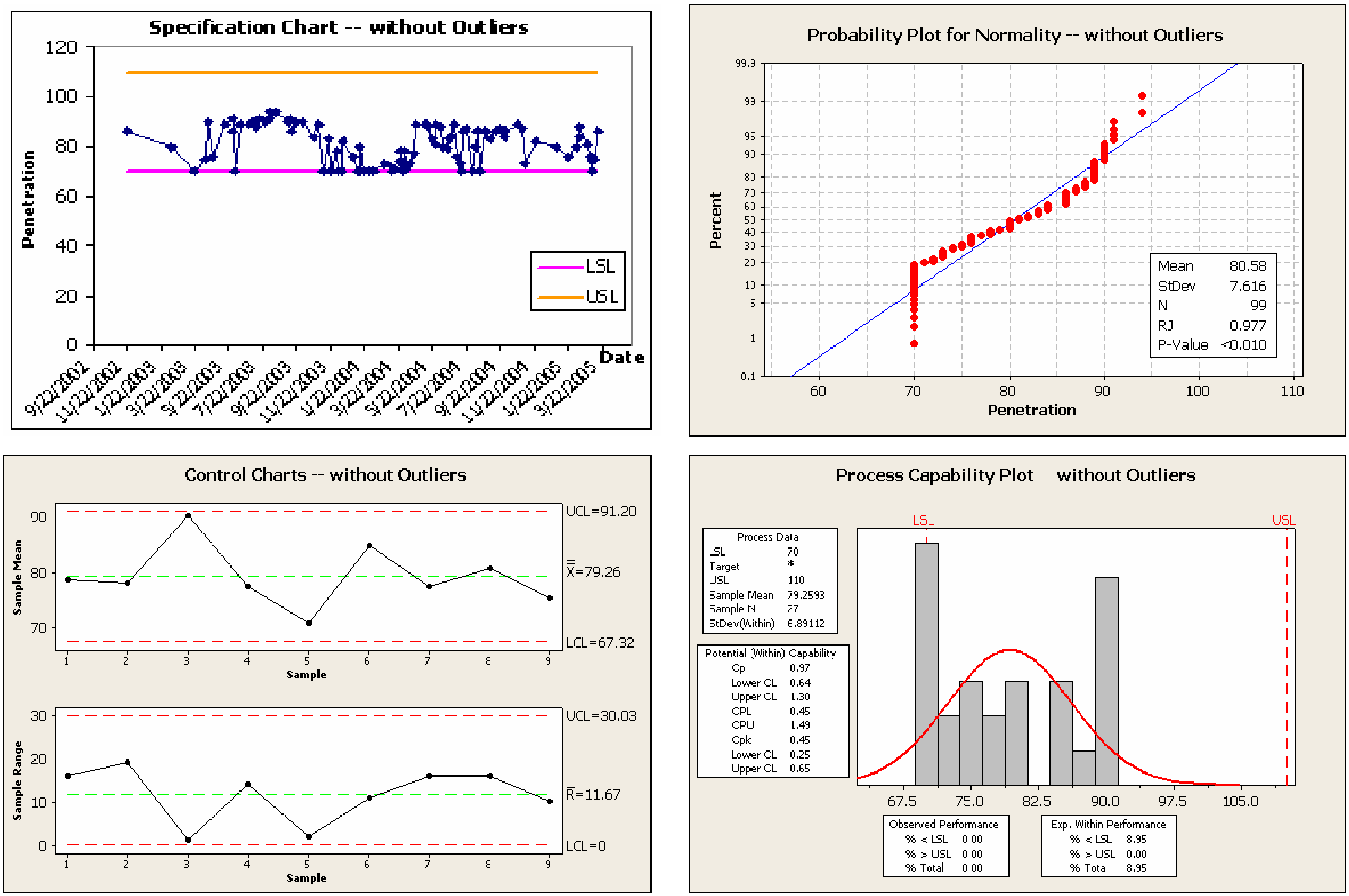


Figure E-57 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CSS-1H Test: Penetration

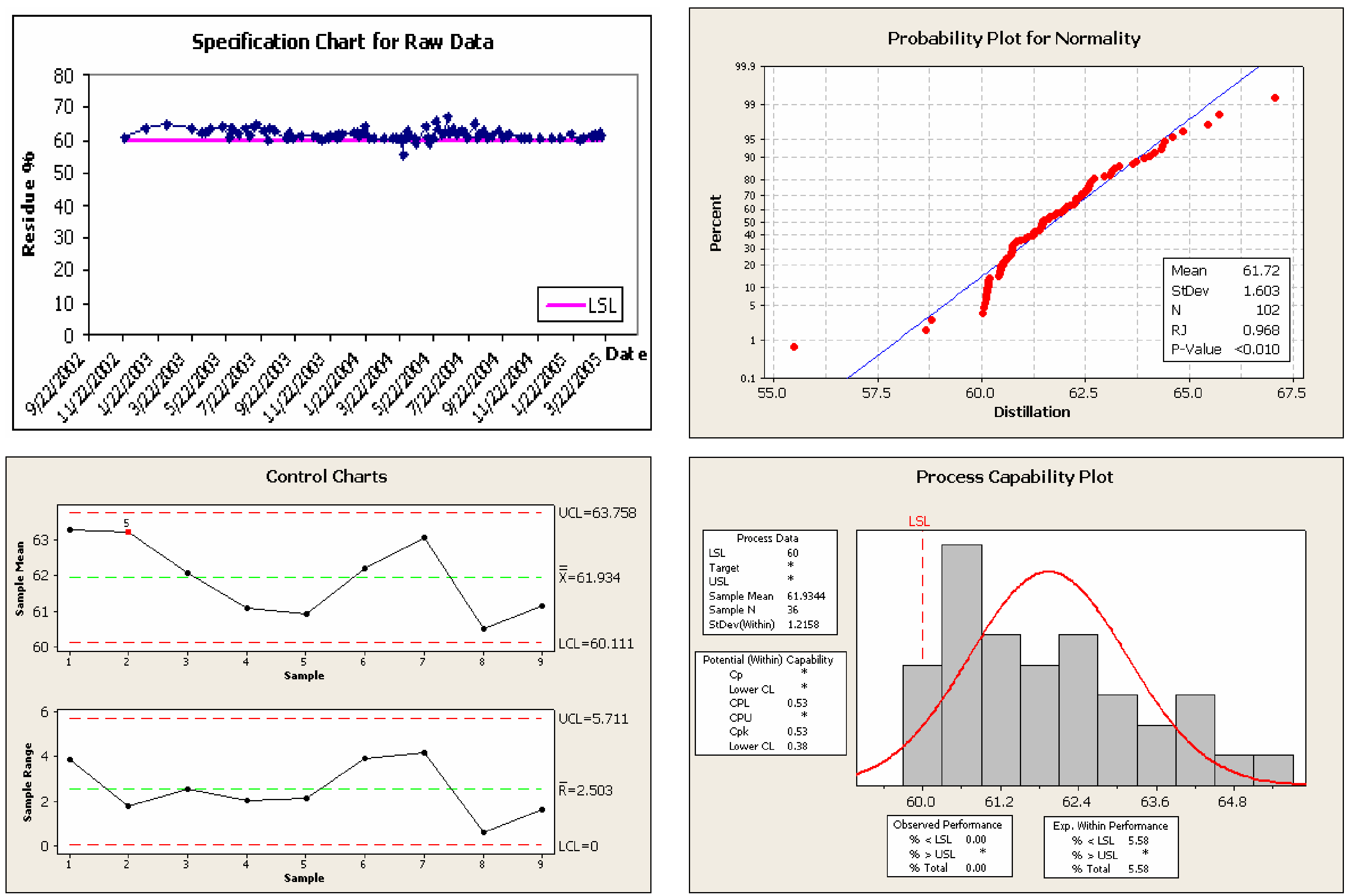


Figure E-58 Statistical Analysis Charts for Supplier: 0402 Grade: CSS-1H Test: Distillation

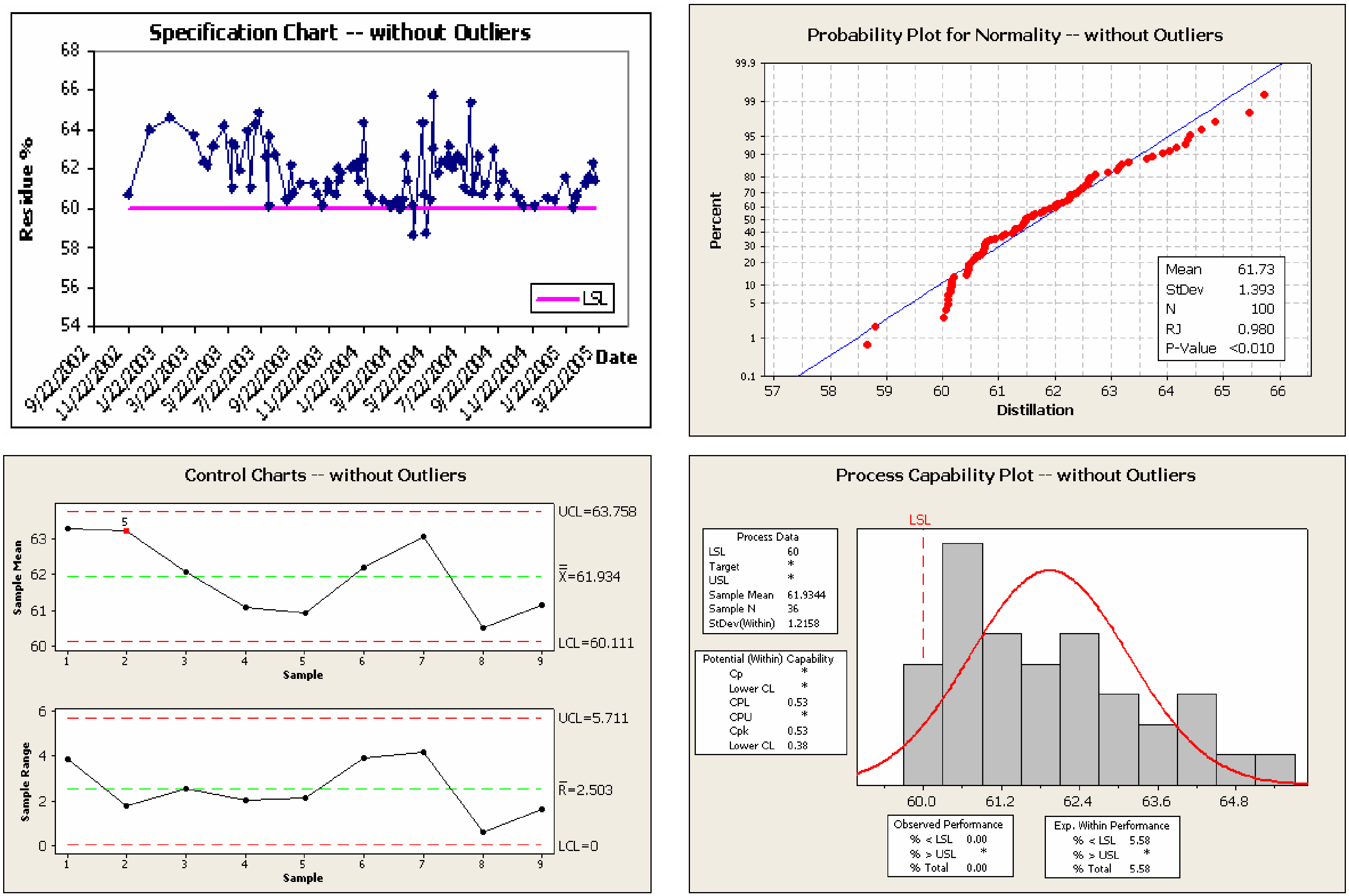


Figure E-59 Statistical Analysis Charts (without Outliers) for Supplier: 0402 Grade: CSS-1H Test: Distillation

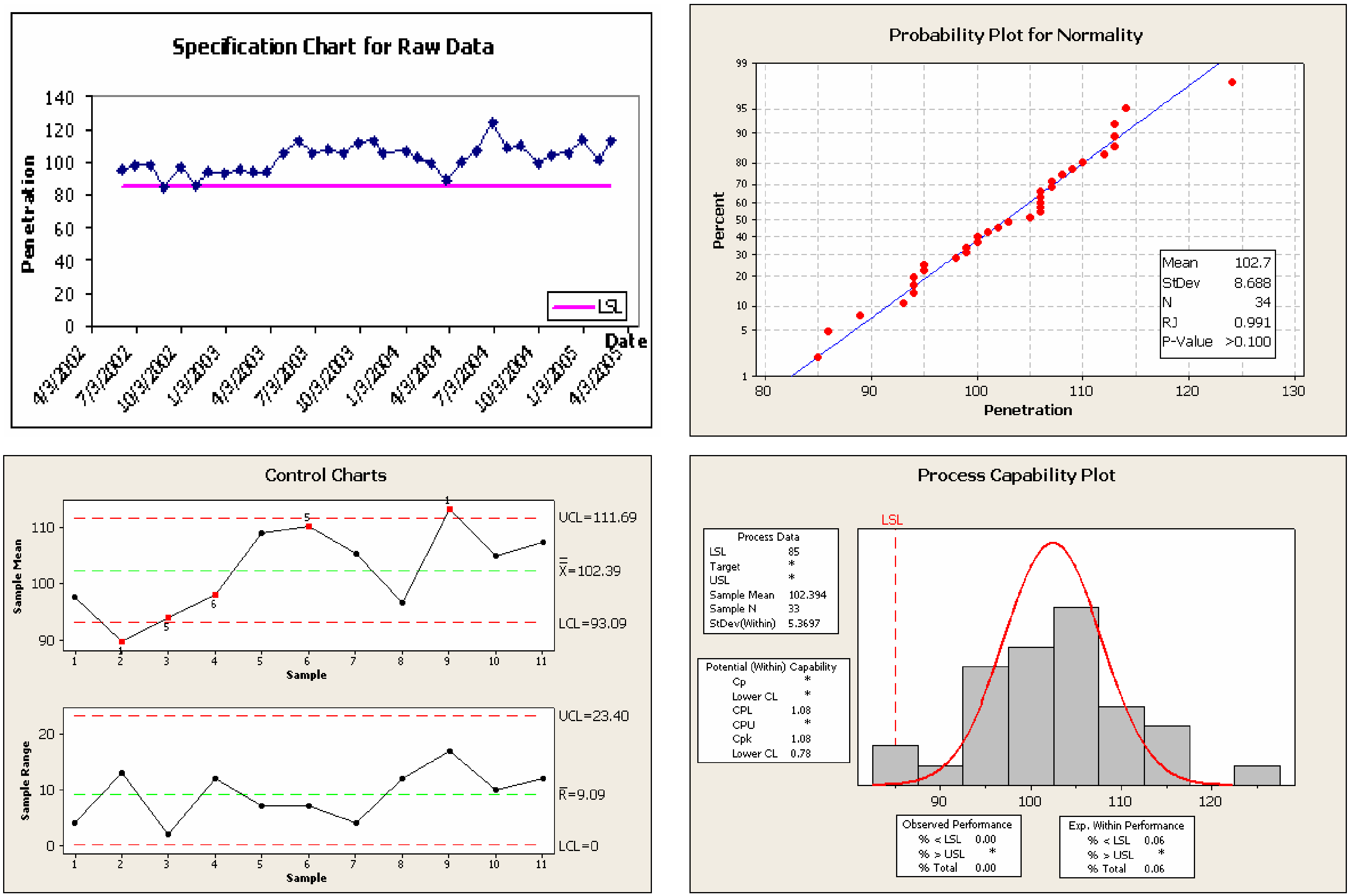


Figure E-60 Statistical Analysis Charts for Supplier: 0501 Grade: AC-10 Test: Penetration

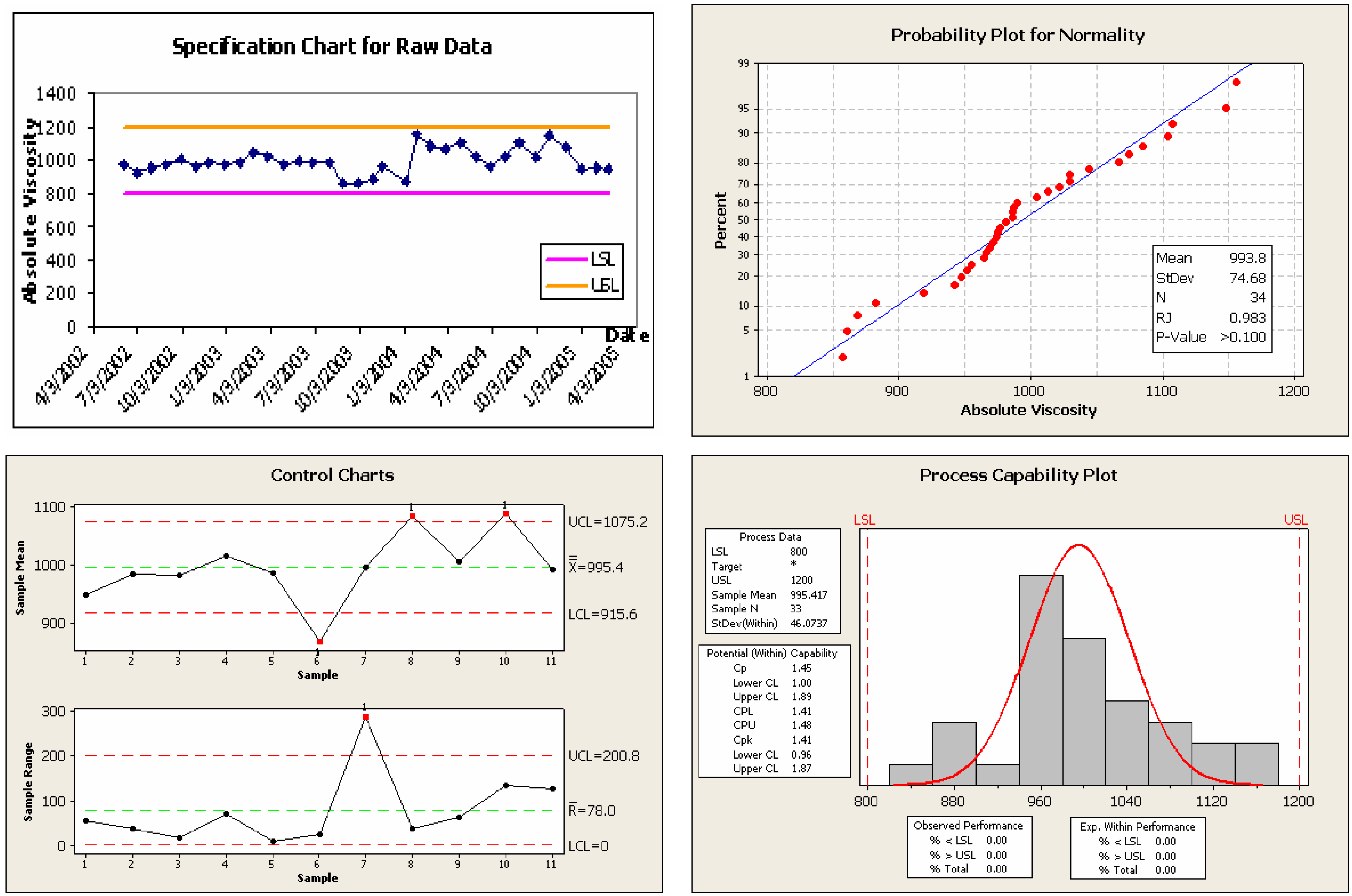


Figure E-61 Statistical Analysis Charts for Supplier: 0501 Grade: AC-10 Test: Absolute Viscosity

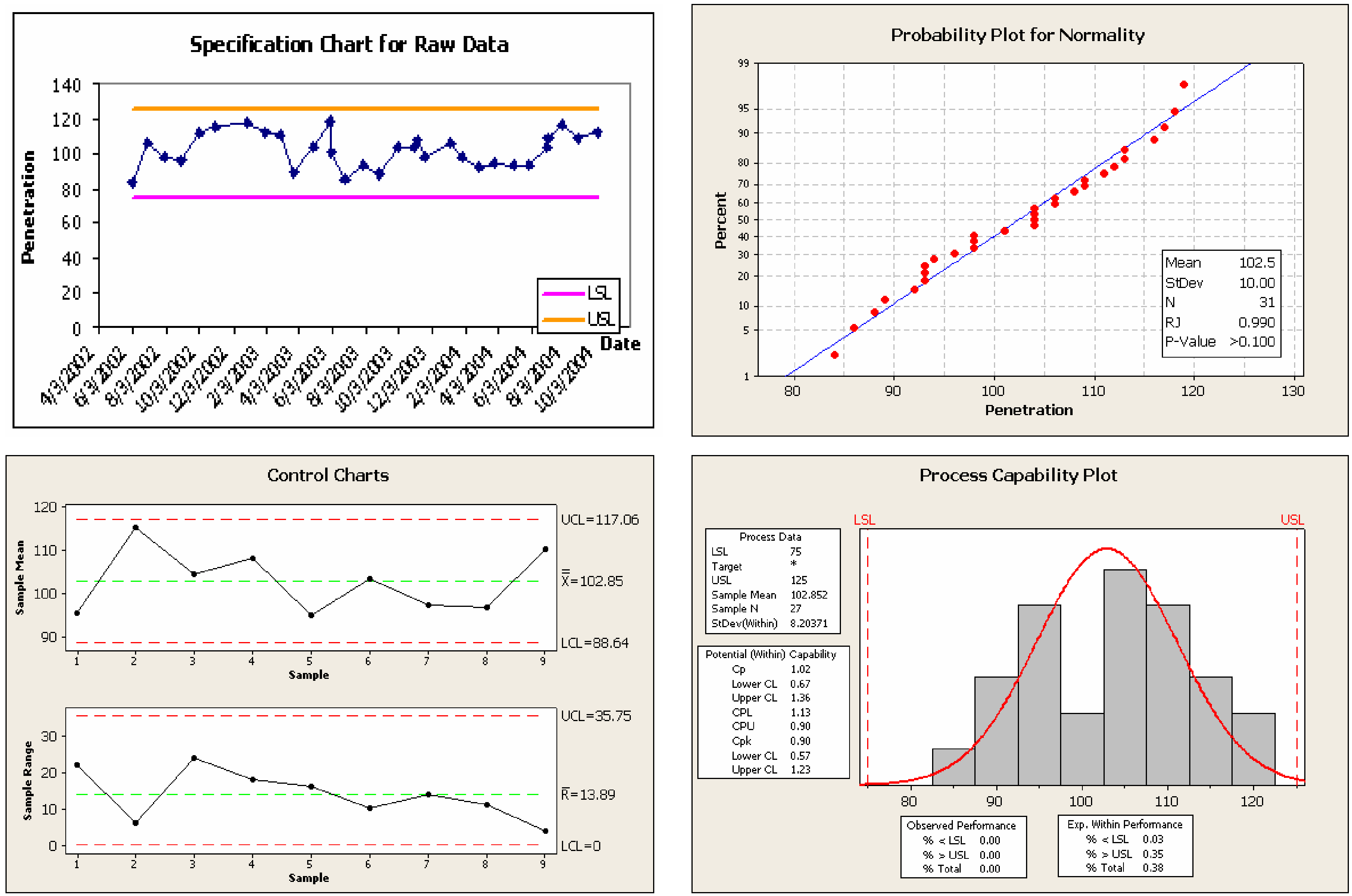


Figure E-62 Statistical Analysis Charts for Supplier: 0501 Grade: AC-15-5TR Test: Penetration

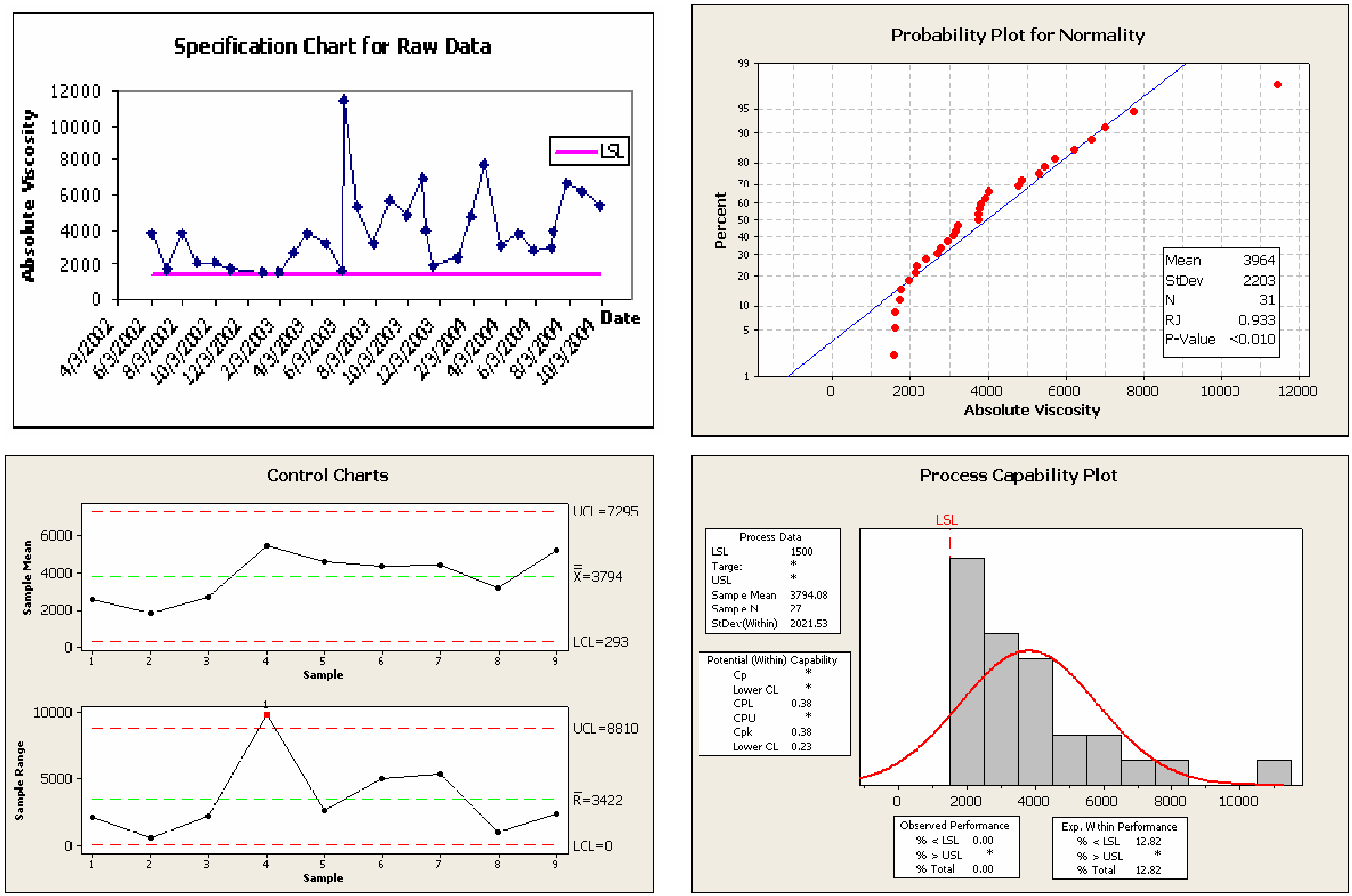


Figure E-63 Statistical Analysis Charts for Supplier: 0501 Grade: AC-15-5TR Test: Absolute Viscosity

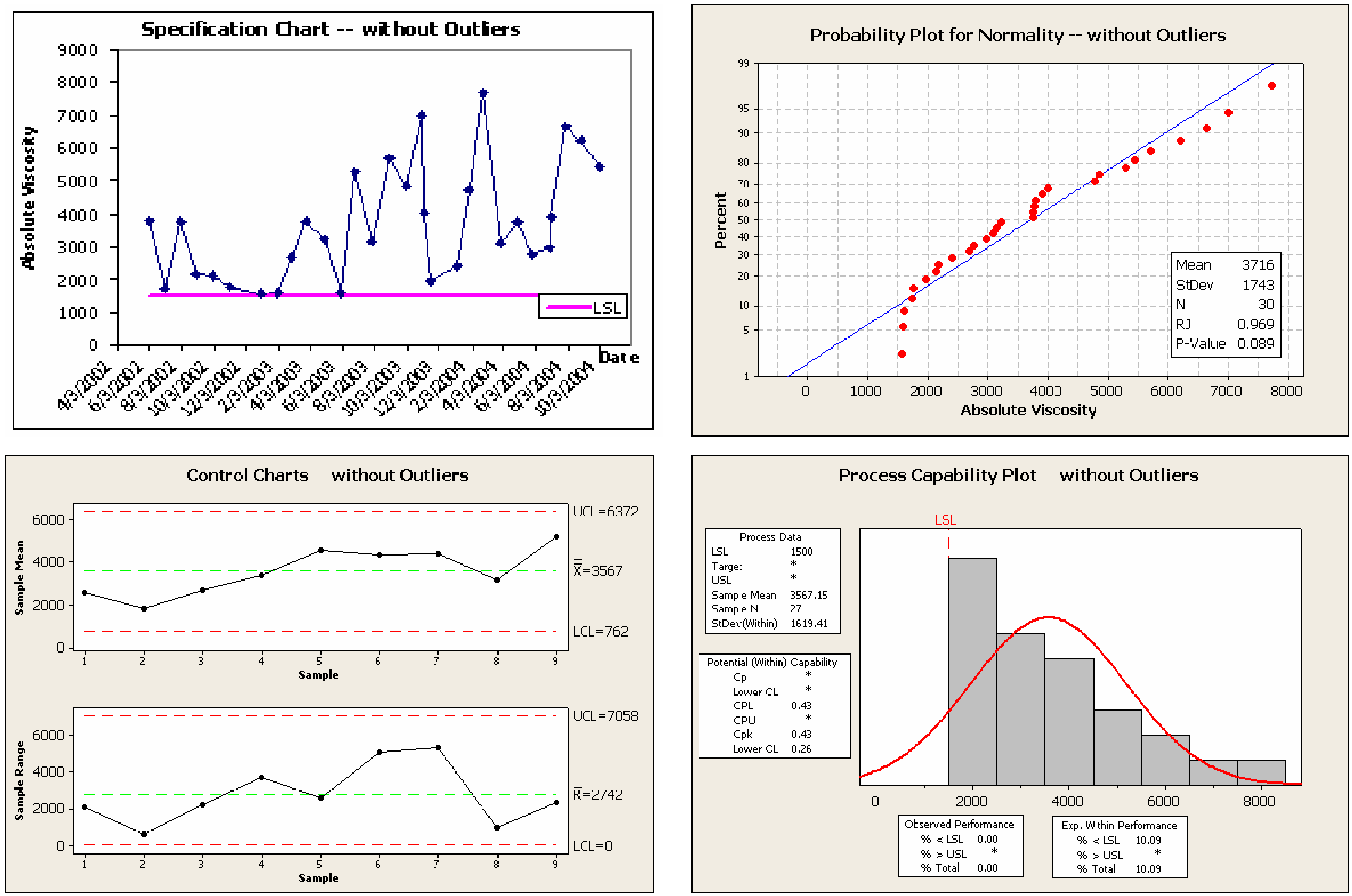


Figure E-64 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: AC-15-5TR Test: Absolute Viscosity

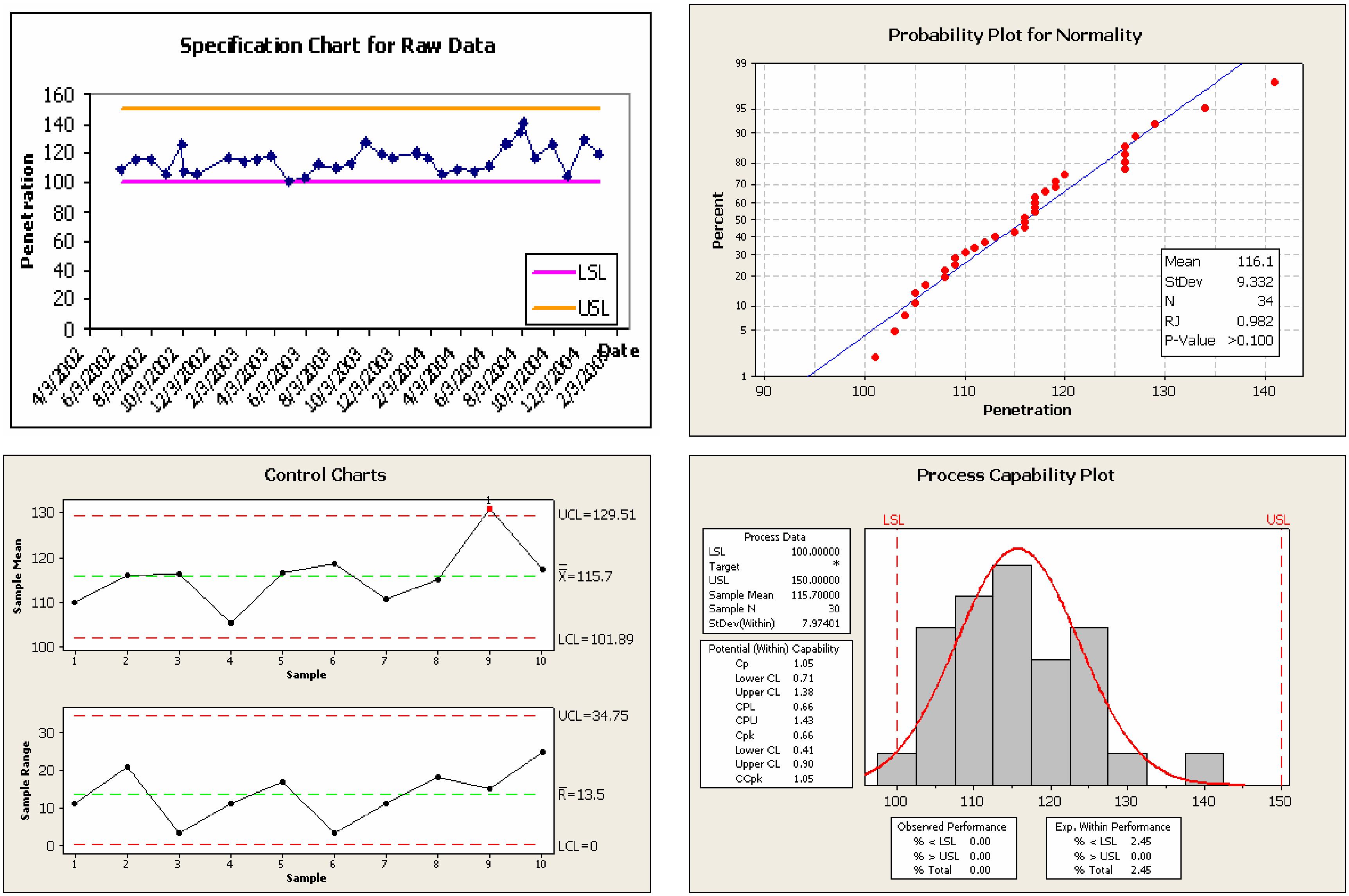


Figure E-65 Statistical Analysis Charts for Supplier: 0501 Grade: AC-15P Test: Penetration

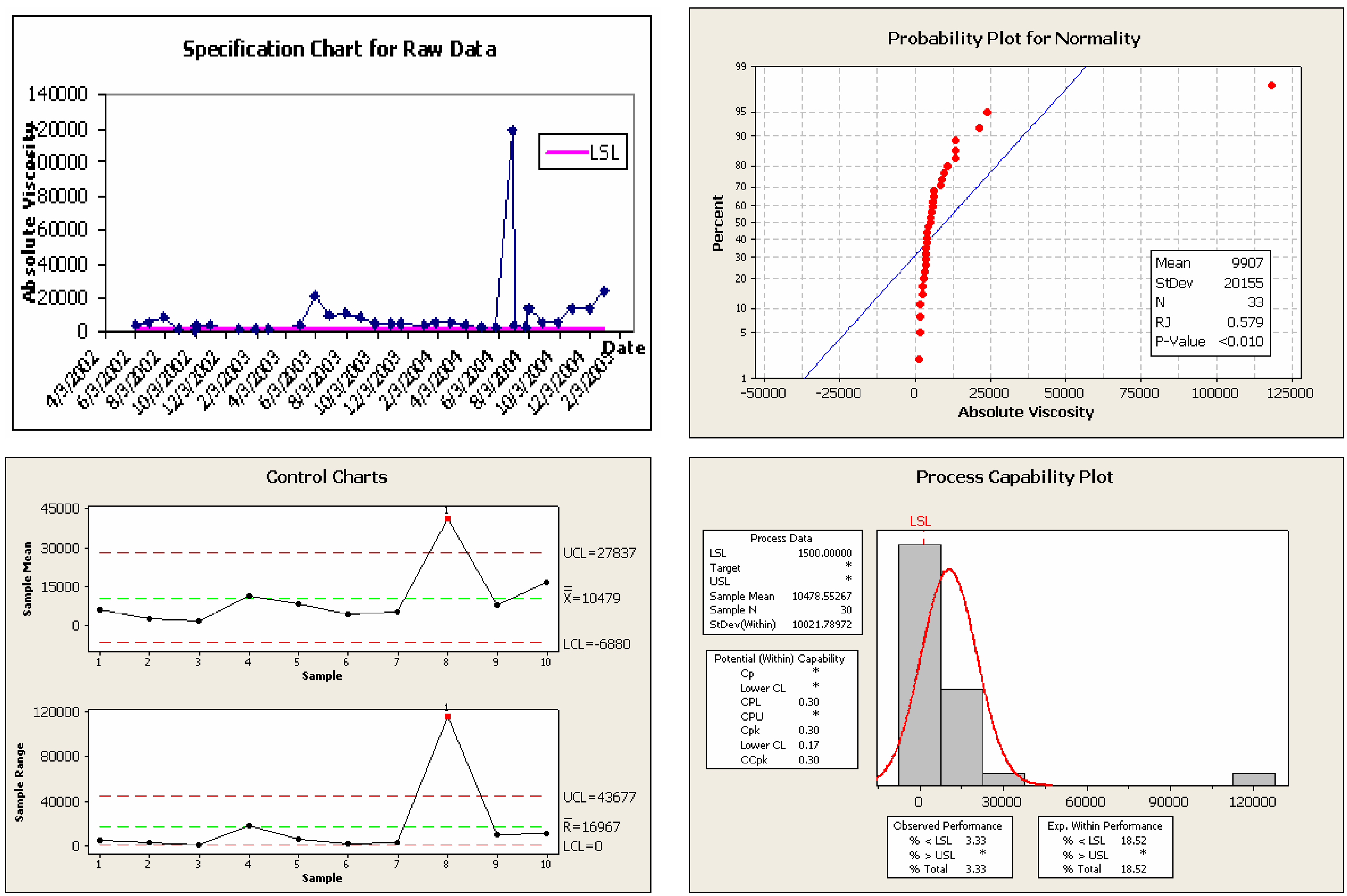


Figure E-66 Statistical Analysis Charts for Supplier: 0501 Grade: AC-15P Test: Absolute Viscosity

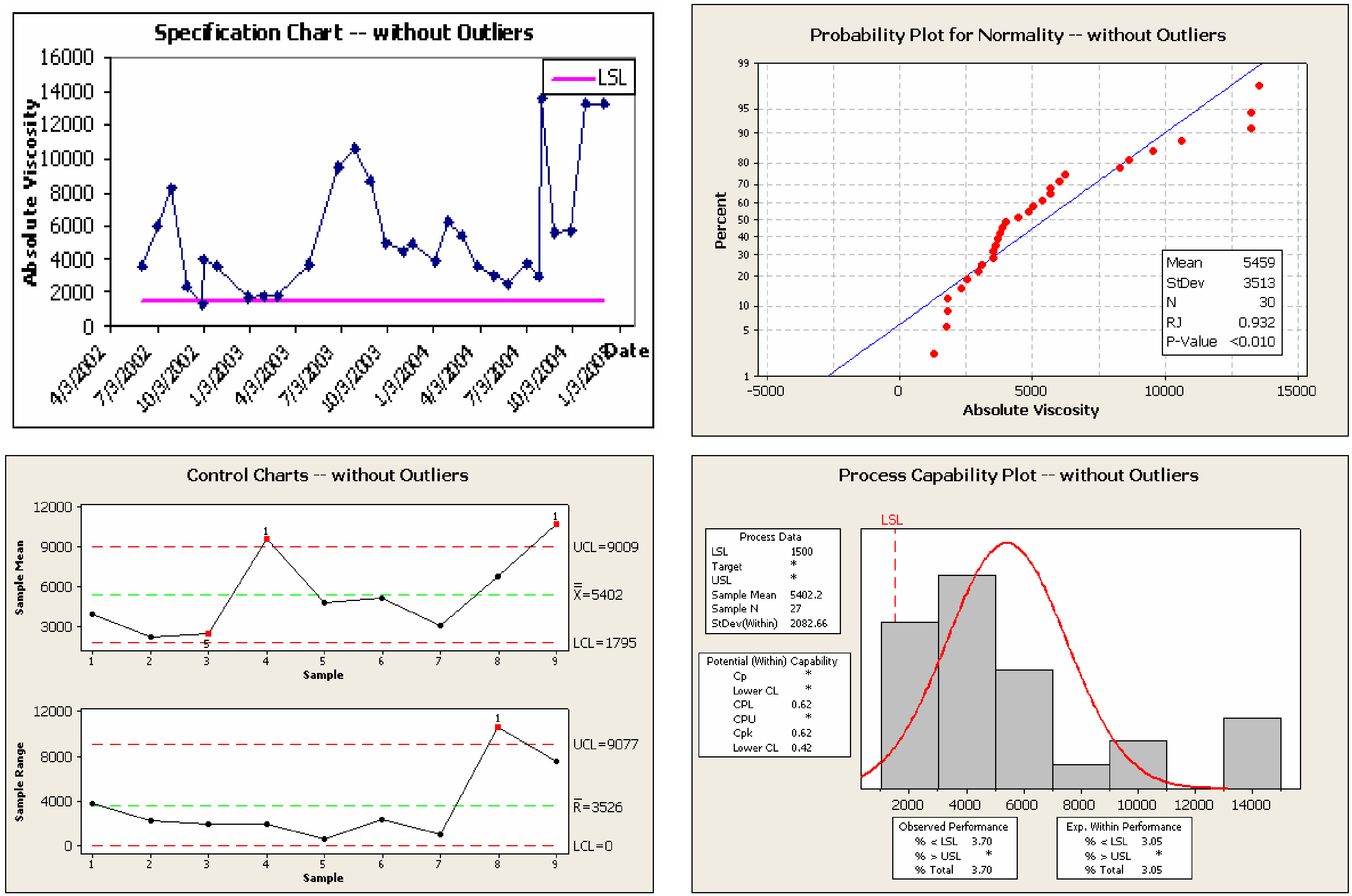


Figure E-67 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: AC-15P Test: Absolute Viscosity

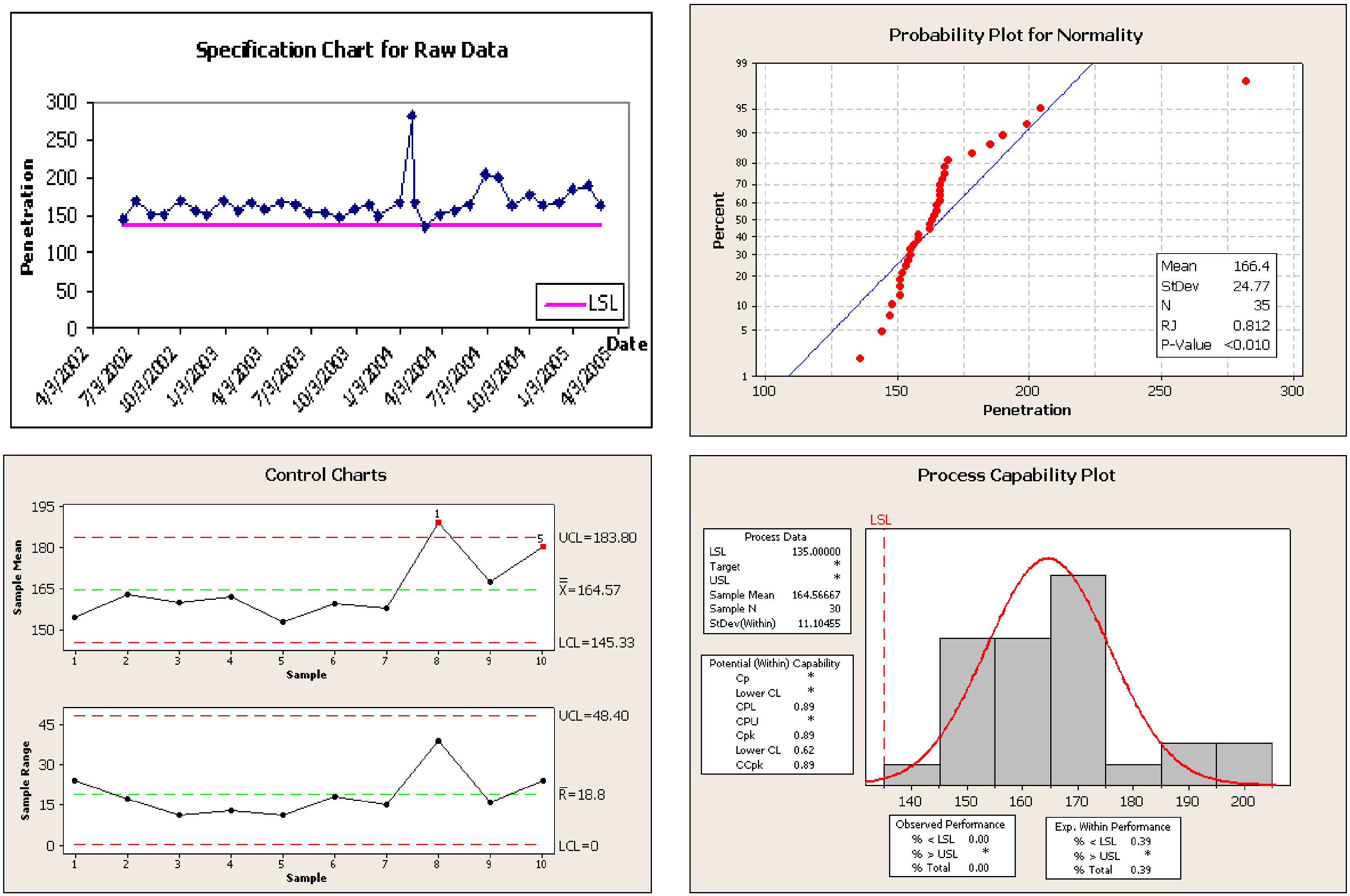


Figure E-68 Statistical Analysis Charts for Supplier: 0501 Grade: AC-5 Test: Penetration

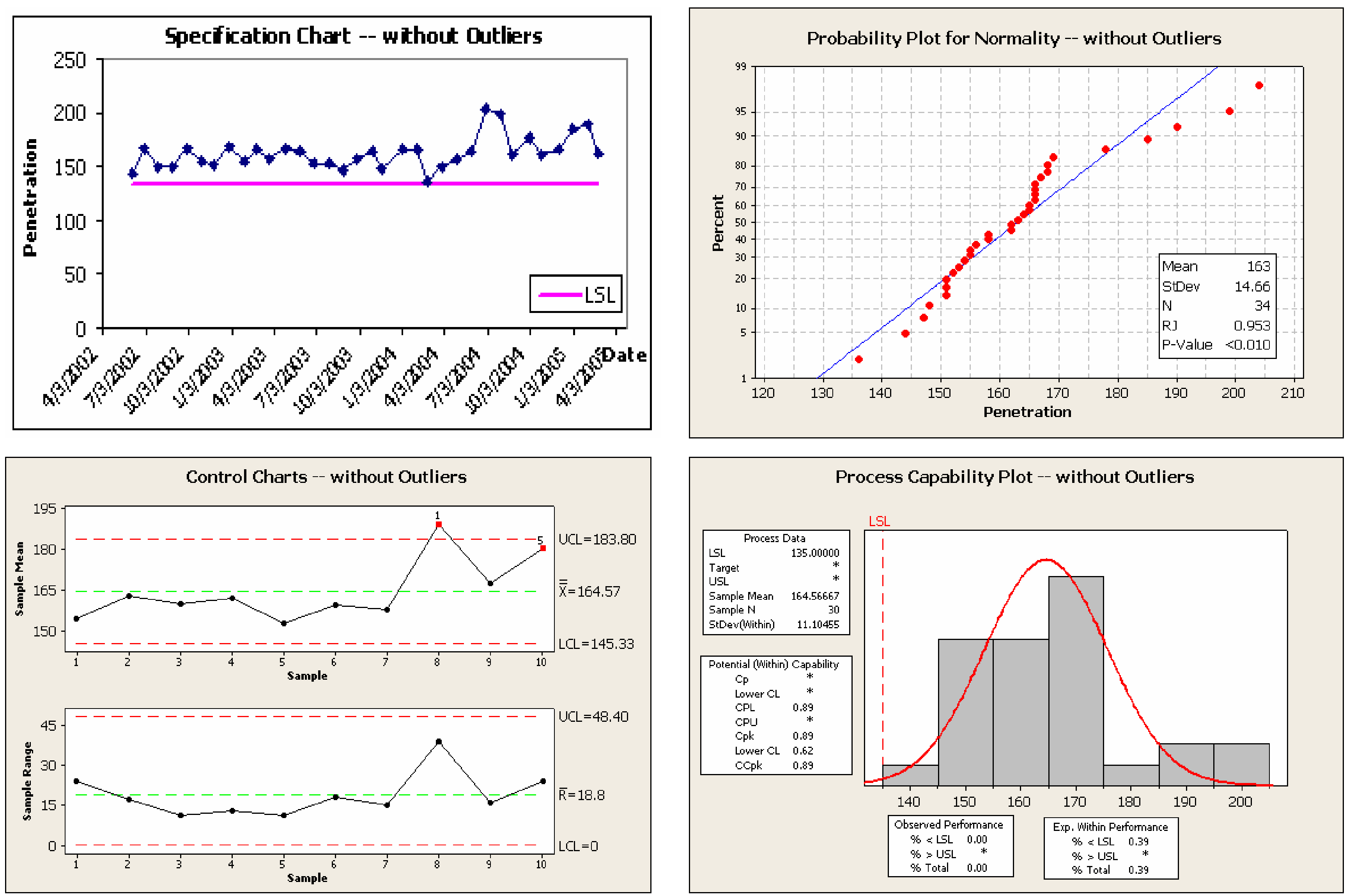


Figure E-69 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: AC-5 Test: Penetration

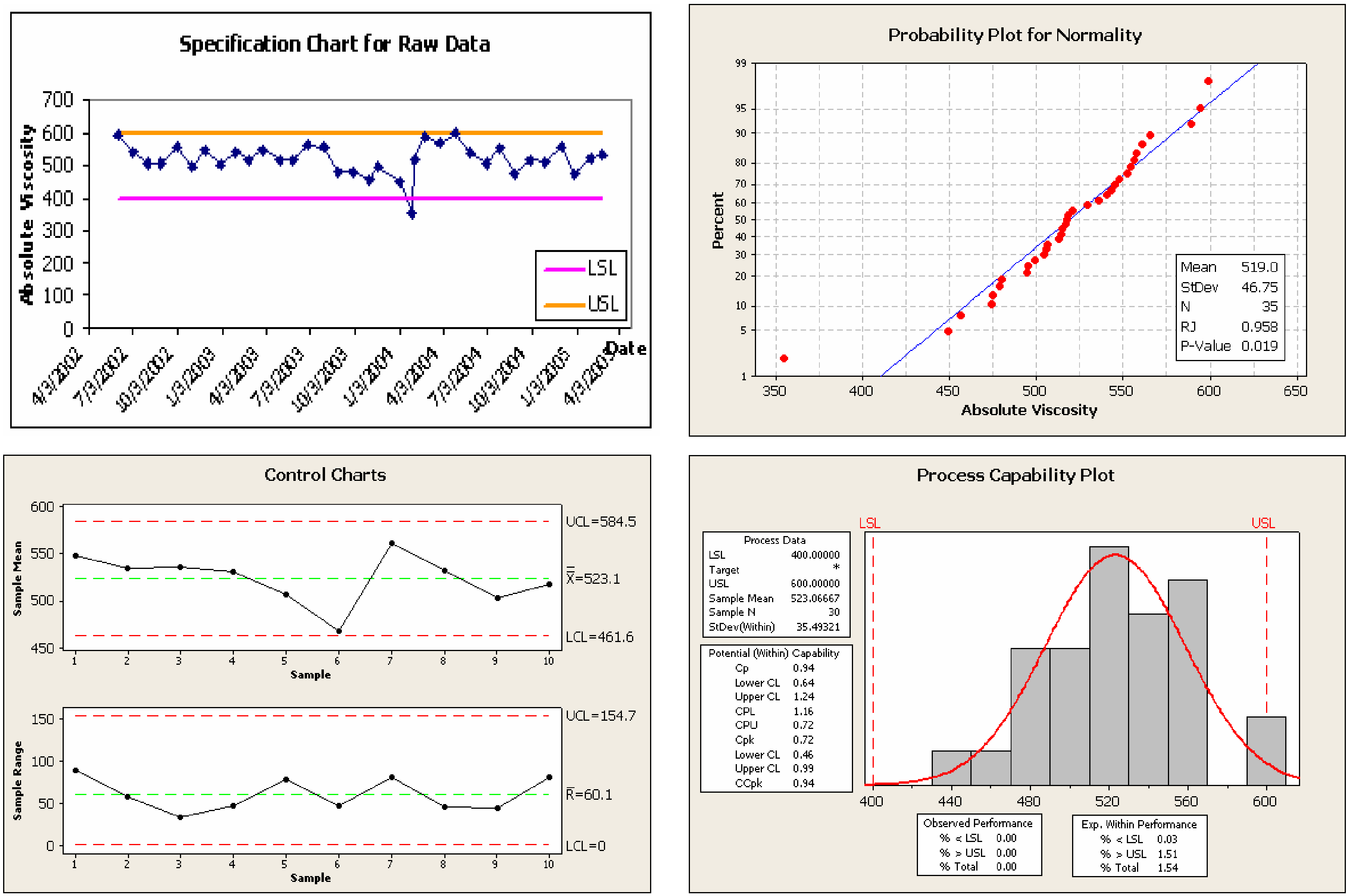


Figure E-70 Statistical Analysis Charts for Supplier: 0501 Grade: AC-5 Test: Absolute Viscosity

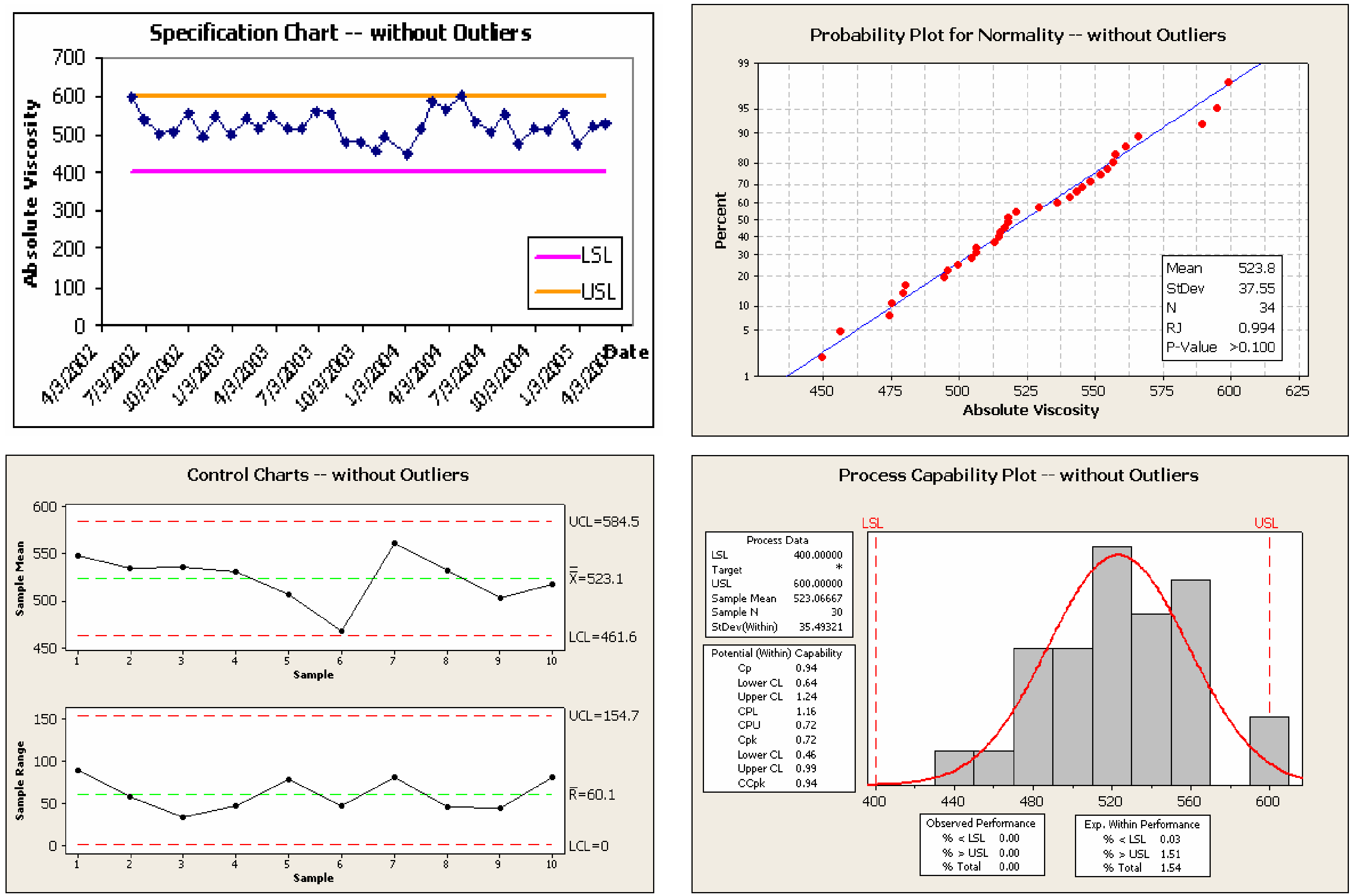


Figure E-71 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: AC-5 Test: Absolute Viscosity

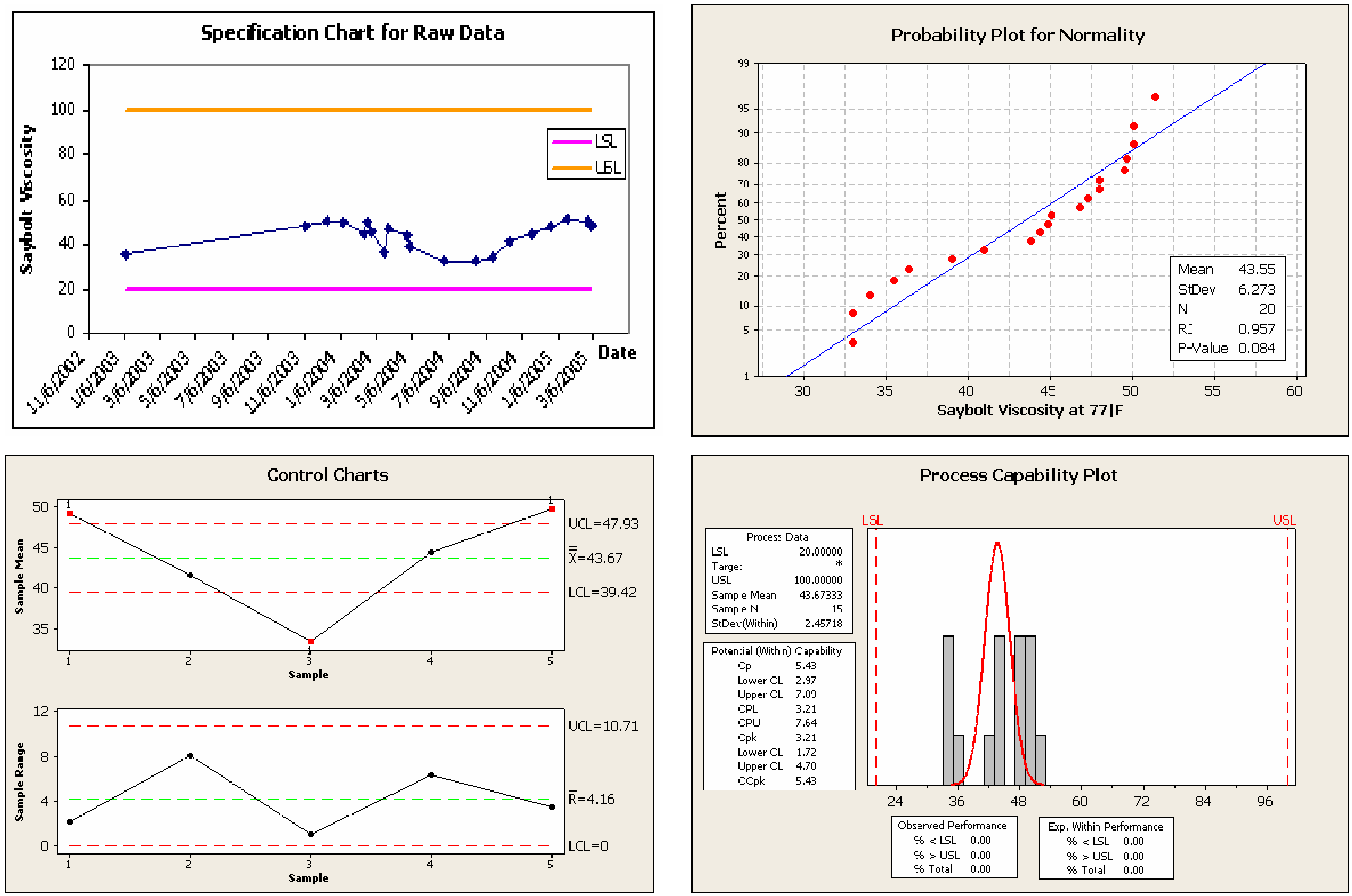


Figure E-72 Statistical Analysis Charts for Supplier: 0501 Grade: SS-1 Test: Saybolt Viscosity

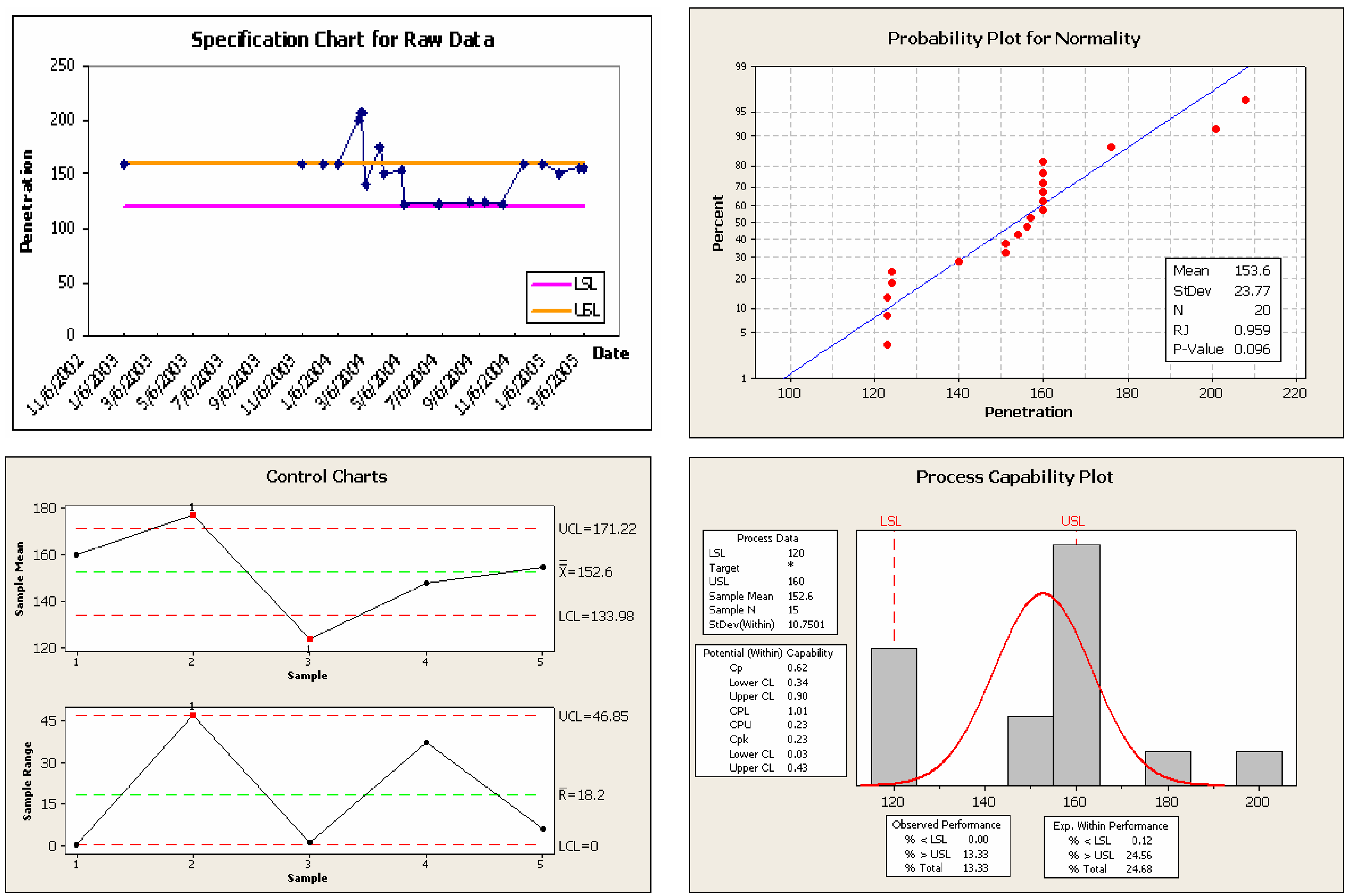


Figure E-73 Statistical Analysis Charts for Supplier: 0501 Grade: SS-1 Test: Penetration

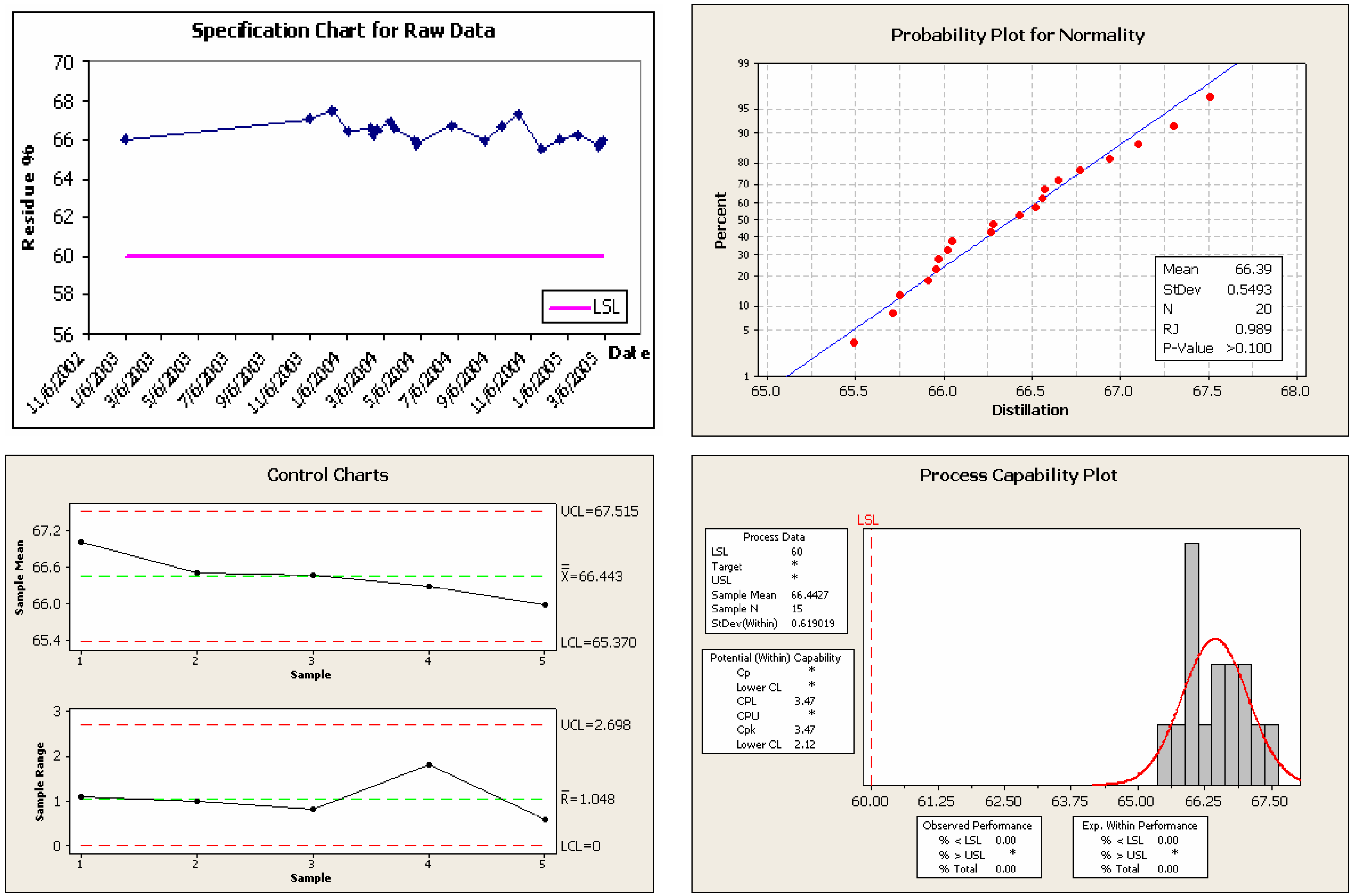
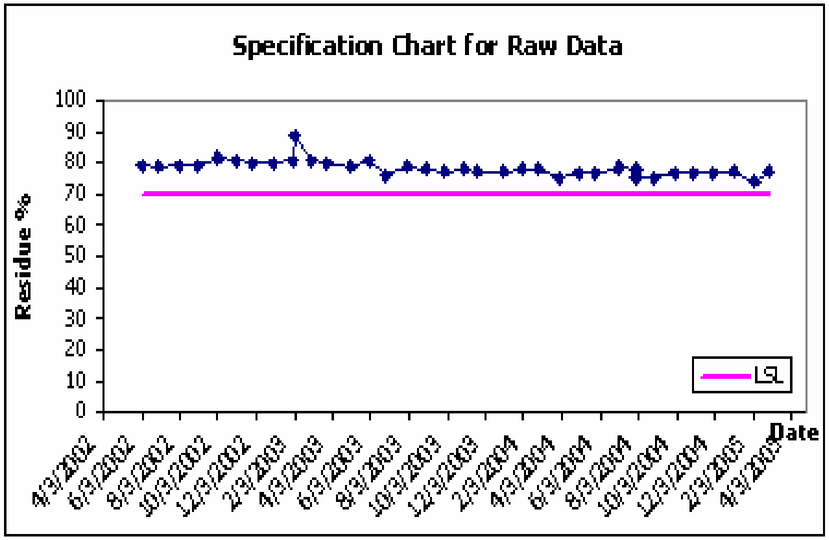
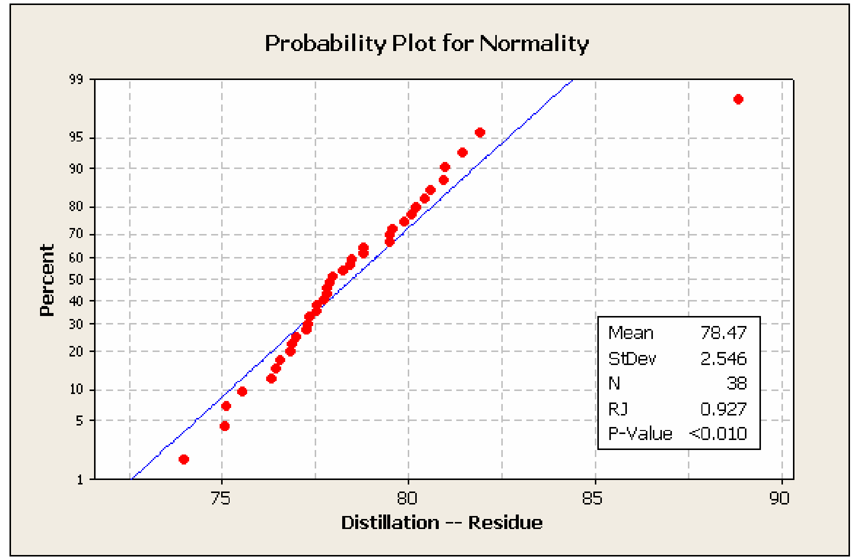
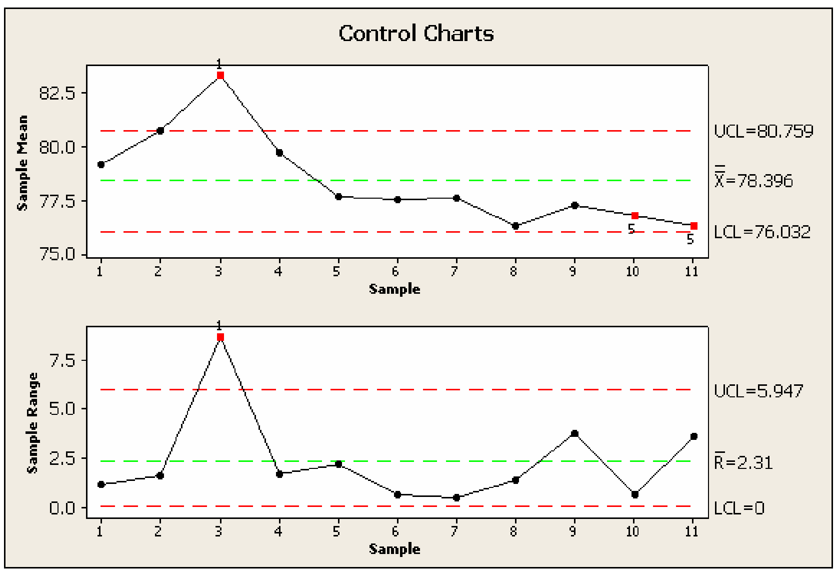


Figure E-74 Statistical Analysis Charts for Supplier: 0501 Grade: SS-1 Test: Distillation







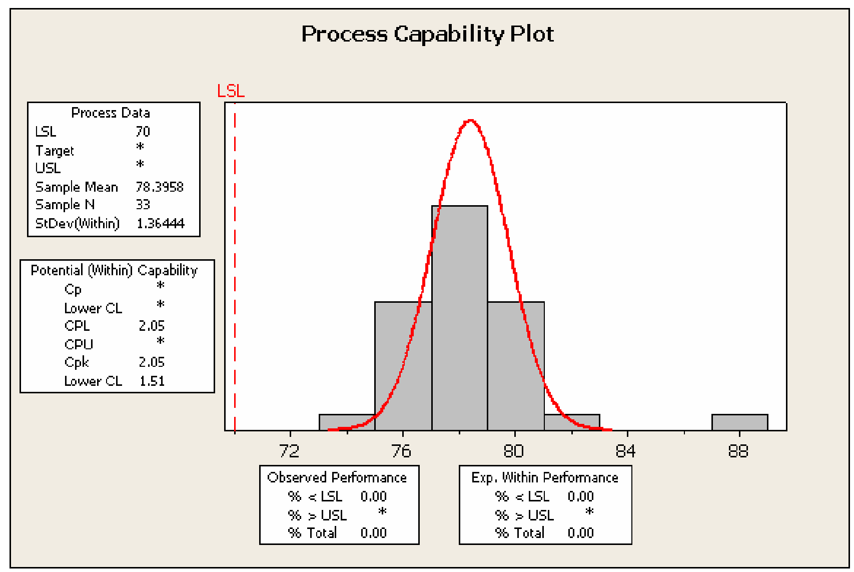


Figure E-75 Statistical Analysis Charts for Supplier: 0501 Grade: RC-250 Test: Distillation-Residue

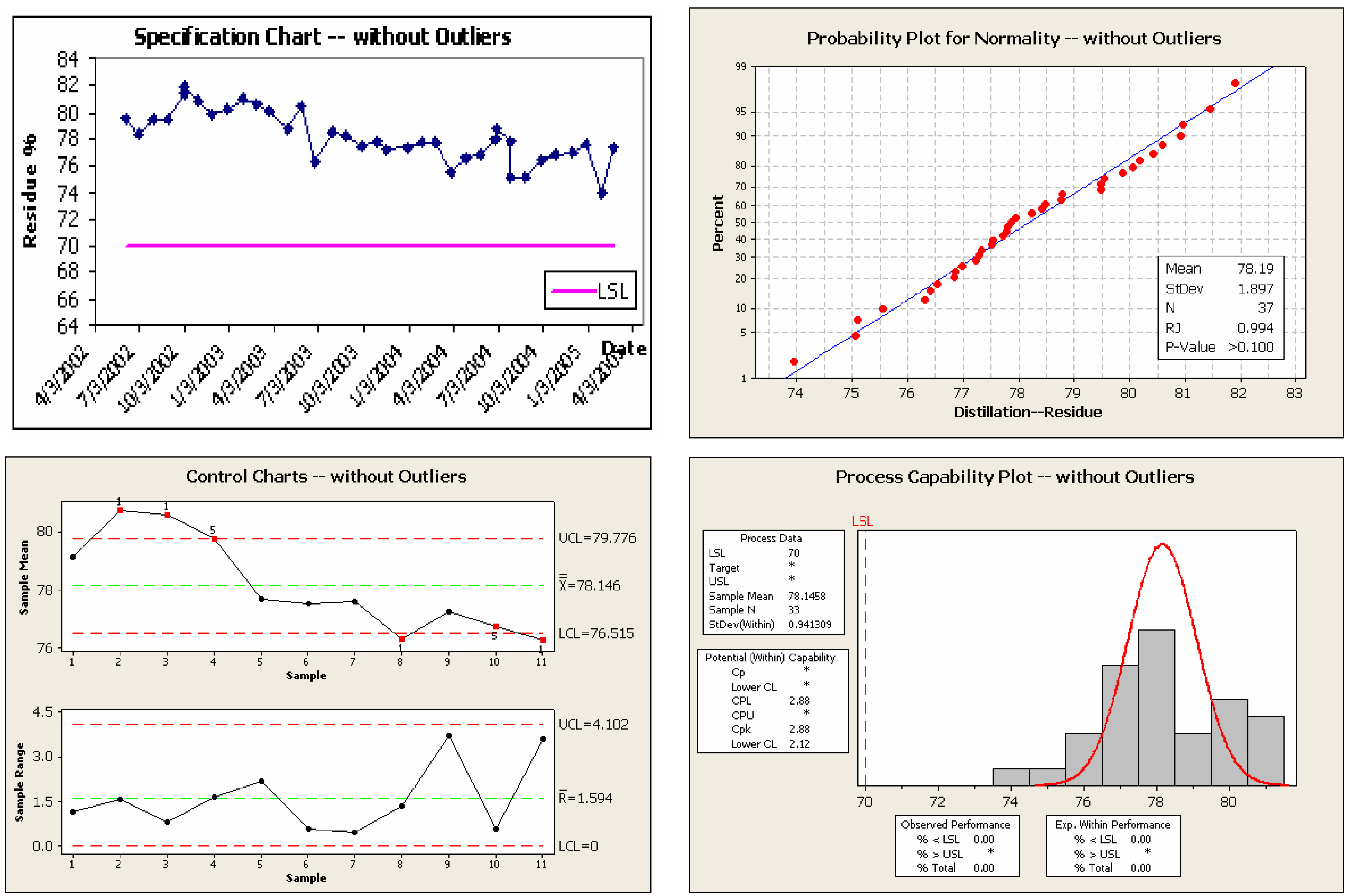


Figure E-76 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: RC-250 Test: Distillation-Residue

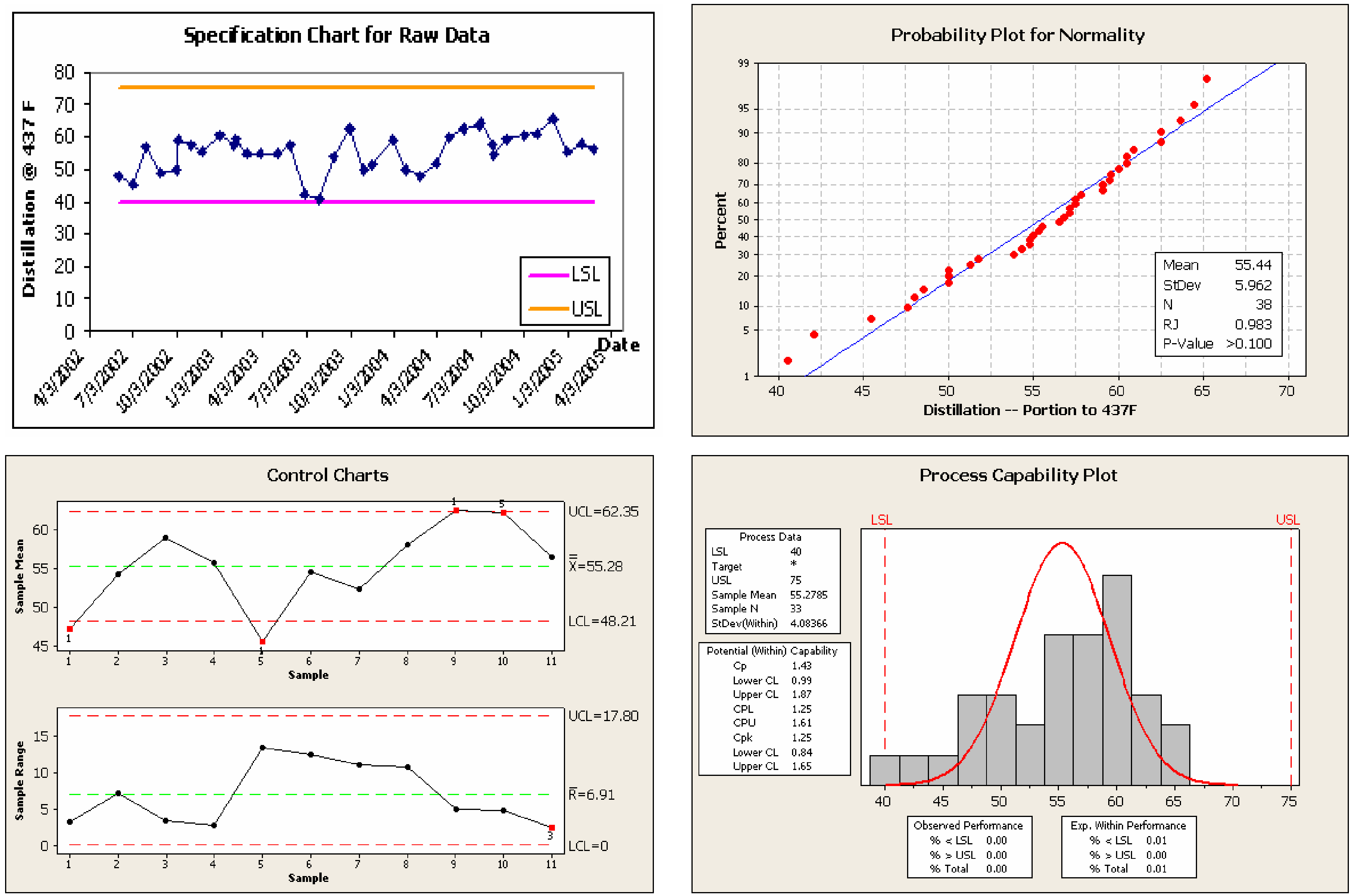


Figure E-77 Statistical Analysis Charts for Supplier: 0501 Grade: RC-250 Test: Distillation @ 437|F

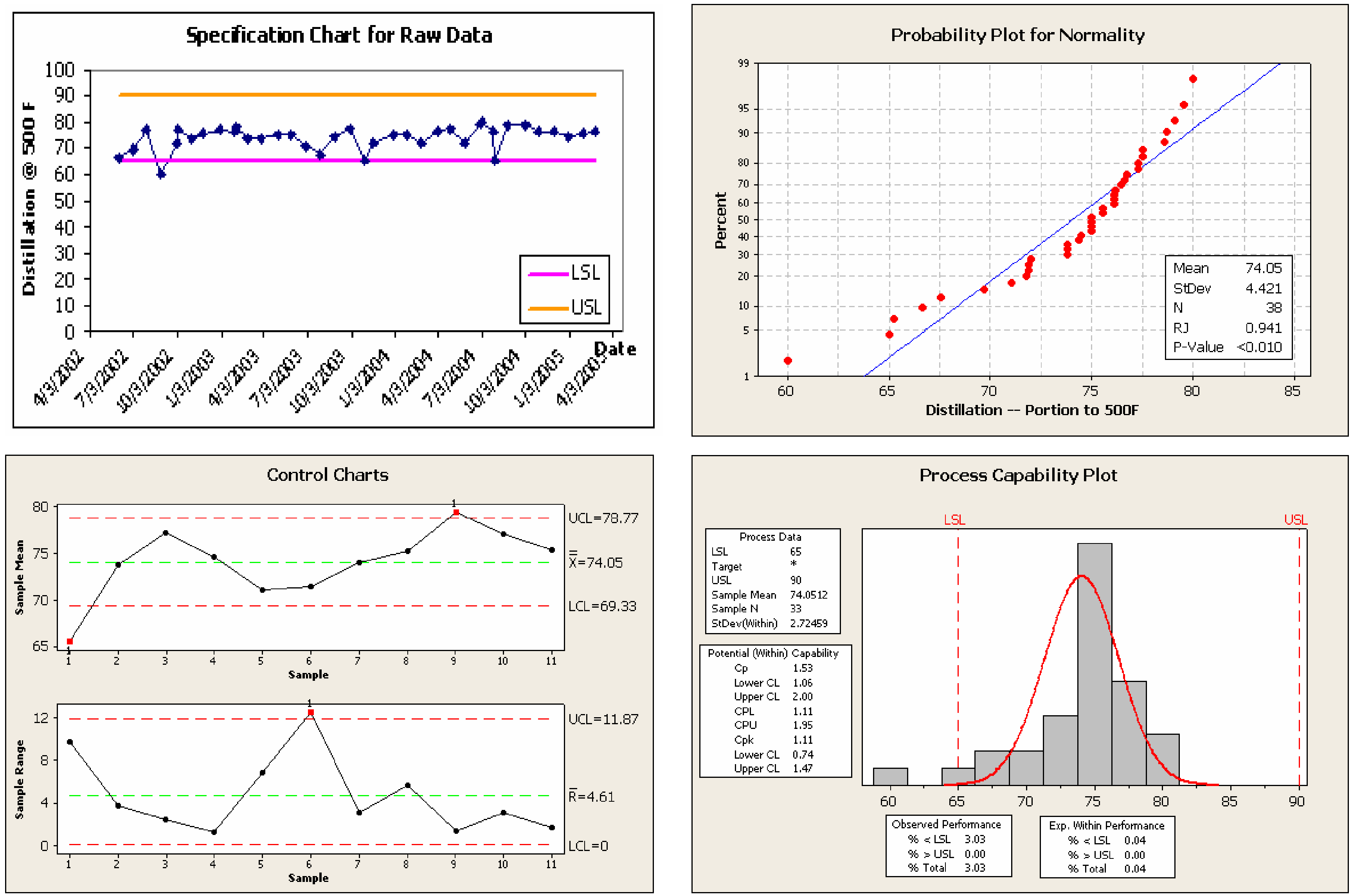


Figure E-78 Statistical Analysis Charts for Supplier: 0501 Grade: RC-250 Test: Distillation @ 500|F

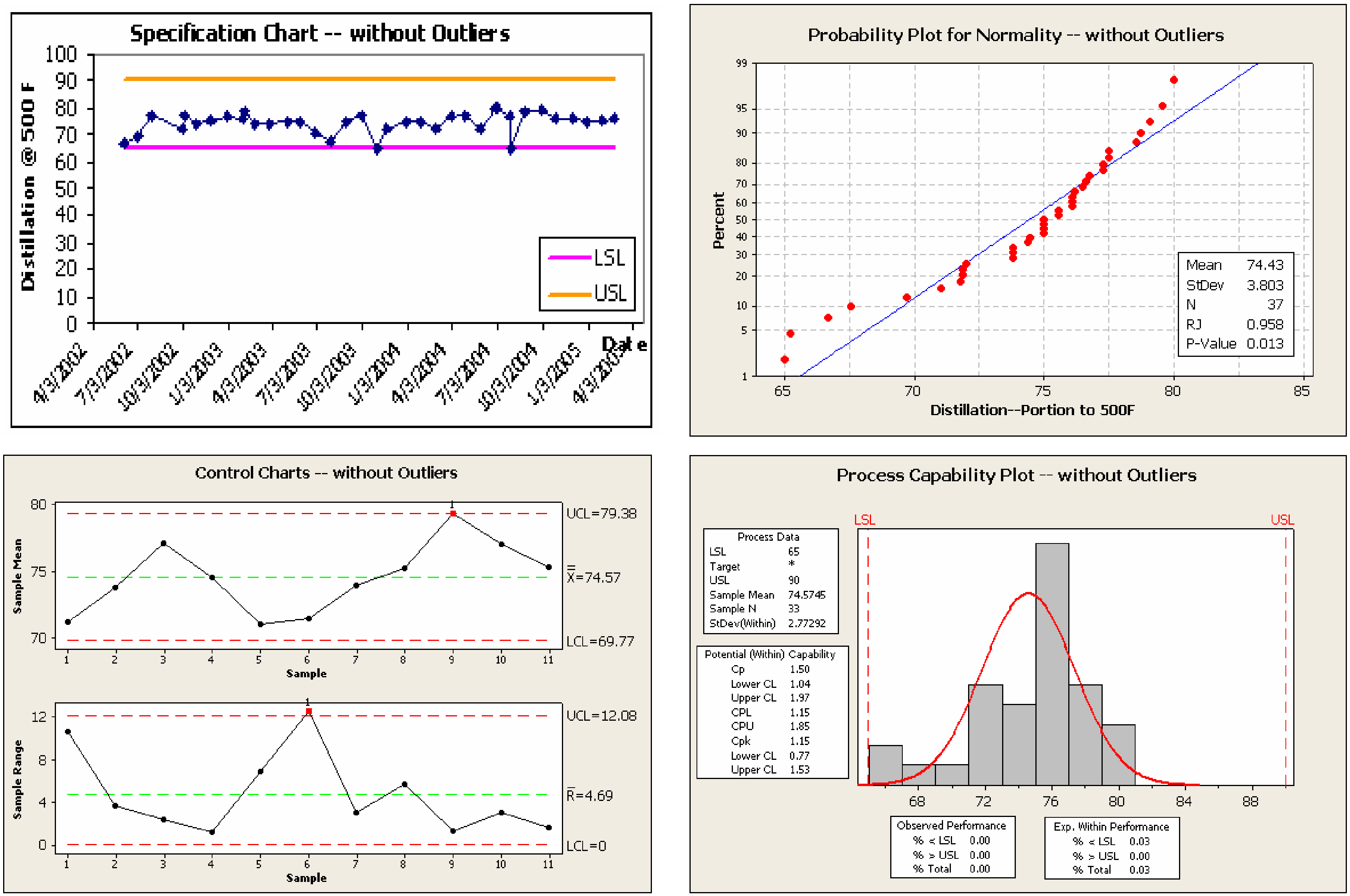


Figure E-79 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: RC-250 Test: Distillation @ 500|F

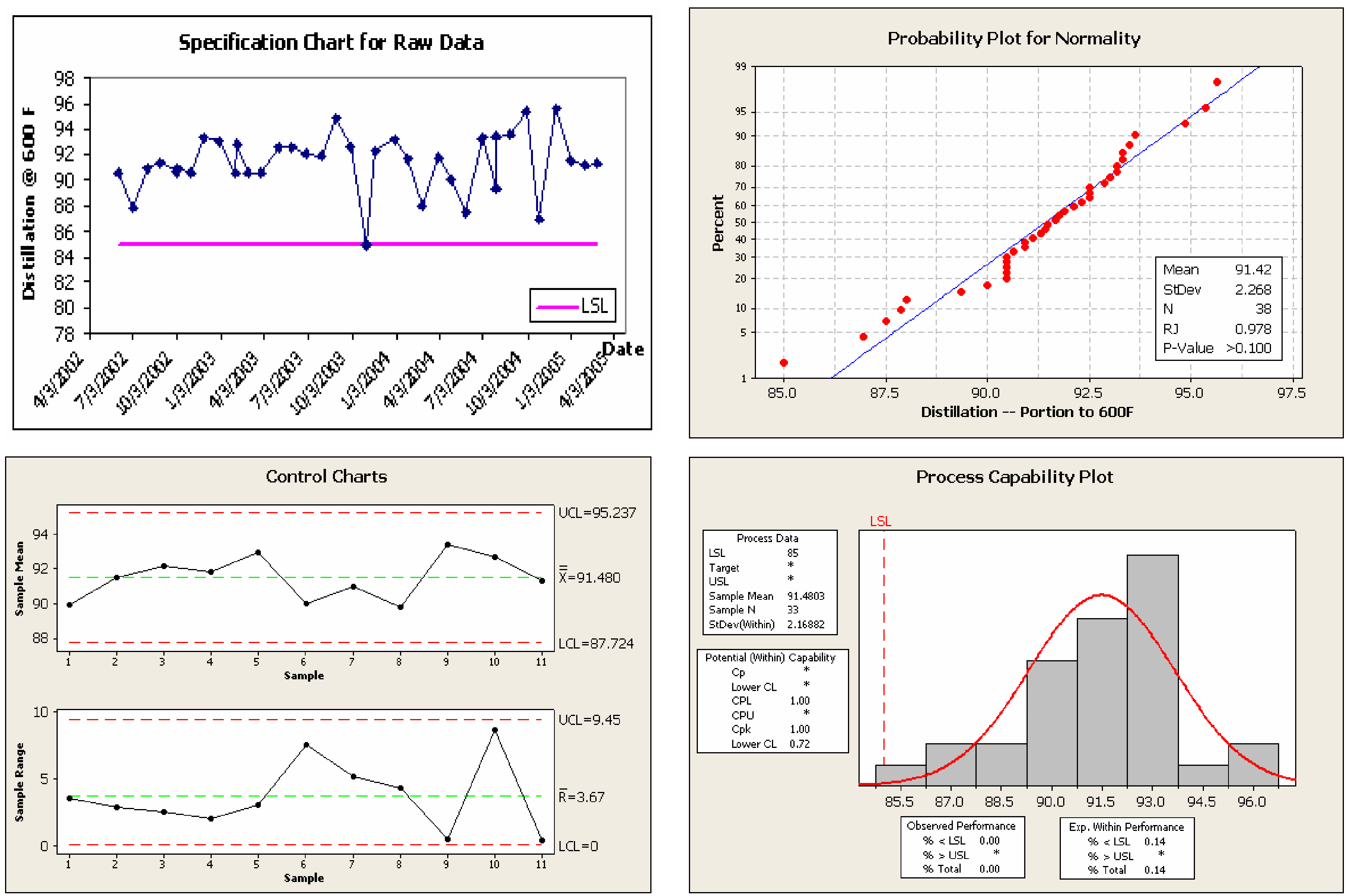


Figure E-80 Statistical Analysis Charts for Supplier: 0501 Grade: RC-250 Test: Distillation @ 600|F

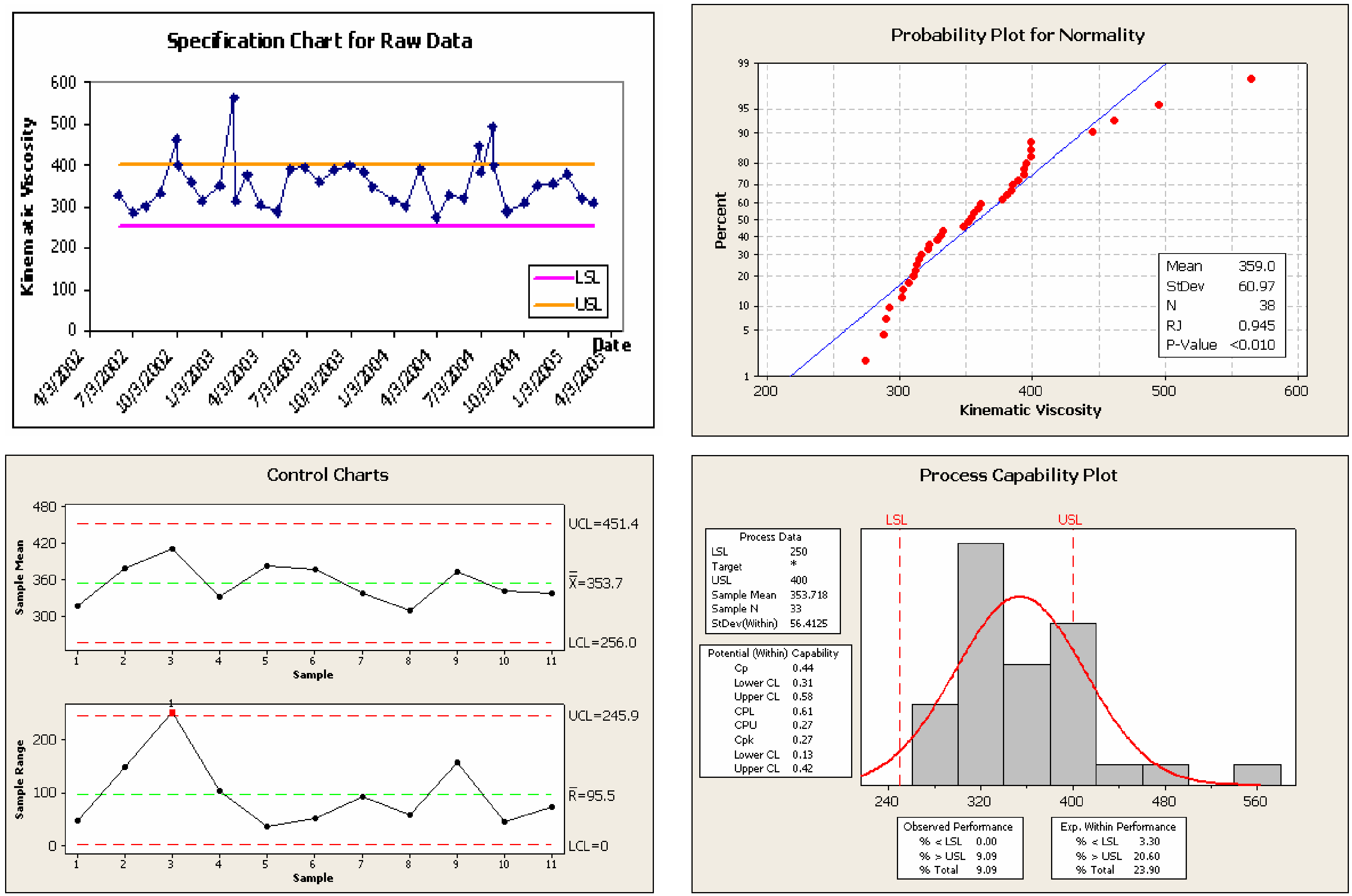


Figure E-81 Statistical Analysis Charts for Supplier: 0501 Grade: RC-250 Test: Kinematic Viscosity

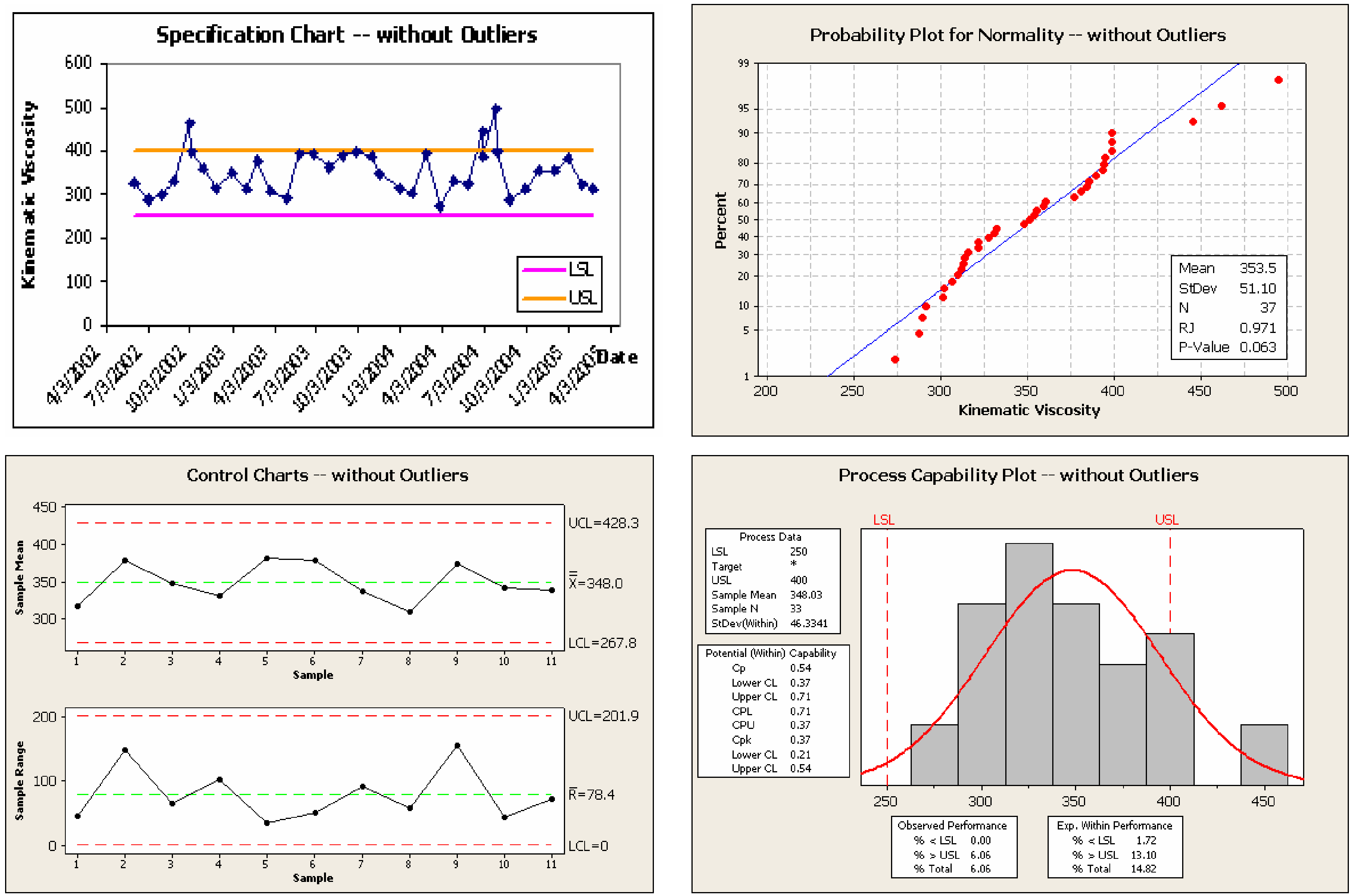


Figure E-82 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: RC-250 Test: Kinematic Viscosity

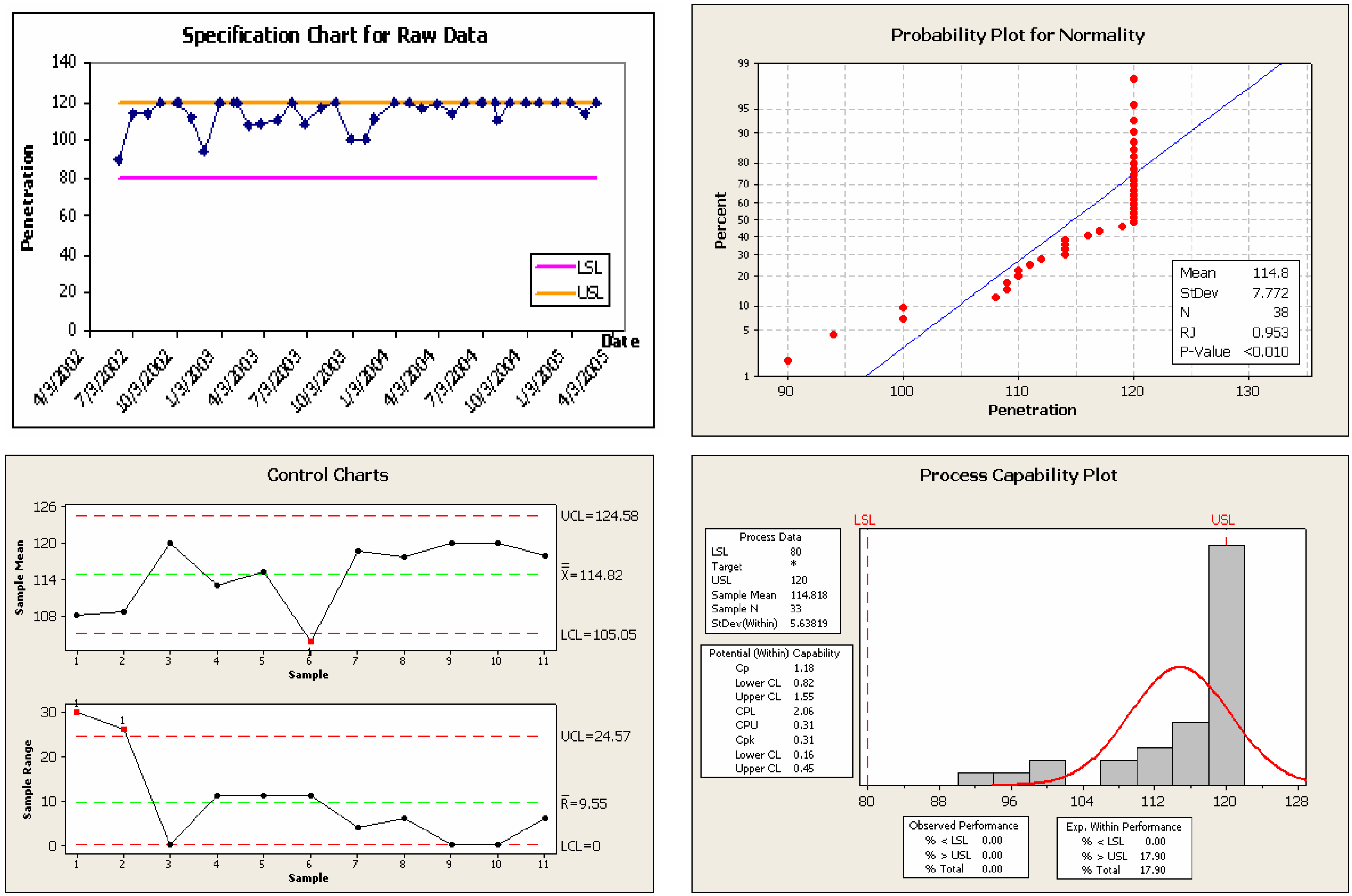


Figure E-83 Statistical Analysis Charts for Supplier: 0501 Grade: RC-250 Test: Penetration

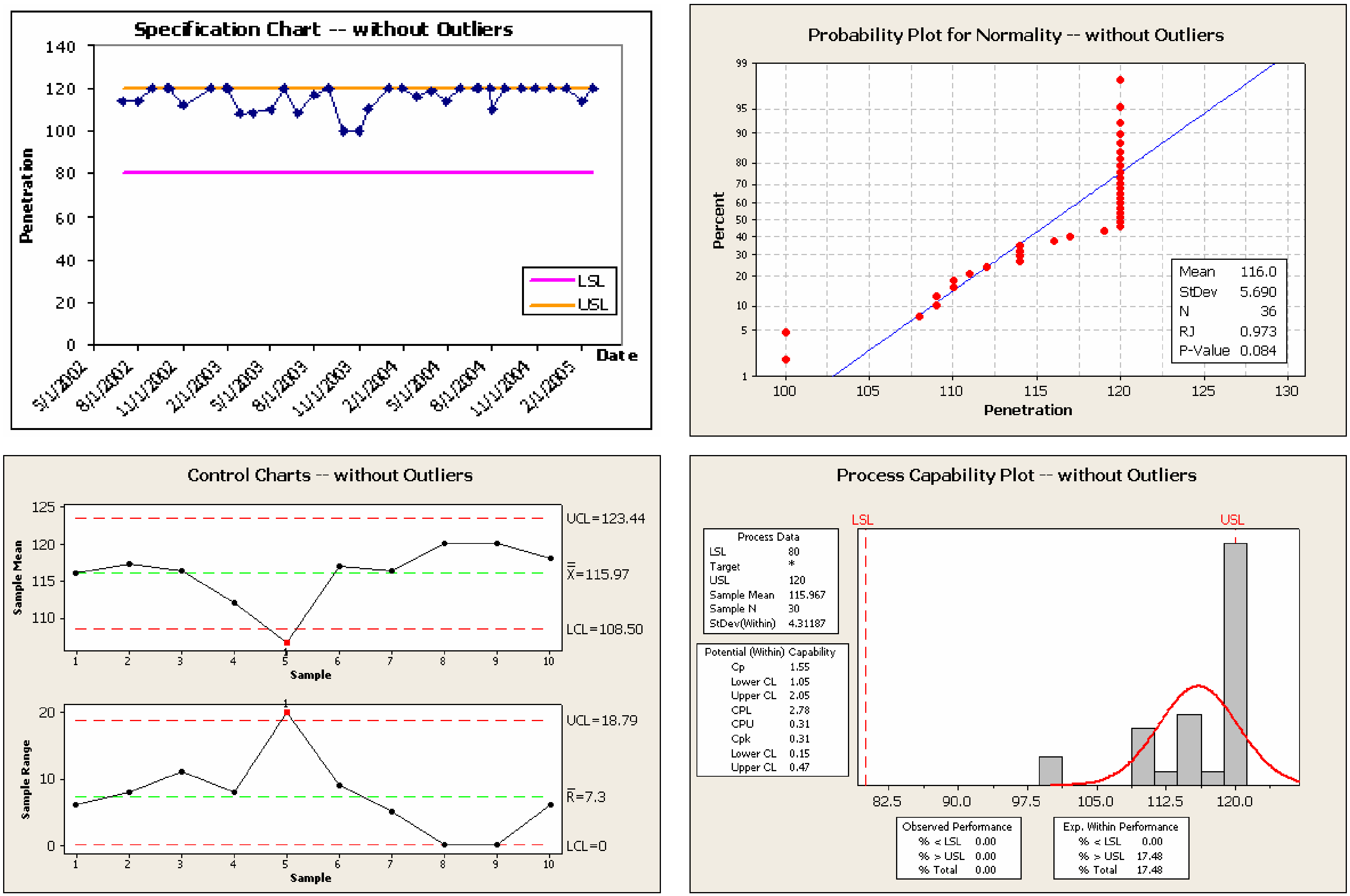


Figure E-84 Statistical Analysis Charts (without Outliers) for Supplier: 0501 Grade: RC-250 Test: Penetration

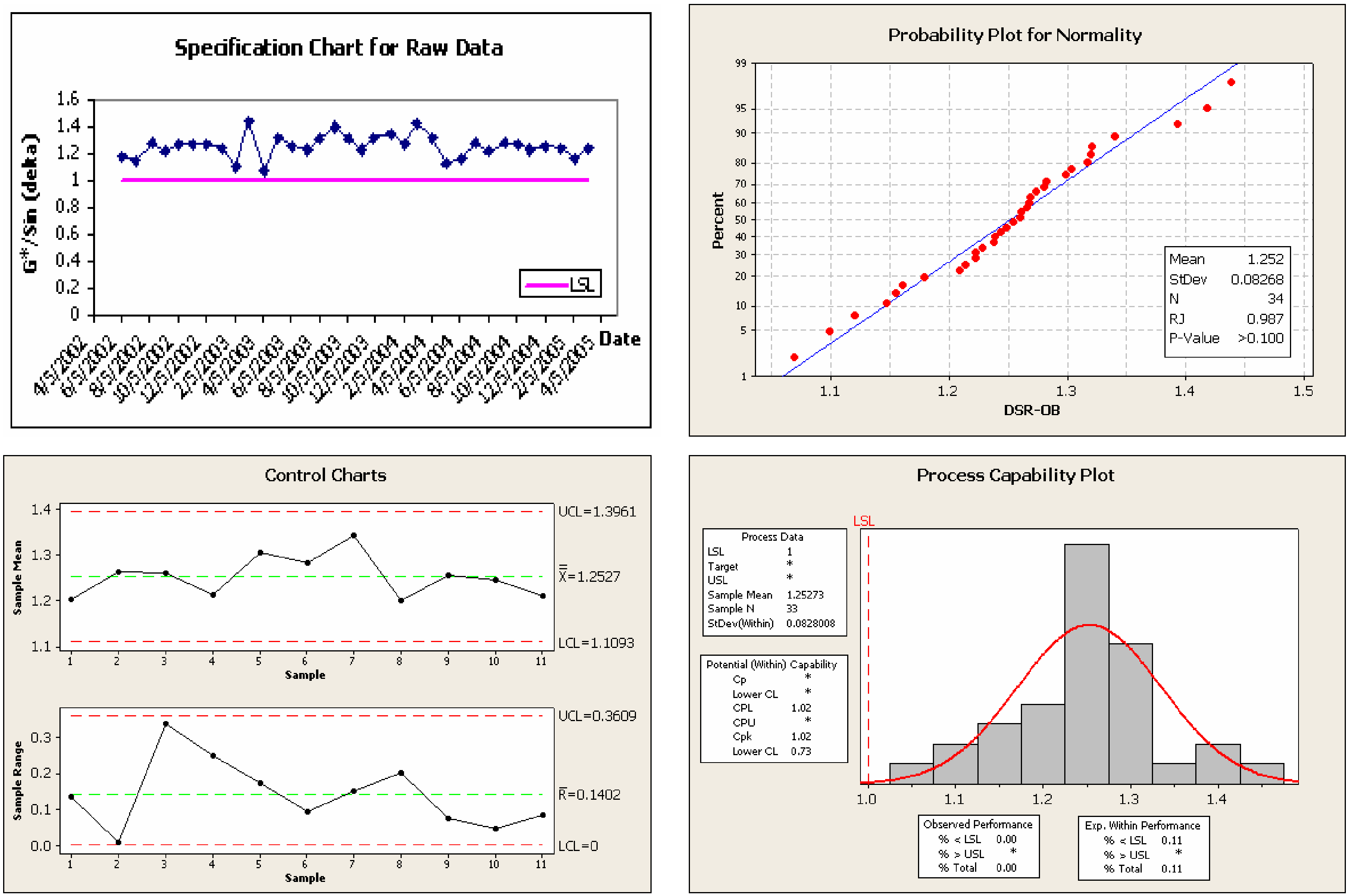


Figure E-85 Statistical Analysis Charts for Supplier: 0601 Grade: PG 64-22 Test: DSR-OB

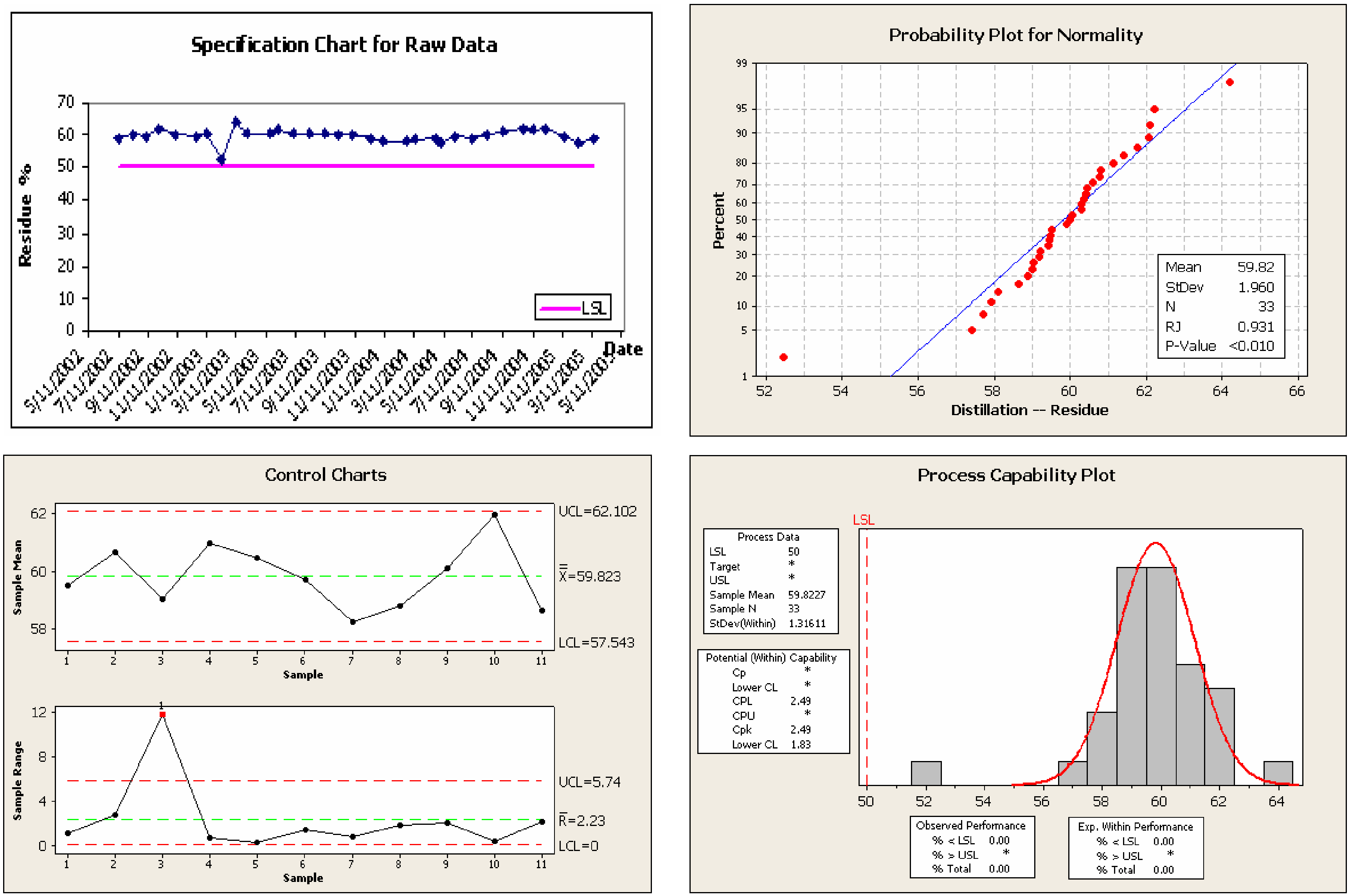


Figure E-86 Statistical Analysis Charts for Supplier: 0601 Grade: MC-30 Test: Distillation-Residue

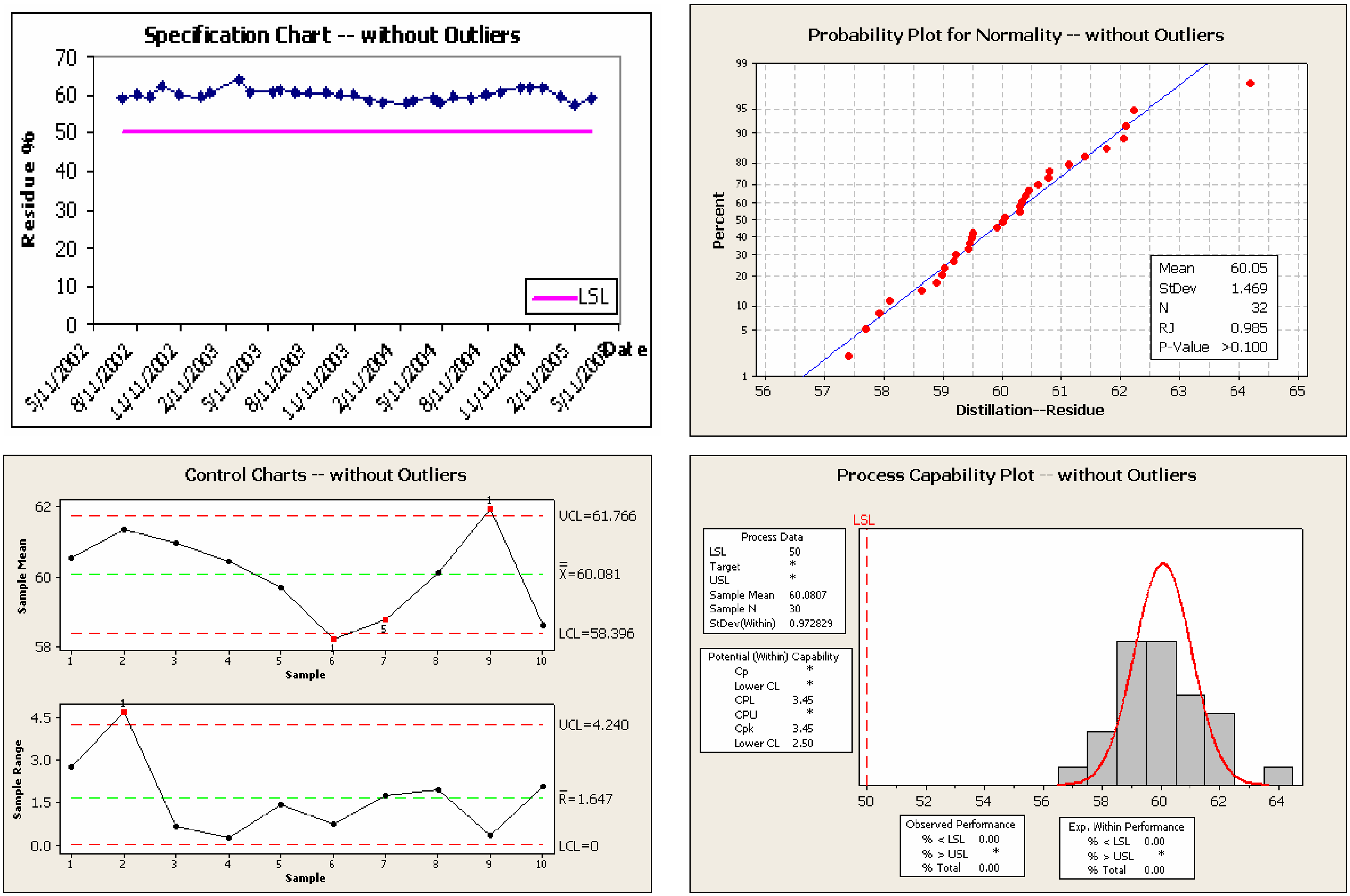


Figure E-87 Statistical Analysis Charts (without Outliers) for Supplier: 0601 Grade: MC-30 Test: Distillation-Residue

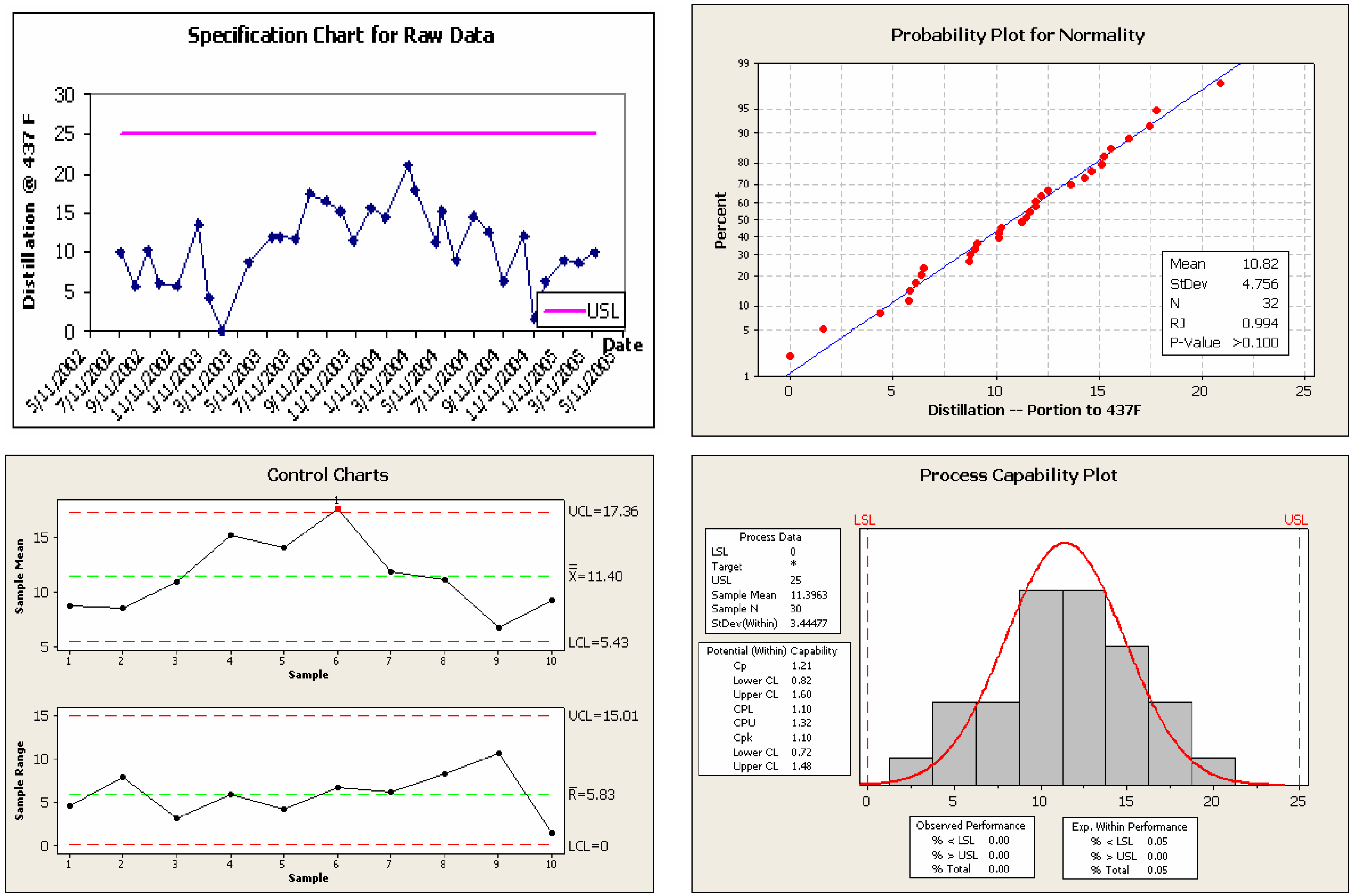


Figure E-88 Statistical Analysis Charts for Supplier: 0601 Grade: MC-30 Test: Distillation @ 437|F

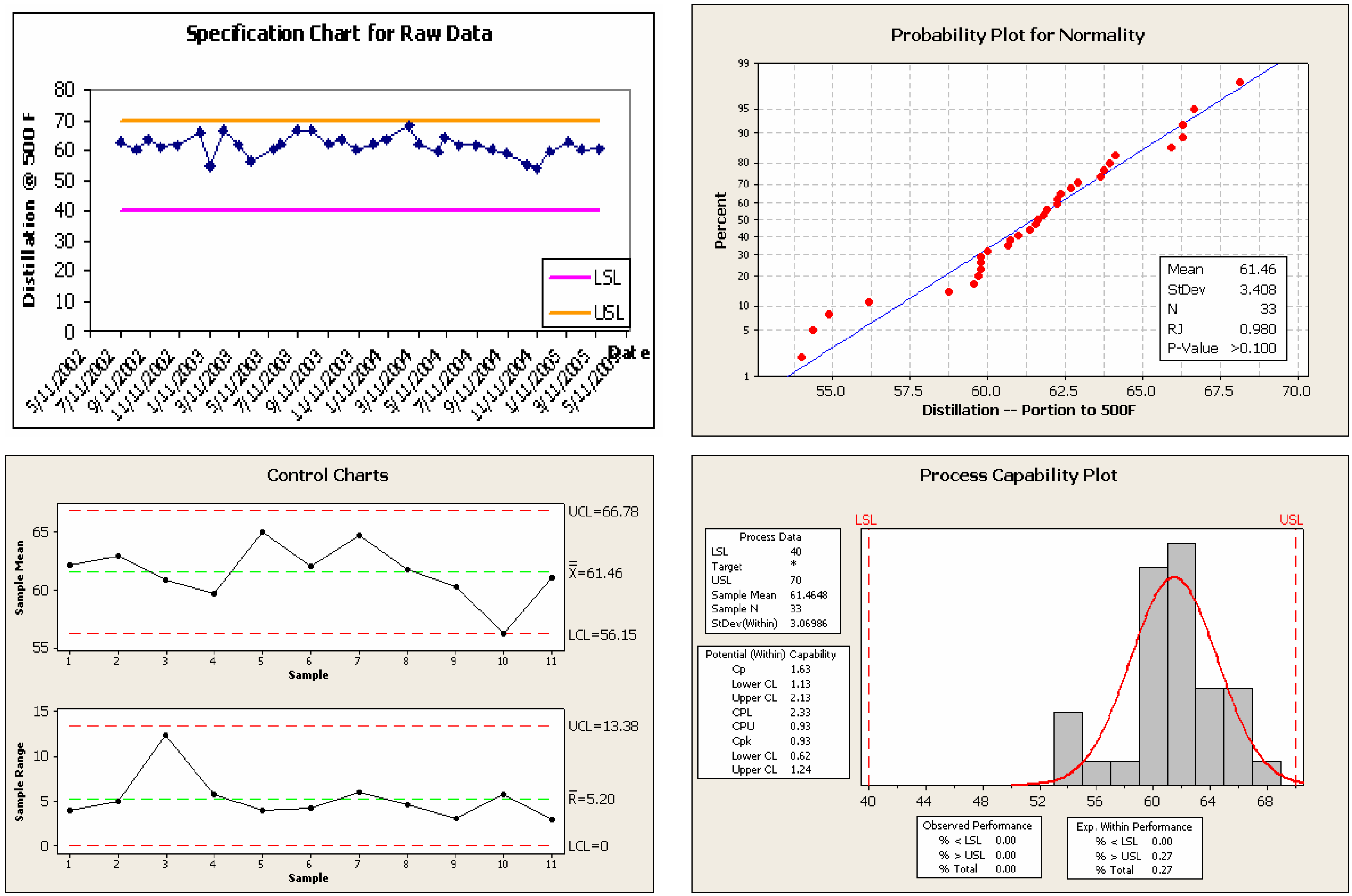


Figure E-89 Statistical Analysis Charts for Supplier: 0601 Grade: MC-30 Test: Distillation @ 500|F

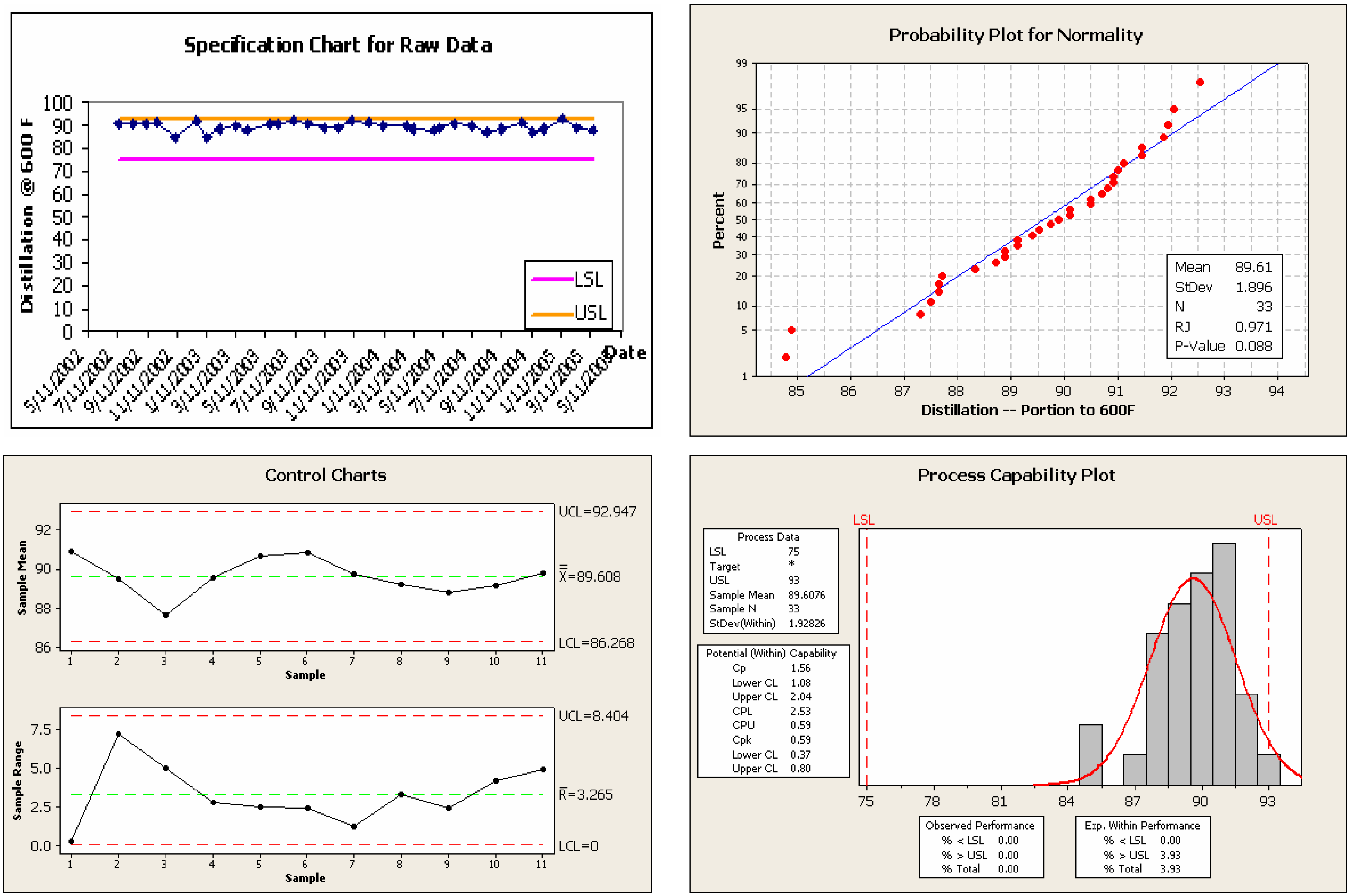


Figure E-90 Statistical Analysis Charts for Supplier: 0601 Grade: MC-30 Test: Distillation @ 600|F

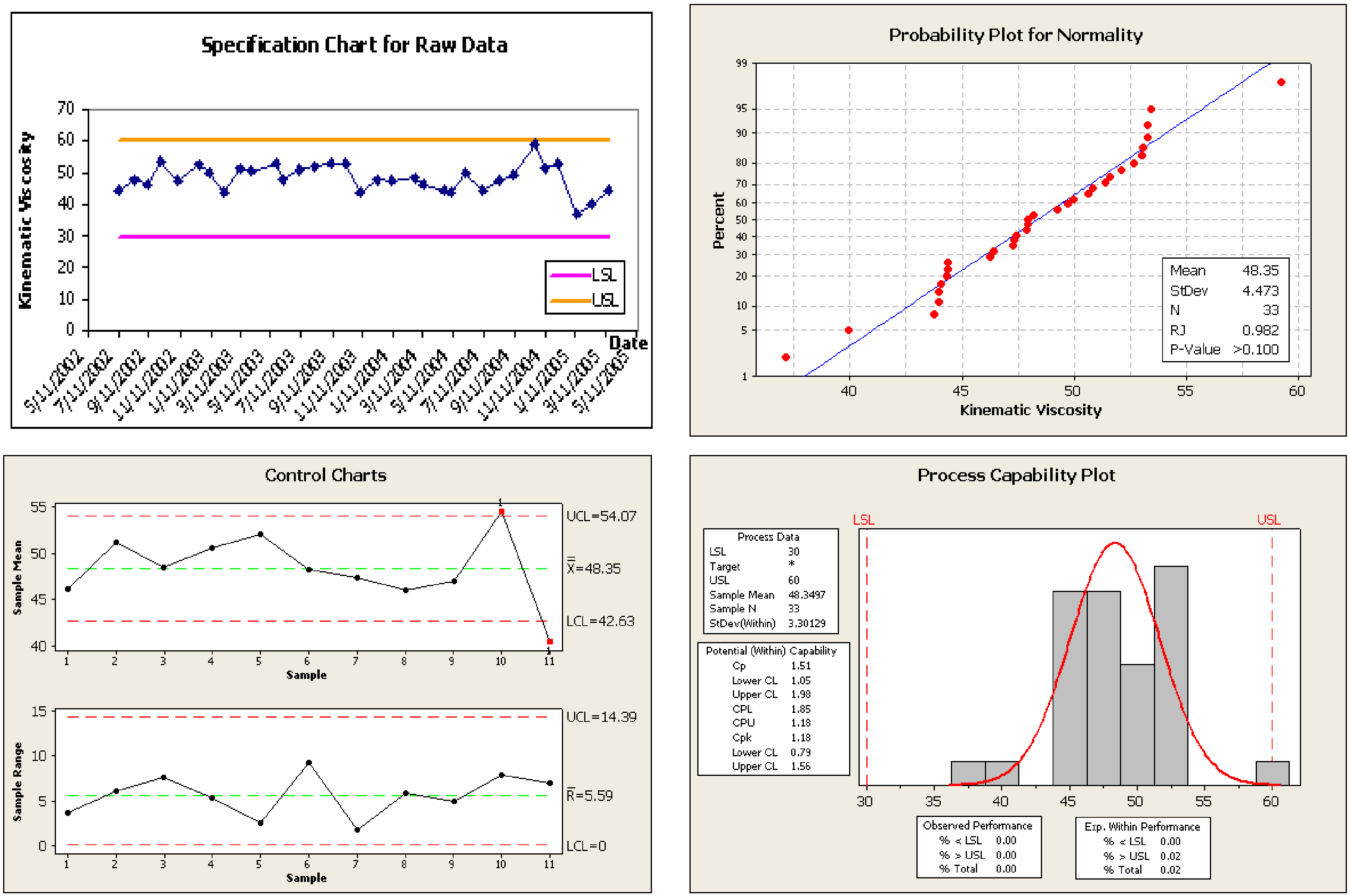


Figure E-91 Statistical Analysis Charts for Supplier: 0601 Grade: MC-30 Test: Kinematic Viscosity

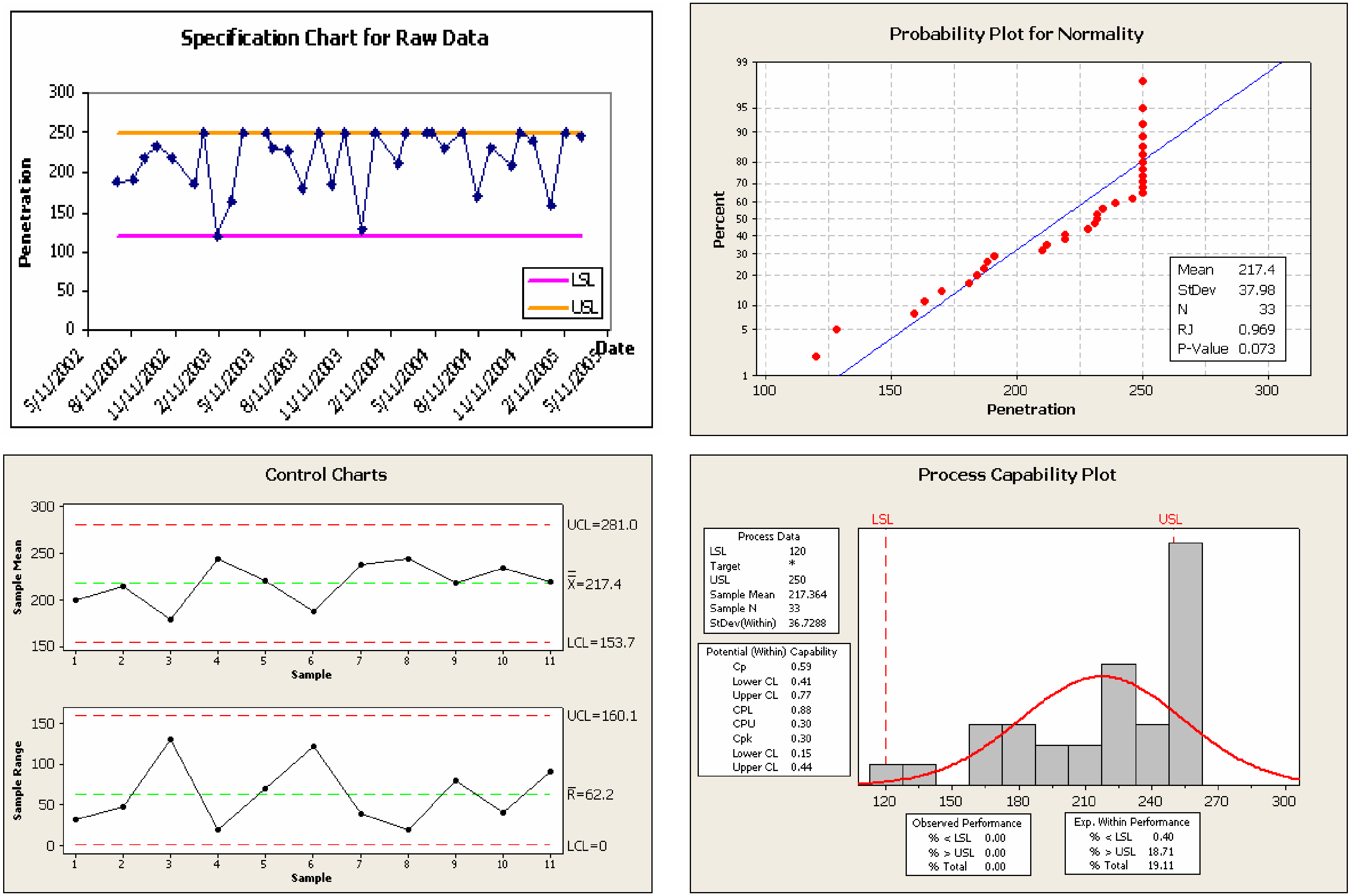


Figure E-92 Statistical Analysis Charts for Supplier: 0601 Grade: MC-30 Test: Penetration

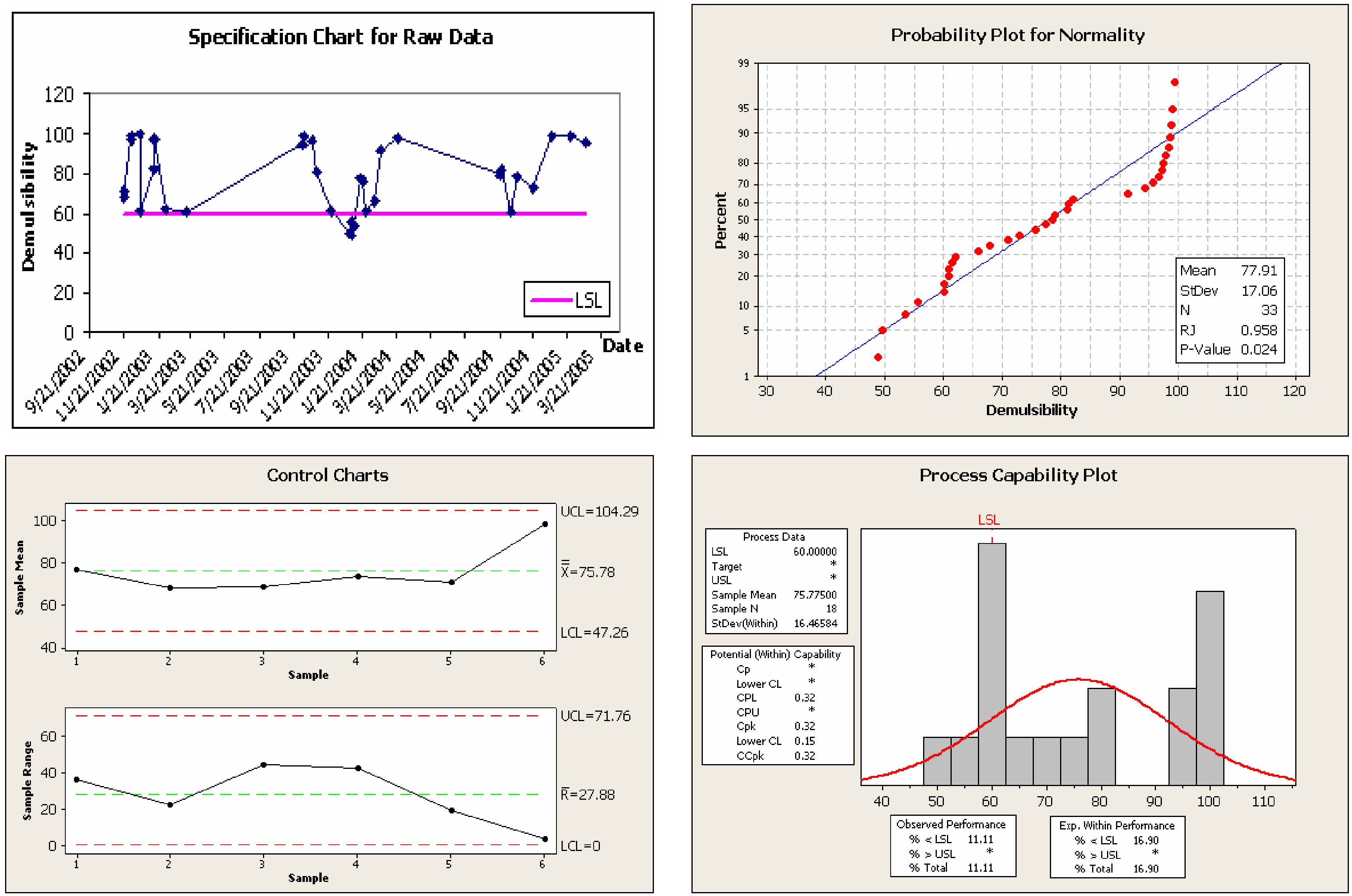


Figure E-93 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-1P Test: Demulsibility

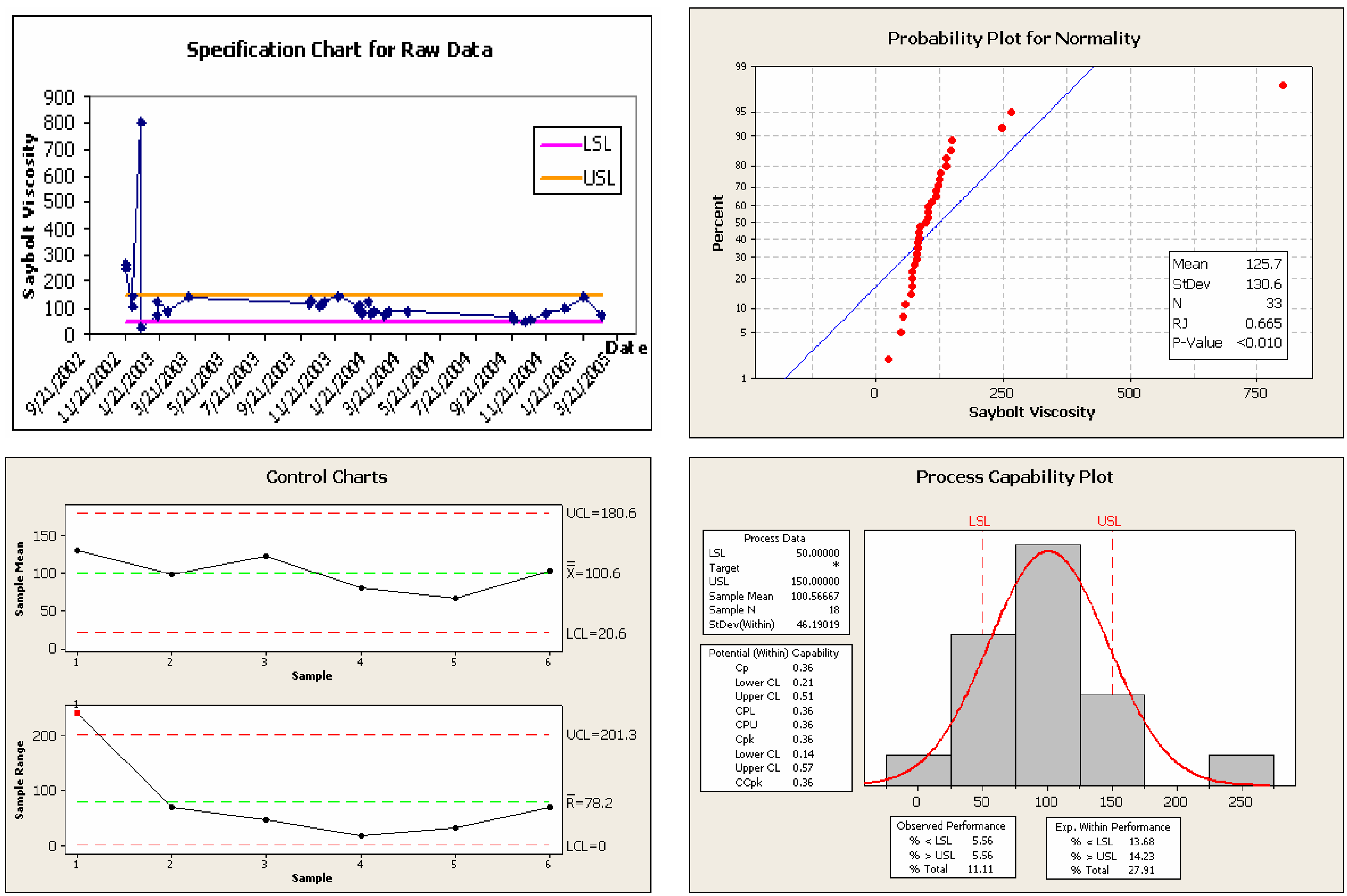


Figure E-94 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-1P Test: Saybolt Viscosity

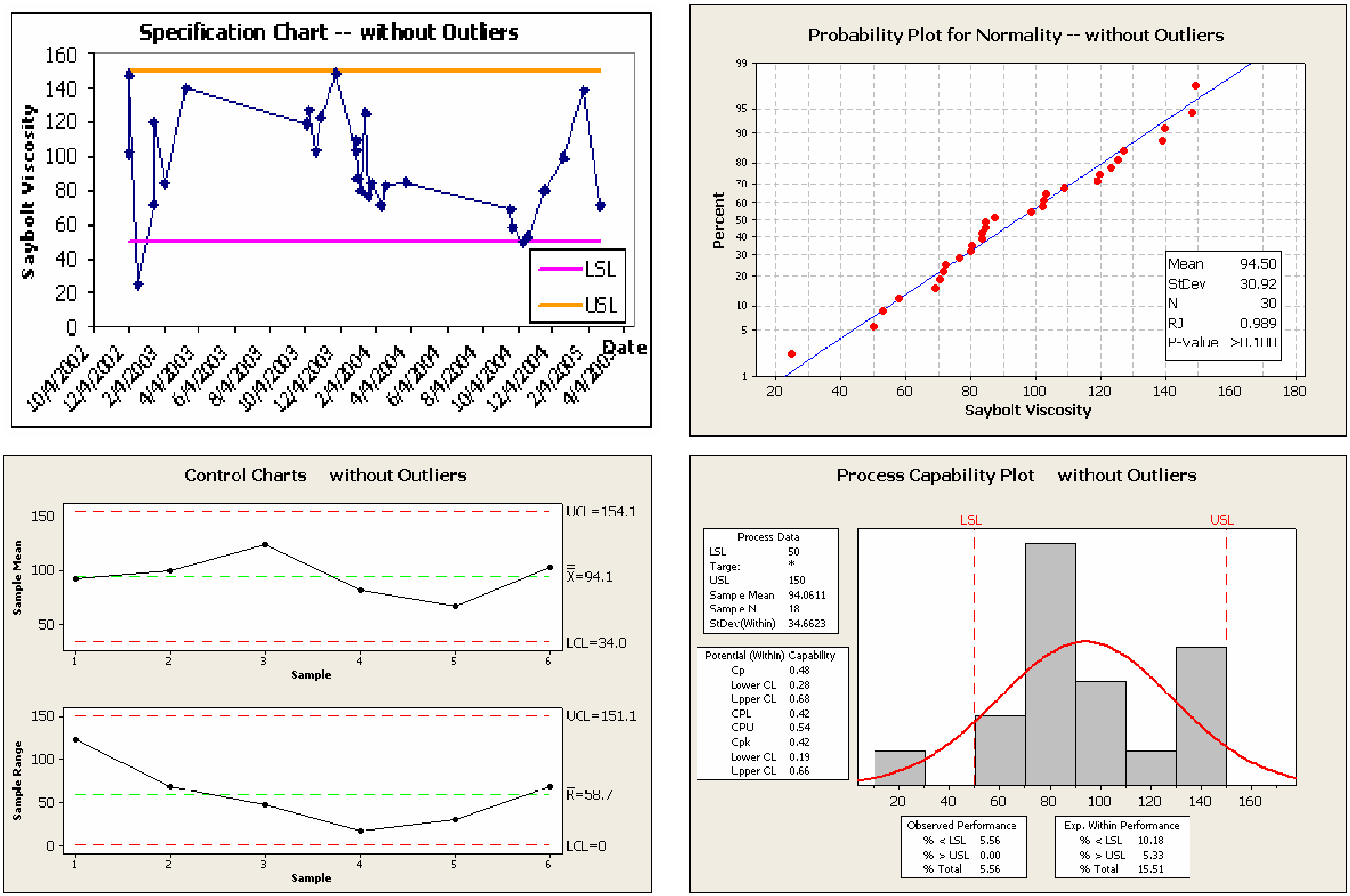


Figure E-95 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CRS-1P Test: Saybolt Viscosity

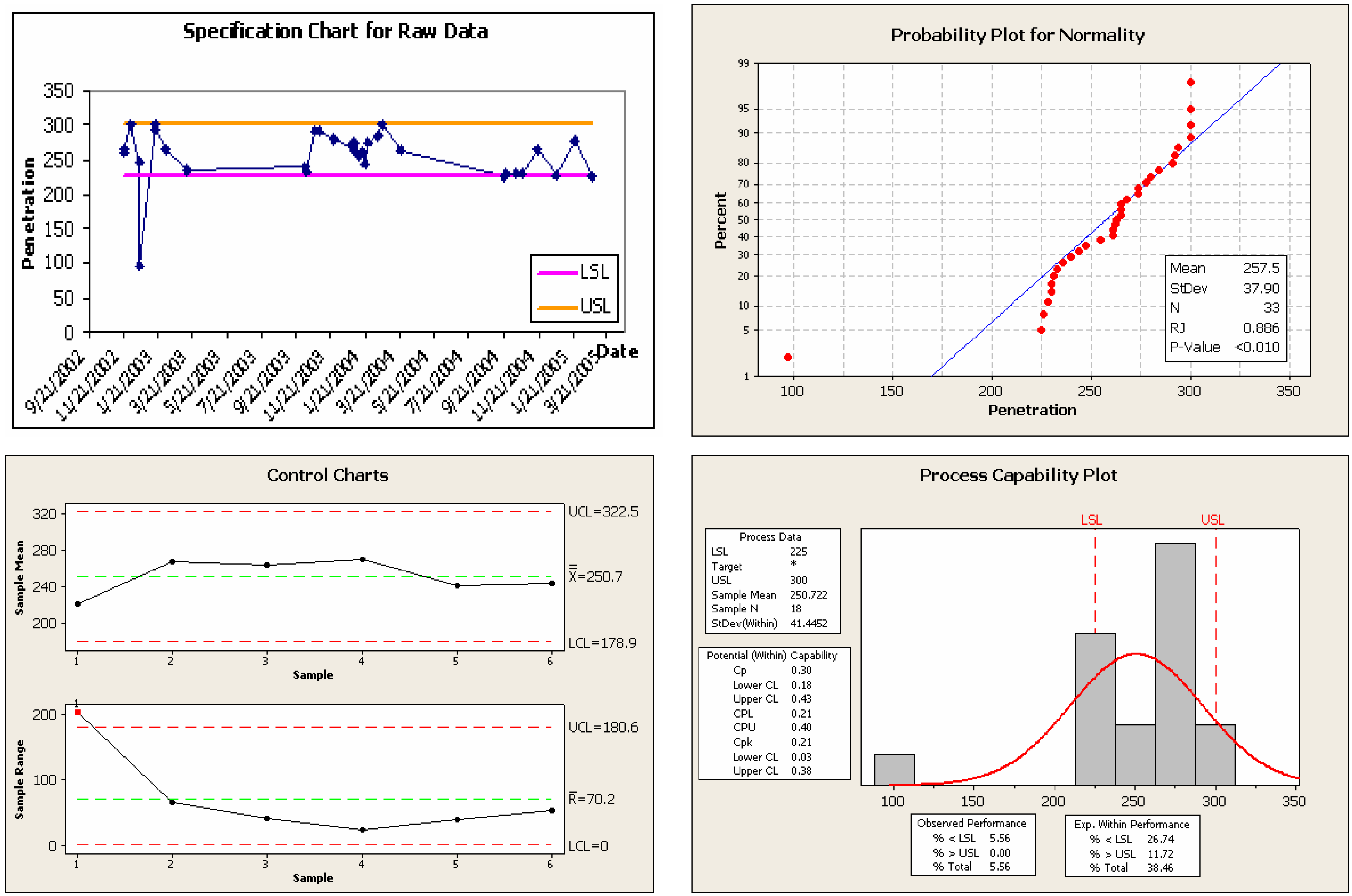


Figure E-96 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-1P Test: Penetration

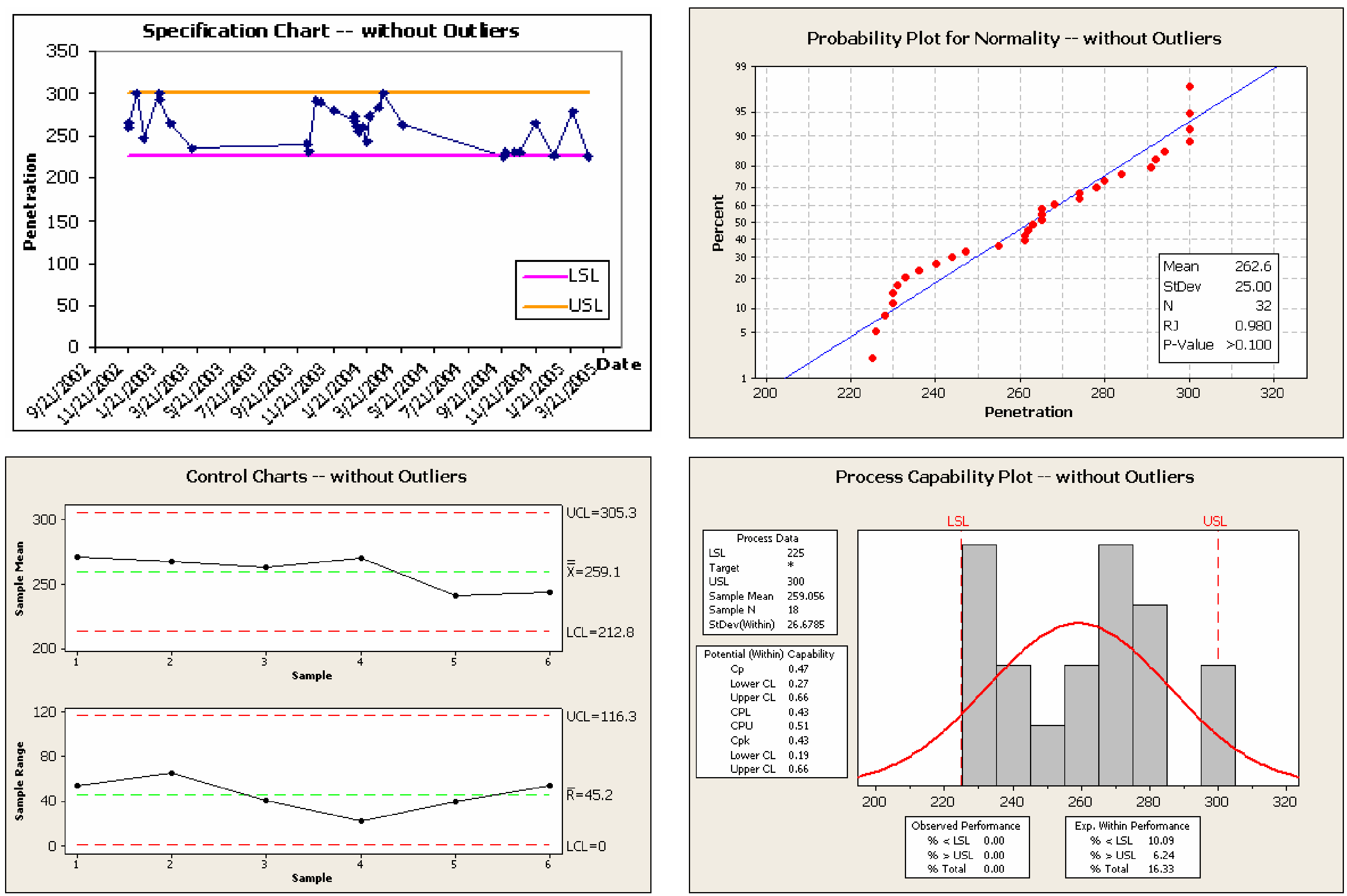


Figure E-97 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CRS-1P Test: Penetration

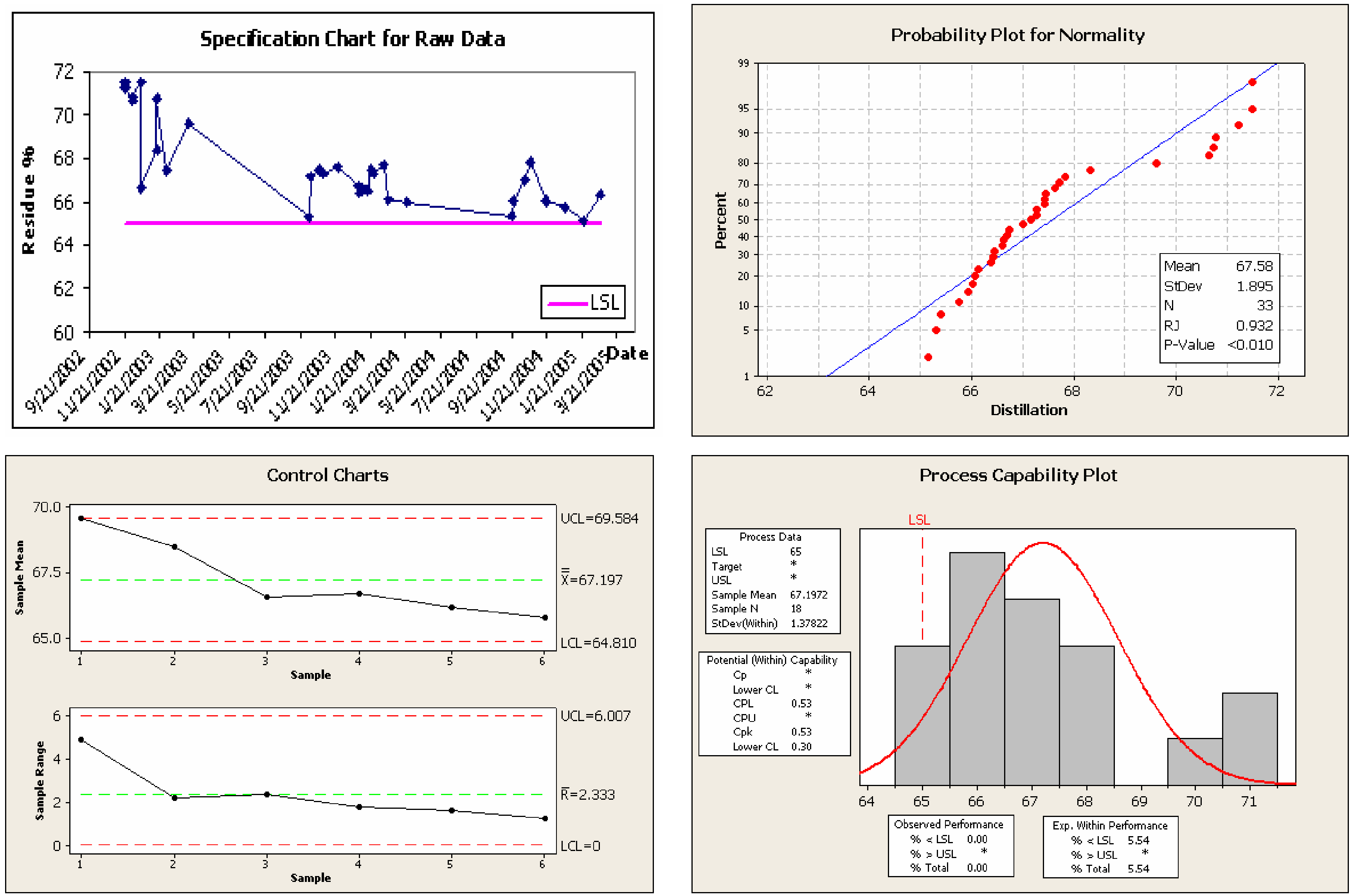


Figure E-98 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-1P Test: Distillation

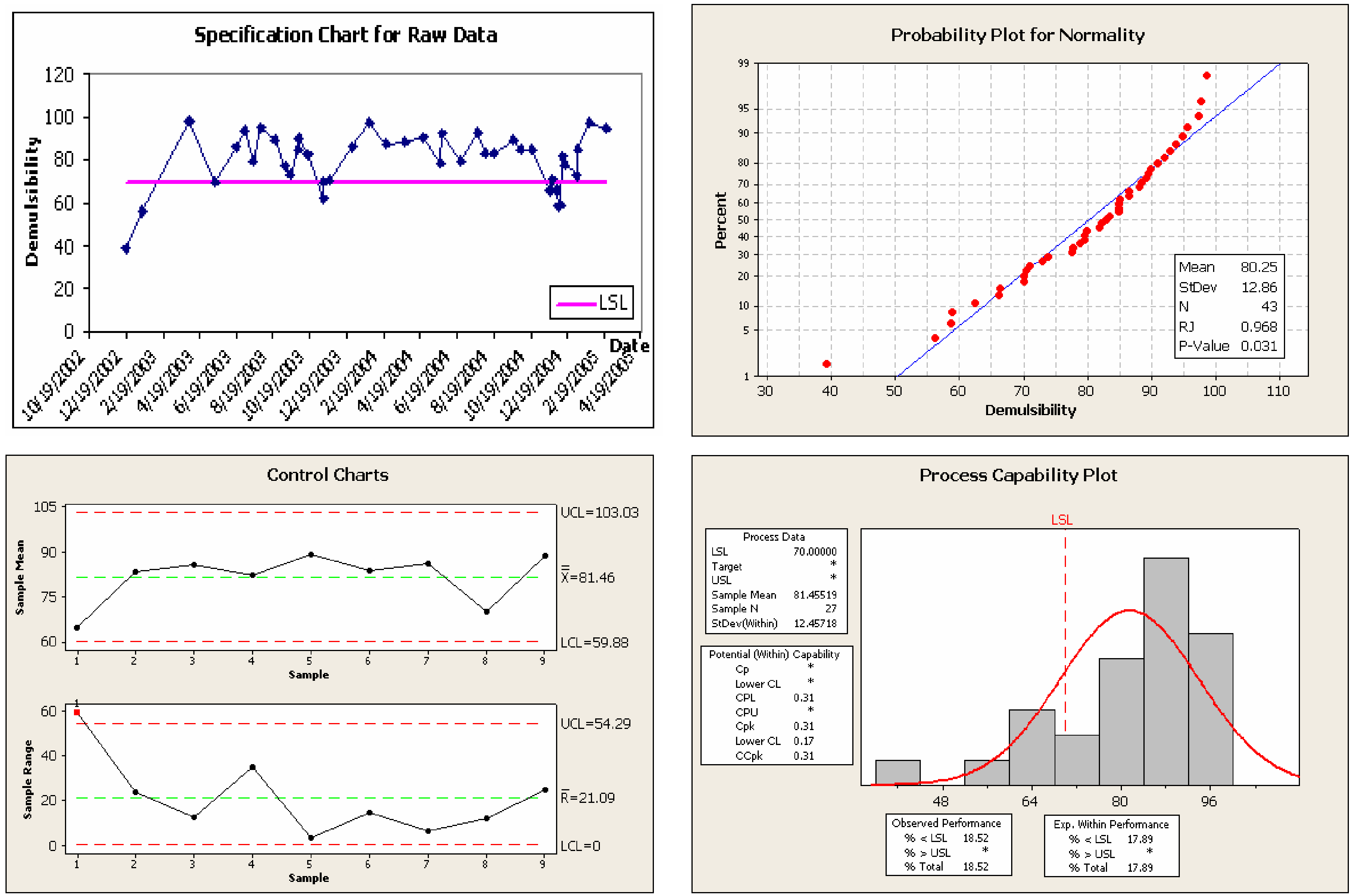


Figure E-99 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Demulsibility

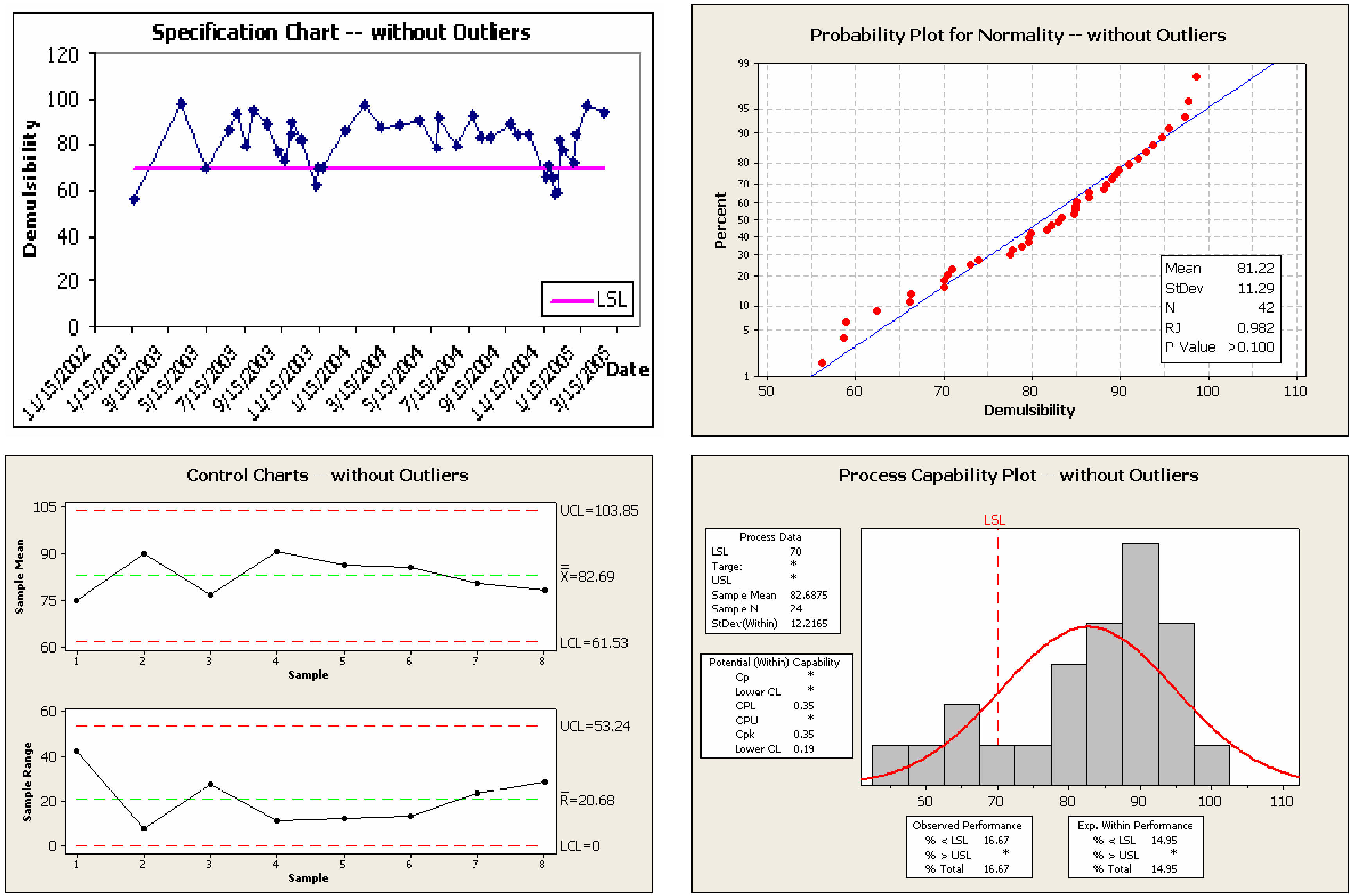


Figure E-100 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CRS-2 Test: Demulsibility

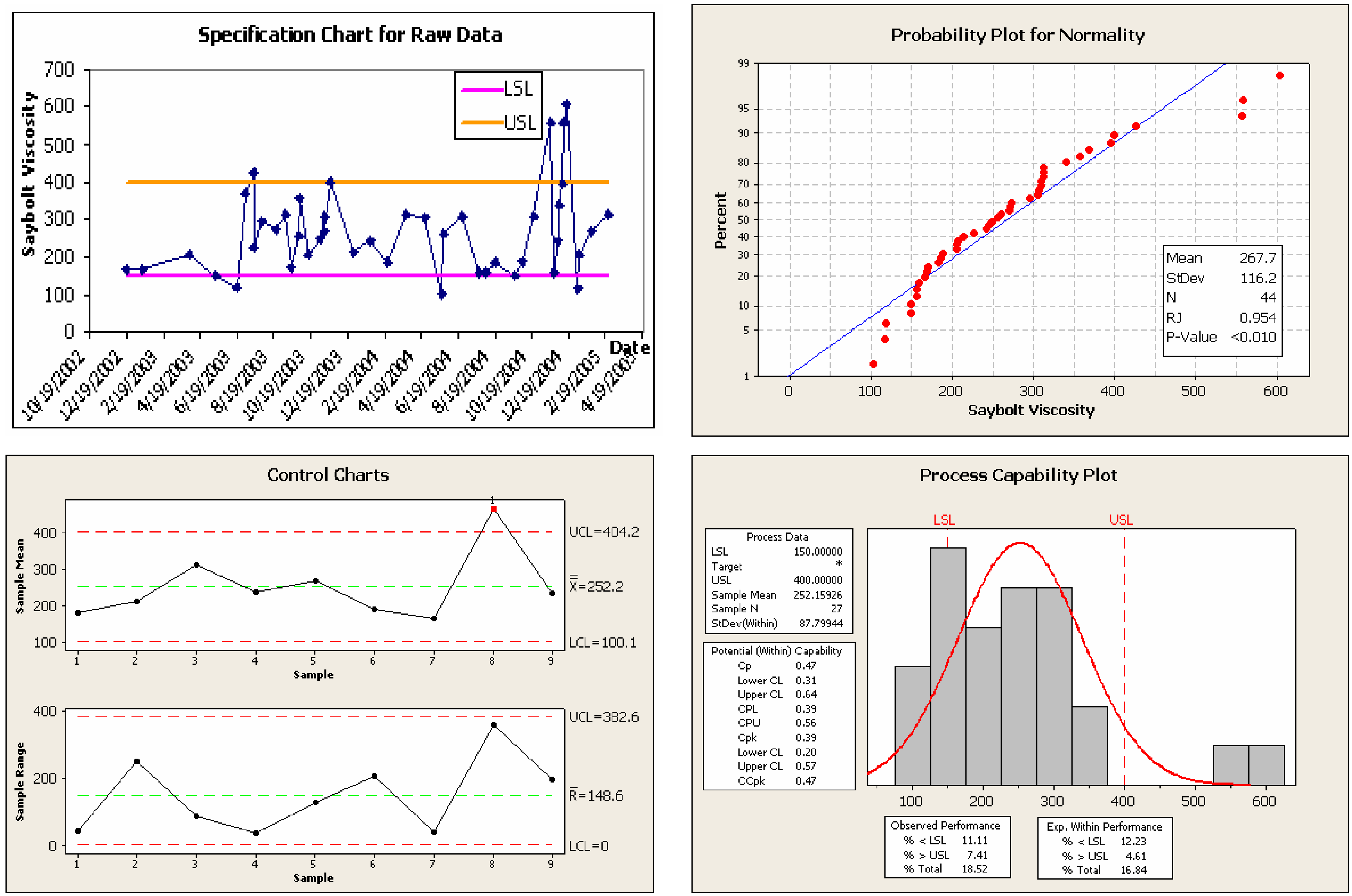


Figure E-101 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Saybolt Viscosity

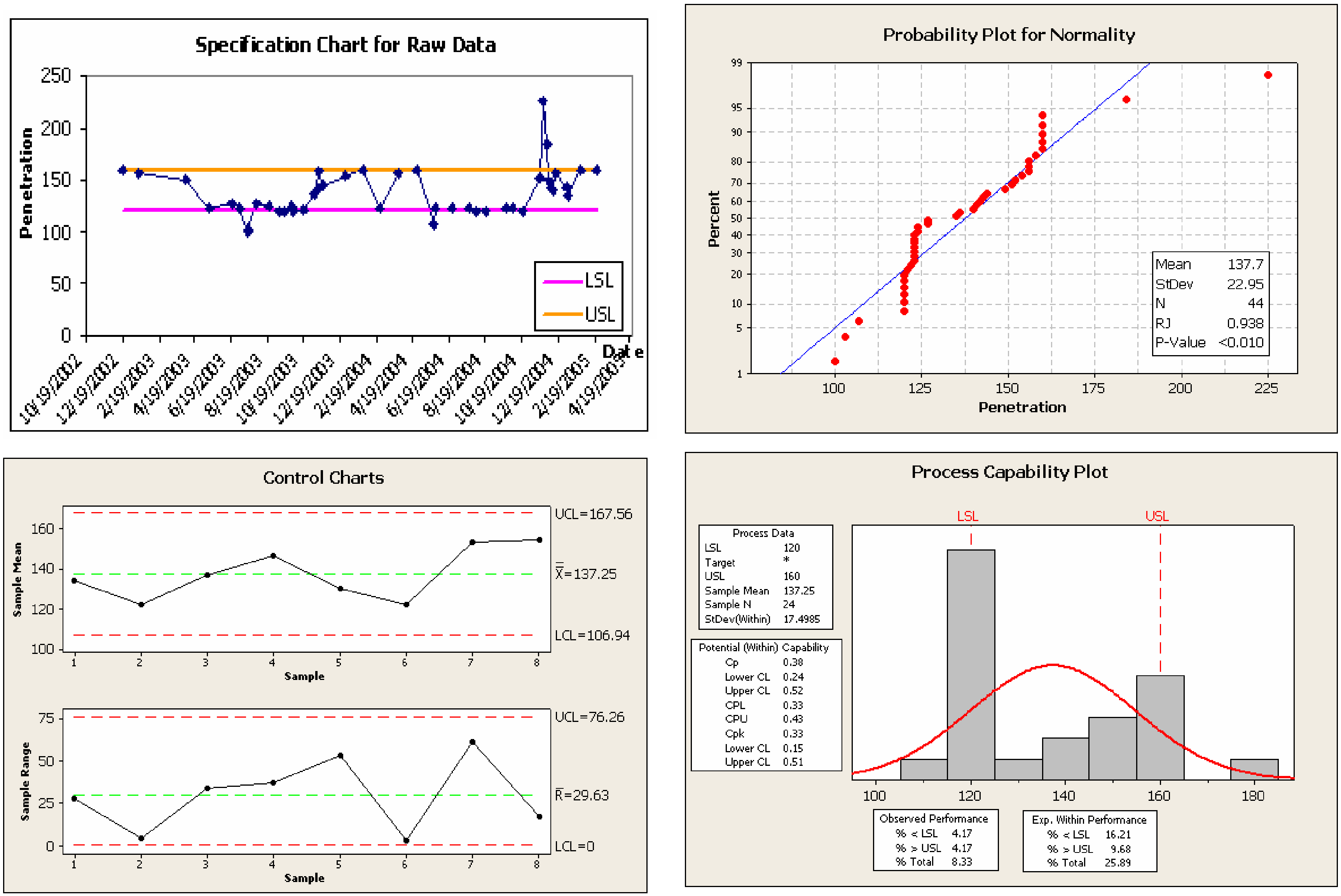


Figure E-102 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Penetration

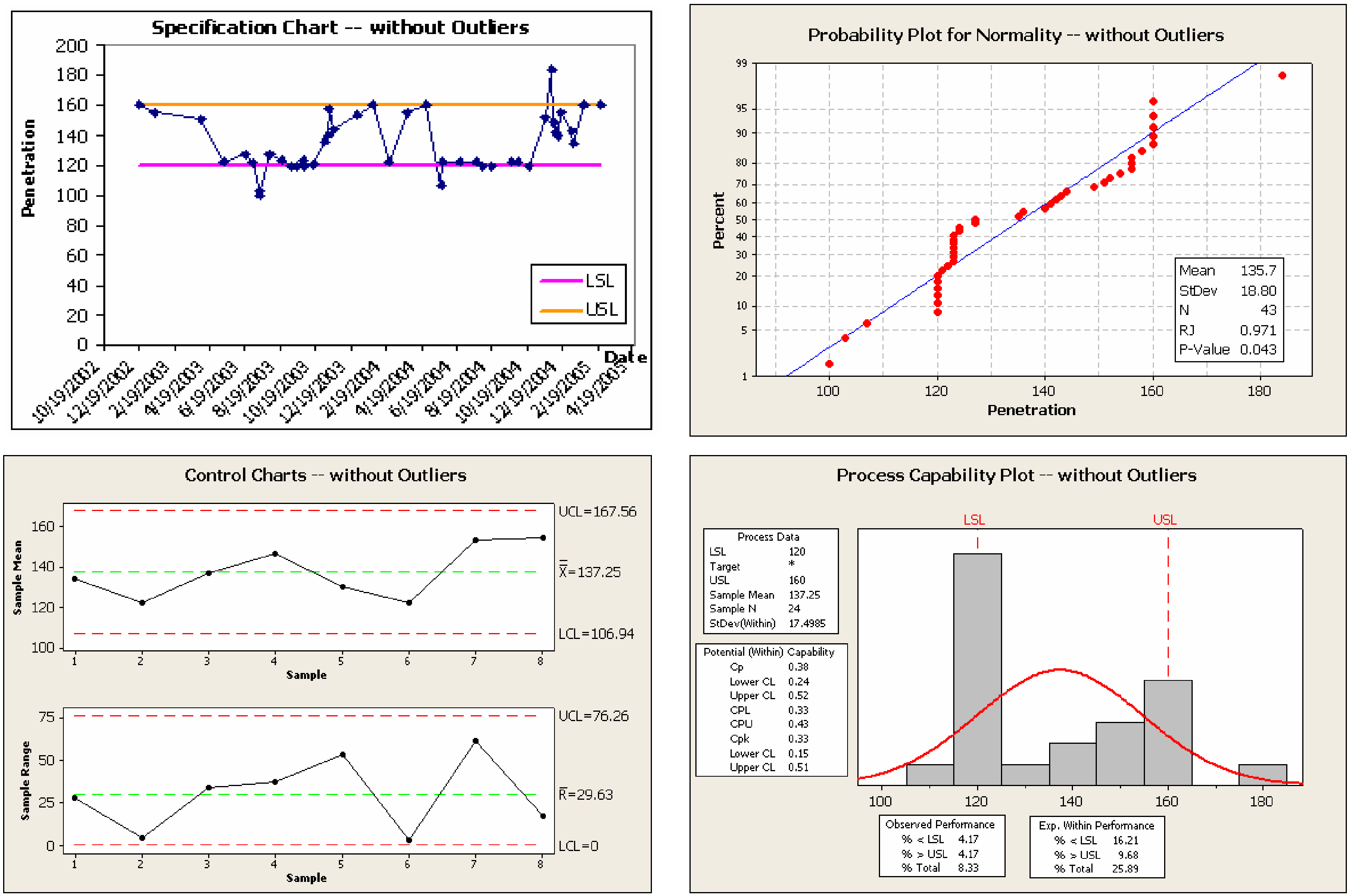


Figure E-103 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CRS-2 Test: Penetration

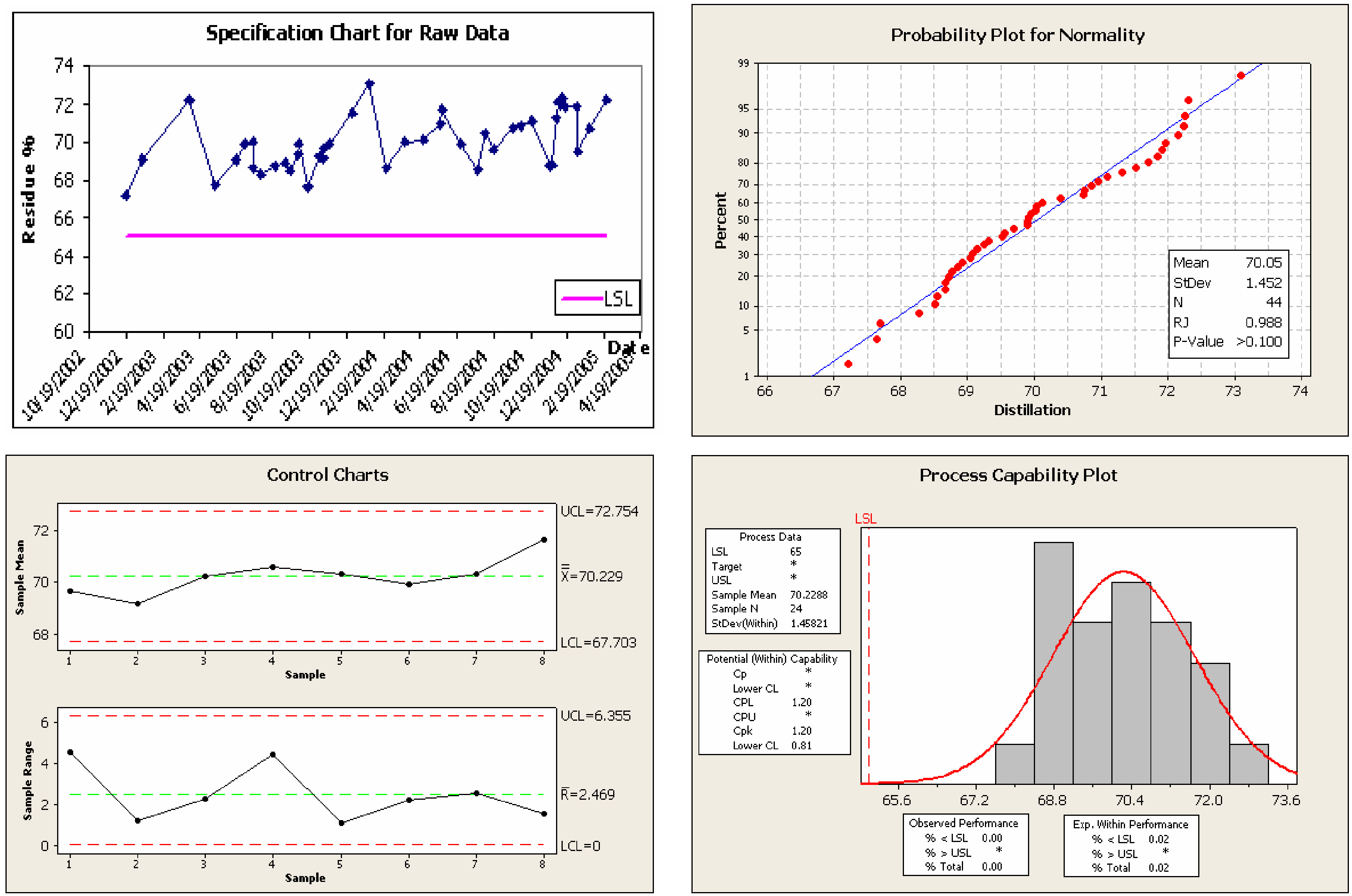


Figure E-104 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Distillation

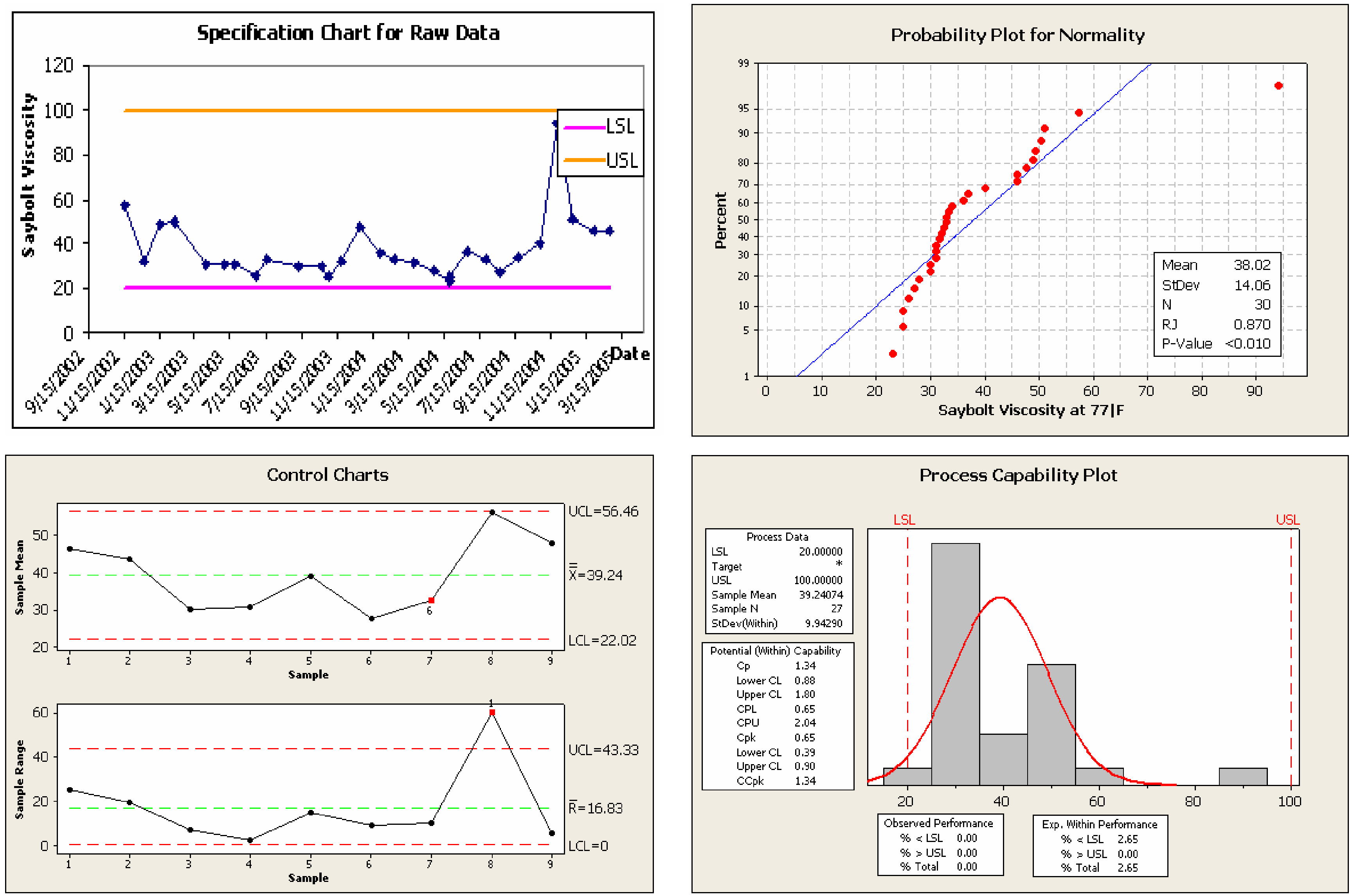


Figure E-105 Statistical Analysis Charts for Supplier: 0702 Grade: CSS-1H Test: Saybolt Viscosity

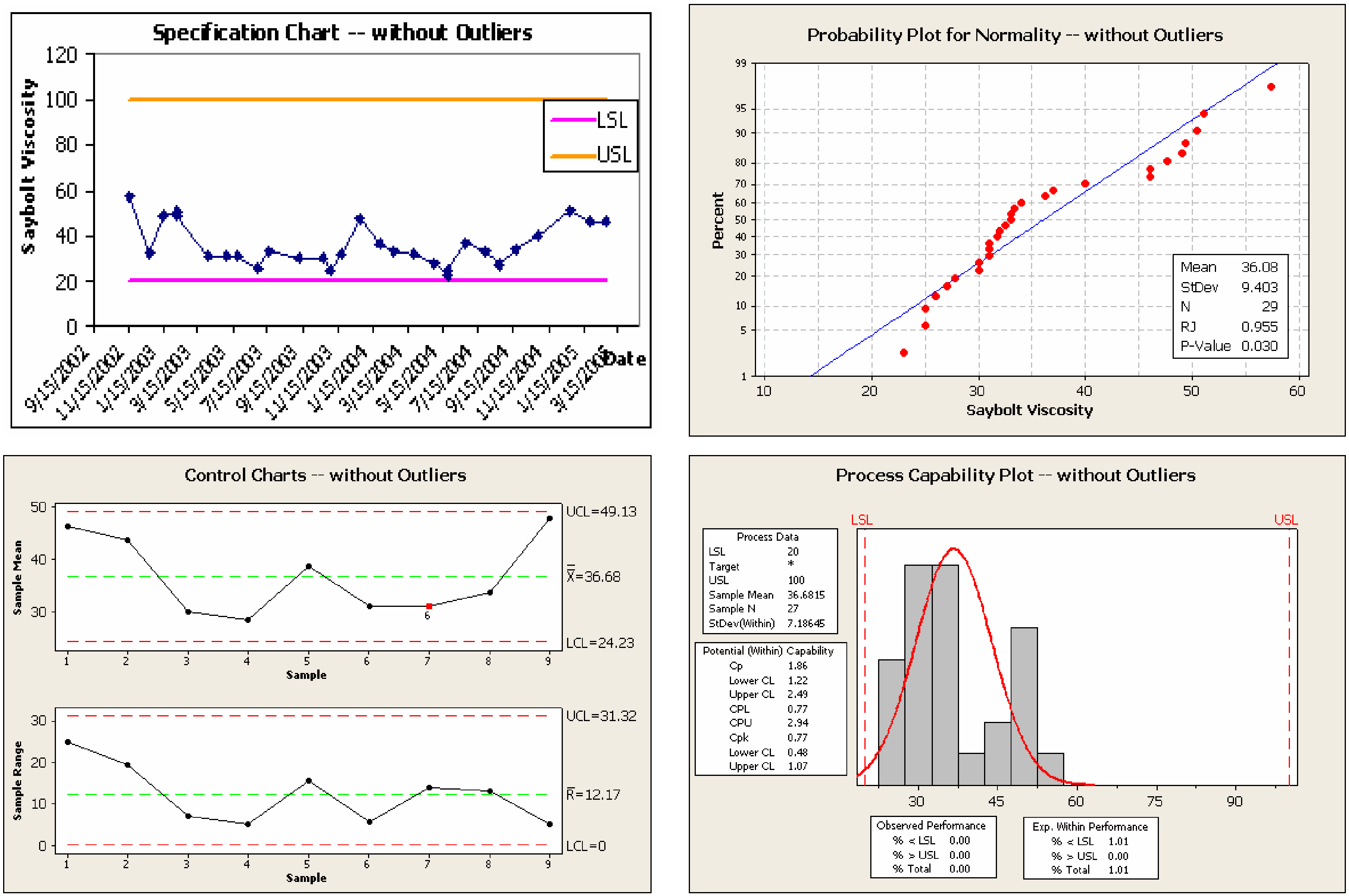


Figure E-106 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CSS-1H Test: Saybolt Viscosity

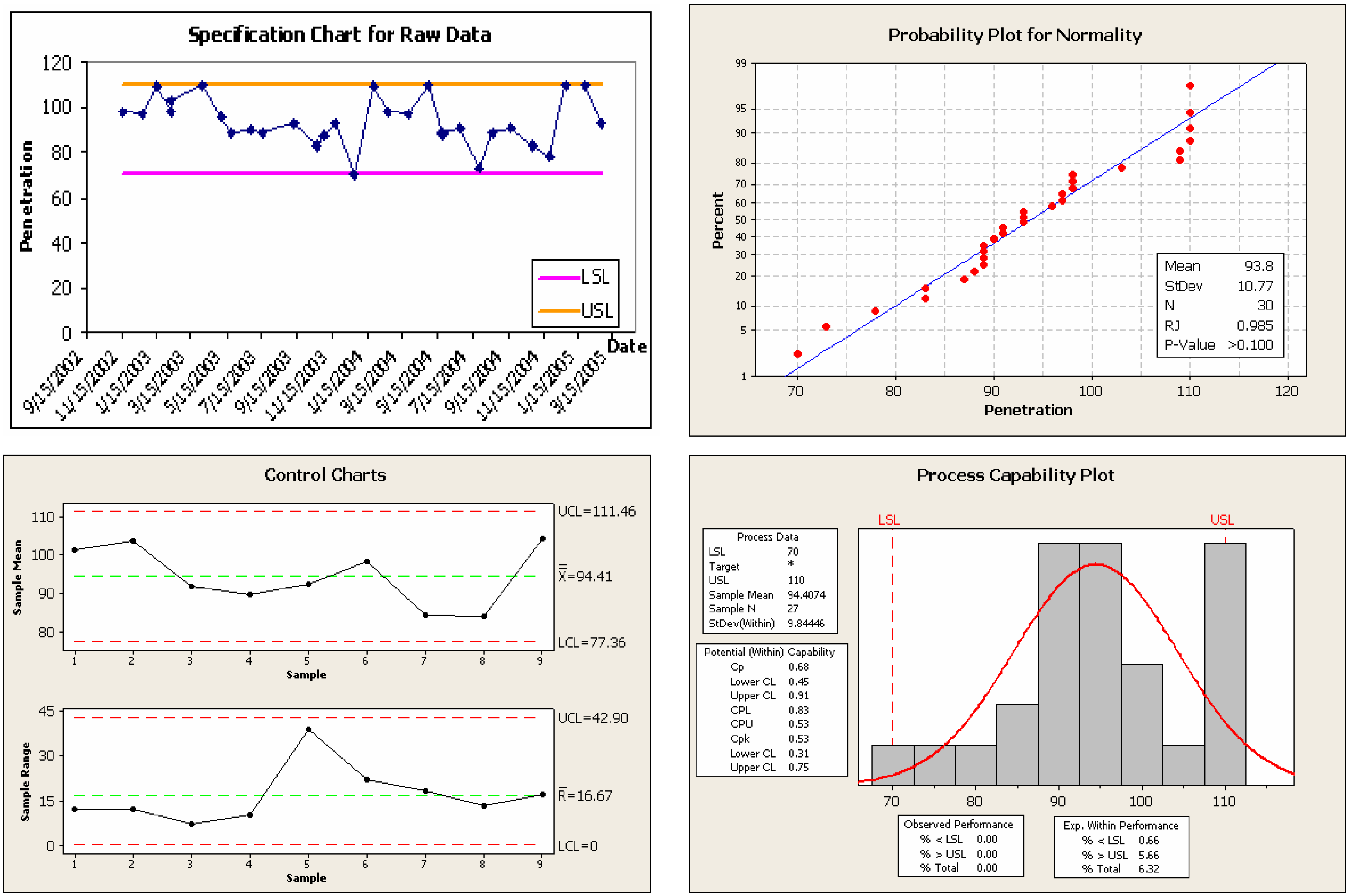


Figure E-107 Statistical Analysis Charts for Supplier: 0702 Grade: CSS-1H Test: Penetration

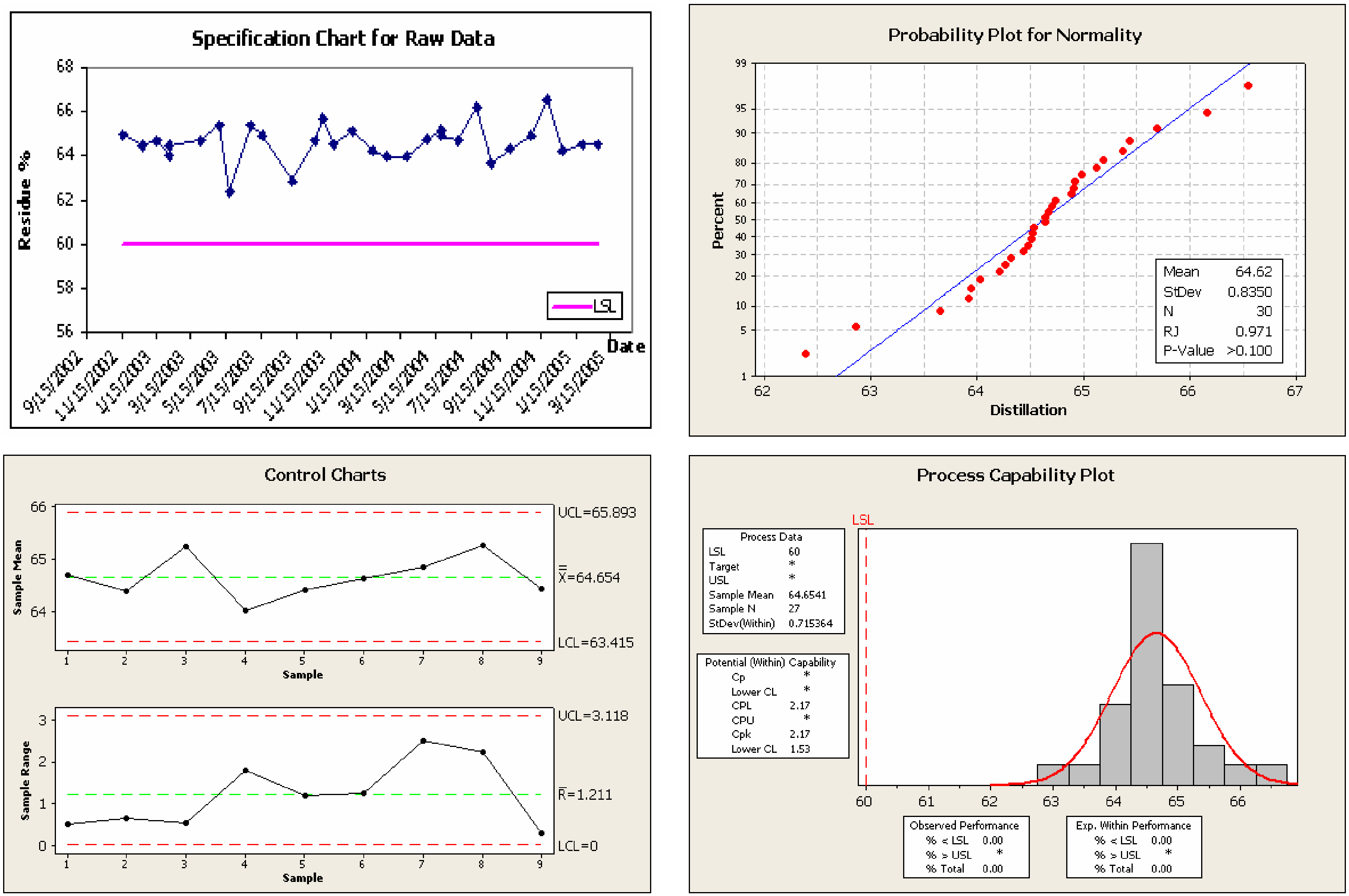


Figure E-108 Statistical Analysis Charts for Supplier: 0702 Grade: CSS-1H Test: Distillation

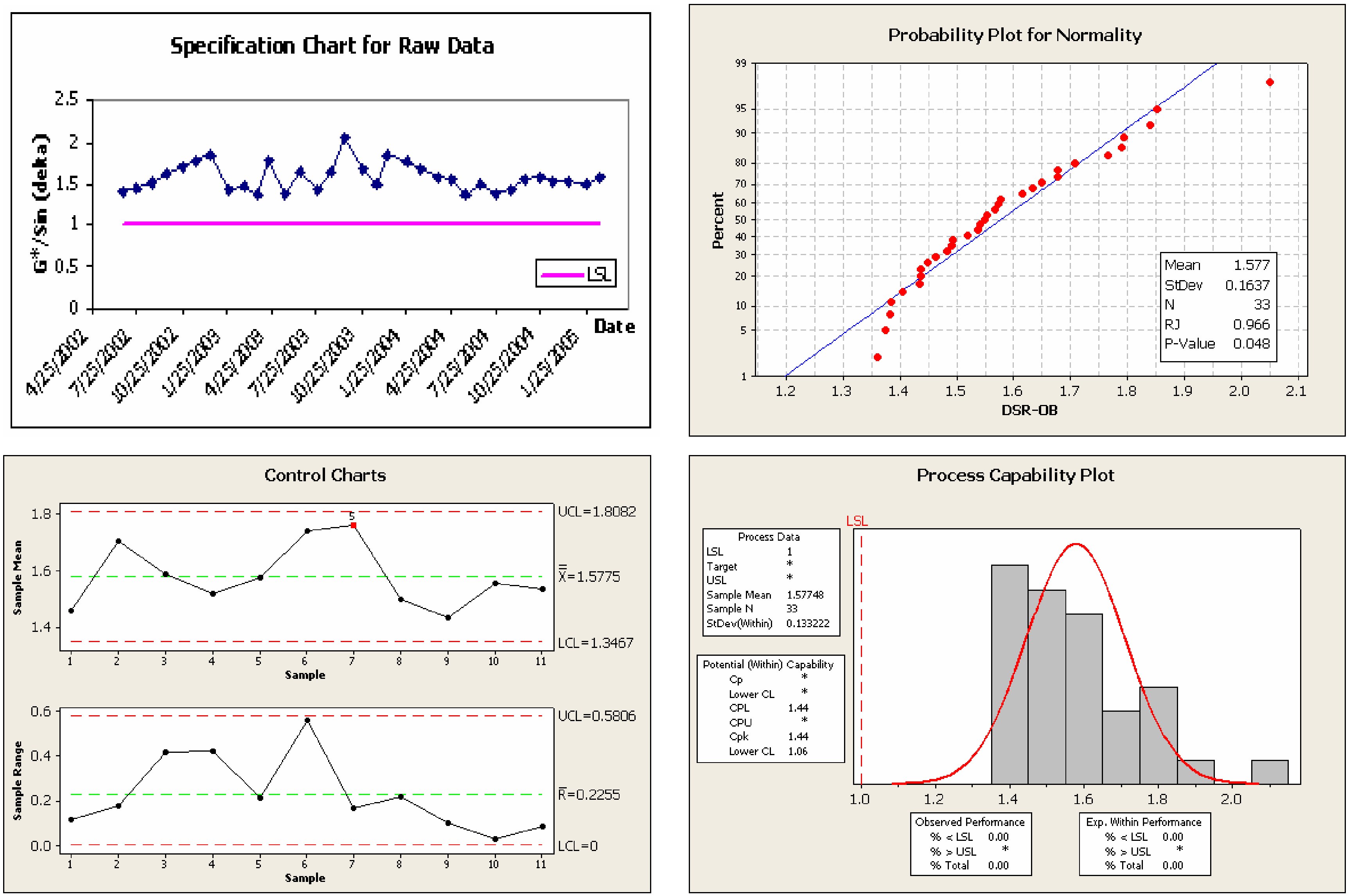


Figure E-109 Statistical Analysis Charts for Supplier: 0703 Grade: PG 64-22 Test: DSR-OB

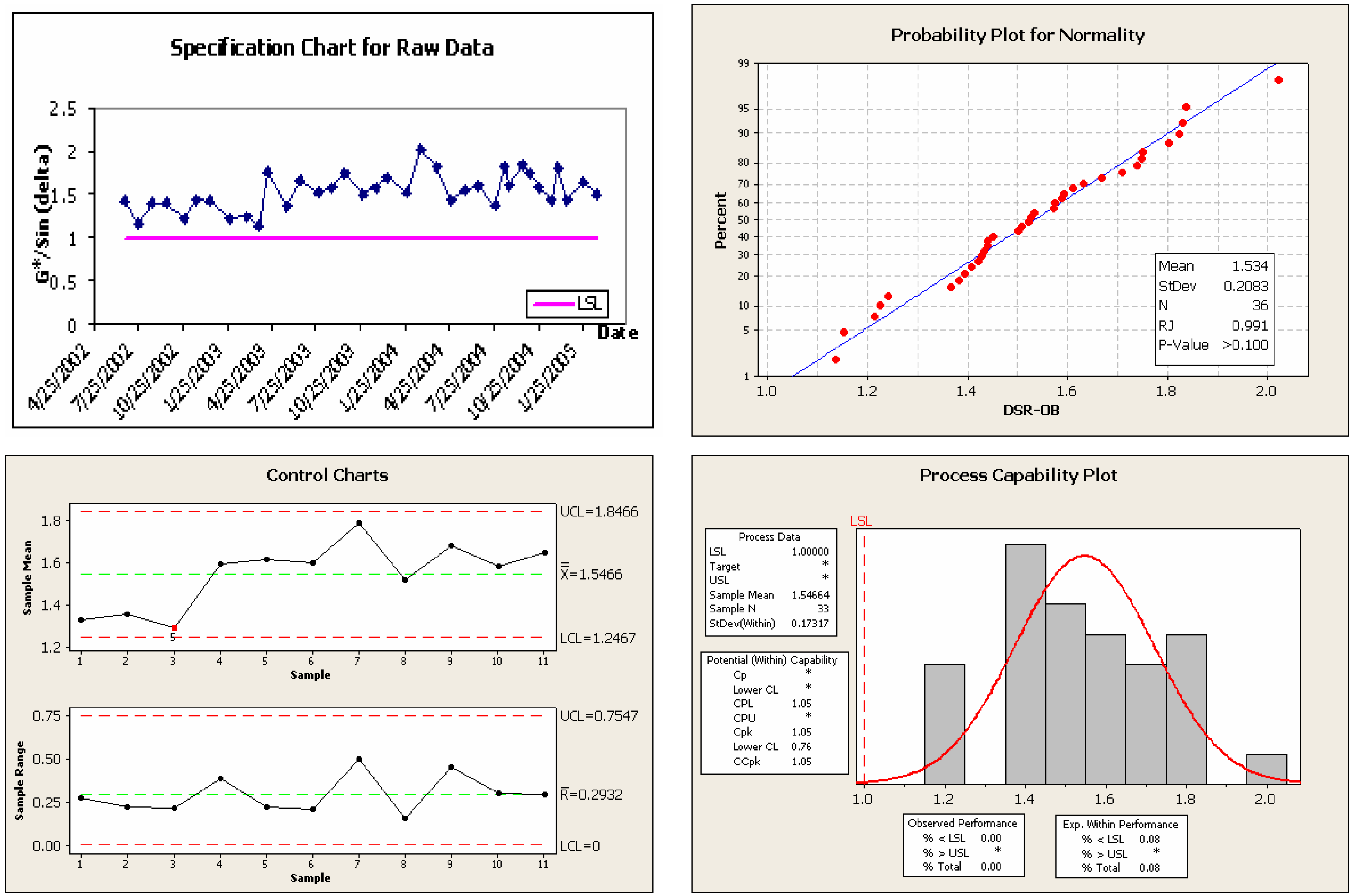


Figure E-110 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

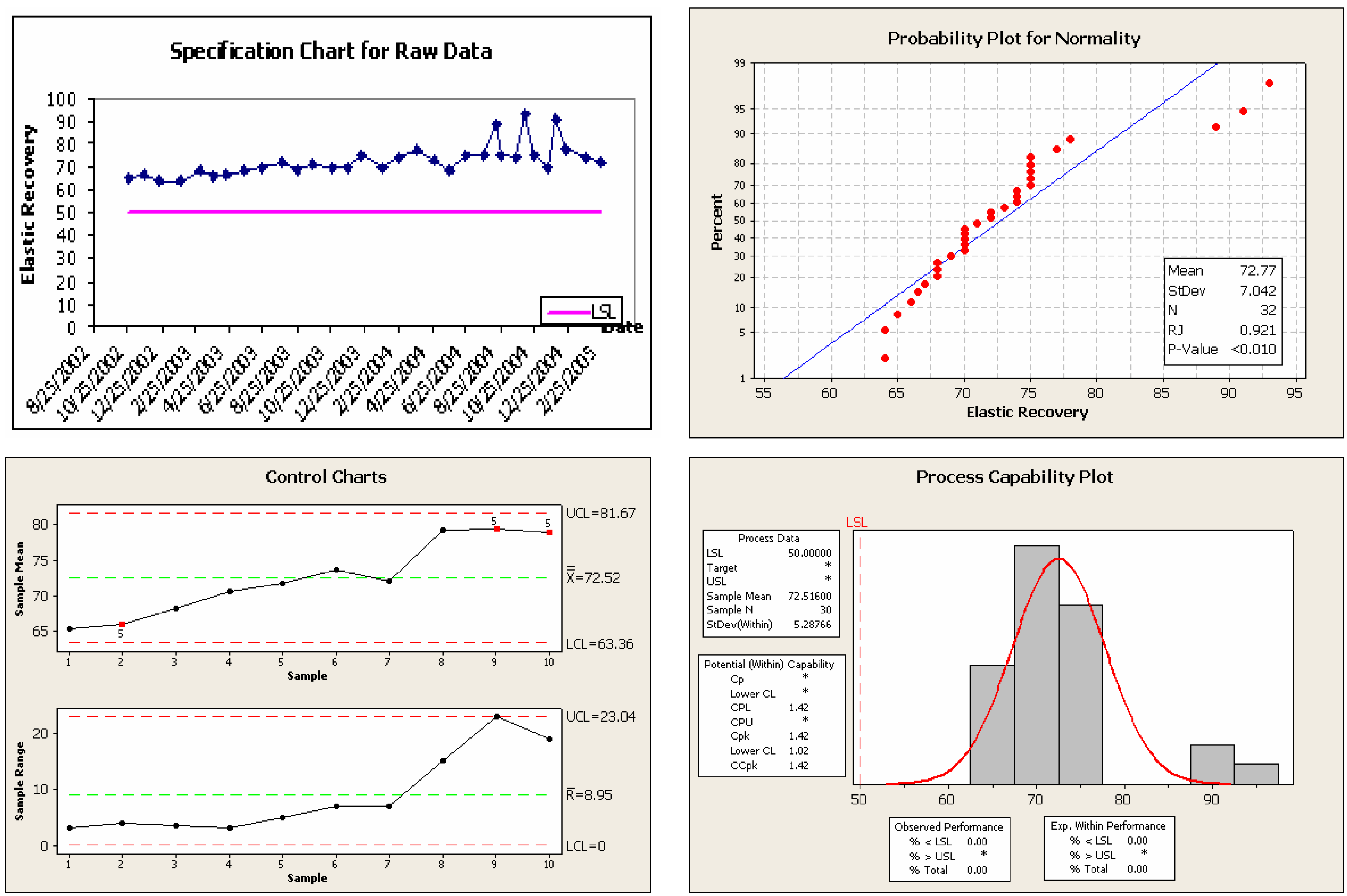


Figure E-111 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-22 Test: Elastic Recovery

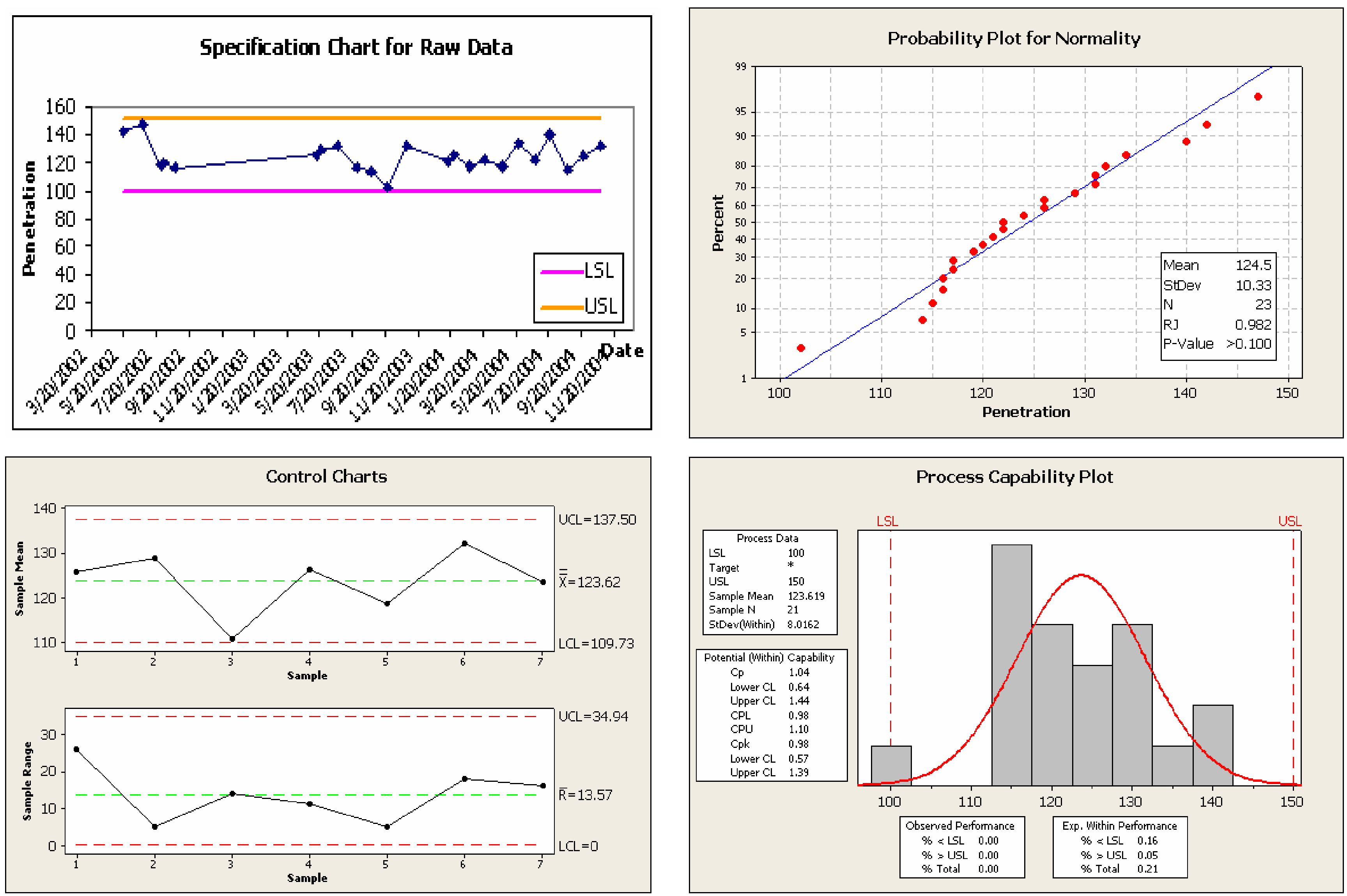


Figure E-112 Statistical Analysis Charts for Supplier: 0703 Grade: AC-15P Test: Penetration

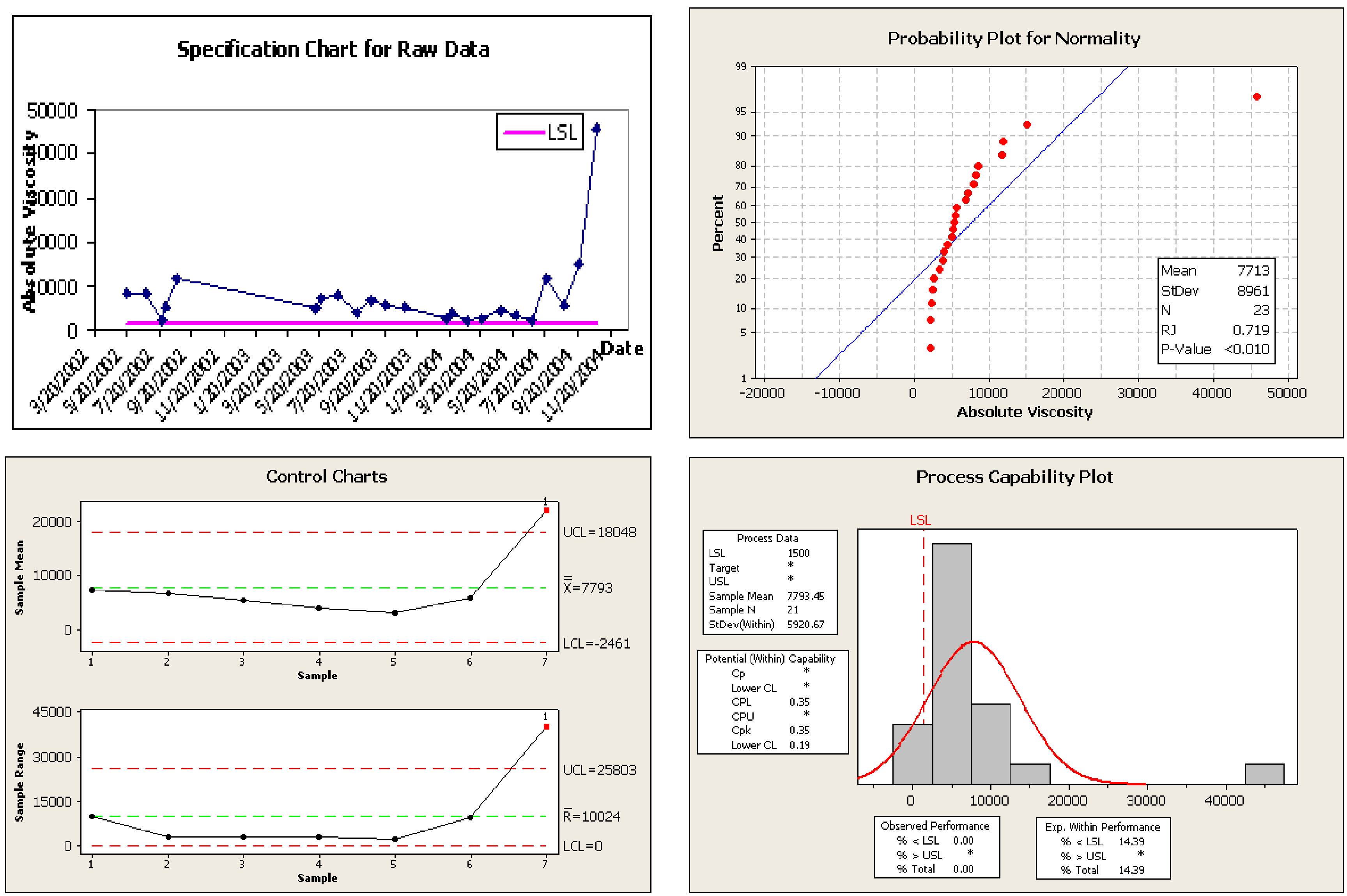


Figure E-113 Statistical Analysis Charts for Supplier: 0703 Grade: AC-15P Test: Absolute Viscosity

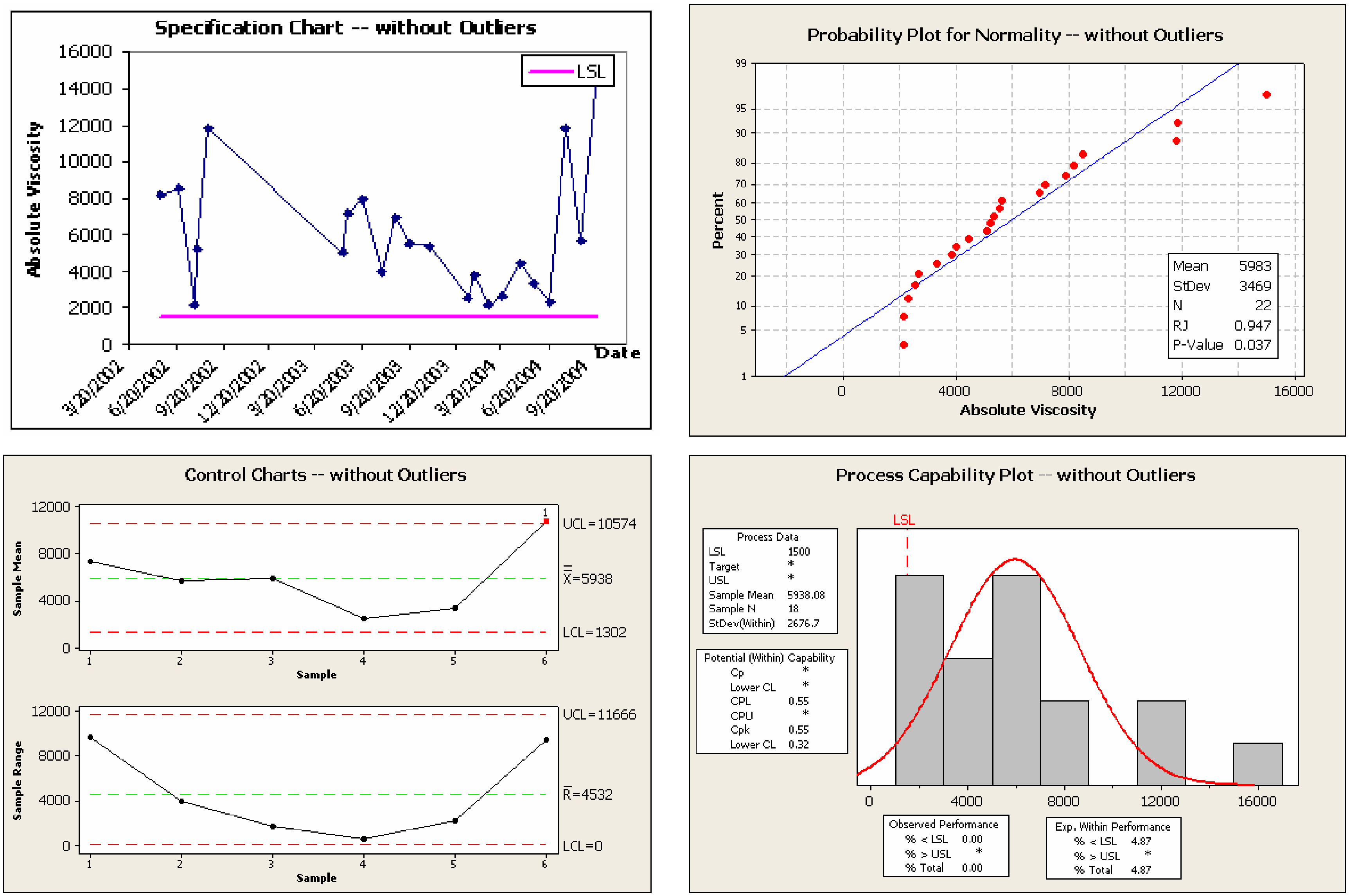


Figure E-114 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: AC-15P Test: Absolute Viscosity

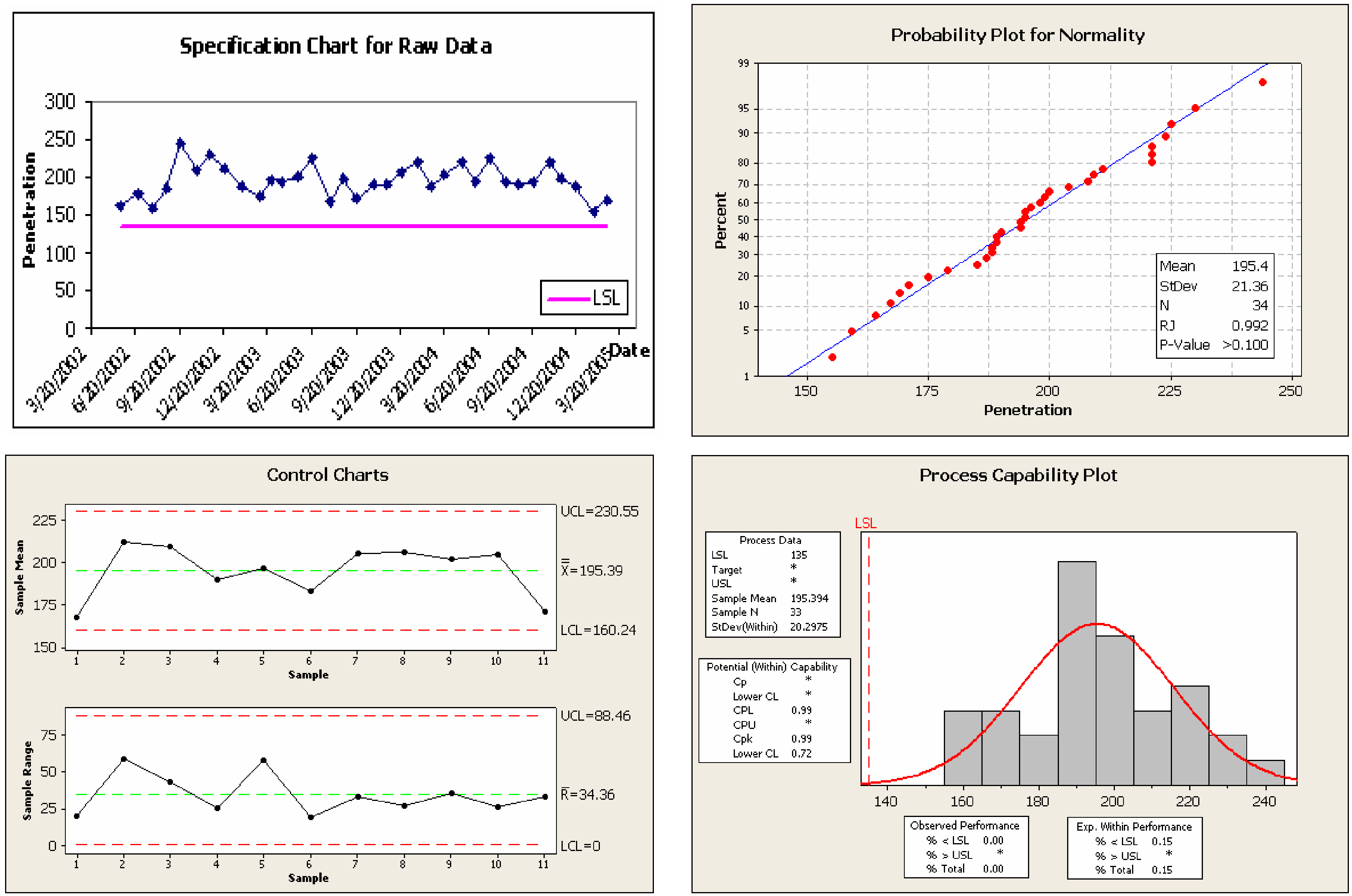


Figure E-115 Statistical Analysis Charts for Supplier: 0703 Grade: AC-5 Test: Penetration

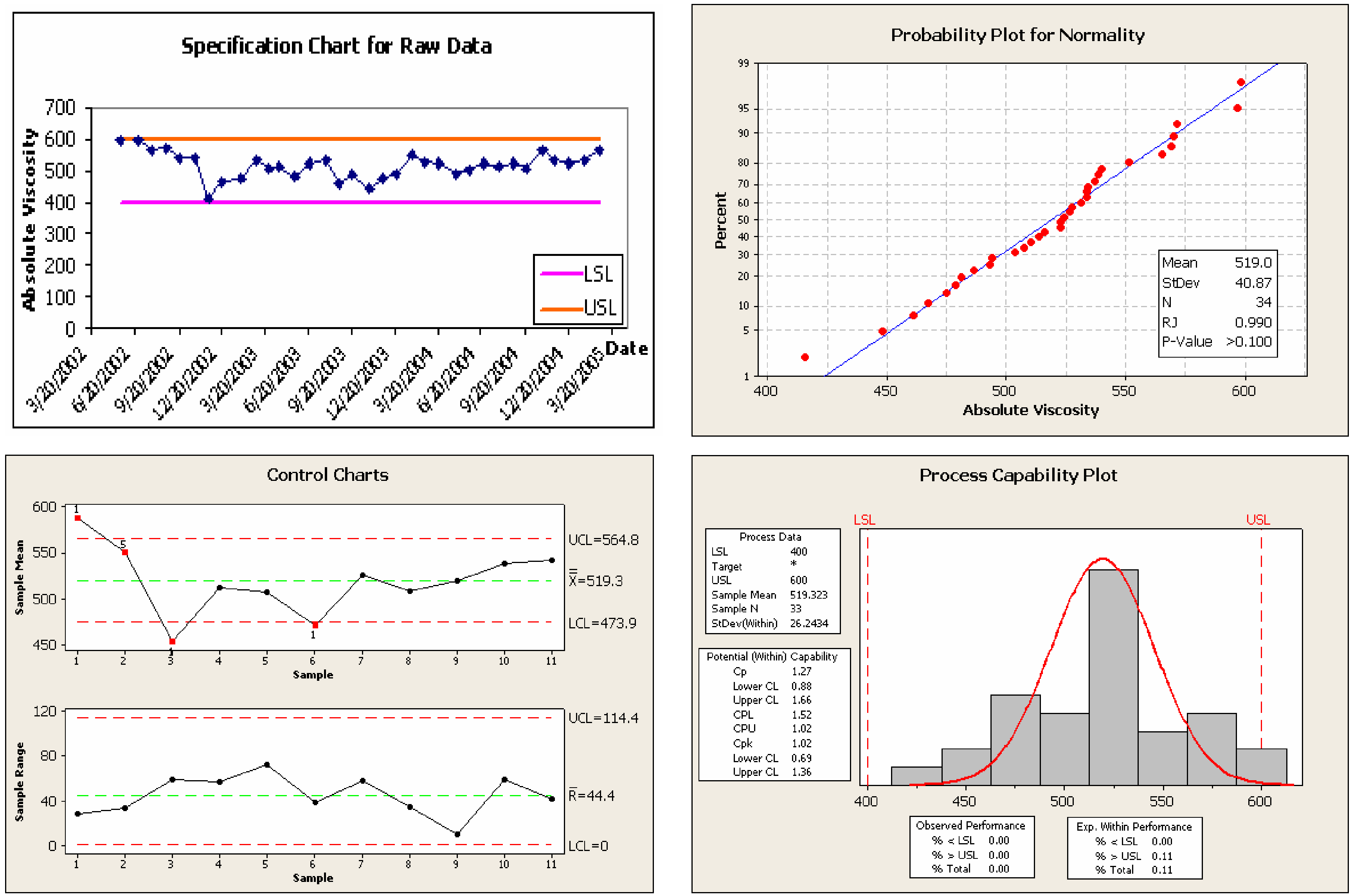


Figure E-116 Statistical Analysis Charts for Supplier: 0703 Grade: AC-5 Test: Absolute Viscosity

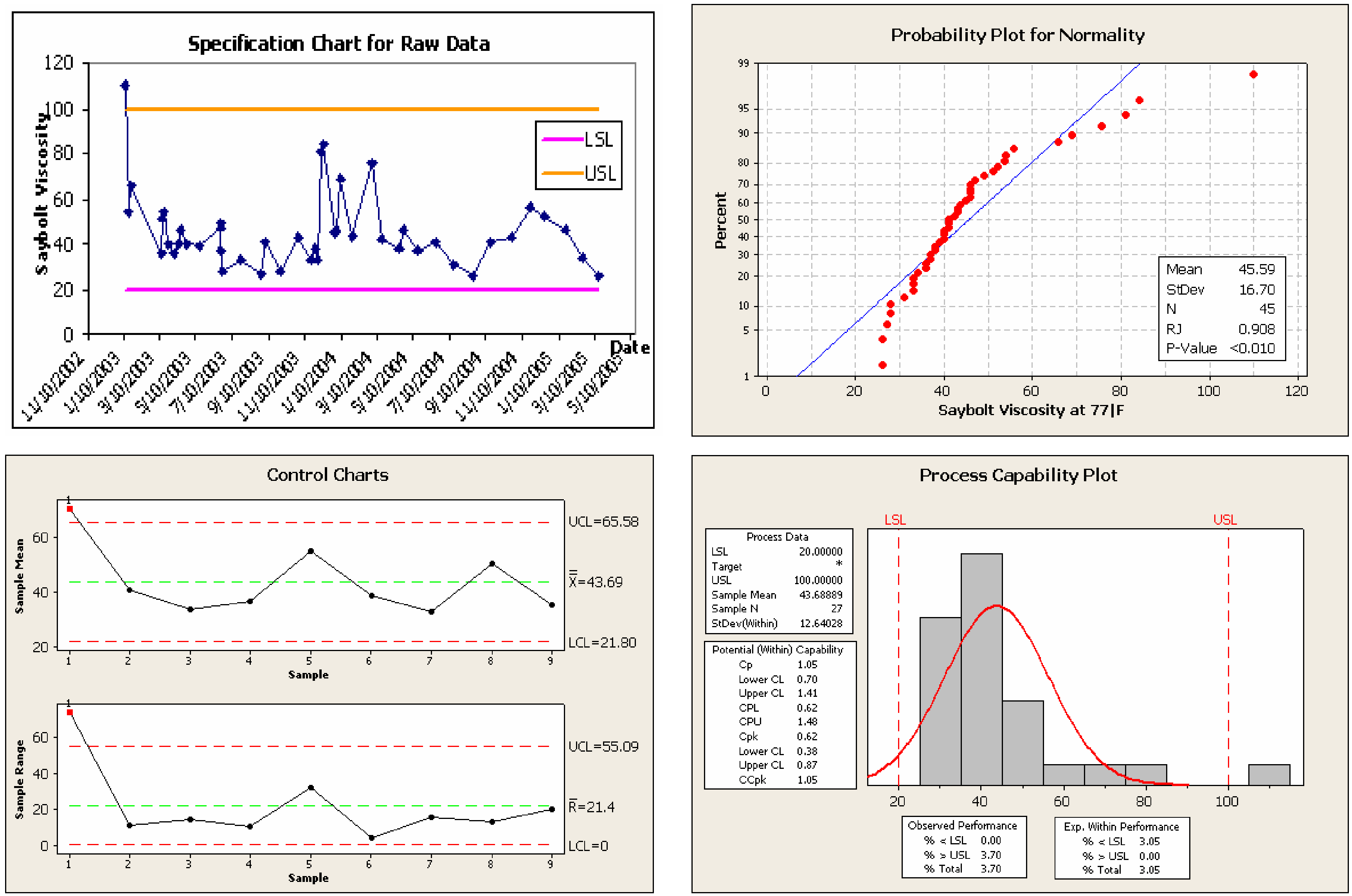


Figure E-117 Statistical Analysis Charts for Supplier: 0703 Grade: SS-1 Test: Saybolt Viscosity

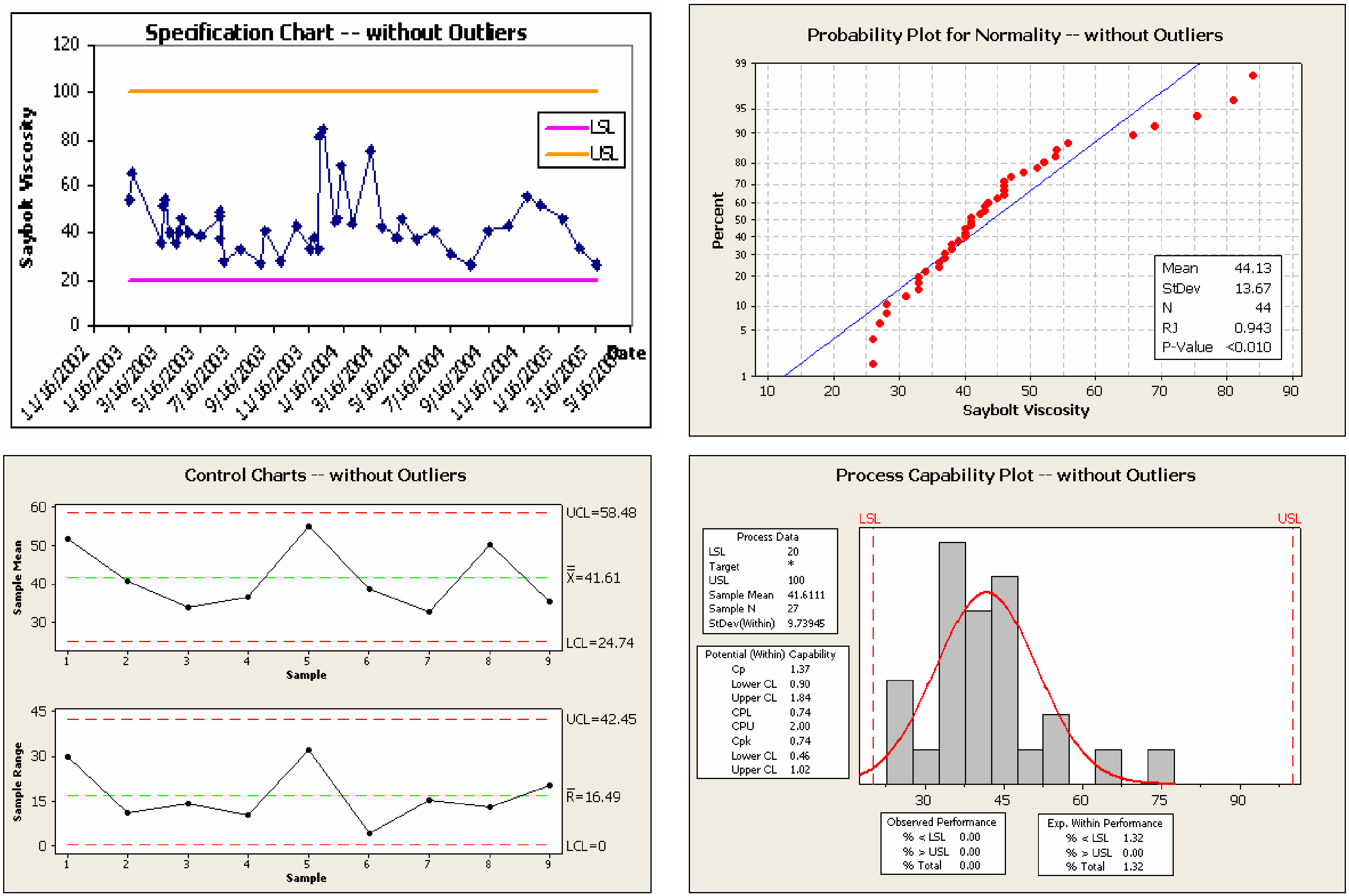


Figure E-118 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: SS-1 Test: Saybolt Viscosity

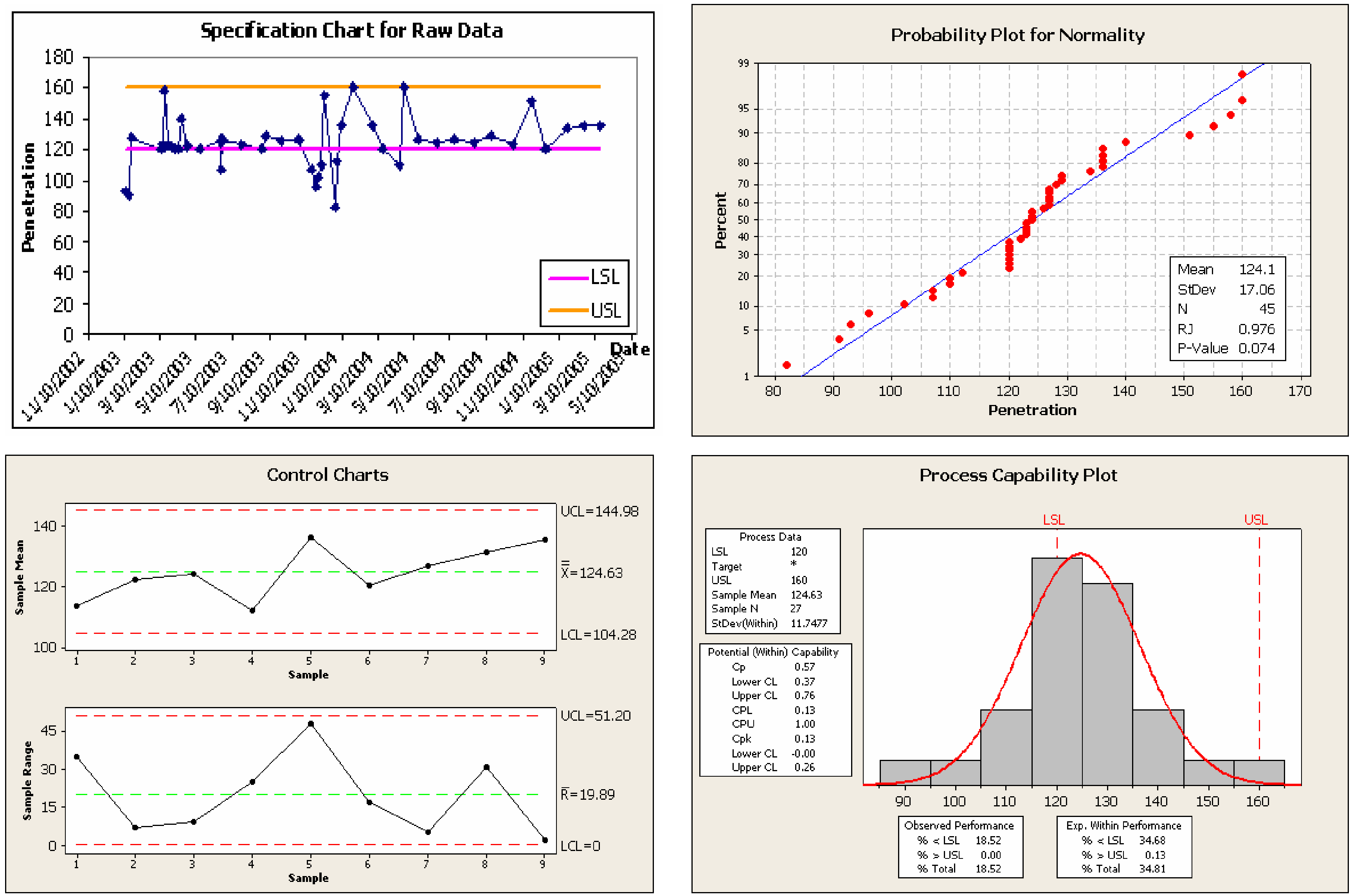


Figure E-119 Statistical Analysis Charts for Supplier: 0703 Grade: SS-1 Test: Penetration

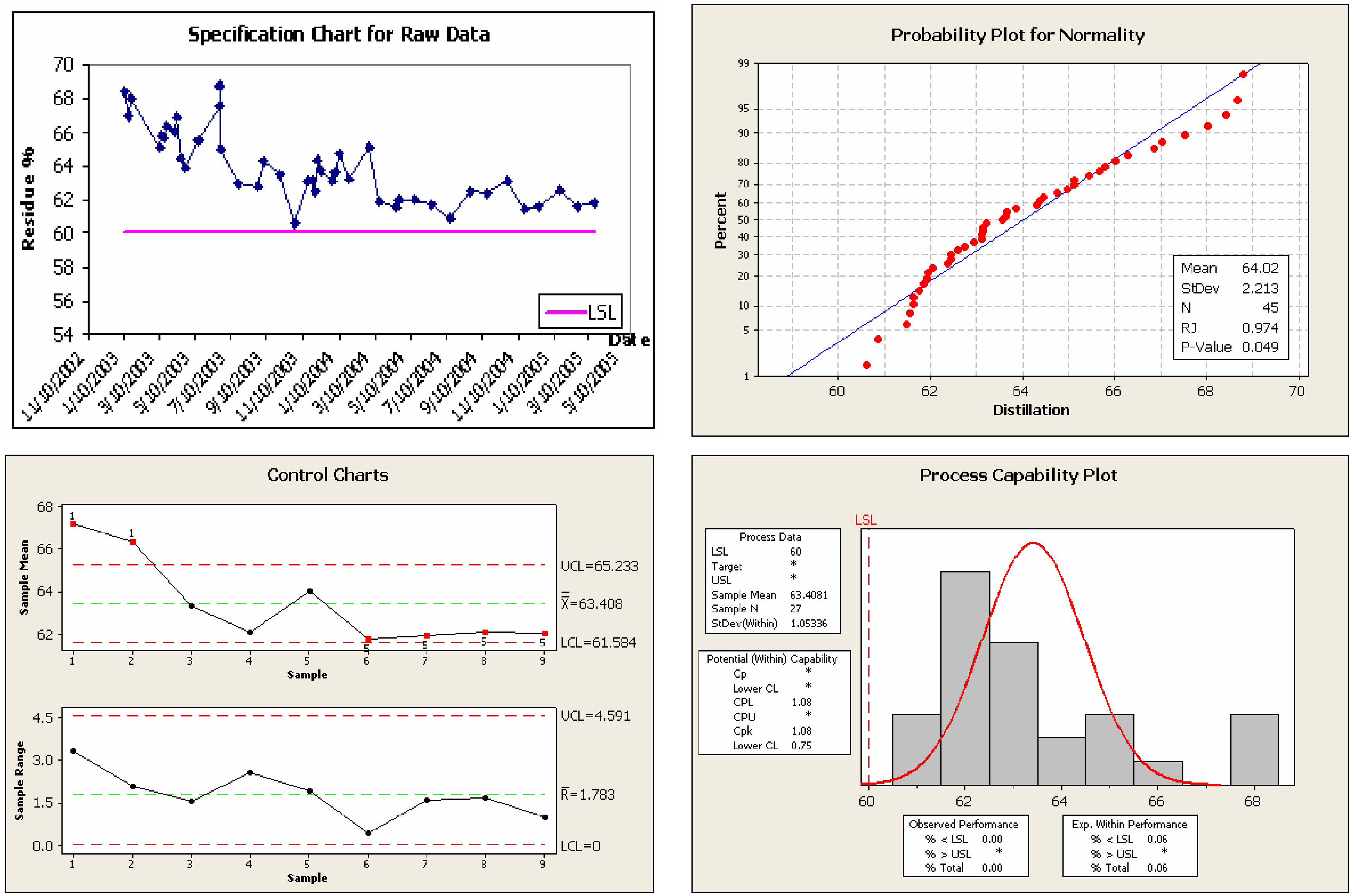


Figure E-120 Statistical Analysis Charts for Supplier: 0703 Grade: SS-1 Test: Distillation

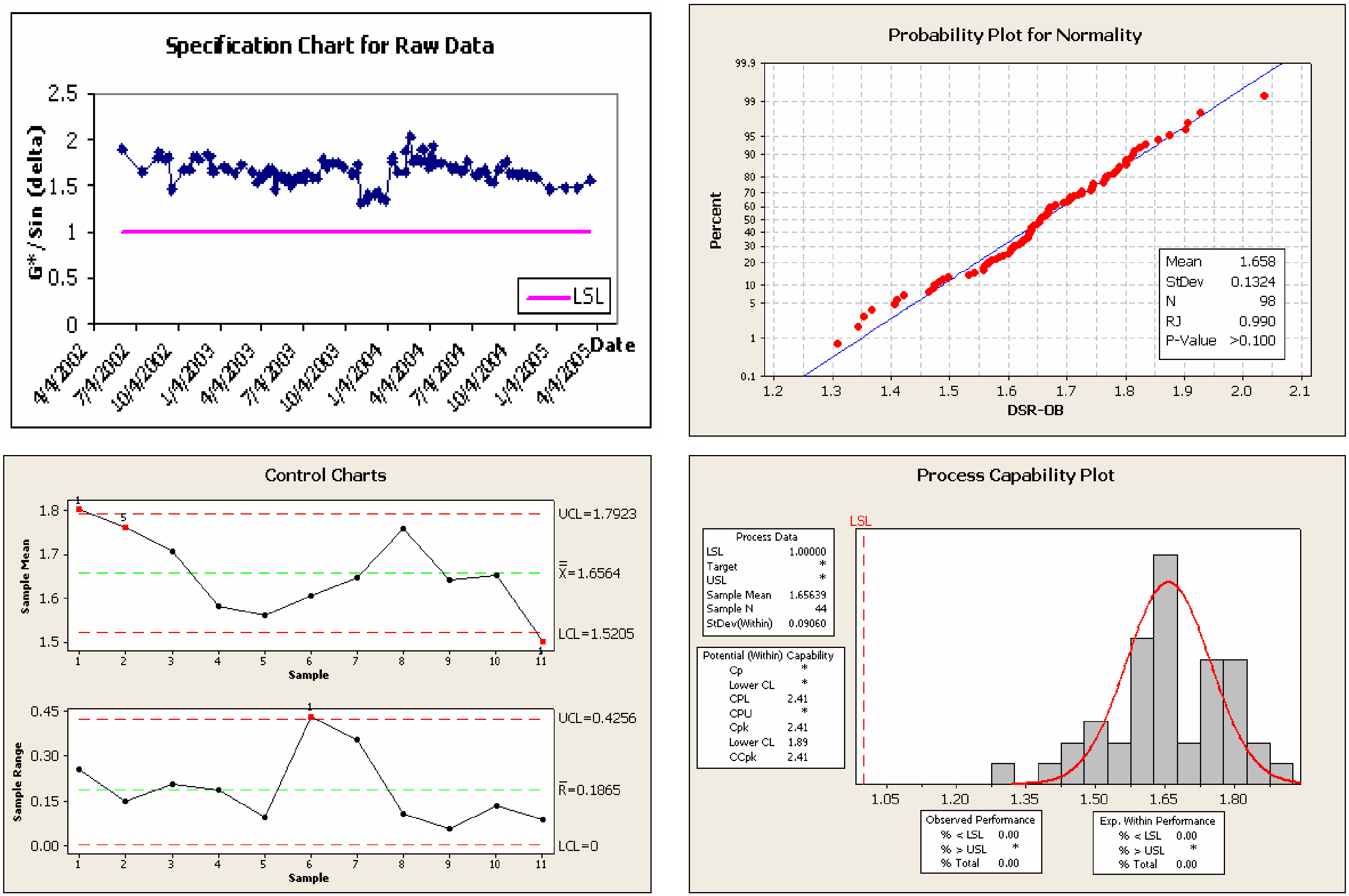


Figure E-121 Statistical Analysis Charts for Supplier: 0801 Grade: PG 64-22 Test: DSR-OB

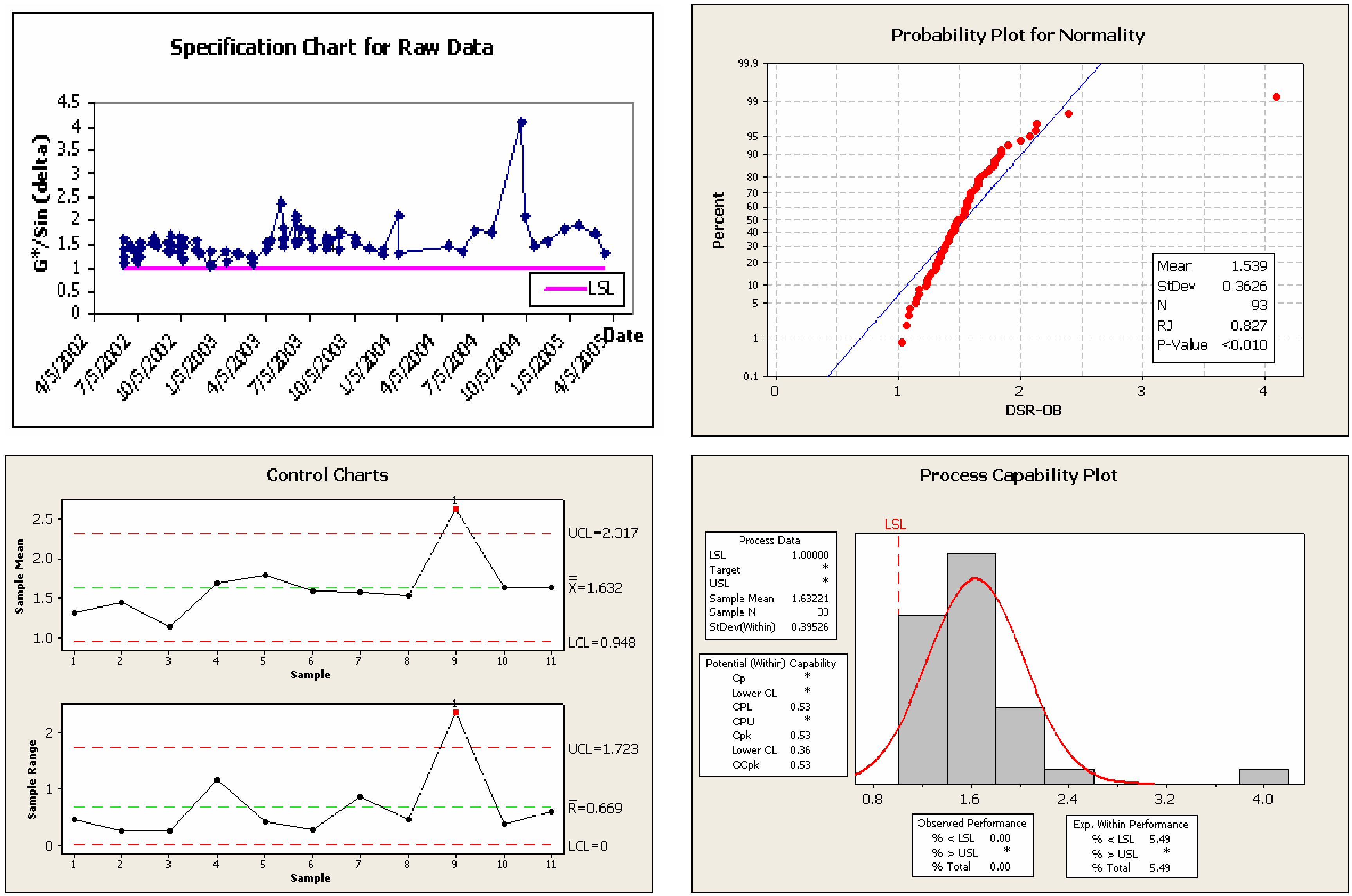


Figure E-122 Statistical Analysis Charts for Supplier: 0802 Grade: PG 76-22 Test: DSR-OB

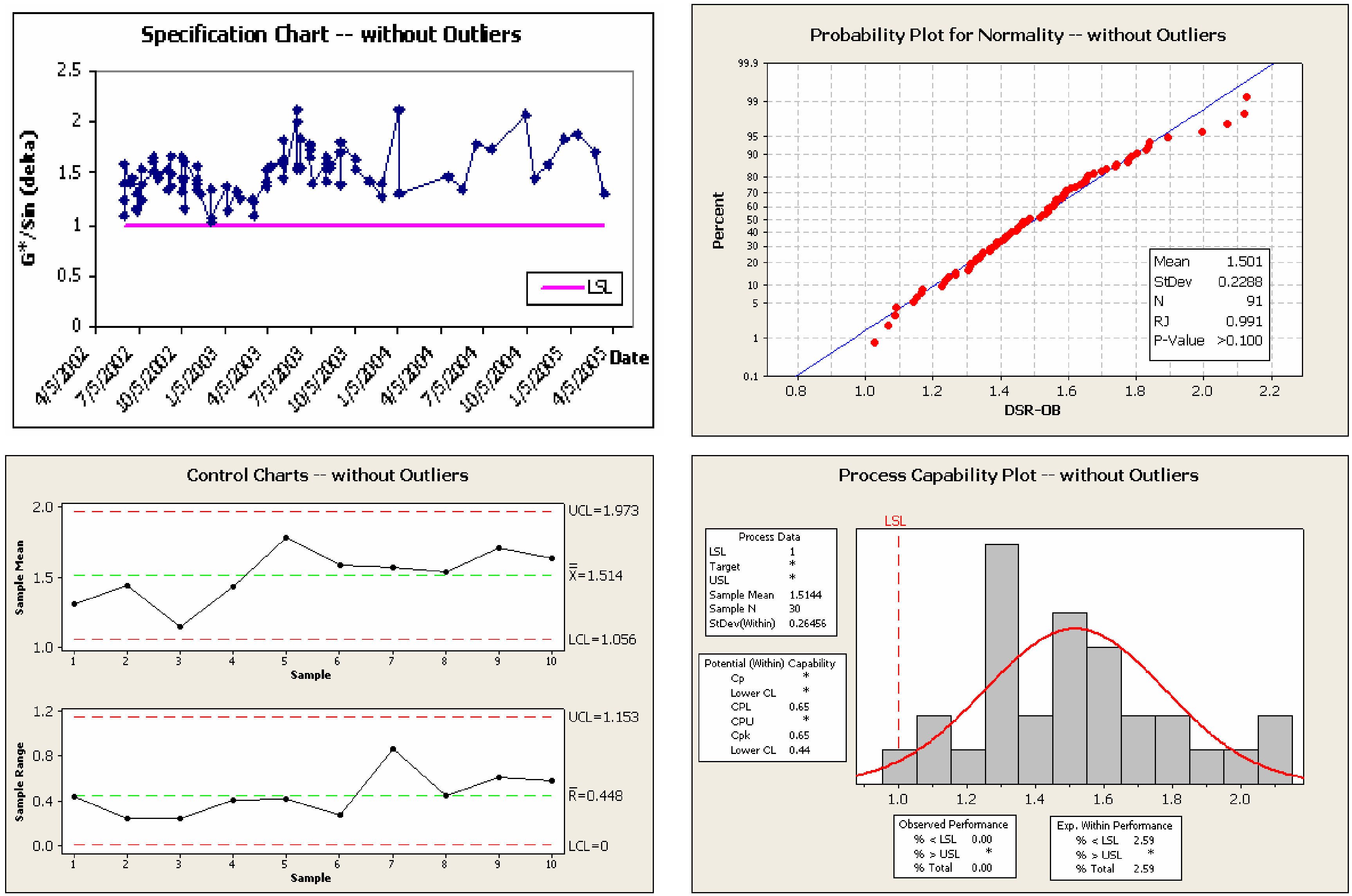


Figure E-123 Statistical Analysis Charts (without Outliers) for Supplier: 0802 Grade: PG 76-22 Test: DSR-OB

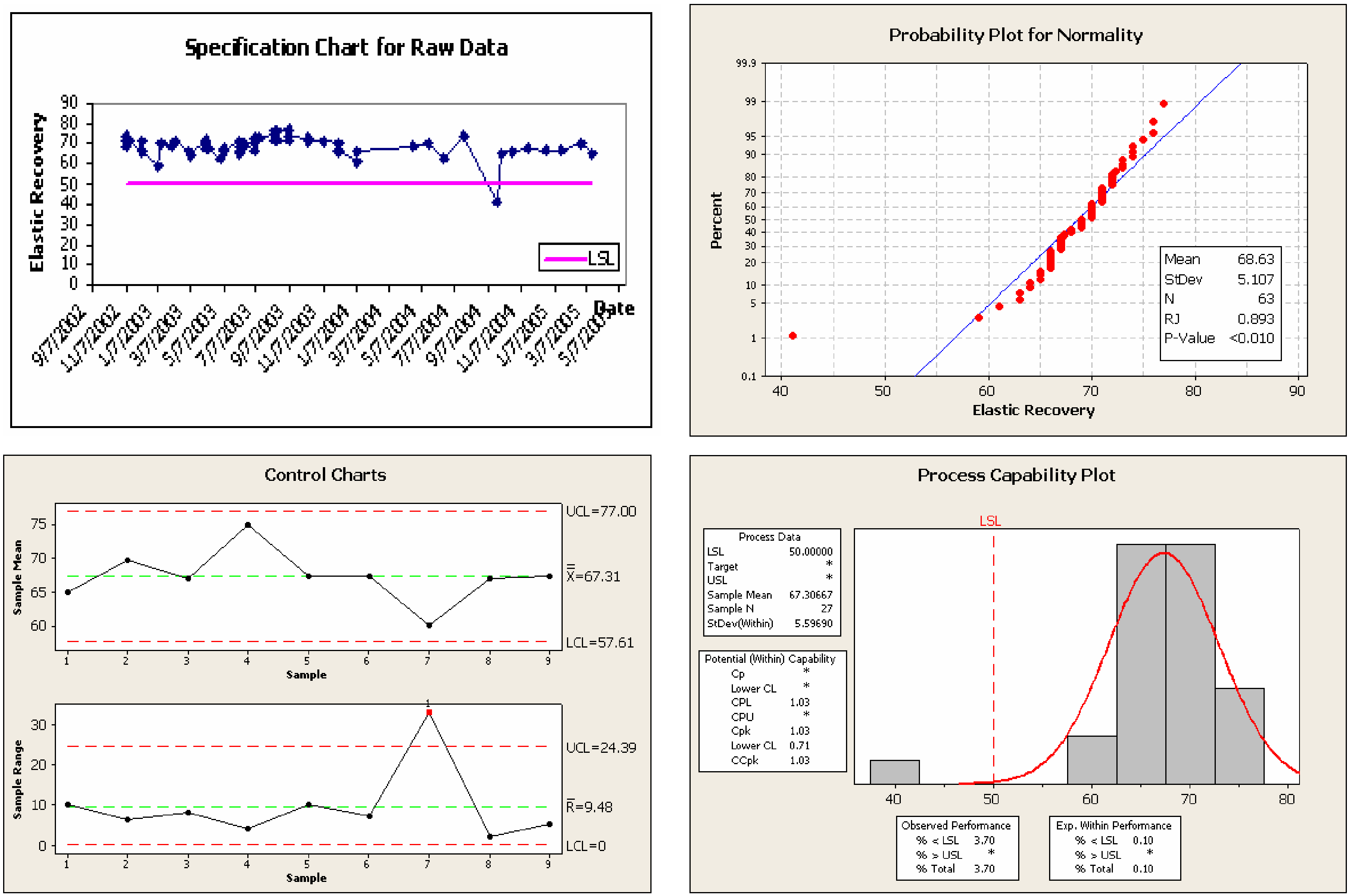


Figure E-124 Statistical Analysis Charts for Supplier: 0802 Grade: PG 76-22 Test: Elastic Recovery

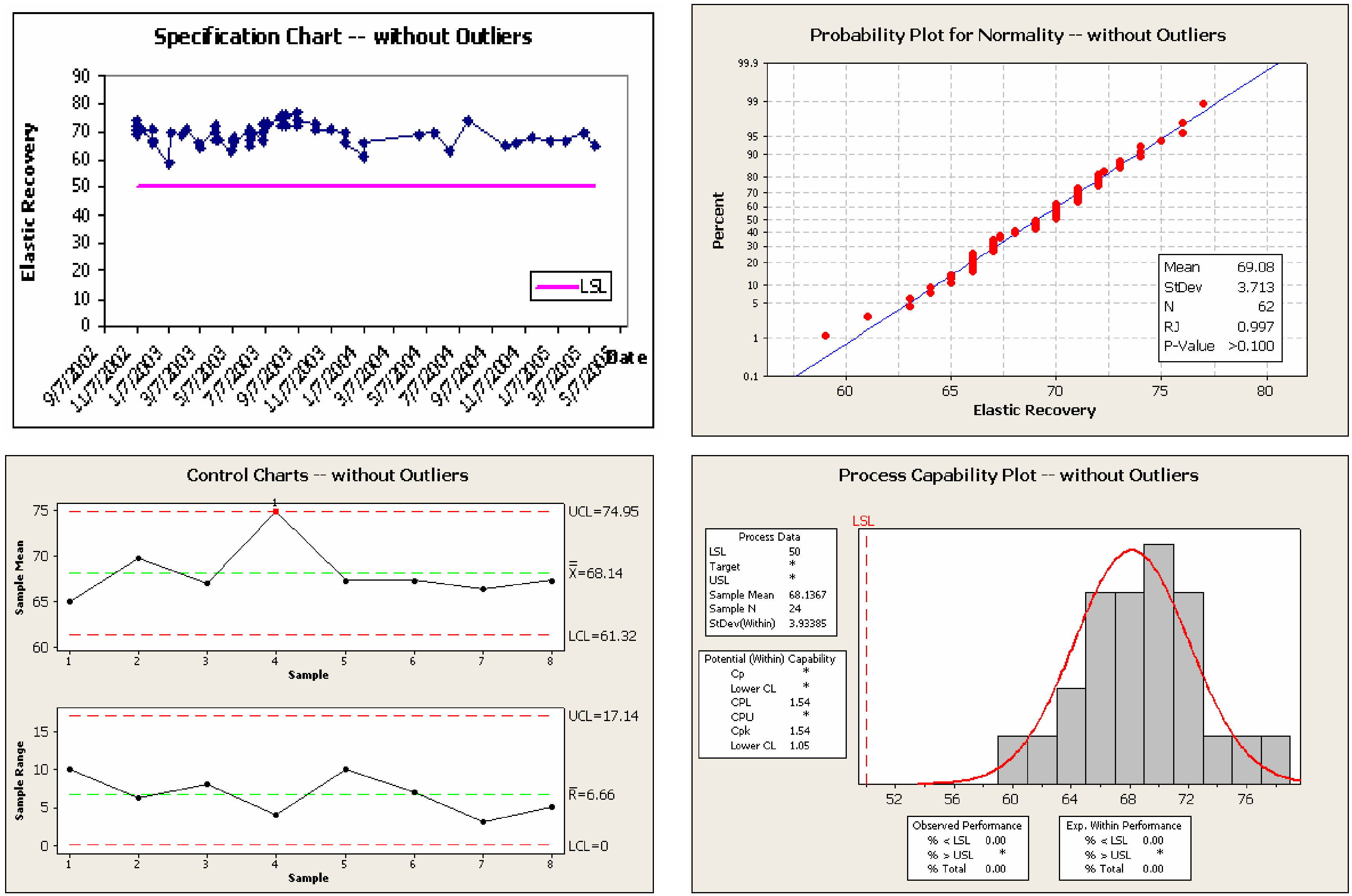


Figure E-125 Statistical Analysis Charts (without Outliers) for Supplier: 0802 Grade: PG 76-22 Test: Elastic Recovery

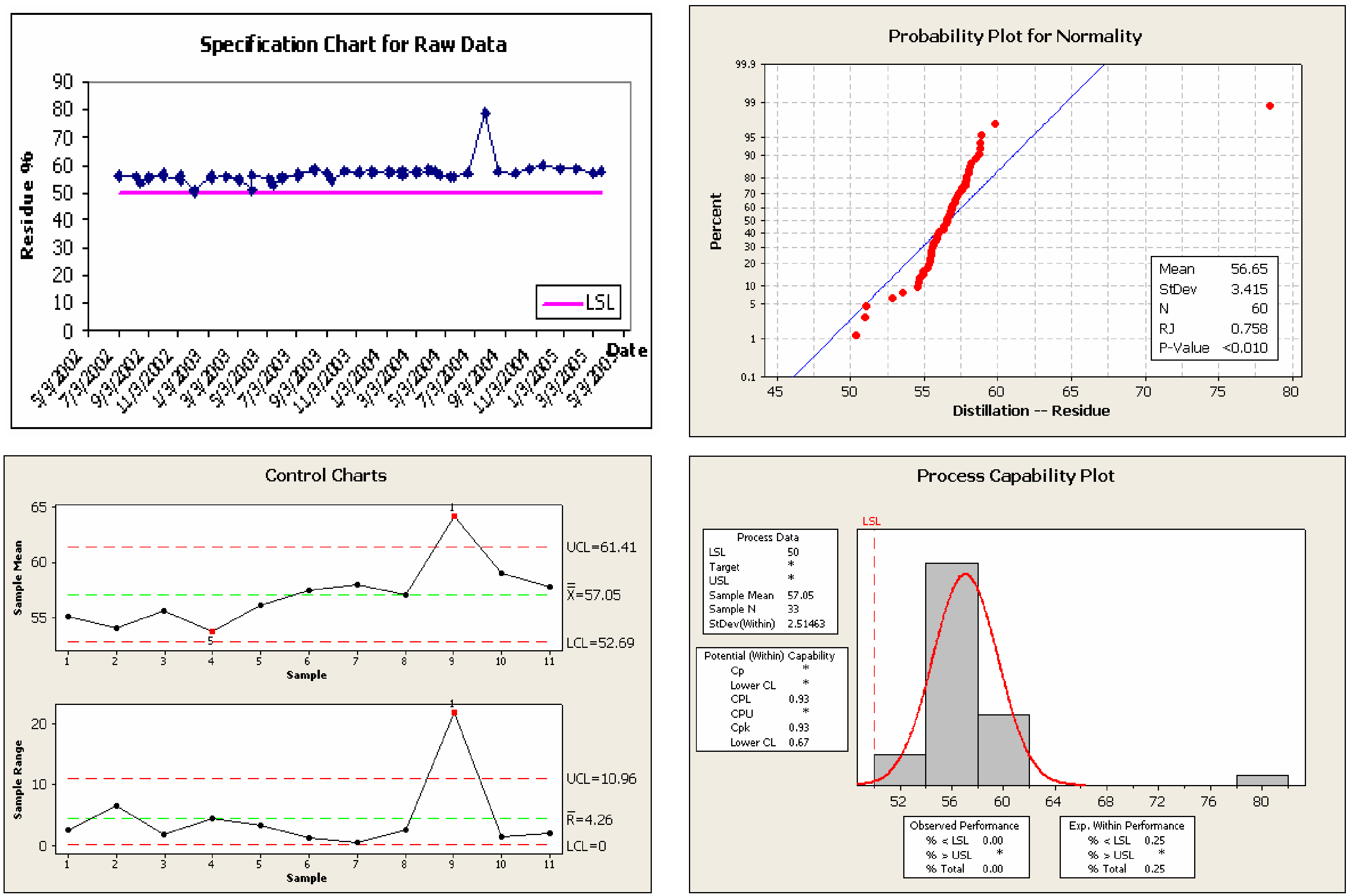


Figure E-126 Statistical Analysis Charts for Supplier: 0802 Grade: MC-30 Test: Distillation-Residue

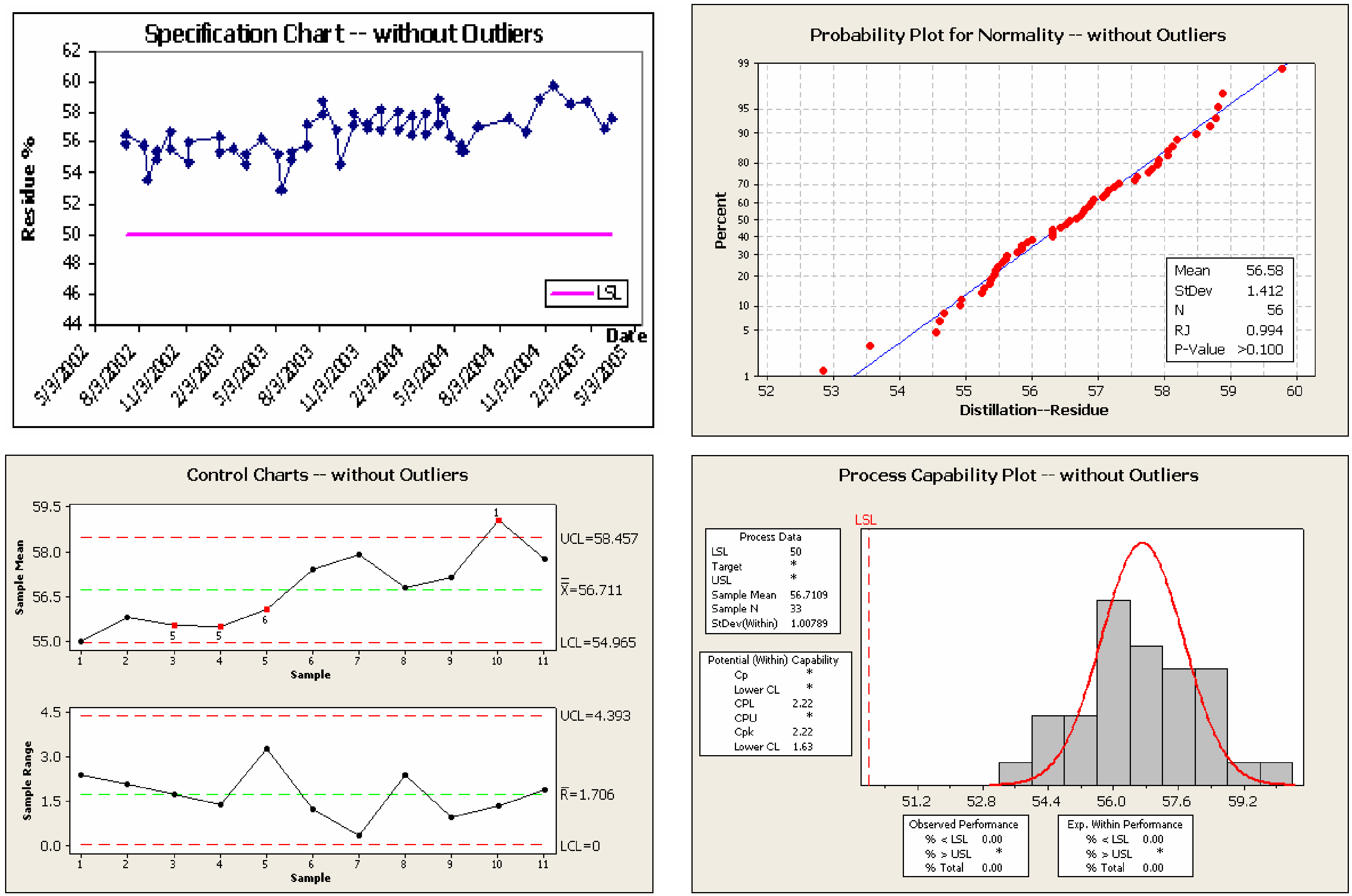


Figure E-127 Statistical Analysis Charts (without Outliers) for Supplier: 0802 Grade: MC-30 Test: Distillation-Residue

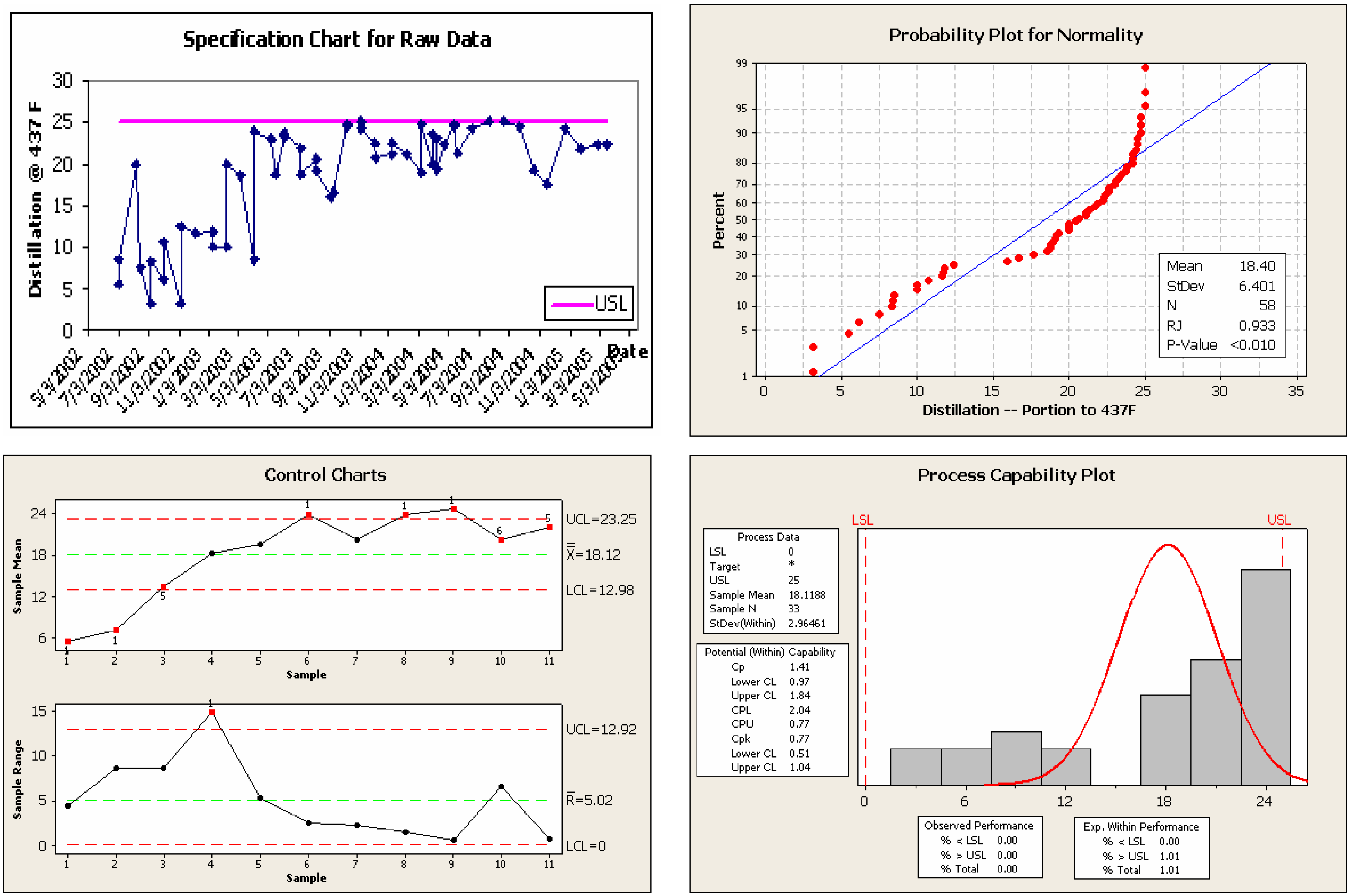


Figure E-128 Statistical Analysis Charts for Supplier: 0802 Grade: MC-30 Test: Distillation @ 437|F

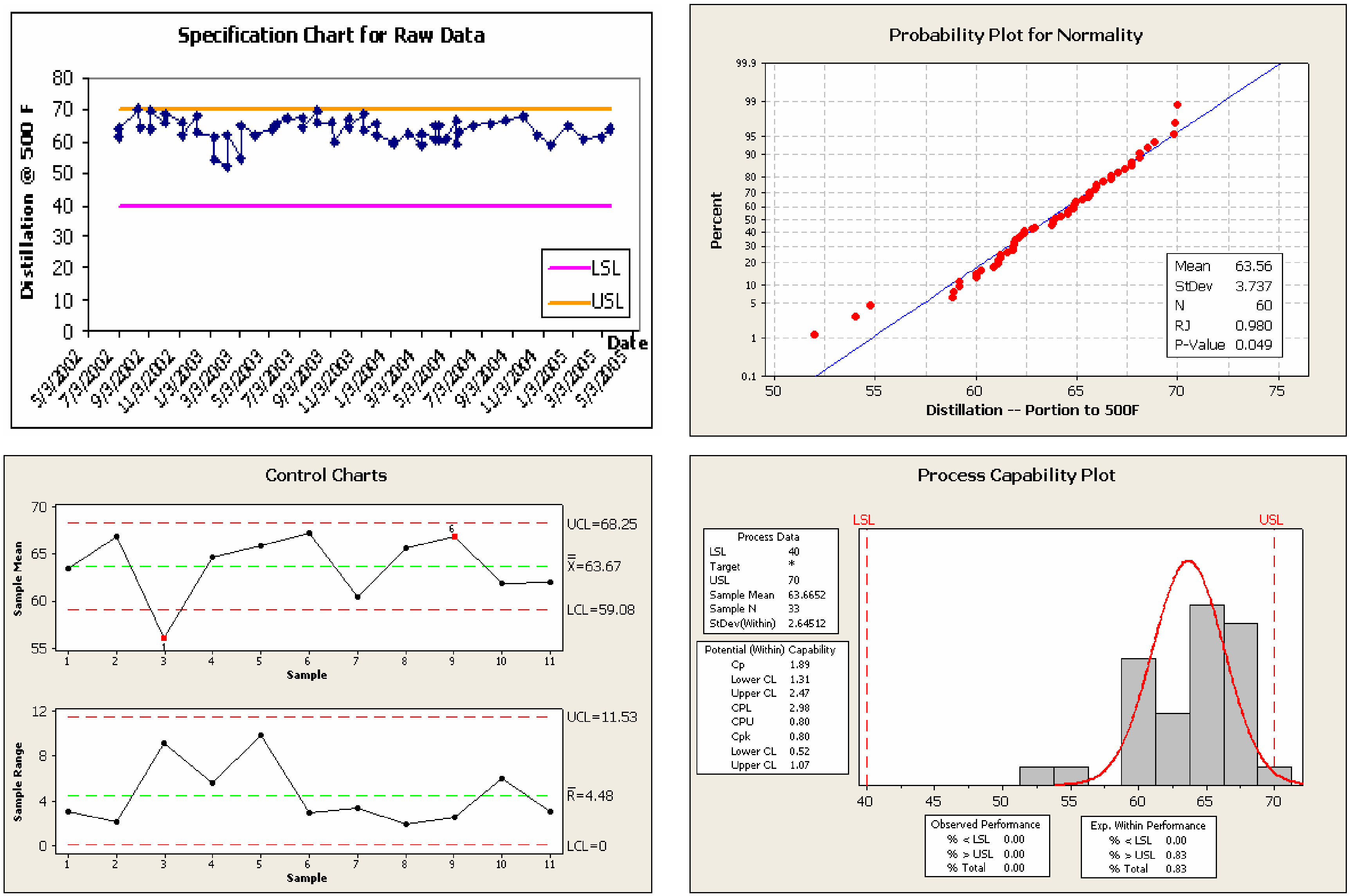


Figure E-129 Statistical Analysis Charts for Supplier: 0802 Grade: MC-30 Test: Distillation @ 500|F

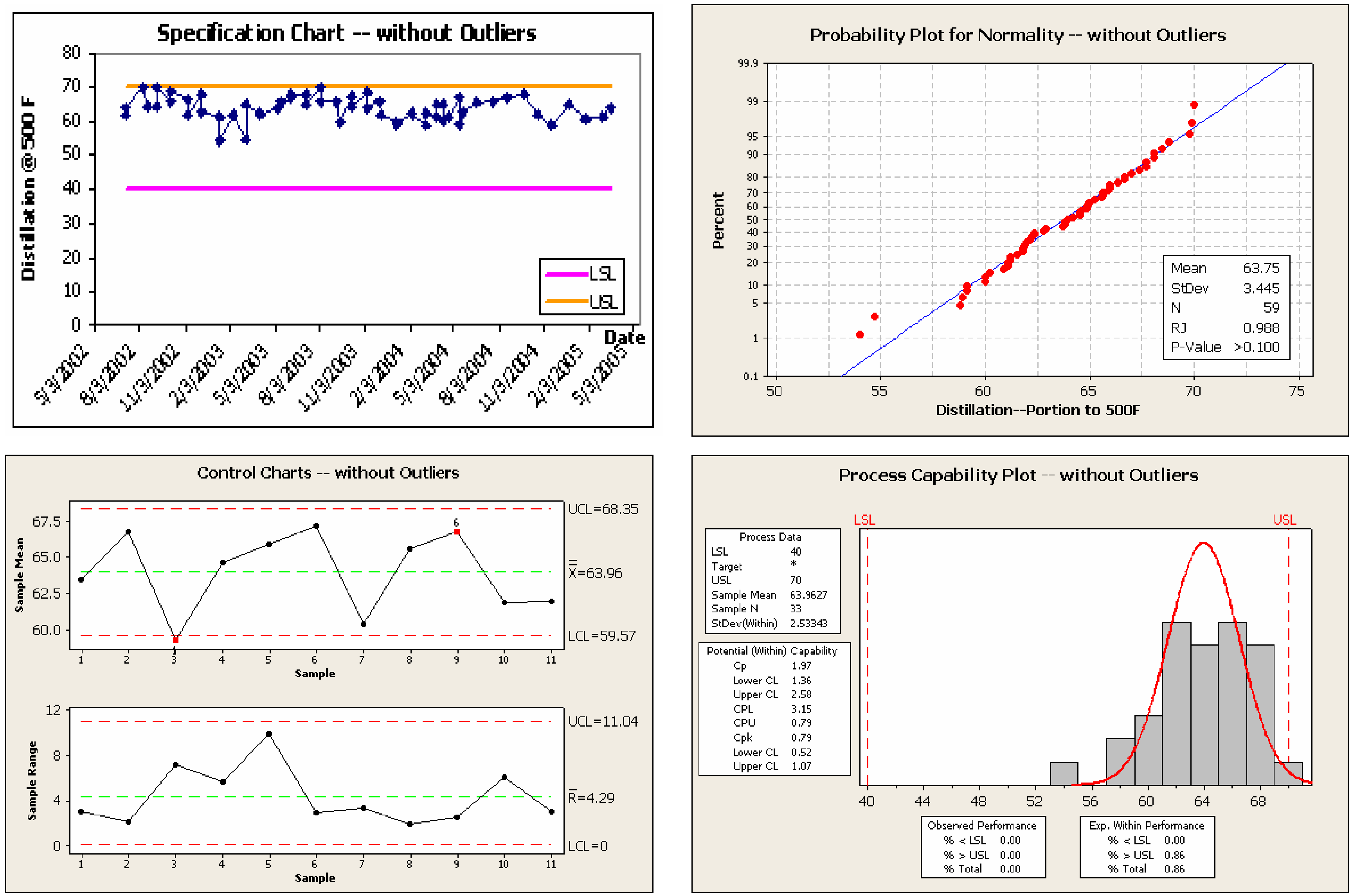


Figure E-130 Statistical Analysis Charts (without Outliers) for Supplier: 0802 Grade: MC-30 Test: Distillation @ 500|F

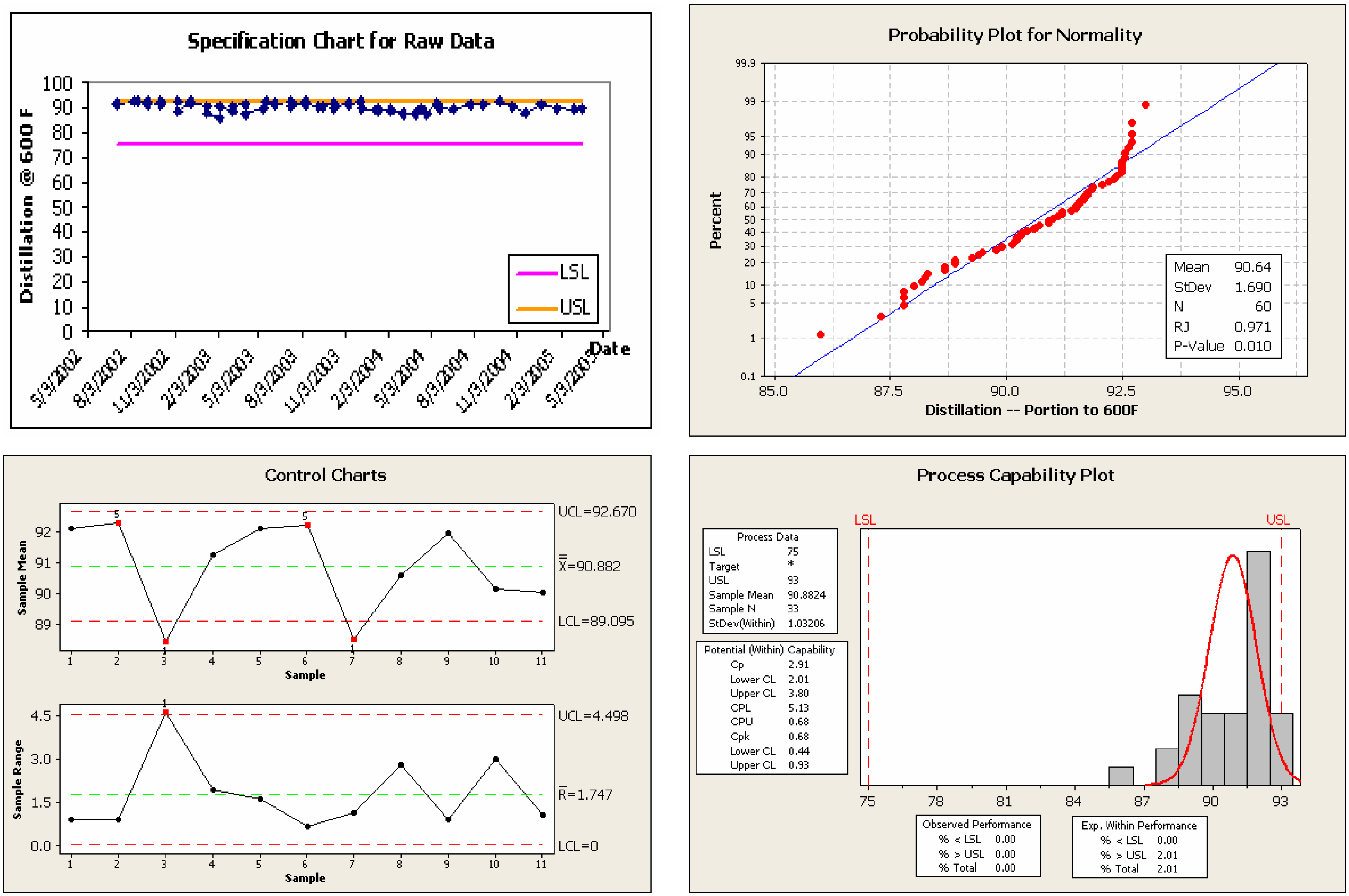


Figure E-131 Statistical Analysis Charts for Supplier: 0802 Grade: MC-30 Test: Distillation @ 600|F

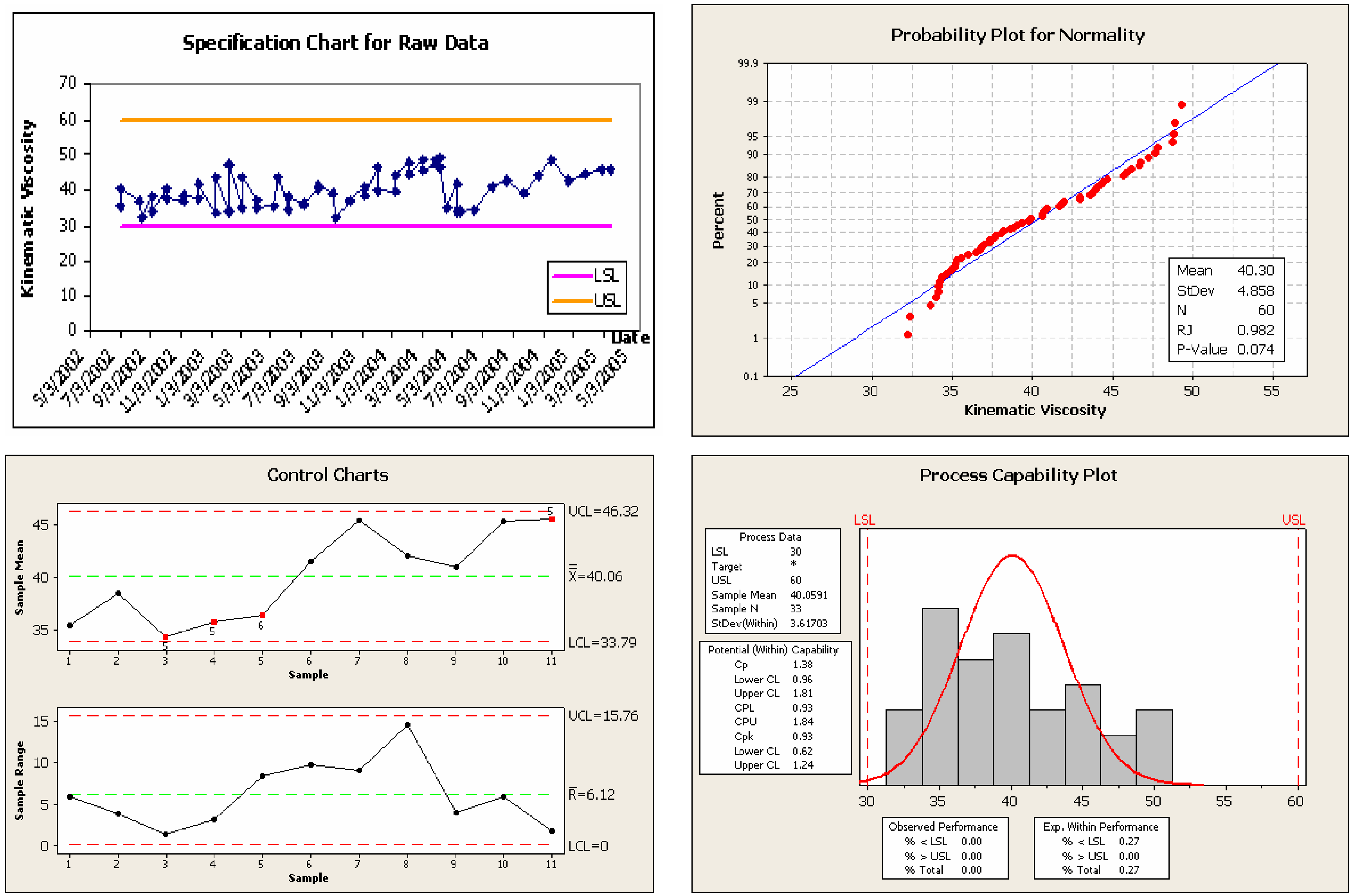


Figure E-132 Statistical Analysis Charts for Supplier: 0802 Grade: MC-30 Test: Kinematic Viscosity

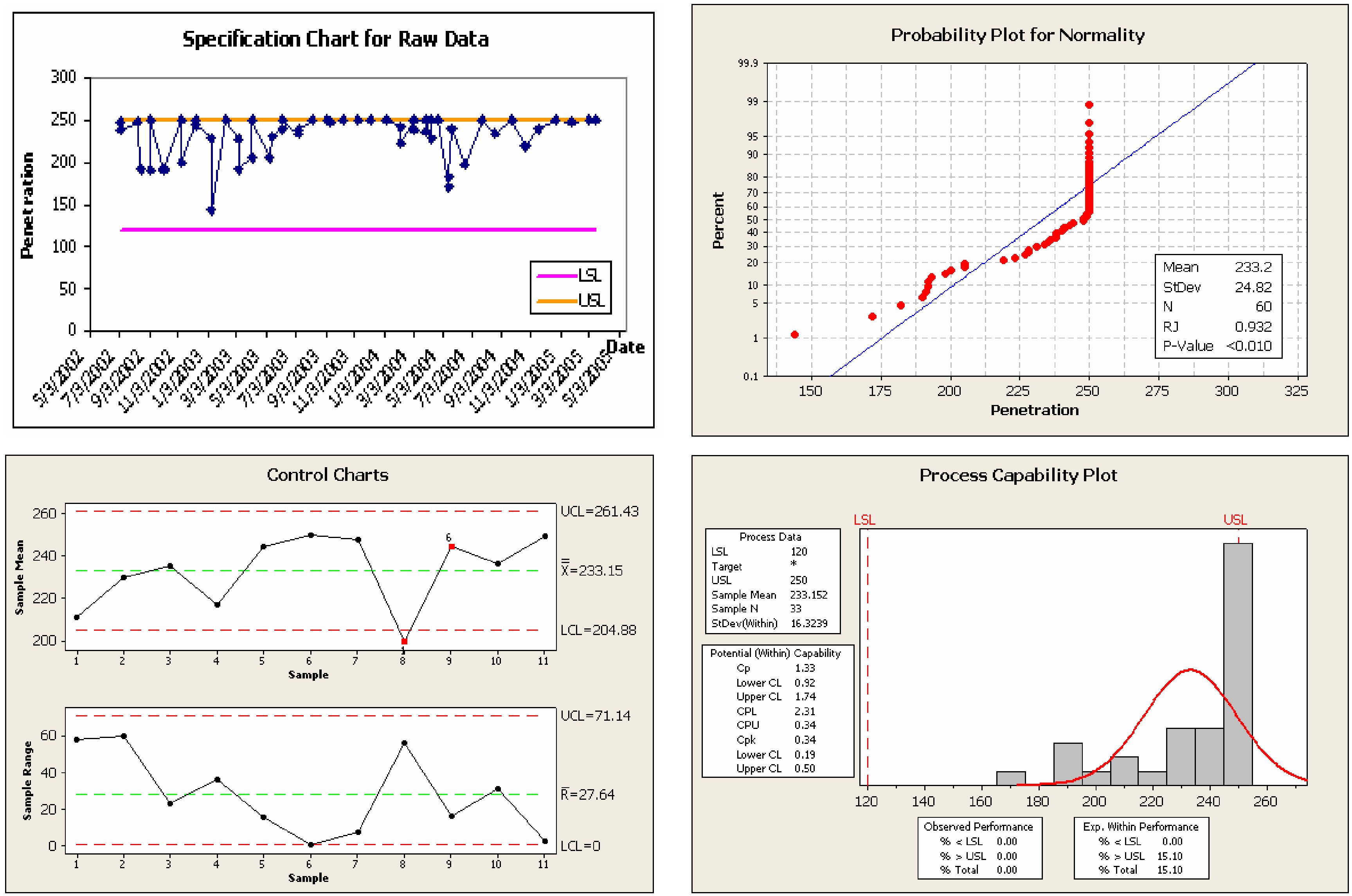


Figure E-133 Statistical Analysis Charts for Supplier: 0802 Grade: MC-30 Test: Penetration

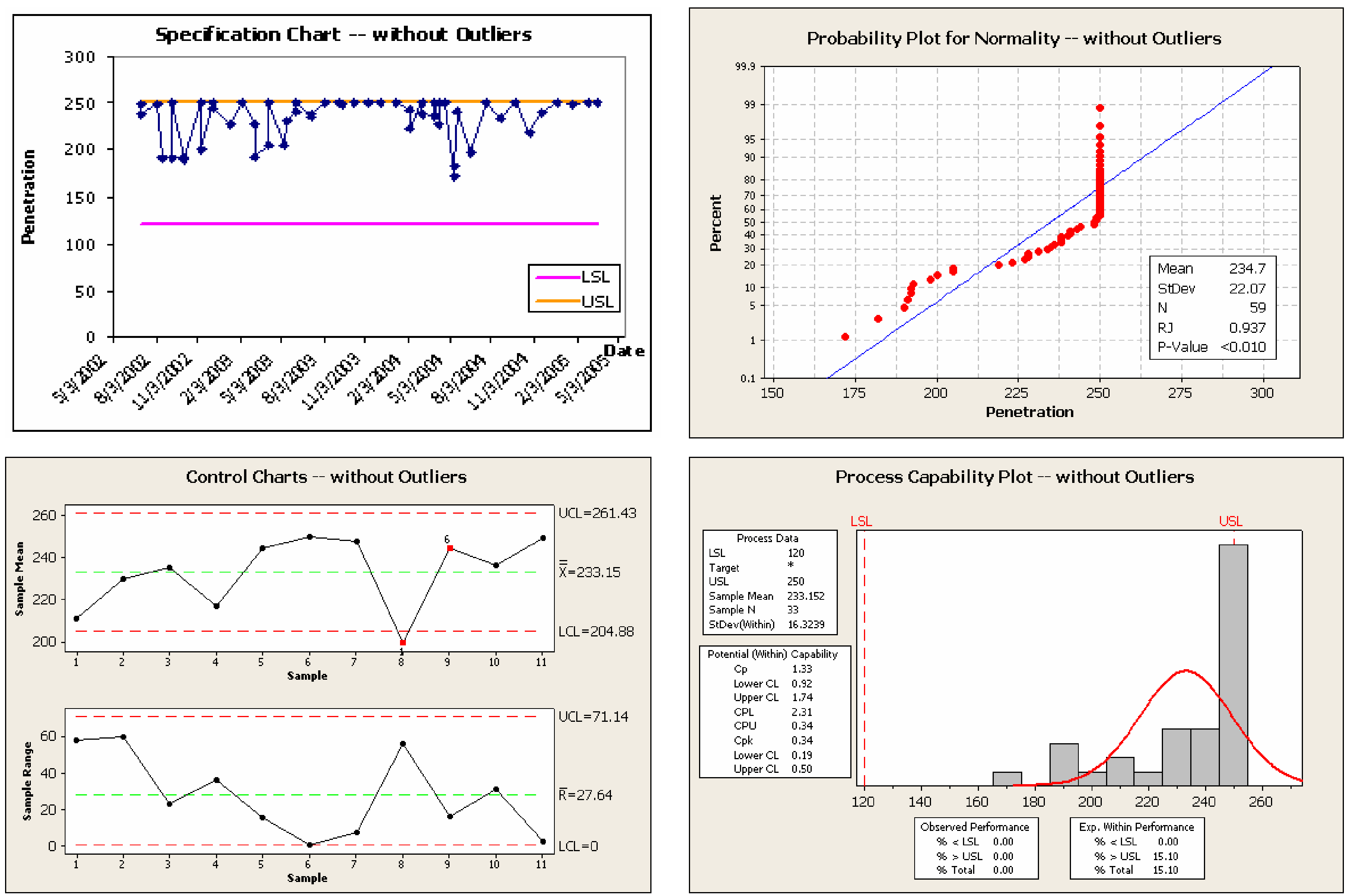


Figure E-134 Statistical Analysis Charts (without Outliers) for Supplier: 0802 Grade: MC-30 Test: Penetration

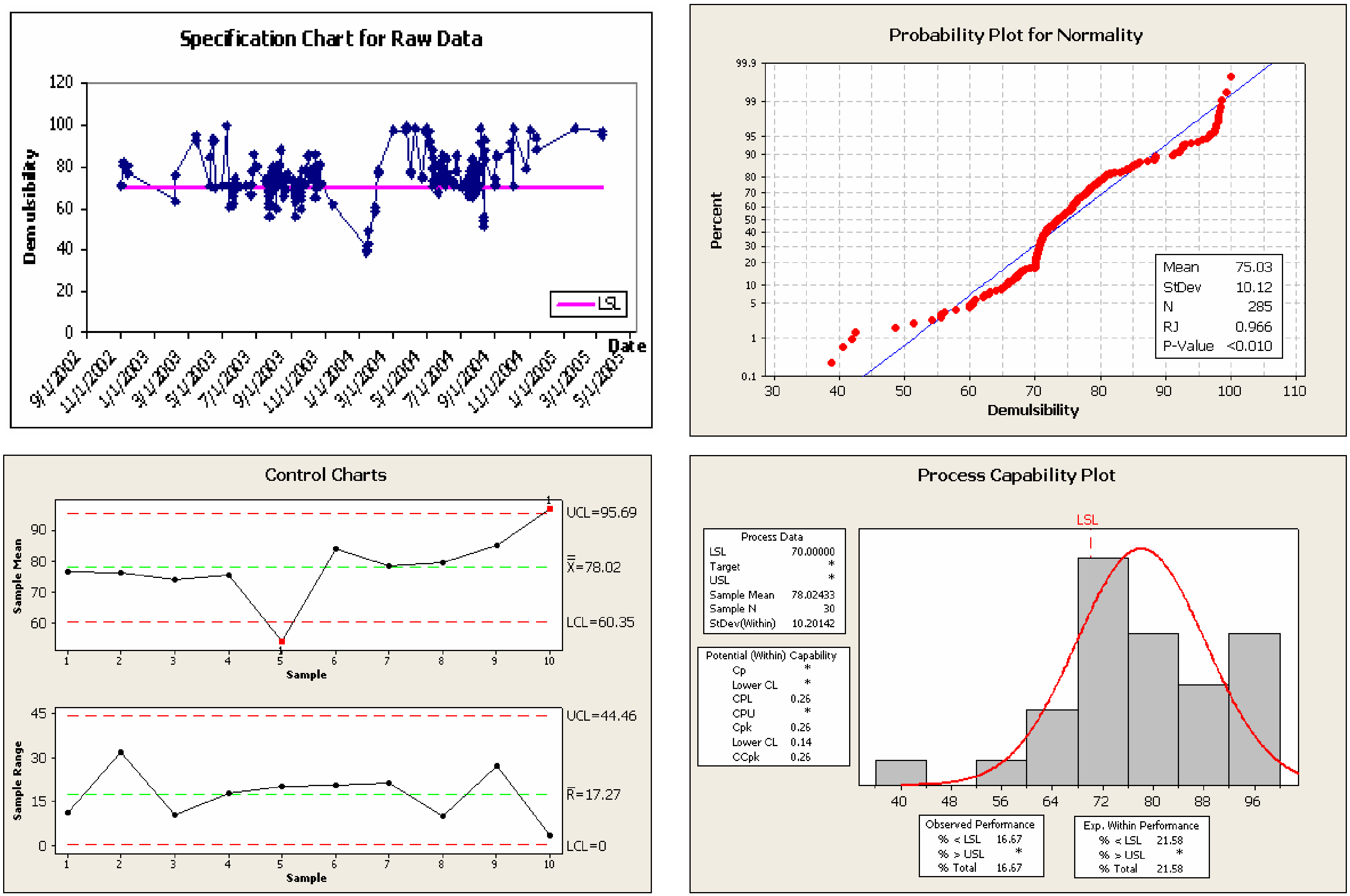


Figure E-135 Statistical Analysis Charts for Supplier: 0901 Grade: CRS-2P Test: Demulsibility

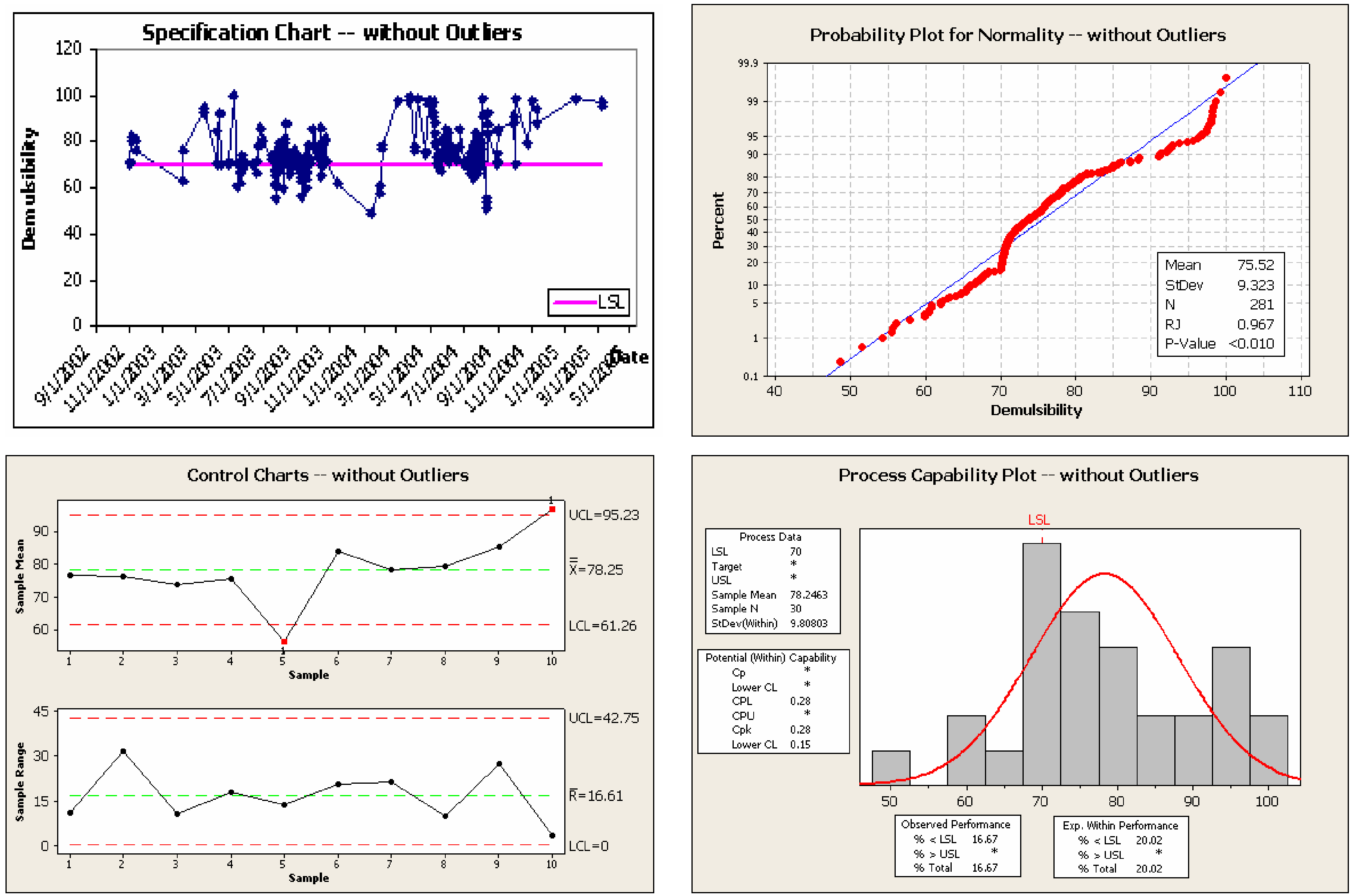


Figure E-136 Statistical Analysis Charts (without Outliers) for Supplier: 0901 Grade: CRS-2P Test: Demulsibility

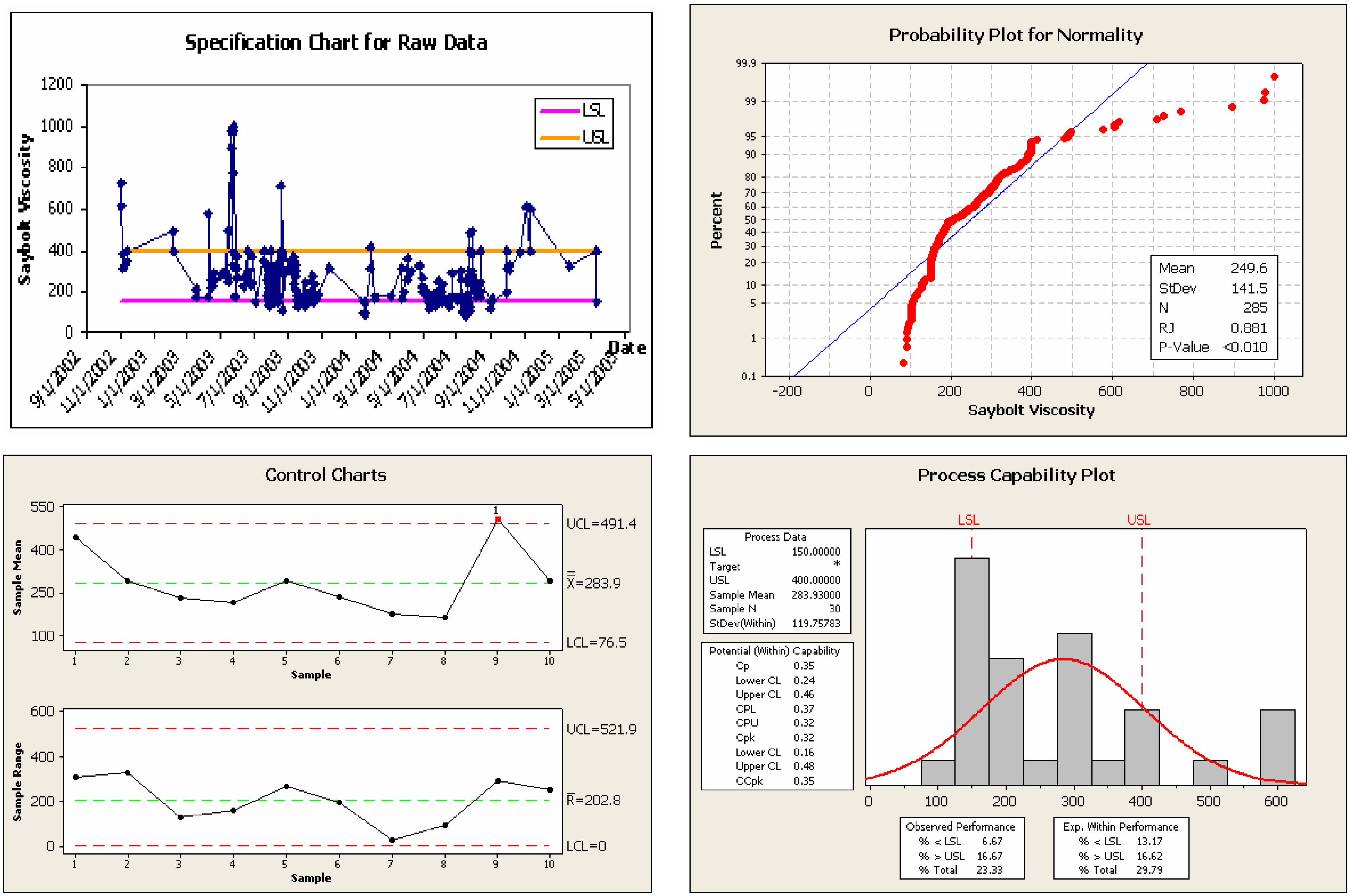


Figure E-137 Statistical Analysis Charts for Supplier: 0901 Grade: CRS-2P Test: Saybolt Viscosity

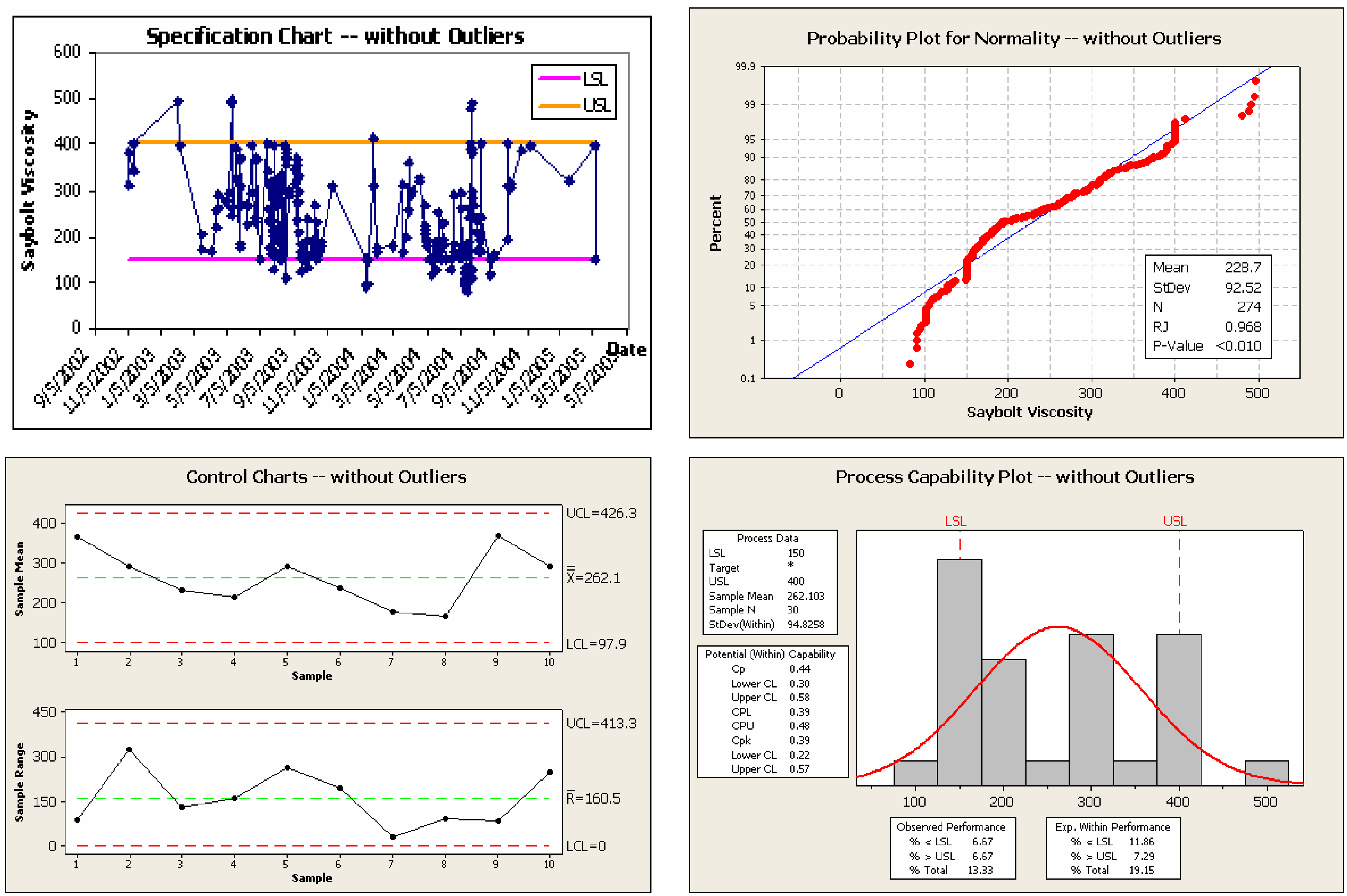


Figure E-138 Statistical Analysis Charts (without Outliers) for Supplier: 0901 Grade: CRS-2P Test: Saybolt Viscosity

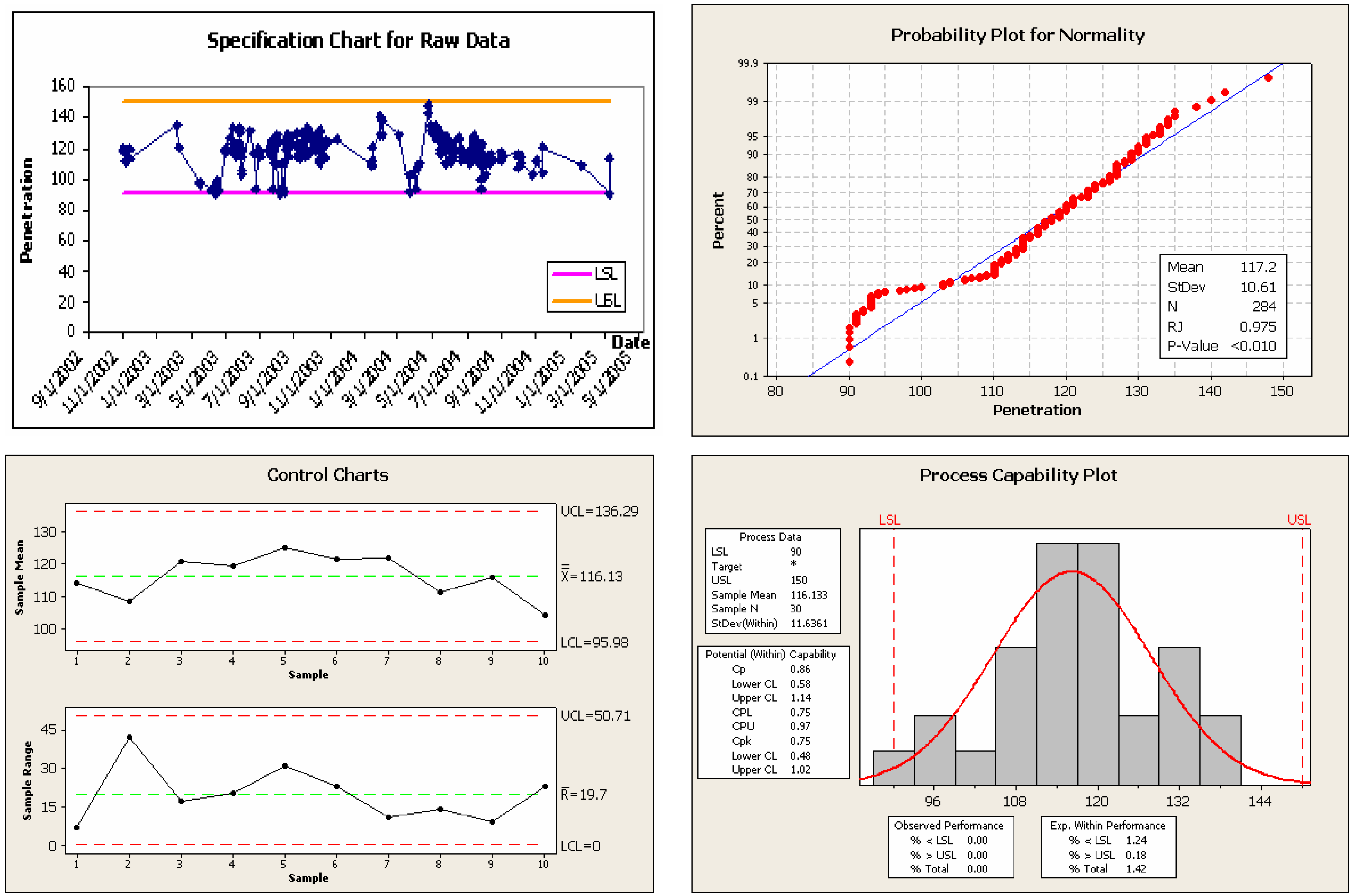


Figure E-139 Statistical Analysis Charts for Supplier: 0901 Grade: CRS-2P Test: Penetration

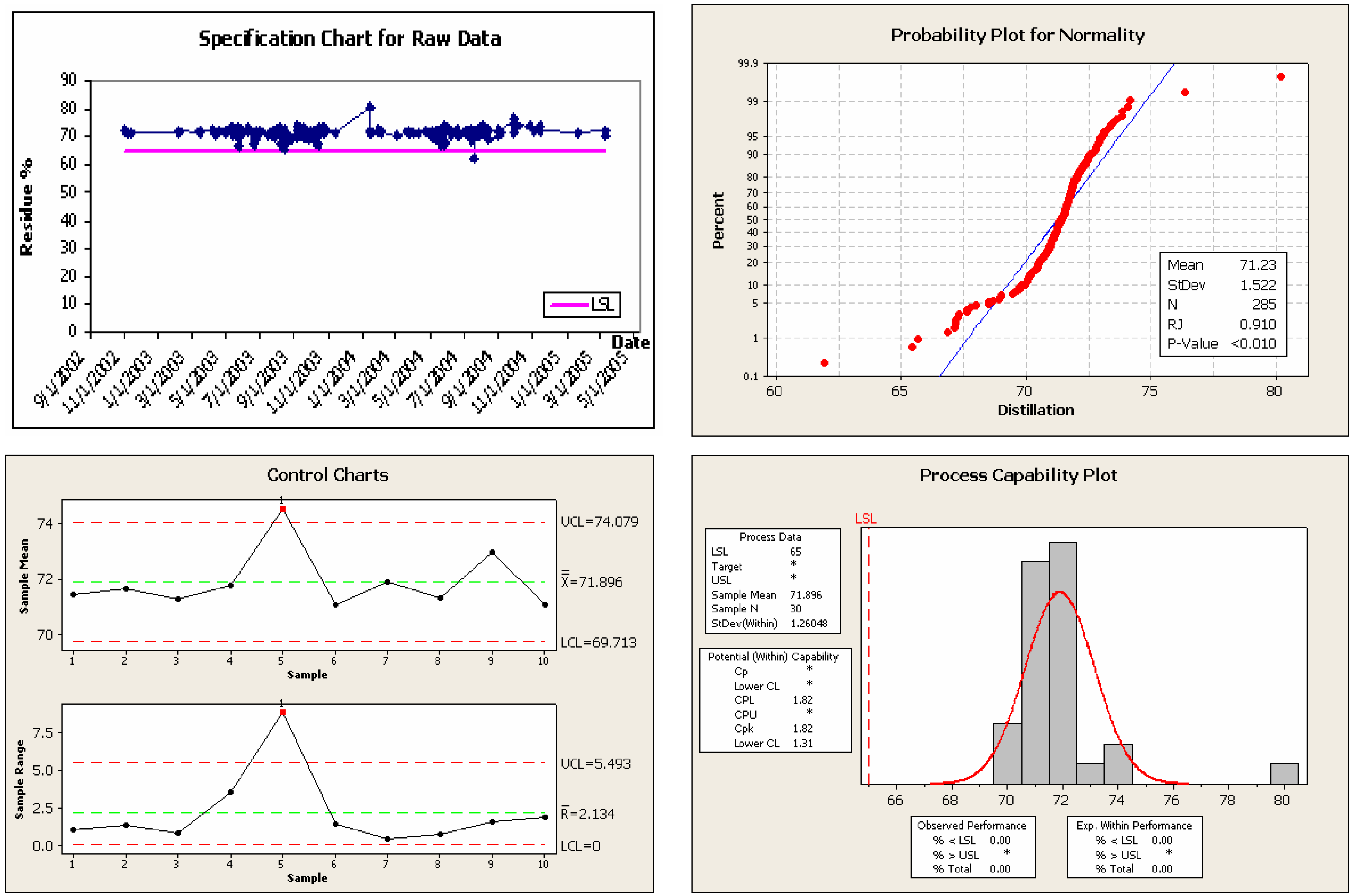


Figure E-140 Statistical Analysis Charts for Supplier: 0901 Grade: CRS-2P Test: Distillation

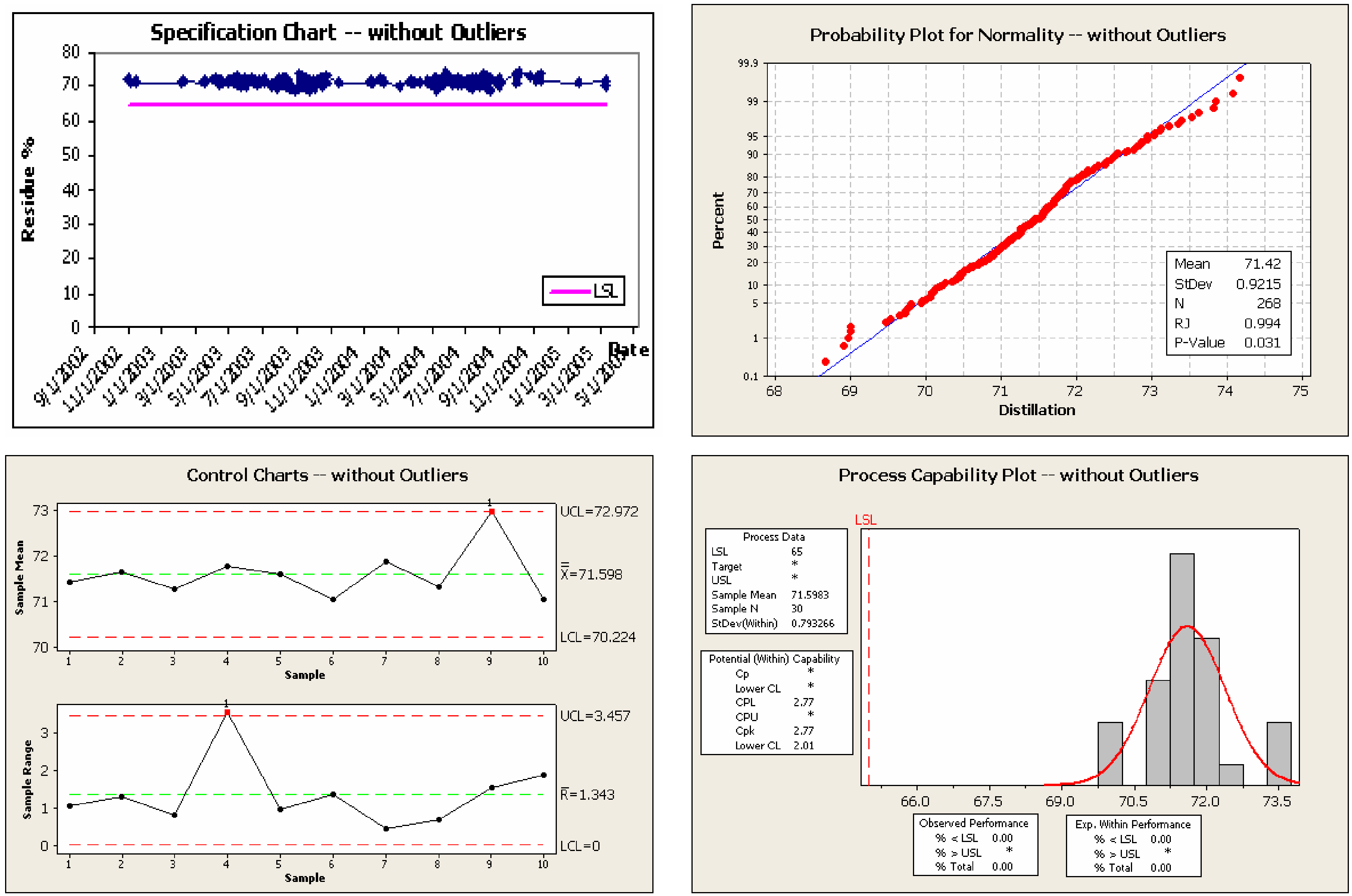


Figure E-141 Statistical Analysis Charts (without Outliers) for Supplier: 0901 Grade: CRS-2P Test: Distillation

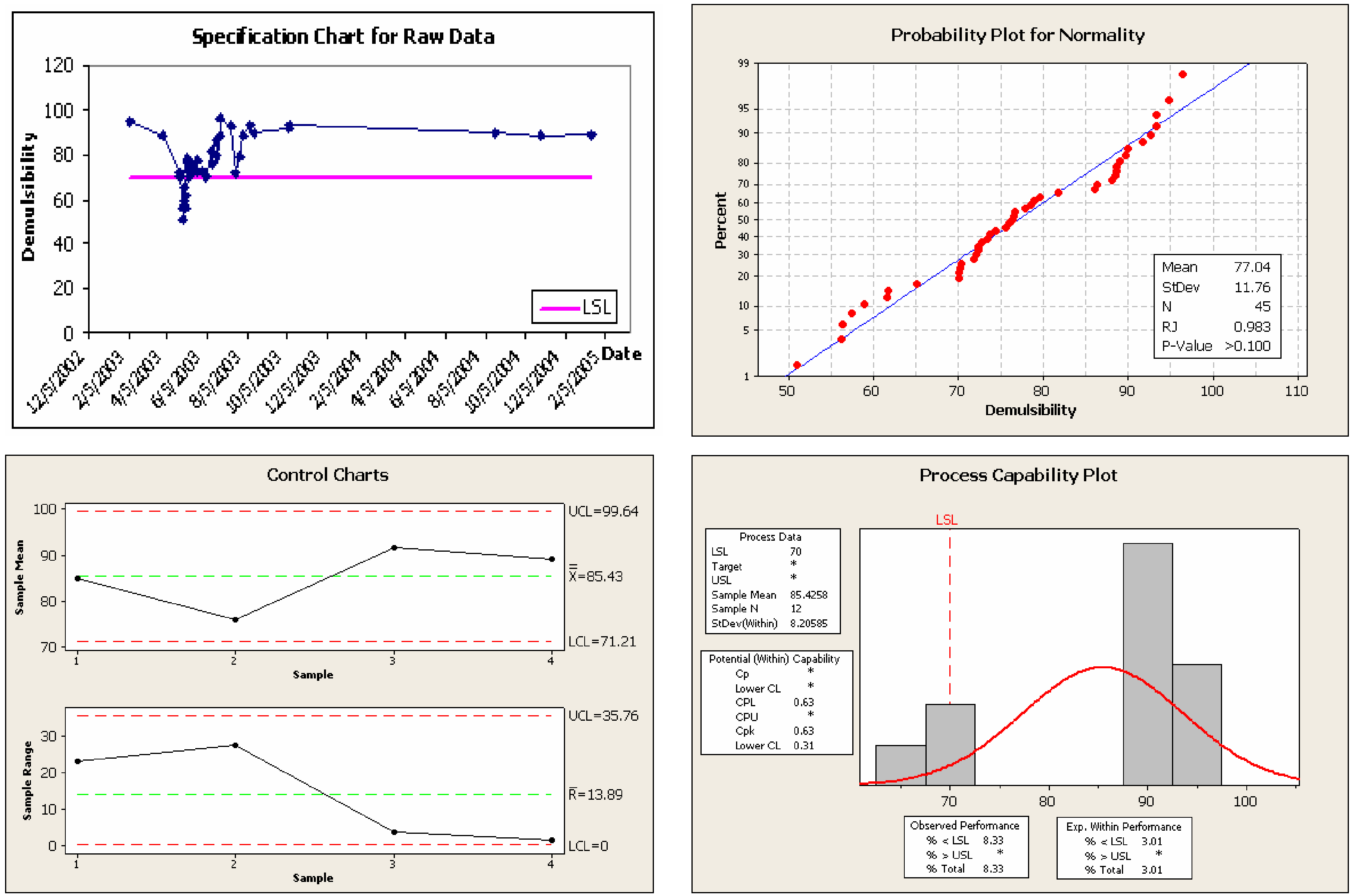


Figure E-142 Statistical Analysis Charts for Supplier: 1001 Grade: CRS-2P Test: Demulsibility

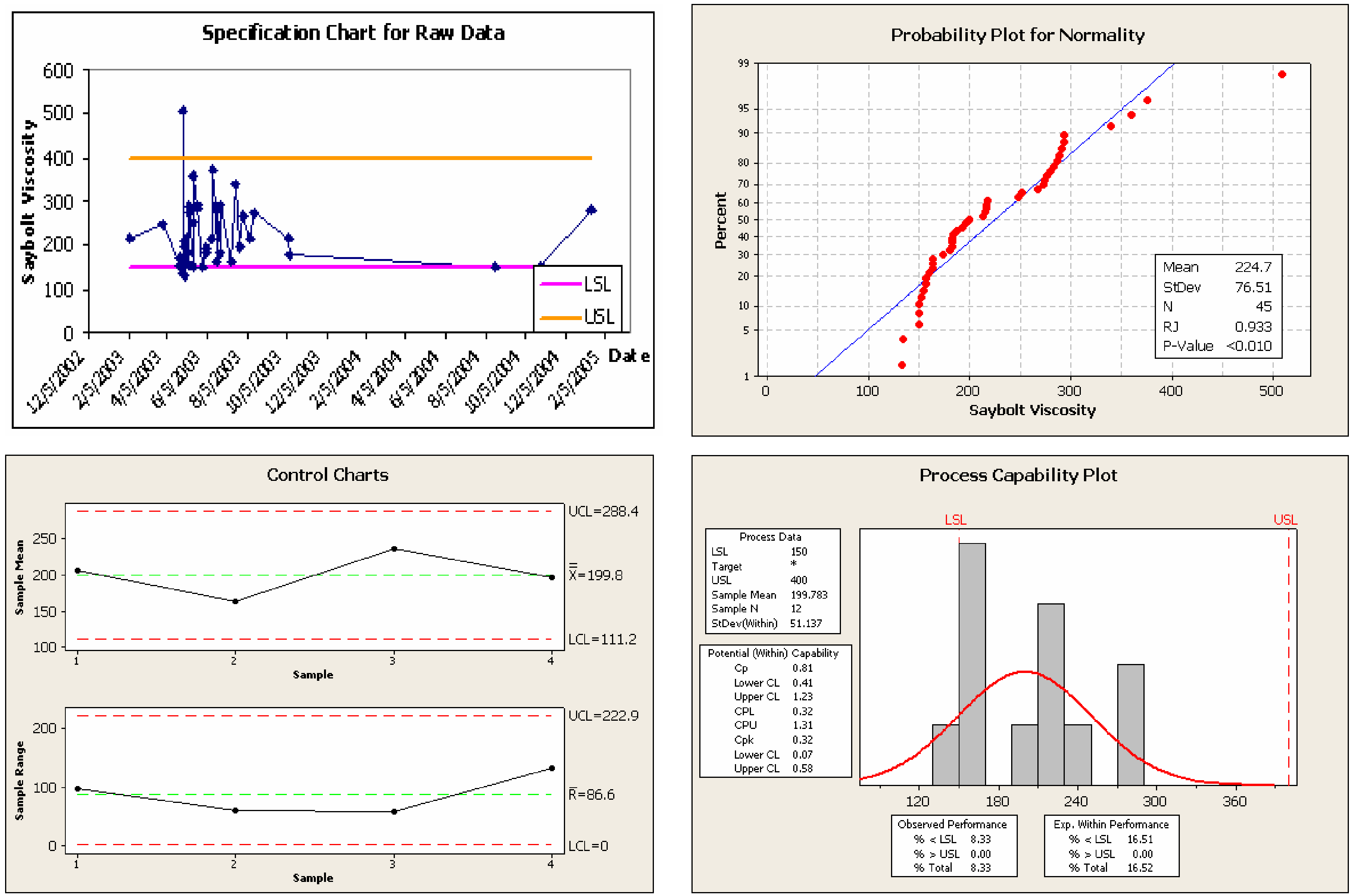


Figure E-143 Statistical Analysis Charts for Supplier: 1001 Grade: CRS-2P Test: Saybolt Viscosity

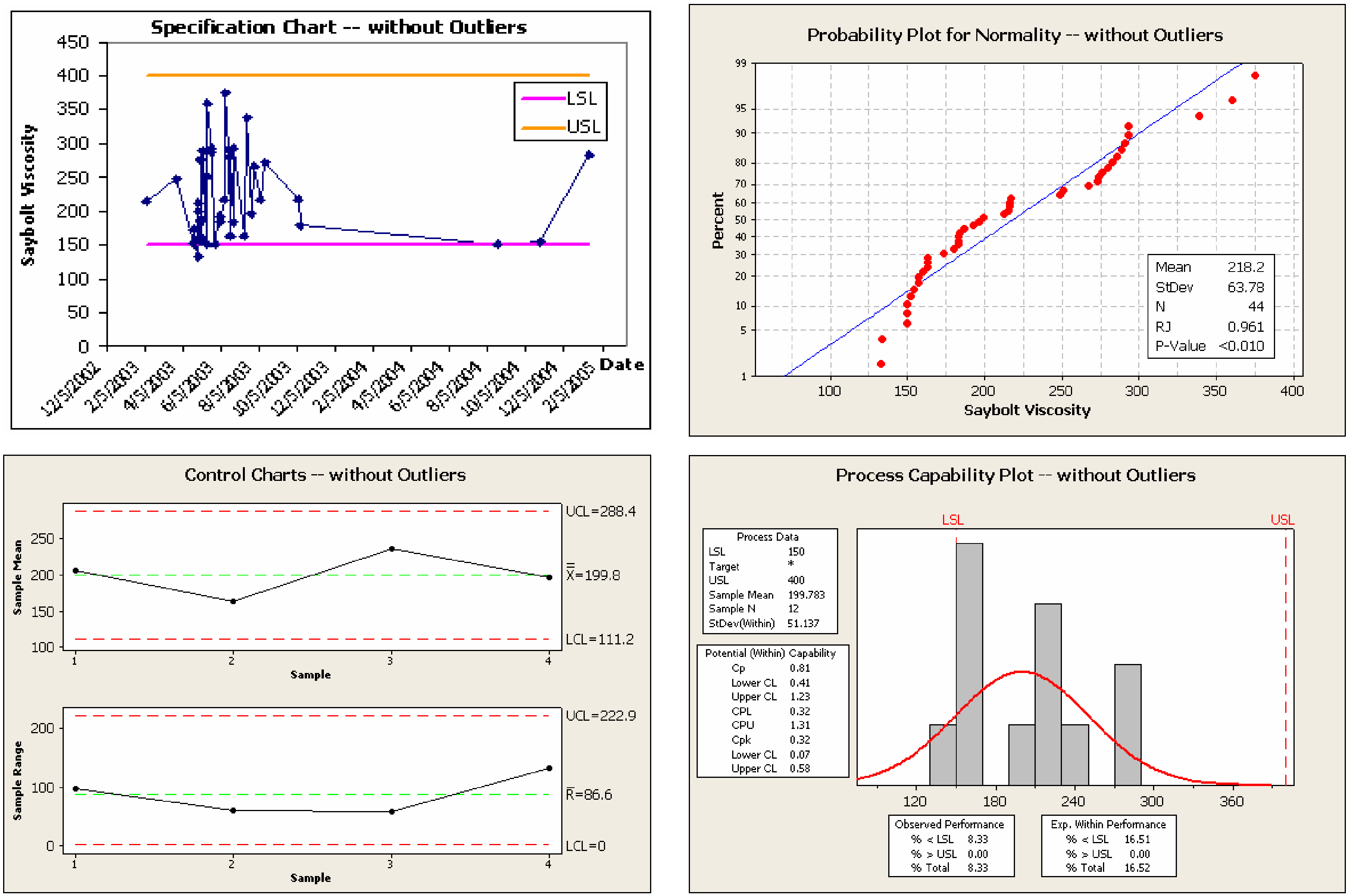


Figure E-144 Statistical Analysis Charts (without Outliers) for Supplier: 1001 Grade: CRS-2P Test: Saybolt Viscosity

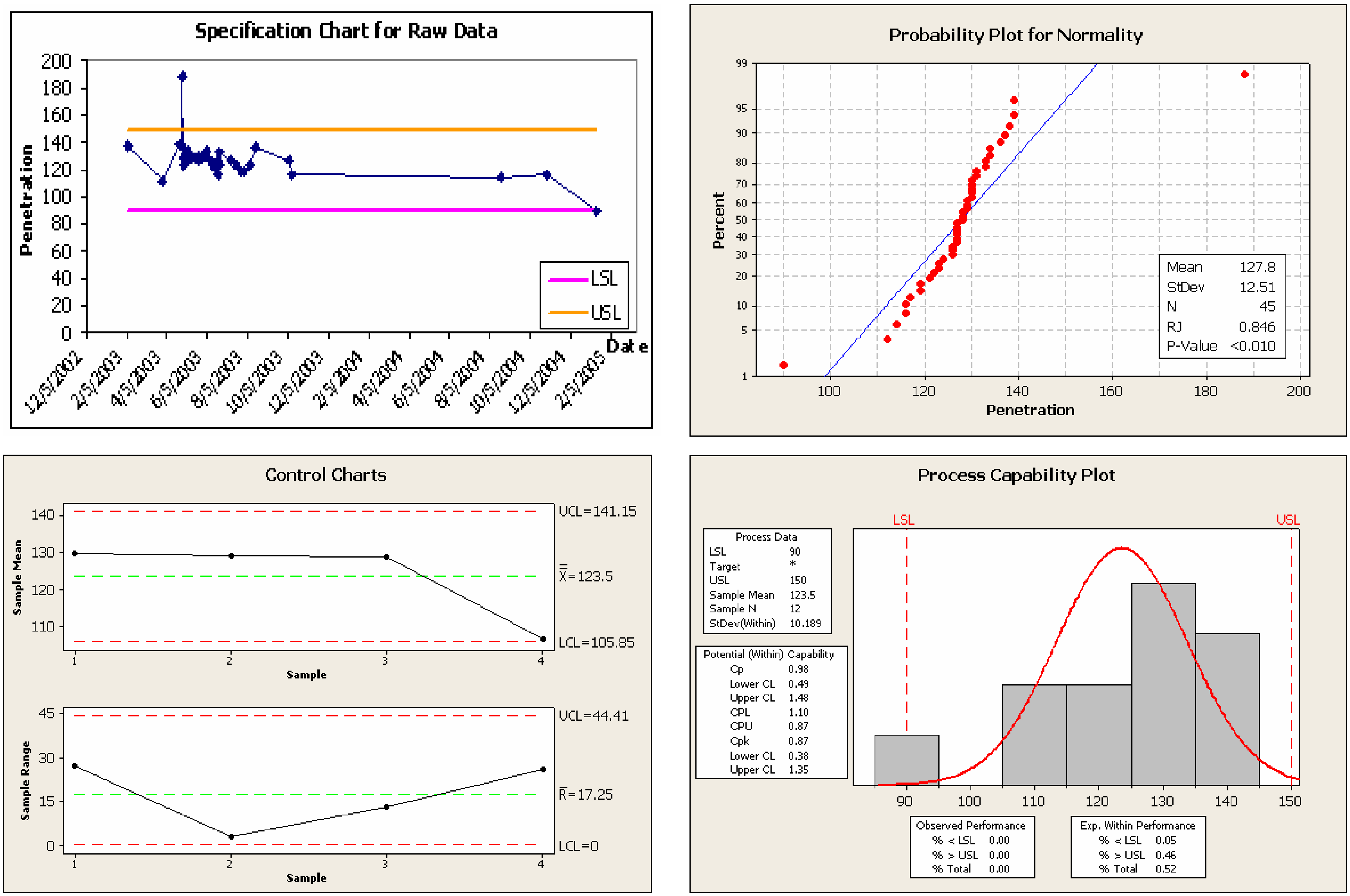


Figure E-145 Statistical Analysis Charts for Supplier: 1001 Grade: CRS-2P Test: Penetration

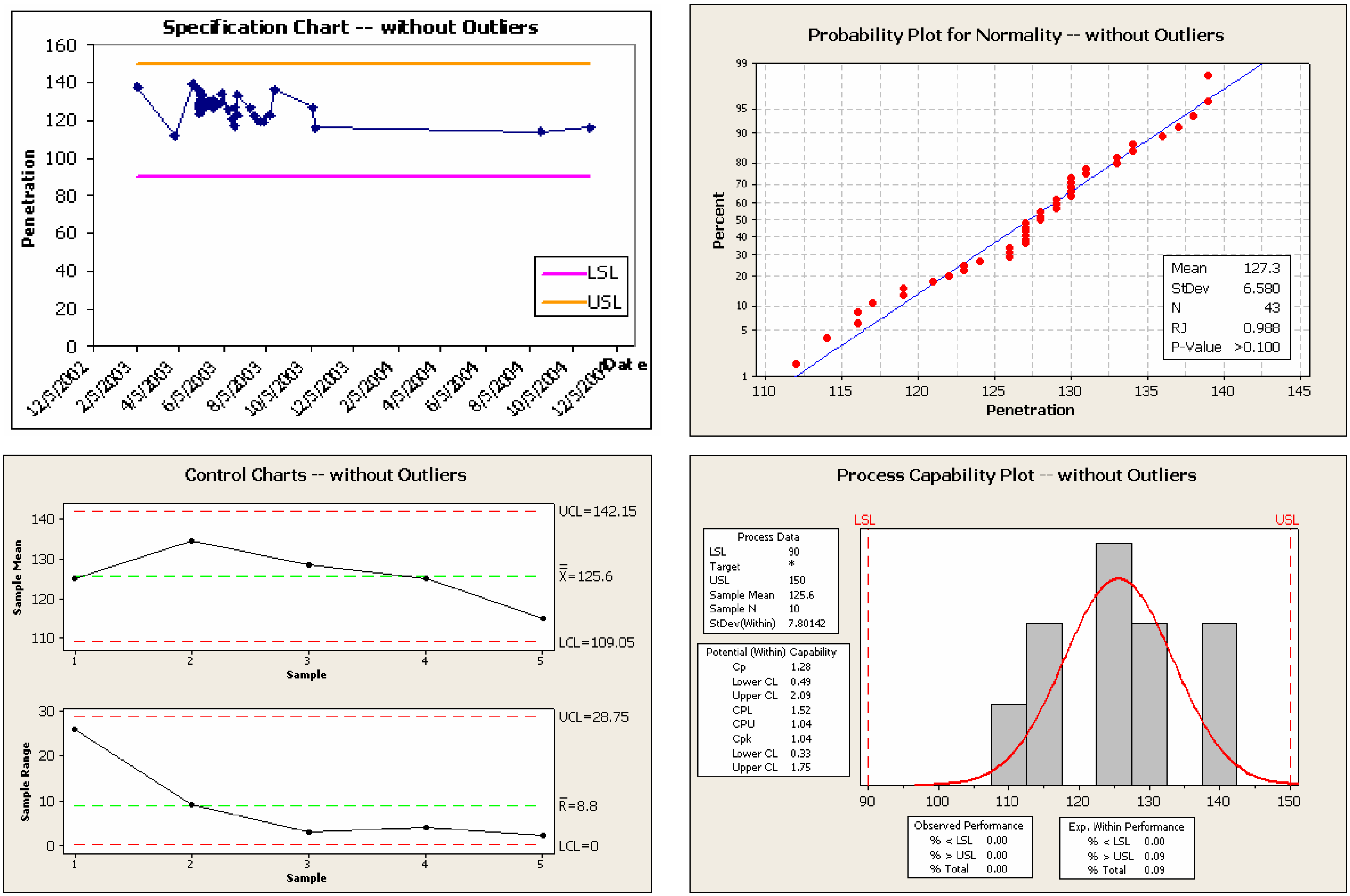
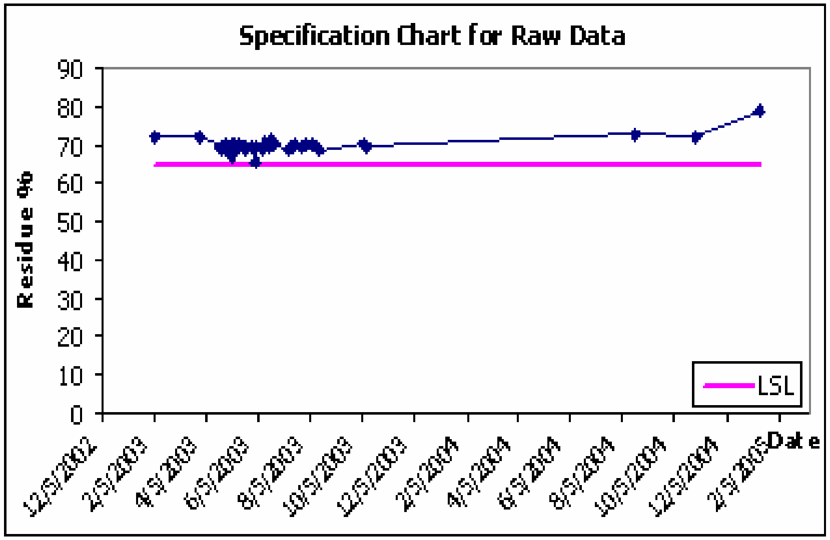
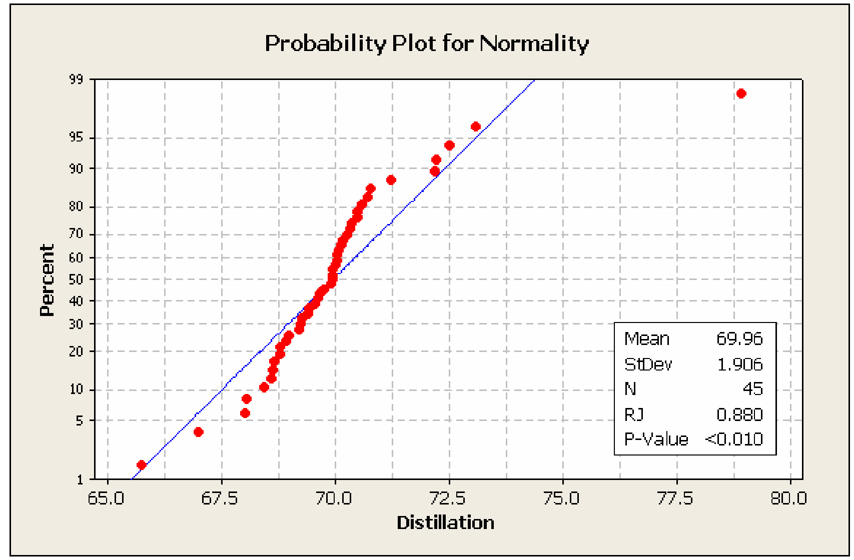
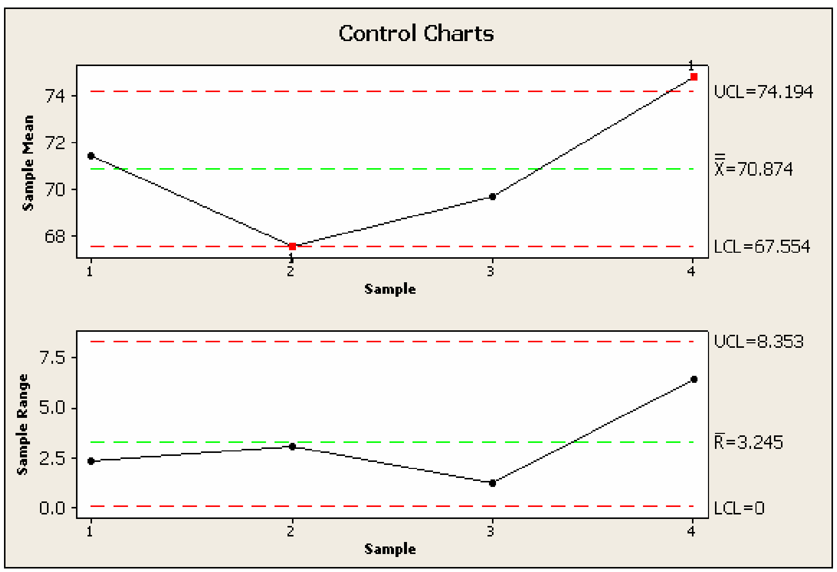


Figure E-146 Statistical Analysis Charts (without Outliers) for Supplier: 1001 Grade: CRS-2P Test: Penetration







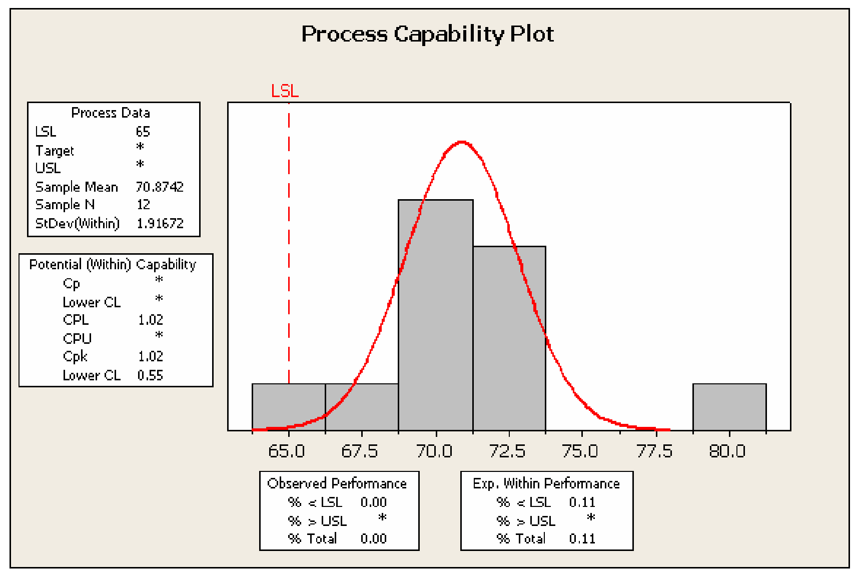


Figure E-147 Statistical Analysis Charts for Supplier: 1001 Grade: CRS-2P Test: Distillation

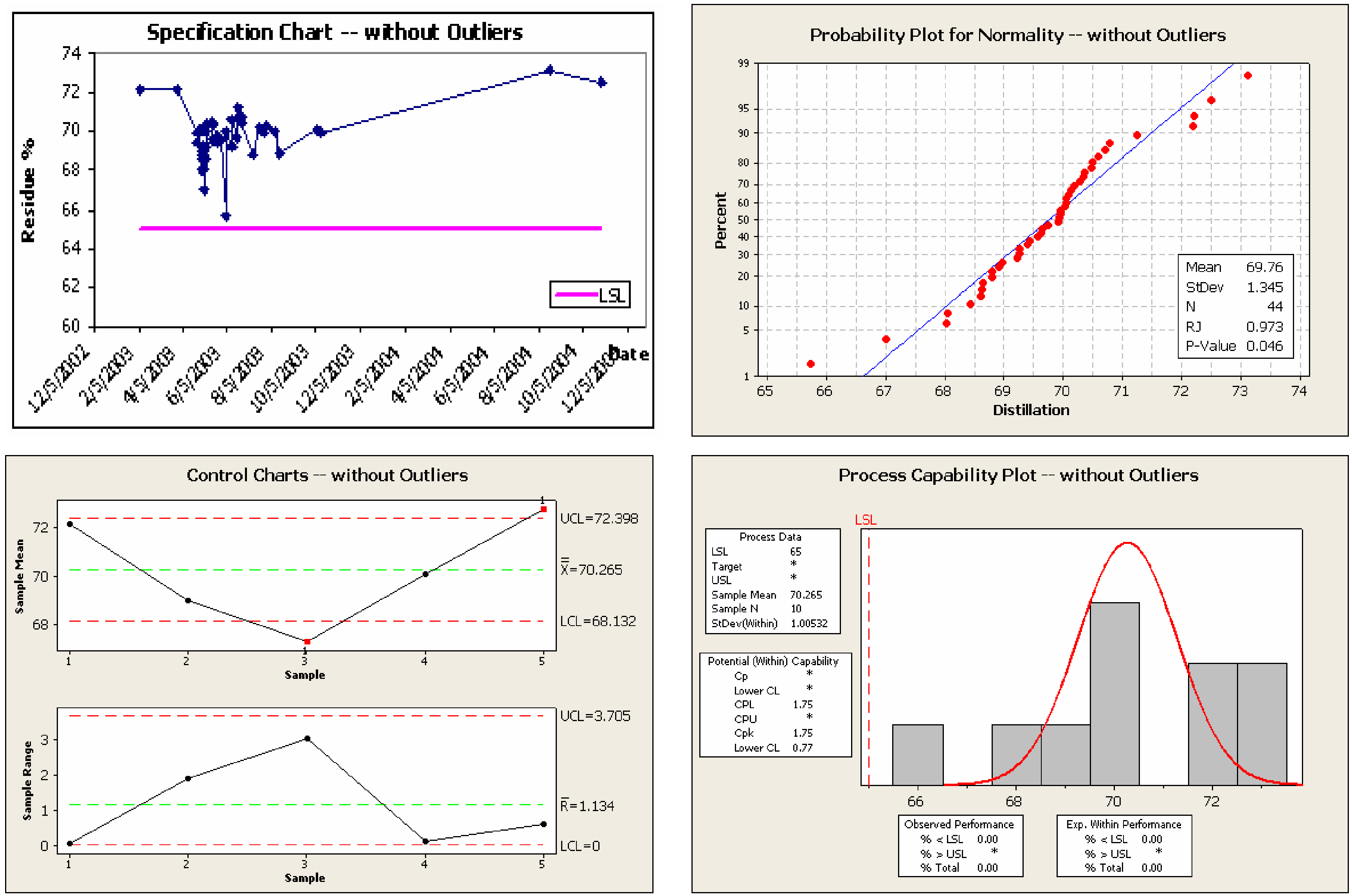


Figure E-148 Statistical Analysis Charts (without Outliers) for Supplier: 1001 Grade: CRS-2P Test: Distillation

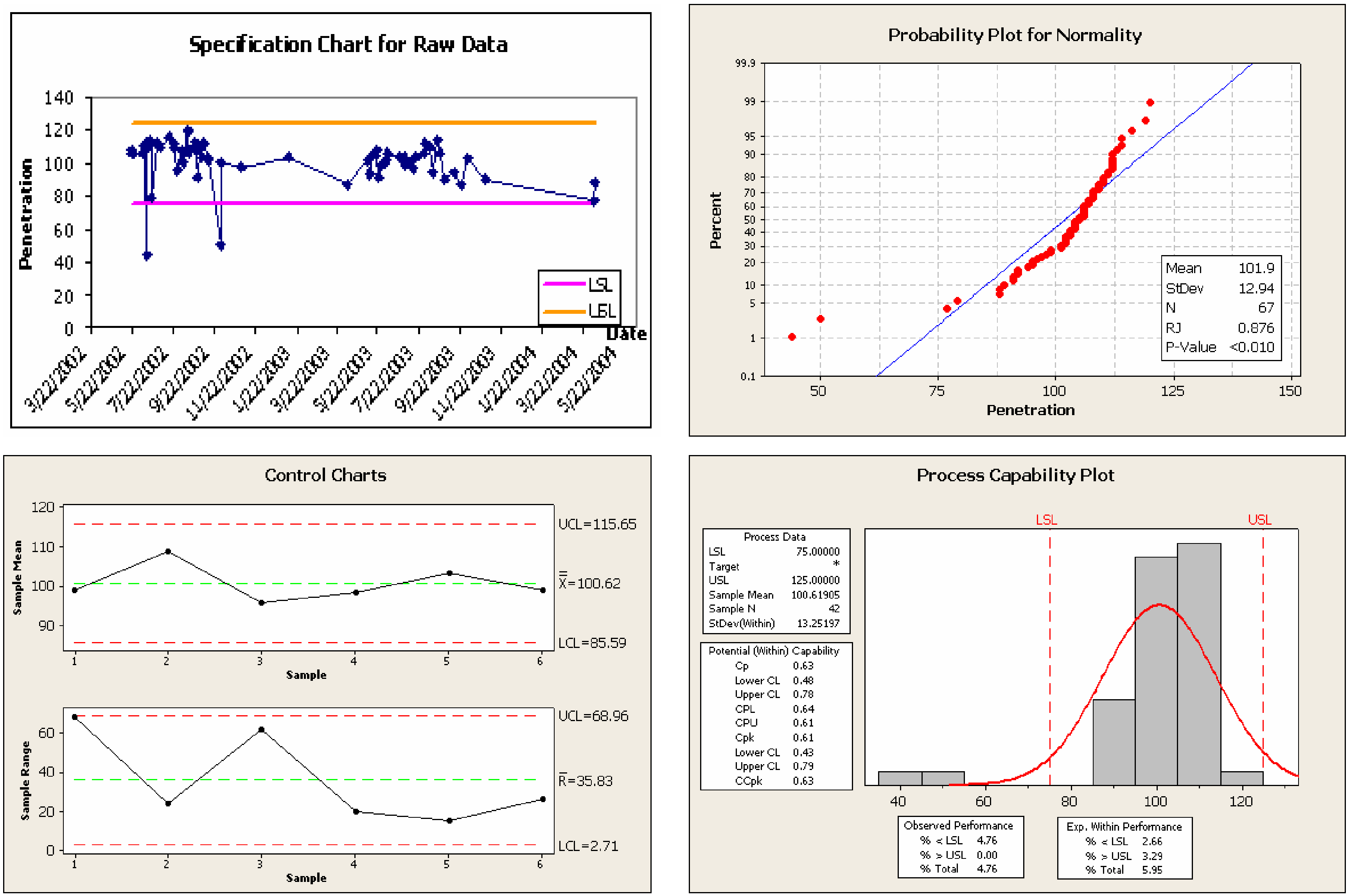


Figure E-149 Statistical Analysis Charts for Supplier: 1101 Grade: AC-15-5TR Test: Penetration

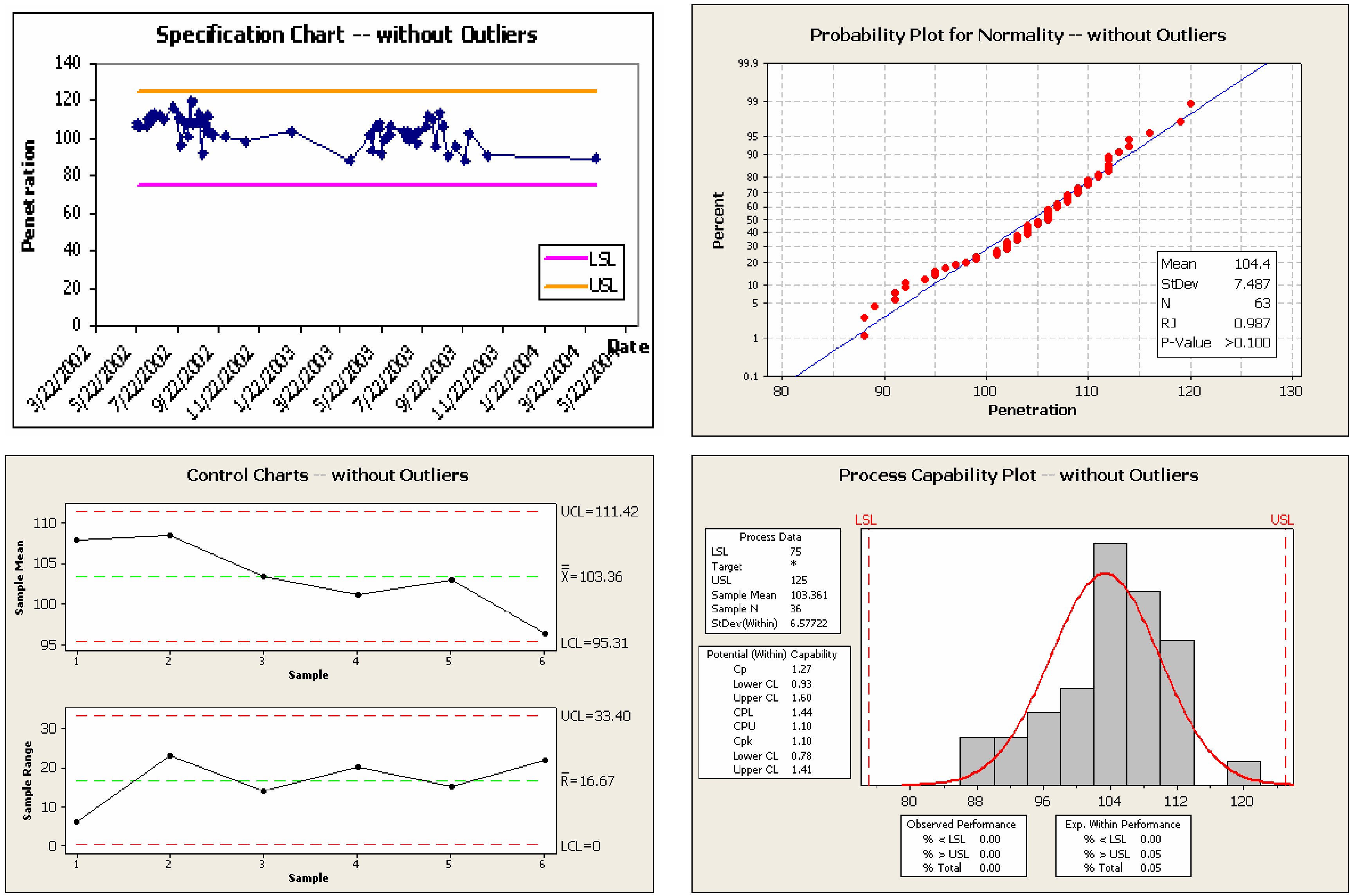


Figure E-150 Statistical Analysis Charts (without Outliers) for Supplier: 1101 Grade: AC-15-5TR Test: Penetration

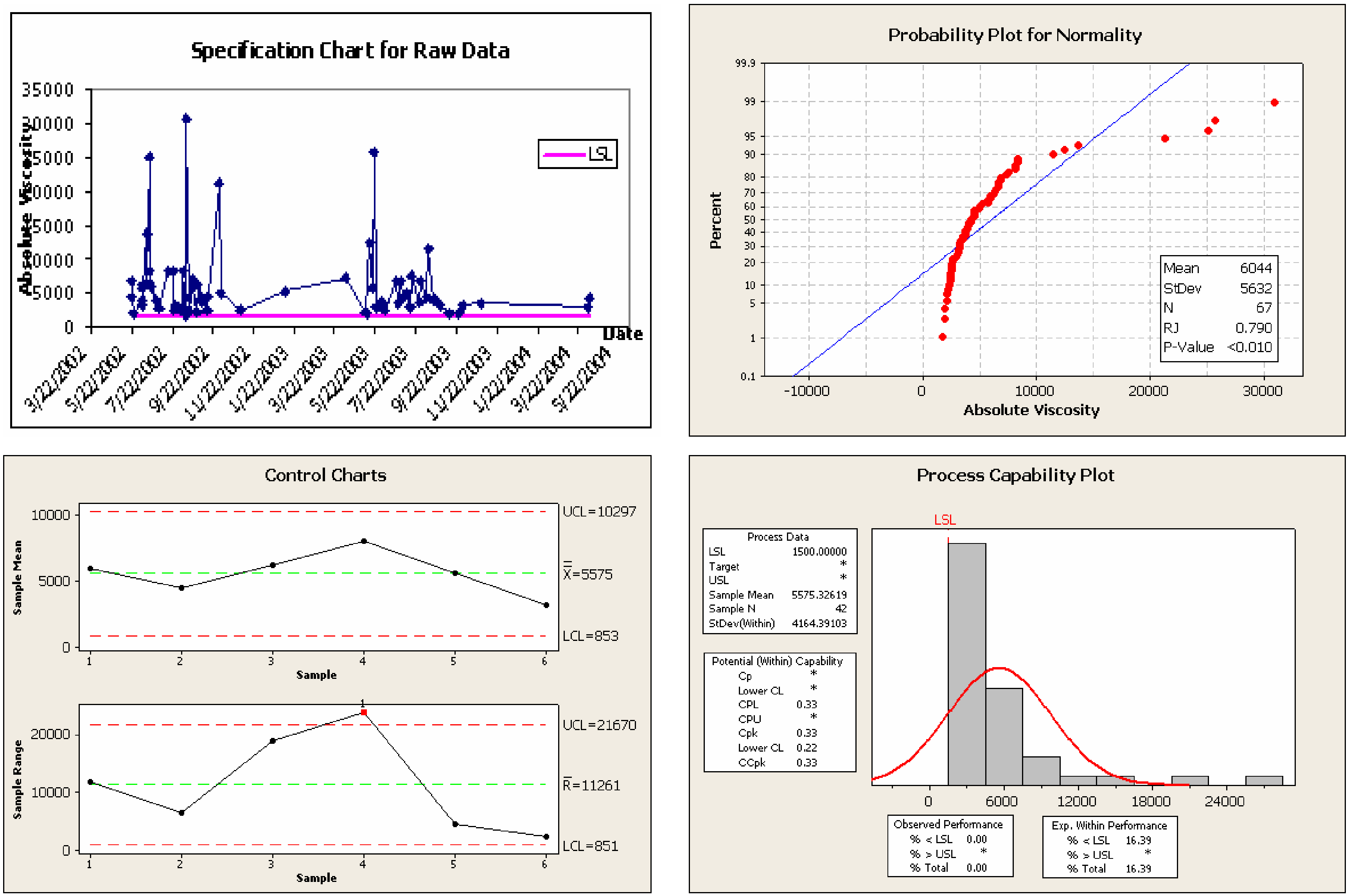


Figure E-151 Statistical Analysis Charts for Supplier: 1101 Grade: AC-15-5TR Test: Absolute Viscosity

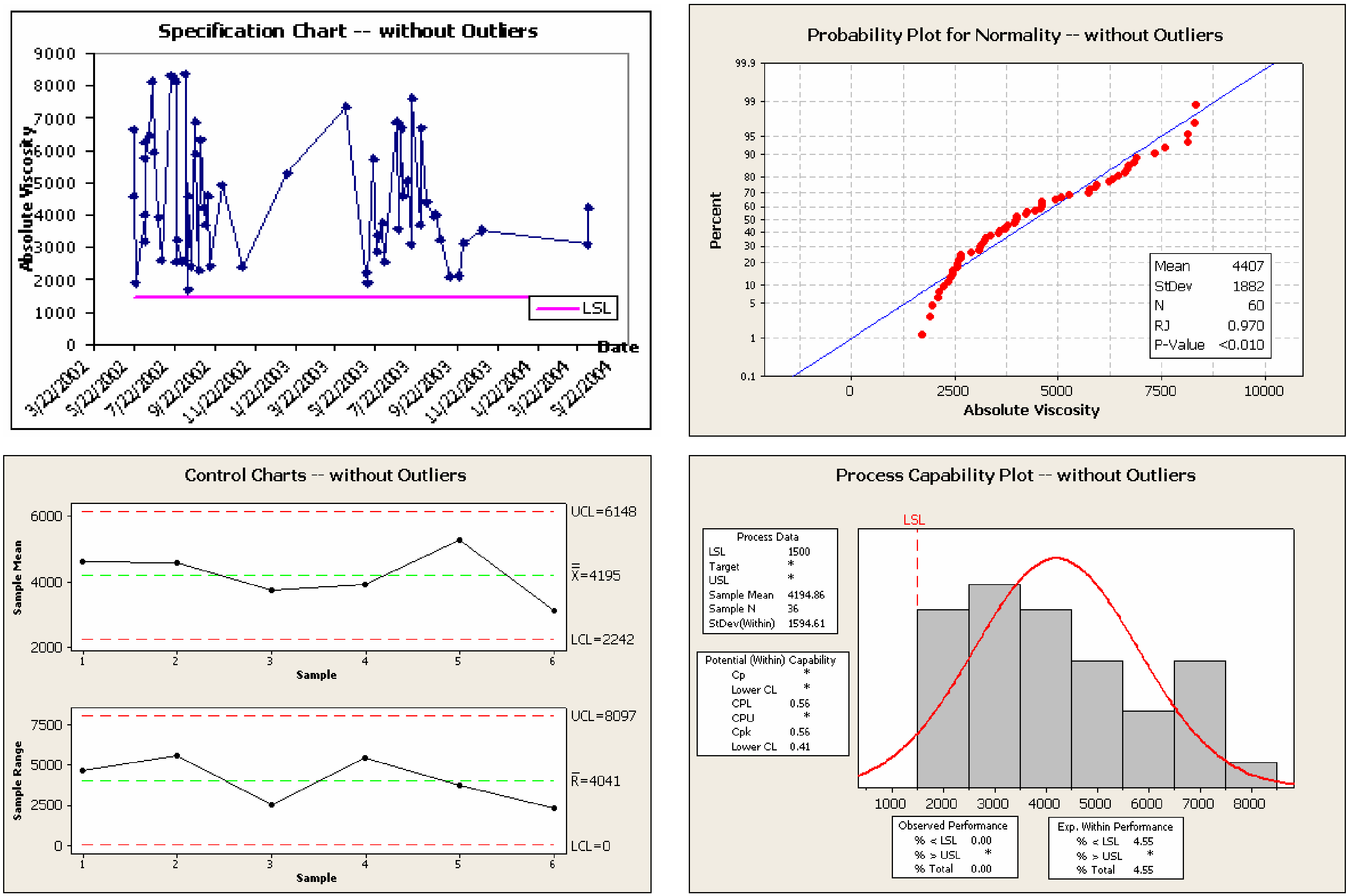


Figure E-152 Statistical Analysis Charts (without Outliers) for Supplier: 1101 Grade: AC-15-5TR Test: Absolute Viscosity

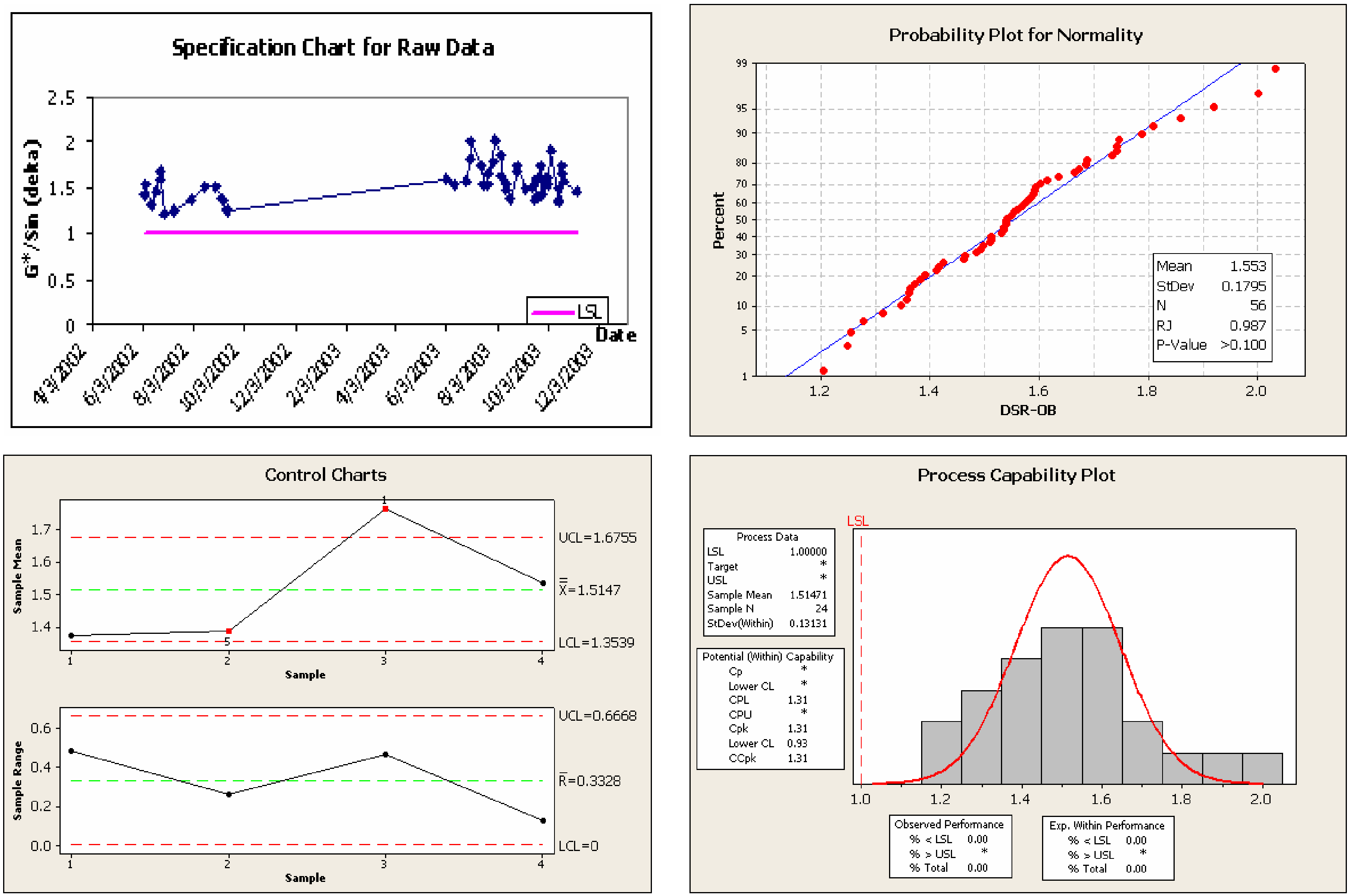
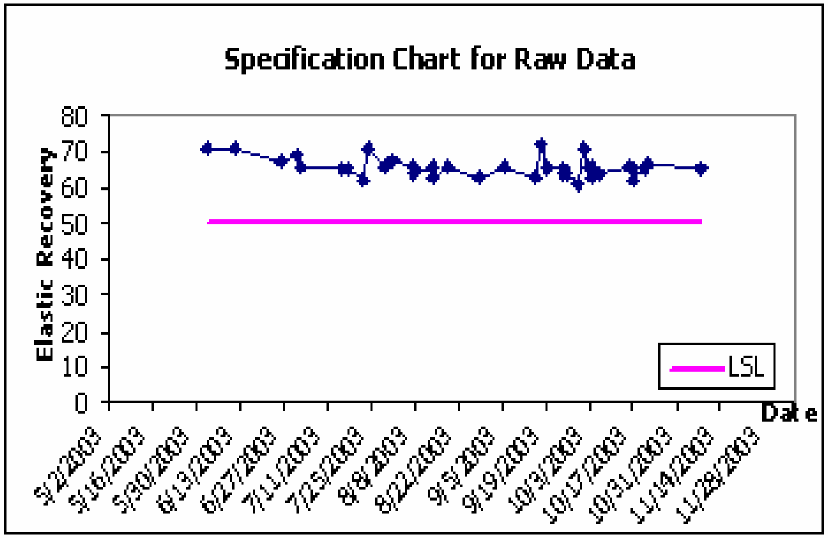
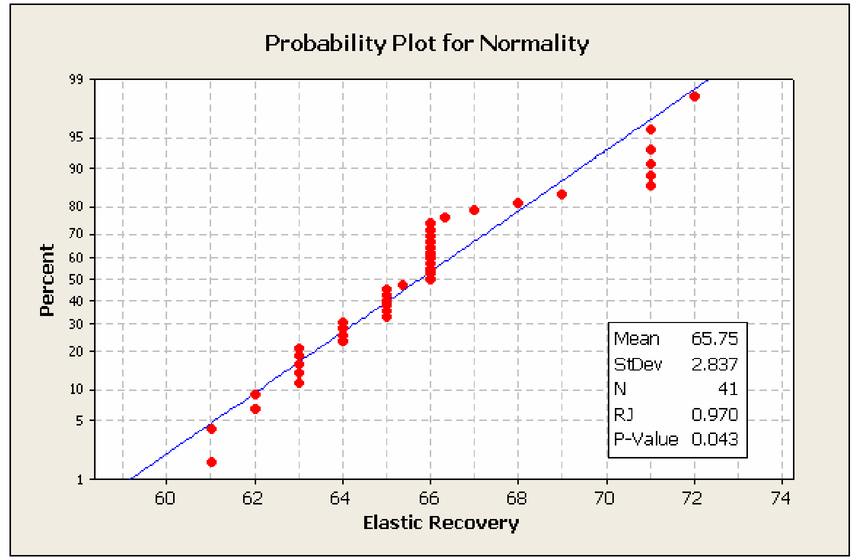
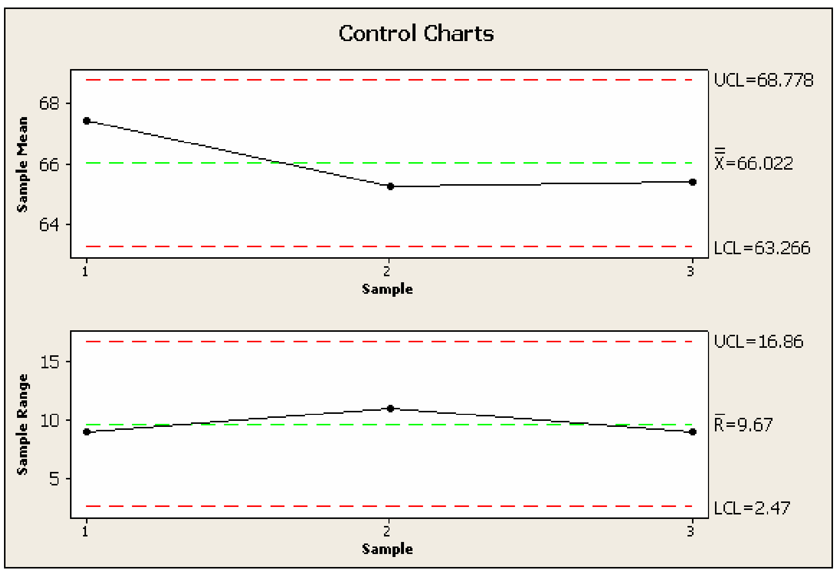


Figure E-153 Statistical Analysis Charts for Supplier: 1102 Grade: PG 76-22S Test: DSR-OB







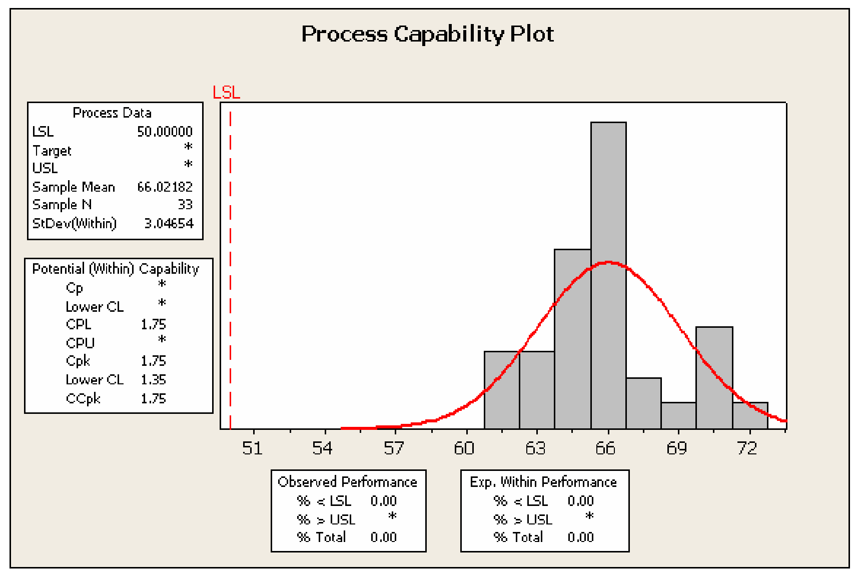


Figure E-154 Statistical Analysis Charts for Supplier: 1102 Grade: PG 76-22S Test: Elastic Recovery

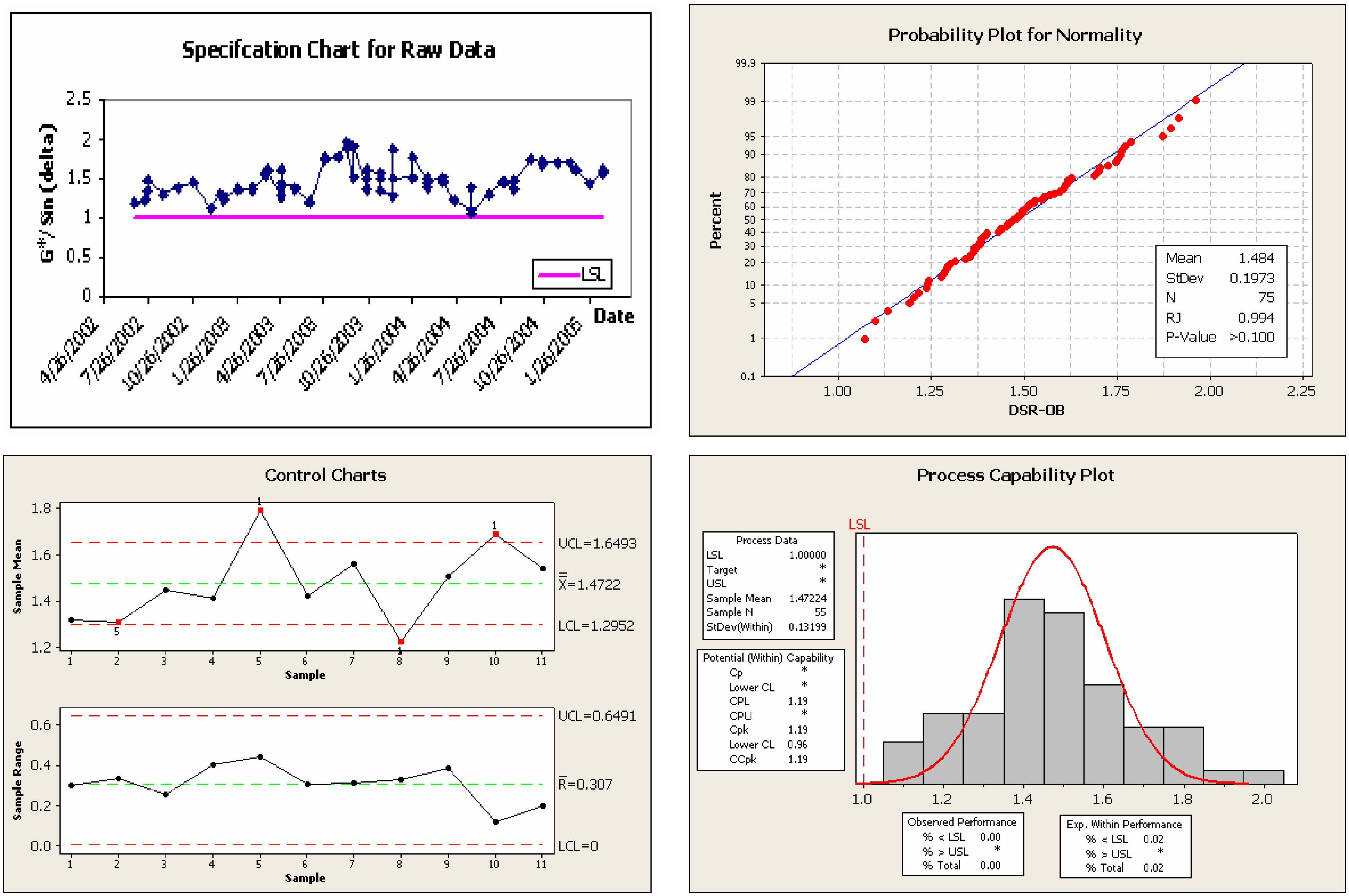


Figure E-155 Statistical Analysis Charts for Supplier: 1201 Grade: PG 64-22 Test: DSR-OB

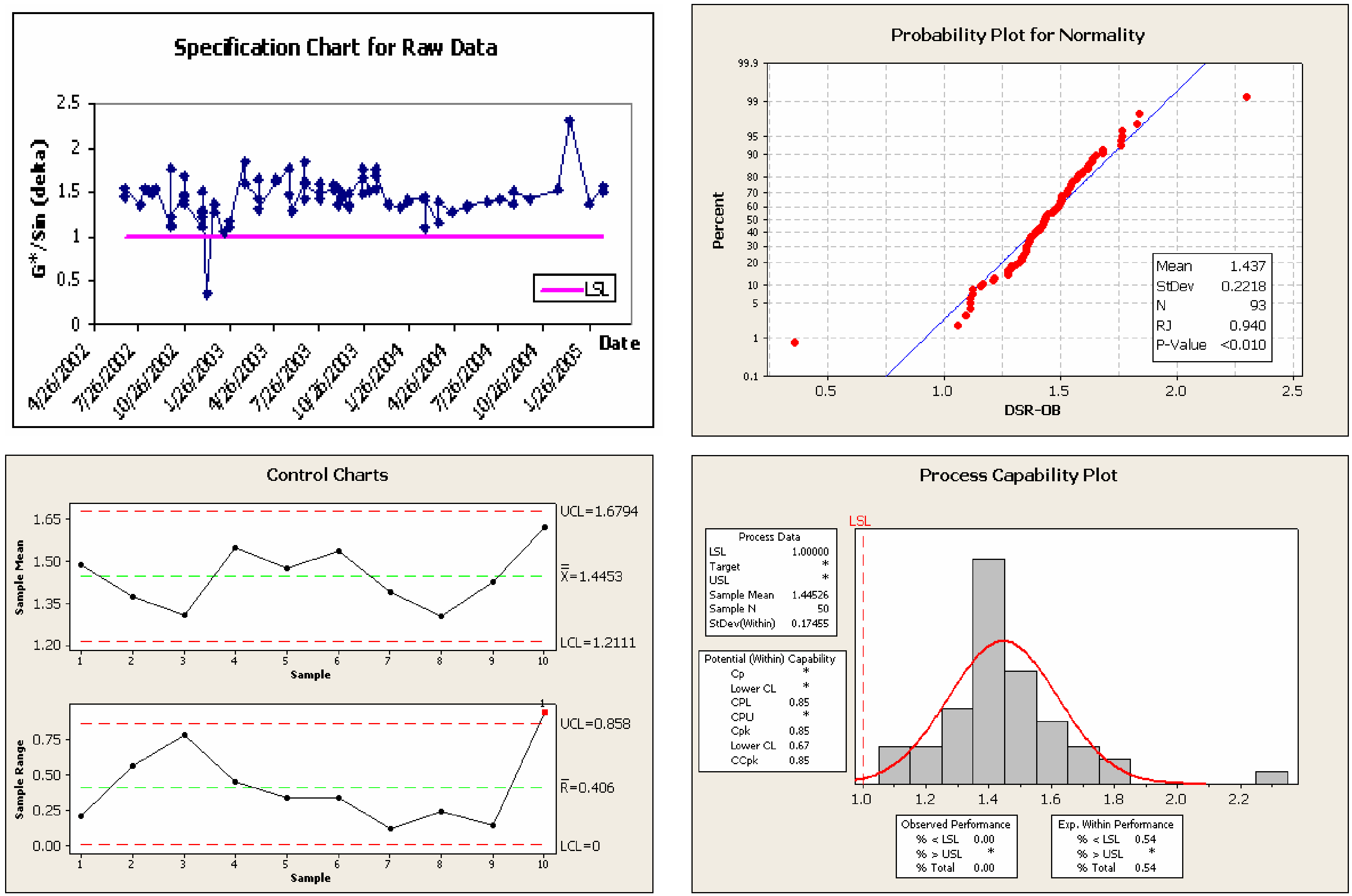


Figure E-156 Statistical Analysis Charts for Supplier: 1201 Grade: PG 76-22S Test: DSR-OB

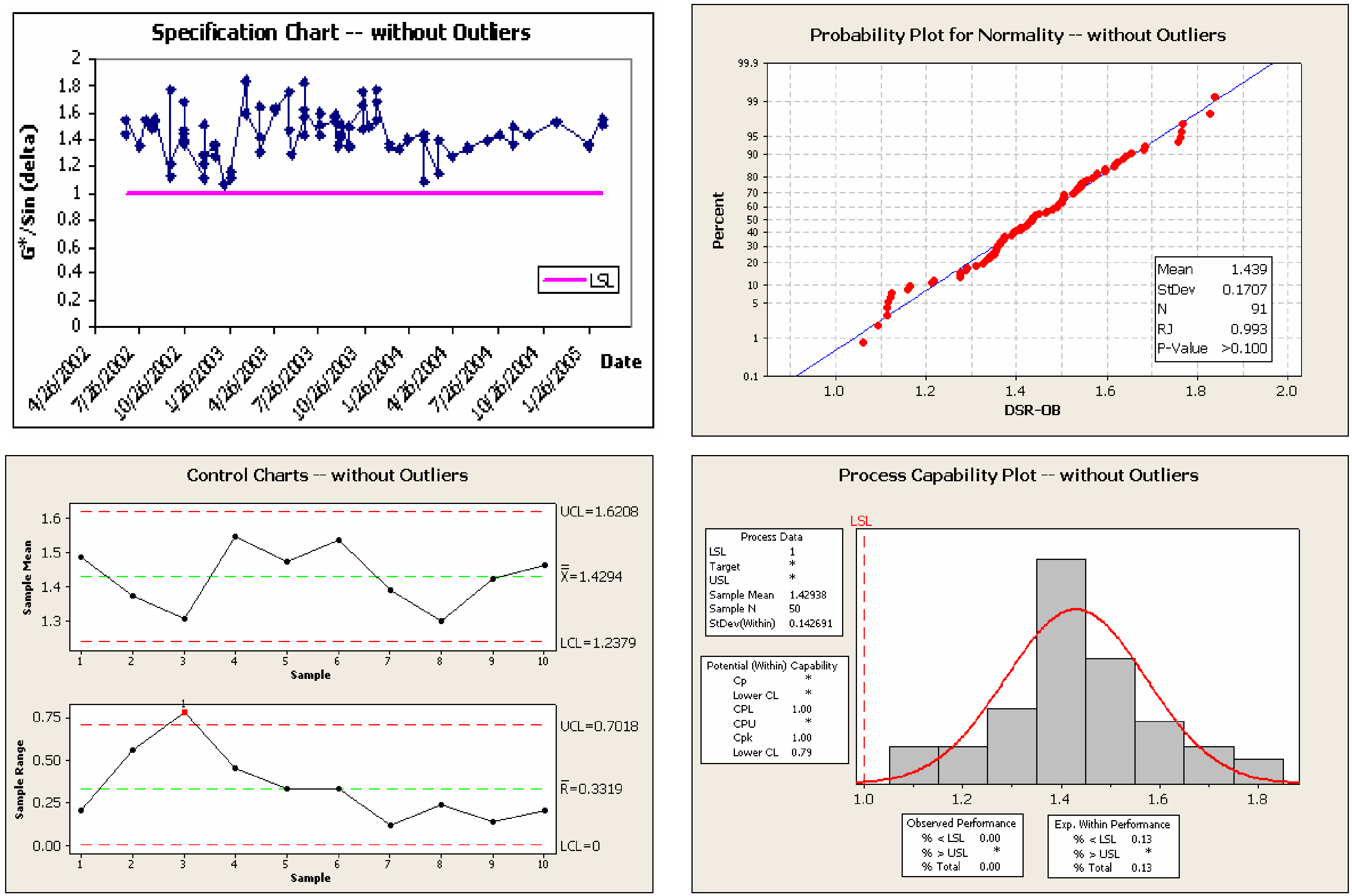


Figure E-157 Statistical Analysis Charts (without Outliers) for Supplier: 1201 Grade: PG 76-22S Test: DSR-OB

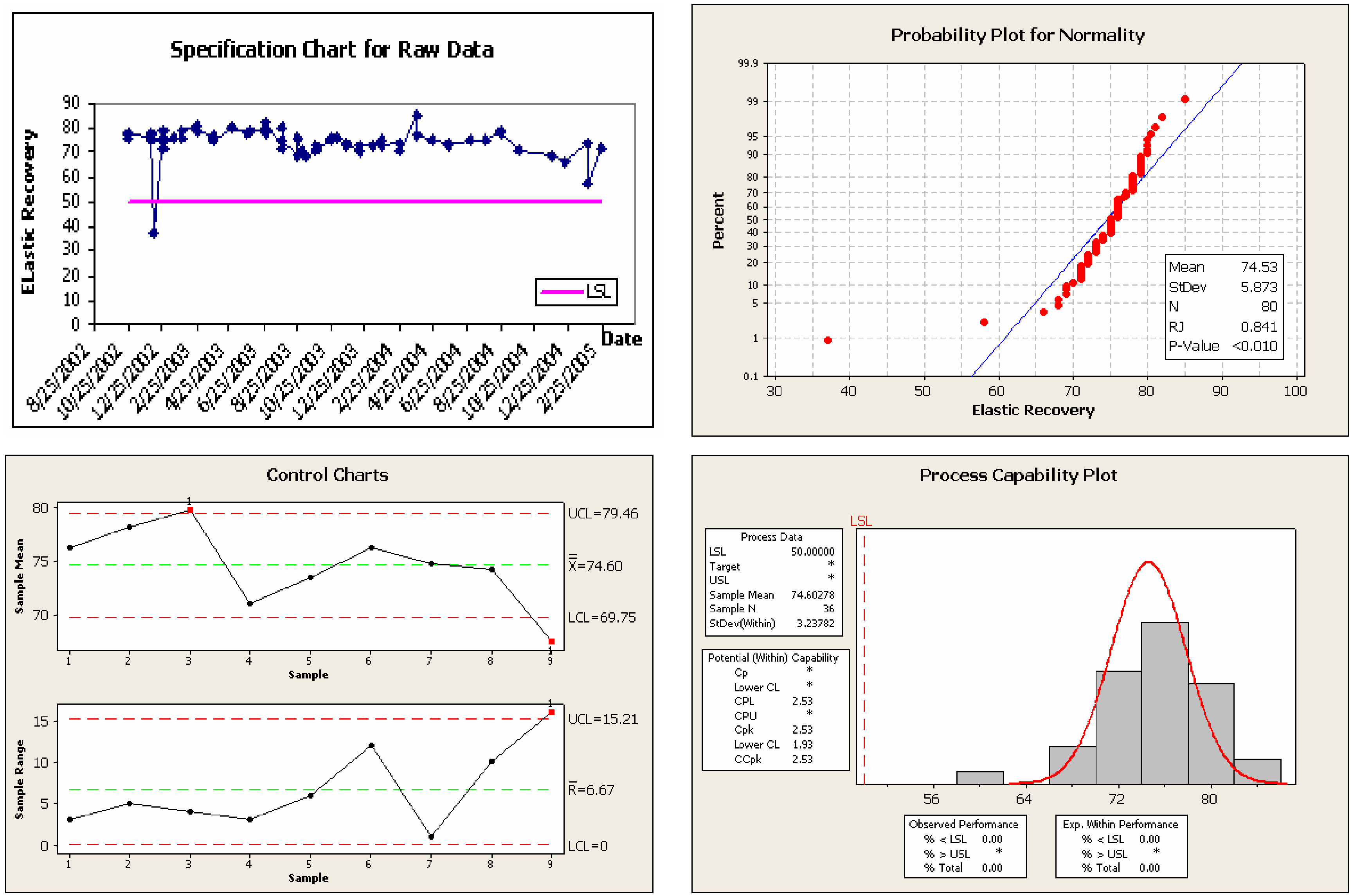


Figure E-158 Statistical Analysis Charts for Supplier: 1201 Grade: PG 76-22S Test: Elastic Recovery

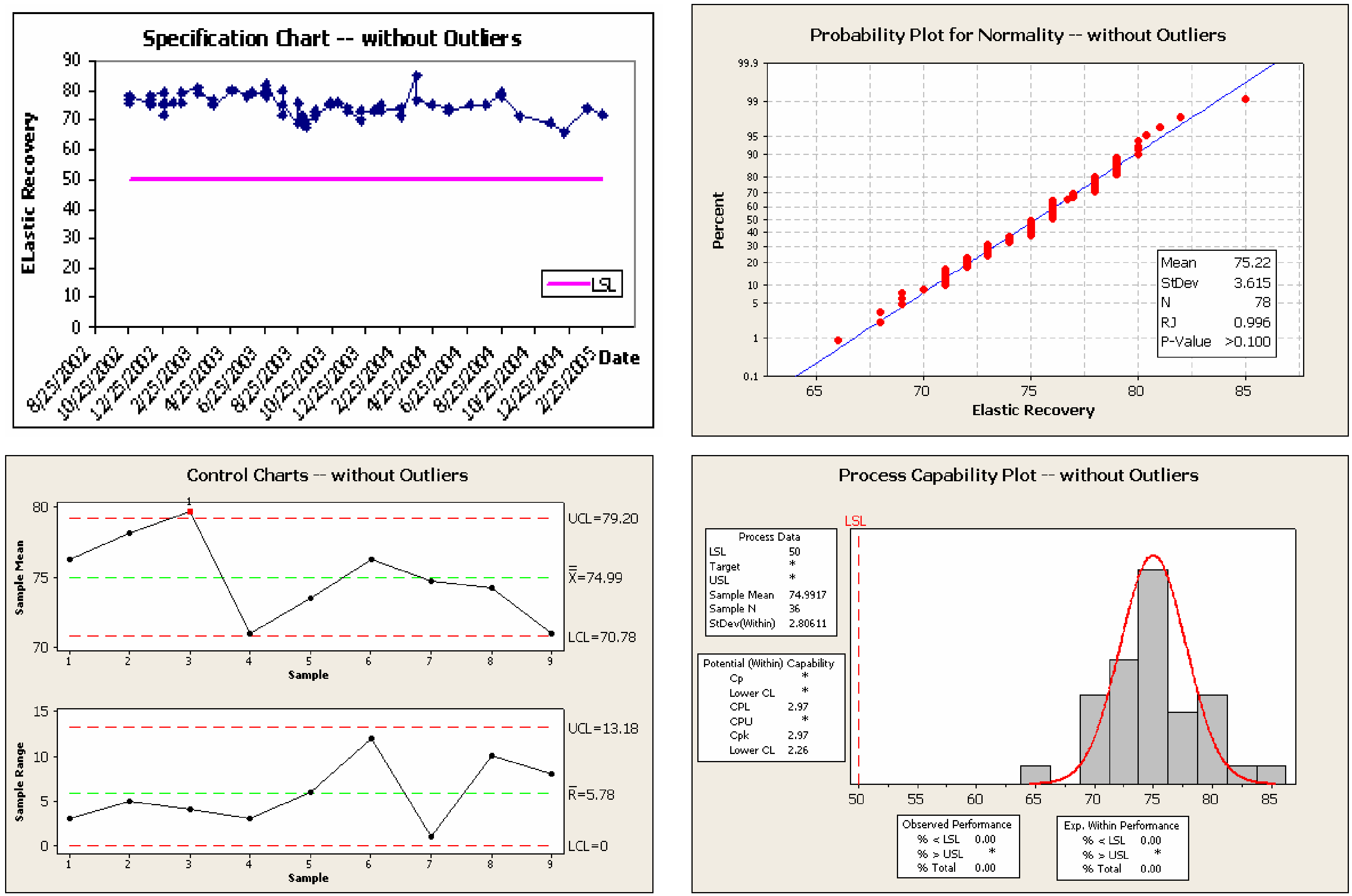


Figure E-159 Statistical Analysis Charts (without Outliers) for Supplier: 1201 Grade: PG 76-22S Test: Elastic Recovery

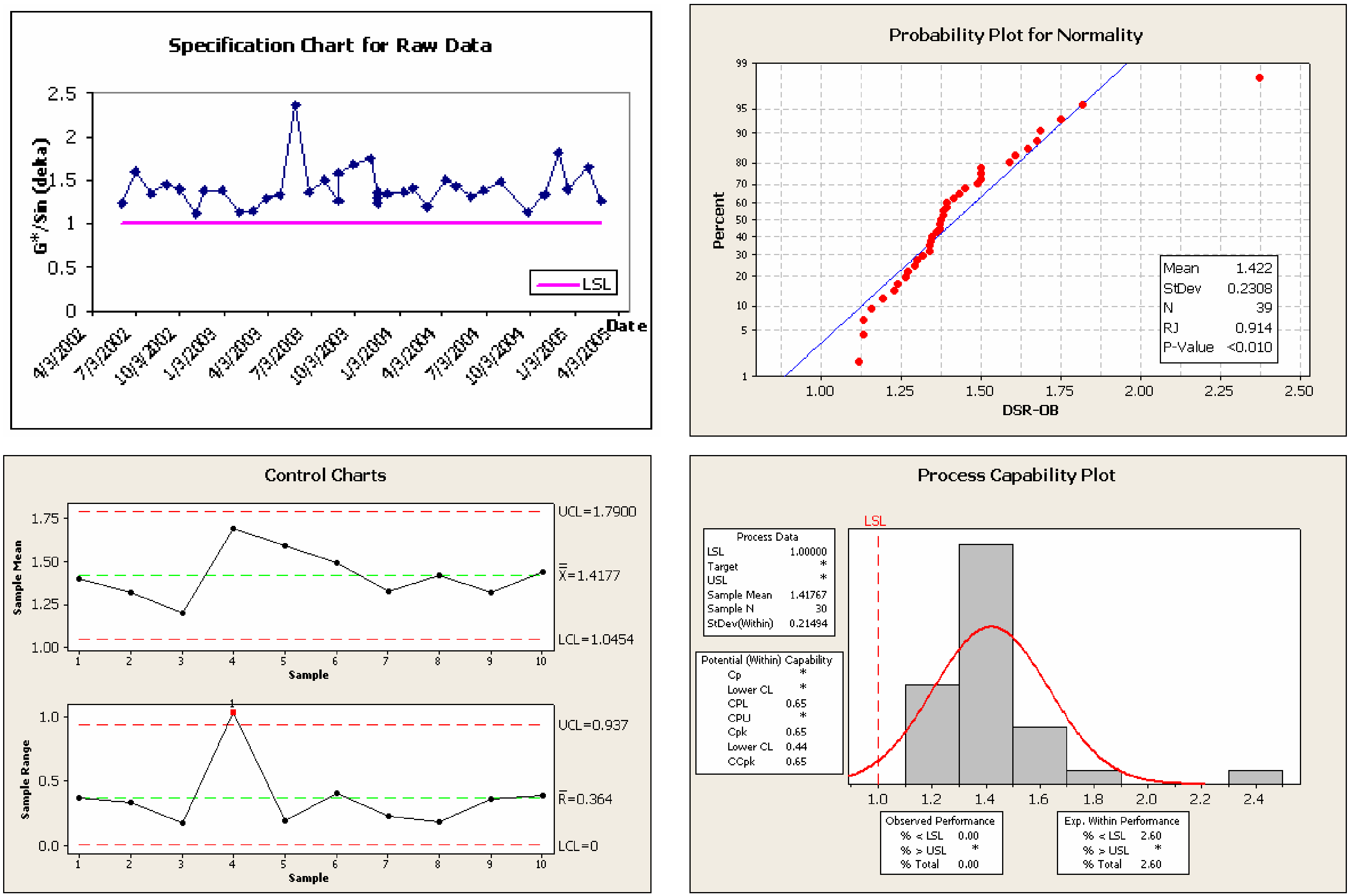


Figure E-160 Statistical Analysis Charts for Supplier: 1301 Grade: PG 70-22 Test: DSR-OB

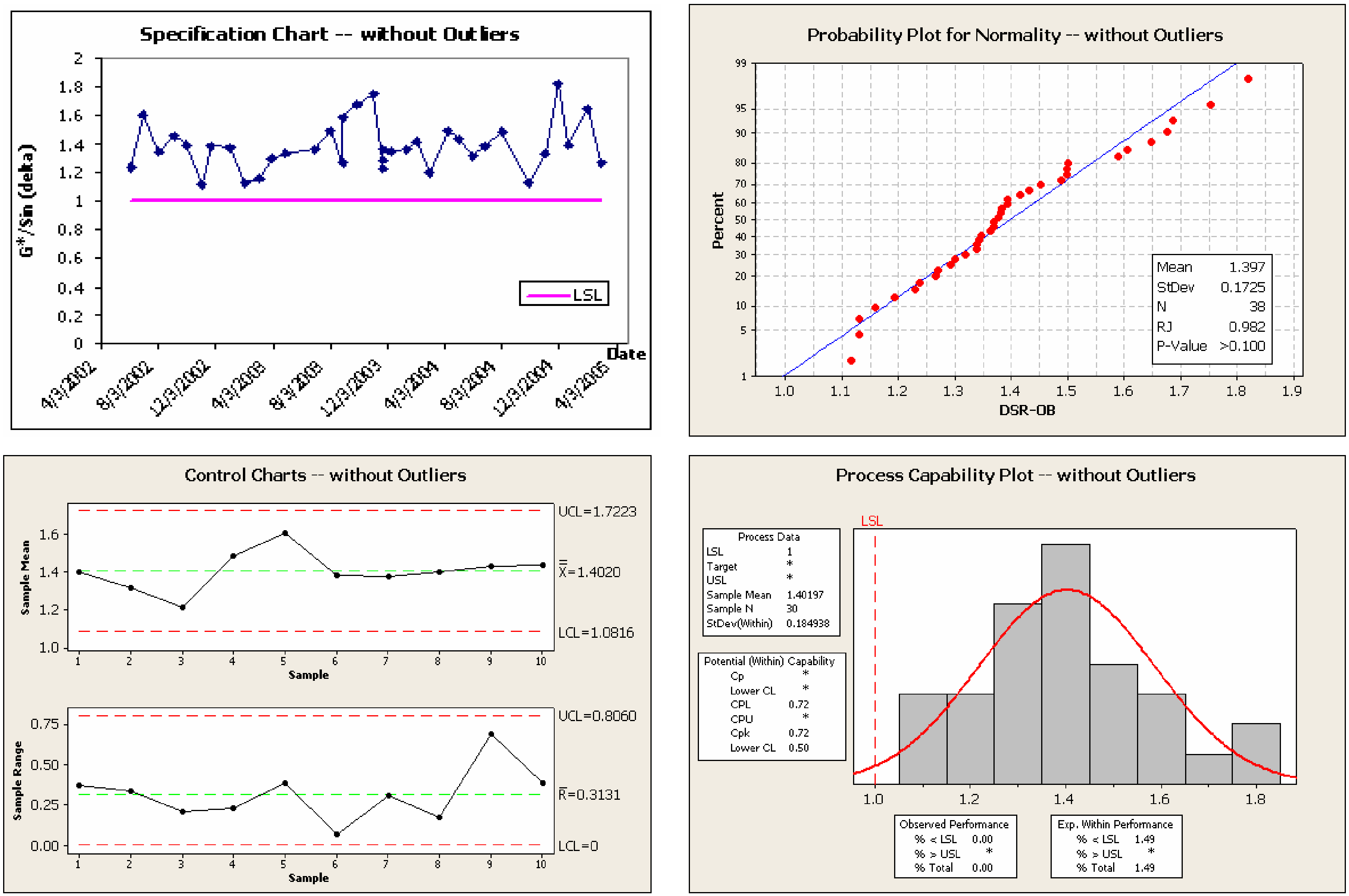


Figure E-161 Statistical Analysis Charts (without Outliers) for Supplier: 1301 Grade: PG 70-22 Test: DSR-OB

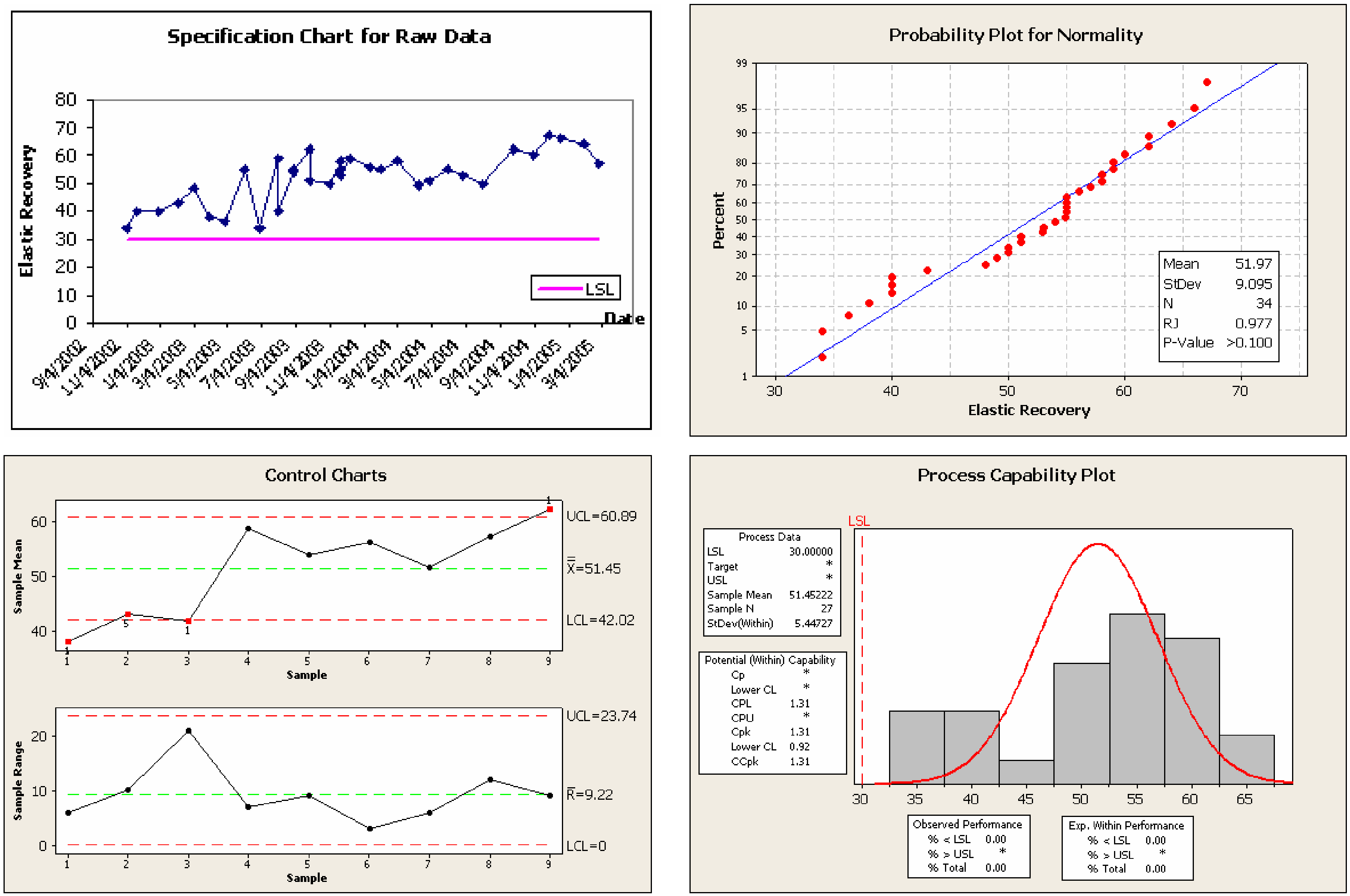


Figure E-162 Statistical Analysis Charts for Supplier: 1301 Grade: PG 70-22 Test: Elastic Recovery

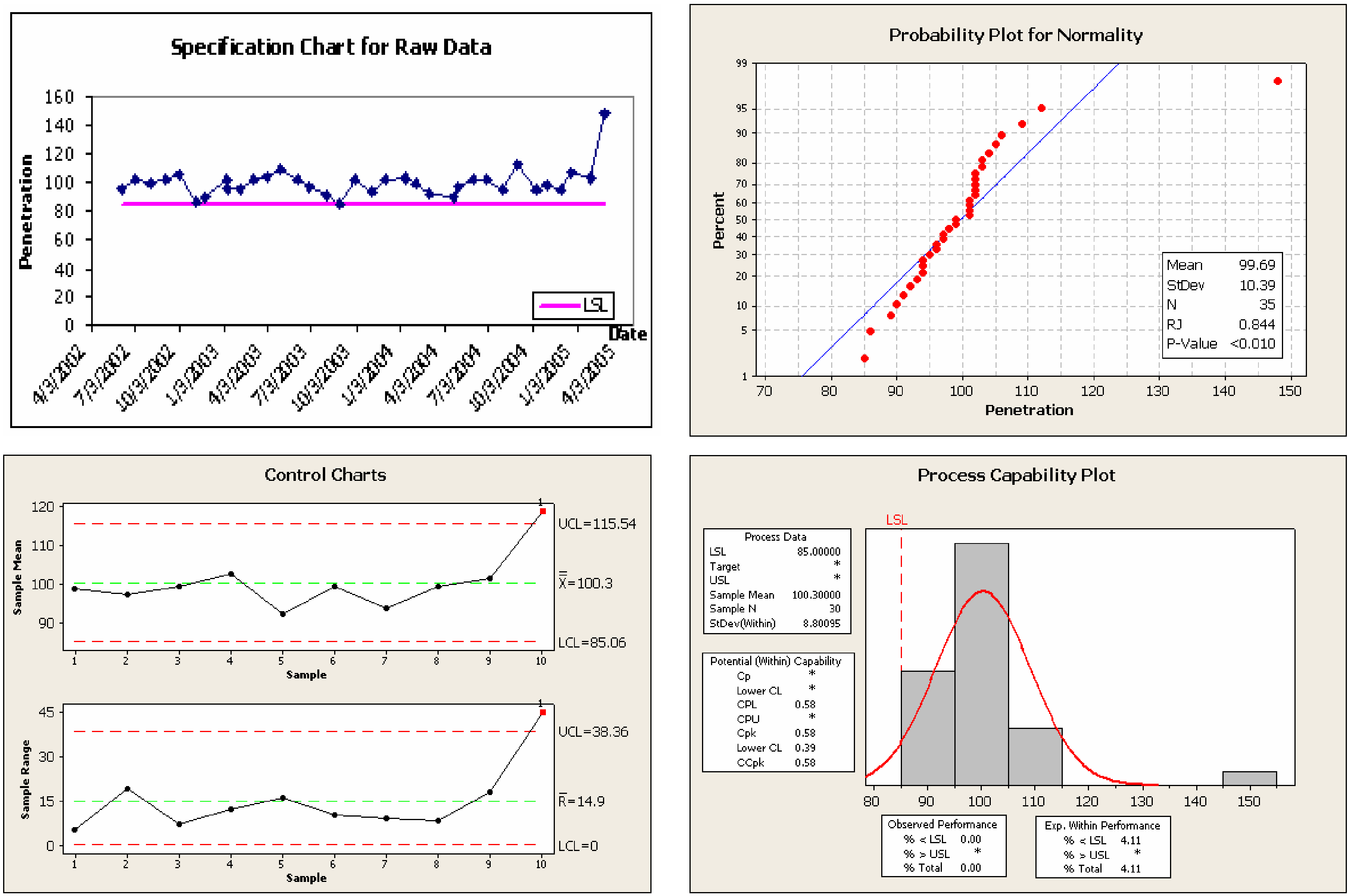


Figure E-163 Statistical Analysis Charts for Supplier: 1301 Grade: AC-10 Test: Penetration

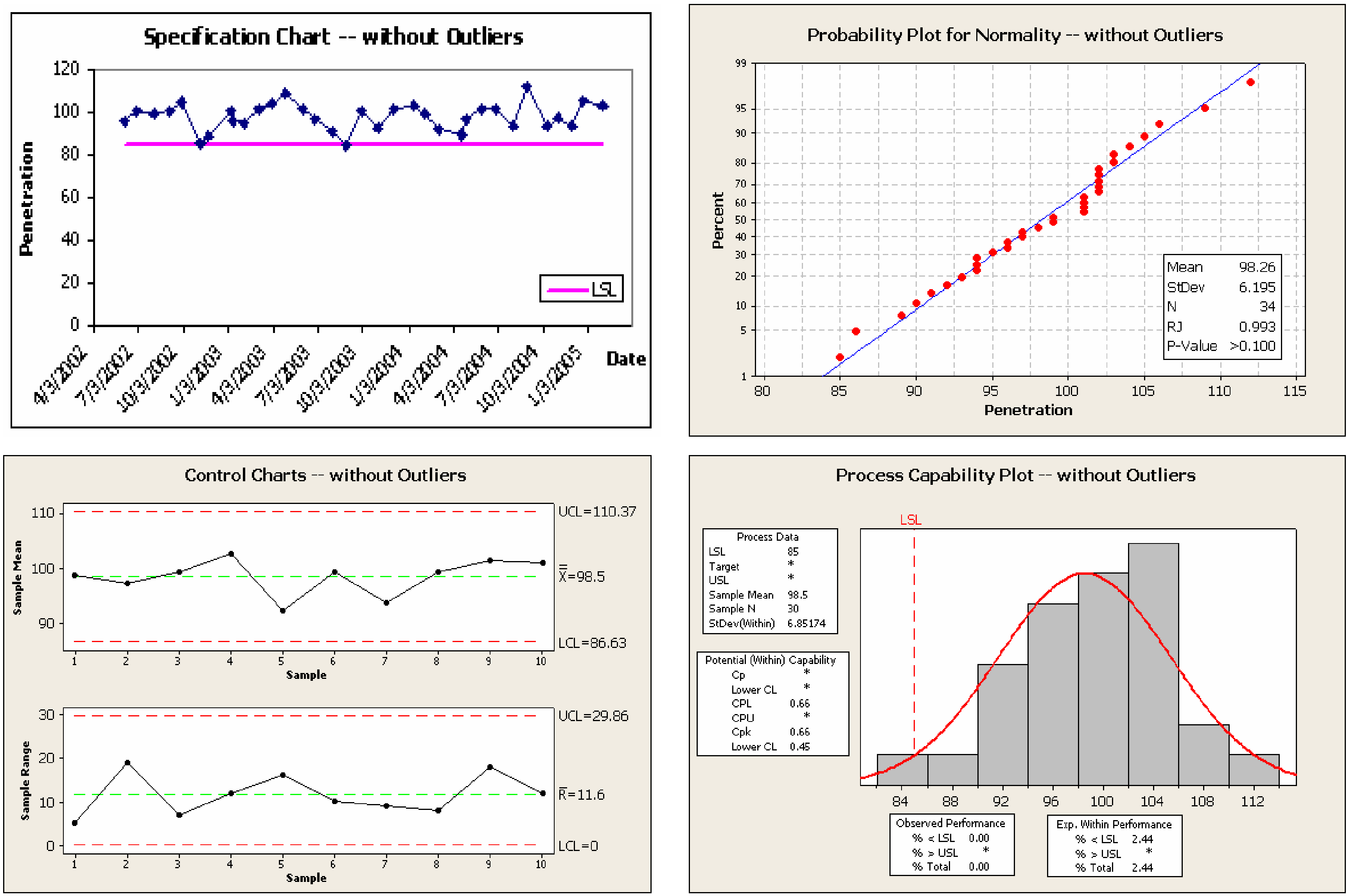


Figure E-164 Statistical Analysis Charts (without Outliers) for Supplier: 1301 Grade: AC-10 Test: Penetration

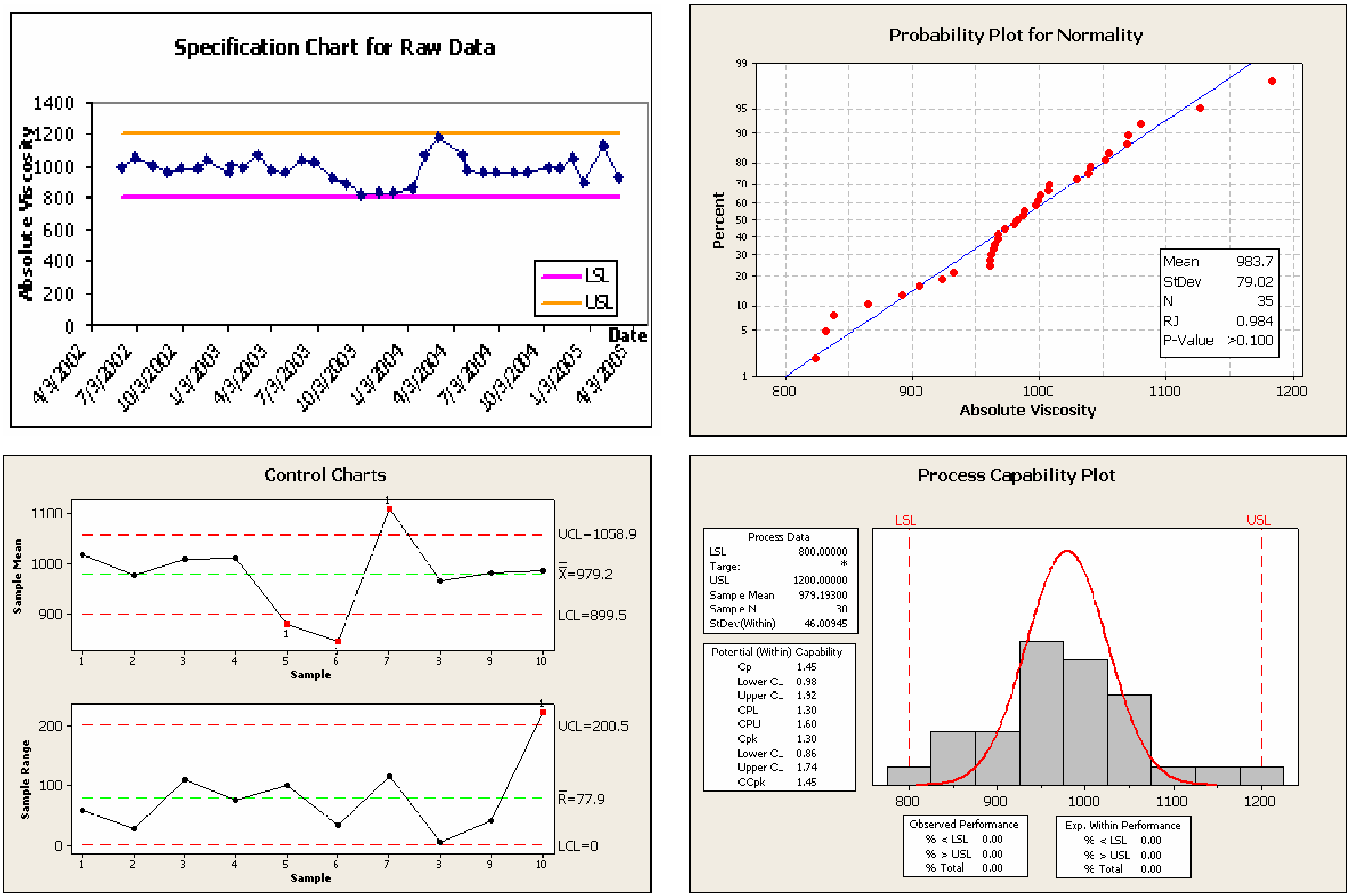


Figure E-165 Statistical Analysis Charts for Supplier: 1301 Grade: AC-10 Test: Absolute Viscosity

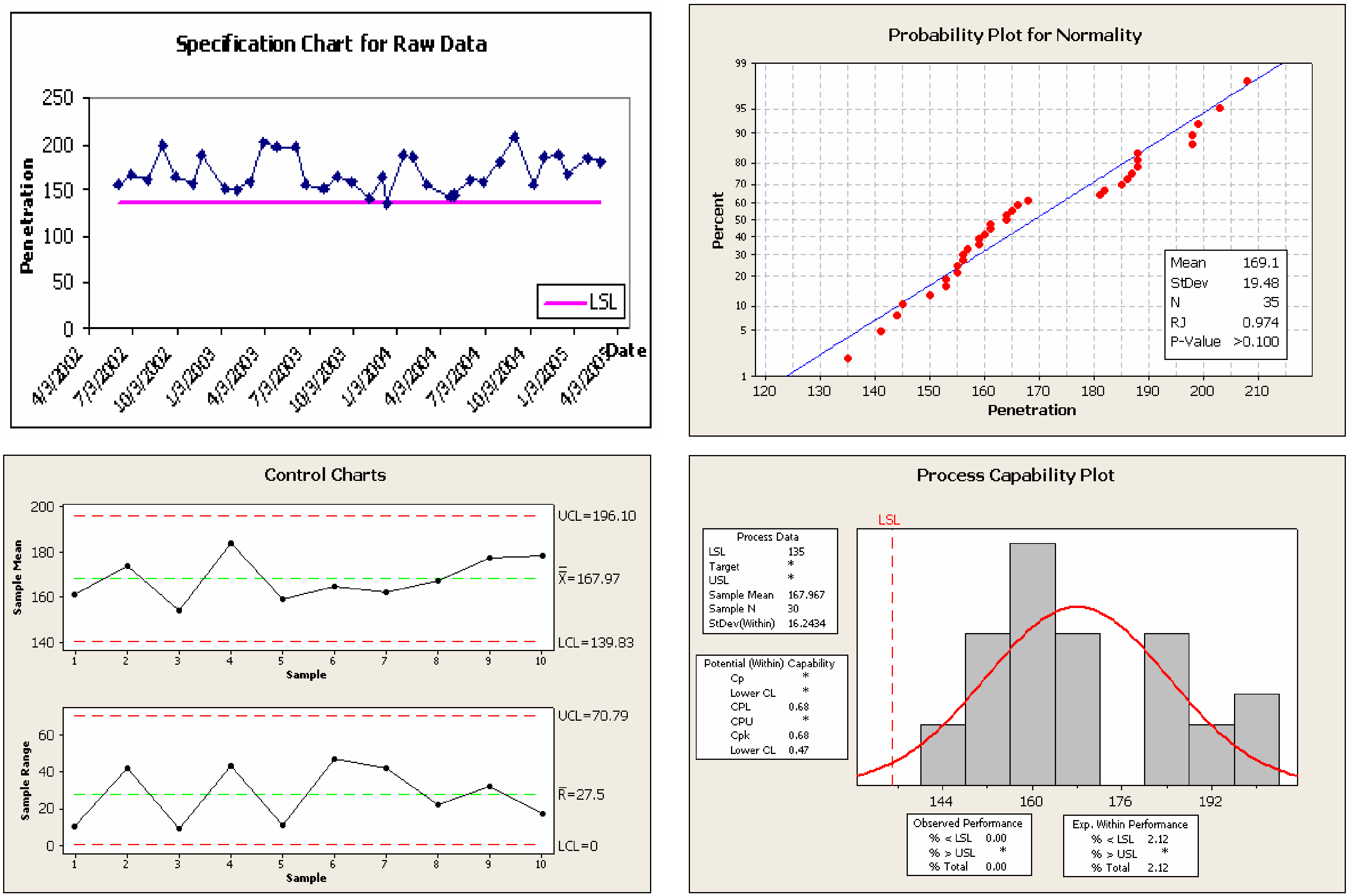
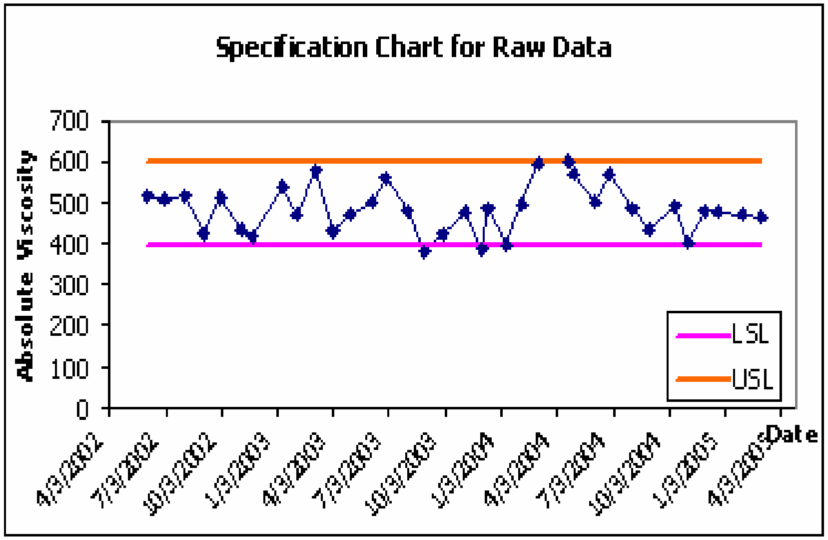
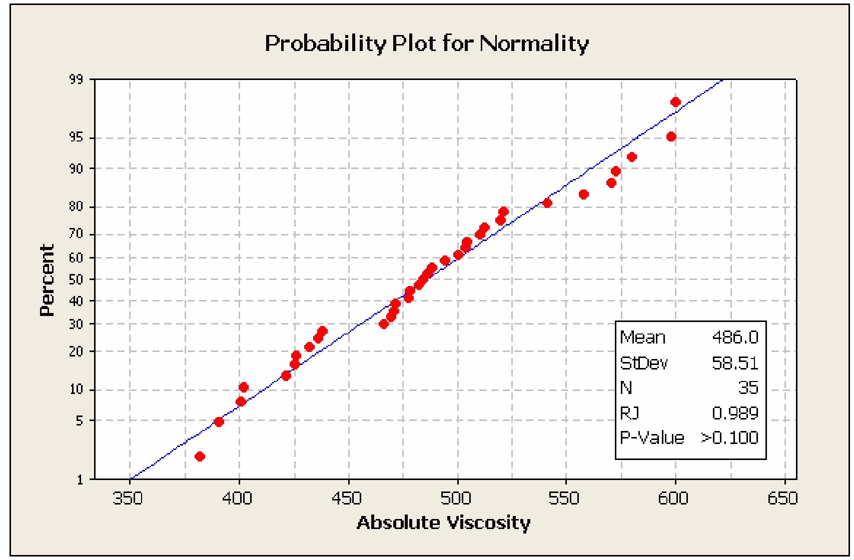
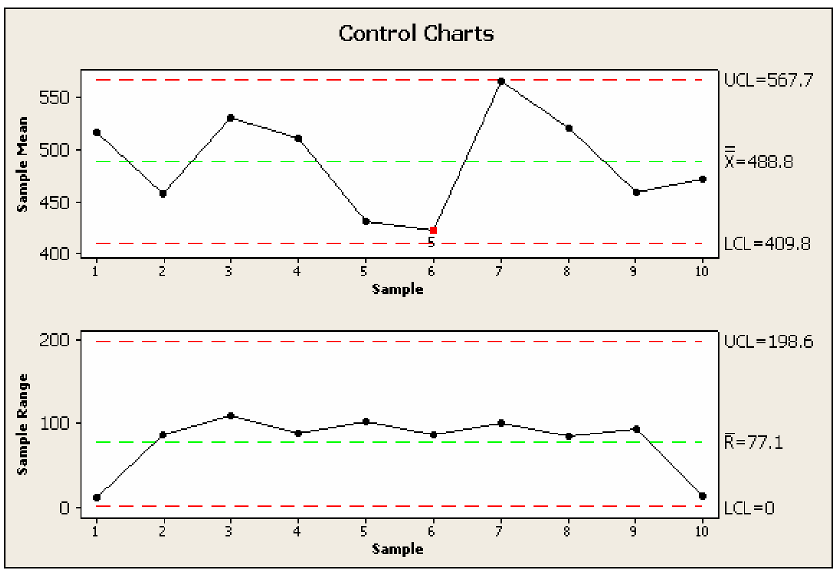


Figure E-166 Statistical Analysis Charts for Supplier: 1301 Grade: AC-5 Test: Penetration







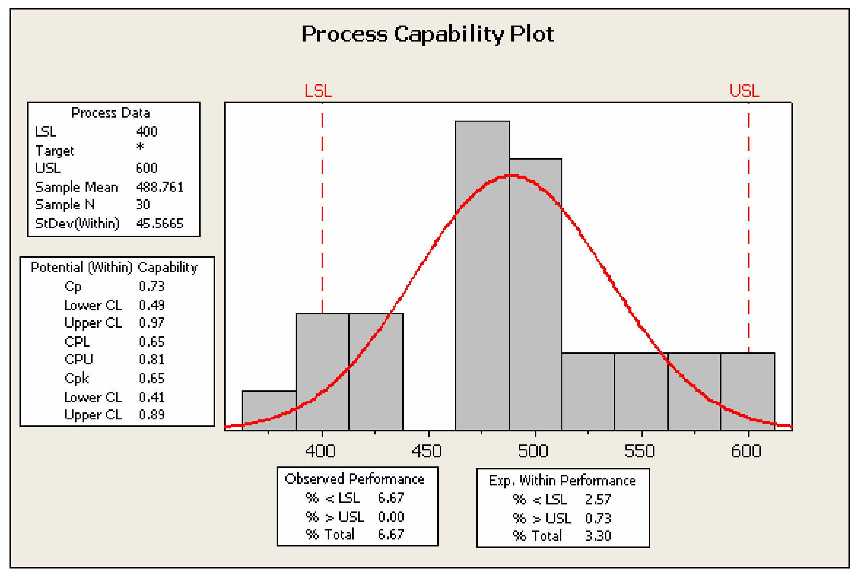


Figure E-167 Statistical Analysis Charts for Supplier: 1301 Grade: AC-5 Test: Absolute Viscosity

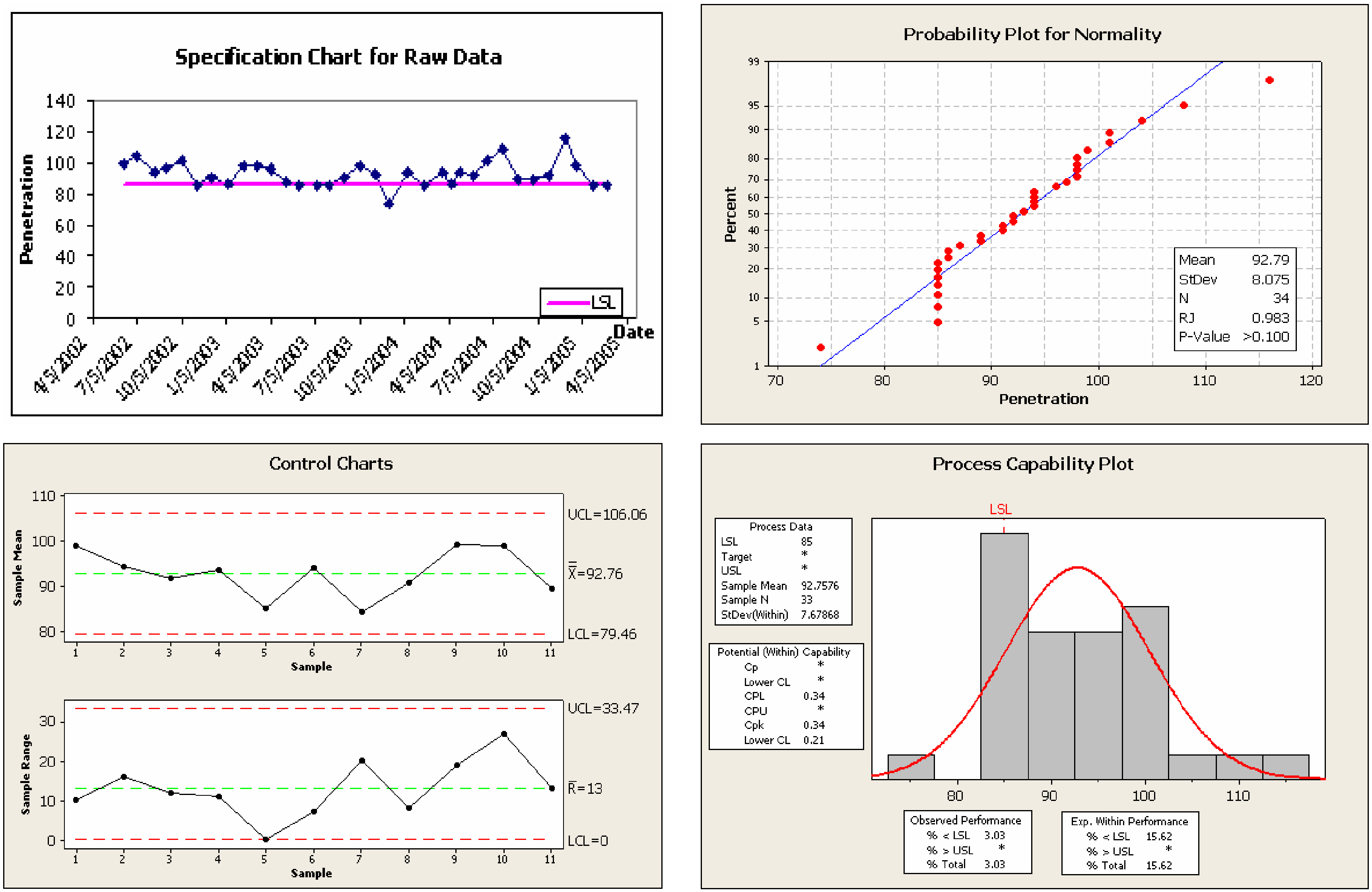


Figure E-168 Statistical Analysis Charts for Supplier: 1302 Grade: AC-10 Test: Penetration

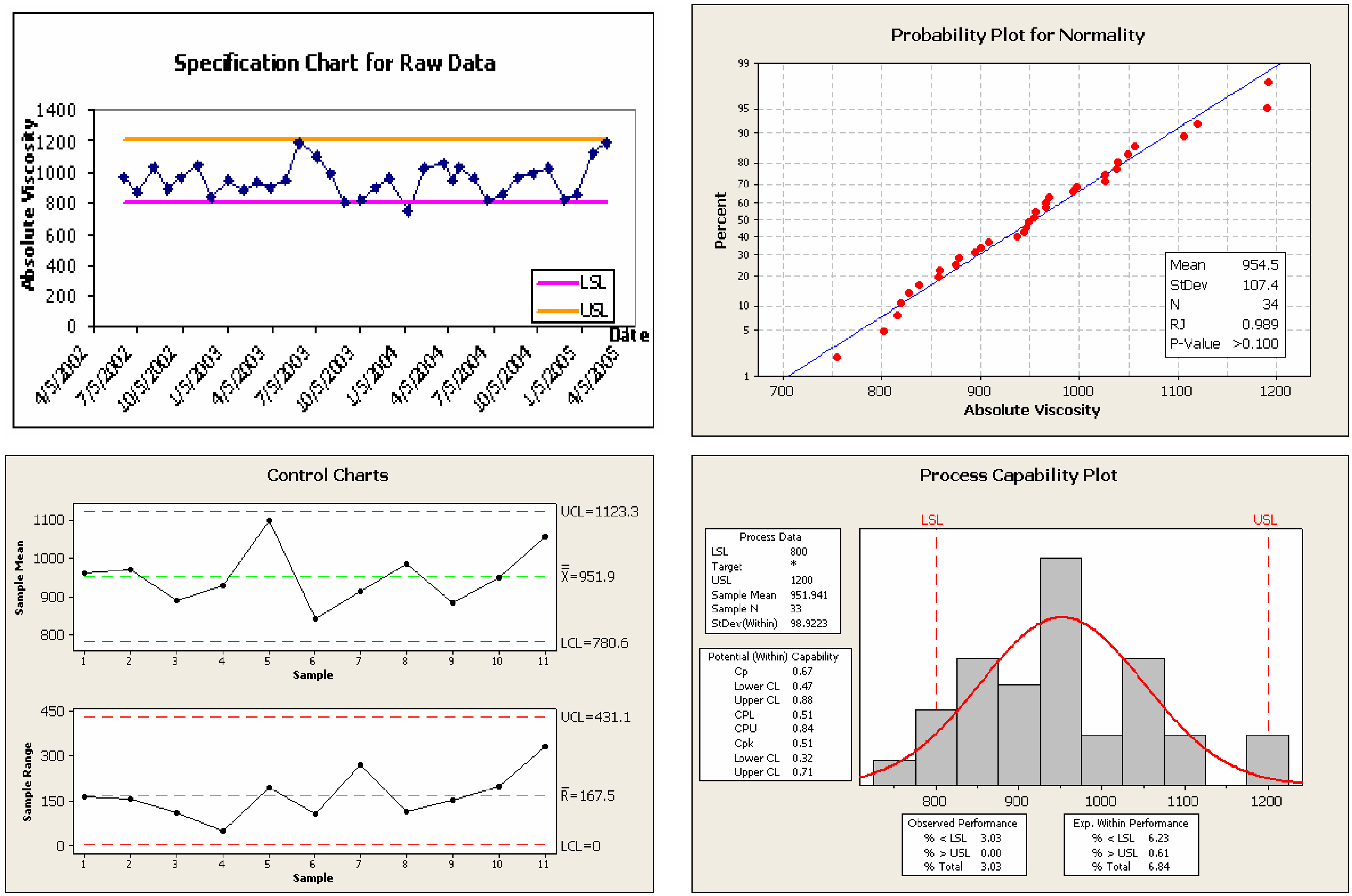


Figure E-169 Statistical Analysis Charts for Supplier: 1302 Grade: AC-10 Test: Absolute Viscosity

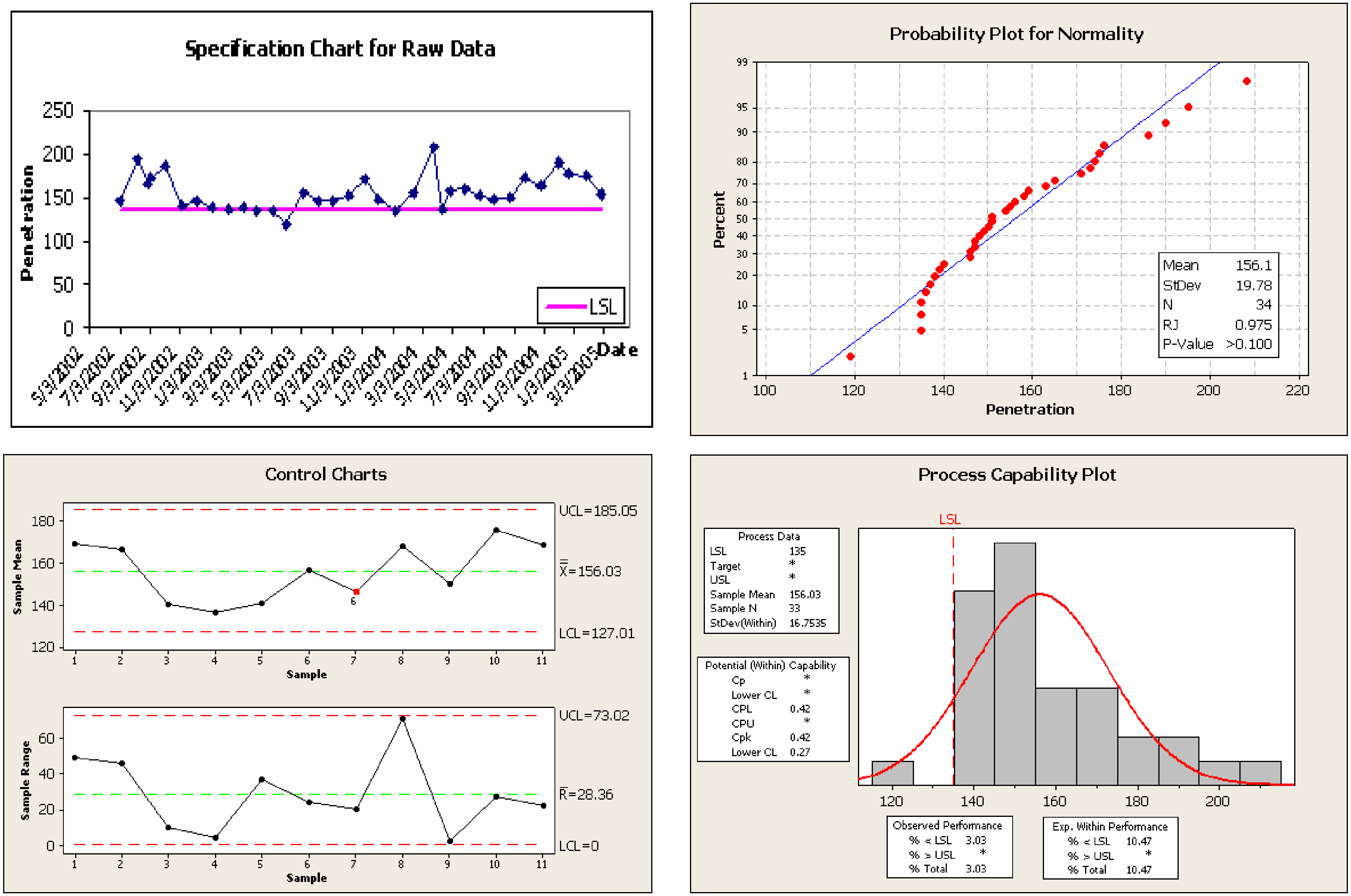


Figure E-170 Statistical Analysis Charts for Supplier: 1302 Grade: AC-5 Test: Penetration

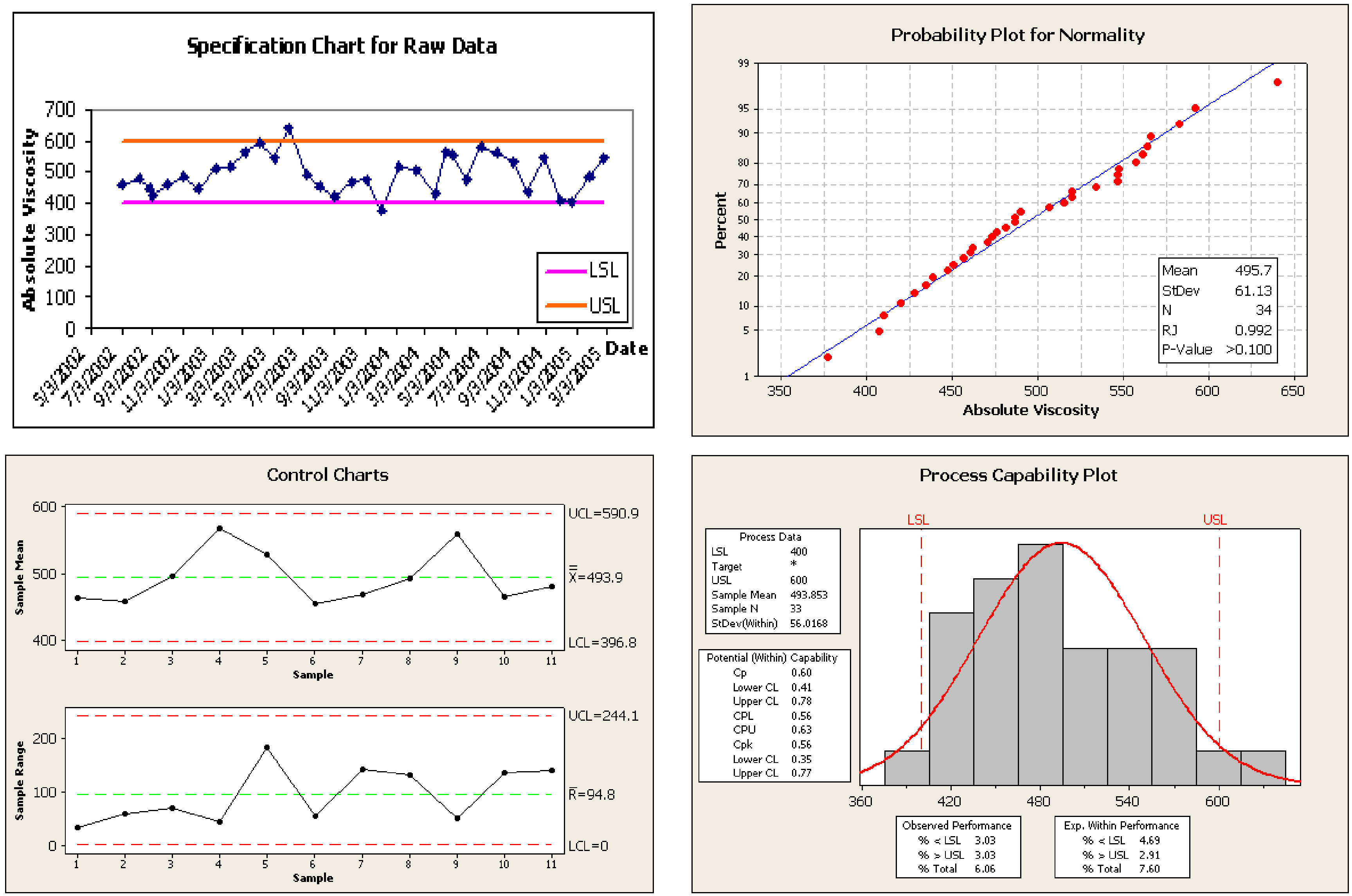


Figure E-171 Statistical Analysis Charts for Supplier: 1302 Grade: AC-5 Test: Absolute Viscosity

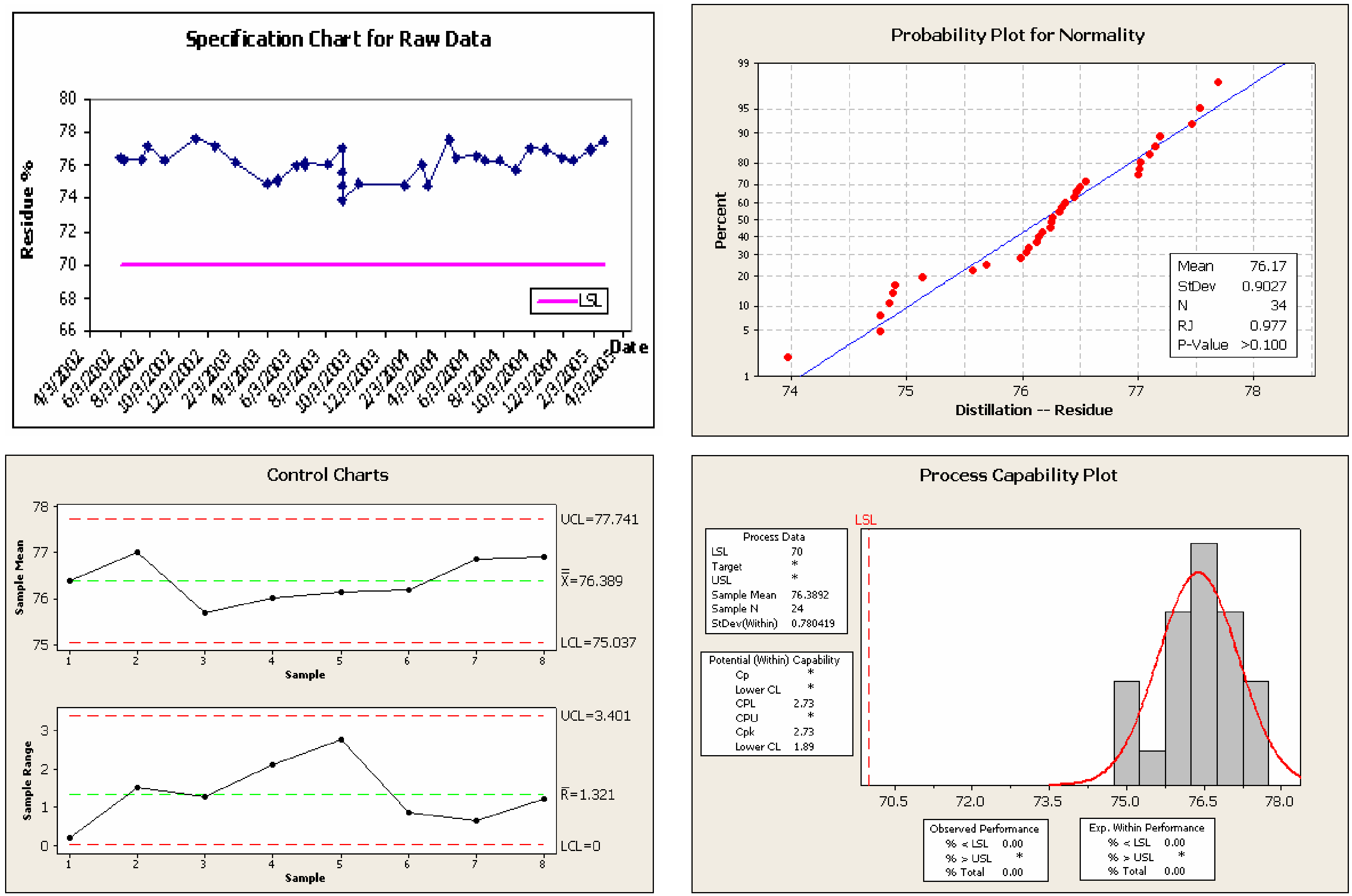


Figure E-172 Statistical Analysis Charts for Supplier: 1302 Grade: RC-250 Test: Distillation-Residue

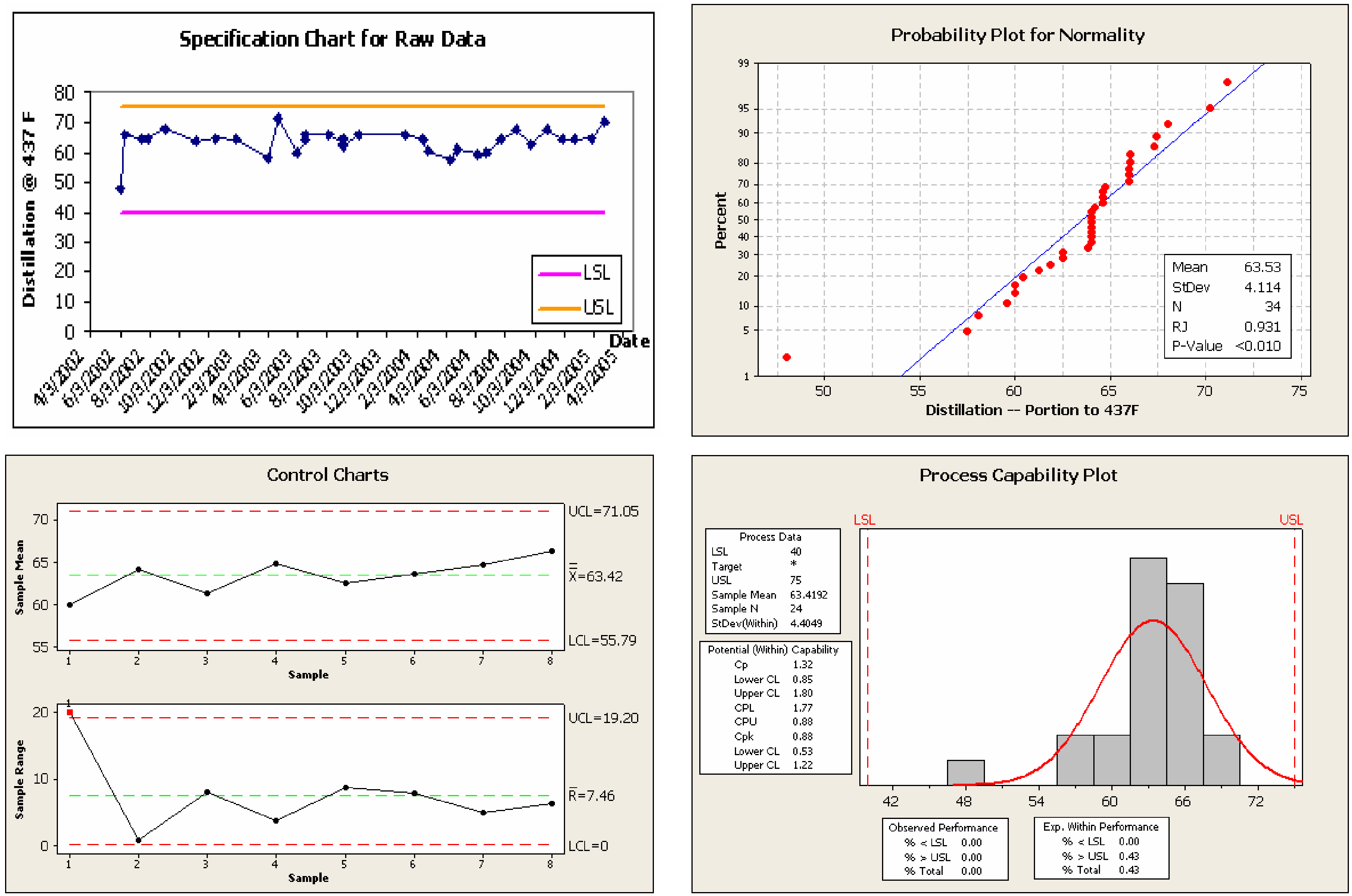


Figure E-173 Statistical Analysis Charts for Supplier: 1302 Grade: RC-250 Test: Distillation @ 437|F

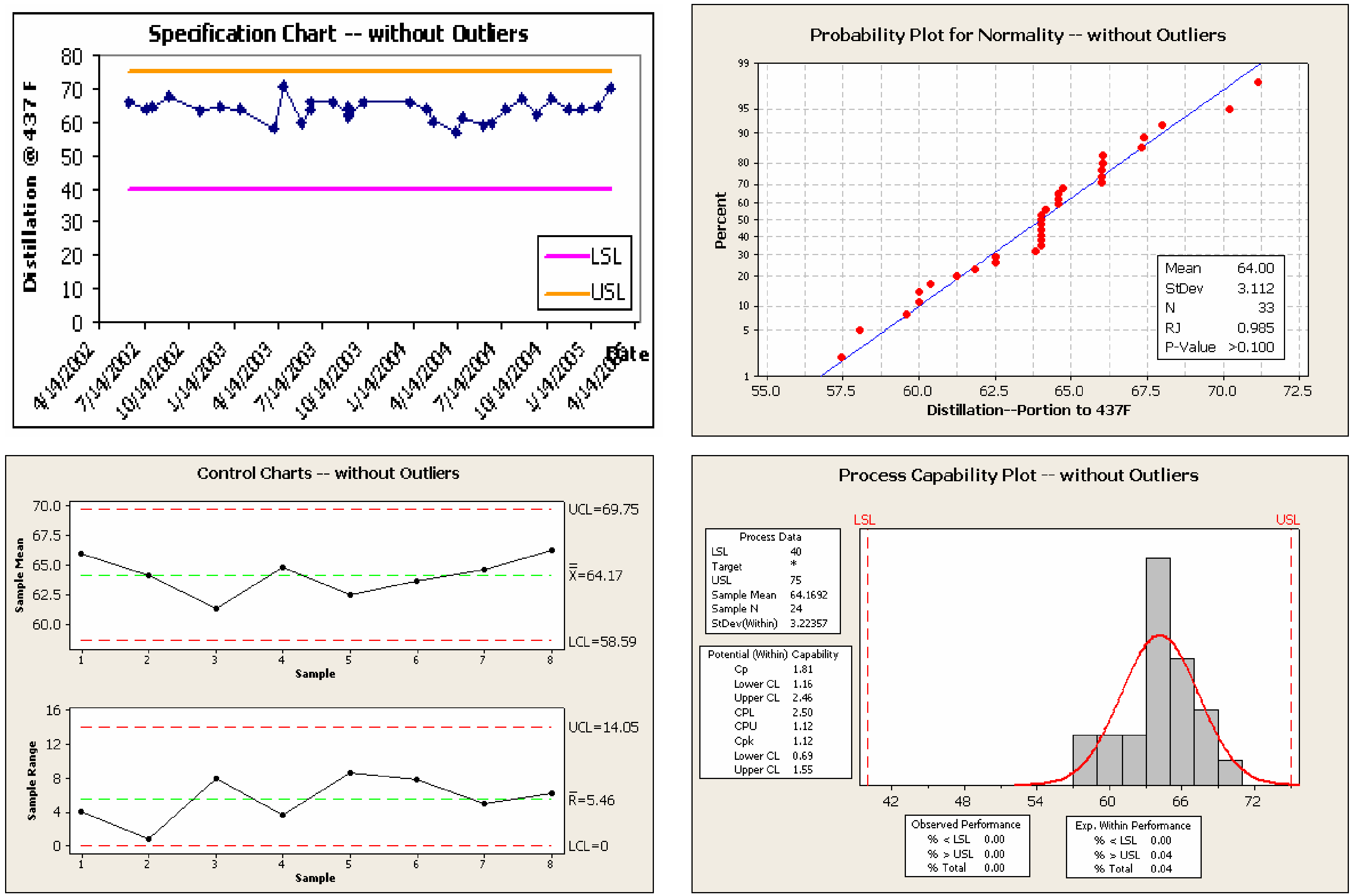


Figure E-174 Statistical Analysis Charts (without Outliers) for Supplier: 1302 Grade: RC-250 Test: Distillation @ 437|F

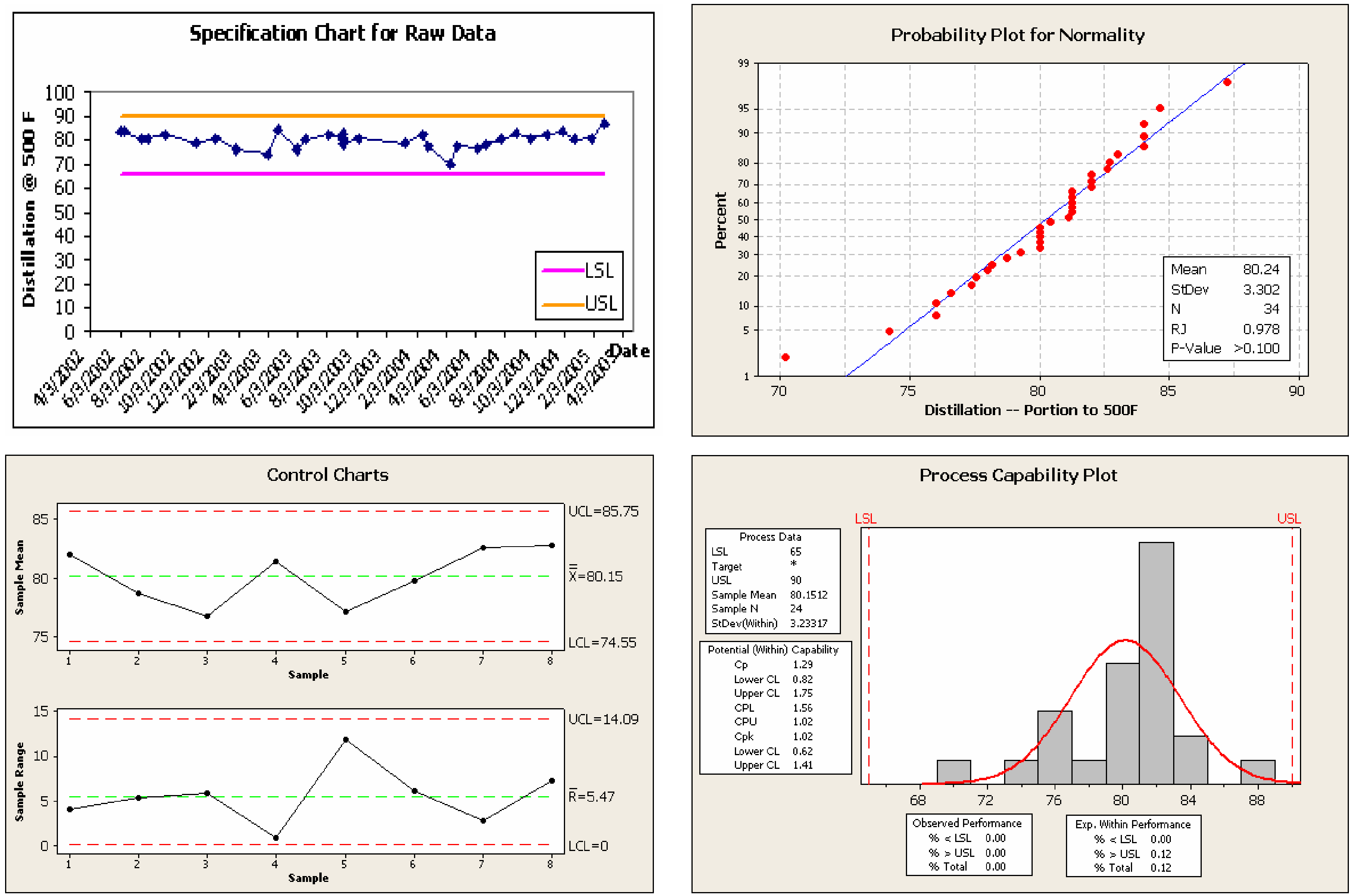


Figure E-175 Statistical Analysis Charts for Supplier: 1302 Grade: RC-250 Test: Distillation @ 500|F

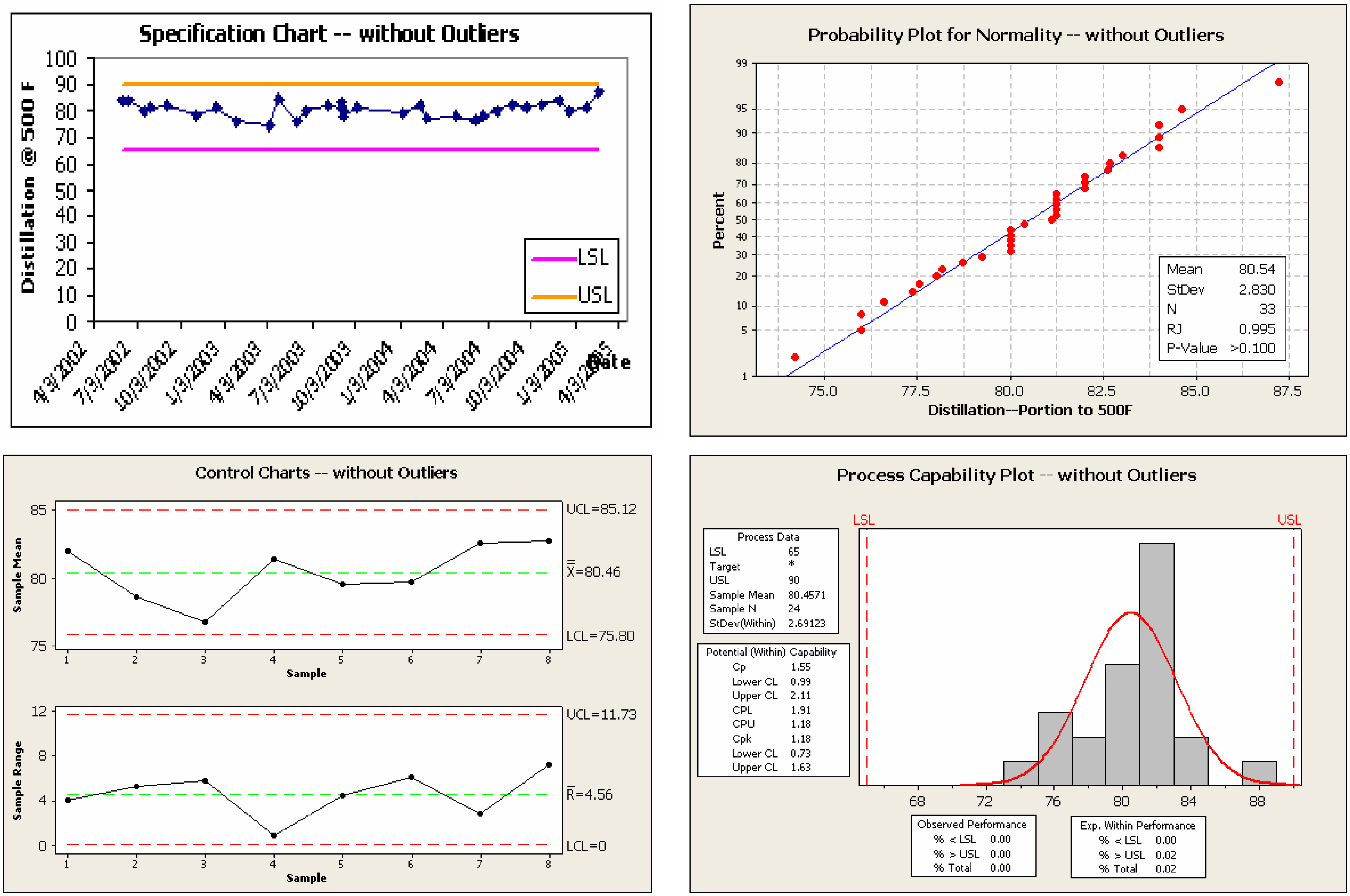


Figure E-176 Statistical Analysis Charts (without Outliers) for Supplier: 1302 Grade: RC-250 Test: Distillation @ 500|F

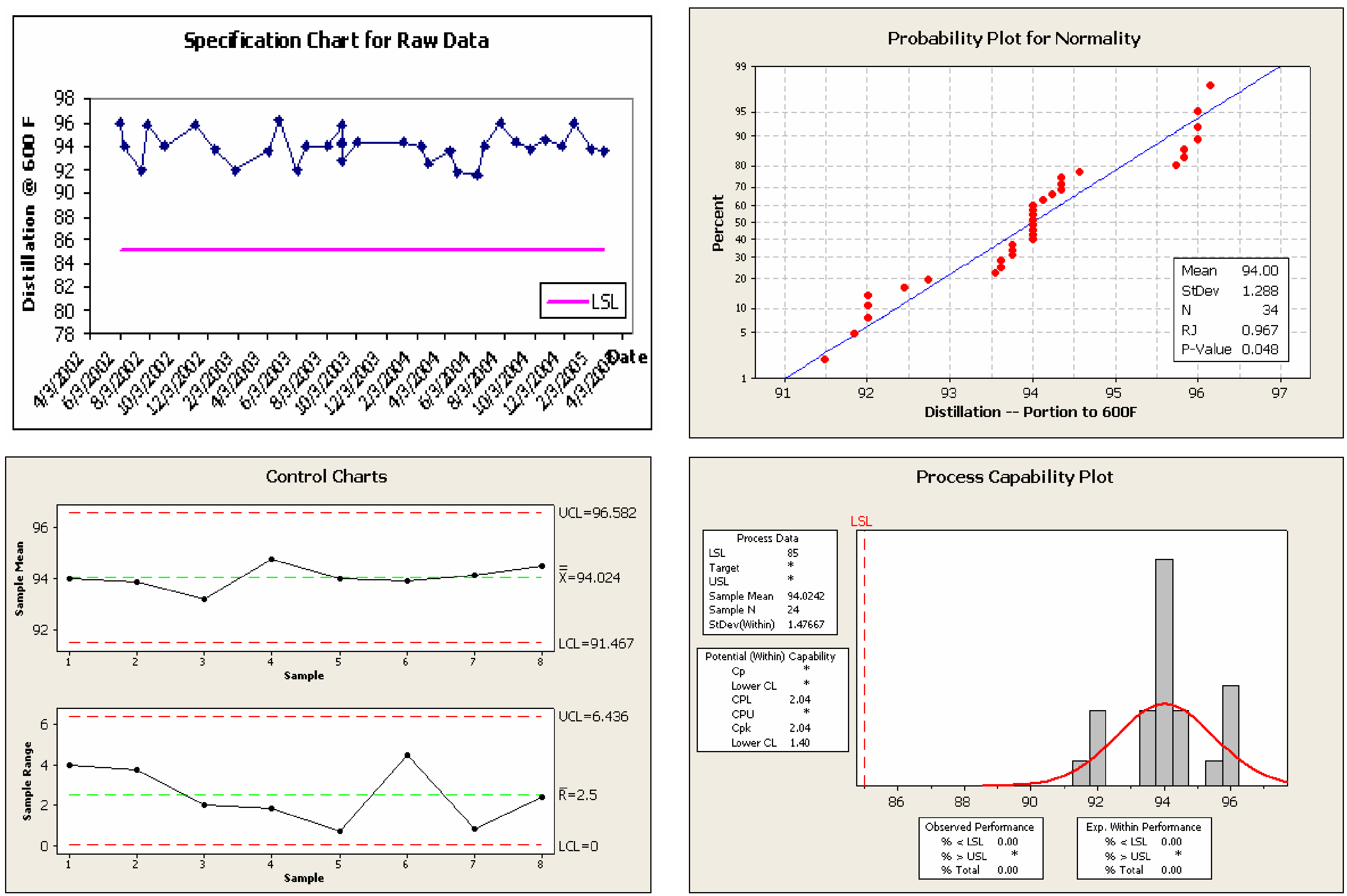


Figure E-177 Statistical Analysis Charts for Supplier: 1302 Grade: RC-250 Test: Distillation @ 600|F

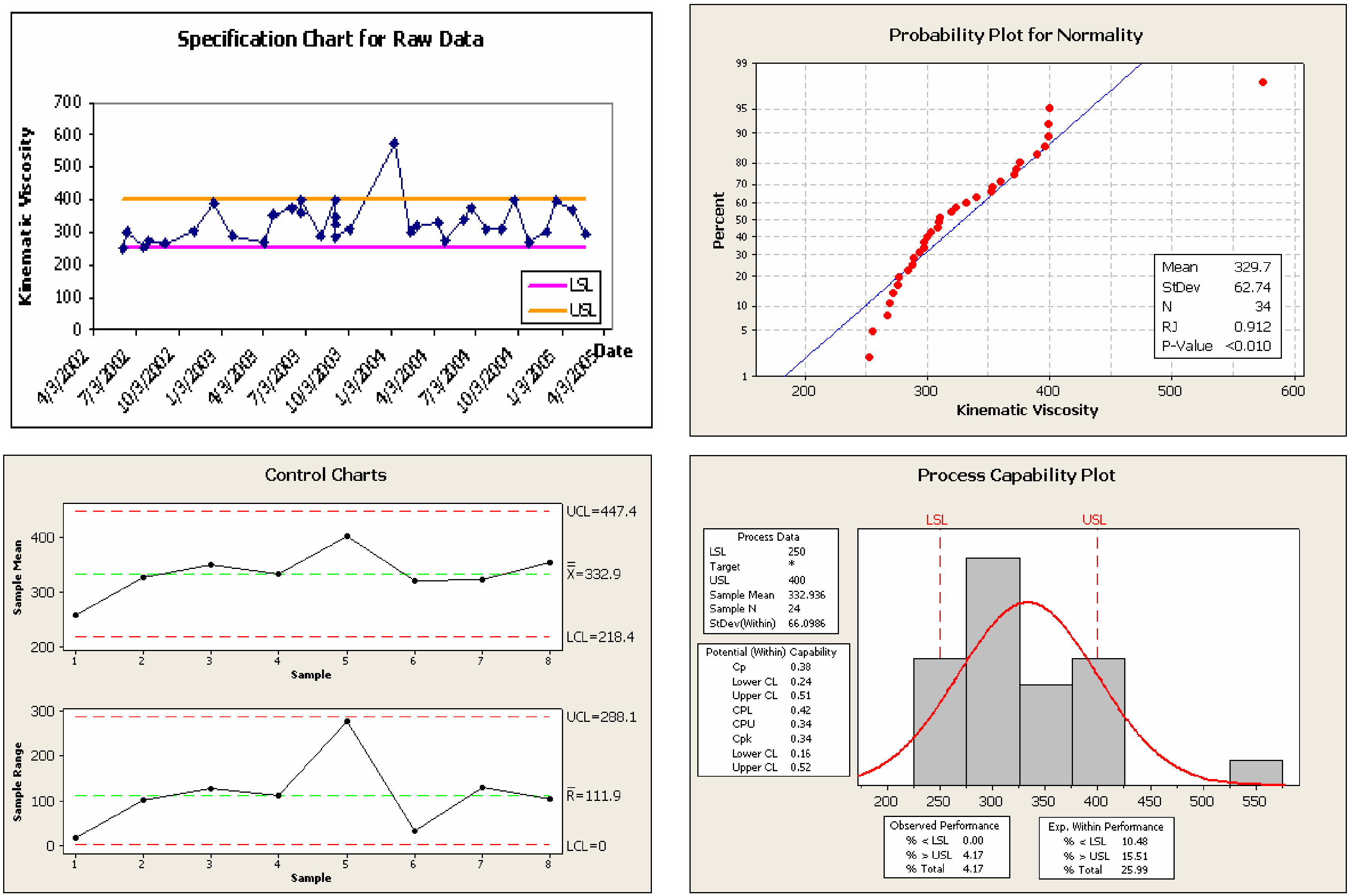


Figure E-178 Statistical Analysis Charts for Supplier: 1302 Grade: RC-250 Test: Kinematic Viscosity

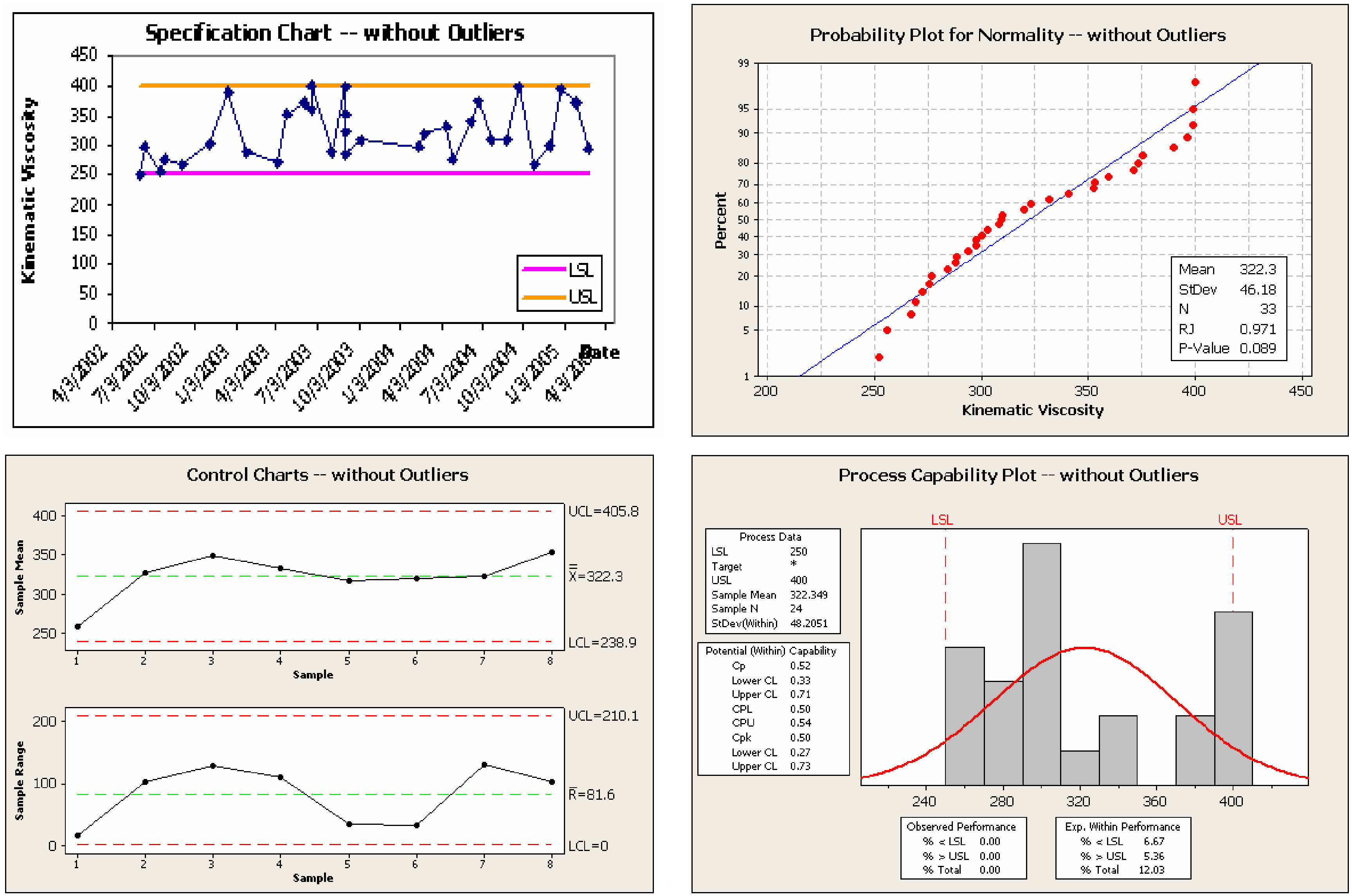


Figure E-179 Statistical Analysis Charts (without Outliers) for Supplier: 1302 Grade: RC-250 Test: Kinematic Viscosity

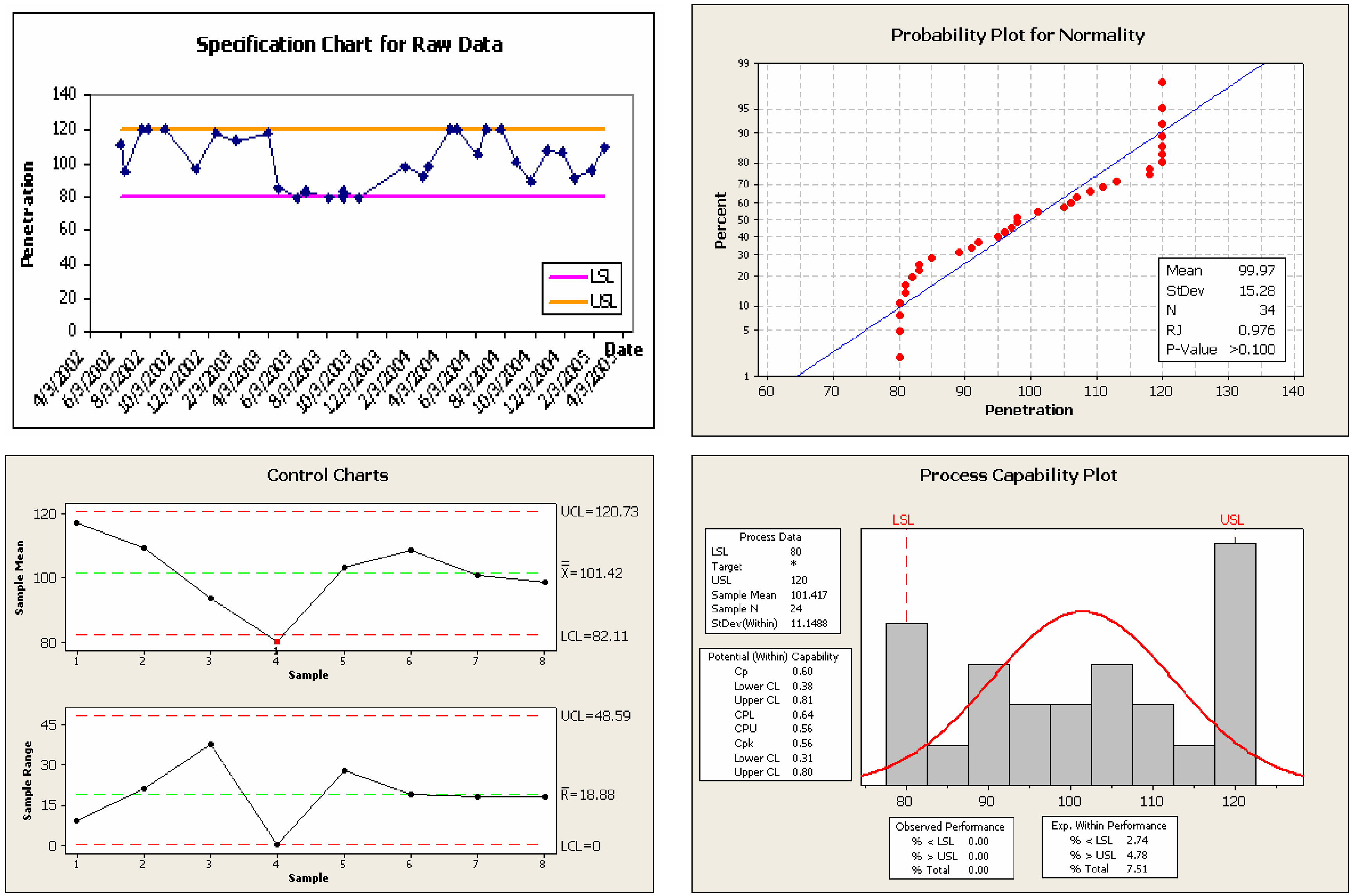


Figure E-180 Statistical Analysis Charts for Supplier: 1302 Grade: RC-250 Test: Penetration

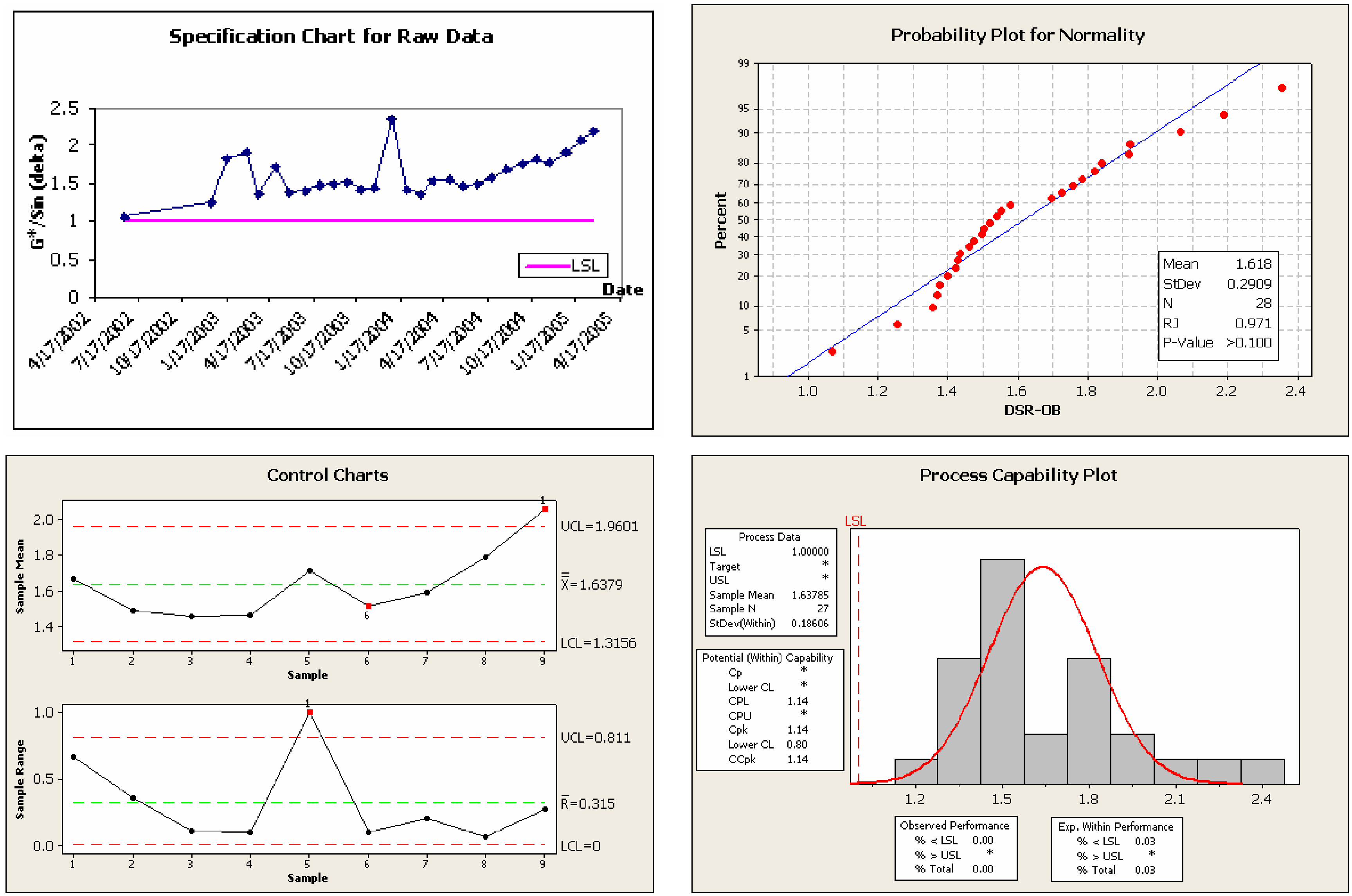


Figure E-181 Statistical Analysis Charts for Supplier: 1401 Grade: PG 70-22 Test: DSR-OB

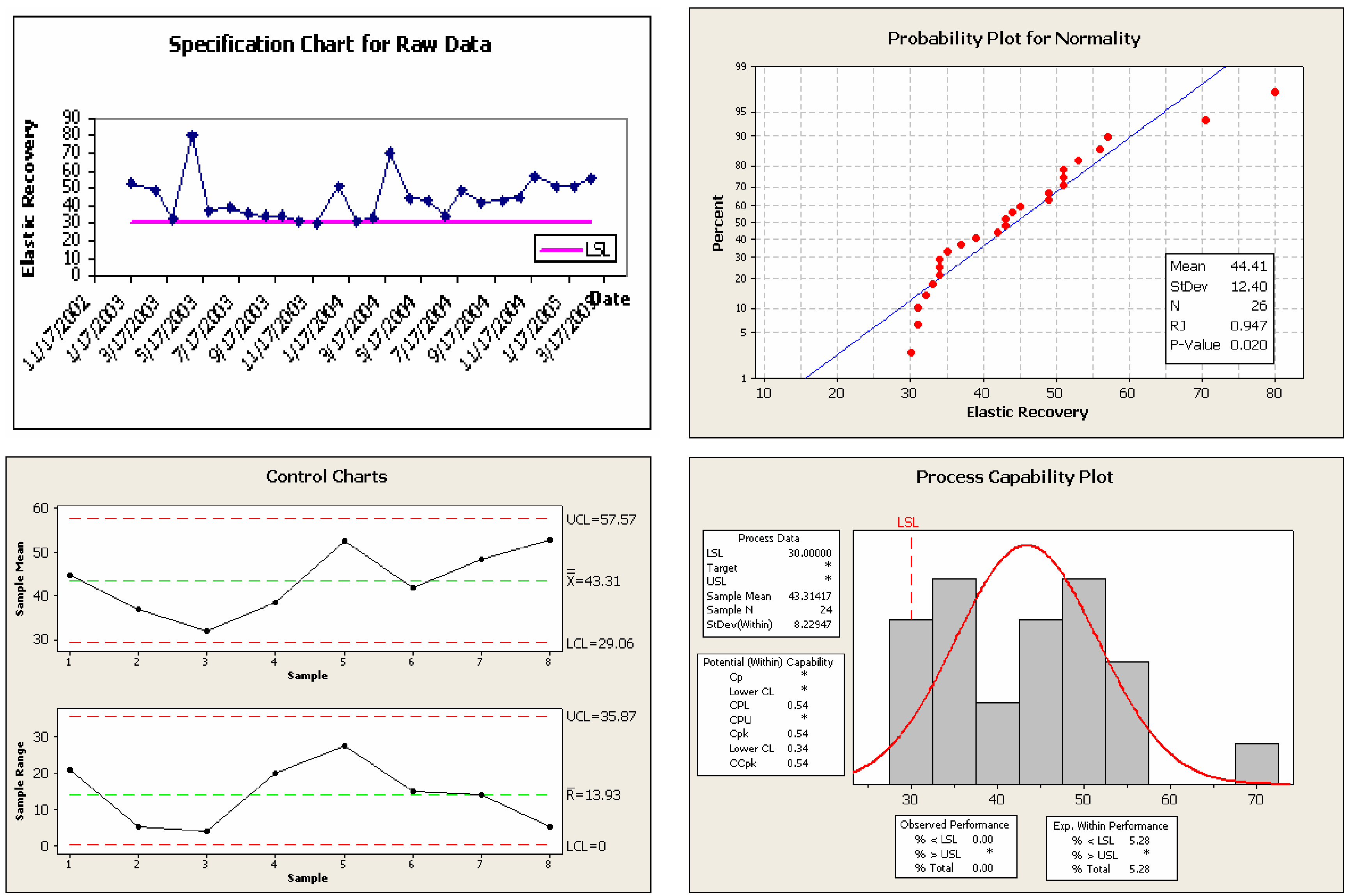
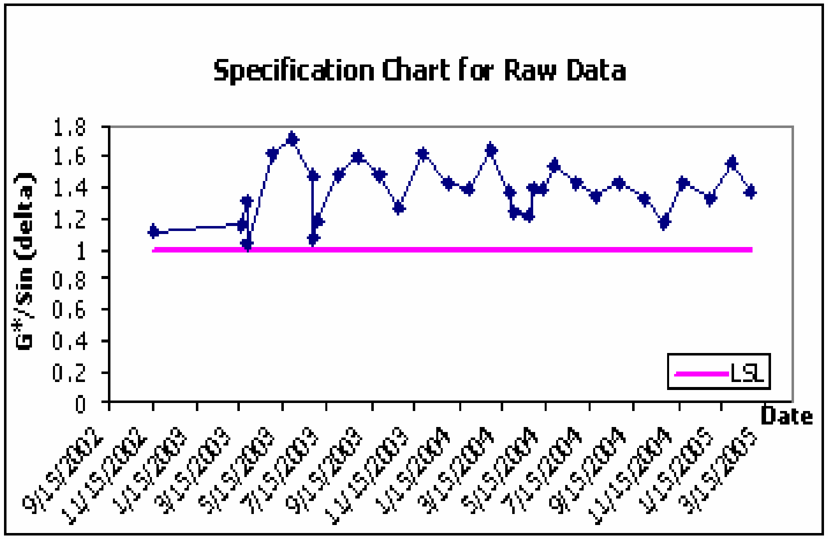
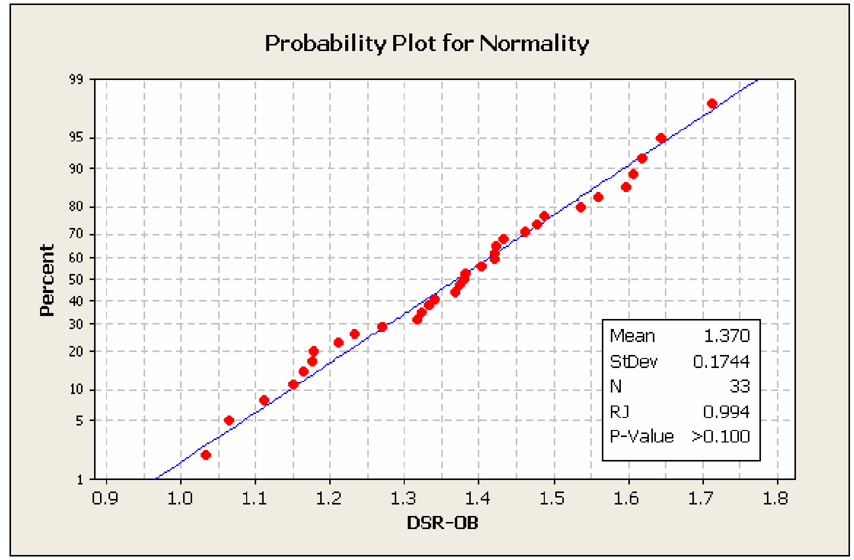
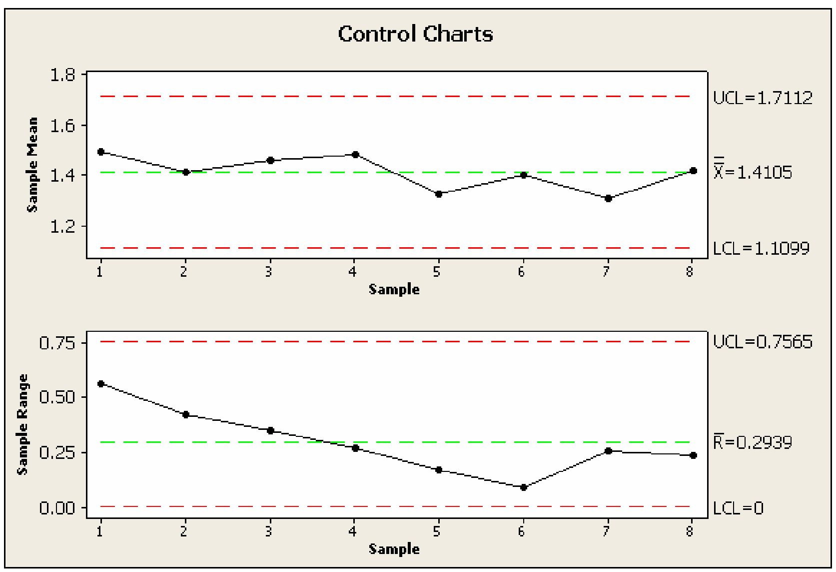


Figure E-182 Statistical Analysis Charts for Supplier: 1401 Grade: PG 70-22 Test: Elastic Recovery







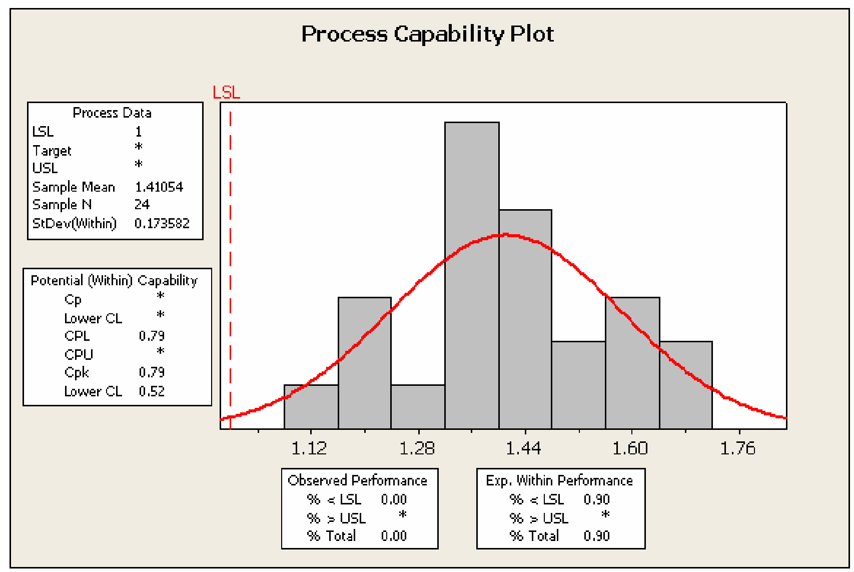


Figure E-183 Statistical Analysis Charts for Supplier: 1401 Grade: PG 76-22 Test: DSR-OB

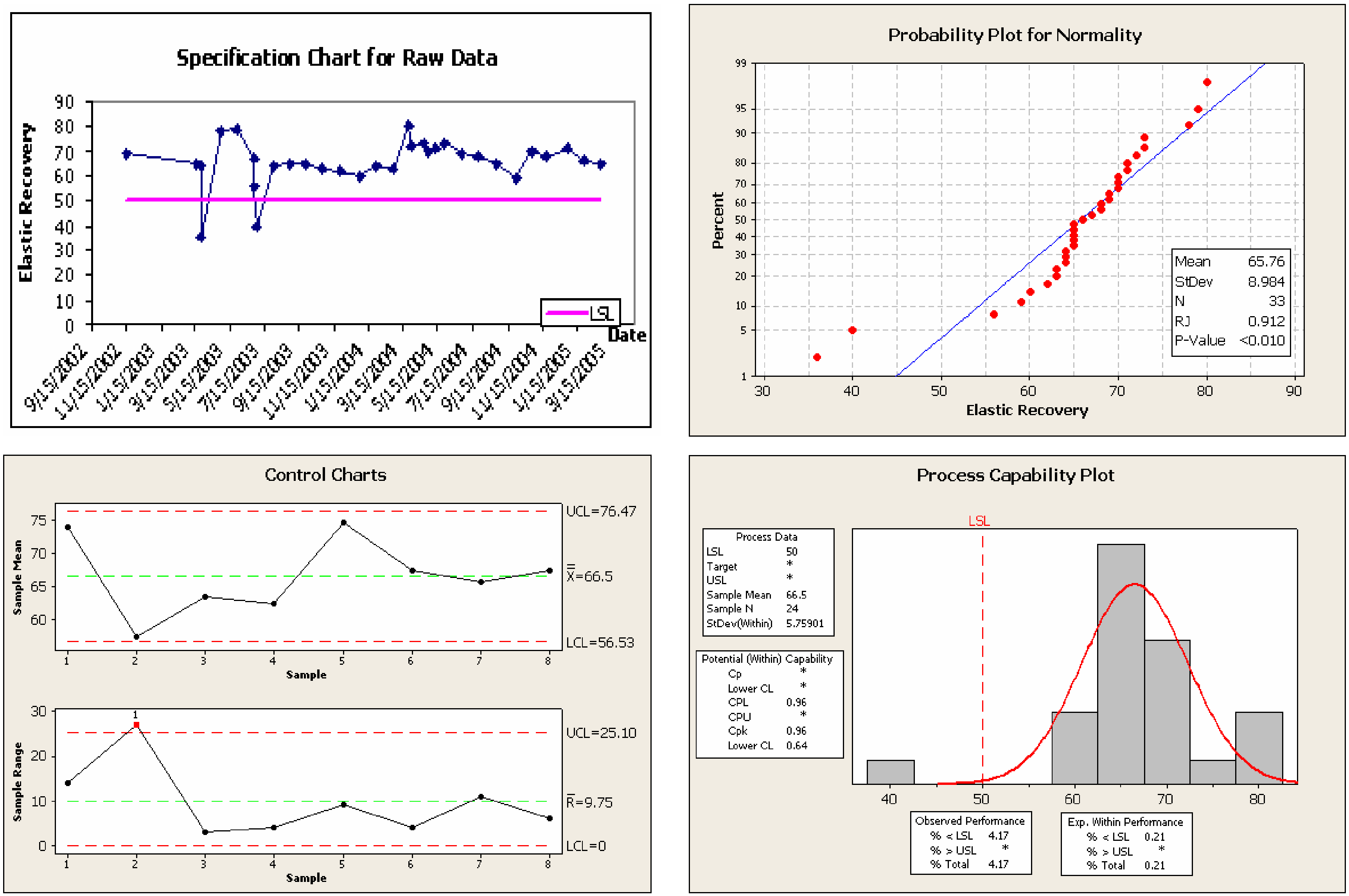


Figure E-184 Statistical Analysis Charts for Supplier: 1401 Grade: PG 76-22 Test: Elastic Recovery

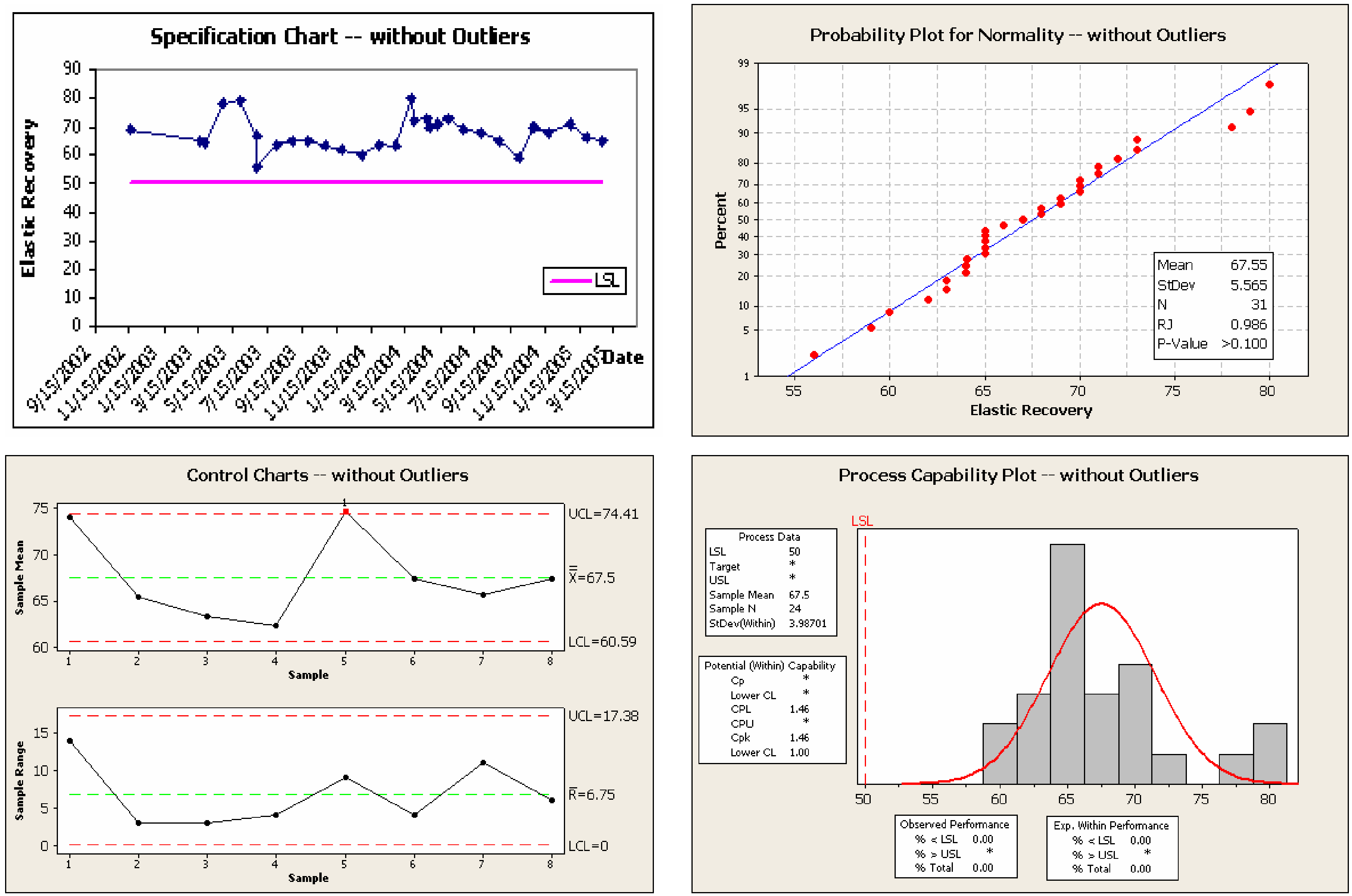


Figure E-185 Statistical Analysis Charts (without Outliers) for Supplier: 1401 Grade: PG 76-22 Test: Elastic Recovery

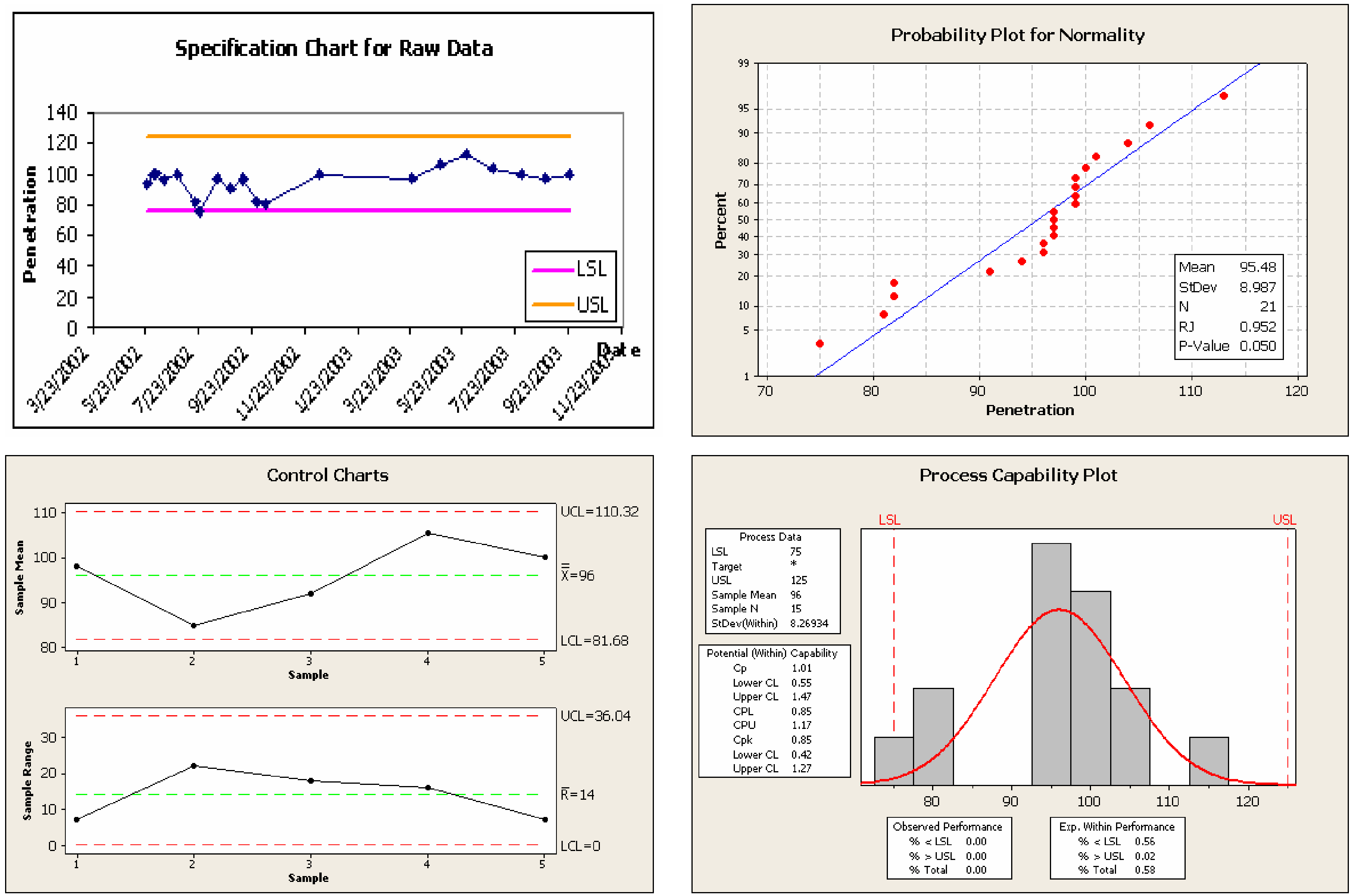


Figure E-186 Statistical Analysis Charts for Supplier: 1401 Grade: AC-15-5TR Test: Penetration

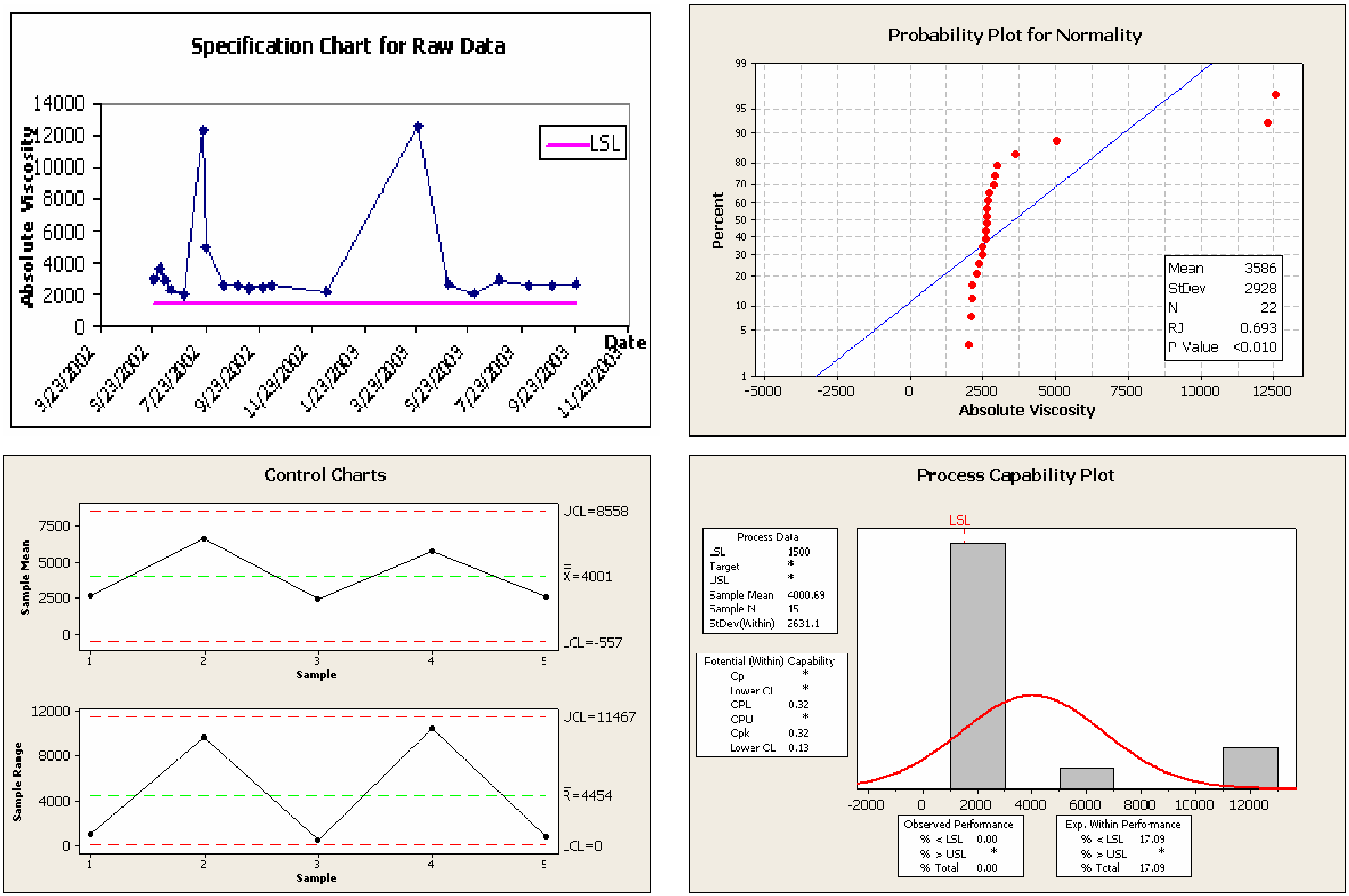


Figure E-187 Statistical Analysis Charts for Supplier: 1401 Grade: AC-15-5TR Test: Absolute Viscosity

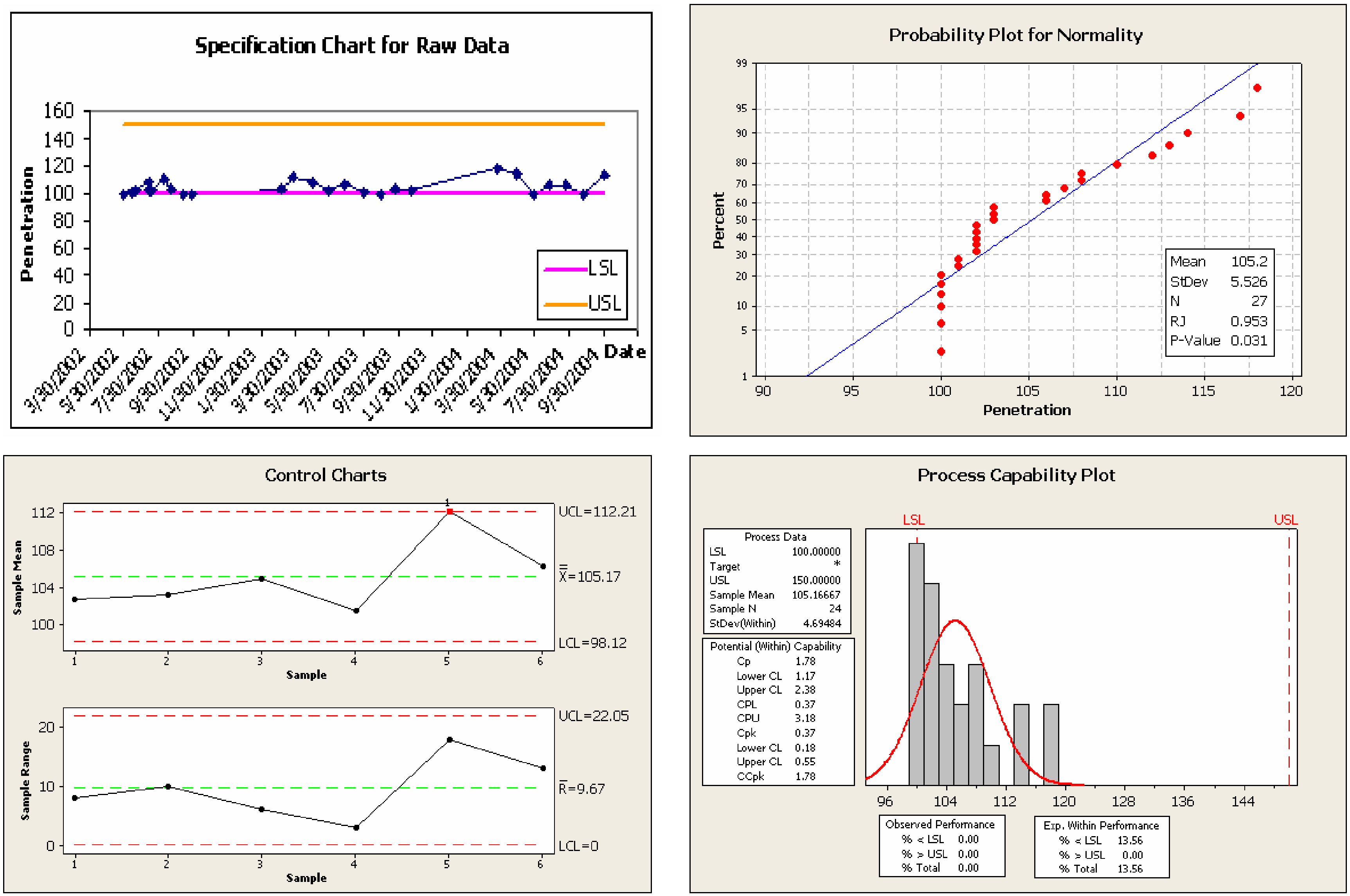


Figure E-188 Statistical Analysis Charts for Supplier: 1401 Grade: AC-15P Test: Penetration

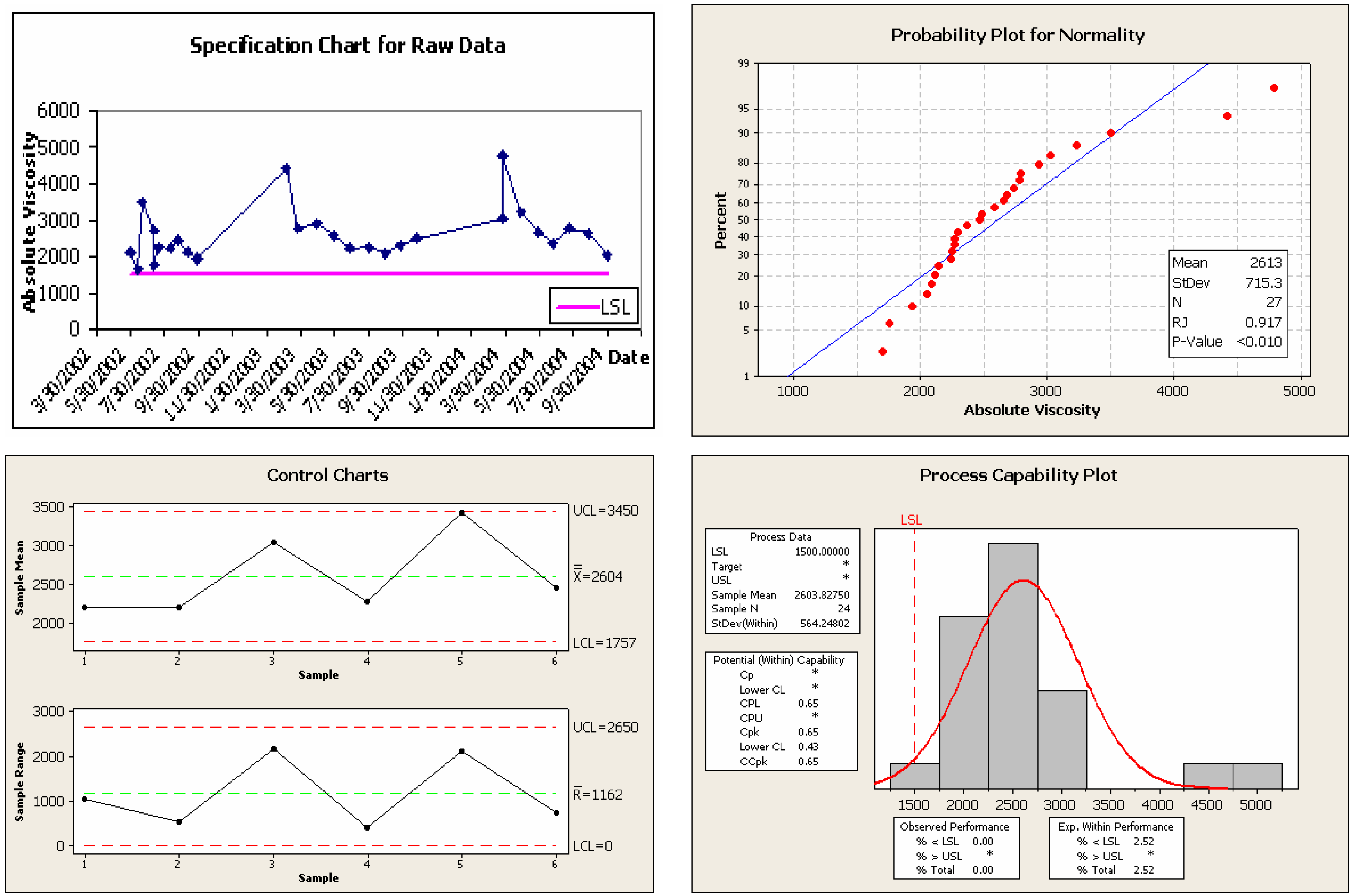
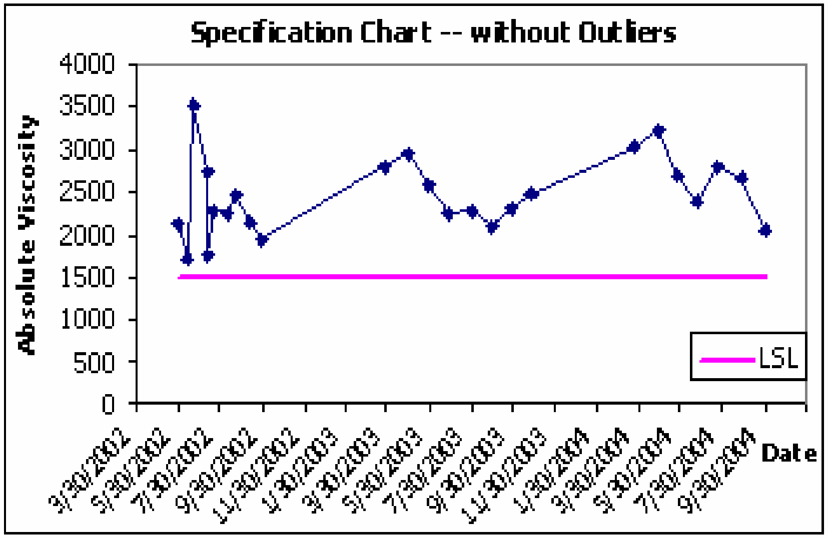
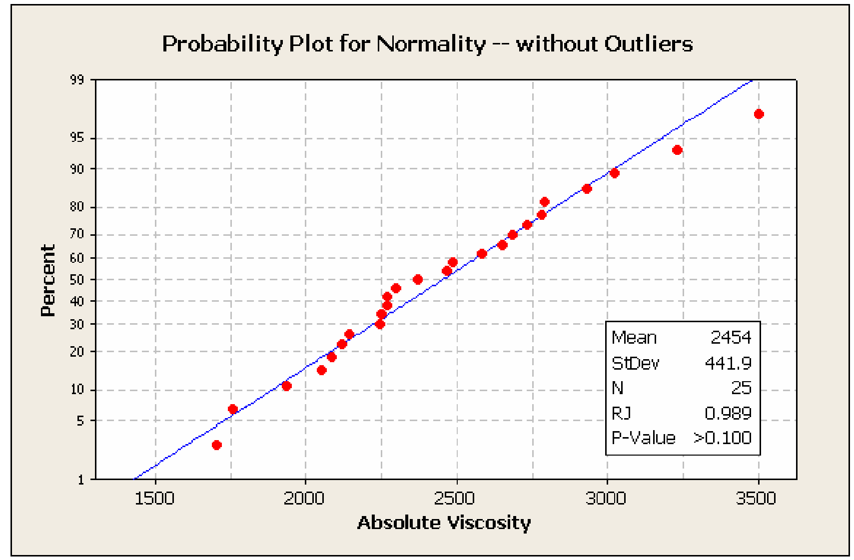
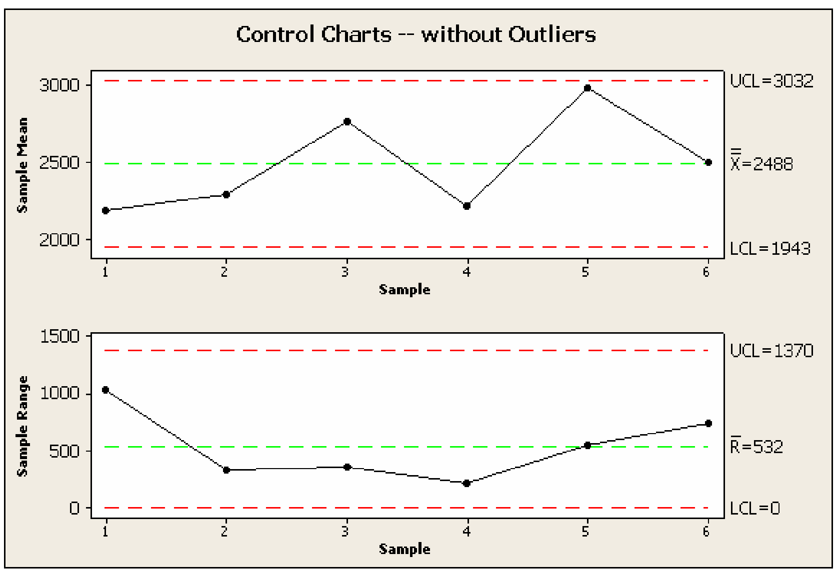


Figure E-189 Statistical Analysis Charts for Supplier: 1401 Grade: AC-15P Test: Absolute Viscosity







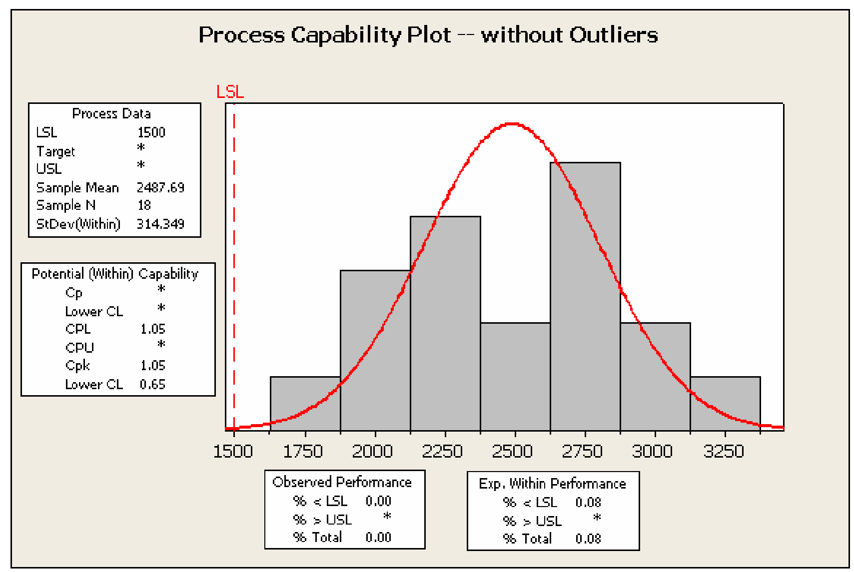


Figure E-190 Statistical Analysis Charts (without Outliers) for Supplier: 1401 Grade: AC-15P Test: Absolute Viscosity

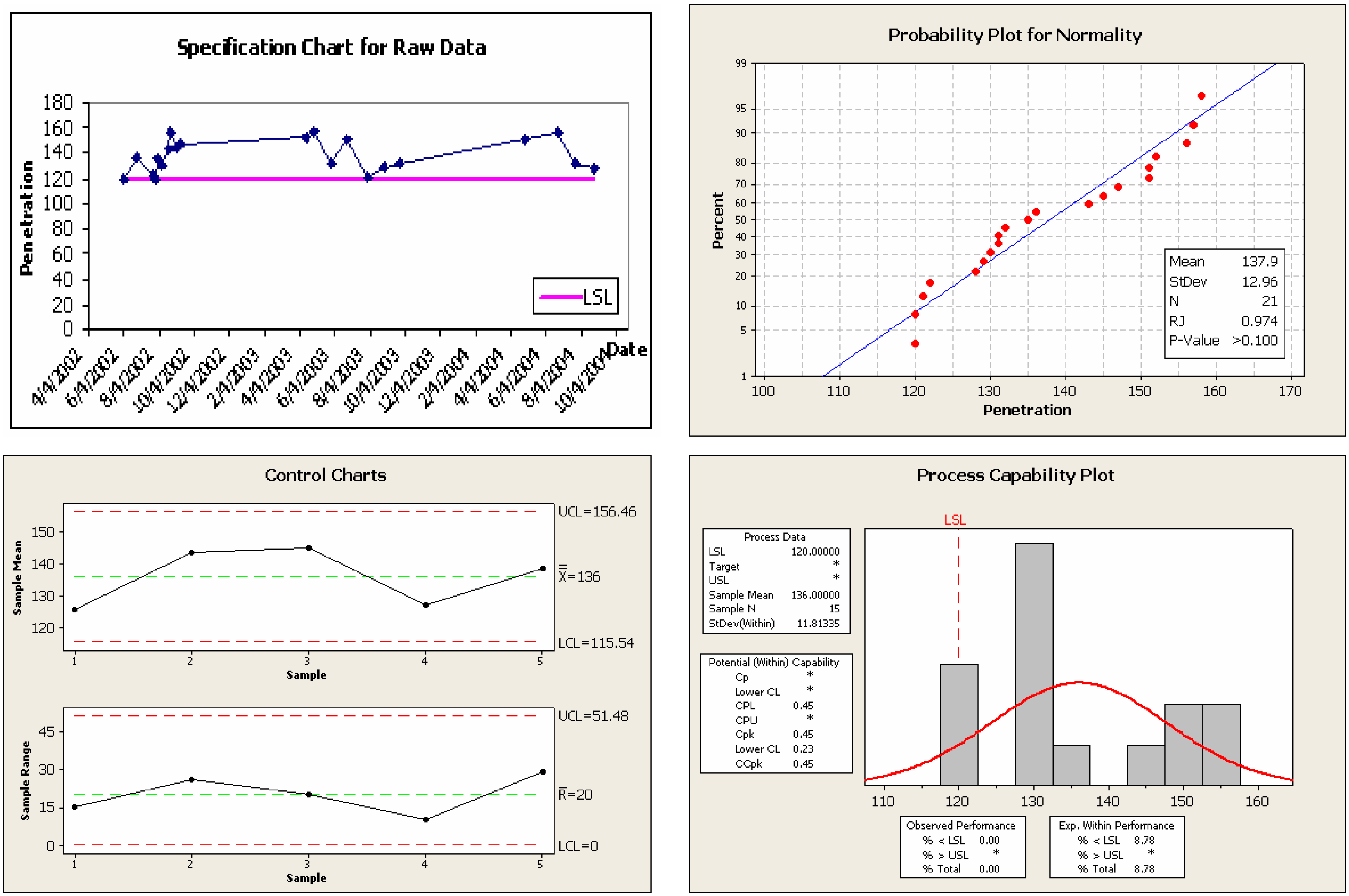


Figure E-191 Statistical Analysis Charts for Supplier: 1401 Grade: AC-5L2% Test: Penetration

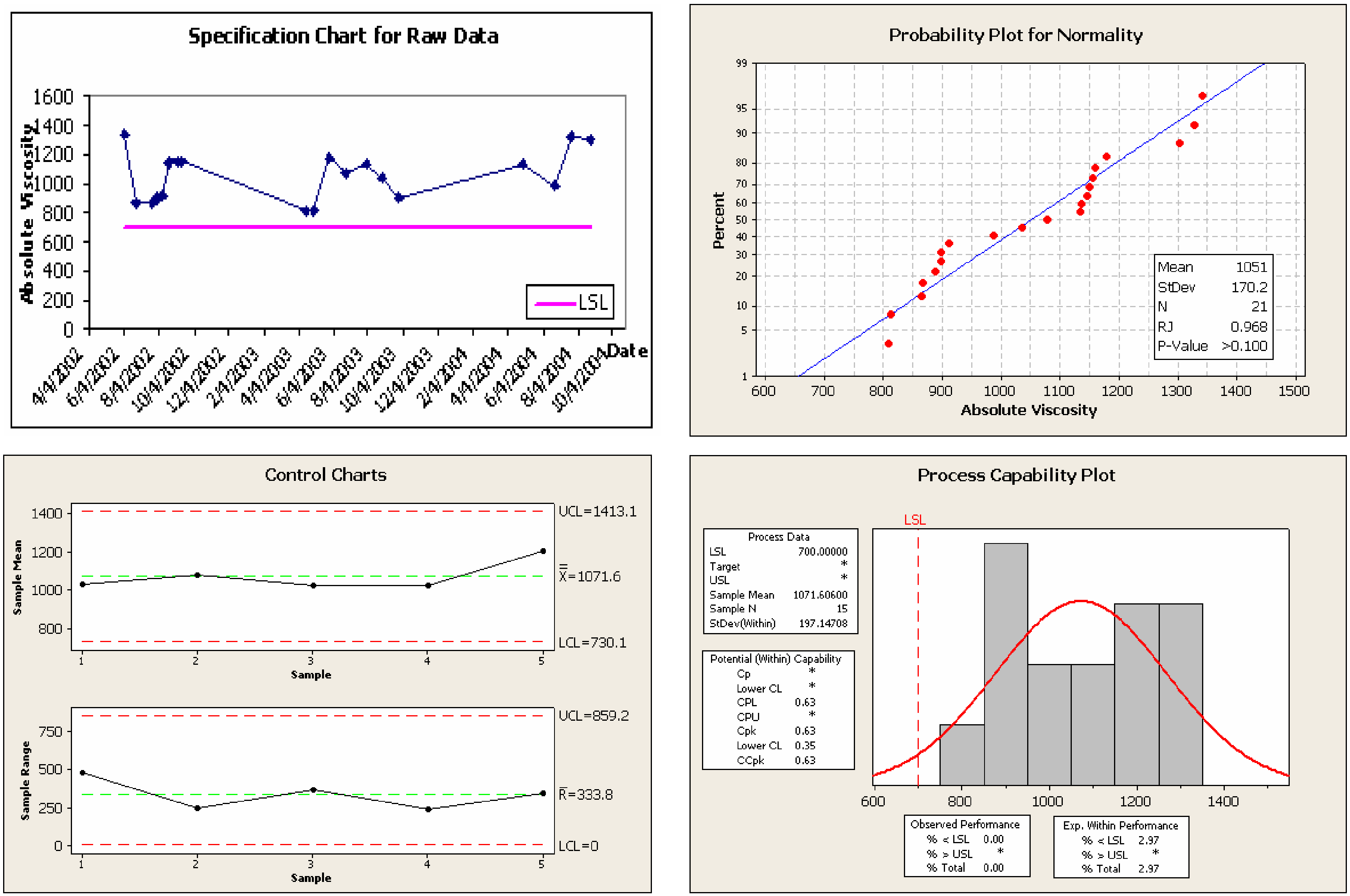


Figure E-192 Statistical Analysis Charts for Supplier: 1401 Grade: AC-5L2% Test: Absolute Viscosity

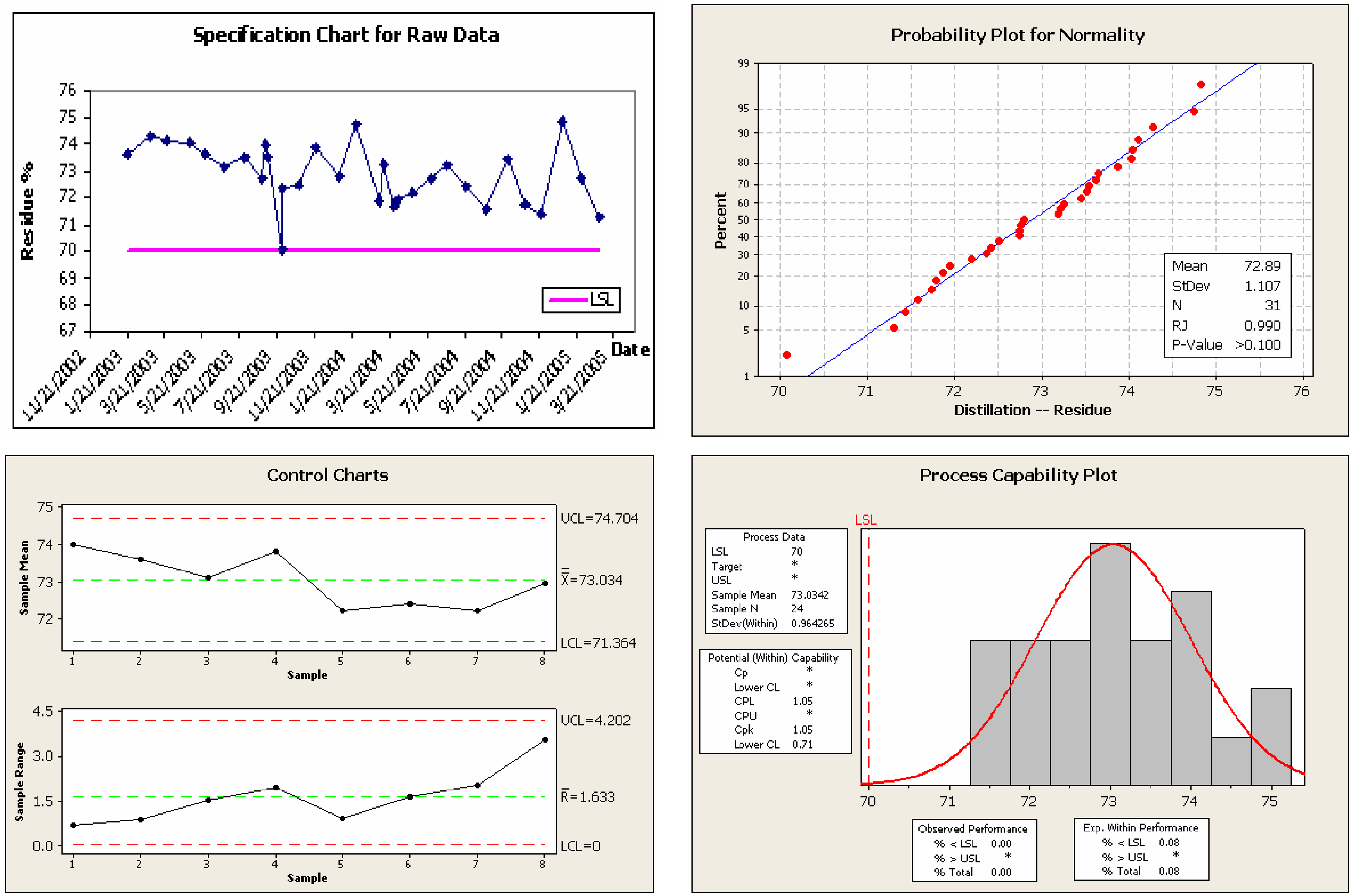


Figure E-193 Statistical Analysis Charts for Supplier: 1401 Grade: RC-250 Test: Distillation-Residue

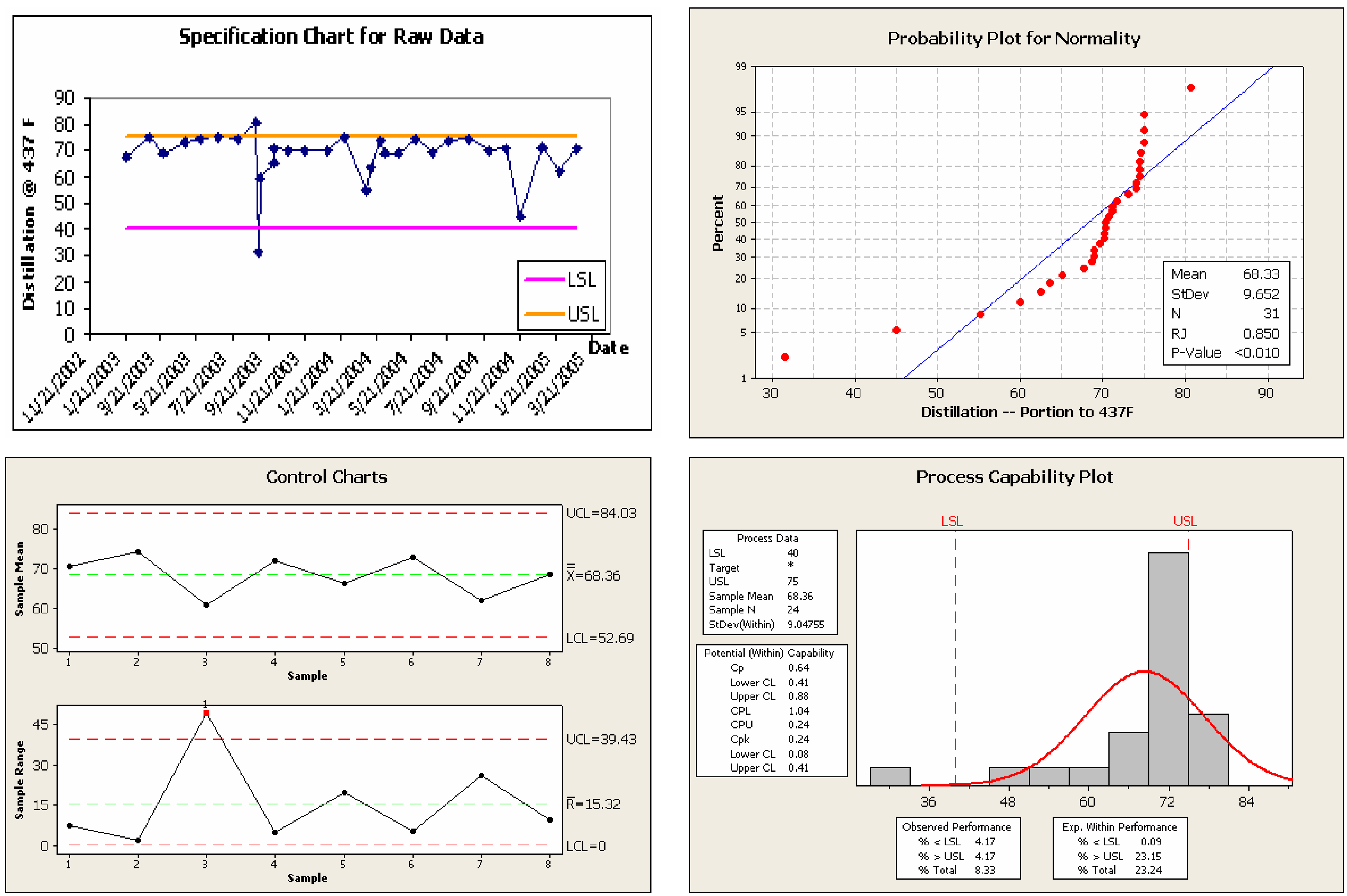


Figure E-194 Statistical Analysis Charts for Supplier: 1401 Grade: RC-250 Test: Distillation @ 437|F

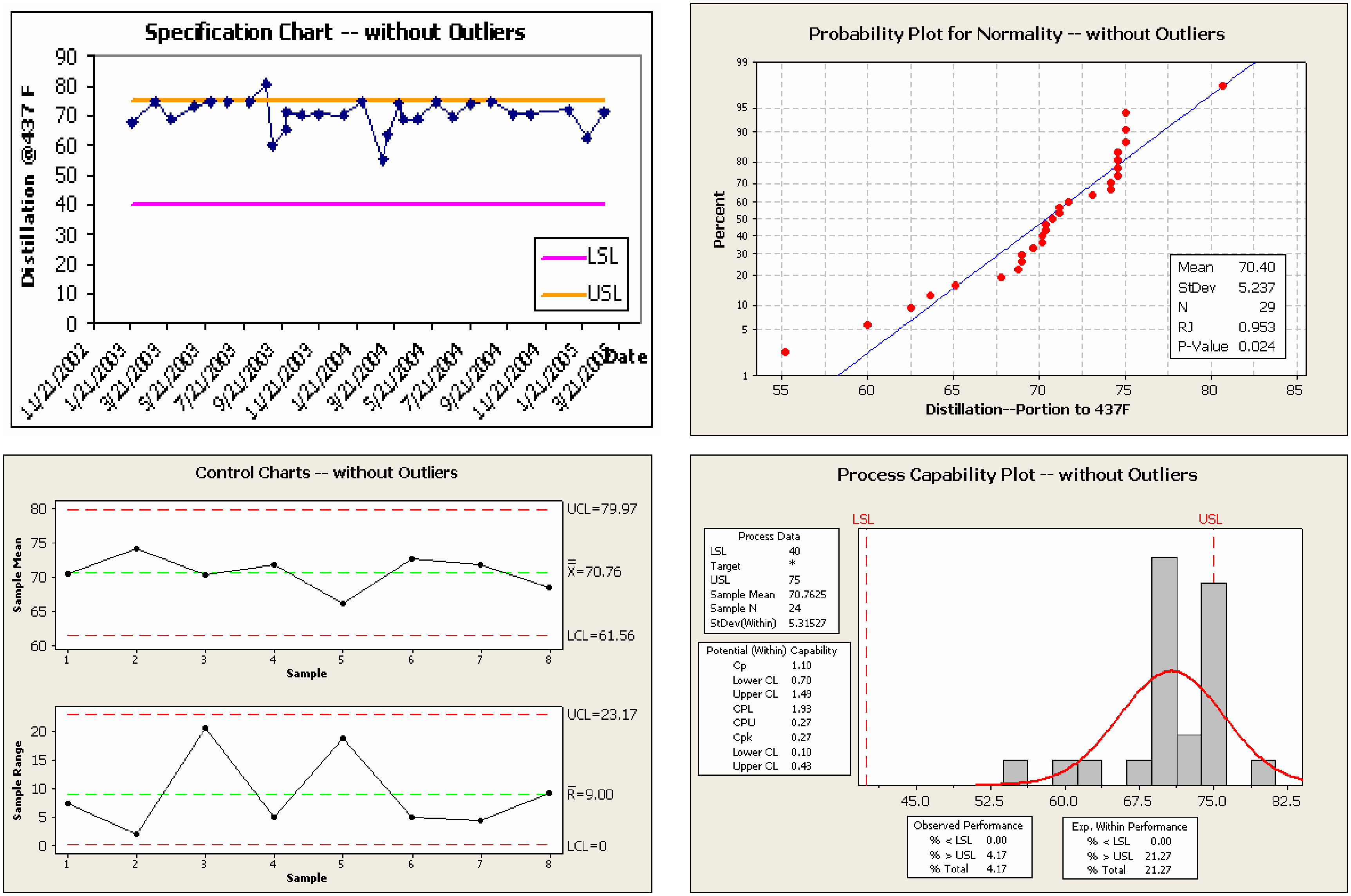


Figure E-195 Statistical Analysis Charts (without Outliers) for Supplier: 1401 Grade: RC-250 Test: Distillation @ 437|F

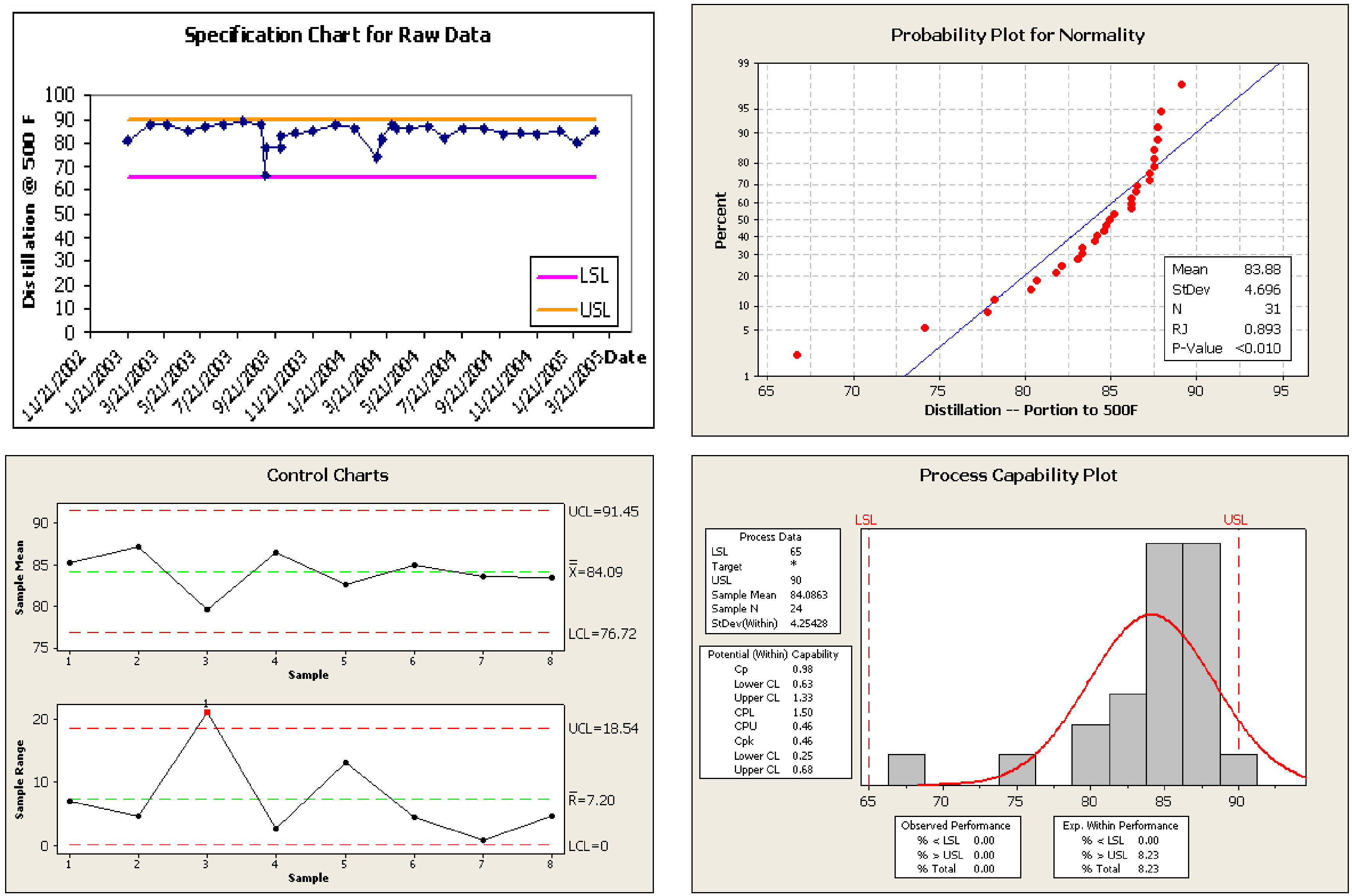


Figure E-196 Statistical Analysis Charts for Supplier: 1401 Grade: RC-250 Test: Distillation @ 500|F

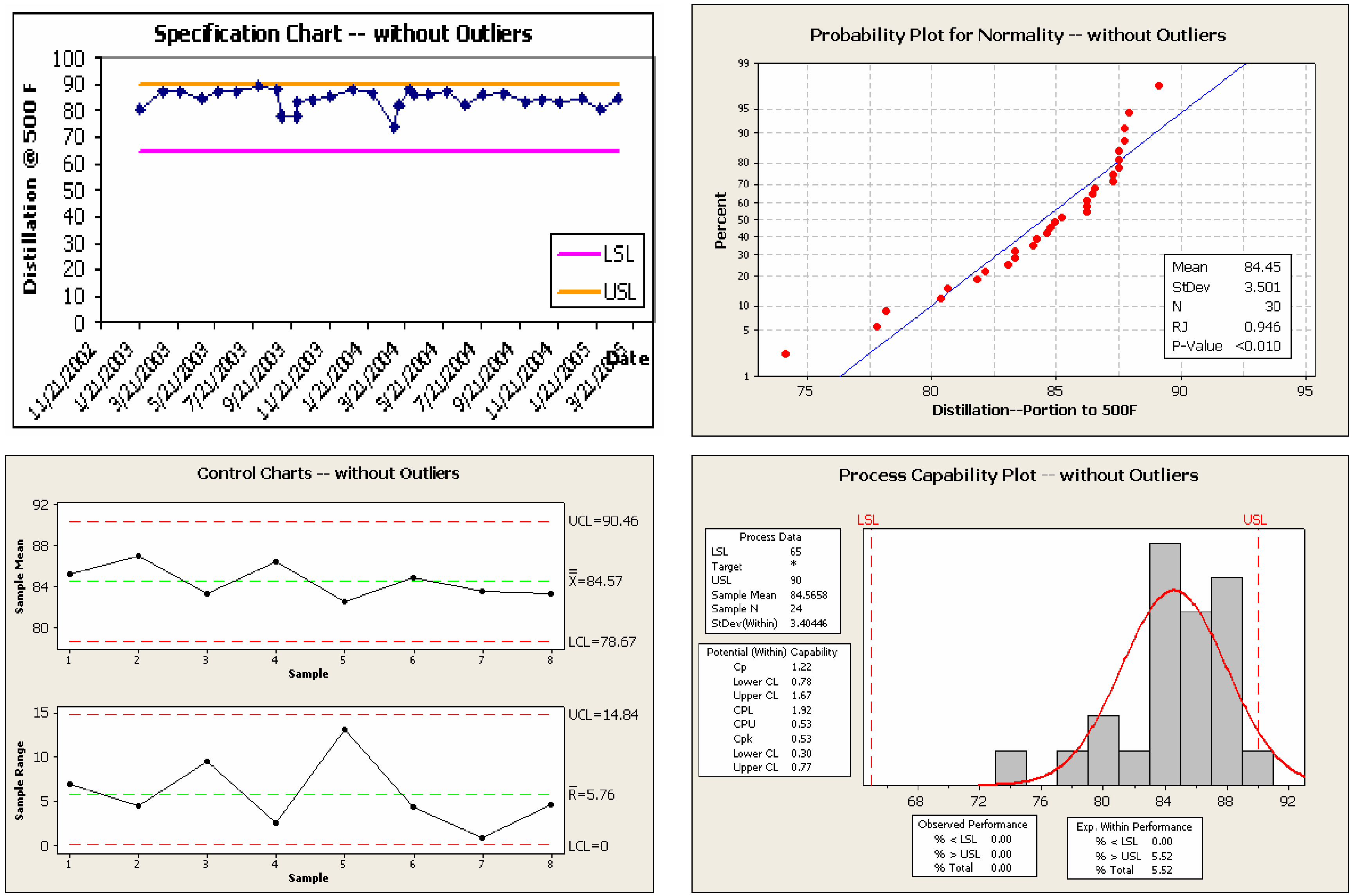


Figure E-197 Statistical Analysis Charts (without Outliers) for Supplier: 1401 Grade: RC-250 Test: Distillation @ 500|F

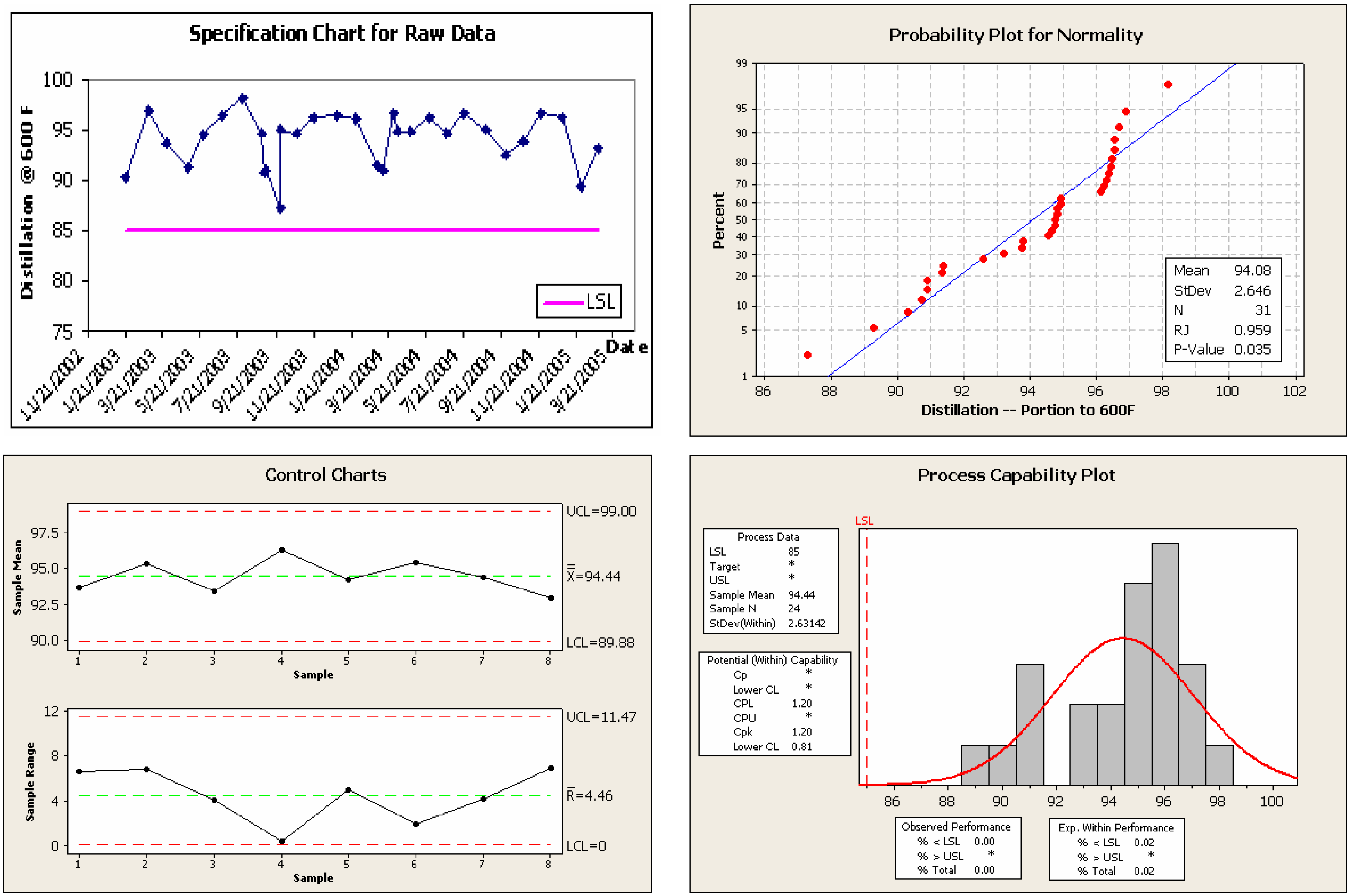


Figure E-198 Statistical Analysis Charts for Supplier: 1401 Grade: RC-250 Test: Distillation @ 600|F

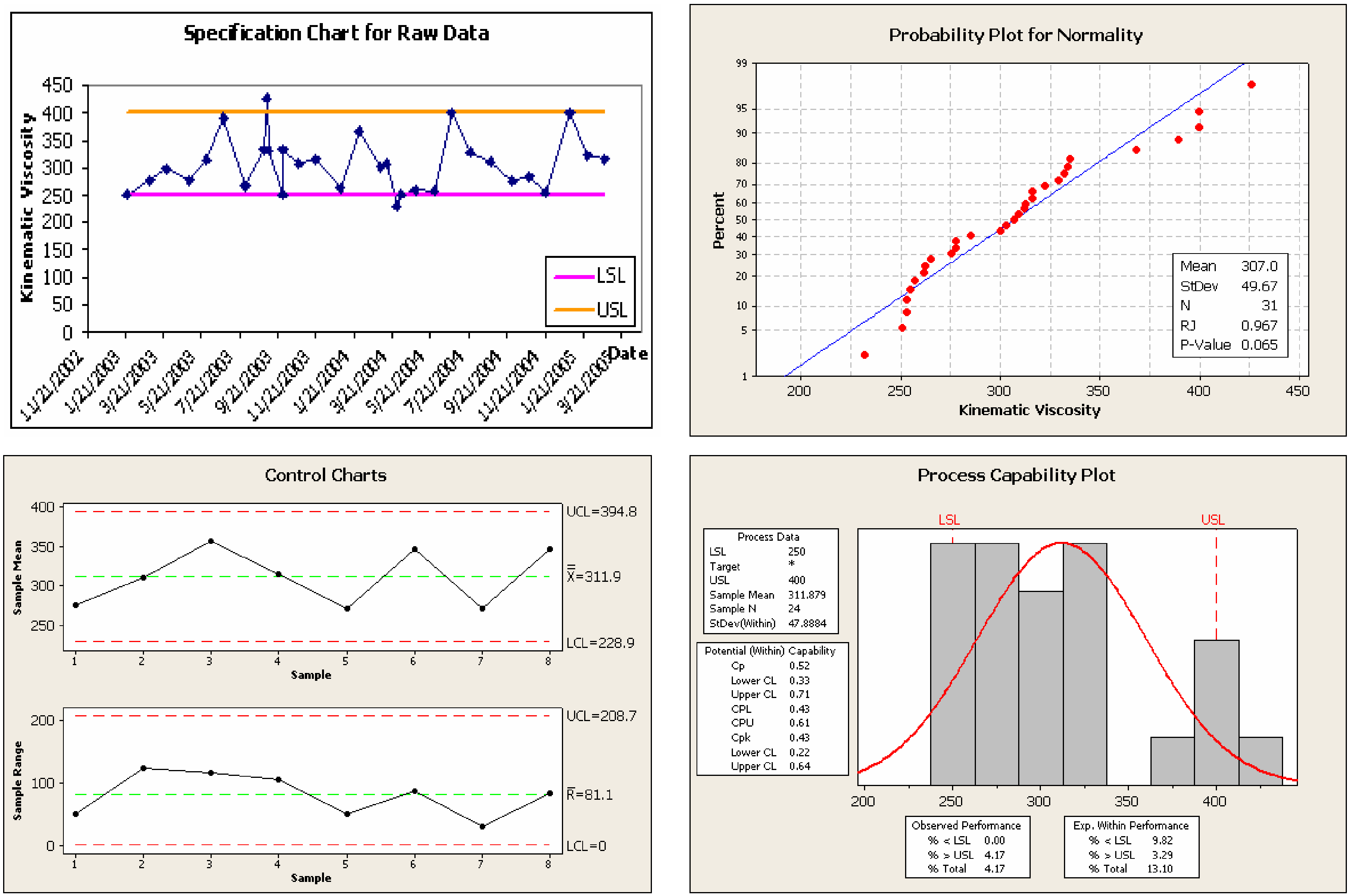


Figure E-199 Statistical Analysis Charts for Supplier: 1401 Grade: RC-250 Test: Kinematic Viscosity

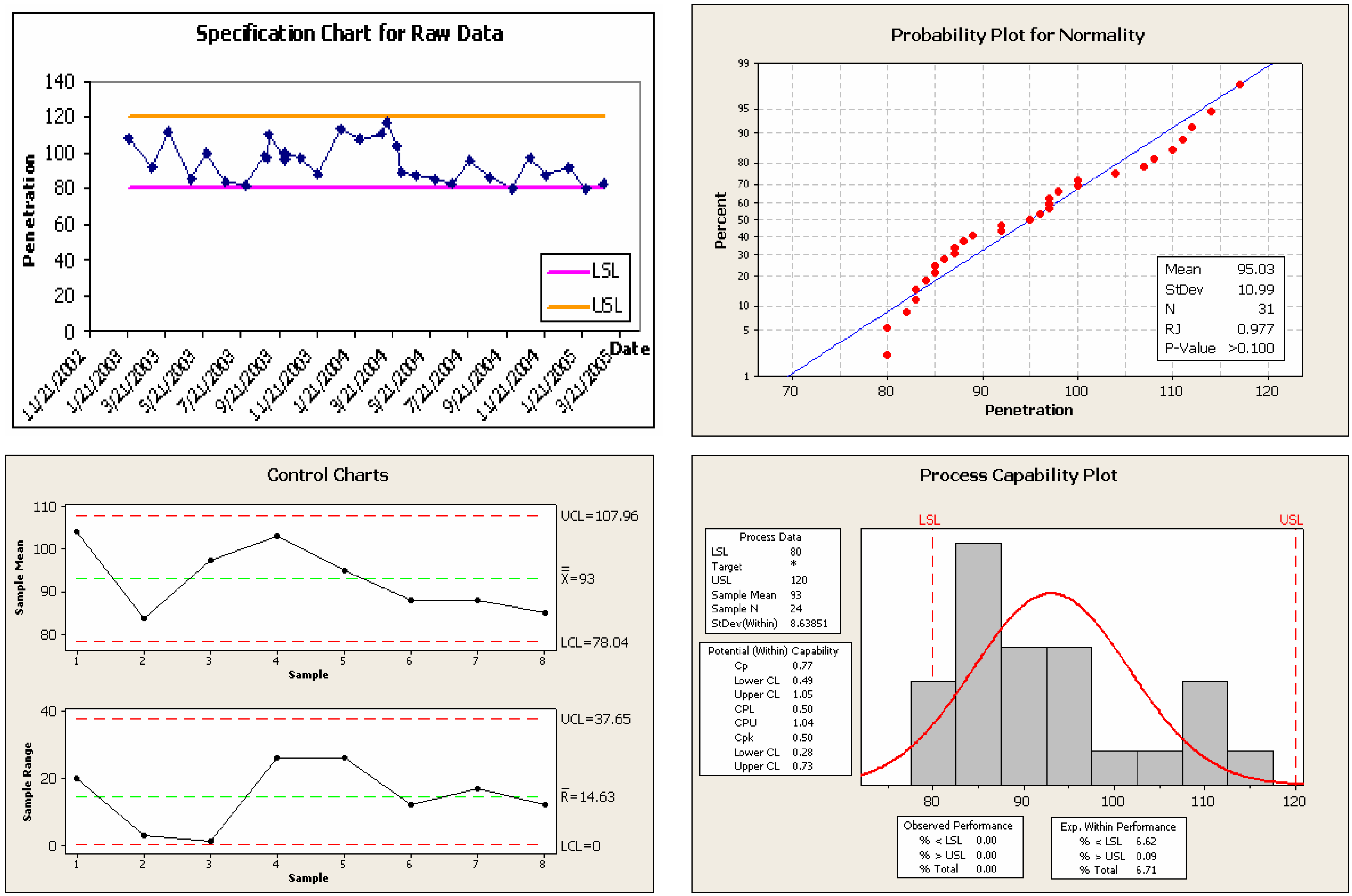


Figure E-200 Statistical Analysis Charts for Supplier: 1401 Grade: RC-250 Test: Penetration

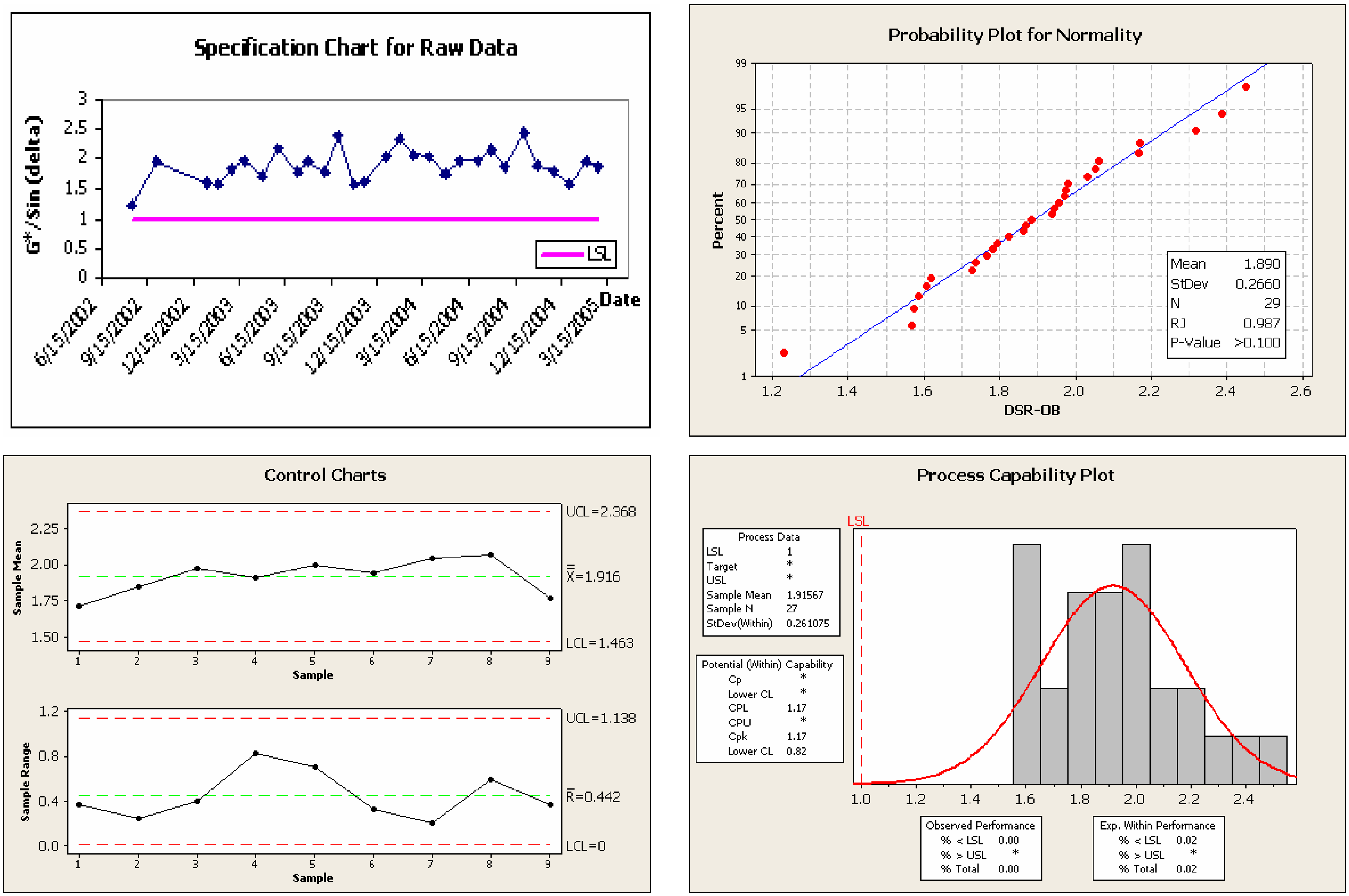


Figure E-201 Statistical Analysis Charts for Supplier: 1402 Grade: PG 64-22 Test: DSR-OB

Appendix F
0-4681

Summary of QC Data Analysis Results

Grade	Test (Specifications)	Supplier	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																				Proc. Cap. (% outside Spec.)	
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Ryan-Joiner Original	Ryan-Joiner Without Outliers	X-bar Chart Original					X-bar Chart Without Outliers					R Chart Original					R Chart Without Outliers					Original	Without Outliers
										I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V		
PG64-22	DSR-OB (LSL=1)	0703	91	0%				p<0.01		1		1								2										0.00%	
		Period 1	38	0%				p>0.1																						0.68%	
		Period 2	53	0%				p<0.01		1																				0.00%	
		1201	181	0%				p>0.1			1																			0.56%	
PG64-22S	DSR-OB (LSL=1)	0101	30	0%				p>0.1		1																				0.72%	
	BBR--S (USL=300)	0101	30	0%				p>0.1																						0.00%	
	BBR--m (LSL=0.3)	0101	30	0%				p>0.1																						4.92%	
PG64-28S	DSR-OB (LSL=1)	0101	27	0%				p>0.1																						0.58%	
	BBR--S (USL=300)	0101	24	0%				p>0.1		2	1																			0.00%	
	BBR--m (LSL=0.3)	0101	24	0%	1	1	0.391	p<0.01	p>0.1	1					1															0.83%	0.83%
PG70-22	DSR-OB (LSL=1)	0703	173	0.58%	1	1	**0.912**	p>0.1	p>0.1																					1.09%	0.58%
		Period 1	122	0.82%	1	1	**0.912**	p>0.1	p>0.1																					3.34%	1.01%
		Period 2	51	0%				p>0.1																						0.38%	
PG70-22S	DSR-OB (LSL=1)	1201	160	0%				p=0.020																						2.01%	
PG70-28	DSR-OB (LSL=1)	0703	187	0%	1	1	2.167	p<0.01	p<0.01	2	1				4	1				1					0					1.63%	0.65%
PG76-22	DSR-OB (LSL=1)	0802	53	0%	1	1	2.262	p=0.049	p>0.1			1					1													0.79%	0.79%
		0703	291	0%	3	6	3.44 2.11 2.035 1.989 1.878 1.854	p<0.01	p<0.01	1					2					1					0					6.58%	1.42%
		Period 1	158	0%	1	1	2.11	p<0.01	p>0.1																					3.75%	2.17%
		Period 2	133	0%	1	5	3.44 2.035 1.989 1.878 1.854	p<0.01	p<0.01						2					2					0					9.84%	0.72%
	Elastic Recovery (LSL=50)	0703	38	0%				p>0.1																						0.09%	
	BBR--S (USL=300)	0802	53	0%				p<0.01		3		2																		0.00%	
		0703	57	1.75%	1	2	**318** 233.5	p<0.01	p>0.1																					0.00%	0.00%
		Period 1	21	0%				p>0.1																						0.00%	
		Period 2	36	2.78%	1	1	**318**	p<0.01	p=0.088																					0.00%	0.00%
	BBR--m (LSL=0.3)	0802	53	0%				p>0.1		1																				0.16%	
		0703	57	0%	1	2	2.463 1.198	p<0.01	p>0.1	1					0					2					0					26.20%	1.71%
		Period 1	22	0%	1	1	1.198	p<0.01	p>0.1											1					0					25.74%	0.48%
		Period 2	25	0%	1	1	2.463	p<0.01	p>0.1	1					0					1					0					26.40%	2.69%
PG76-22S	DSR-OB (LSL=1)	1201	97	0%				p=0.030			1																			1.28%	
PG76-28	DSR-OB (LSL=1)	0703	118	0%	1	2	2.124 2.013	p<0.005	p<0.005																					2.34%	2.34%
AC-10	Penetration (LSL=85)	1201	73	0%				p>0.1																						0.05%	
		0101	67	0%				p=0.028																						2.68%	
	Absolute Viscosity (LSL=800 USL=1200)	1201	73	6.85%				p=0.057		3	2	2		1																5.24%	
		0101	69	0%				p<0.01		1																				1.00%	
AC-15P	Penetration (LSL=100 USL=150)	0703	112	6.25%				p=0.043			1																			3.64%	
	Absolute Viscosity (LSL=1500)	0703	108	8.33%	1	5	19000 14720 14514 14368 13765	p<0.01	p<0.01	1					1					1					0					8.65%	5.78%

Summary of QC Data Analysis Results

Grade	Test (Specifications)	Supplier	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality Ryan-Joiner		SPC Chart (Type & No. of signals)																				Proc. Cap. (% outside Spec.)	
										X-bar Chart										R Chart											
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Original	Without Outliers	Original					Without Outliers					Original					Without Outliers					Original	Without Outliers
										I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V		
AC-15XP	Penetration (LSL=75 USL=125)	0703	114	0.88%	1	1	**71**	p=0.037	p>0.1	1					0										1					0.40%	0.17%
	Absolute Viscosity (LSL=1500)	0703	120	0%	2	4	4914 4656 4496 4254	p<0.01	p=0.093											1					0					0.75%	0.30%
AC-5	Penetration (LSL=135)	0101	57	29.82%				p<0.01		1										1										26.63%	
	Absolute Viscosity	0101	40	0%				p>0.1																						1.92%	
	(LSL=400 USL=600)	0703	49	16.33%	1	1	**107**	p<0.01	p<0.01																					18.90%	18.90%
AE-P	Demulsibility (USL=70)	0701	66	1.52%	1	3	**144.51** 18.82 18.82	p<0.01	p<0.01	1			1		1	1		0		1			2		0			0		0.00%	0.00%
	Saybolt Viscosity	0701	68	0%				p=0.026		1																				0.00%	
	(LSL=15 USL=150)	0703	69	0%				p<0.01		2	1									1										2.88%	
	Distillation	0701	26	3.85%	1	1	**28.5**	p<0.01	p<0.01											1					0					5.06%	0.97%
	(LSL=40)	0703	27	0%				p>0.1																						0.20%	
CRS-2	Demulsibility	0702	69	5.80%				p>0.1																						5.81%	
	(LSL=70)	0701	78	0%				p=0.013		1										1										0.01%	
		0703	89	1.12%				p=0.012			1	1																		1.52%	
	Saybolt Viscosity	0702	83	2.41%				p<0.01																						8.63%	
	(LSL=150 USL=400)	0701	83	8.43%	4	7	**558 555 551 540 497 493 414**	p<0.01	p=0.069	1					0					1					0					0.86%	0.29%
		0703	100	0%				p=0.041																						7.55%	
	Penetration	0702	30	3.33%				p=0.018		1										1										12.07%	
	(LSL=120 USL=160)	0701	29	3.45%				p<0.01		3	2	2								1										2.46%	
		0703	20	0%				p>0.1		2																				1.02%	
	Distillation	0702	30	0%	1	1	89.2	p<0.01	p>0.1	1					1	1				1					1					0.66%	0.00%
	(LSL=65)	0701	29	0%				p<0.01																						0.00%	
		0703	18	0%	1	1	87.7	p<0.01	p>0.1	1					0					1					0					8.50%	0.64%
CRS-2H	Demulsibility	0703	93	0%				p>0.1																						0.78%	
	(LSL=70)	Period 1	33	0%				p>0.1																						1.04%	
		Period 2	60	0%				p>0.1																						0.63%	
	Saybolt Viscosity	0703	95	2.11%				p=0.042																						4.39%	
	(LSL=150 USL=400)	Period 1	35	5.71%				p>0.1																						15.89%	
		Period 2	60	0%				p=0.090																						0.78%	
CRS-2P	Demulsibility	0703	74	0%				p=0.090		1	2	1																		0.69%	
	(LSL=70)	Period 1	42	0%				p>0.1																						0.71%	
		Period 2	32	0%				p=0.075																						0.67%	
	Saybolt Viscosity	0703	79	29.11%				p=0.032																						17.86%	
	(LSL=150 USL=400)	Period 1	46	50%				p<0.01																						28.86%	
		Period 2	33	0%				p>0.1																						8.30%	

Summary of QC Data Analysis Results

Grade	Test	Supplier	Sample	Raw Data	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																						Proc. Cap.	
	(Specifications)		Size (N)	% outside	Original	Final	Testing Results	Ryan-Joiner		X-bar Chart										R Chart										(% outside Spec.)	
				Spec.	Number	Number	(Outside Spec.	Original	Without	Original					Without Outliers					Original					Without Outliers					Original	Without
							In Bold)		Outliers	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V		Outliers
CSS-1H	Saybolt Viscosity (LSL=20 USL=100)	0702	55	1.82%	2	4	79 **0.004** 66 57.4	p<0.01	p>0.1								1			2					0					12.99%	0.32%
HFRS-2	Demulsibility (LSL=50)	0701	109	0%	3	3	68.6 68.6 75.3	p<0.01	p=0.087						1															0.00%	0.00%
	Saybolt Viscosity (LSL=150 USL=400)	0701	111	5.41%	6	9	**625 616 613 606 598 574** 169 169 383	p<0.01	p=0.083	2		3	2		0		0	0		1					0					0.50%	0.00%
	Penetration (LSL=100 USL=140)	0701	32	0%				p=0.028		1																				0.13%	
	Distillation (LSL=65)	0701	32	0%				p>0.1			1									1										0.00%	
HFRS-2P	Demulsibility (LSL=50)	0701	82	0%				p<0.01		1																				0.00%	
	Saybolt Viscosity (LSL=150 USL=400)	0701	90	0%				p>0.1																						2.67%	
	Penetration (LSL=90 USL=140)	0701	31	6.45%	1	2	**68 74**	p<0.01	p<0.01	2					1					1					0					0.05%	0.00%
	Distillation (LSL=65)	0701	29	3.45%	1	1	**34.8**	p<0.01	p<0.01																					0.15%	0.15%
MS-2	Saybolt Viscosity	0703	57	0%				p>0.1																						7.05%	
	(LSL=100 USL=300)	0702	62	3.23%				p=0.025																						5.89%	
	Penetration	0703	19	0%				p=0.046		4	1																			0.12%	
	(LSL=120 USL=160)	0702	18	0%				p>0.1																						2.19%	
	Distillation	0703	18	0%				p>0.1		3	1																			0.00%	
	(LSL=65)	0702	18	0%	1	2	88.4 65.8	p<0.01	p>0.1	1					0					1					0					0.00%	0.00%
SS-1	Saybolt Viscosity	0703	75	0%				p<0.01		1																				3.77%	
	(LSL=20 USL=100)	0702	52	0%	3	4	71 67 67 61	p<0.01	p<0.01	6	1	1			1	1	0			1					1					0.00%	0.00%
	Penetration (LSL=120 USL=160)	0703	17	0%				p>0.1																						15.28%	
MC-30	Distillation--Residue (LSL=50)	0101	52	0%	1	1	75	p<0.01	p=0.039																					0.00%	0.00%
	Distillation--% to 500|F (LSL=40 USL=70)	0101	53	1.89%	1	1	**17**	p<0.01	p>0.1	5	2	1			5	2	1			1					1					0.00%	0.00%
	Distillation--% to 600|F (LSL=75 USL=93)	0101	53	1.89%	1	2	**65** 81	p<0.01	p>0.1											1					1					0.00%	0.00%
	Kinematic Viscosity (LSL=30 USL=60)	0101	52	0%				p=0.019		2	1	1																		0.00%	
	Penetration (LSL=120 USL=250)	0101	53	0%				p<0.01																						11.03%	

Summary of QC Data Analysis Results

Grade	Test (Specifications)	Supplier	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.) Original Number	Outlier Final Number	Outlier Testing Results (Outside Spec. In Bold)	Normality Ryan-Joiner Original	Normality Ryan-Joiner Without Outliers	X-bar Chart Original I	X-bar Chart Original II	X-bar Chart Original III	X-bar Chart Original IV	X-bar Chart Original V	X-bar Chart Without Outliers I	X-bar Chart Without Outliers II	X-bar Chart Without Outliers III	X-bar Chart Without Outliers IV	X-bar Chart Without Outliers V	R Chart Original I	R Chart Original II	R Chart Original III	R Chart Original IV	R Chart Original V	R Chart Without Outliers I	R Chart Without Outliers II	R Chart Without Outliers III	R Chart Without Outliers IV	R Chart Without Outliers V	Proc. Cap. (% outside Spec.) Original	Proc. Cap. (% outside Spec.) Without Outliers
RC-250	Distillation--Residue (LSL=70)	0101	11	0%				p>0.1																						0.00%	
	Distillation--% to 437|F (LSL=40 USL=75)	0101	12	8.33%	1	1	**17**	p<0.01	p>0.1	1					3					1					0					1.89%	0.00%
	Distillation--% to 500|F (LSL=65 USL=90)	0101	12	8.33%	1	1	**23**	p<0.01	p>0.1	1					0					1					0					22.30%	0.00%
	Distillation--% to 600|F (LSL=85)	0101	12	8.33%	1	1	**29**	p<0.01	p>0.1	1					0					1					0					43.65%	0.00%
	Kinematic Viscosity (LSL=250 USL=400)	0101	11	0%				p>0.1																						6.10%	
	Penetration (LSL=80 USL=120)	0101	10	0%				p>0.1																						20.43%	

Remarks:

Types of Signals:
I. 1 point > 3 standard deviations from center line
II. 2 out of 3 points > 2 standard deviations from center line (same side)
III. 4 out of 5 points > 1 standard deviation from center line (same side)
IV. 6 points in a row, all increasing or decreasing
V. 8 points in a row > 1 standard deviation from center line (either side)

Pink Cells &	Specification Chart:	≥ 5% outside specification
	Normality:	p < 0.05
Purple Cells	Control Chart:	Signals
	Process Capability:	≥ 5% outside specification

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.) Original Number	Outlier Final Number	Outlier Testing Results (Outside Spec. In Bold)	Normality Ryan-Joiner Original	Normality Ryan-Joiner Without Outliers	X-bar Original I	X-bar Original II	X-bar Original III	X-bar Original IV	X-bar Original V	X-bar Without Outliers I	X-bar Without Outliers II	X-bar Without Outliers III	X-bar Without Outliers IV	X-bar Without Outliers V	R Original I	R Original II	R Original III	R Original IV	R Original V	R Without Outliers I	R Without Outliers II	R Without Outliers III	R Without Outliers IV	R Without Outliers V	Proc. Cap. (% outside Spec.) Original	Proc. Cap. (% outside Spec.) Without Outliers
0101	PG64-22S	DSR-OB	30	0%				p>0.1		1																				0.72%	
		BBR (stiffness)	30	0%				p>0.1																						0.00%	
		BBR (m-value)	30	0%				p>0.1																						4.92%	
	PG64-28S	DSR-OB	27	0%				p>0.1																						0.58%	
		BBR (stiffness)	24	0%				p>0.1		2	1																			0.00%	
		BBR (m-value)	24	0%	1	1	0.391	p<0.01	p>0.1	1					1															0.83%	0.83%
	AC-10	Penetration	67	0%				p=0.028																						2.68%	
		Absolute Viscosity	69	0%				p<0.01		1																				1.00%	
	AC-5	Penetration	57	29.82%				p<0.01		1										1										26.63%	
		Absolute Viscosity	40	0%				p>0.1																						1.92%	
	MC-30	Distillation--Residue	52	0%	1	1	75	p<0.01	p=0.039																					0.00%	0.00%
		Distillation--% to 500|F	53	1.89%	1	1	**17**	p<0.01	p>0.1	5	2	1			5	2	1			1					1					0.00%	0.00%
		Distillation--% to 600|F	53	1.89%	1	2	**65** 81	p<0.01	p>0.1											1					1					0.00%	0.00%
		Kinematic Viscosity	52	0%				p=0.019		2	1	1																		0.00%	
		Penetration	53	0%				p<0.01																						11.03%	
	RC-250	Distillation--Residue	11	0%				p>0.1																						0.00%	
		Distillation--% to 437|F	12	8.33%	1	1	**17**	p<0.01	p>0.1	1					3					1					0					1.89%	0.00%
		Distillation--% to 500|F	12	8.33%	1	1	**23**	p<0.01	p>0.1	1					0					1					0					22.30%	0.00%
		Distillation--% to 600|F	12	8.33%	1	1	**29**	p<0.01	p>0.1	1					0					1					0					43.65%	0.00%
		Kinematic Viscosity	11	0%				p>0.1																						6.10%	
		Penetration	10	0%				p>0.1																						20.43%	
0701	AE-P	Demulsibility	66	1.52%	1	3	**144.51** 18.82 18.82	p<0.01	p<0.01	1			1		1	1		0		1			2		0			0		0.00%	0.00%
		Saybolt Viscosity	68	0%				p=0.026		1																				0.00%	
		Distillation	26	3.85%	1	1	**28.5**	p<0.01	p<0.01											1					0					5.06%	0.97%
	CRS-2	Demulsibility	78	0%				p=0.013		1										1										0.01%	
		Saybolt Viscosity	83	8.43%	4	7	**558 555 551 540 497 493 414**	p<0.01	p=0.069	1					0					1					0					0.86%	0.29%
		Penetration	29	3.45%				p<0.01		3	2	2								1										2.46%	
		Distillation	29	0%				p<0.01																						0.00%	
	HFRS-2	Demulsibility	109	0%	3	3	68.6 68.6 75.3	p<0.01	p=0.087						1															0.00%	0.00%
		Saybolt Viscosity	111	5.41%	6	9	**625 616 613 606 598 574** 169 169 282	p<0.01	p=0.083	2		3	2		0		0	0		1					0					0.50%	0.00%
		Penetration	32	0%				p=0.028		1																				0.13%	
		Distillation	32	0%				p>0.1			1									1										0.00%	
	HFRS-2P	Demulsibility	82	0%				p<0.01		1																				0.00%	
		Saybolt Viscosity	90	0%				p>0.1																						2.67%	
		Penetration	31	6.45%	1	2	**68 74**	p<0.01	p<0.01	2					1					1					0					0.05%	0.00%
		Distillation	29	3.45%	1	1	**34.8**	p<0.01	p<0.01																					0.15%	0.15%

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.) Original Number	Outlier Final Number	Outlier Testing Results (Outside Spec. In Bold)	Normality Ryan-Joiner Original	Normality Ryan-Joiner Without Outliers	SPC Chart (Type & No. of signals) X-bar Chart Original I	II	III	IV	V	X-bar Chart Without Outliers I	II	III	IV	V	R Chart Original I	II	III	IV	V	R Chart Without Outliers I	II	III	IV	V	Proc. Cap. (% outside Spec.) Original	Proc. Cap. (% outside Spec.) Without Outliers
0702	CRS-2	Demulsibility	69	5.80%				p>0.1																						5.81%	
		Saybolt Viscosity	83	2.41%				p<0.01																						8.63%	
		Penetration	30	3.33%				p=0.018		1										1										12.07%	
		Distillation	30	0%	1	1	89.2	p<0.01	p>0.1	1					1	1				1					1					0.66%	0.00%
	CSS-1H	Saybolt Viscosity	55	1.82%	2	4	79 **0.004** 66 57.4	p<0.01	p>0.1								1			2					0					12.99%	0.32%
	MS-2	Saybolt Viscosity	62	3.23%				p=0.025																						5.89%	
		Penetration	18	0%				p>0.1																						2.19%	
		Distillation	18	0%	1	2	88.4 65.8	p<0.01	p>0.1	1					0					1					0					0.00%	0.00%
	SS-1	Saybolt Viscosity	52	0%	3	4	71 67 67 61	p<0.01	p<0.01	6	1	1			1	1	0			1					1					0.00%	0.00%
0703	PG64-22	DSR-OB	91	0%				p<0.01		1		1								2										0.00%	
		Period 1	38	0%				p>0.1																						0.68%	
		Period 2	53	0%				p<0.01		1																				0.00%	
	PG70-22	DSR-OB	173	0.58%	1	1	**0.912**	p>0.1	p>0.1																					1.09%	0.58%
		Period 1	122	0.82%	1	1	**0.912**	p>0.1	p>0.1																					3.34%	1.01%
		Period 2	51	0%				p>0.1																						0.38%	
	PG70-28	DSR-OB	187	0%	1	1	2.167	p<0.01	p<0.01	2	1				4	1				1					0					1.63%	0.65%
	PG76-22	DSR-OB	291	0%	3	6	3.44 2.11 2.035 1.989 1.878 1.854	p<0.01	p<0.01	1					2					1					0					6.58%	1.42%
		Period 1	158	0%	1	1	2.11	p<0.01	p>0.1																					3.75%	2.17%
		Period 2	133	0%	1	5	3.44 2.035 1.989 1.878 1.854	p<0.01	p<0.01						2					2					0					9.84%	0.72%
		Elastic Recovery	38	0%				p>0.1																						0.09%	
		BBR (stiffness)	57	1.75%	1	2	**318** 233.5	p<0.01	p>0.1																					0.00%	0.00%
		Period 1	21	0%				p>0.1																						0.00%	
		Period 2	36	2.78%	1	1	**318**	p<0.01	p=0.088																					0.00%	0.00%
		BBR (m-value)	57	0%	1	2	2.463 1.198	p<0.01	p>0.1	1					0					2					0					26.20%	1.71%
		Period 1	22	0%	1	1	1.198	p<0.01	p>0.1											1					0					25.74%	0.48%
		Period 2	25	0%	1	1	2.463	p<0.01	p>0.1	1					0					1					0					26.40%	2.69%
	PG76-28	DSR-OB	118	0%	1	2	2.124 2.013	p<0.005	p<0.005																					2.34%	2.34%
	AC-15P	Penetration	112	6.25%				p=0.043			1																			3.64%	
		Absolute Viscosity	108	8.33%	1	5	19000 14720 14514 14368 13765	p<0.01	p<0.01	1					1					1					0					8.65%	5.78%
	AC-15XP	Penetration	114	0.88%	1	1	**71**	p=0.037	p>0.1	1					0										1					0.40%	0.17%
		Absolute Viscosity	120	0%	2	4	4914 4656 4496 4254	p<0.01	p=0.093											1					0					0.75%	0.30%
	AC-5	Absolute Viscosity	49	16.33%	1	1	**107**	p<0.01	p<0.01																					18.90%	18.90%
	AE-P	Saybolt Viscosity	69	0%				p<0.01		2	1									1										2.88%	
		Distillation	27	0%				p>0.1																						0.20%	
	CRS-2	Demulsibility	89	1.12%				p=0.012			1	1																		1.52%	
		Saybolt Viscosity	100	0%				p=0.041																						7.55%	
		Penetration	20	0%				p>0.1		2																				1.02%	
		Distillation	18	0%	1	1	87.7	p<0.01	p>0.1	1					0					1					0					8.50%	0.64%
	CRS-2H	Demulsibility	93	0%				p>0.1																						0.78%	
		Period 1	33	0%				p>0.1																						1.04%	

Supplier	Grade	Test	Sample Size (N)	Raw Data % outside Spec.	Outlier (≥ 3 Std.Dev.)			Normality		SPC Chart (Type & No. of signals)																				Proc. Cap. (% outside Spec.)	
					Original Number	Final Number	Testing Results (Outside Spec. In Bold)	Ryan-Joiner		X-bar Chart										R Chart											
								Original	Without Outliers	Original					Without Outliers					Original					Without Outliers					Original	Without Outliers
										I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V		
		Period 2	60	0%				p>0.1																						0.63%	
		Saybolt Viscosity	95	2.11%				p=0.042																						4.39%	
		Period 1	35	5.71%				p>0.1																						15.89%	
		Period 2	60	0%				p=0.090																						0.78%	
	CRS-2P	Demulsibility	74	0%				p=0.090		1	2	1																		0.69%	
		Period 1	42	0%				p>0.1																						0.71%	
		Period 2	32	0%				p=0.075																						0.67%	
		Saybolt Viscosity	79	29.11%				p=0.032																						17.86%	
		Period 1	46	50%				p<0.01																						28.86%	
		Period 2	33	0%				p>0.1																						8.30%	
	MS-2	Saybolt Viscosity	57	0%				p>0.1																						7.05%	
		Penetration	19	0%				p=0.046		4	1																			0.12%	
		Distillation	18	0%				p>0.1		3	1																			0.00%	
	SS-1	Saybolt Viscosity	75	0%				p<0.01		1																				3.77%	
		Penetration	17	0%				p>0.1																						15.28%	
0802	PG76-22	DSR-OB	53	0%	1	1	2.262	p=0.049	p>0.1			1					1													0.79%	0.79%
		BBR (stiffness)	53	0%				p<0.01		3		2																		0.00%	
		BBR (m-value)	53	0%				p>0.1		1																				0.16%	
1201	PG64-22	DSR-OB	181	0%				p>0.1			1																			0.56%	
	PG70-22S	DSR-OB	160	0%				p=0.020																						2.01%	
	PG76-22S	DSR-OB	97	0%				p=0.030			1																			1.28%	
	AC-10	Penetration	73	0%				p>0.1																						0.05%	
		Absolute Viscosity	73	6.85%				p=0.057		3	2	2		1																5.24%	

Remarks:

Types of Signals:
I. 1 point > 3 standard deviations from center line
II. 2 out of 3 points > 2 standard deviations from center line (same side)
III. 4 out of 5 points > 1 standard deviation from center line (same side)
IV. 6 points in a row, all increasing or decreasing
V. 8 points in a row > 1 standard deviation from center line (either side)

Pink Cells	Specification Chart:	≥ 5% outside specification
	Normality:	p < 0.05
	Control Chart:	Signals
	Process Capability:	≥ 5% outside specification

APPENDIX G

0-4681

Appendix G
Results of QC Data Analysis

This section presents the graphical results of statistical analysis for each supplier-grade-test combination of QC data. The results are presented by the order of suppliers, then grades within each supplier, and tests within each grade. Due to the privacy of suppliers, codes were used instead of the suppliers' name.

For each supplier-grade-test combination, the following results of QC data analyis are presented:

- Specification Chart
- Probability Plot for Normality
- Control Charts
- Process Capability Plot

There is a large time interval in some cases of QC data, during which there is no record of the test available. It was considered a two-period patten (Period 1 and Period 2) data was analyzed for both periods.

Actual testing values are illustrated in specification charts with the specification limits. The abscissa of the specification chart is the date in which the test was conducted. The ordinate is the value of the specific test. In some cases, many testing values lie in the same date because the raw data shows only the month of those tests but not the exact dates. The specification charts are presented for both raw data and data without outliers.

The abscissa of probability plot for normality is the value of the specific test. The ordinate is the rescaled percentile for normal distribution. If the data are perfect normal, they lie on the straight line as shown in the plot for reference. The more deviation the sample points are away from the line, the less likely the population is normally distributed. A box in the lower-right corner of the probability plot contains quantitative values of sample mean, sample standard deviation, sample size (N), Ryan-Joiner test statistic, and p-value. The probability plots for normality are presented for both raw data and data without outliers.

Control Charts include $\overline{X}$ chart and R chart. UCL/LCL and CL ($\overline{\overline{X}}$ for $\overline{X}$ chart and $\overline{R}$ for R chart) are presented as dash lines. The abscissa of control charts is the subgroup number. The ordinate of the $\overline{X}$ chart is the average value of testing values in a subgroup, while that of the R chart is the range of the testing values in a subgroup. The control charts are presented with and without outliers.

Normal distribution is assumed for the process capability plot. The estimated percentage outside the specifications are presented graphically and quantitatively. The abscissa of process capability plot is the value of the specific test. The ordinate is the frequency of occurrence. The two boxes on the left side show the basic process data and simple process capability indices. The two boxes on the bottom present the observed and expected percentage outside the specifications. The process capability plots are presented with and without outliers.

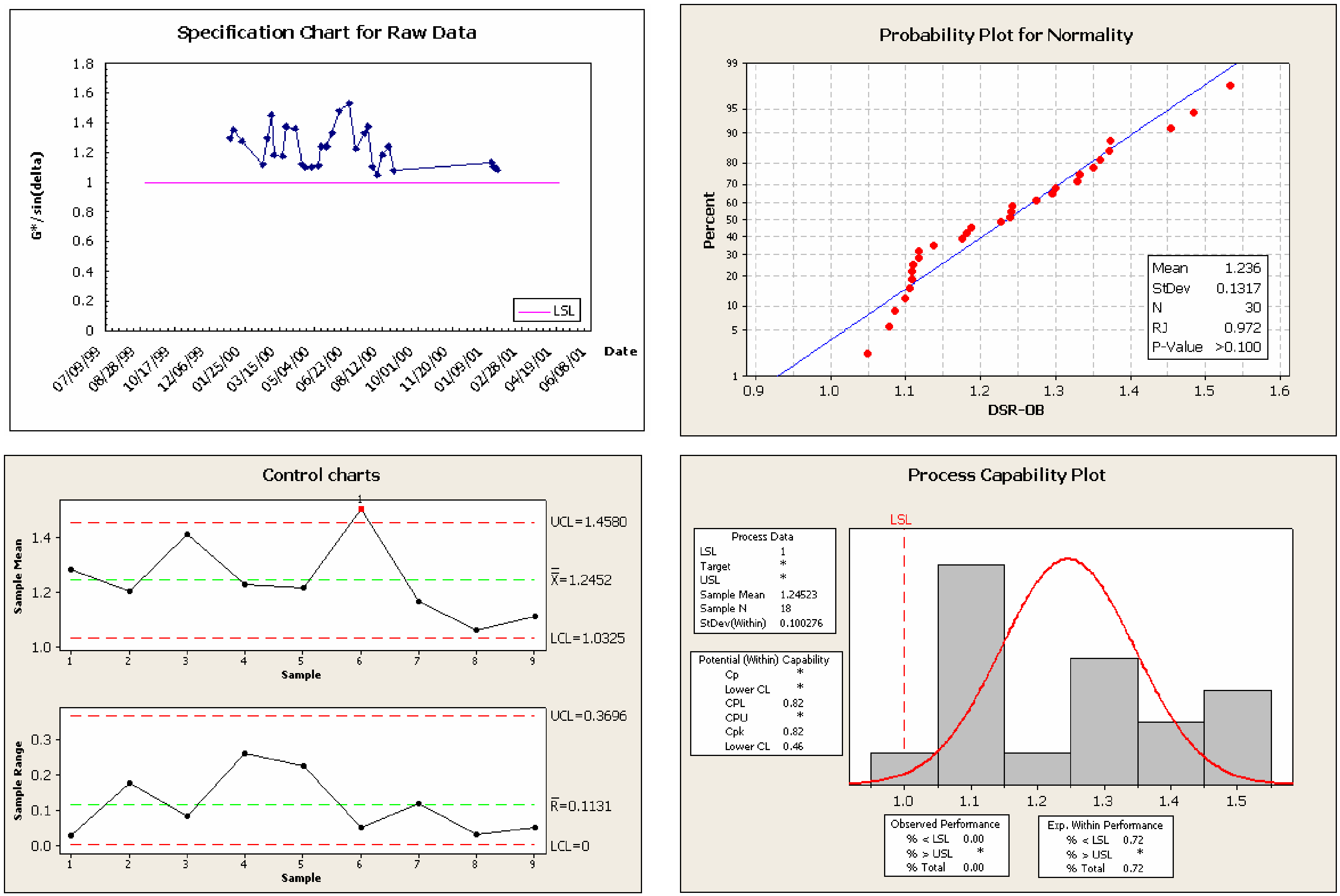


Figure G-1 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-22S Test: DSR-OB

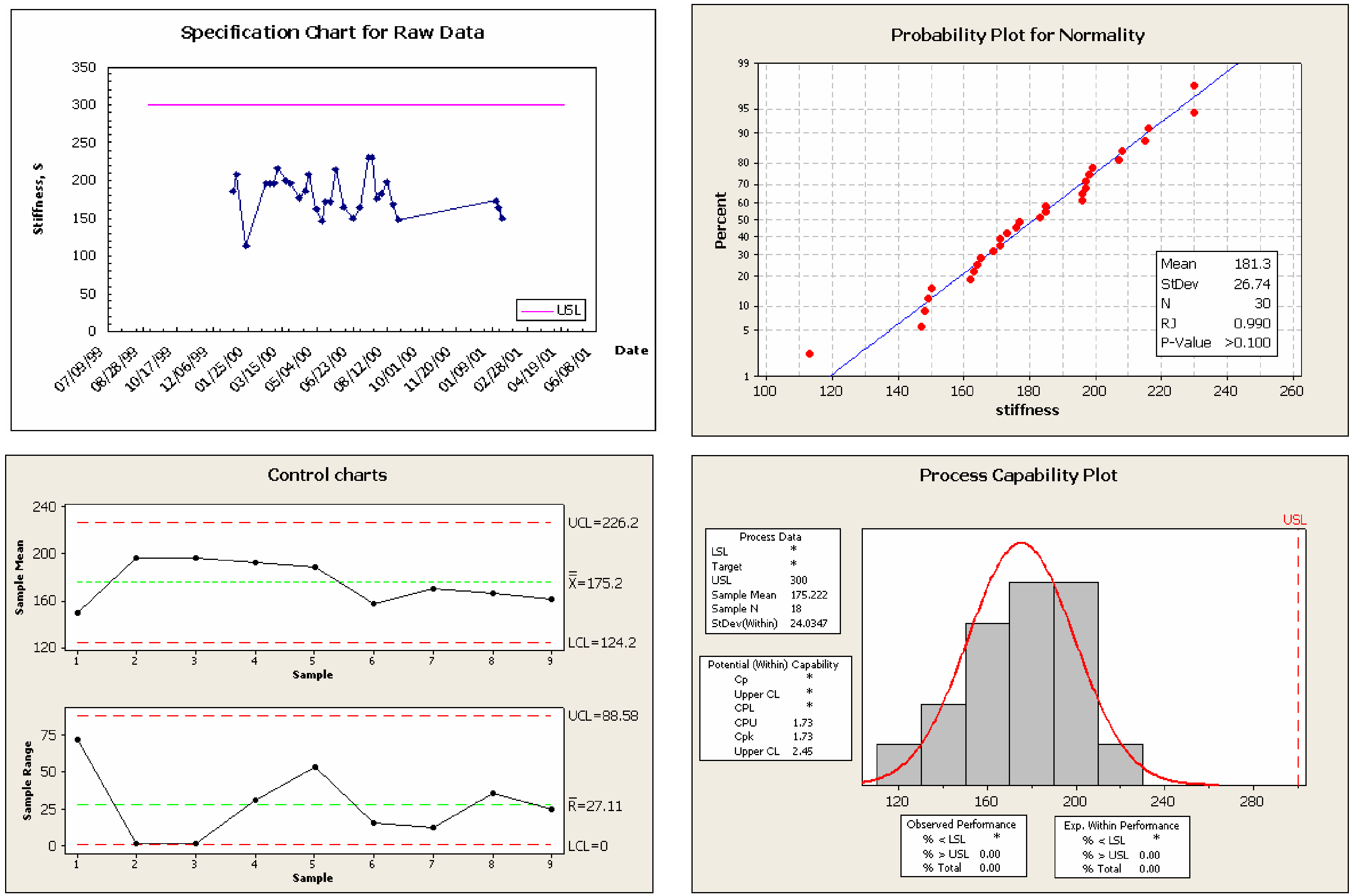


Figure G-2 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-22S Test: BBR-Stiffness

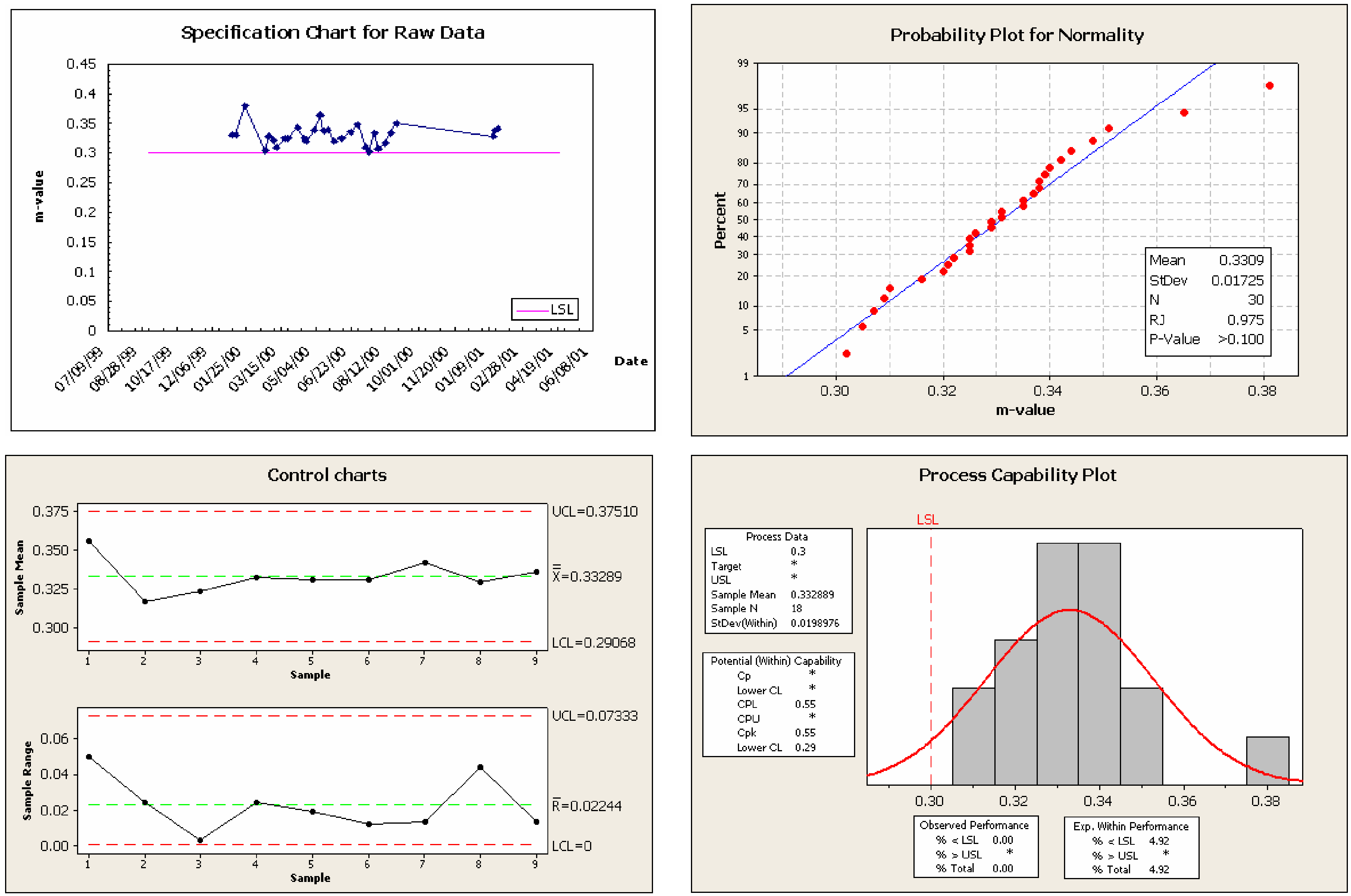


Figure G-3 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-22S Test: BBR-m-value

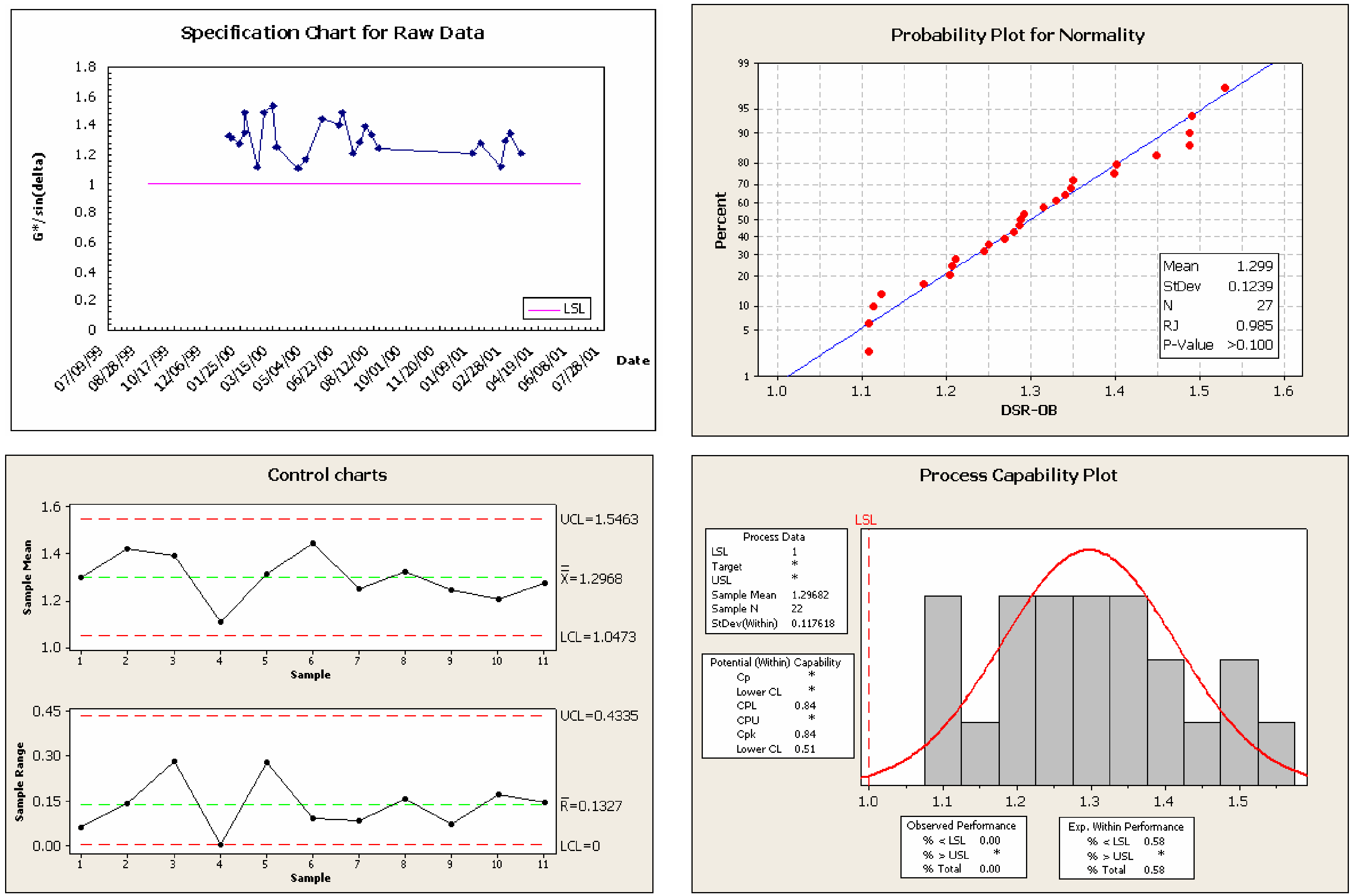


Figure G-4 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-28S Test: DSR-OB

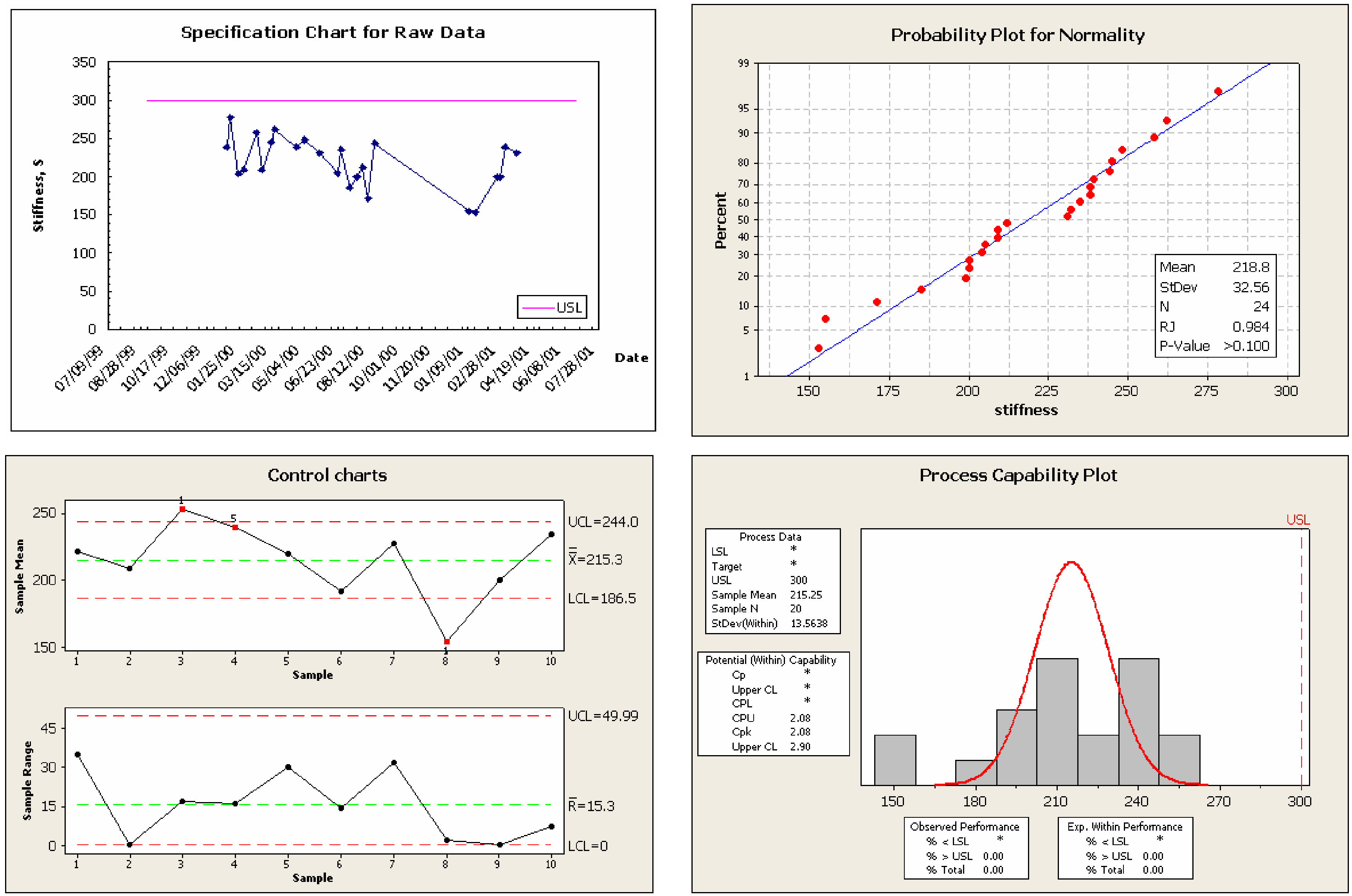


Figure G-5 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-28S Test: BBR-Stiffness

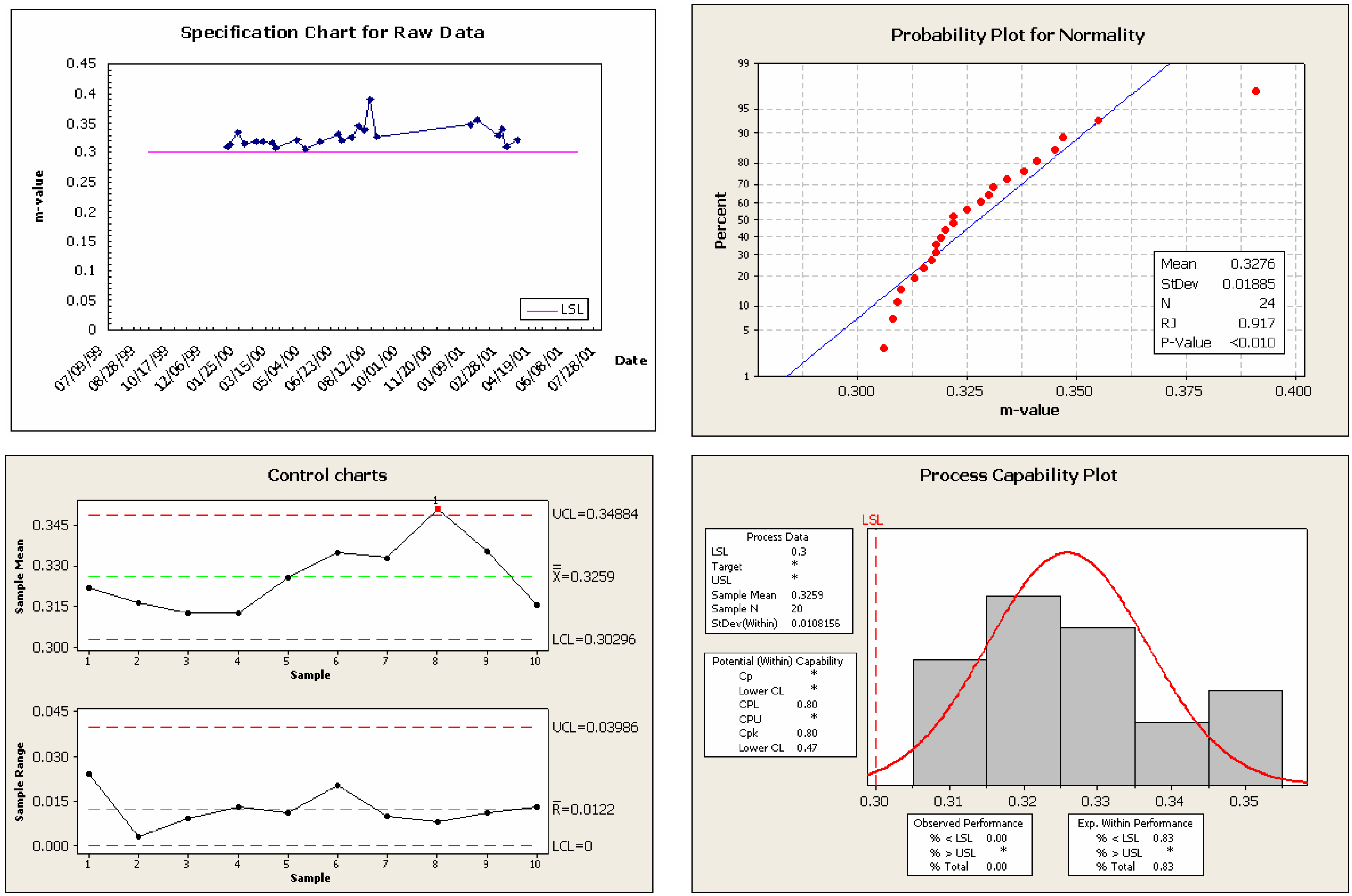


Figure G-6 Statistical Analysis Charts for Supplier: 0101 Grade: PG 64-28S Test: BBR-m-value

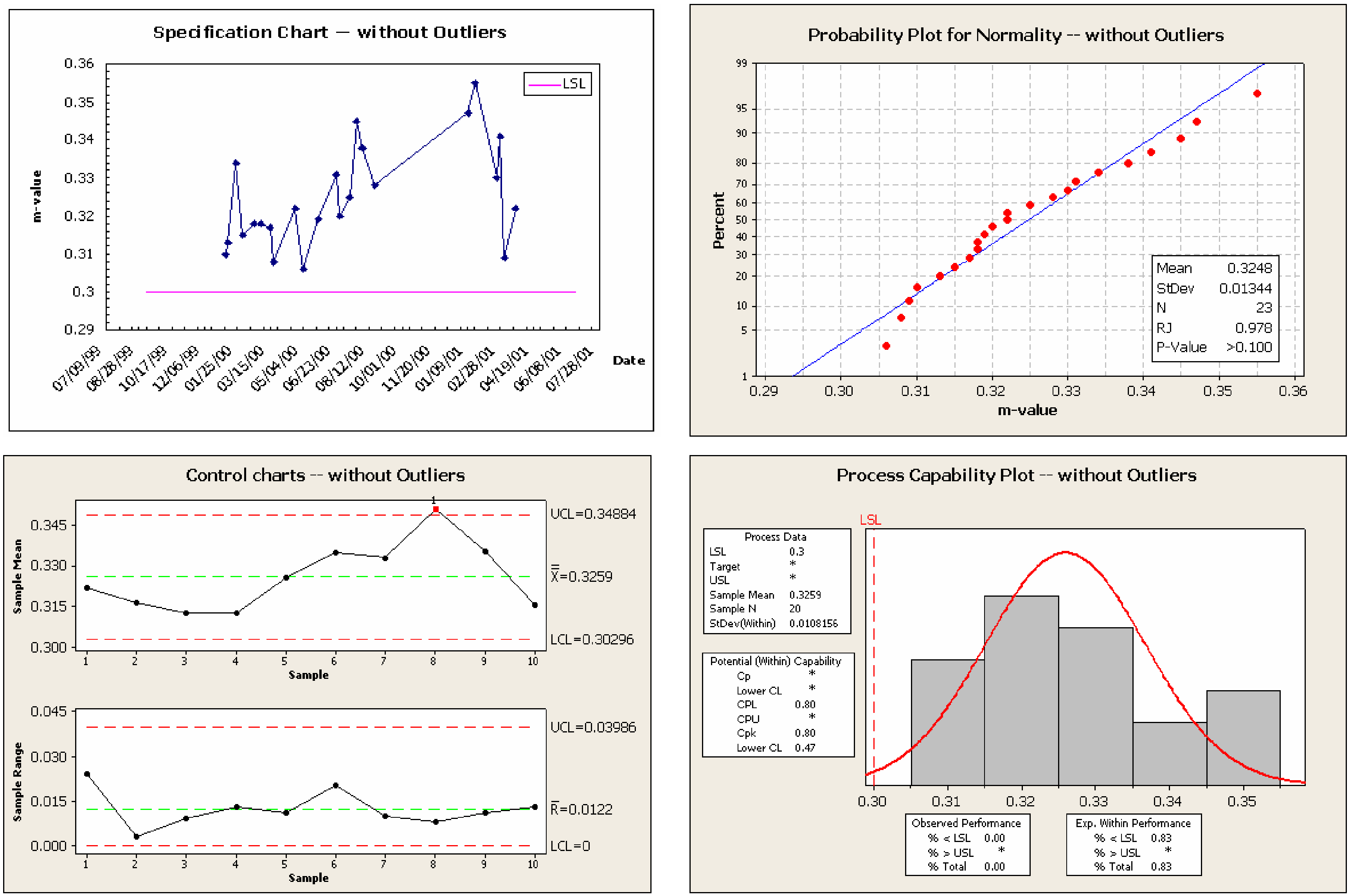


Figure G-7 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: PG 64-28S Test: BBR-m-value

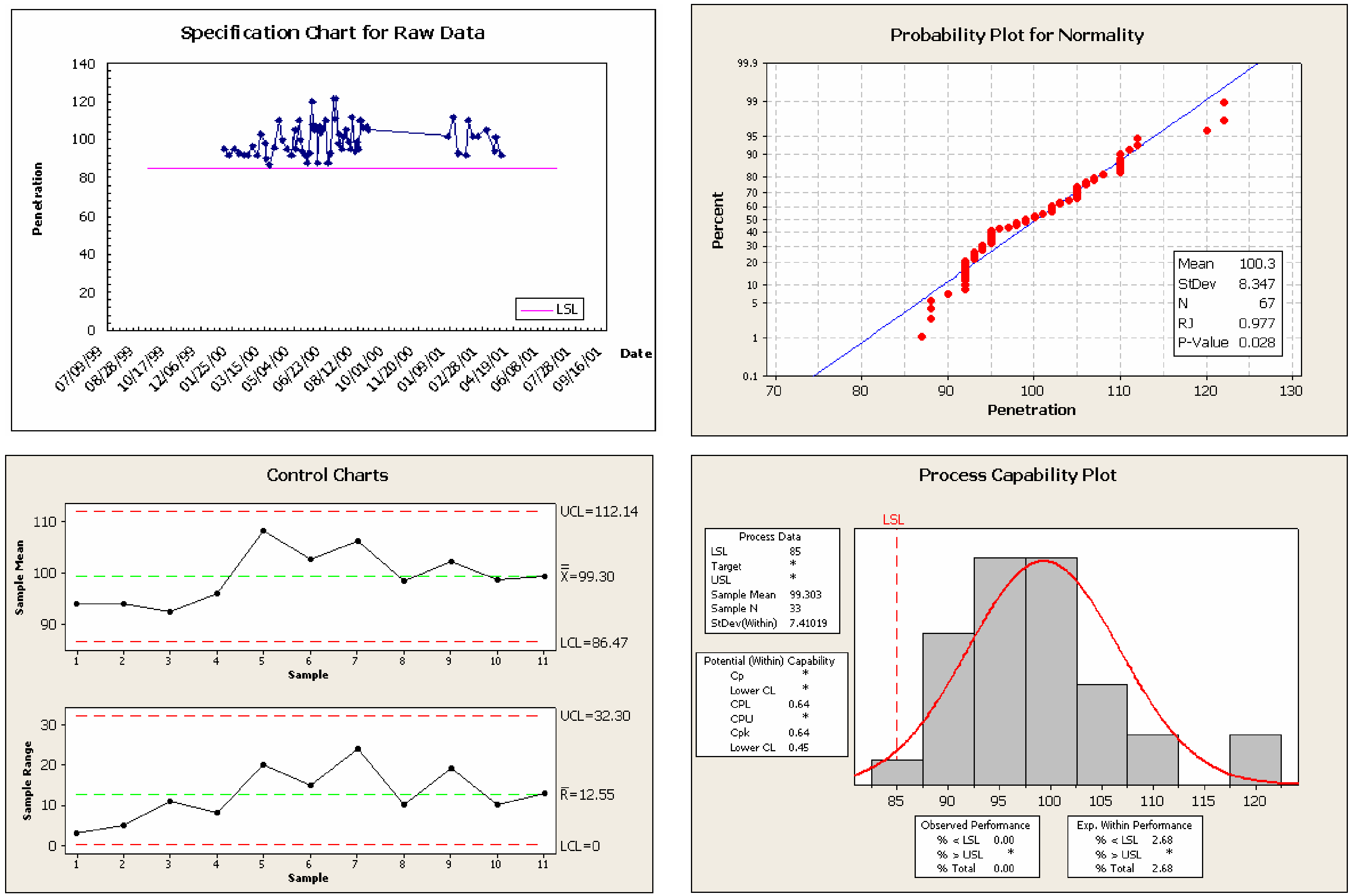


Figure G-8 Statistical Analysis Charts for Supplier: 0101 Grade: AC-10 Test: Penetration

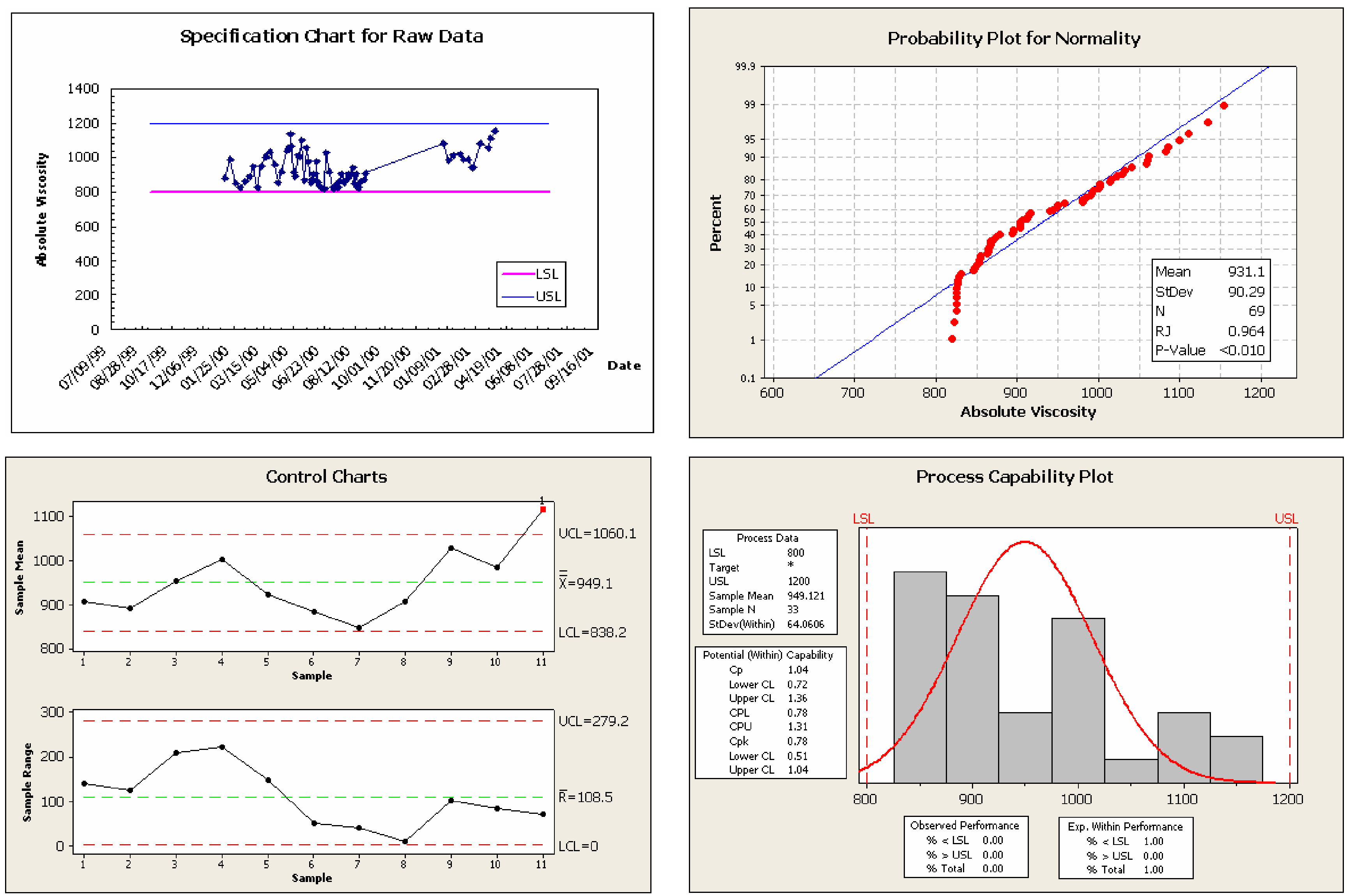


Figure G-9 Statistical Analysis Charts for Supplier: 0101 Grade: AC-10 Test: Absolute Viscosity

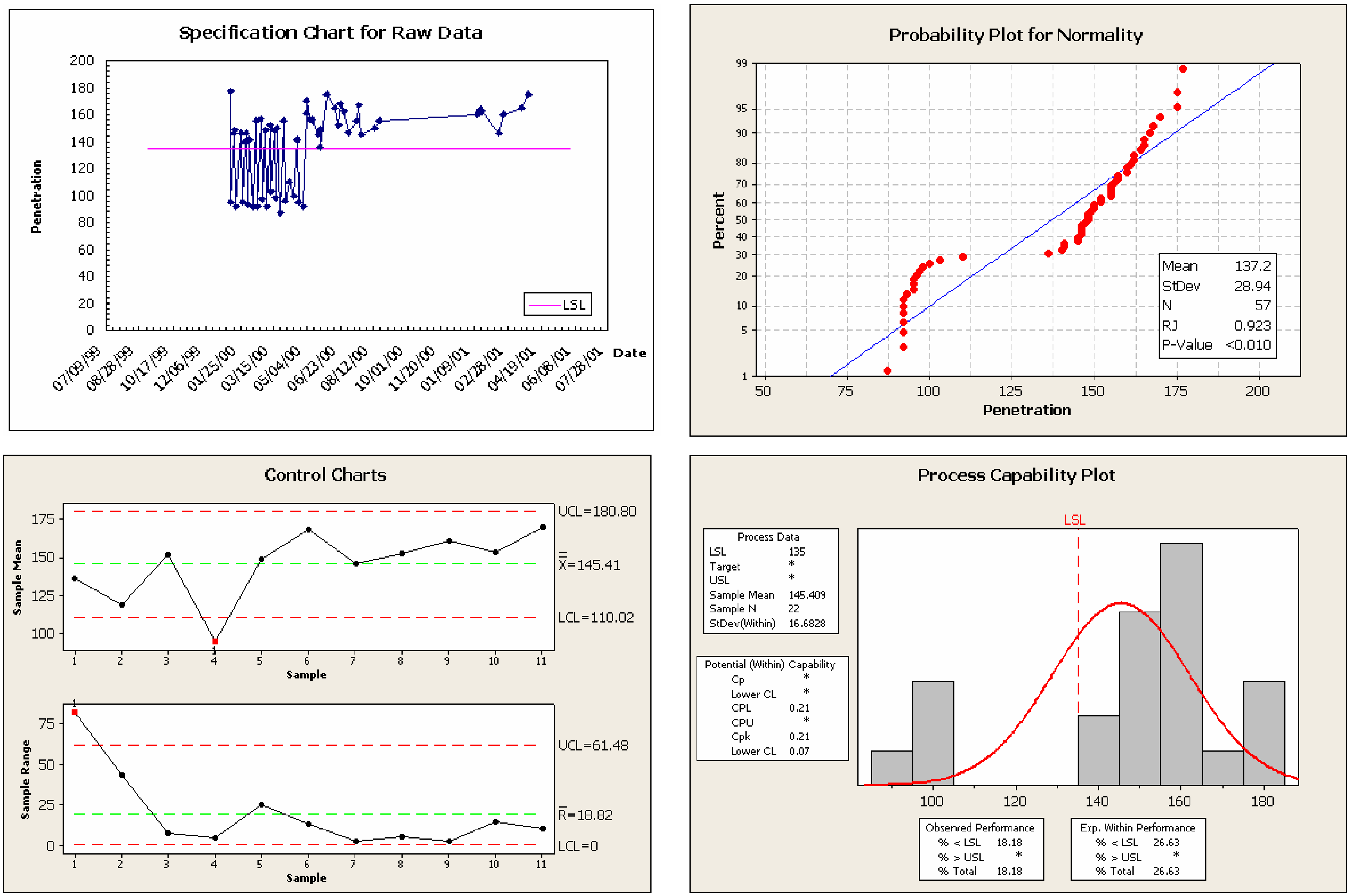


Figure G-10 Statistical Analysis Charts for Supplier: 0101 Grade: AC-5 Test: Penetration

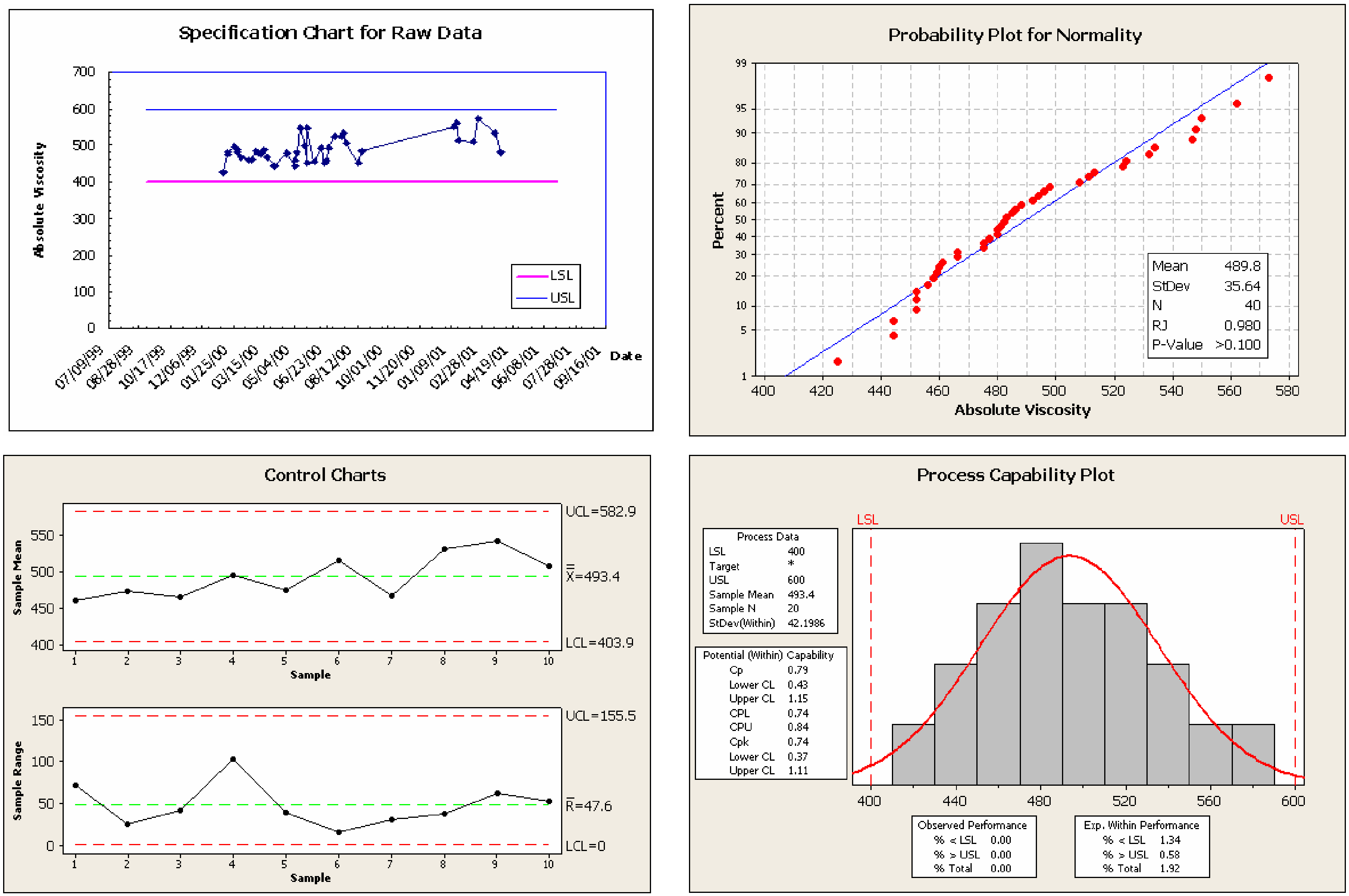


Figure G-11 Statistical Analysis Charts for Supplier: 0101 Grade: AC-5 Test: Absolute Viscosity

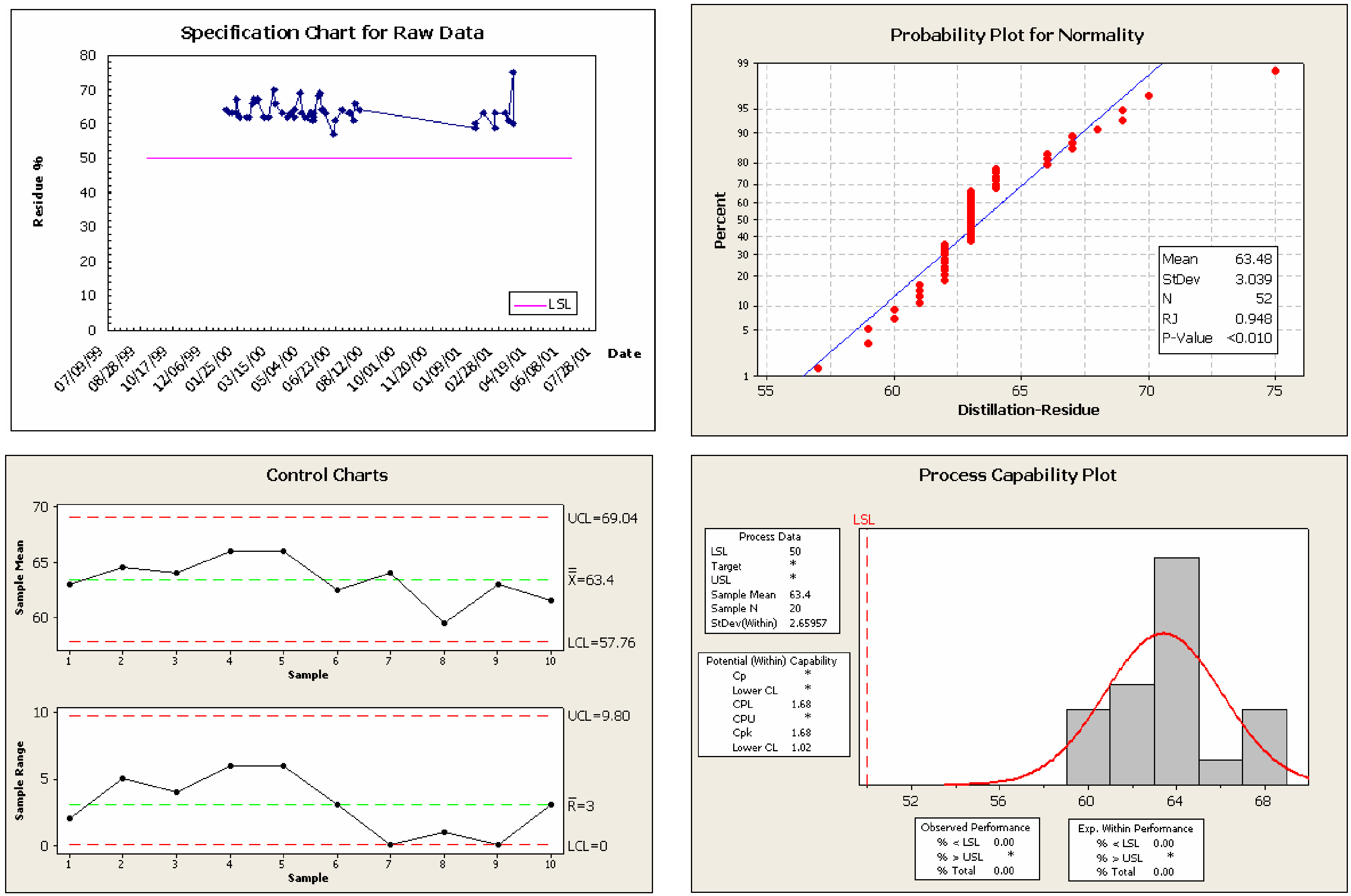


Figure G-12 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation-Residue

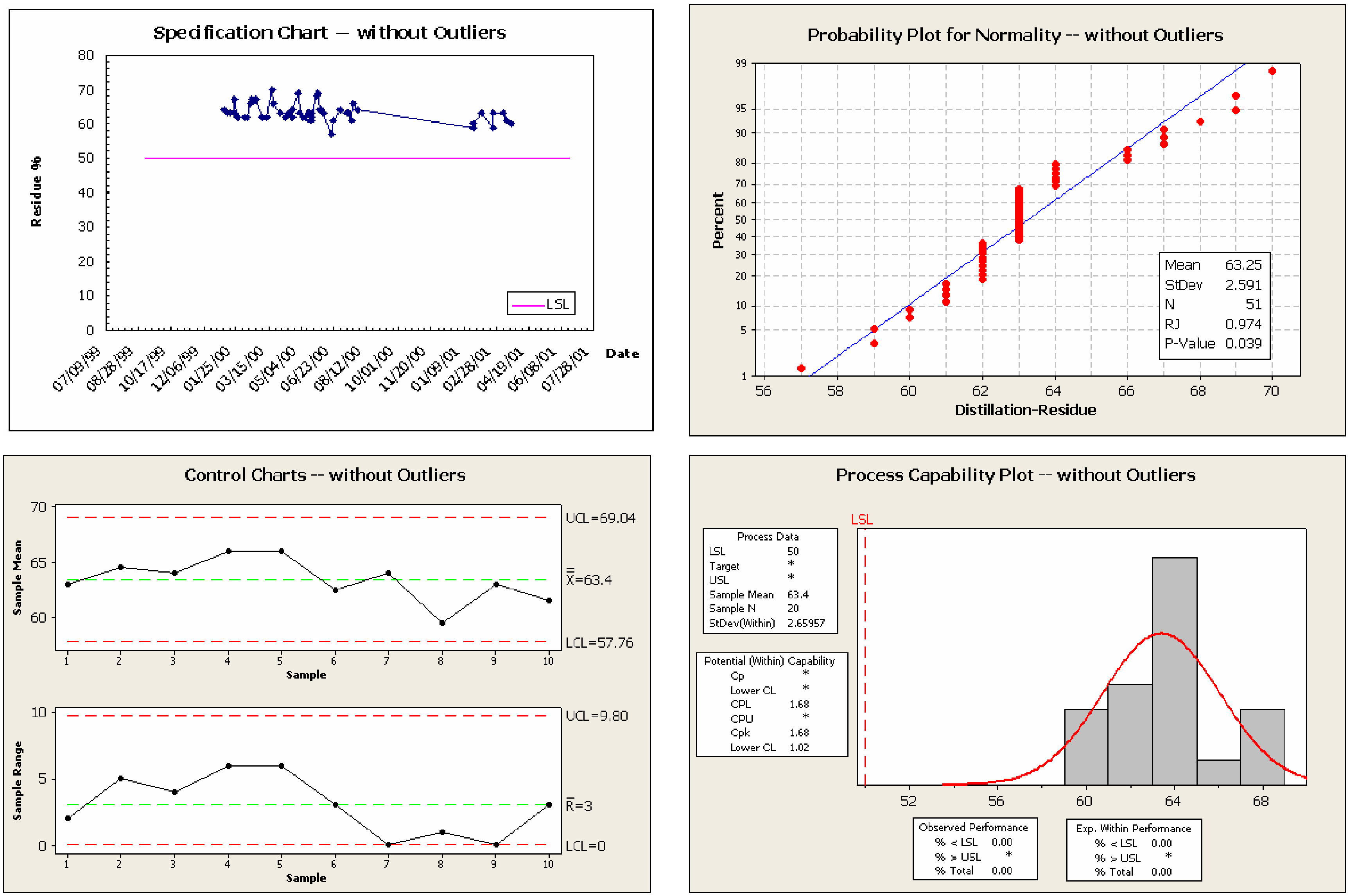


Figure G-13 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: MC-30 Test: Distillation-Residue

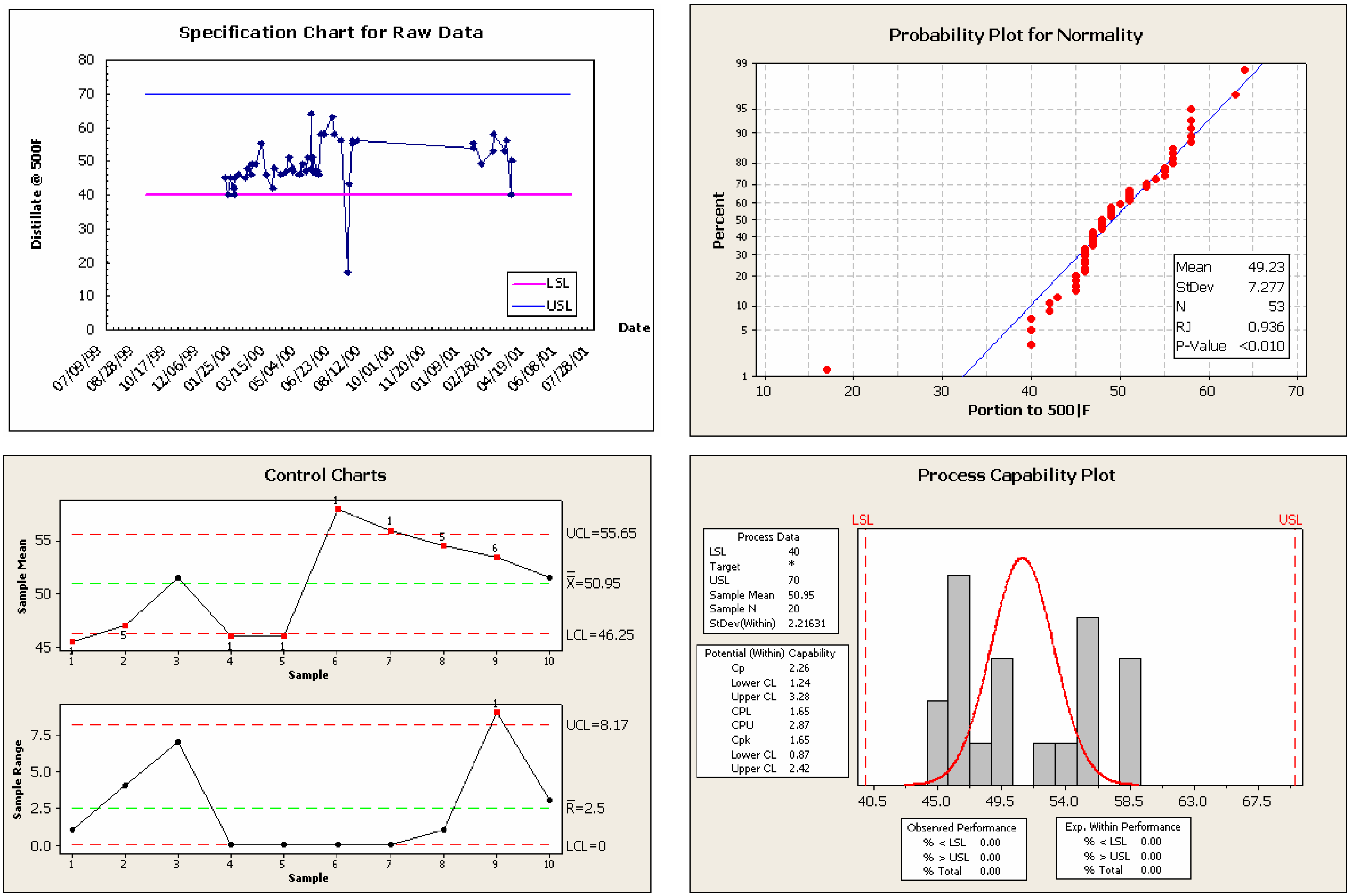


Figure G-14 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation @ 500|F

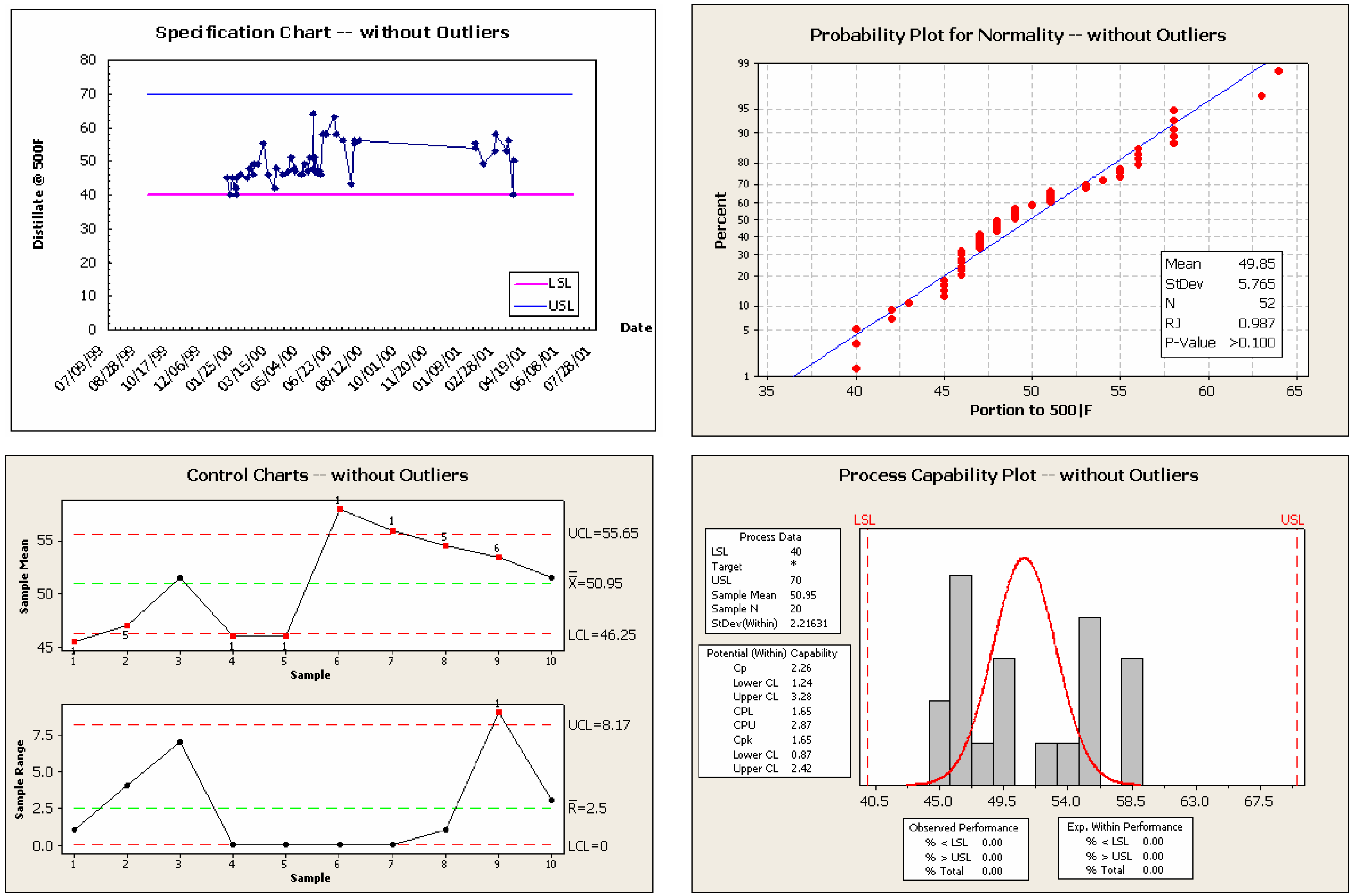


Figure G-15 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: MC-30 Test: Distillation @ 500|F

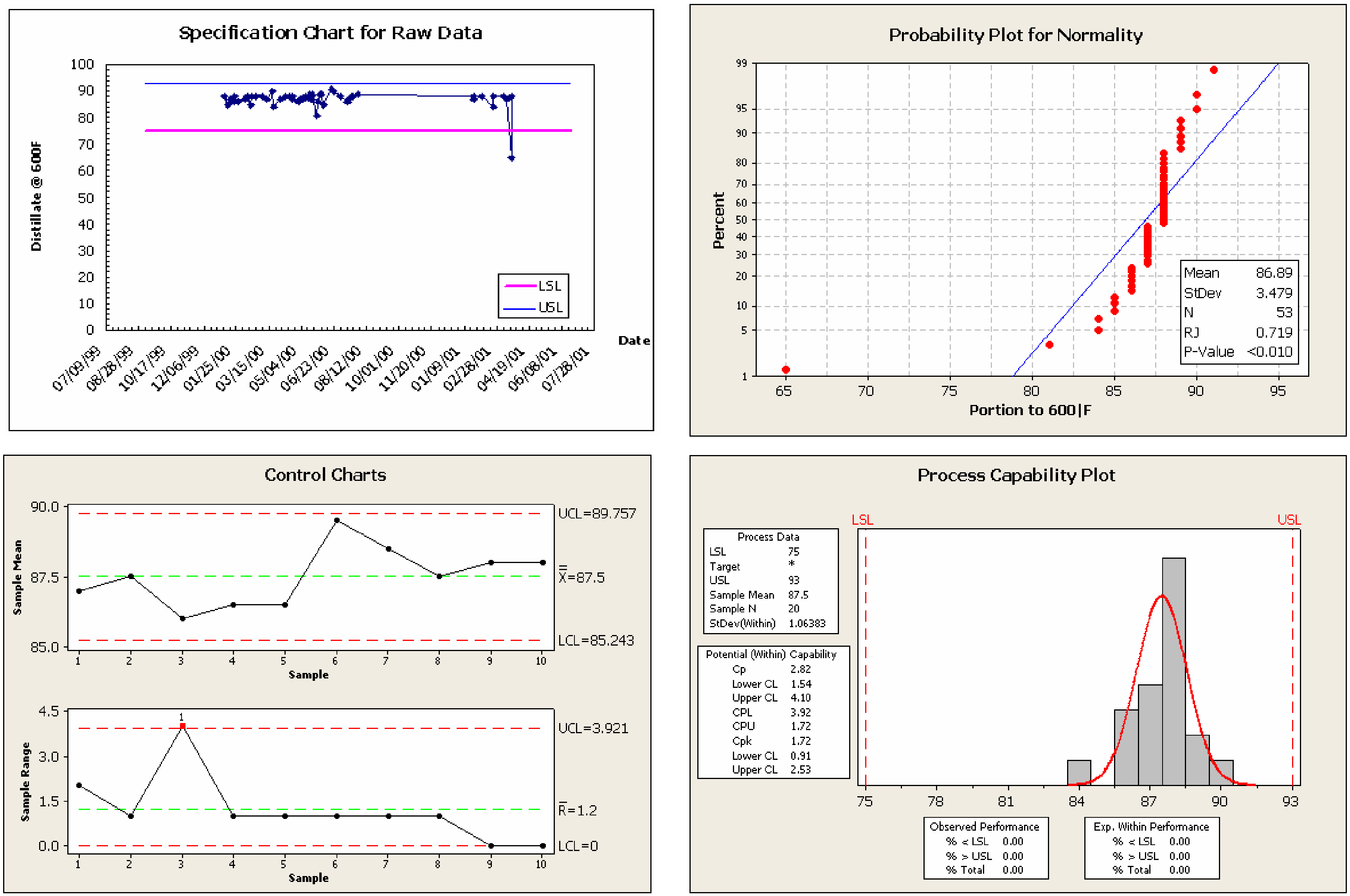


Figure G-16 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Distillation @ 600|F

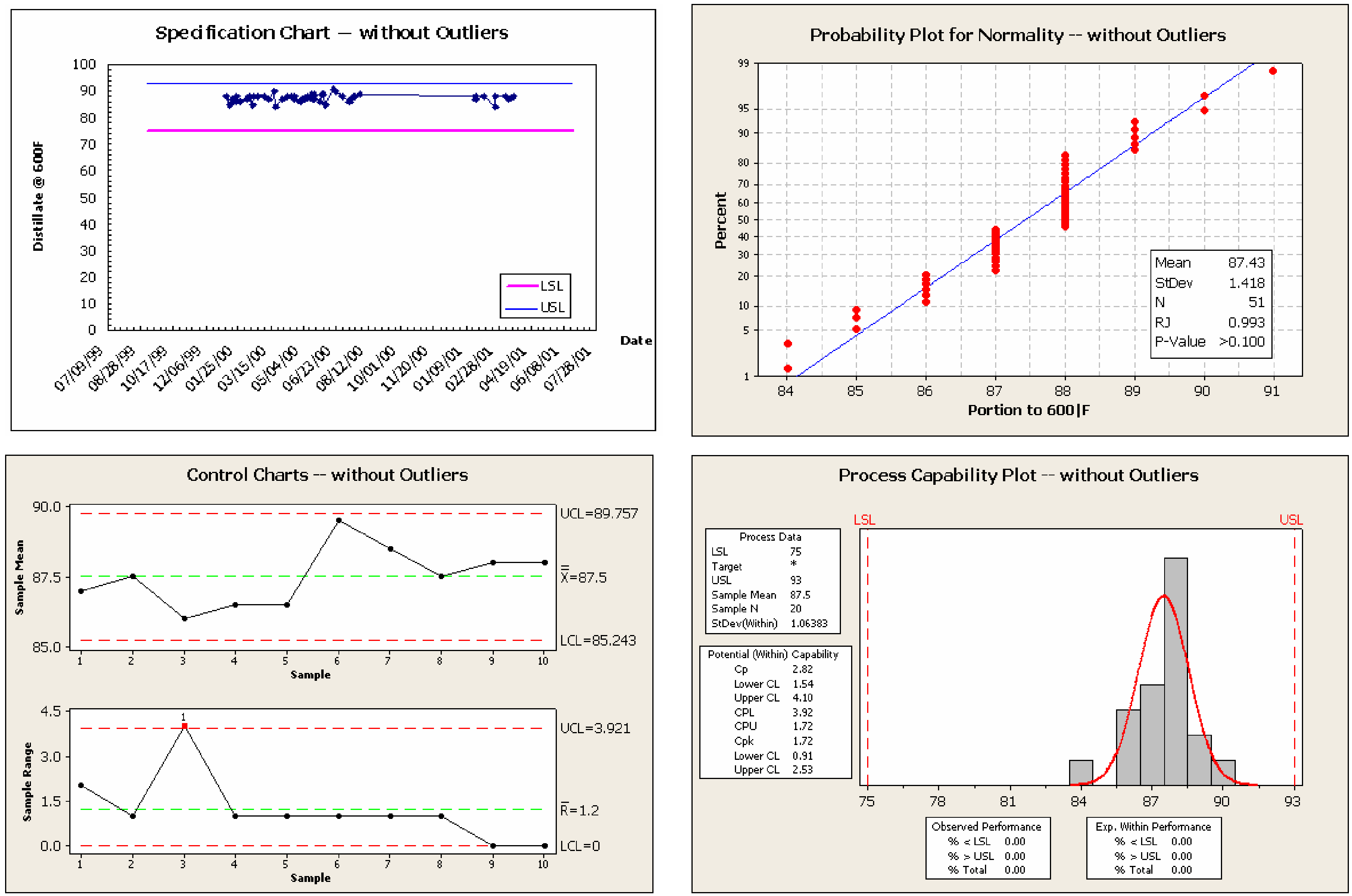


Figure G-17 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: MC-30 Test: Distillation @ 600|F

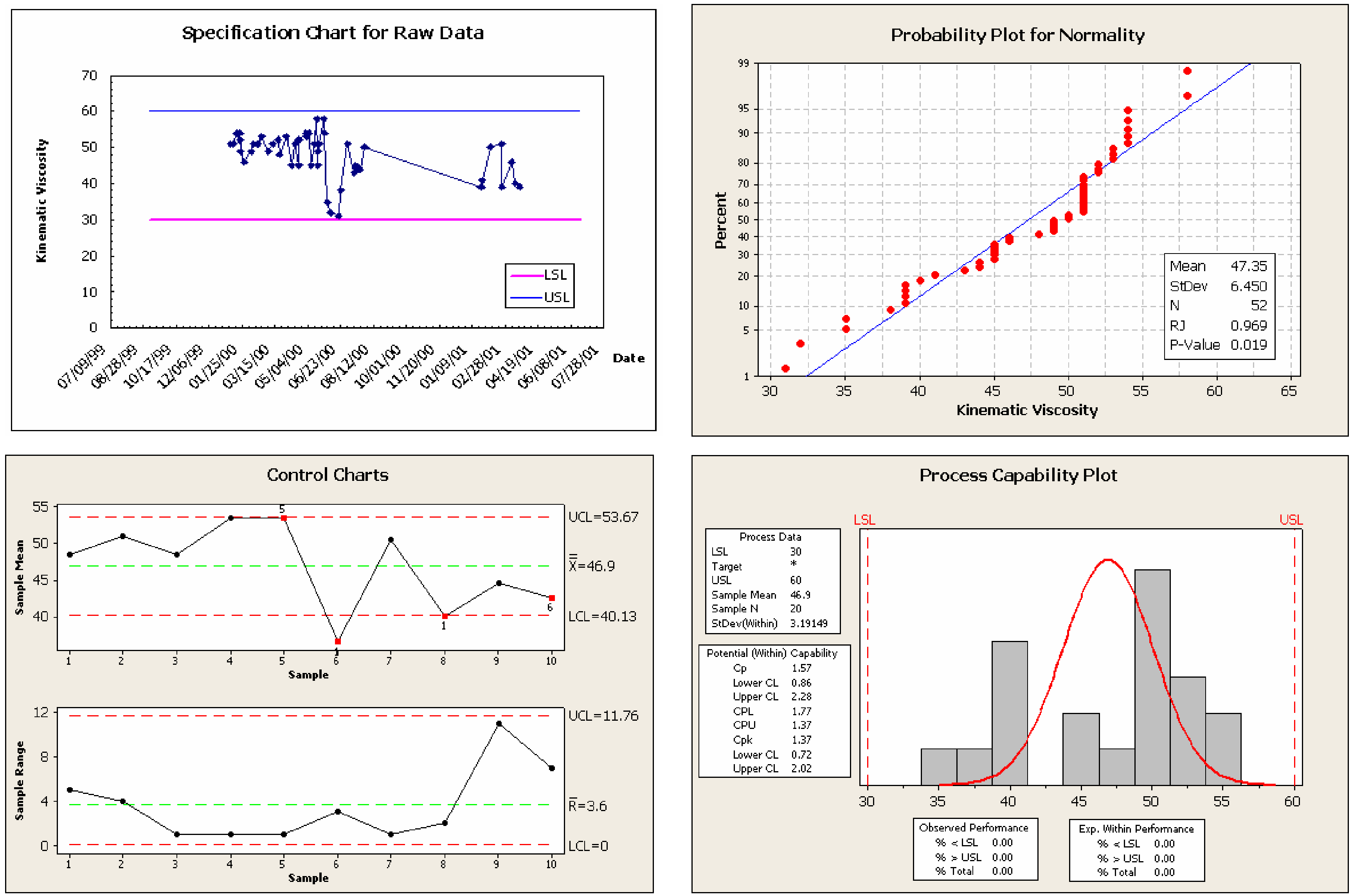


Figure G-18 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Kinematic Viscosity

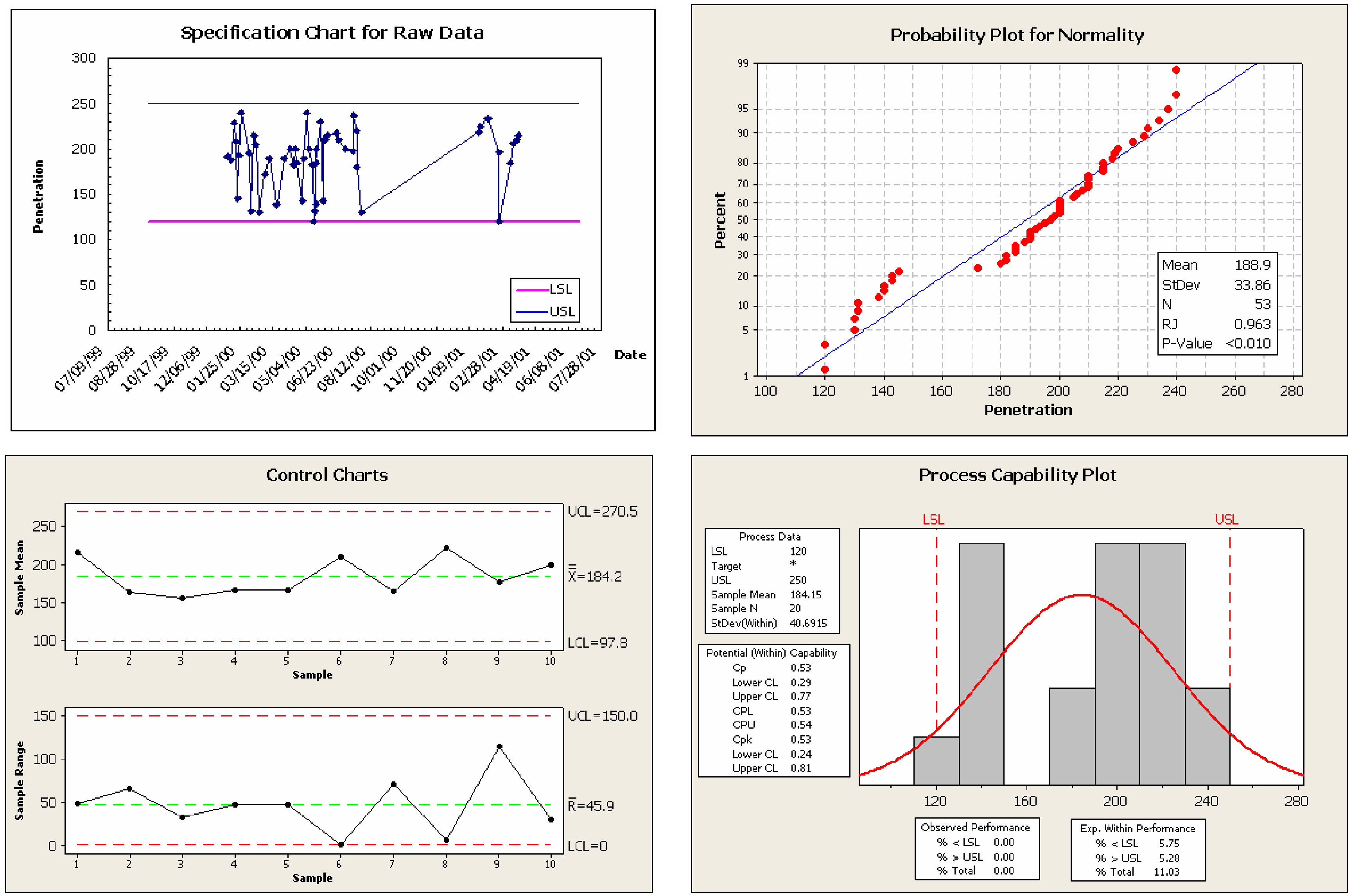


Figure G-19 Statistical Analysis Charts for Supplier: 0101 Grade: MC-30 Test: Penetration

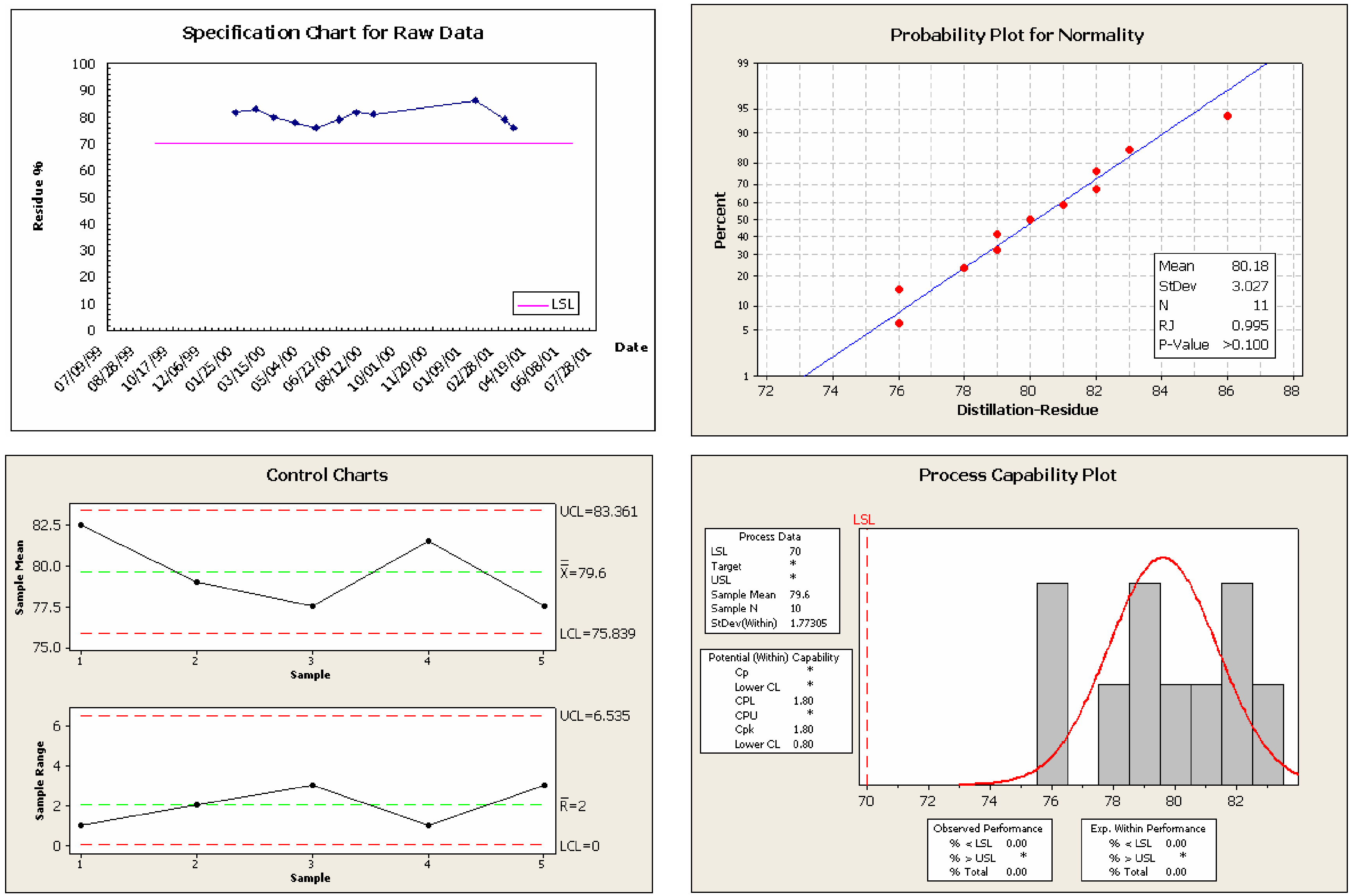


Figure G-20 Statistical Analysis Charts for Supplier: 0101 Grade: RC-250 Test: Distillation-Residue

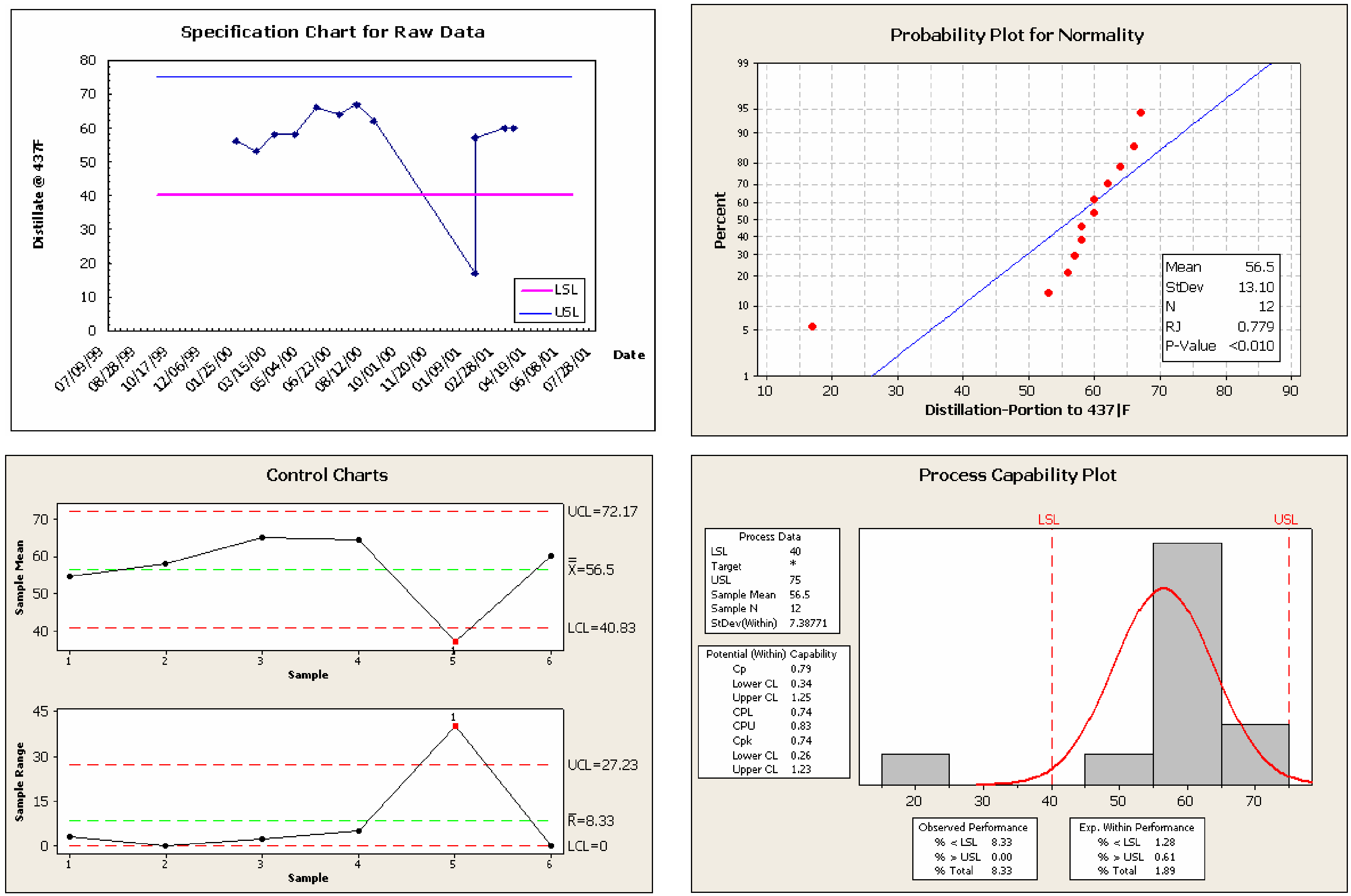


Figure G-21 Statistical Analysis Charts for Supplier: 0101 Grade: RC-250 Test: Distillation @ 437|F

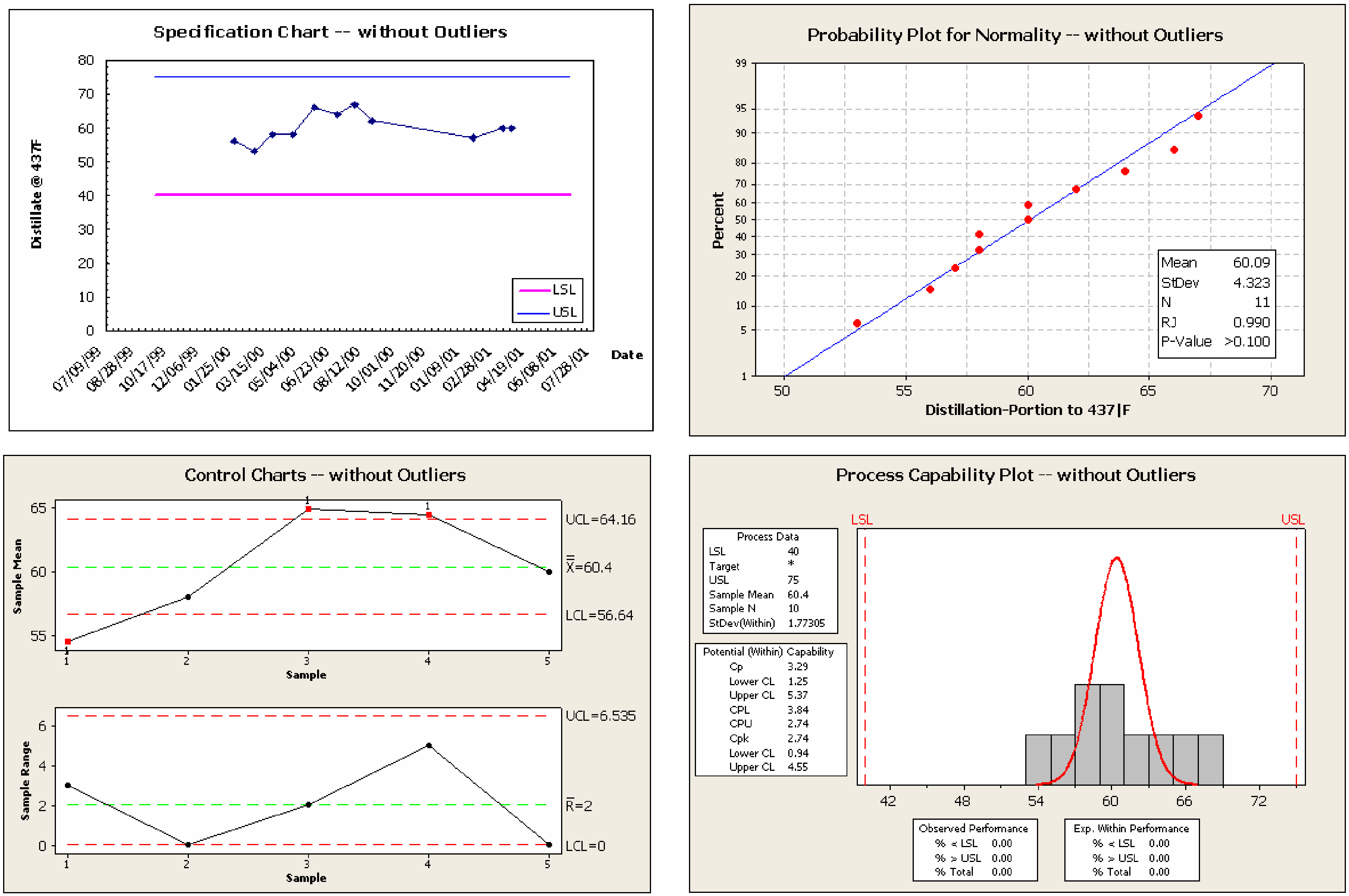


Figure G-22 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: RC-250 Test: Distillation @ 437|F

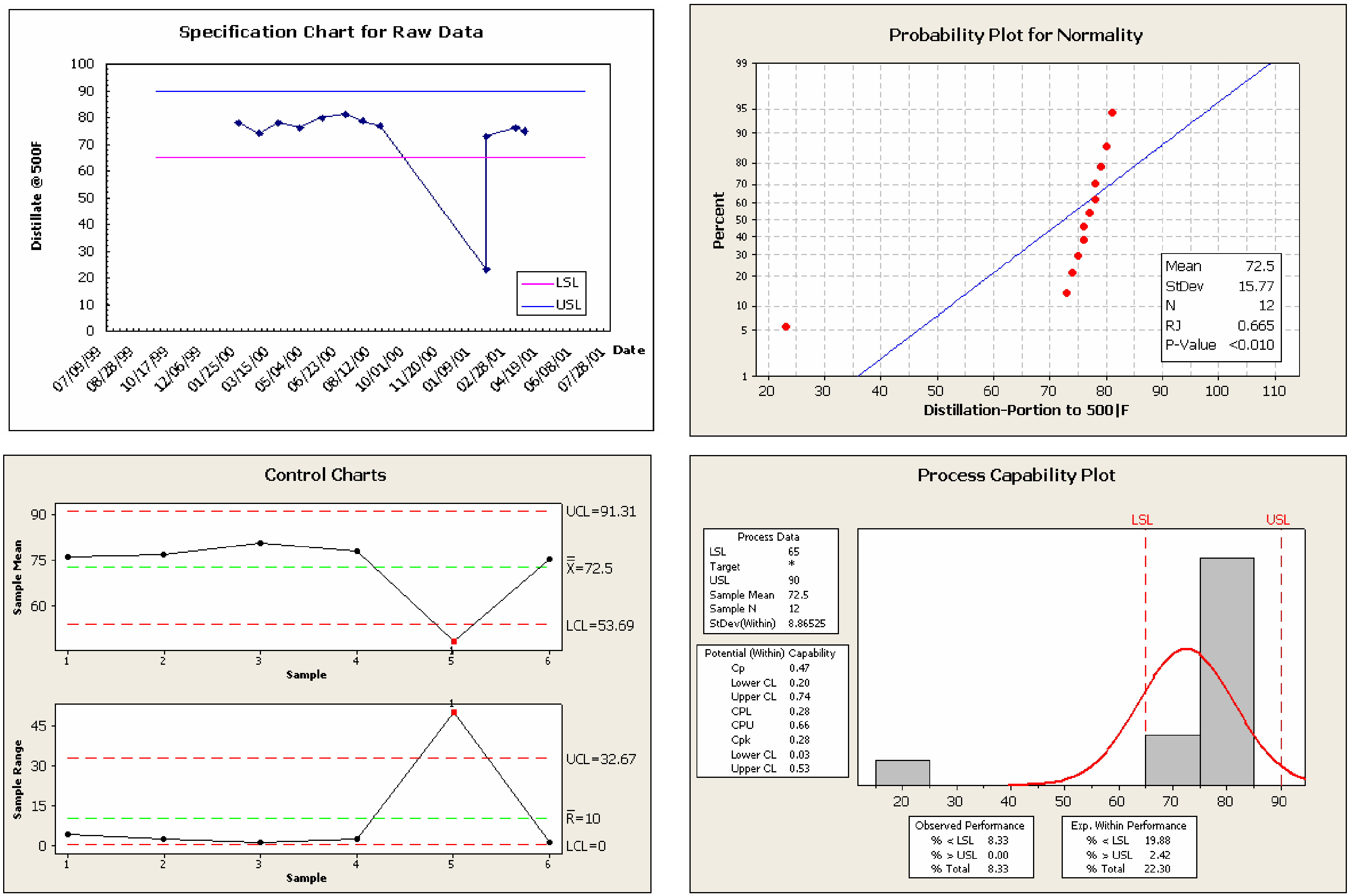


Figure G-23 Statistical Analysis Charts for Supplier: 0101 Grade: RC-250 Test: Distillation @ 500|F

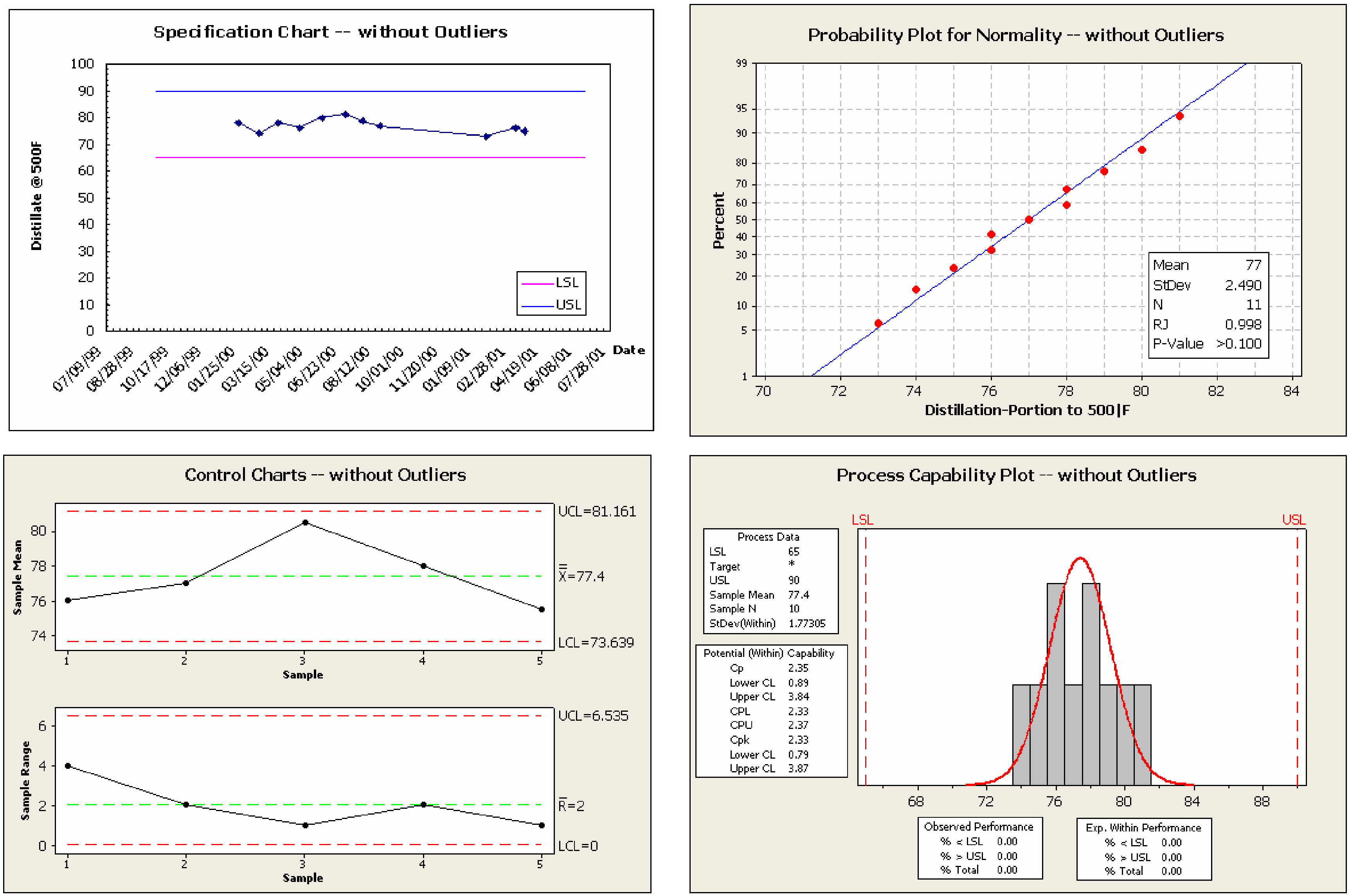


Figure G-24 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: RC-250 Test: Distillation @ 500|F

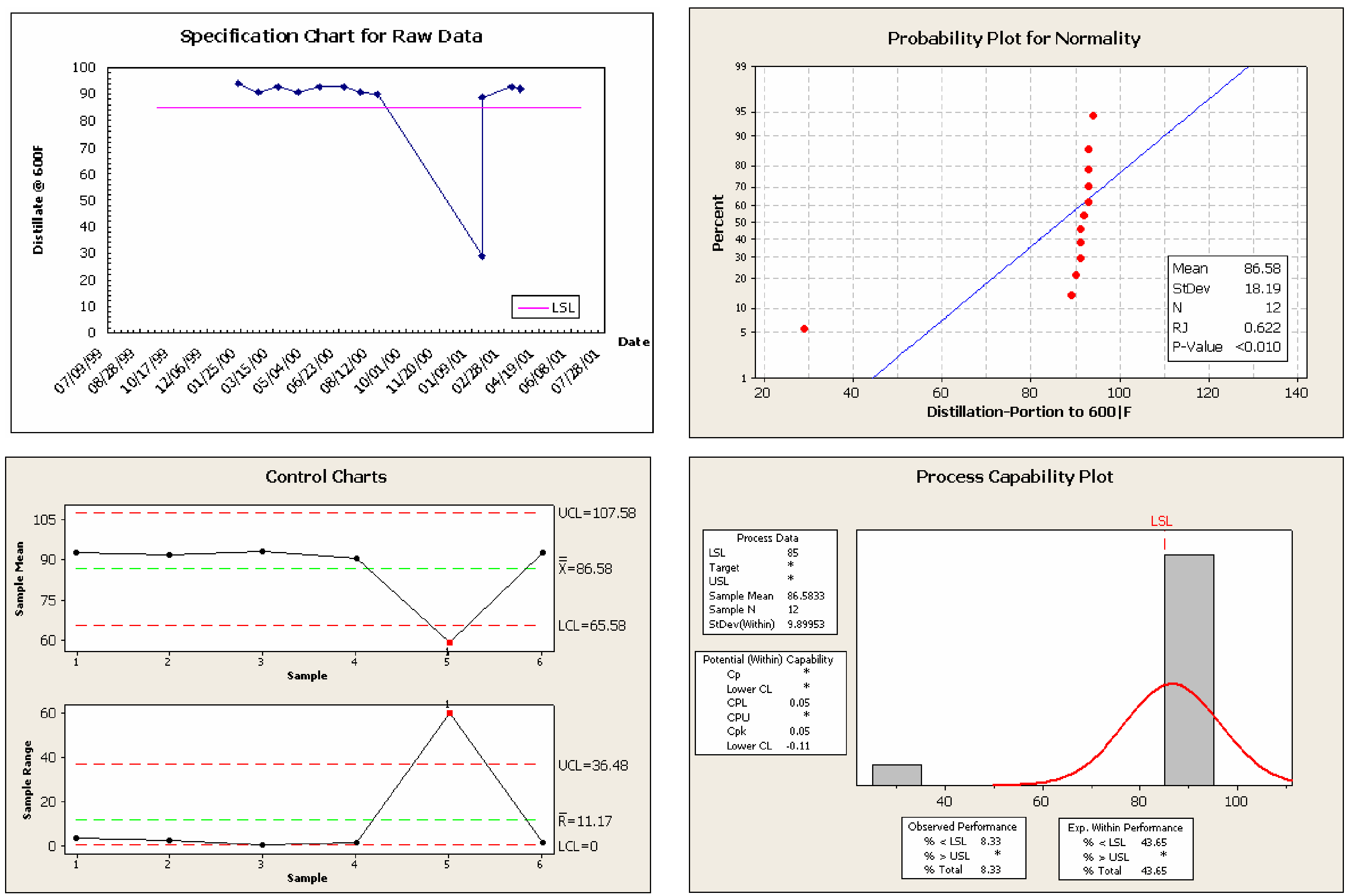


Figure G-25 Statistical Analysis Charts for Supplier: 0101 Grade: RC-250 Test: Distillation @ 600|F

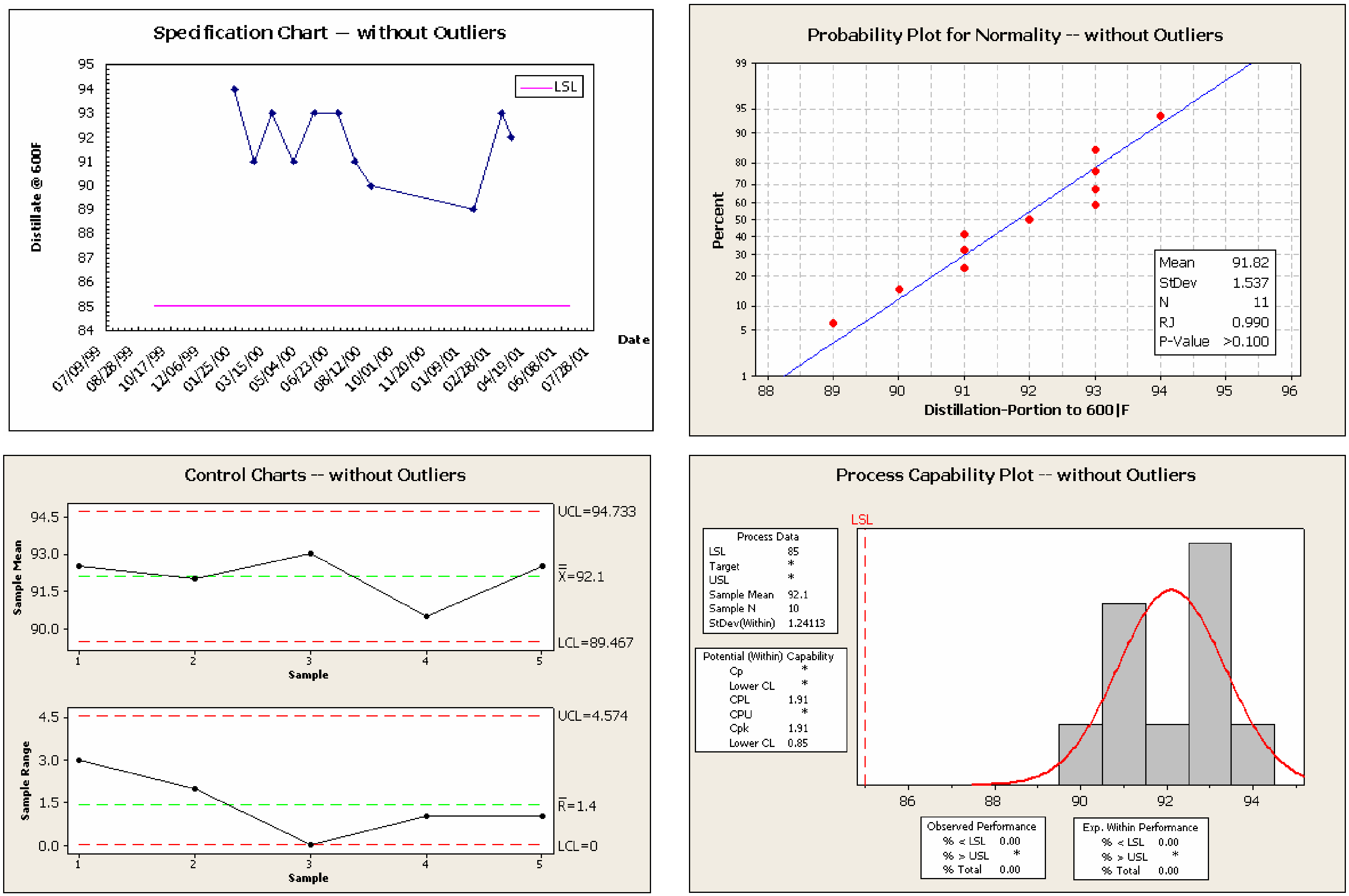


Figure G-26 Statistical Analysis Charts (without Outliers) for Supplier: 0101 Grade: RC-250 Test: Distillation @ 600|F

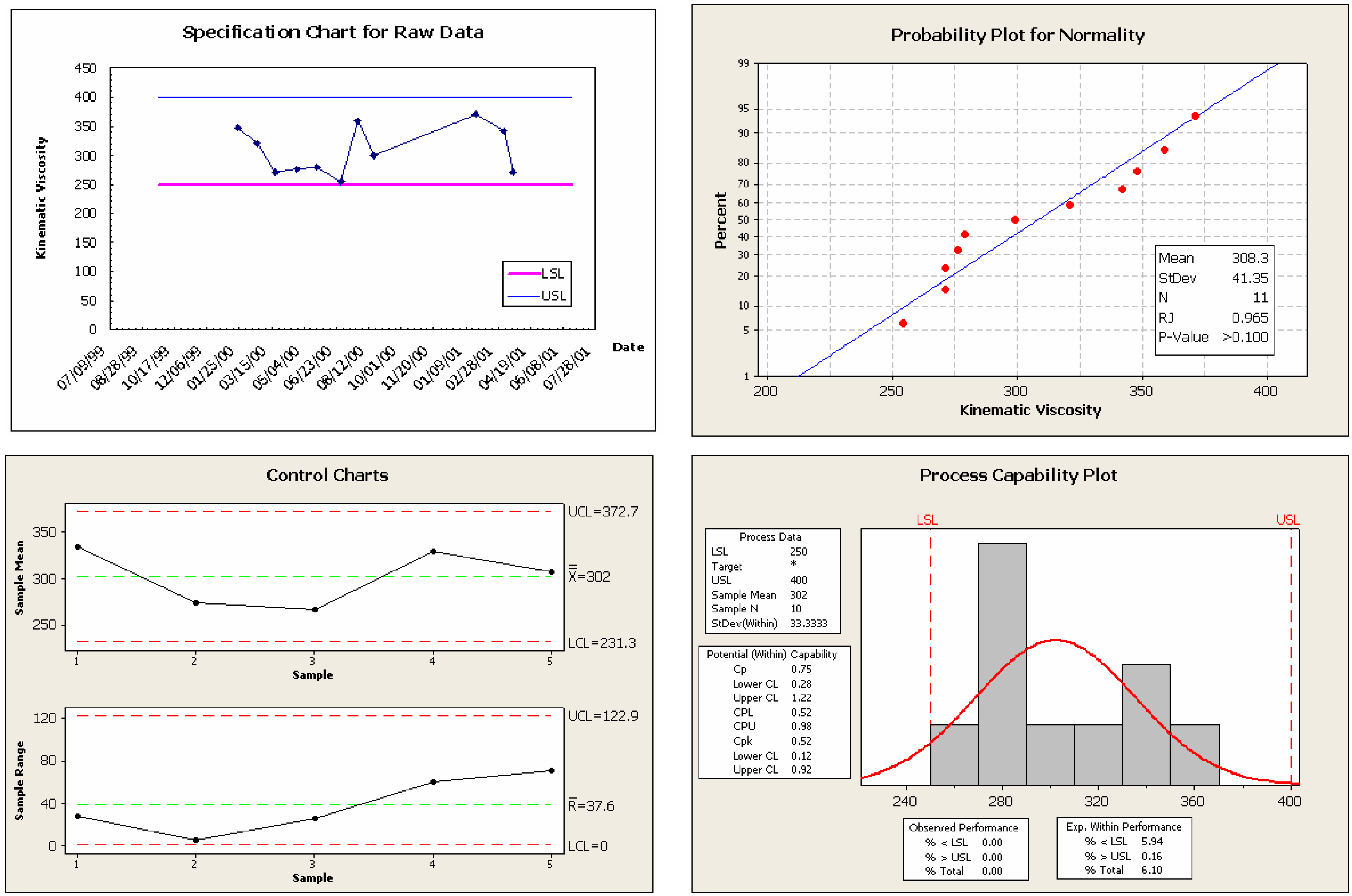


Figure G-27 Statistical Analysis Charts for Supplier: 0101 Grade: RC-250 Test: Kinematic Viscosity

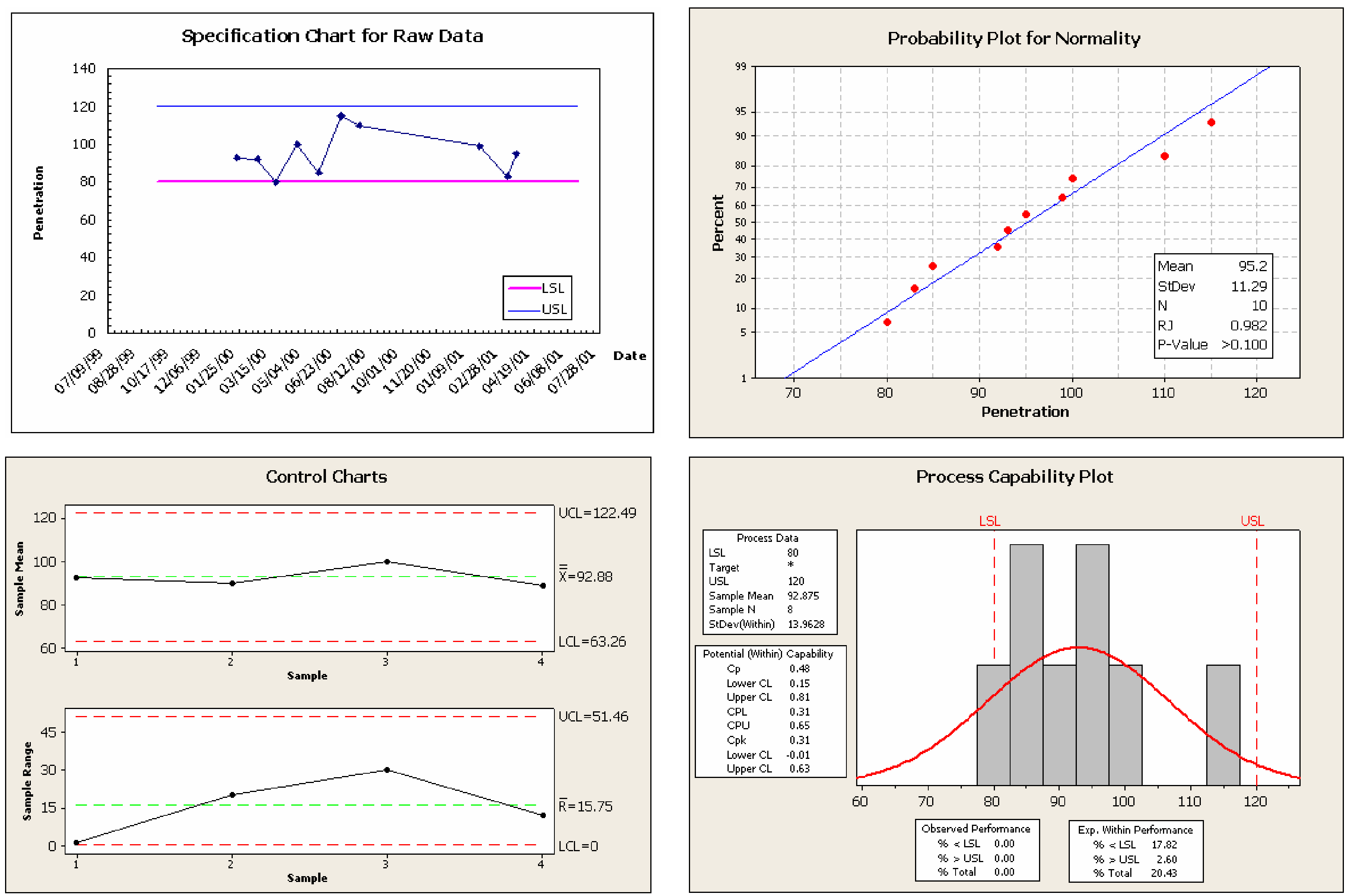


Figure G-28 Statistical Analysis Charts for Supplier: 0101 Grade: RC-250 Test: Penetration

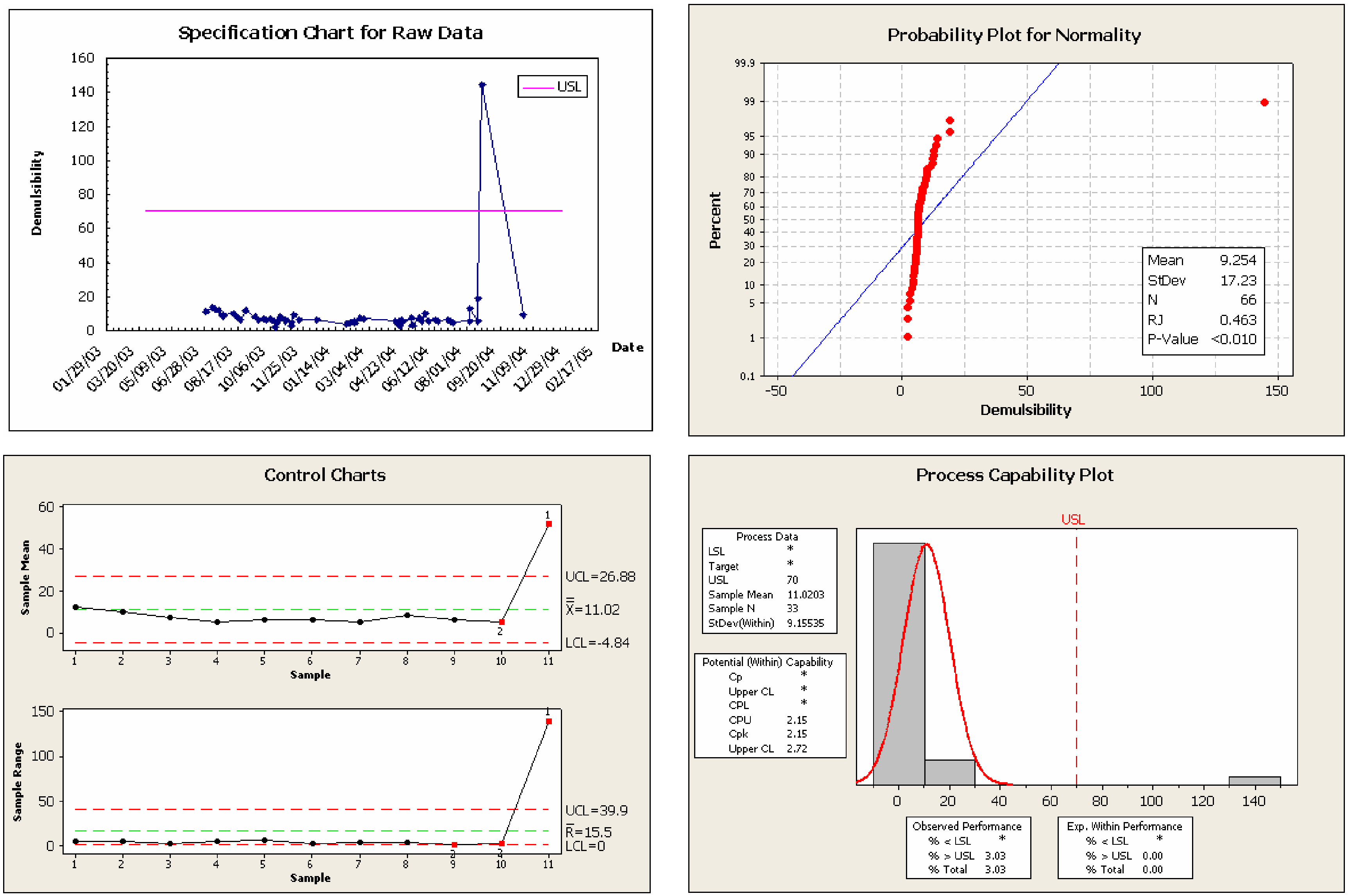


Figure G-29 Statistical Analysis Charts for Supplier: 0701 Grade: AE-P Test: Demulsibility

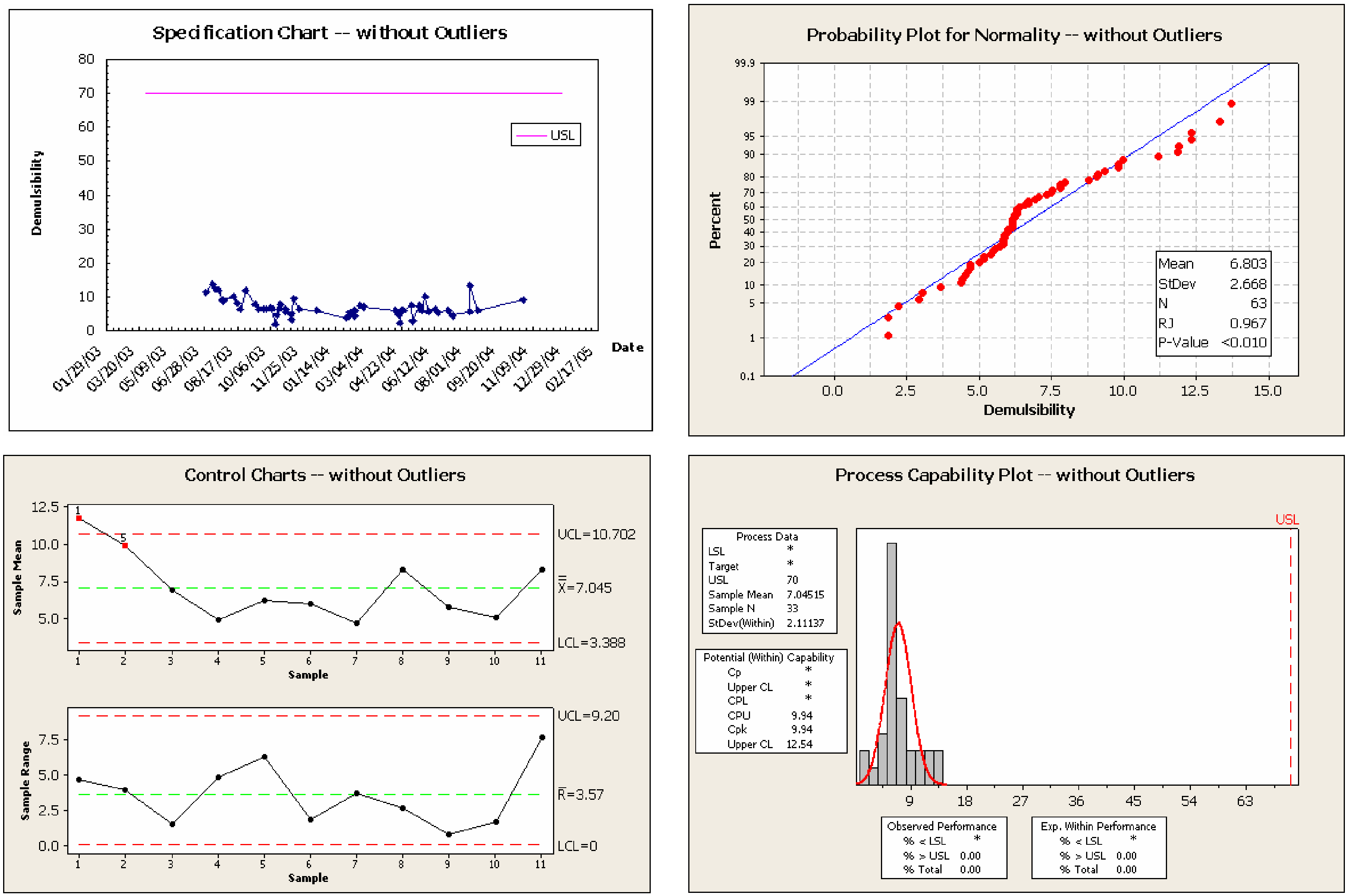


Figure G-30 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: AE-P Test: Demulsibility

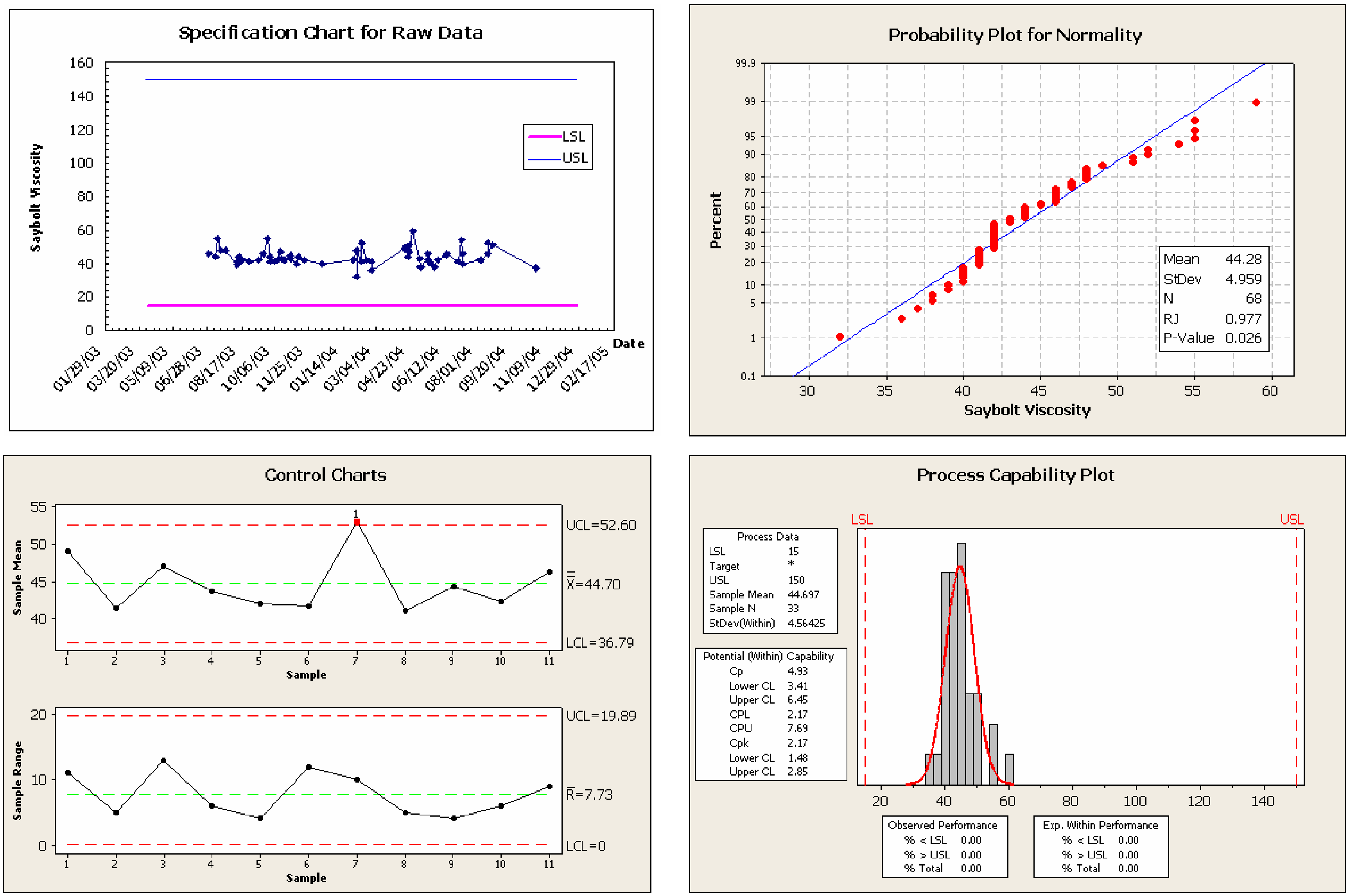


Figure G-31 Statistical Analysis Charts for Supplier: 0701 Grade: AE-P Test: Saybolt Viscosity

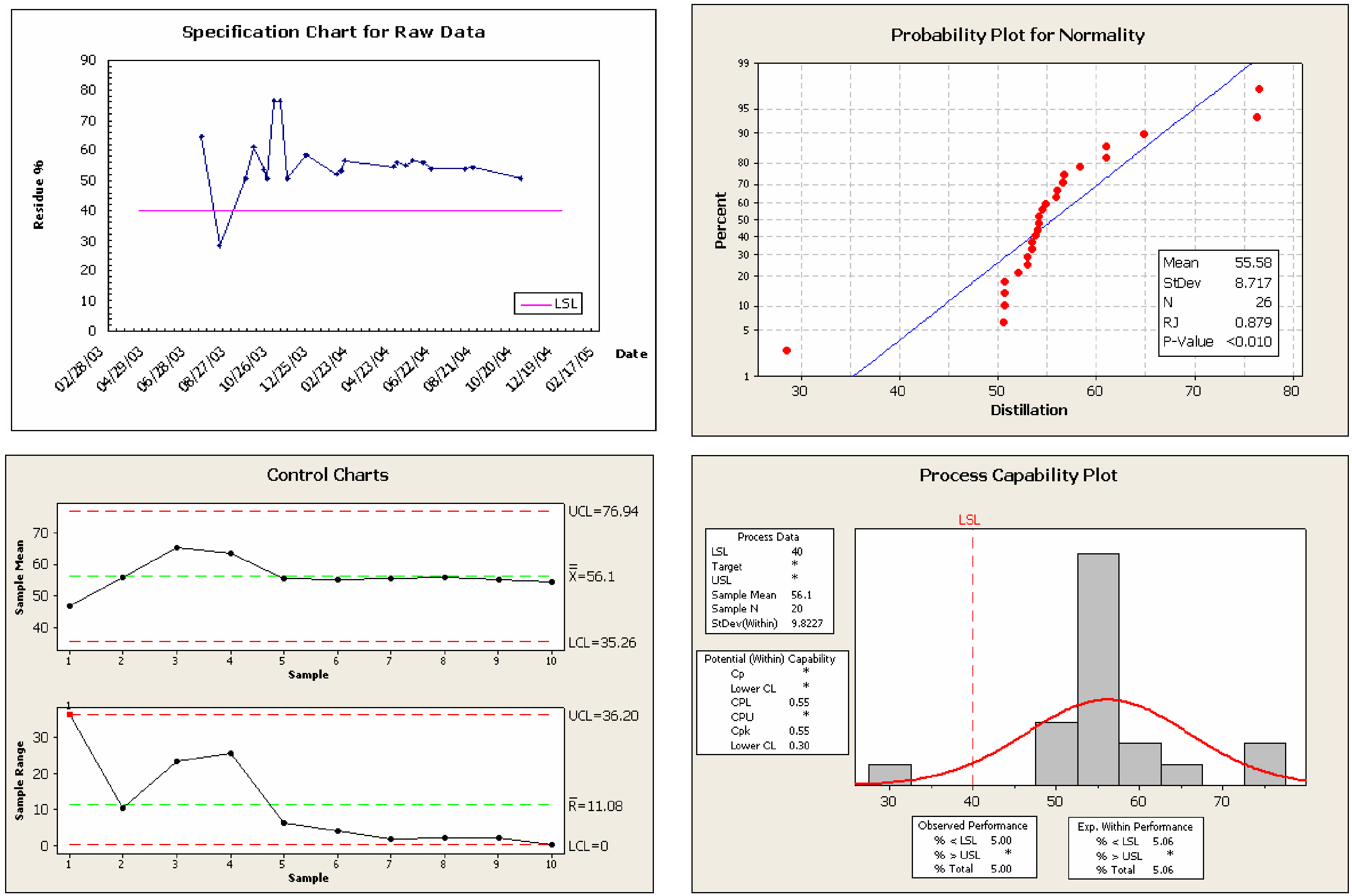


Figure G-32 Statistical Analysis Charts for Supplier: 0701 Grade: AE-P Test: Distillation

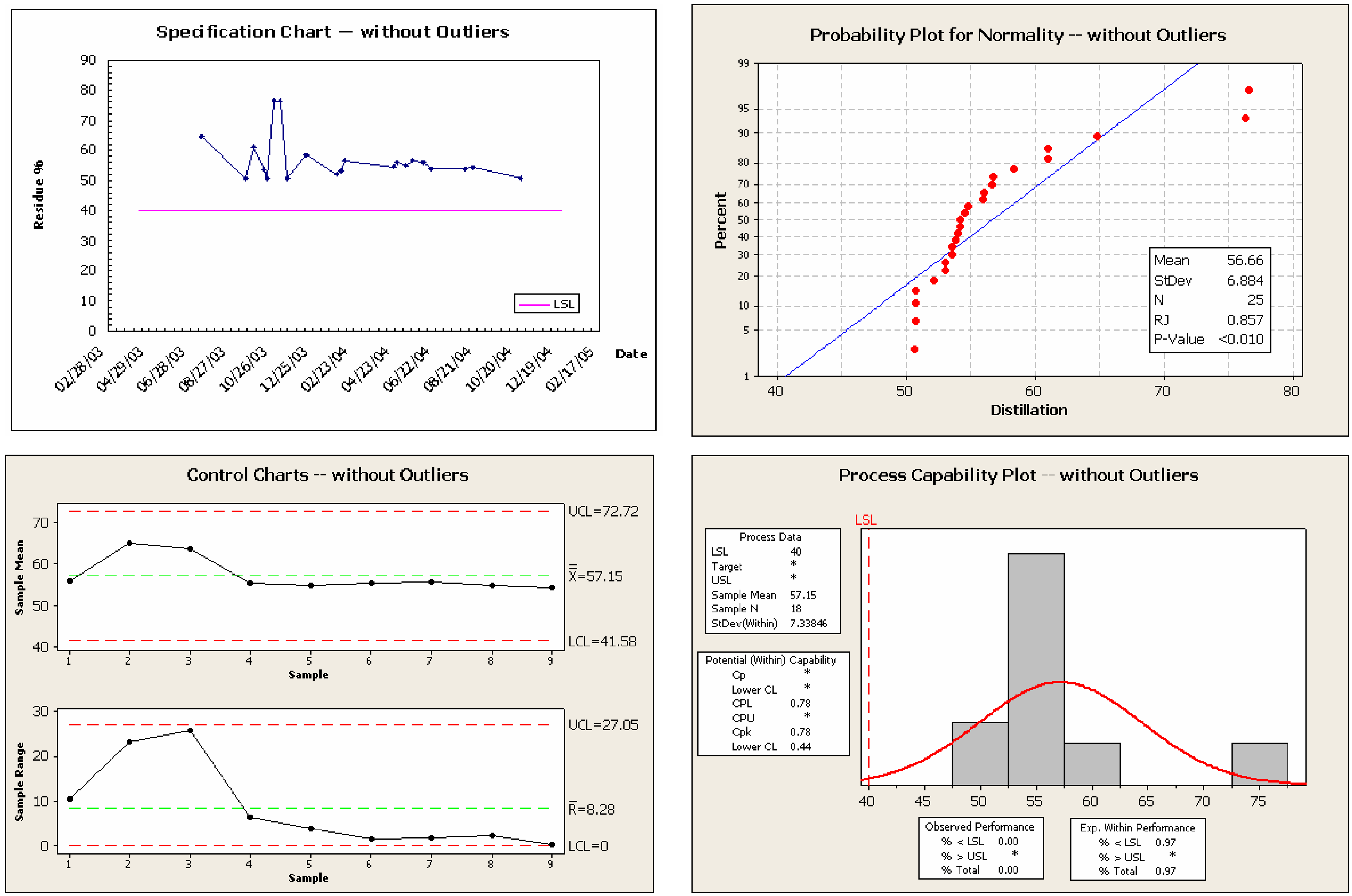


Figure G-33 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: AE-P Test: Distillation

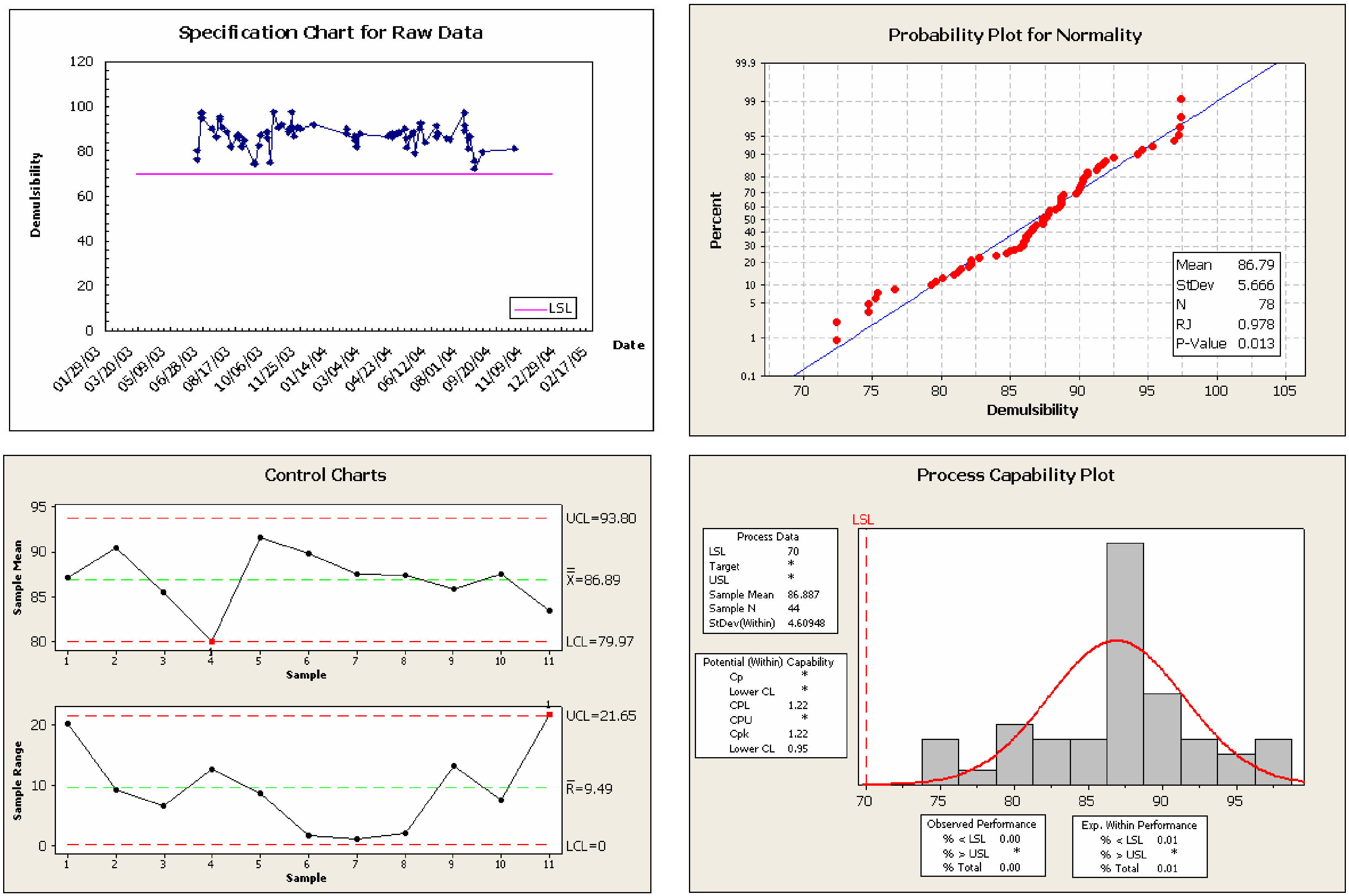


Figure G-34 Statistical Analysis Charts for Supplier: 0701 Grade: CRS-2 Test: Demulsibility

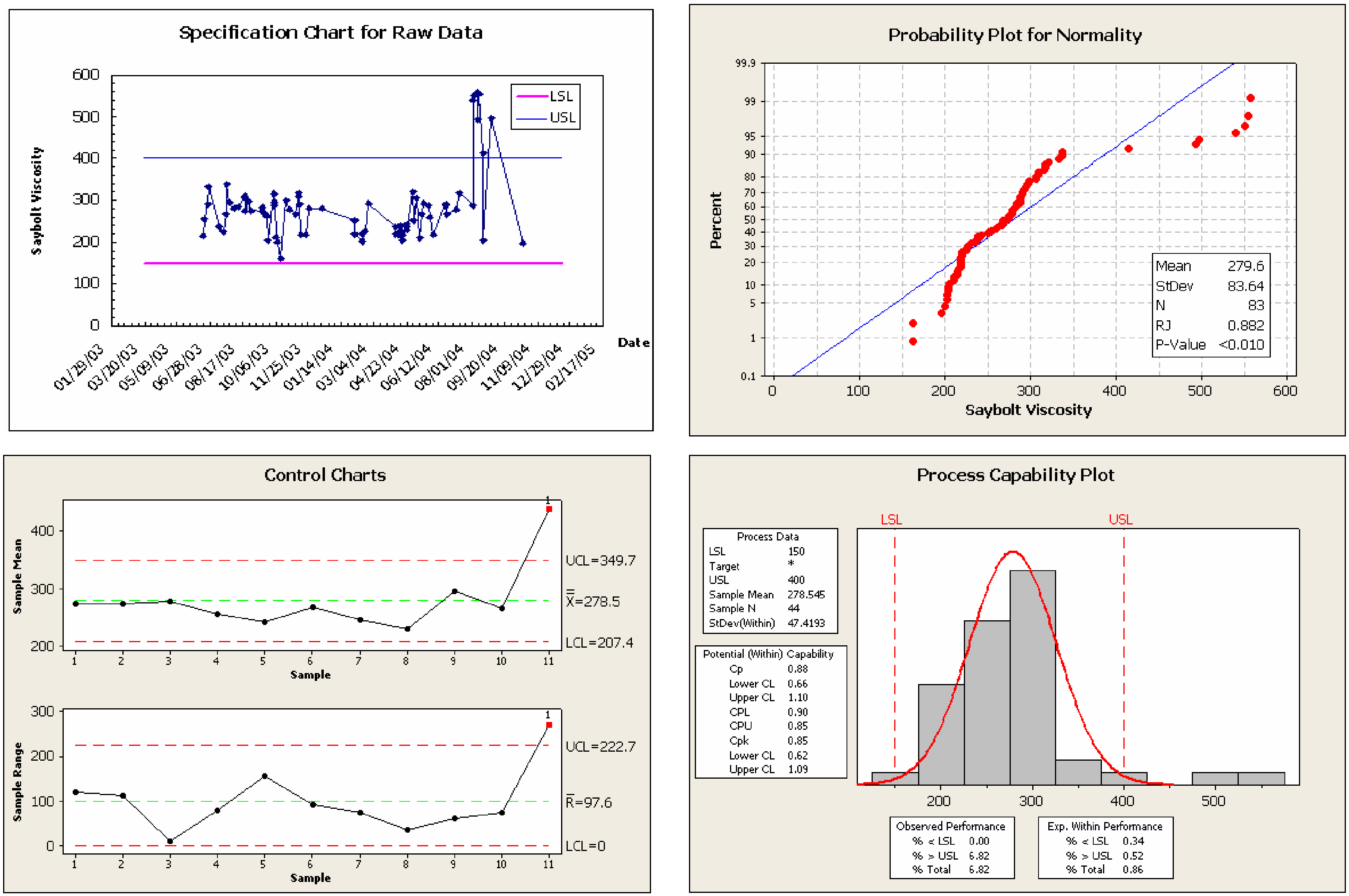


Figure G-35 Statistical Analysis Charts for Supplier: 0701 Grade: CRS-2 Test: Saybolt Viscosity

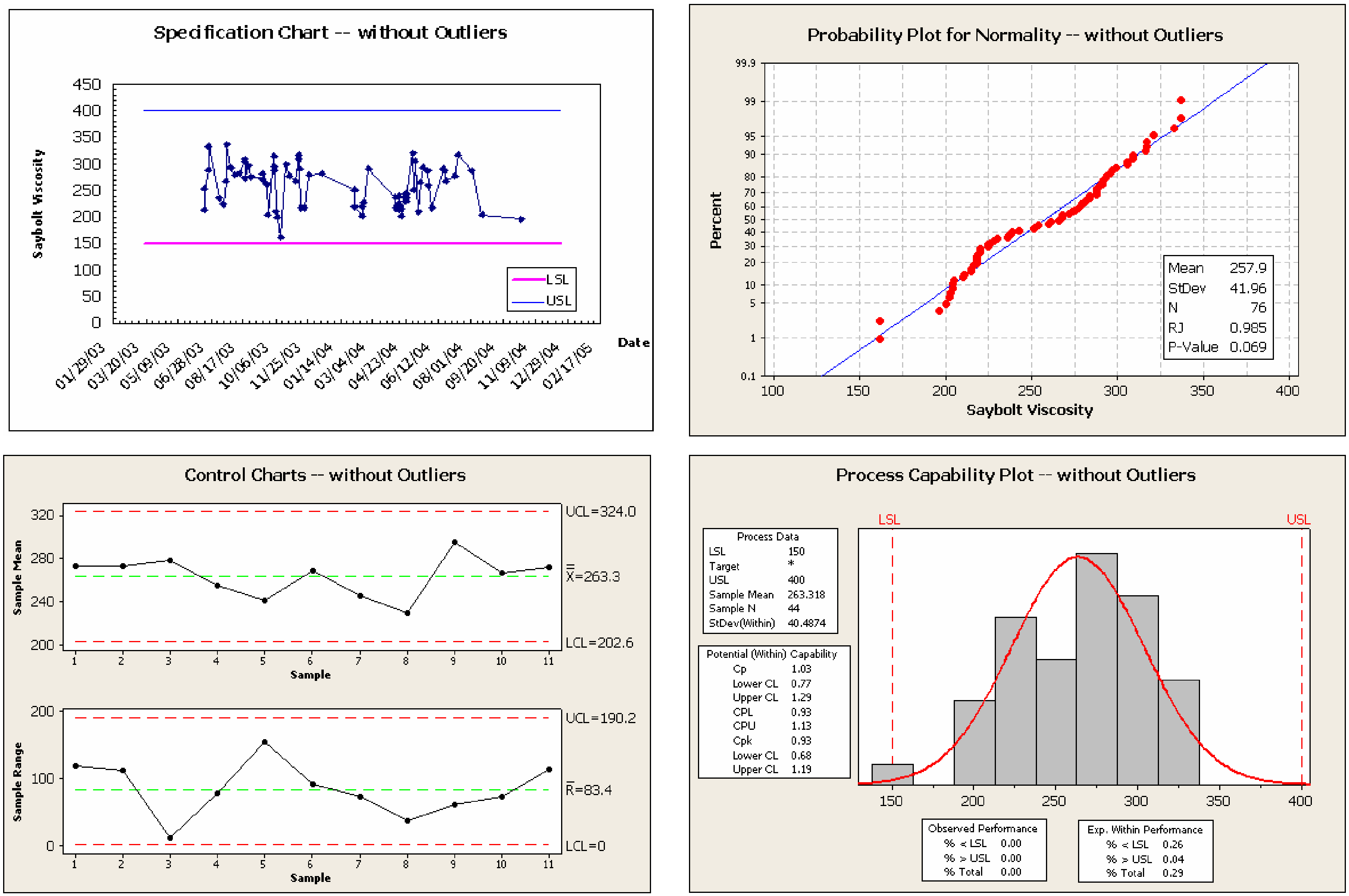


Figure G-36 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: CRS-2 Test: Saybolt Viscosity

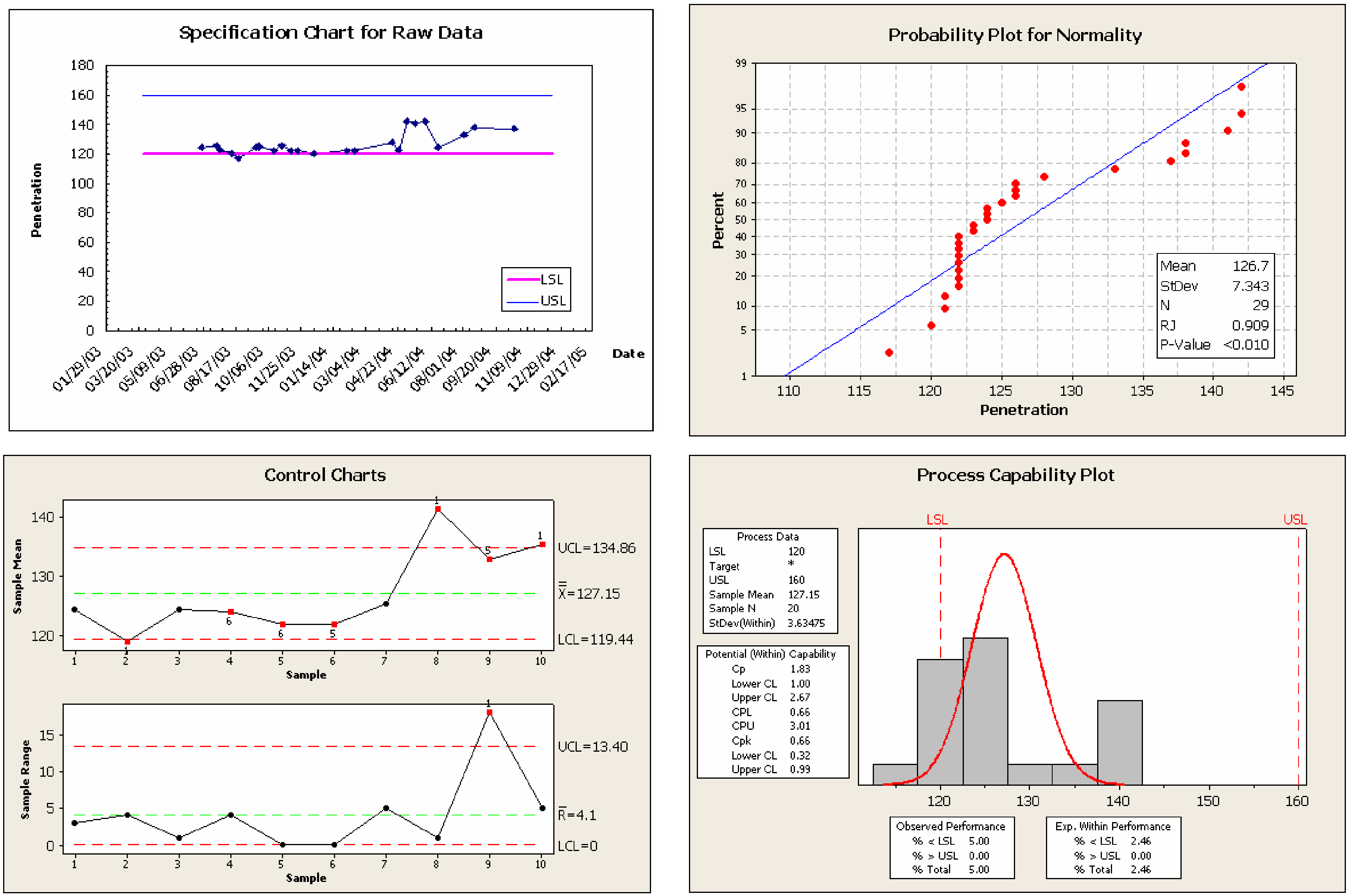


Figure G-37 Statistical Analysis Charts for Supplier: 0701 Grade: CRS-2 Test: Penetration

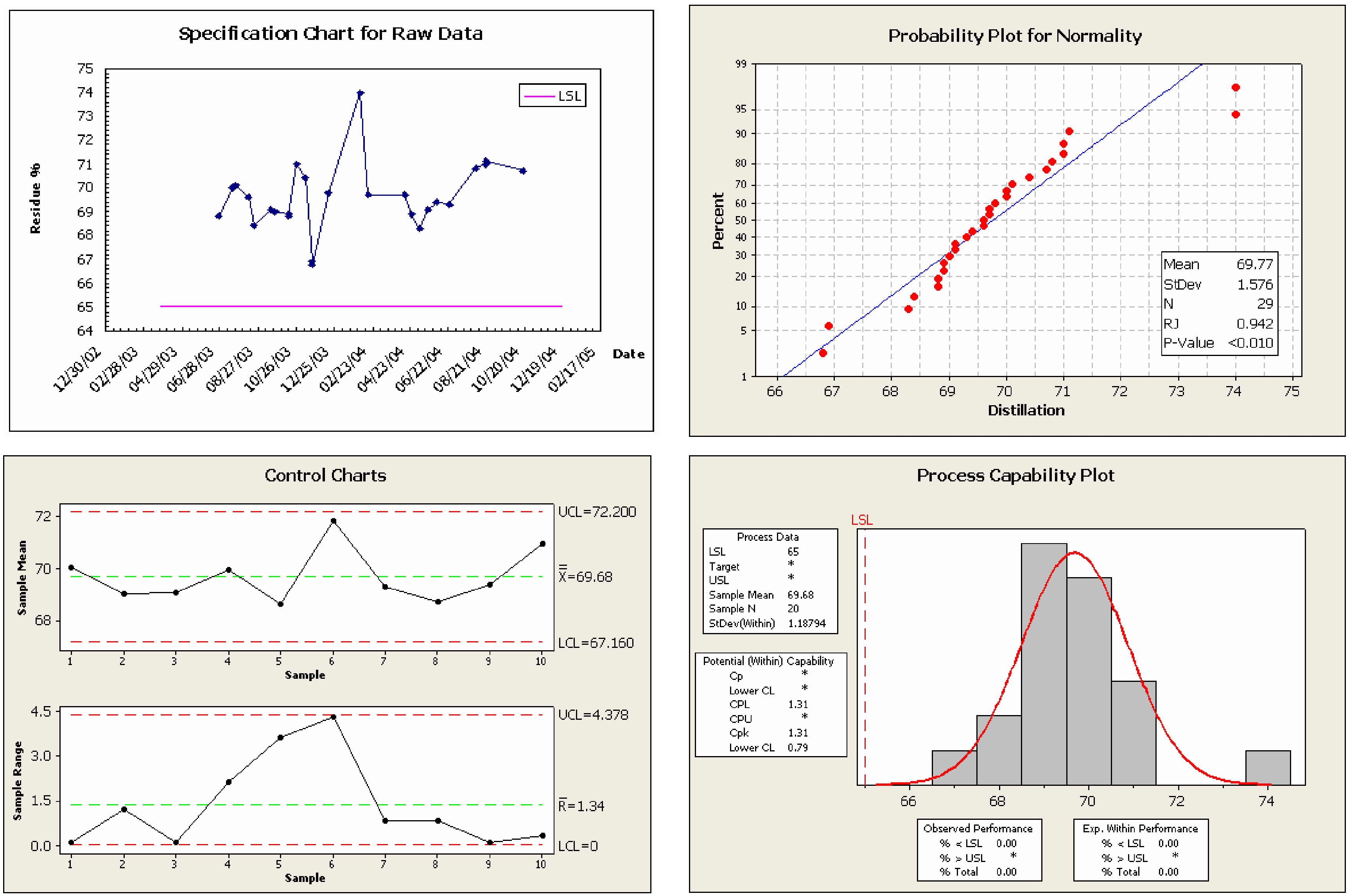


Figure G-38 Statistical Analysis Charts for Supplier: 0701 Grade: CRS-2 Test: Distillation

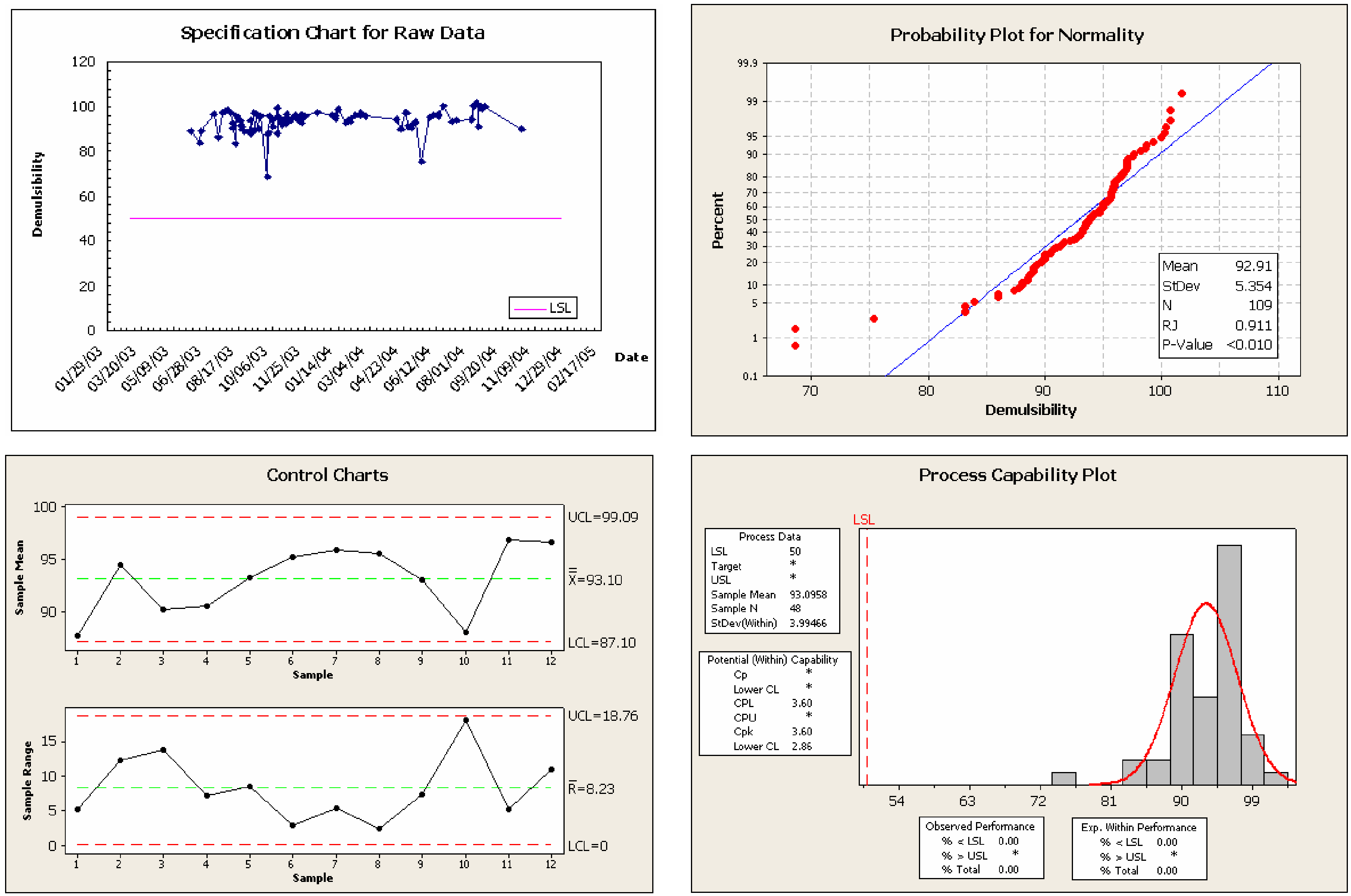


Figure G-39 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2 Test: Demulsibility

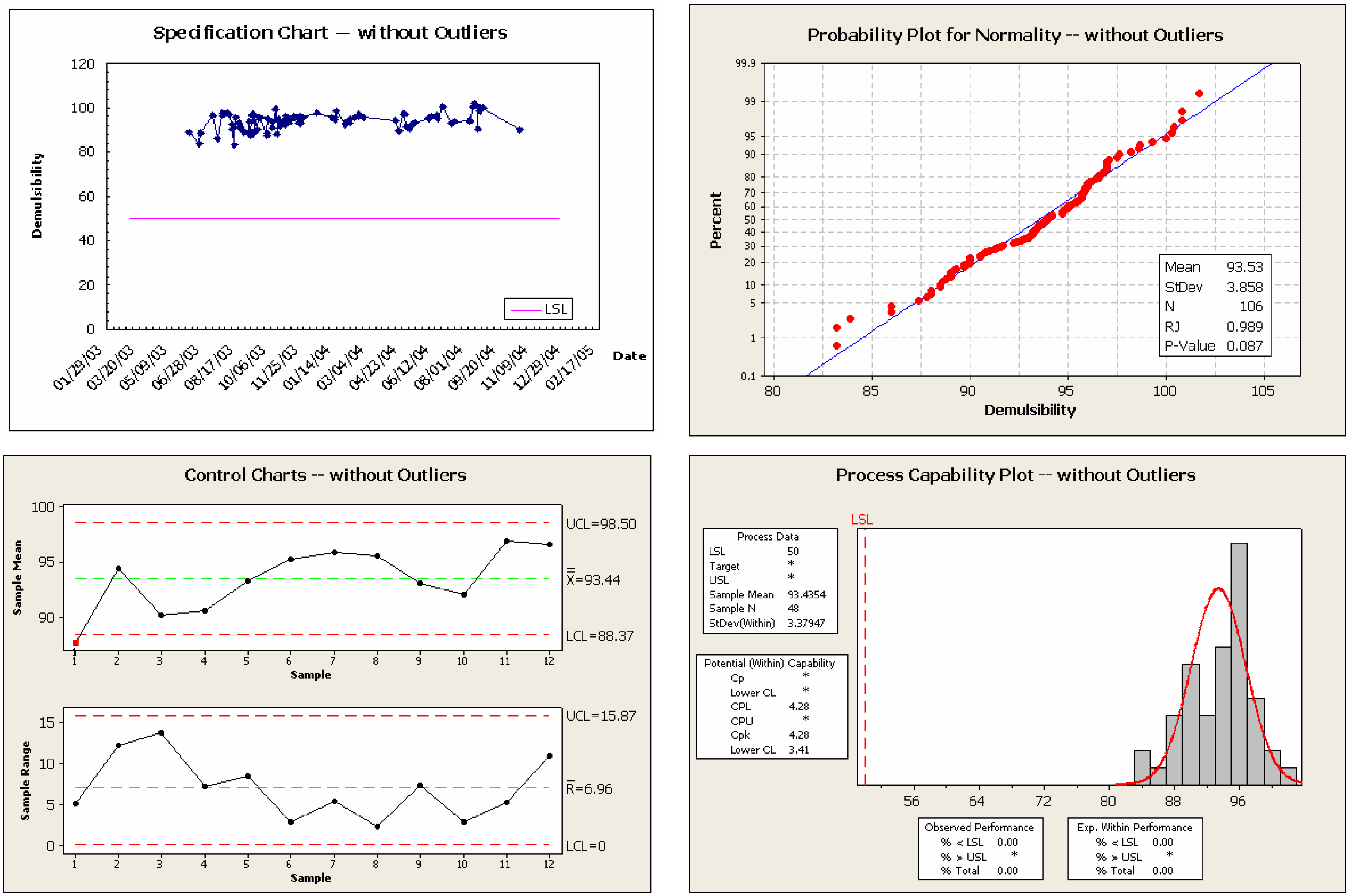


Figure G-40 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: HFRS-2 Test: Demulsibility

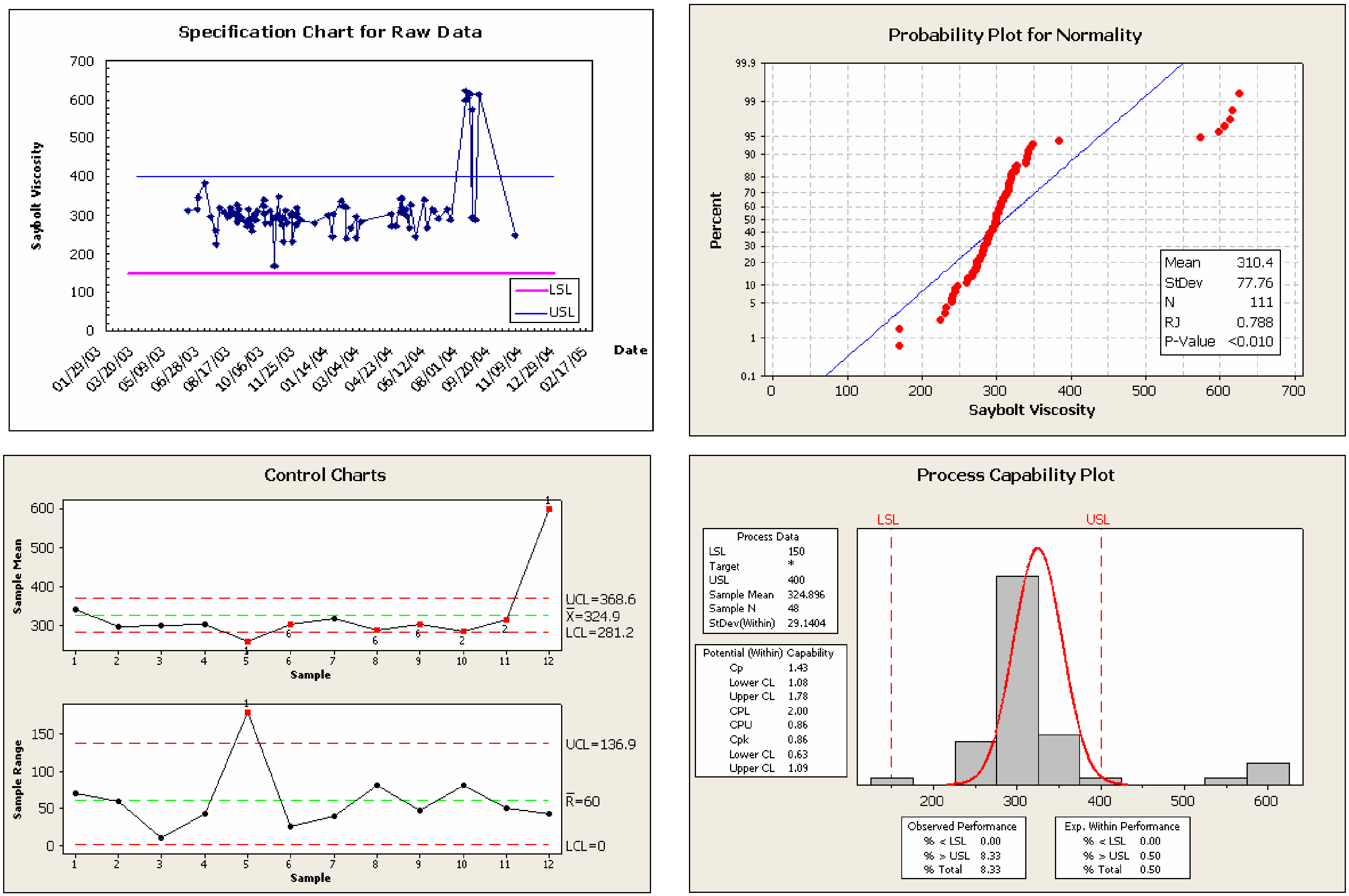


Figure G-41 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2 Test: Saybolt Viscosity

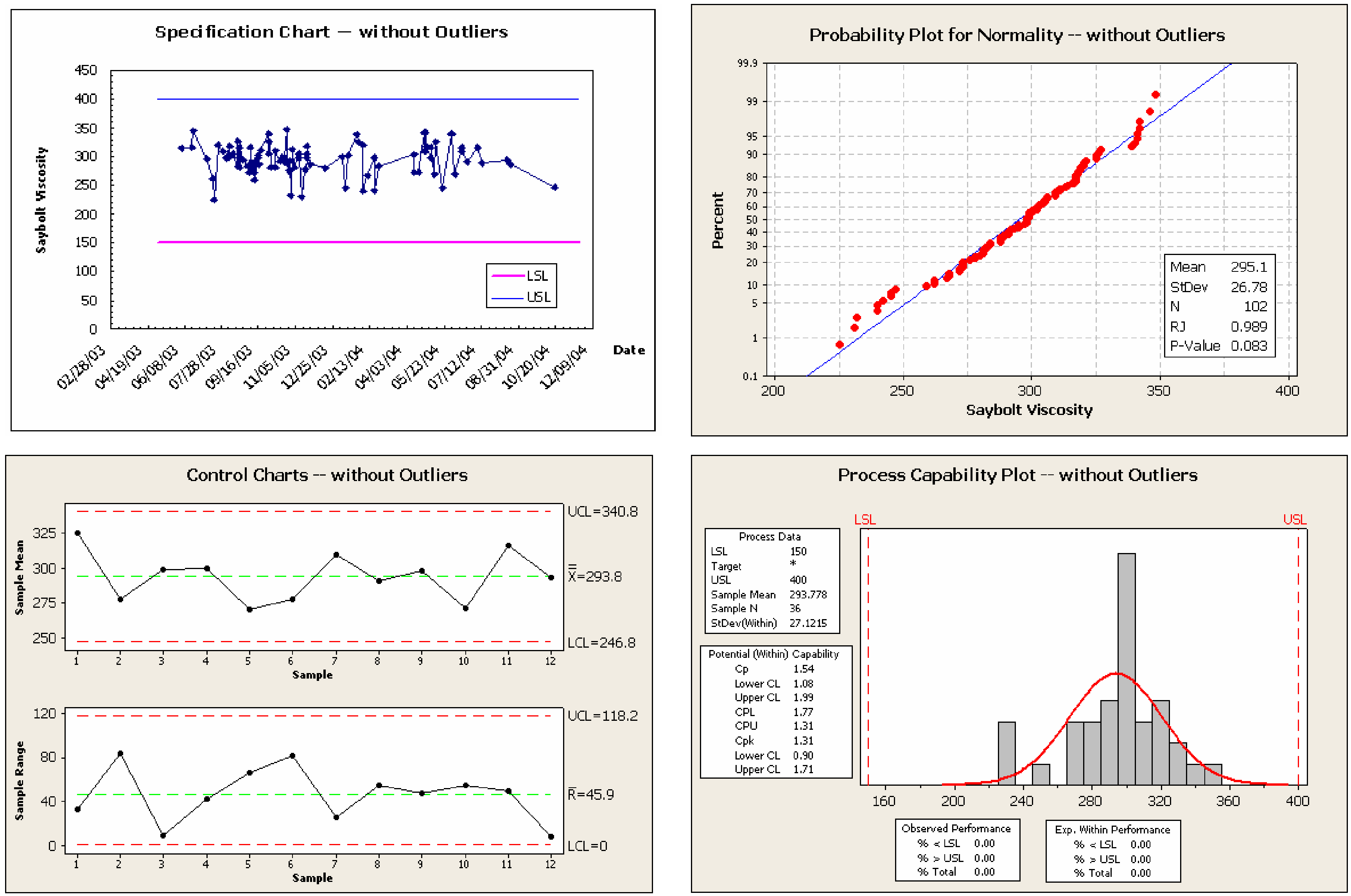


Figure G-42 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: HFRS-2 Test: Saybolt Viscosity

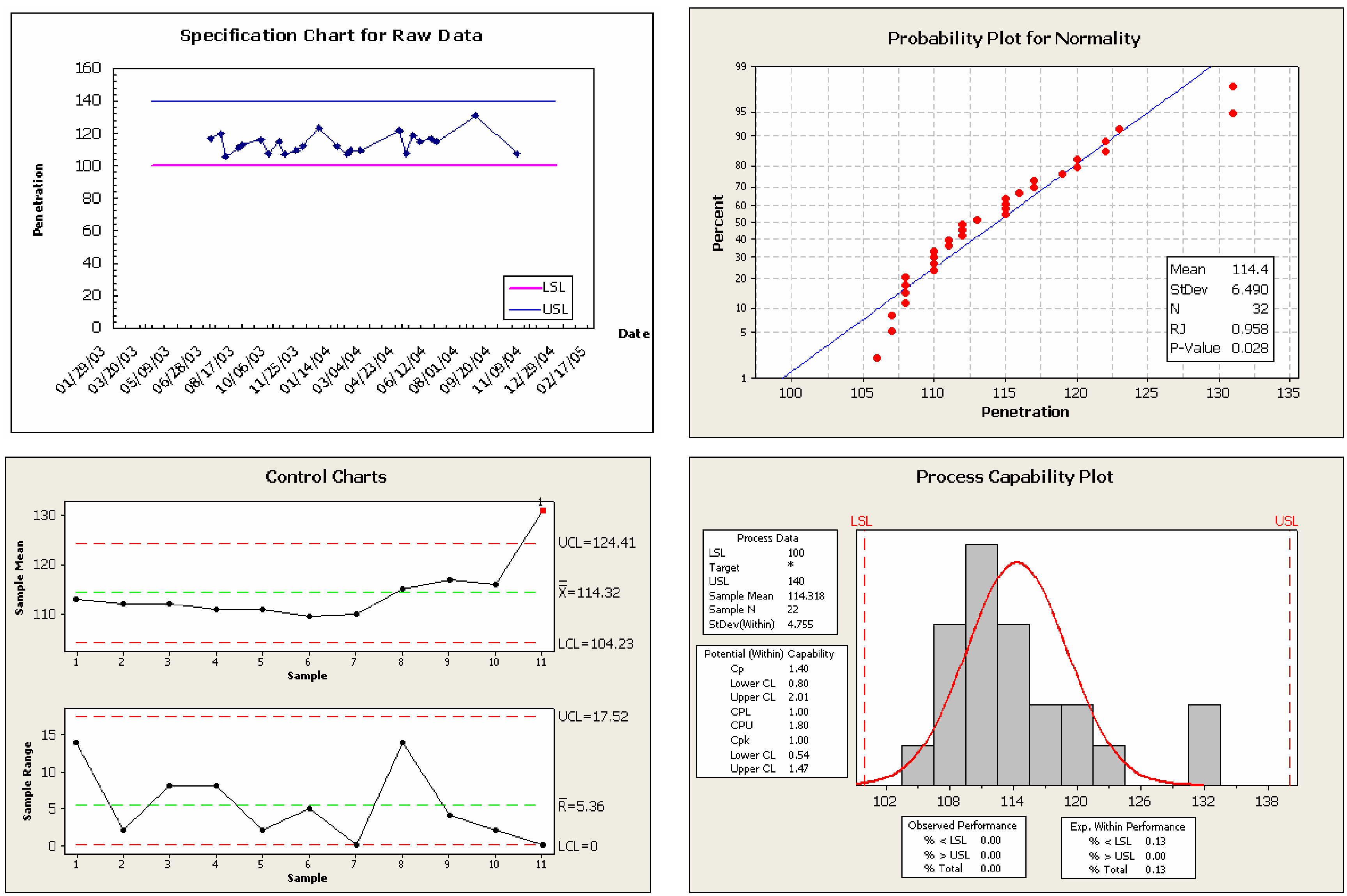


Figure G-43 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2 Test: Penetration

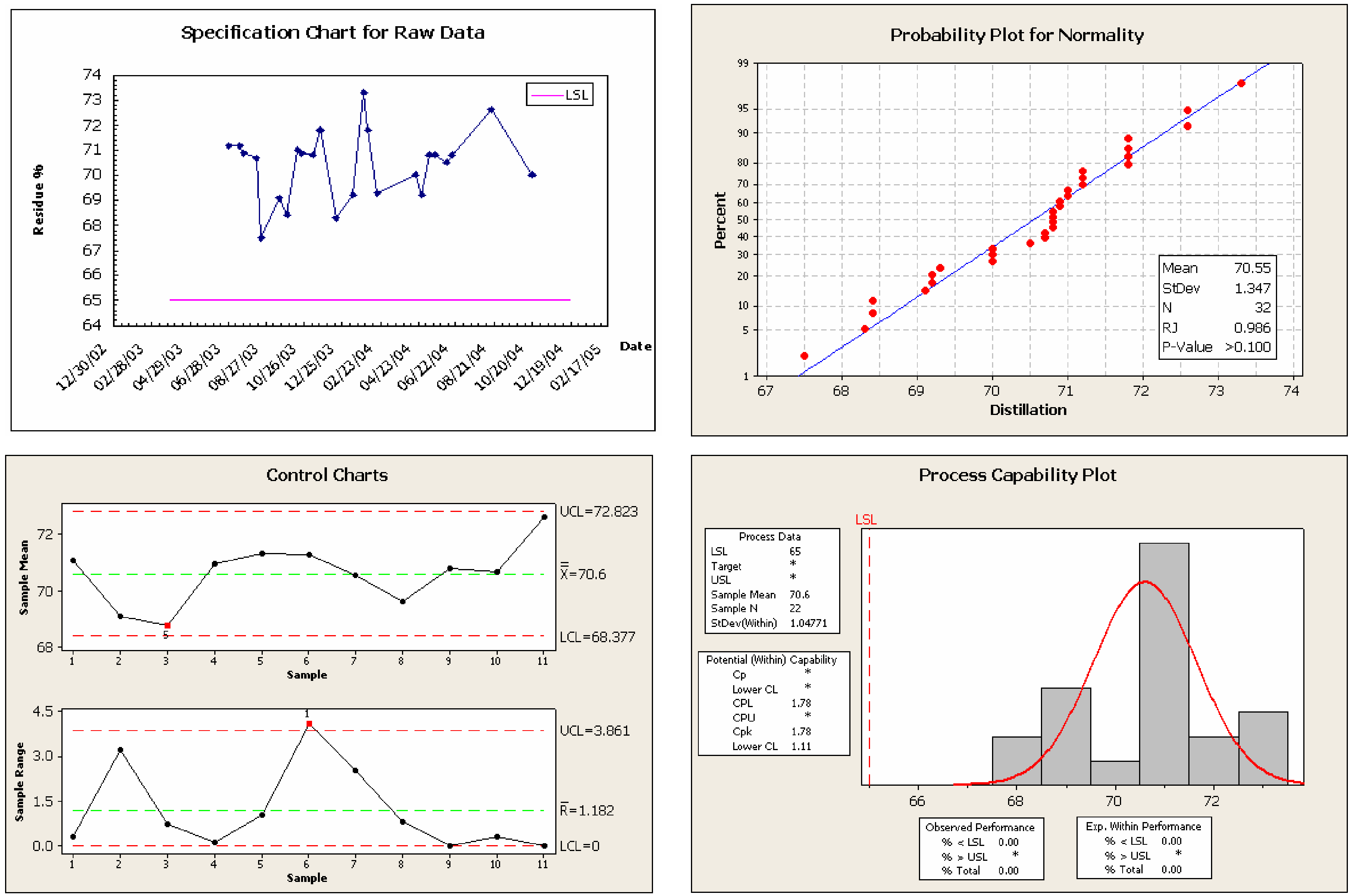


Figure G-44 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2 Test: Distillation

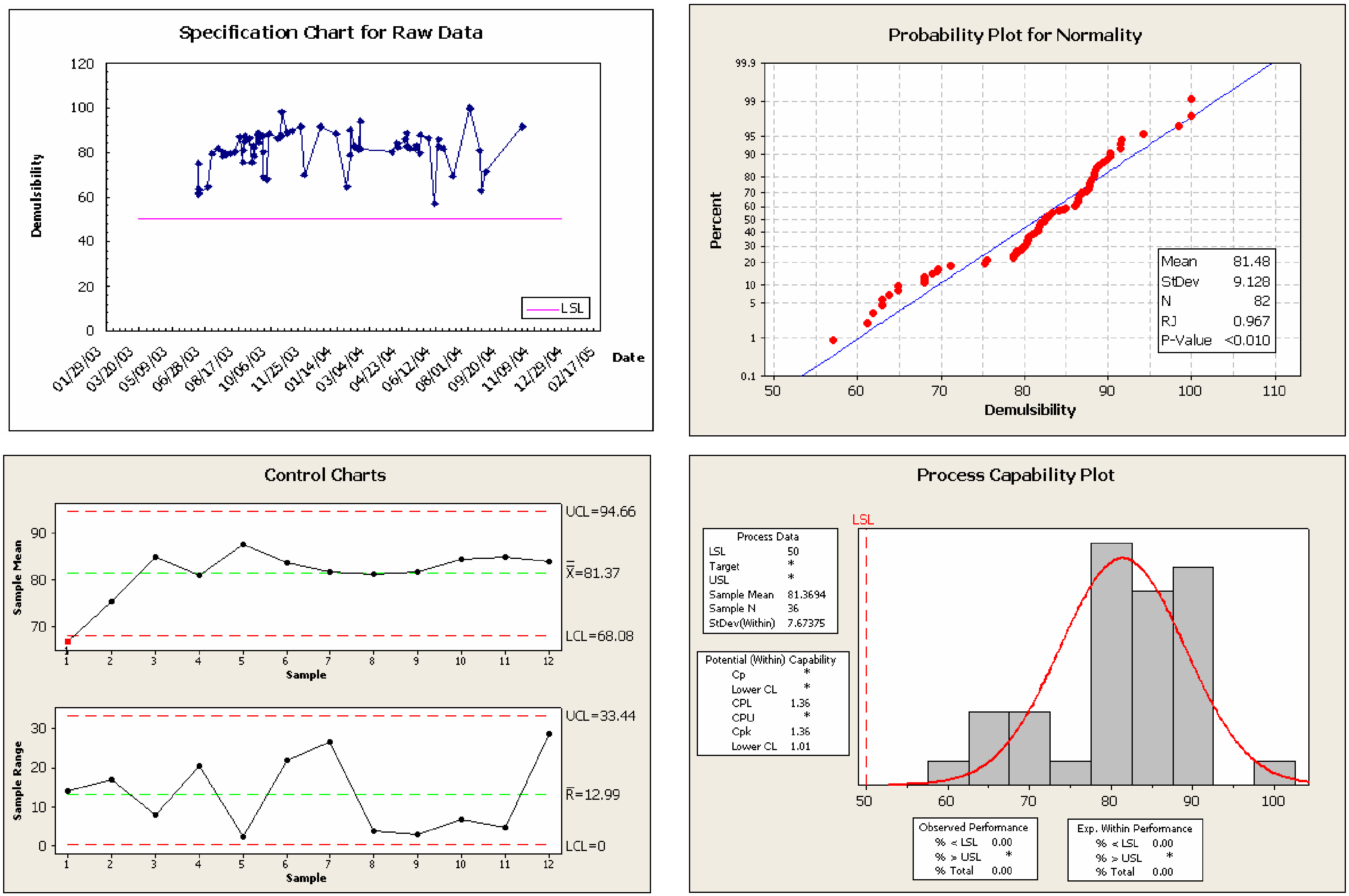


Figure G-45 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2P Test: Demulsibility

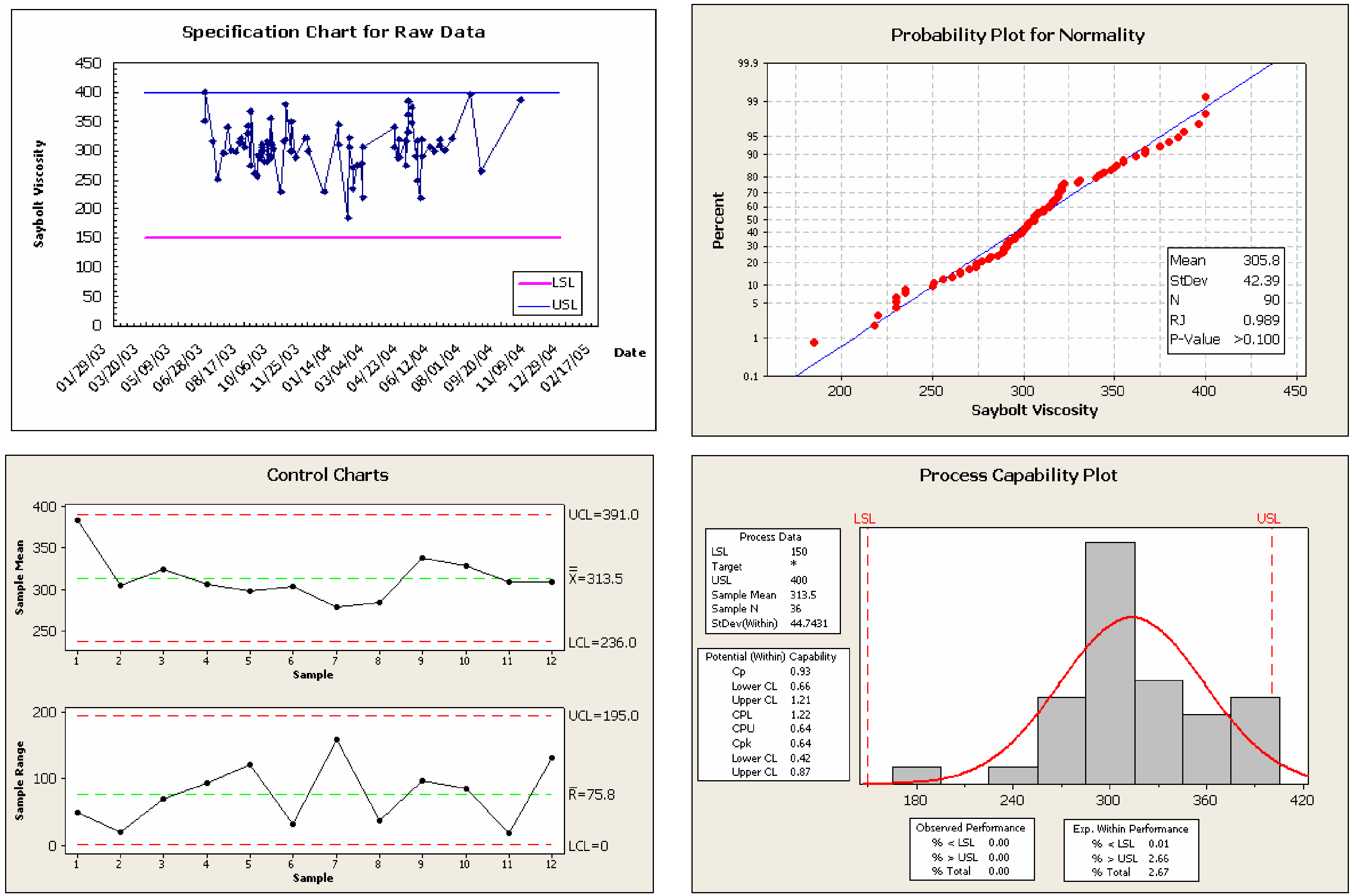


Figure G-46 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2P Test: Saybolt Viscosity

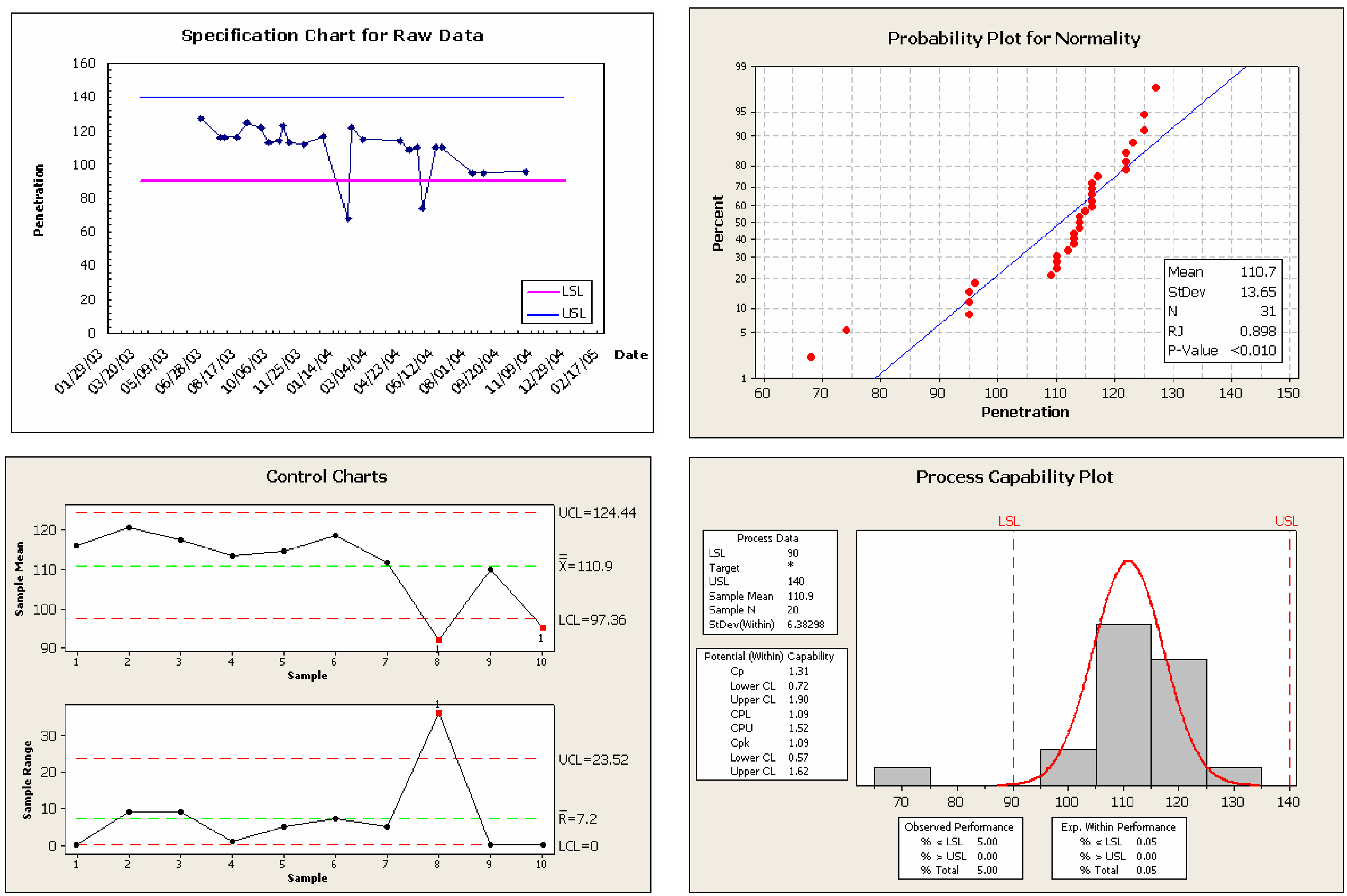


Figure G-47 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2P Test: Penetration

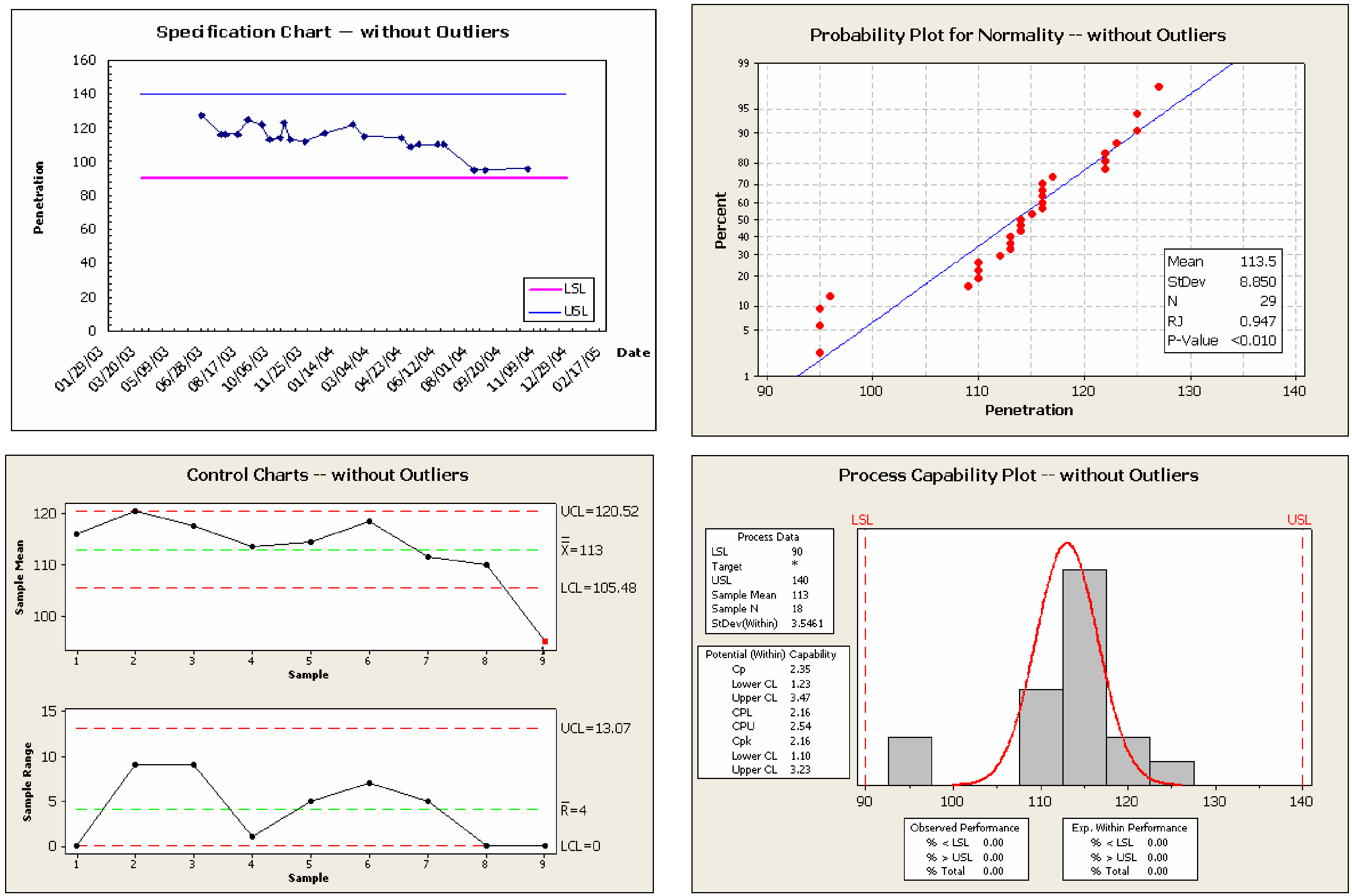


Figure G-48 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: HFRS-2P Test: Penetration

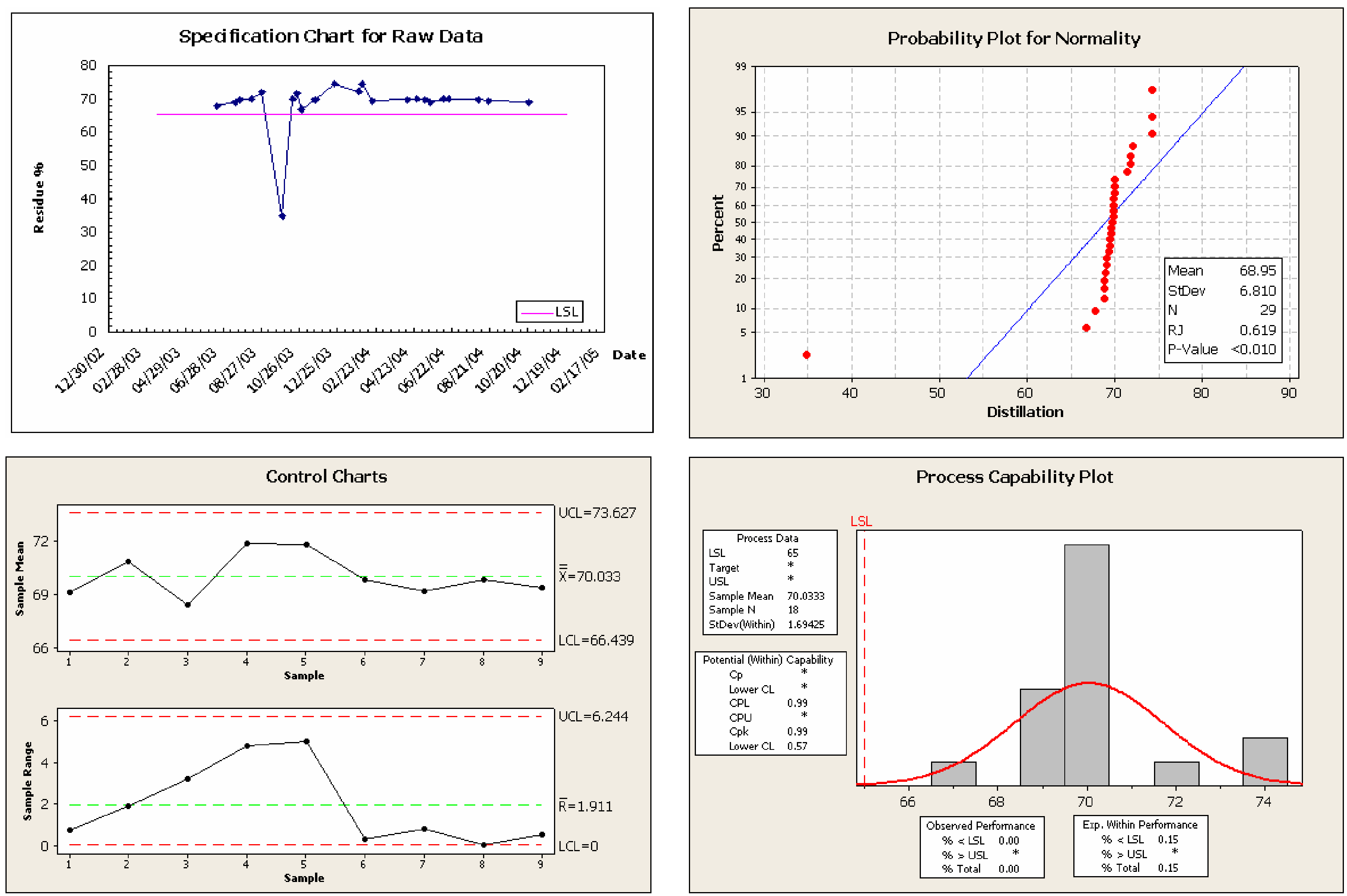


Figure G-49 Statistical Analysis Charts for Supplier: 0701 Grade: HFRS-2P Test: Distillation

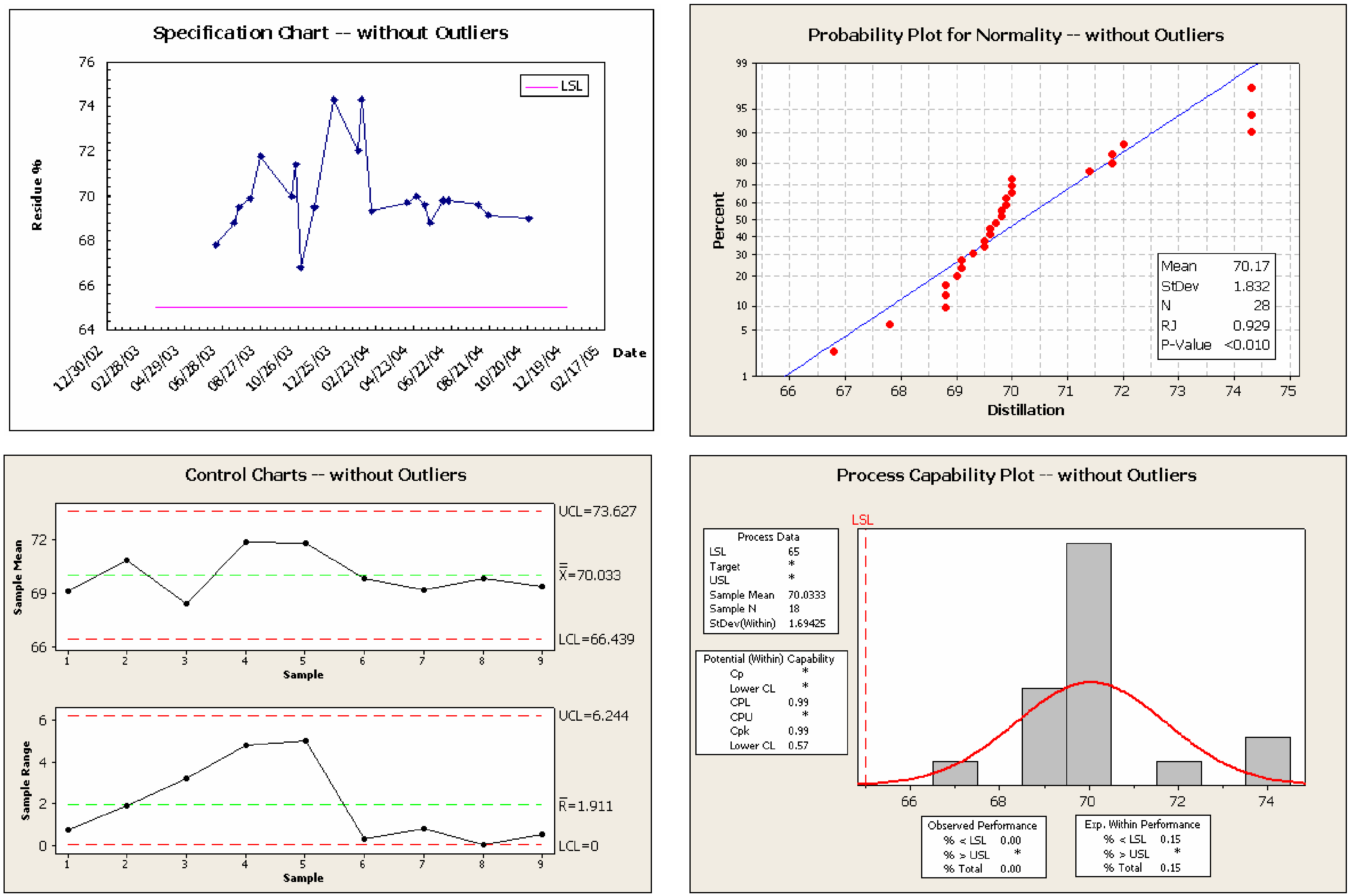


Figure G-50 Statistical Analysis Charts (without Outliers) for Supplier: 0701 Grade: HFRS-2P Test: Distillation

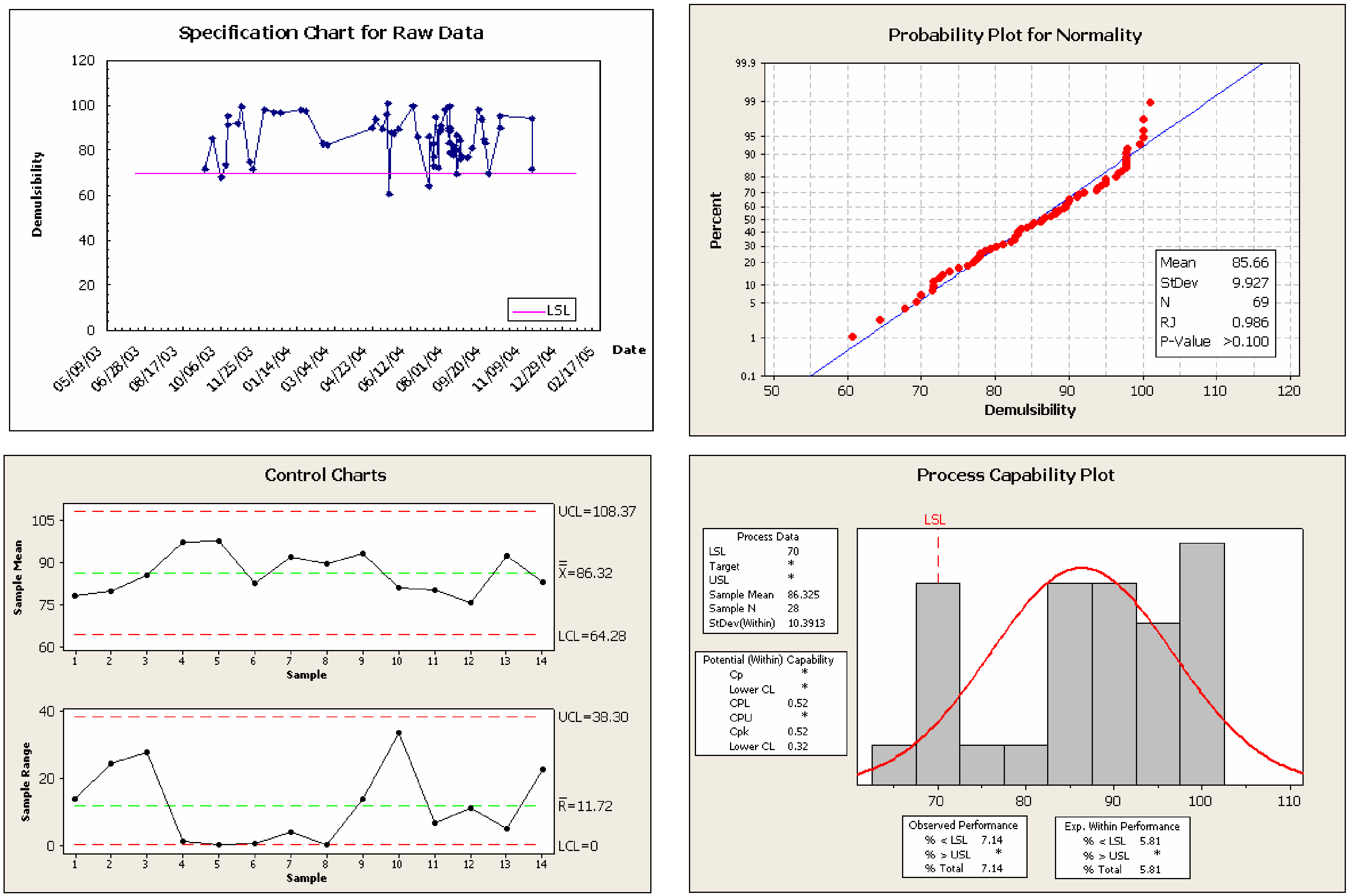


Figure G-51 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Demulsibility

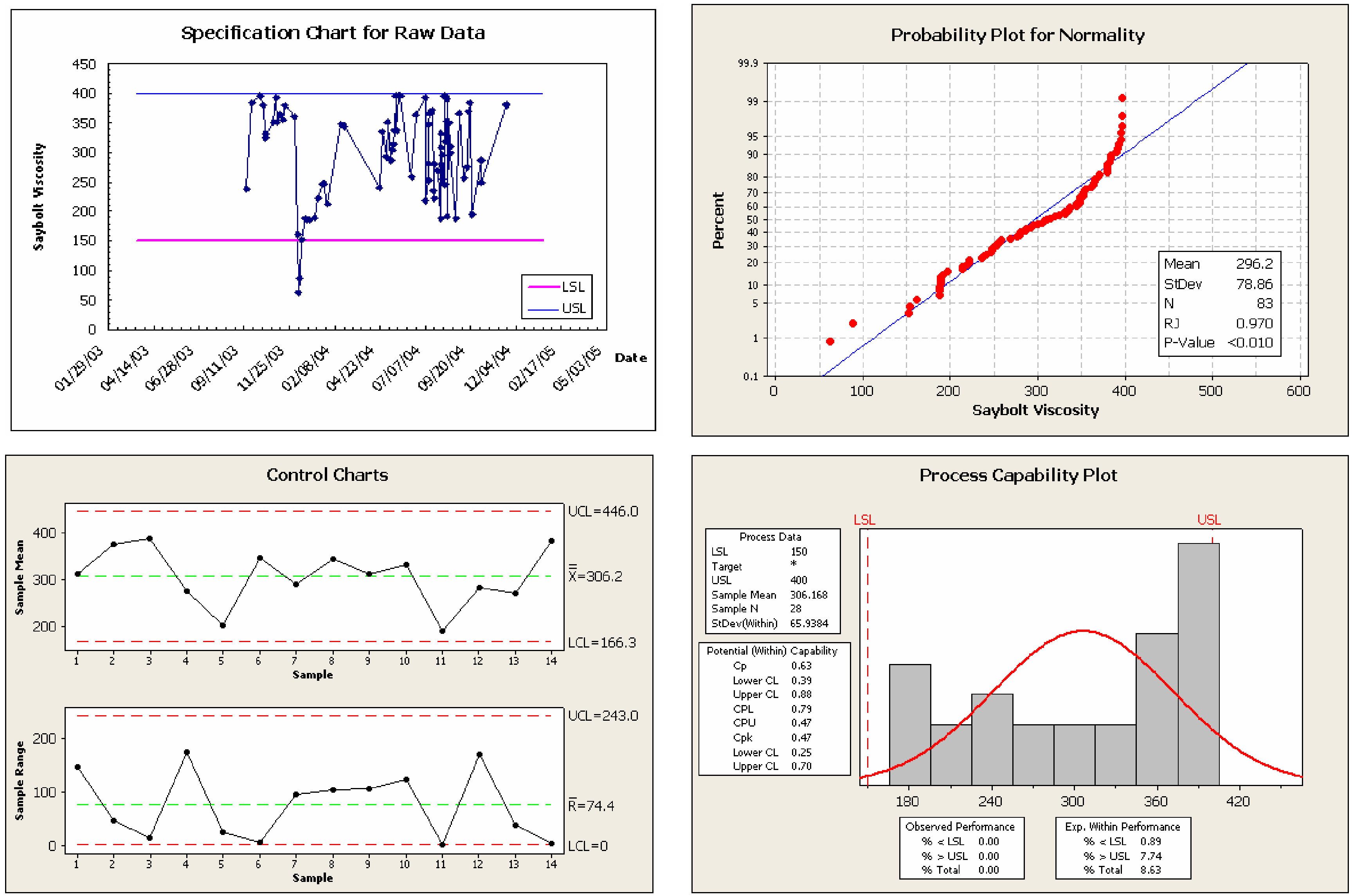


Figure G-52 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Saybolt Viscosity

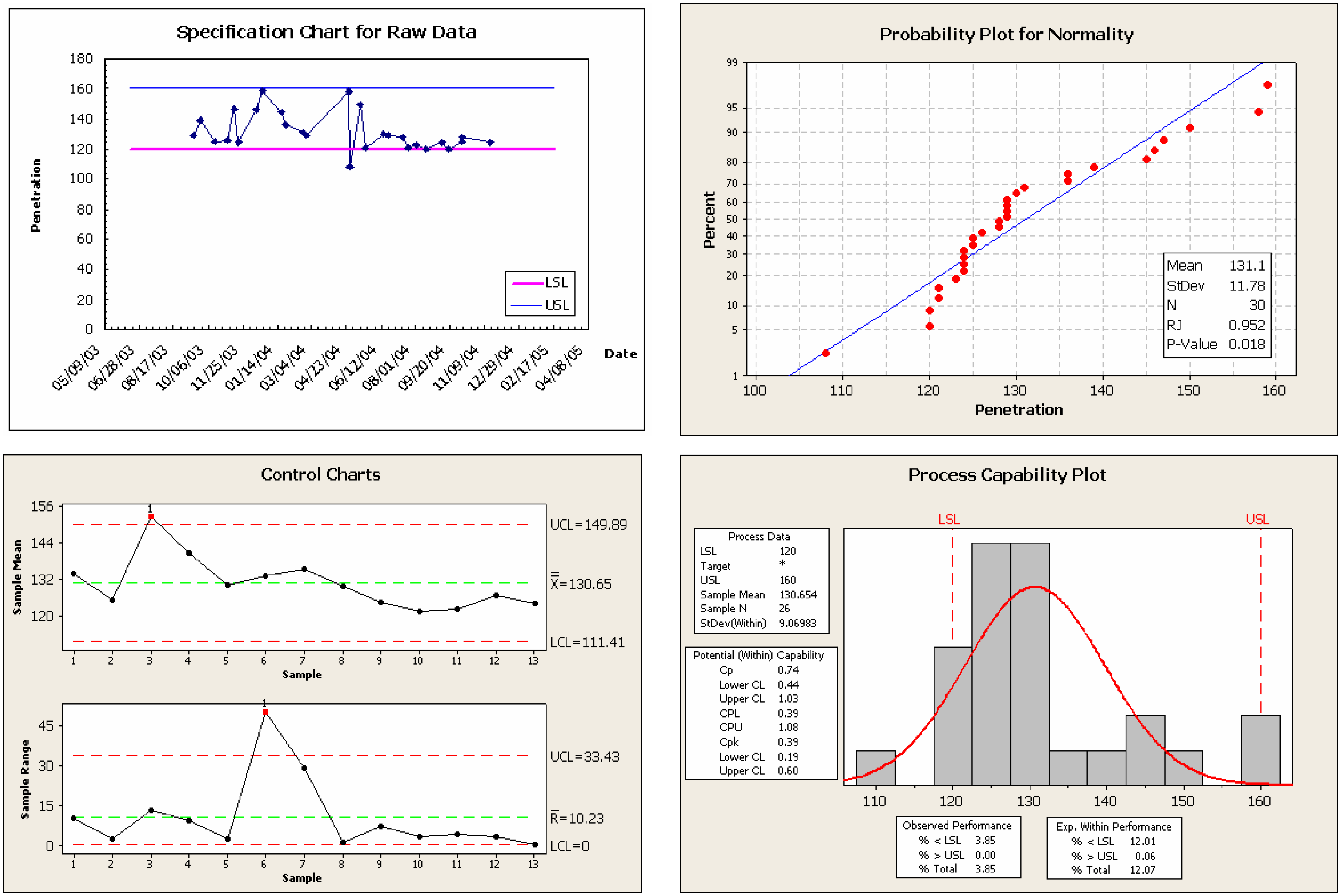
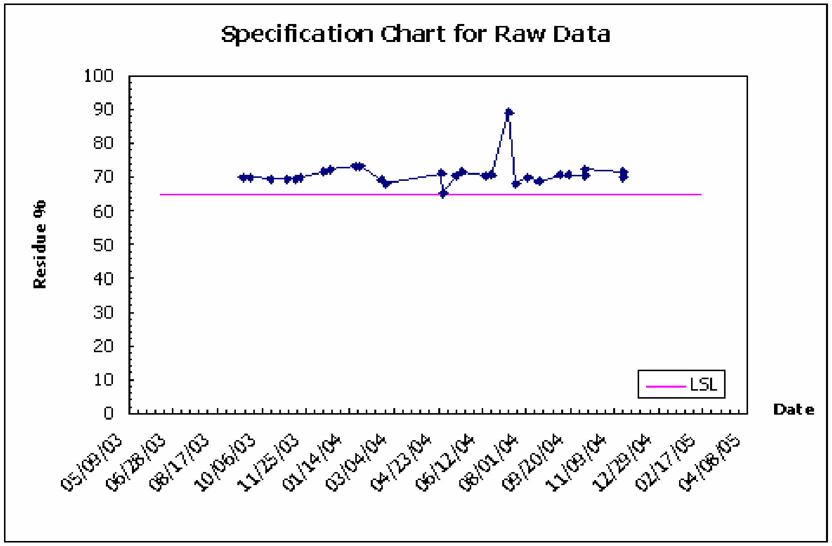
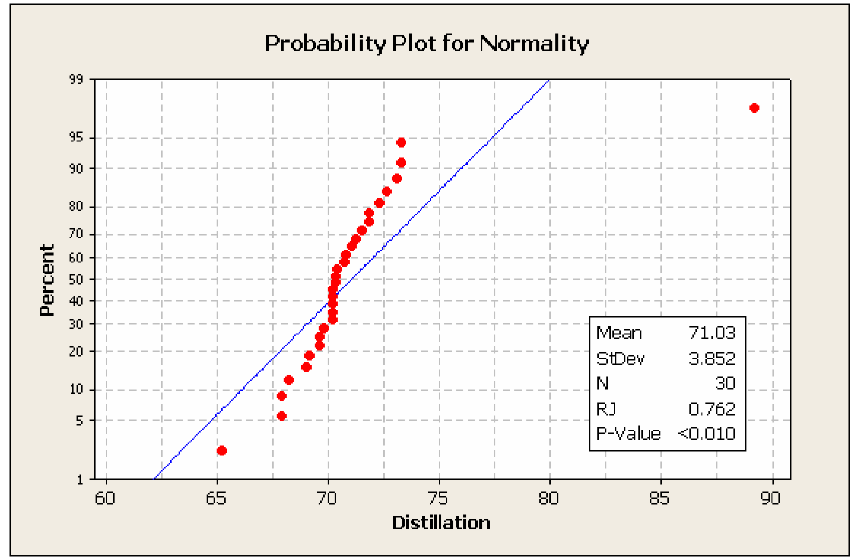
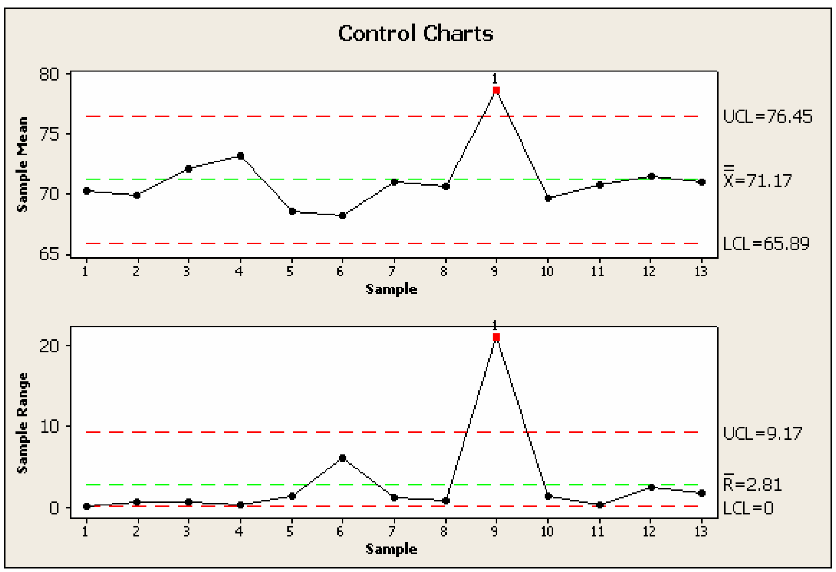


Figure G-53 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Penetration







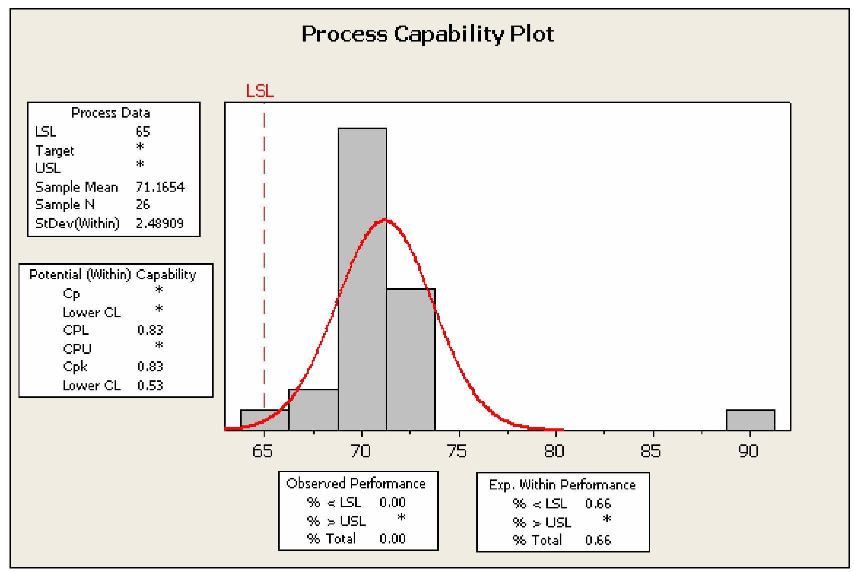


Figure G-54 Statistical Analysis Charts for Supplier: 0702 Grade: CRS-2 Test: Distillation

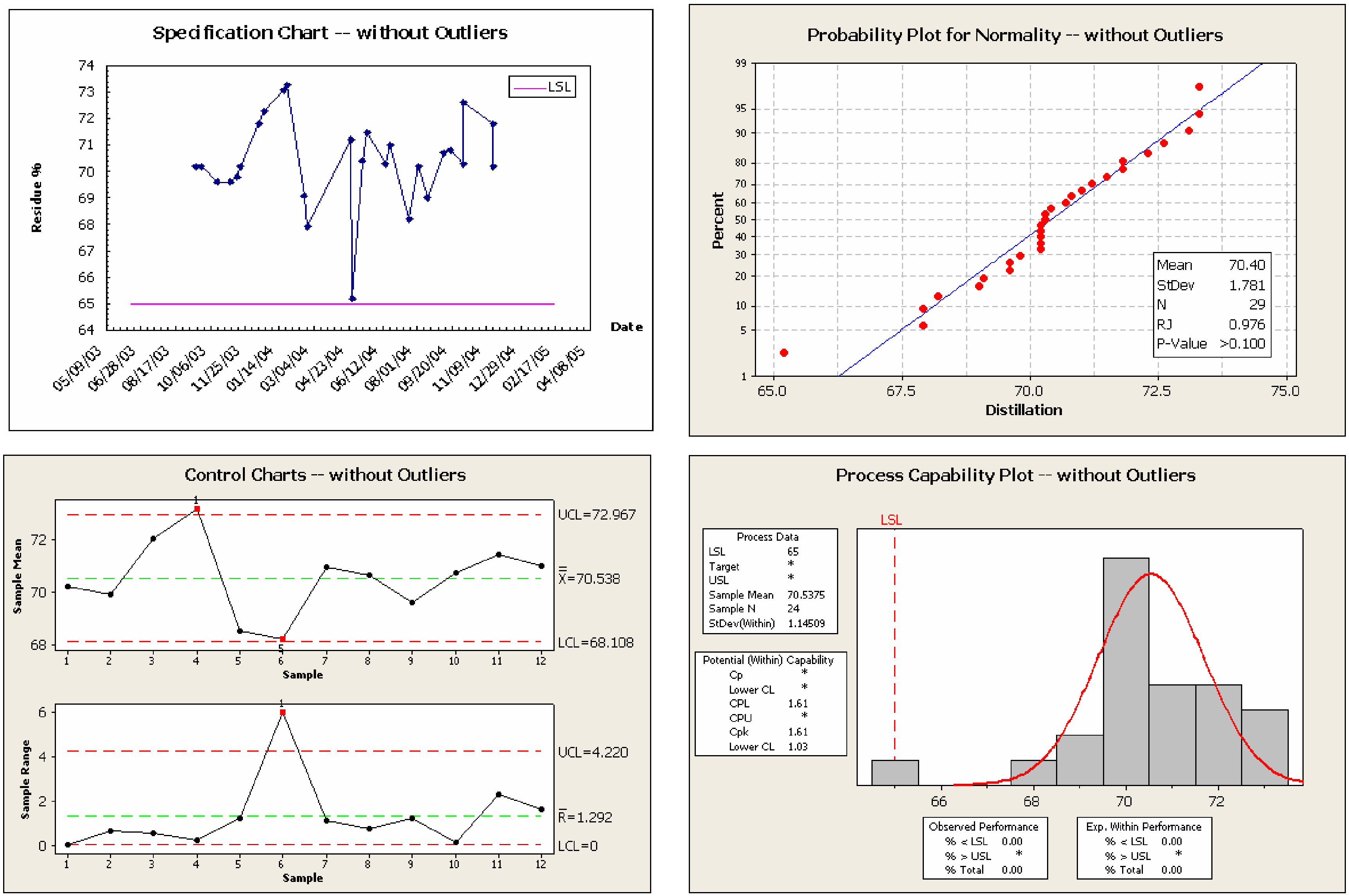


Figure G-55 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CRS-2 Test: Distillation

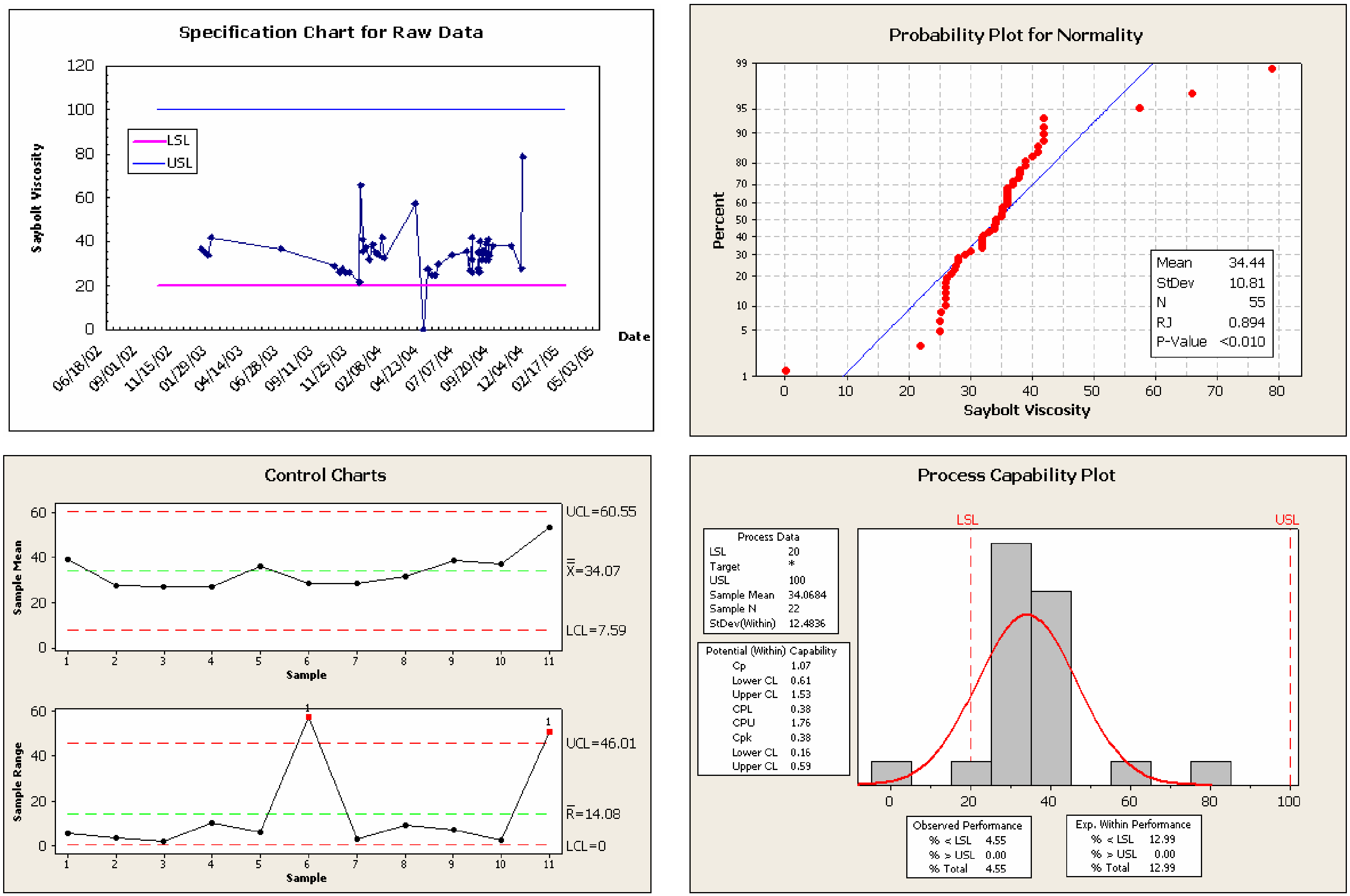


Figure G-56 Statistical Analysis Charts for Supplier: 0702 Grade: CSS-1H Test: Saybolt Viscosity

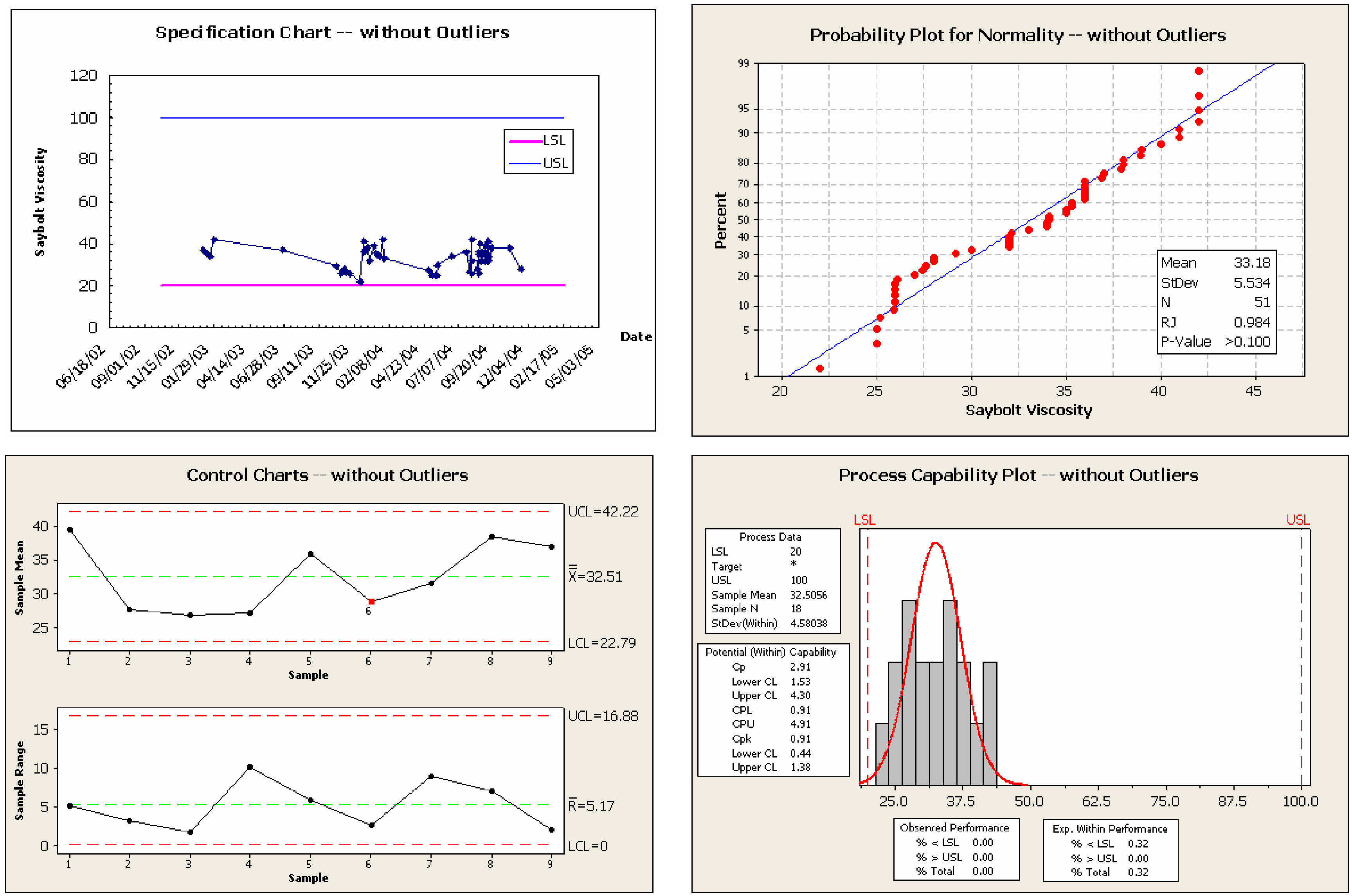


Figure G-57 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: CSS-1H Test: Saybolt Viscosity

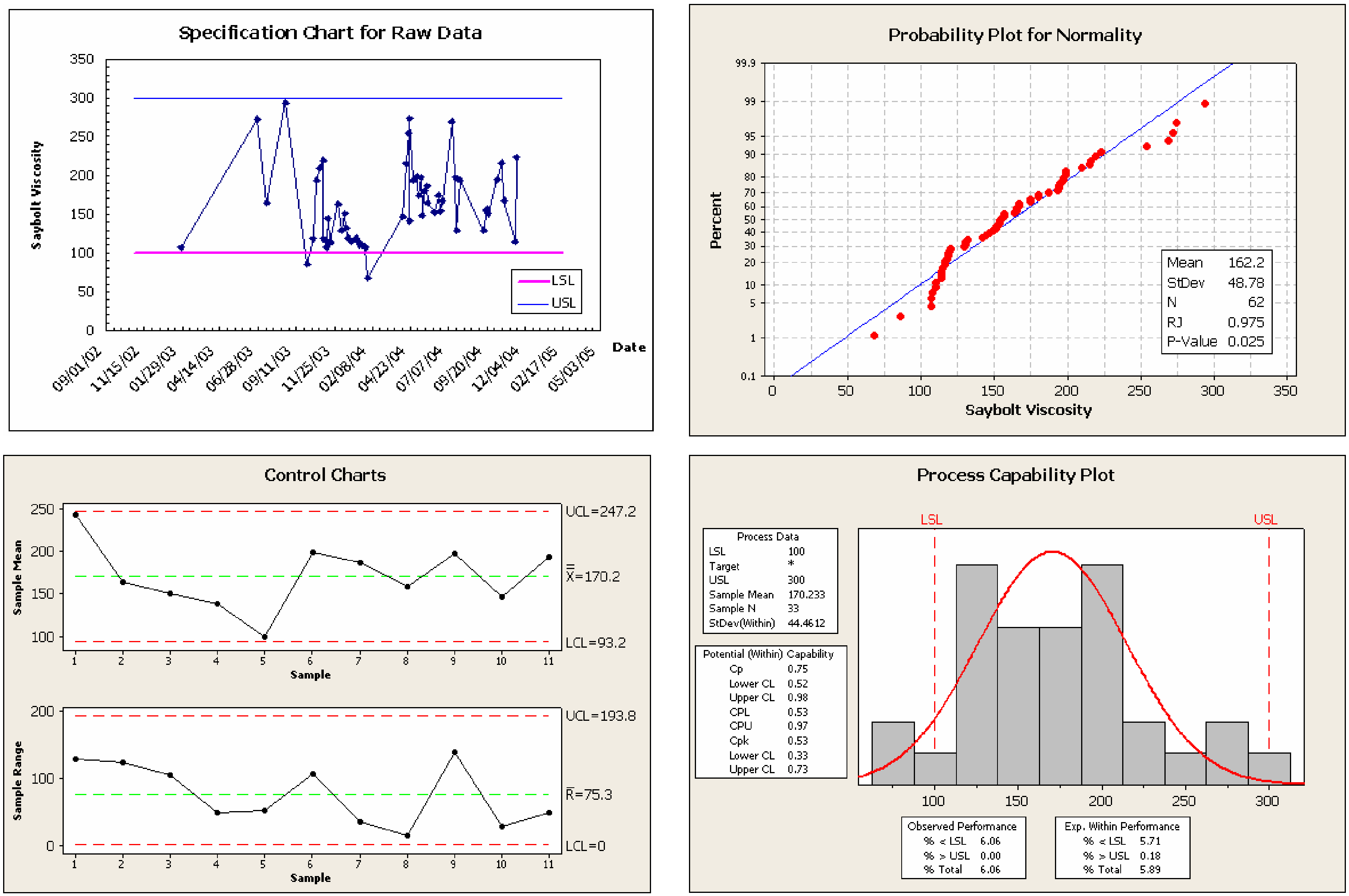


Figure G-58 Statistical Analysis Charts for Supplier: 0702 Grade: MS-2 Test: Saybolt Viscosity

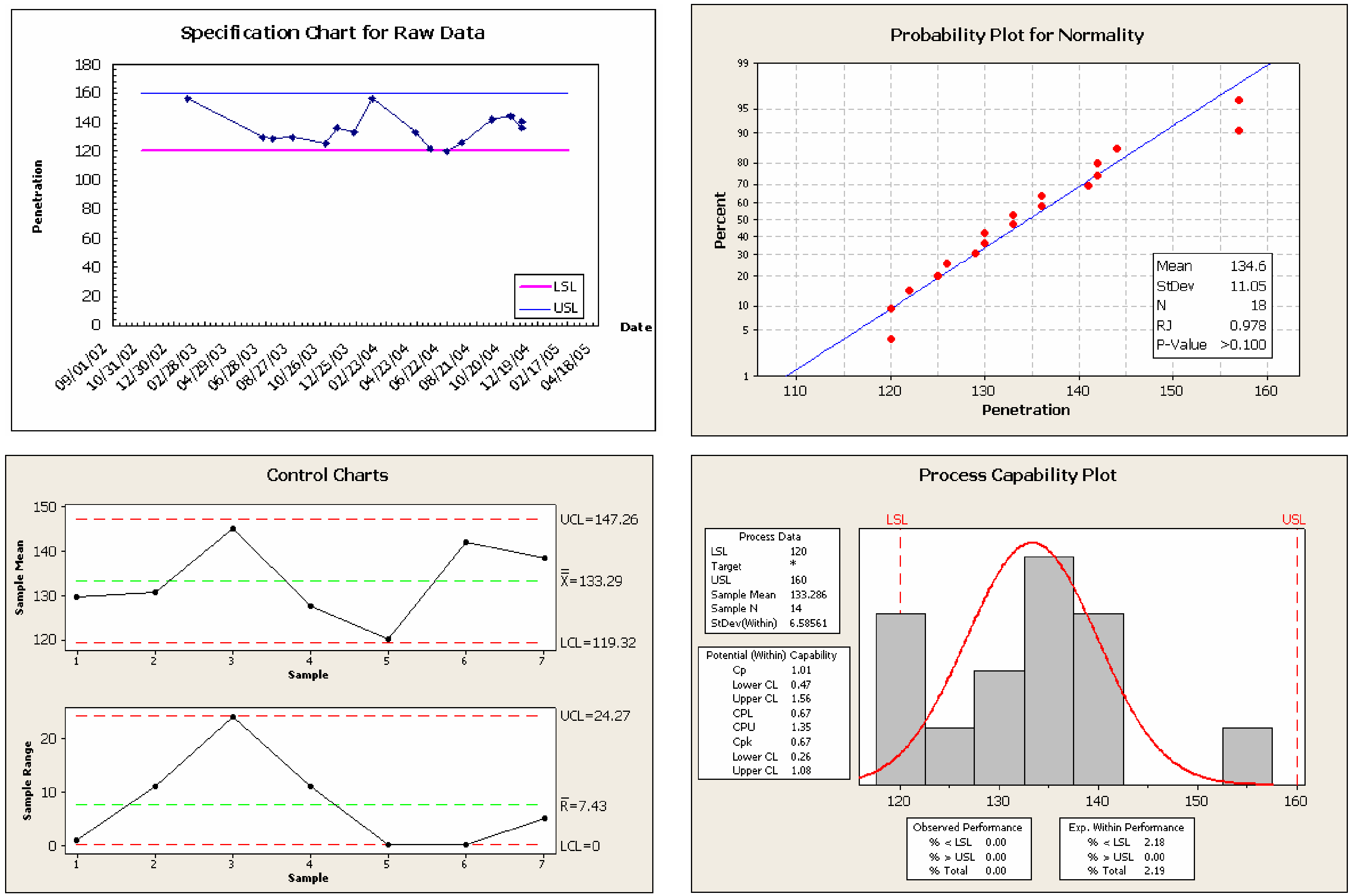


Figure G-59 Statistical Analysis Charts for Supplier: 0702 Grade: MS-2 Test: Penetration

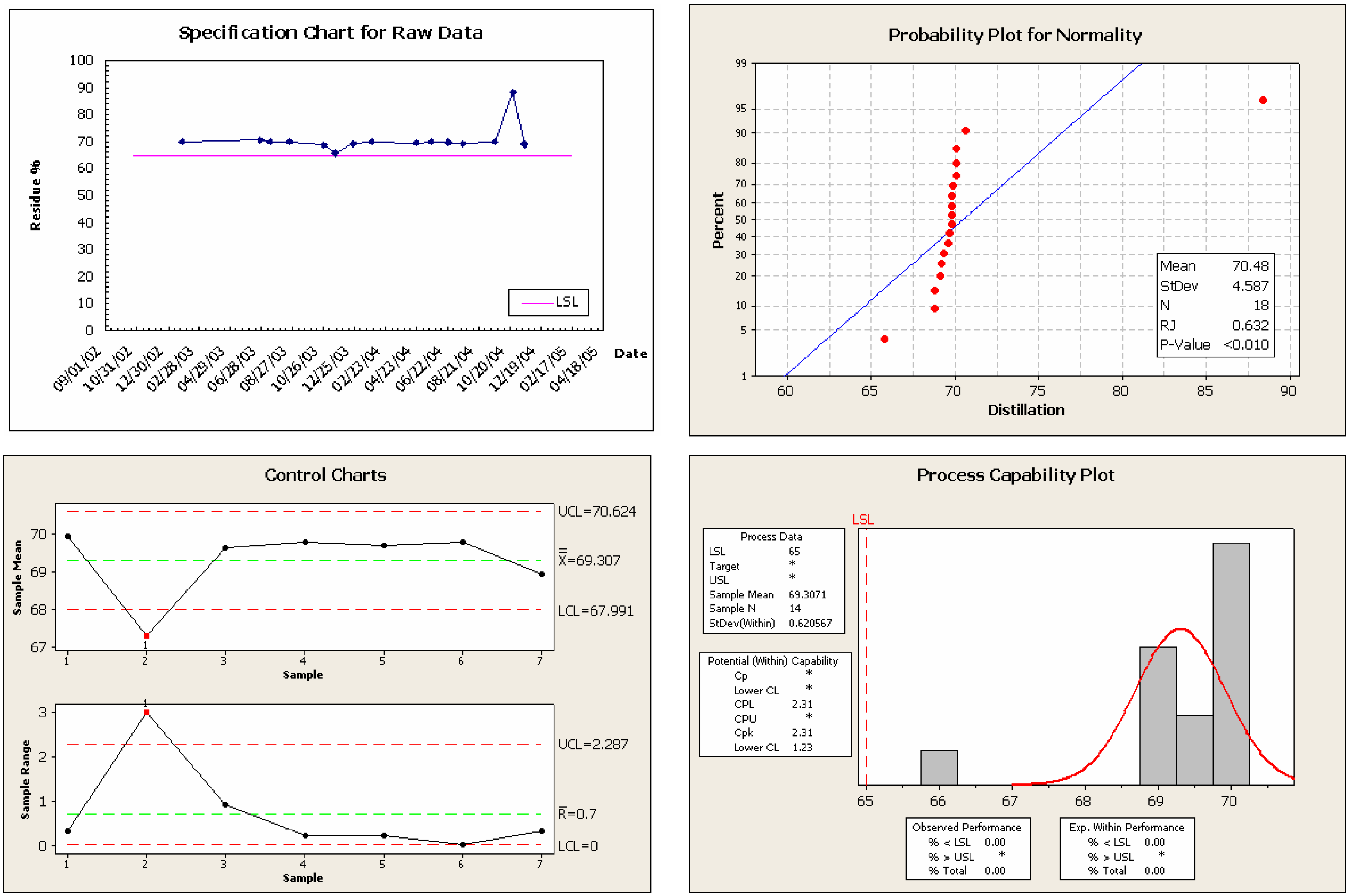


Figure G-60 Statistical Analysis Charts for Supplier: 0702 Grade: MS-2 Test: Distillation

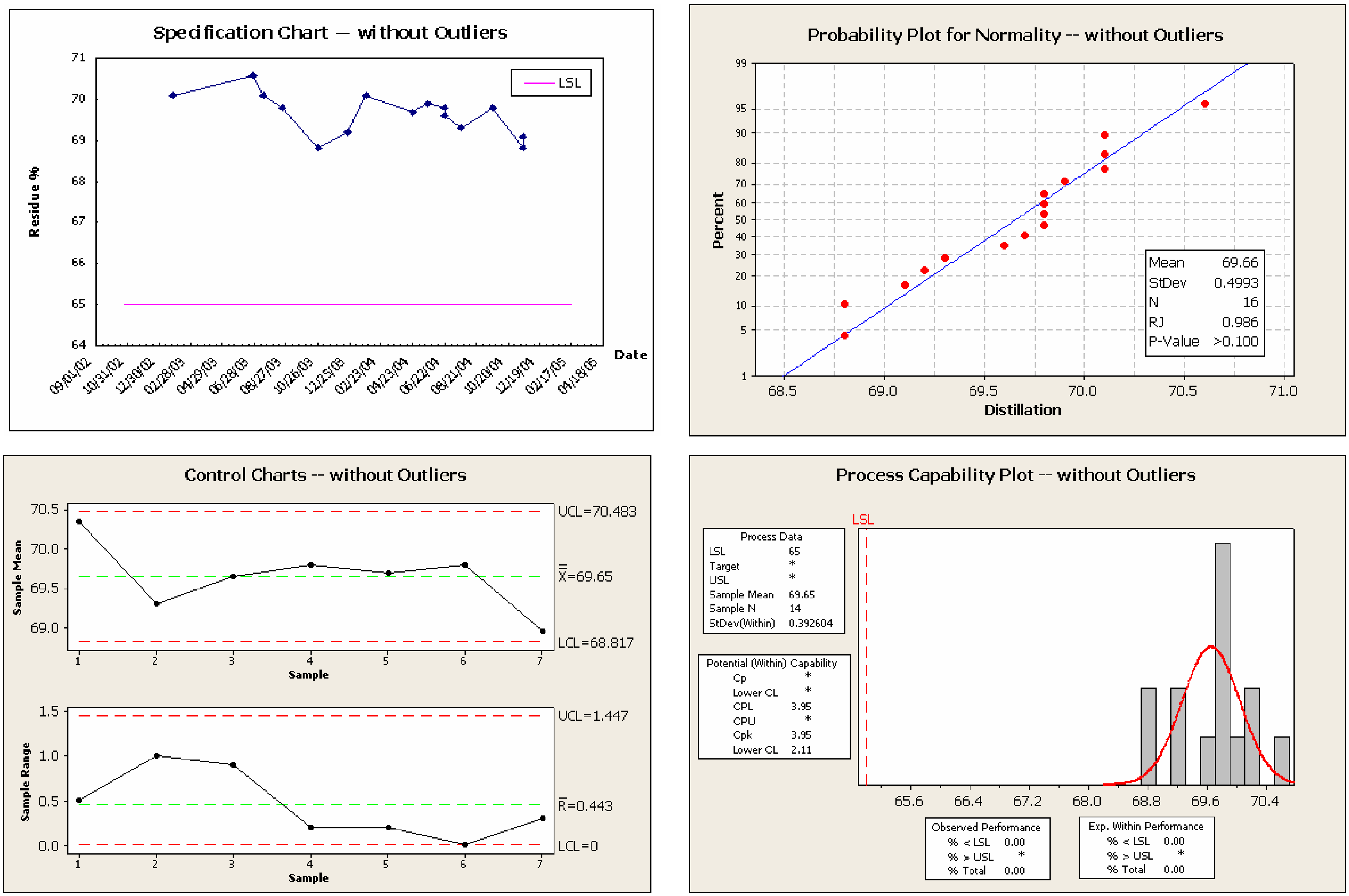


Figure G-61 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: MS-2 Test: Distillation

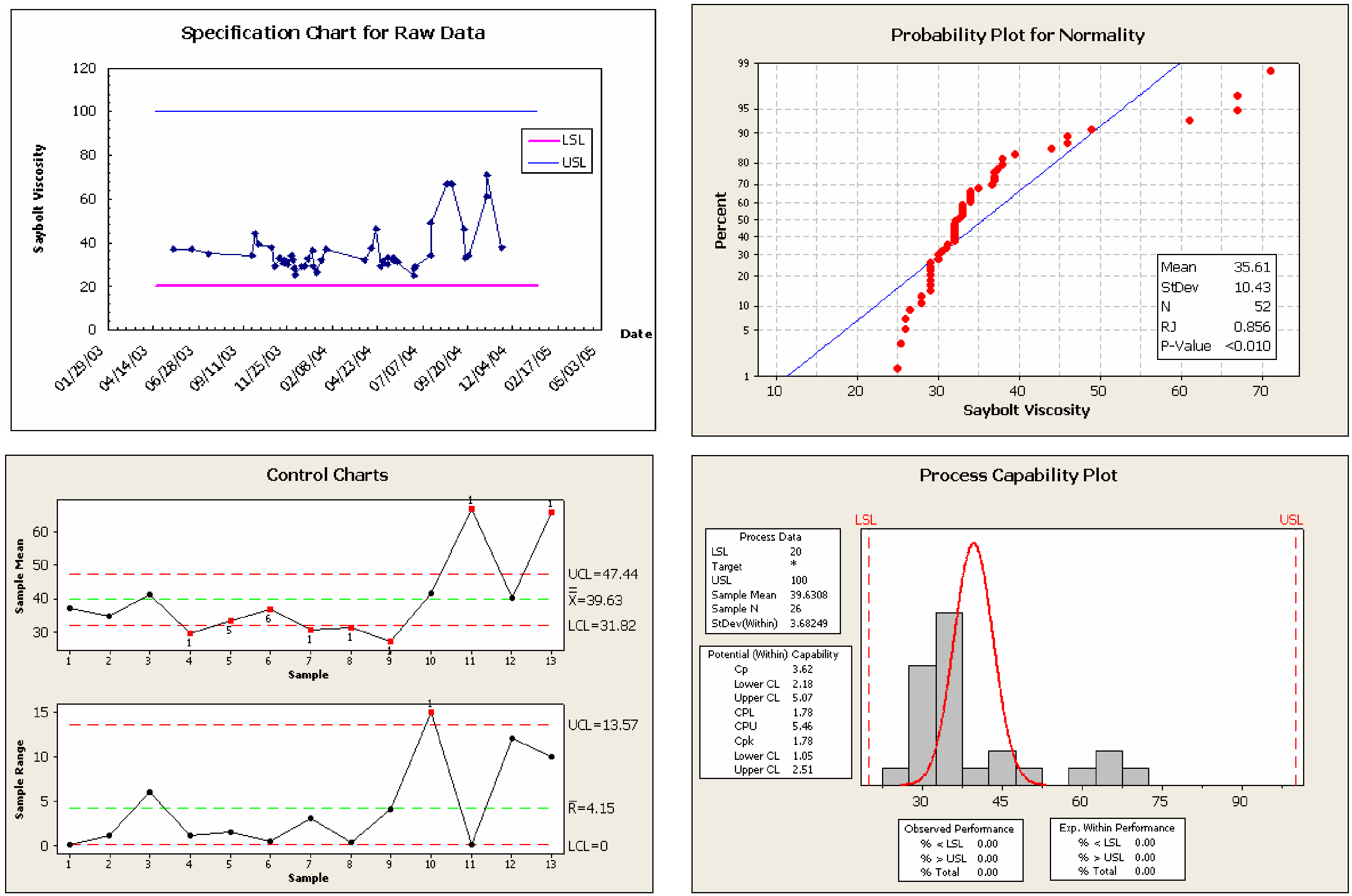


Figure G-62 Statistical Analysis Charts for Supplier: 0702 Grade: SS-1 Test: Saybolt Viscosity

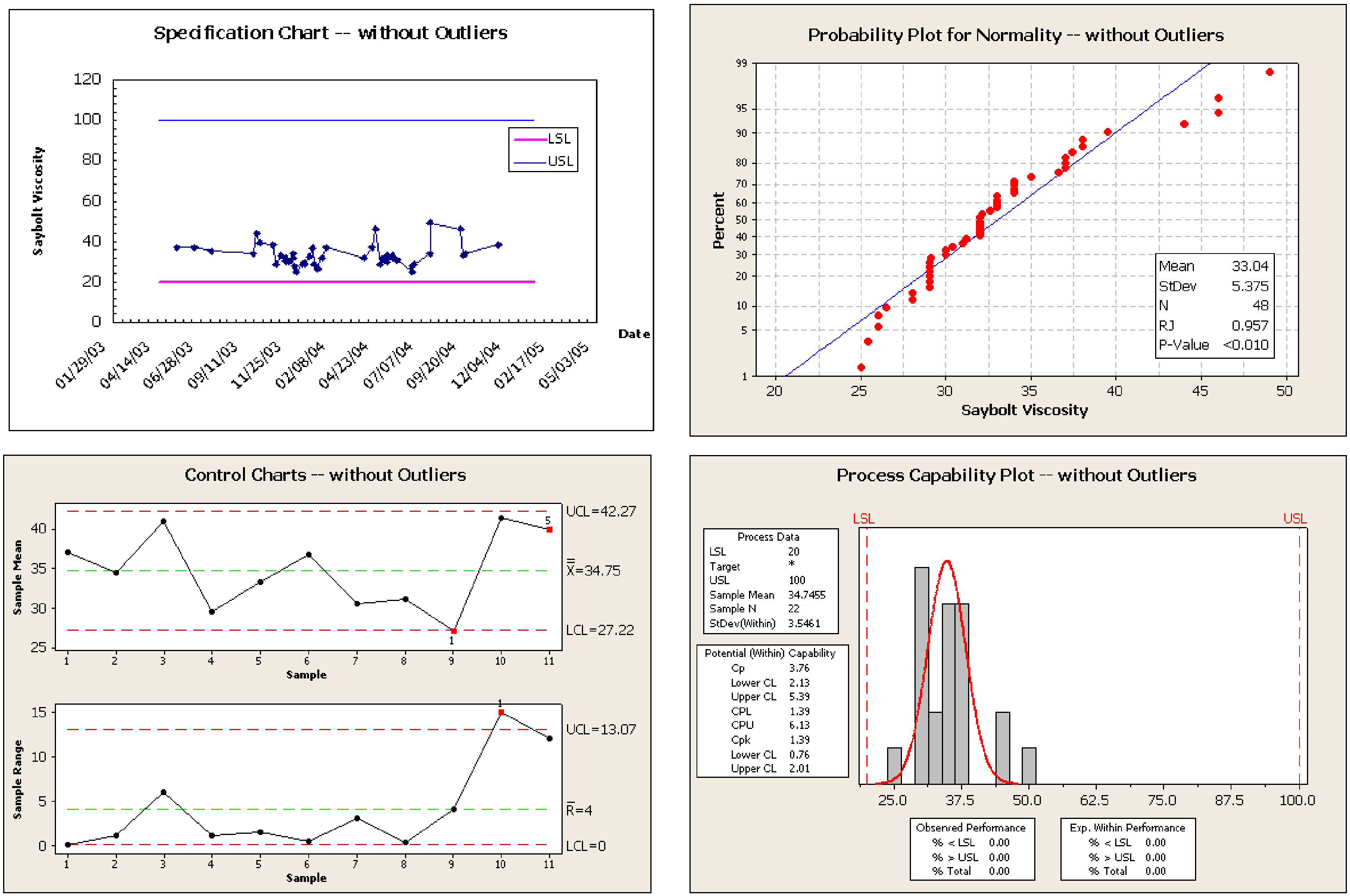


Figure G-63 Statistical Analysis Charts (without Outliers) for Supplier: 0702 Grade: SS-1 Test: Saybolt Viscosity

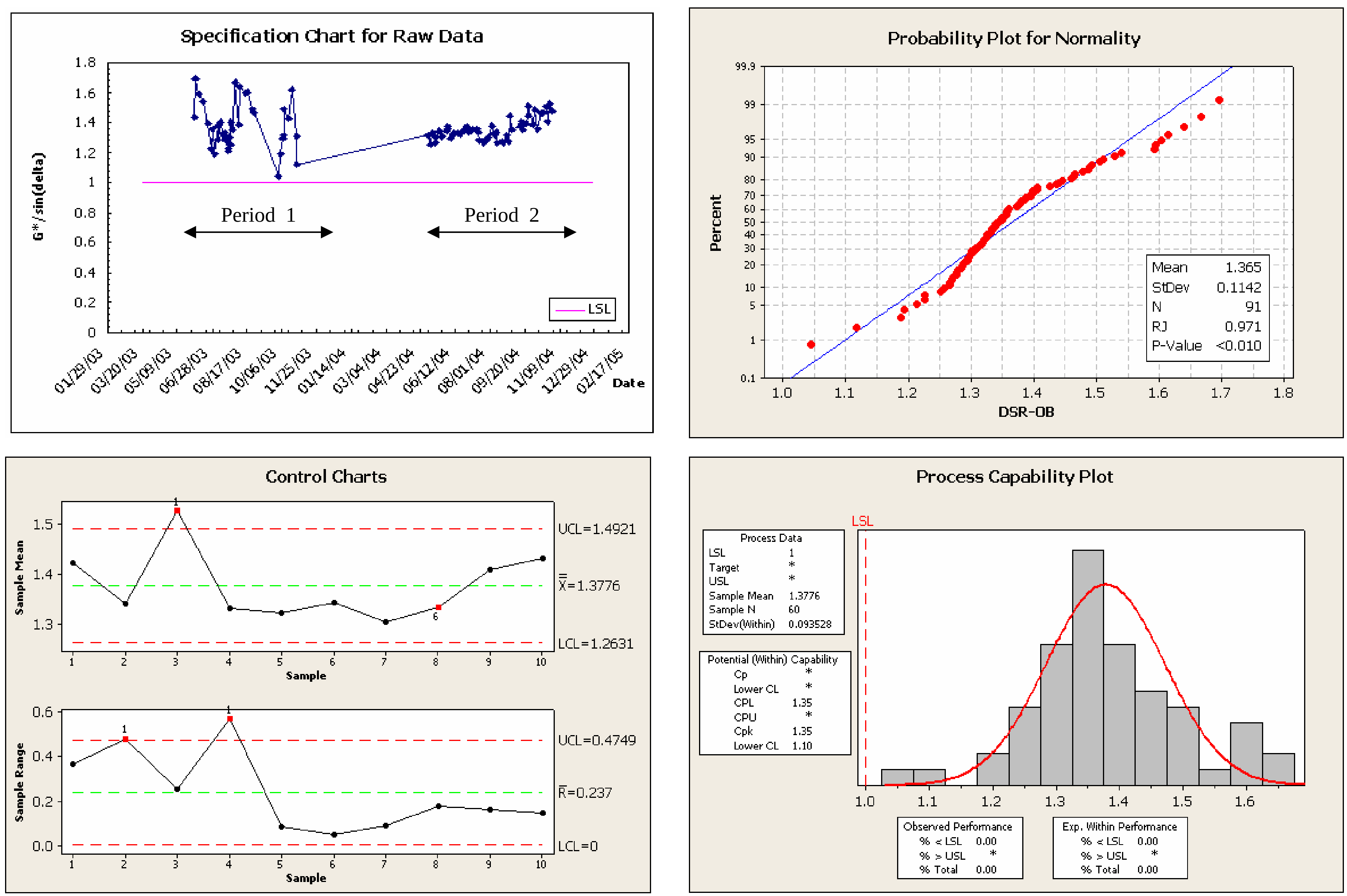


Figure G-64 Statistical Analysis Charts for Supplier: 0703 Grade: PG 64-22 Test: DSR-OB

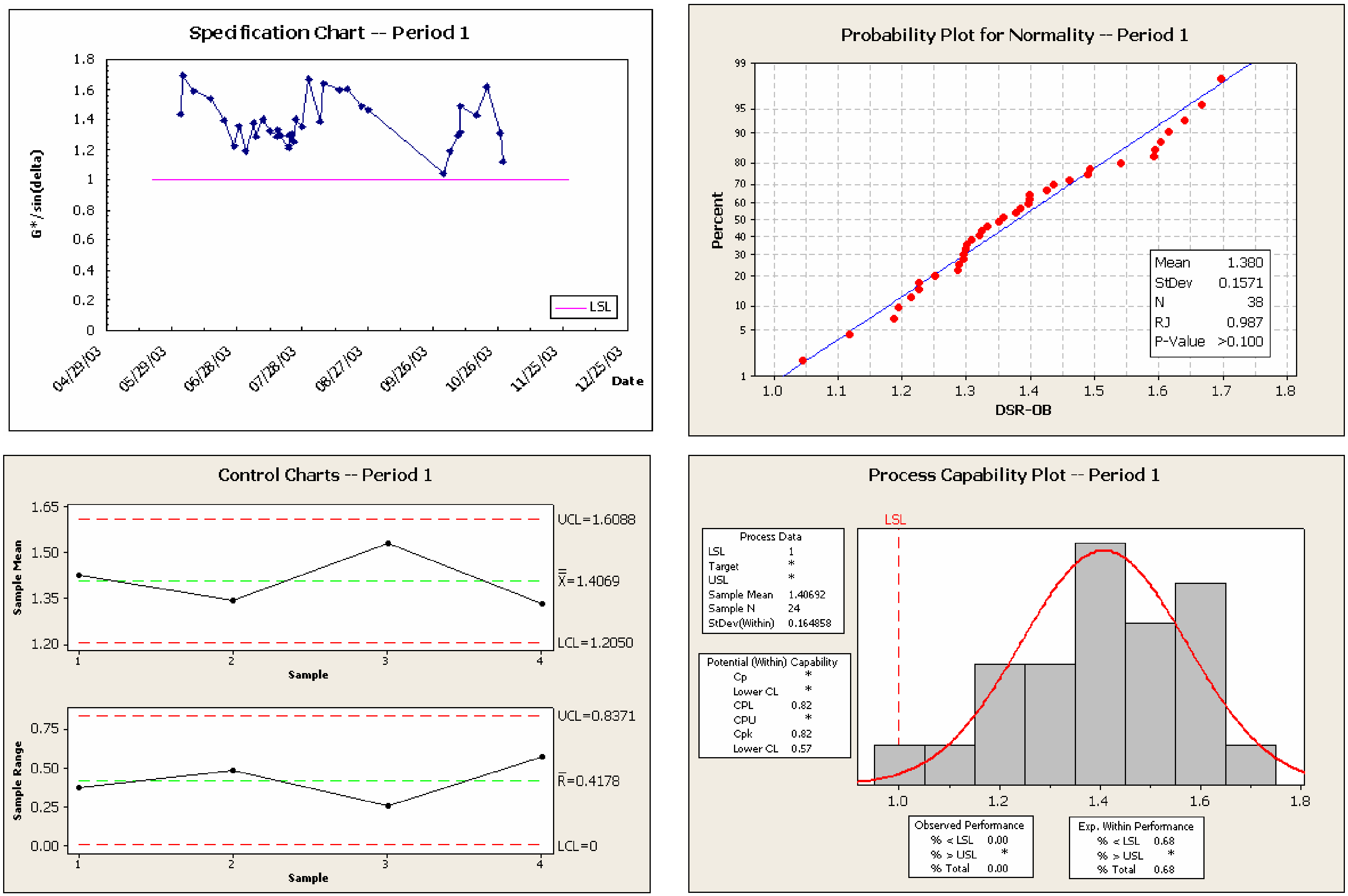


Figure G-65 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: PG 64-22 Test: DSR-OB

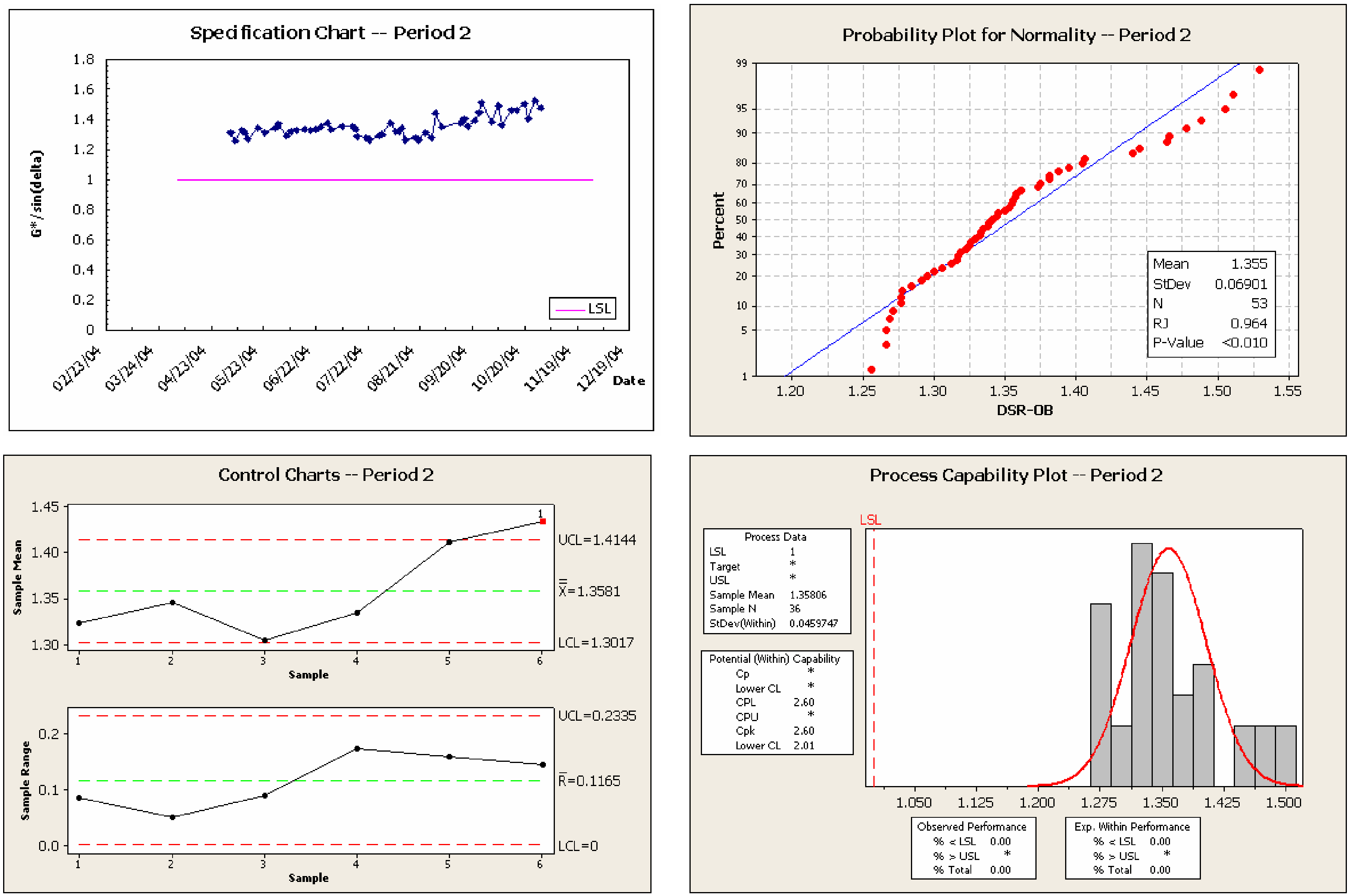


Figure G-66 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: PG 64-22 Test: DSR-OB

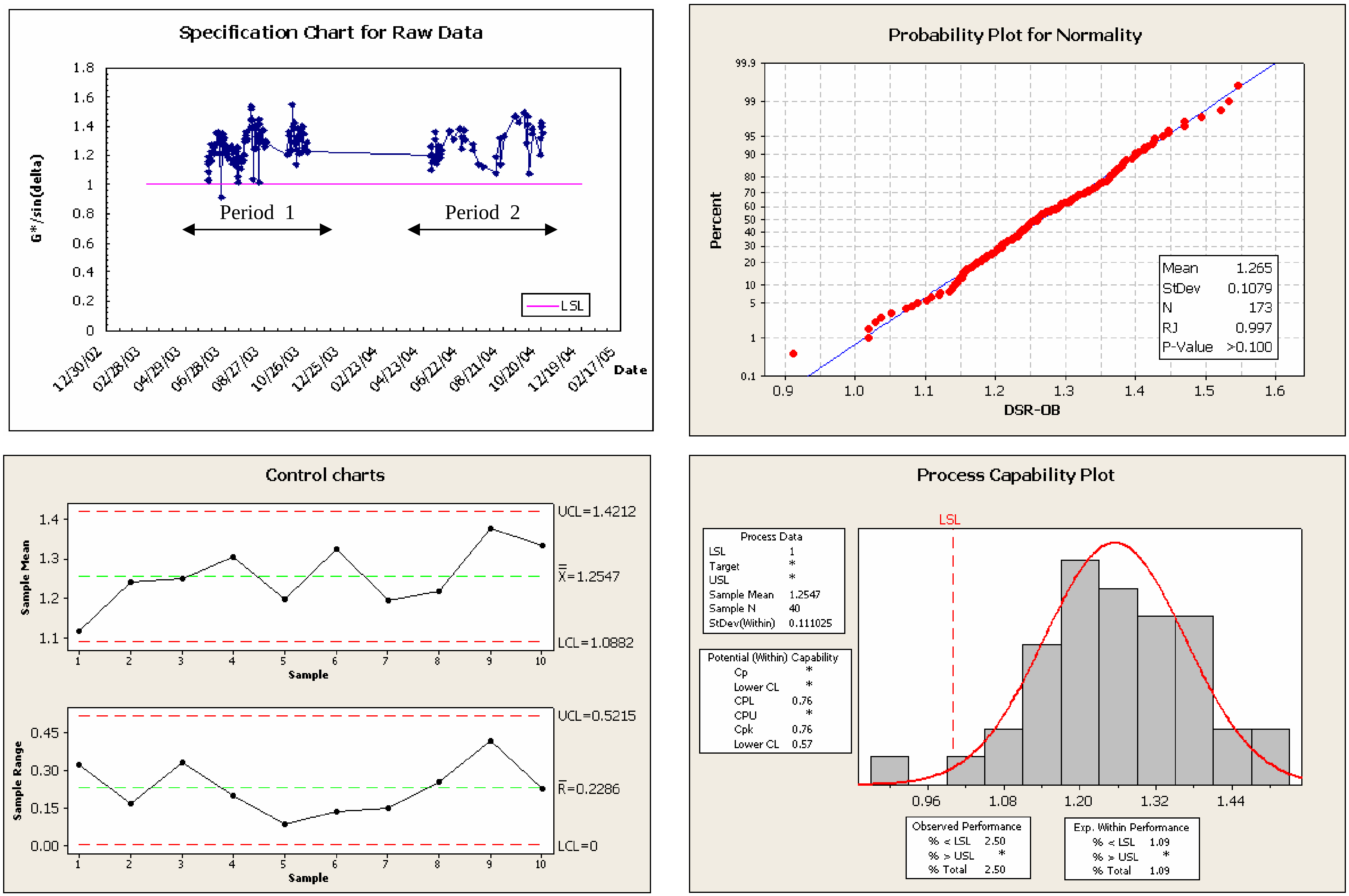


Figure G-67 Statistical Analysis Charts for Supplier: 0703 Grade: PG 70-22 Test: DSR-OB

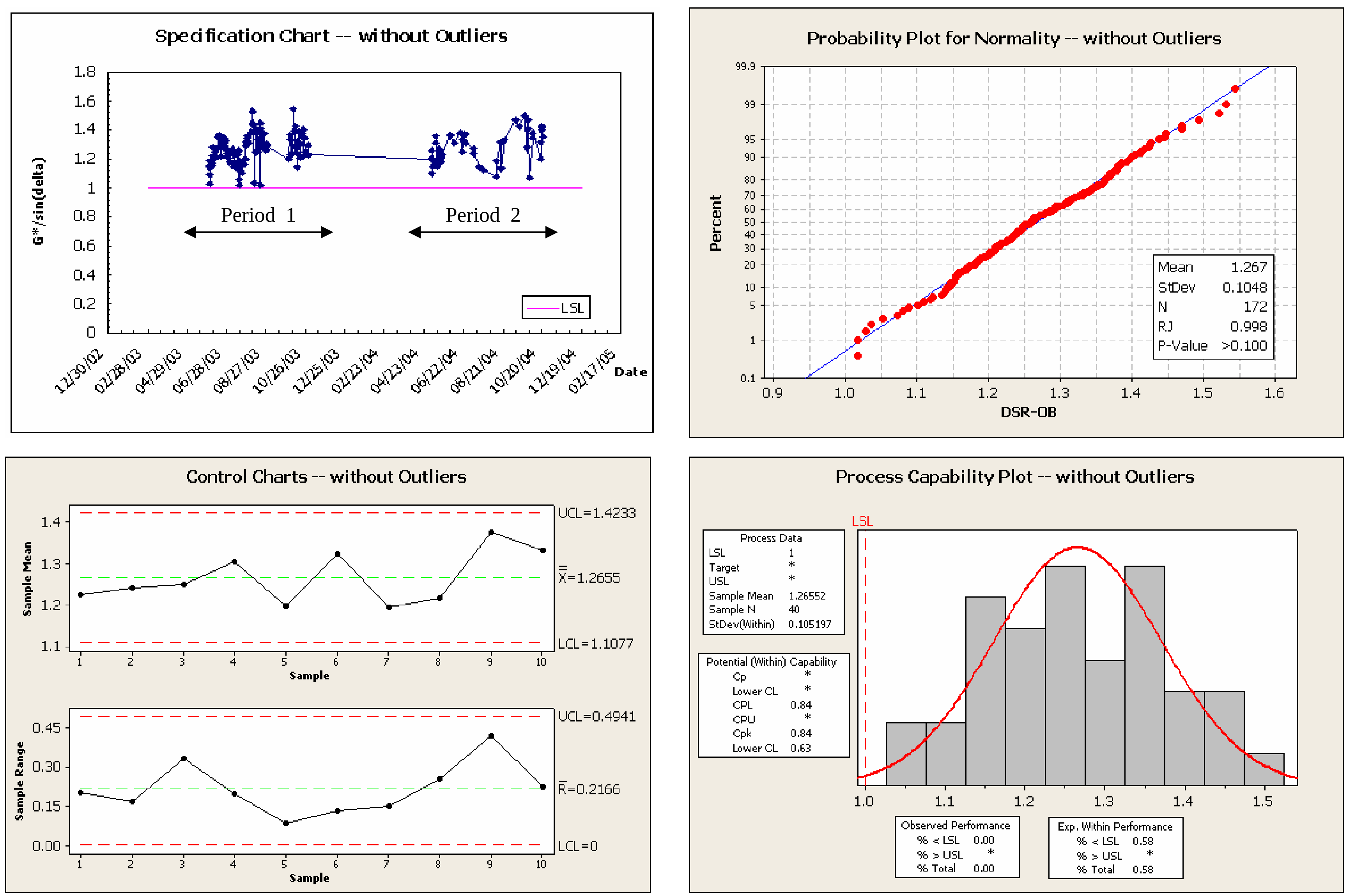


Figure G-68 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: PG 70-22 Test: DSR-OB

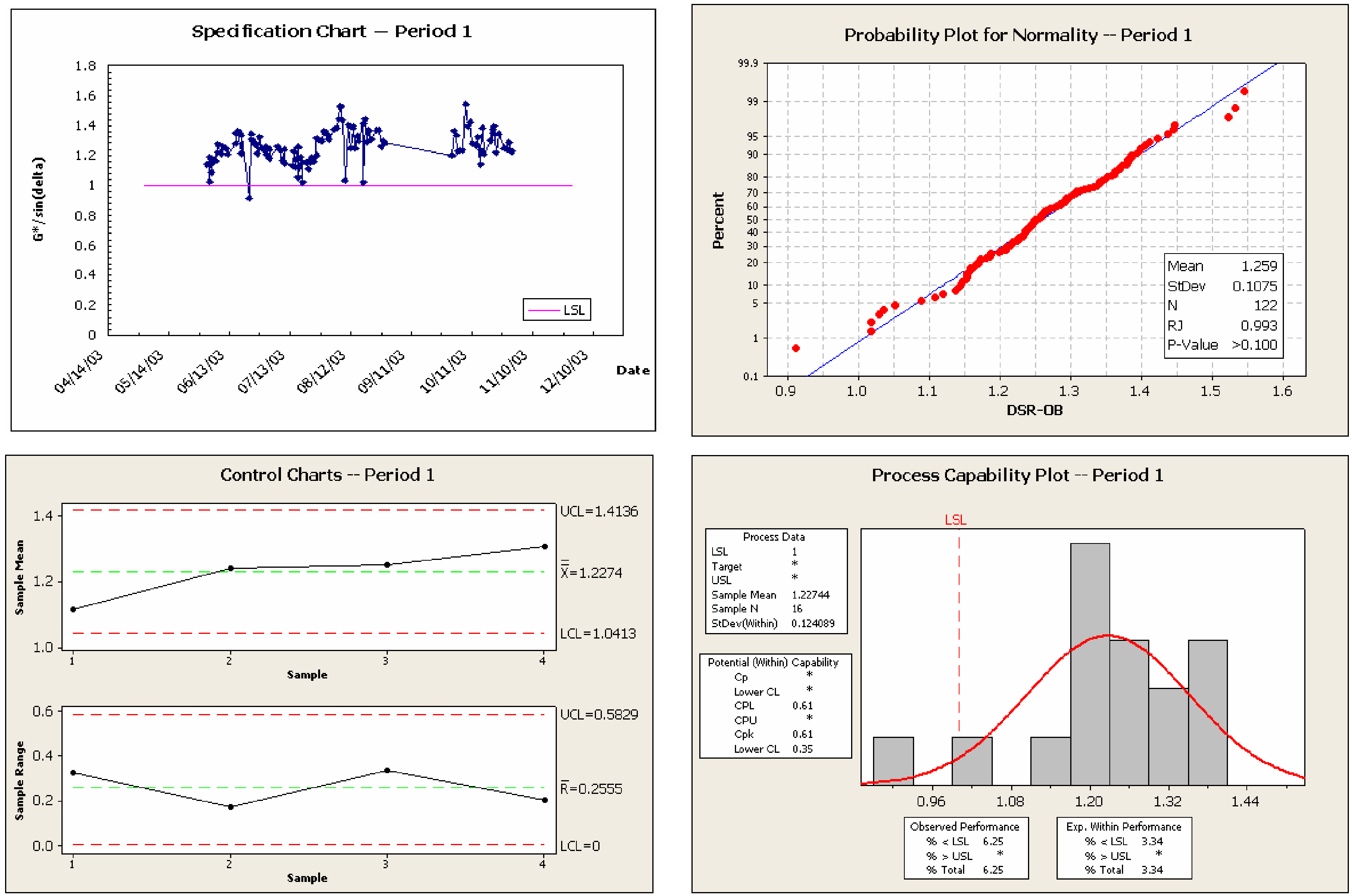


Figure G-69 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: PG 70-22 Test: DSR-OB

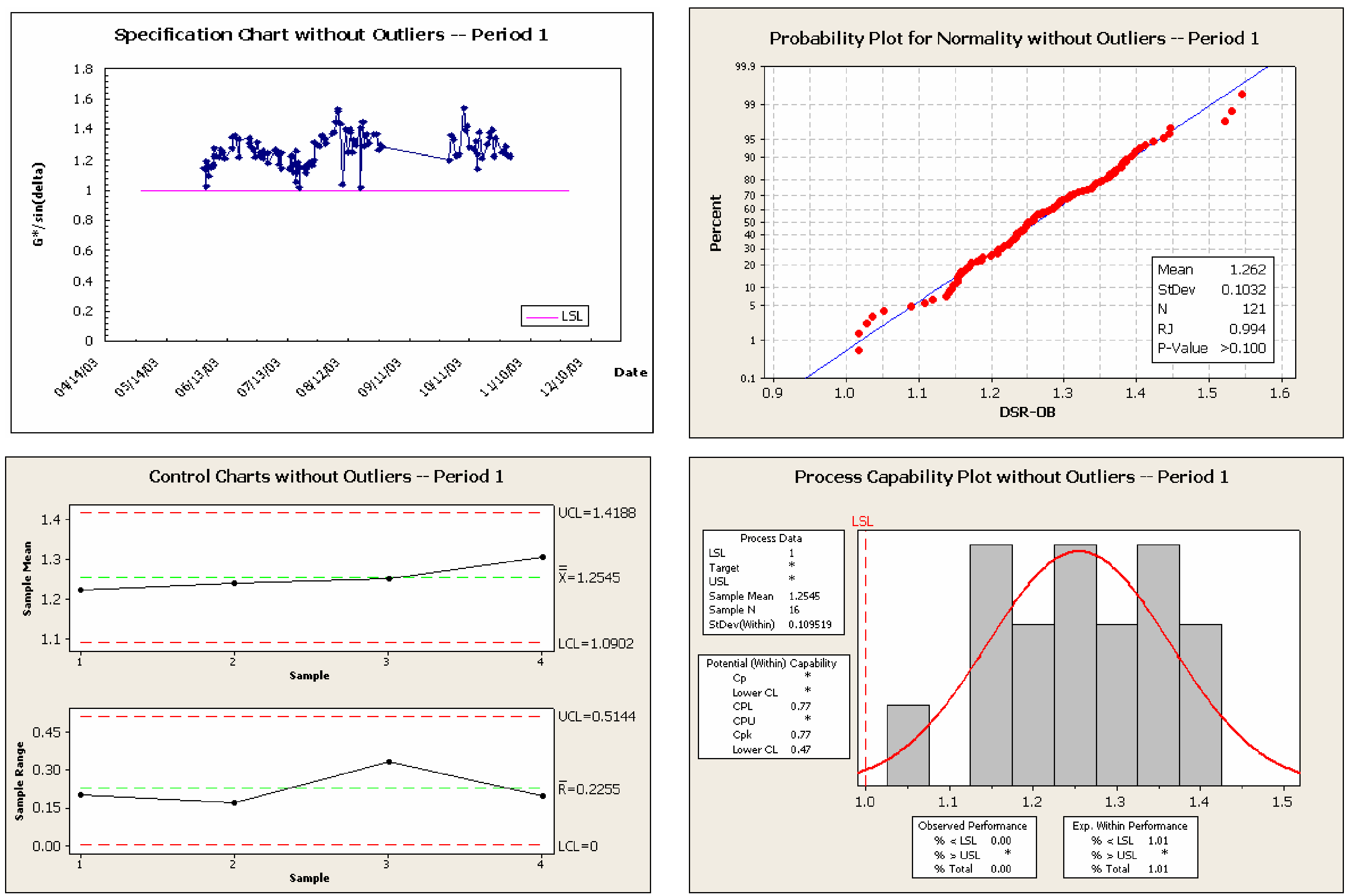


Figure G-70 Statistical Analysis Charts (without Outliers Period 1) for Supplier: 0703 Grade: PG 70-22 Test: DSR-OB

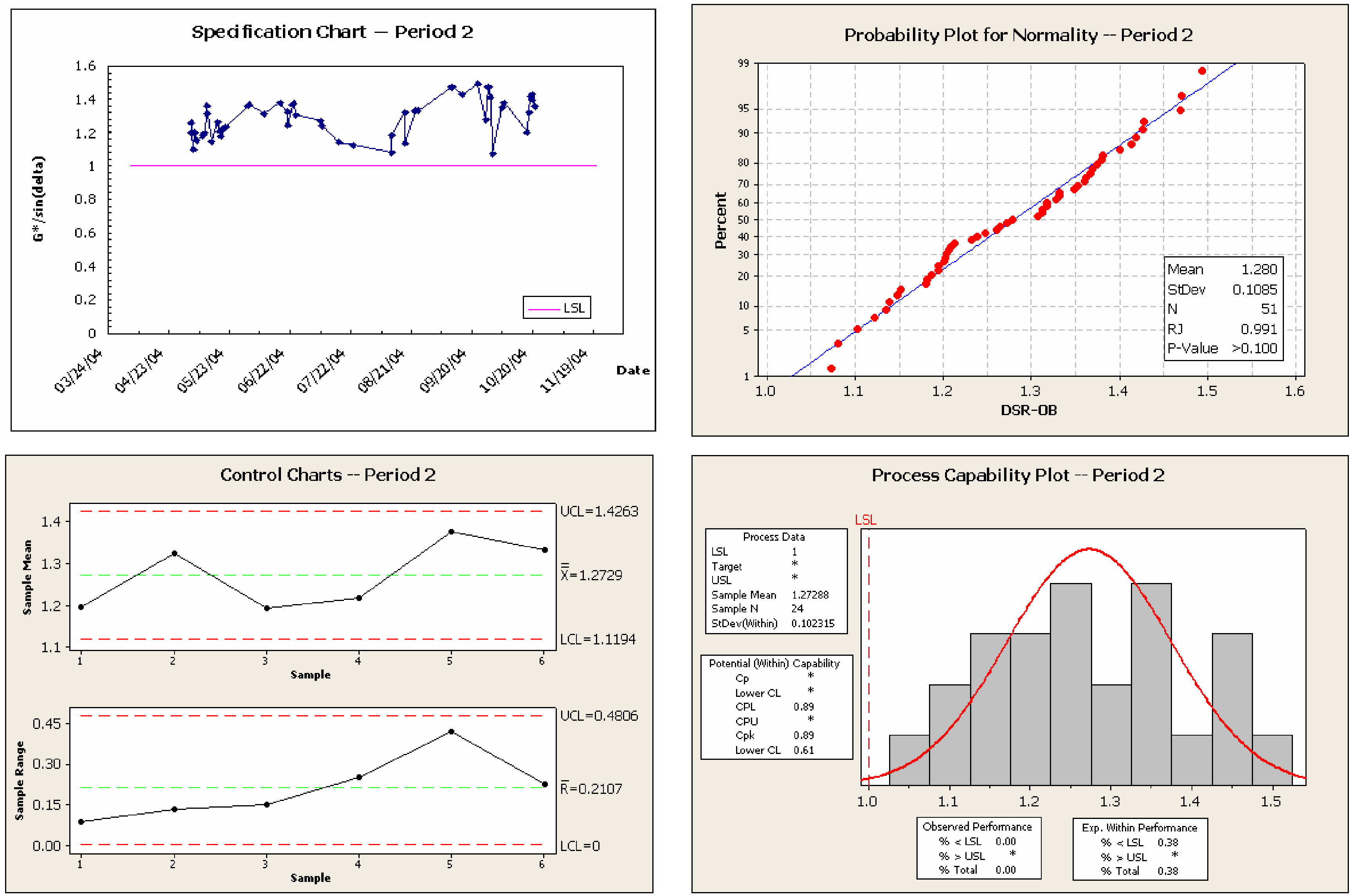


Figure G-71 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: PG 70-22 Test: DSR-OB

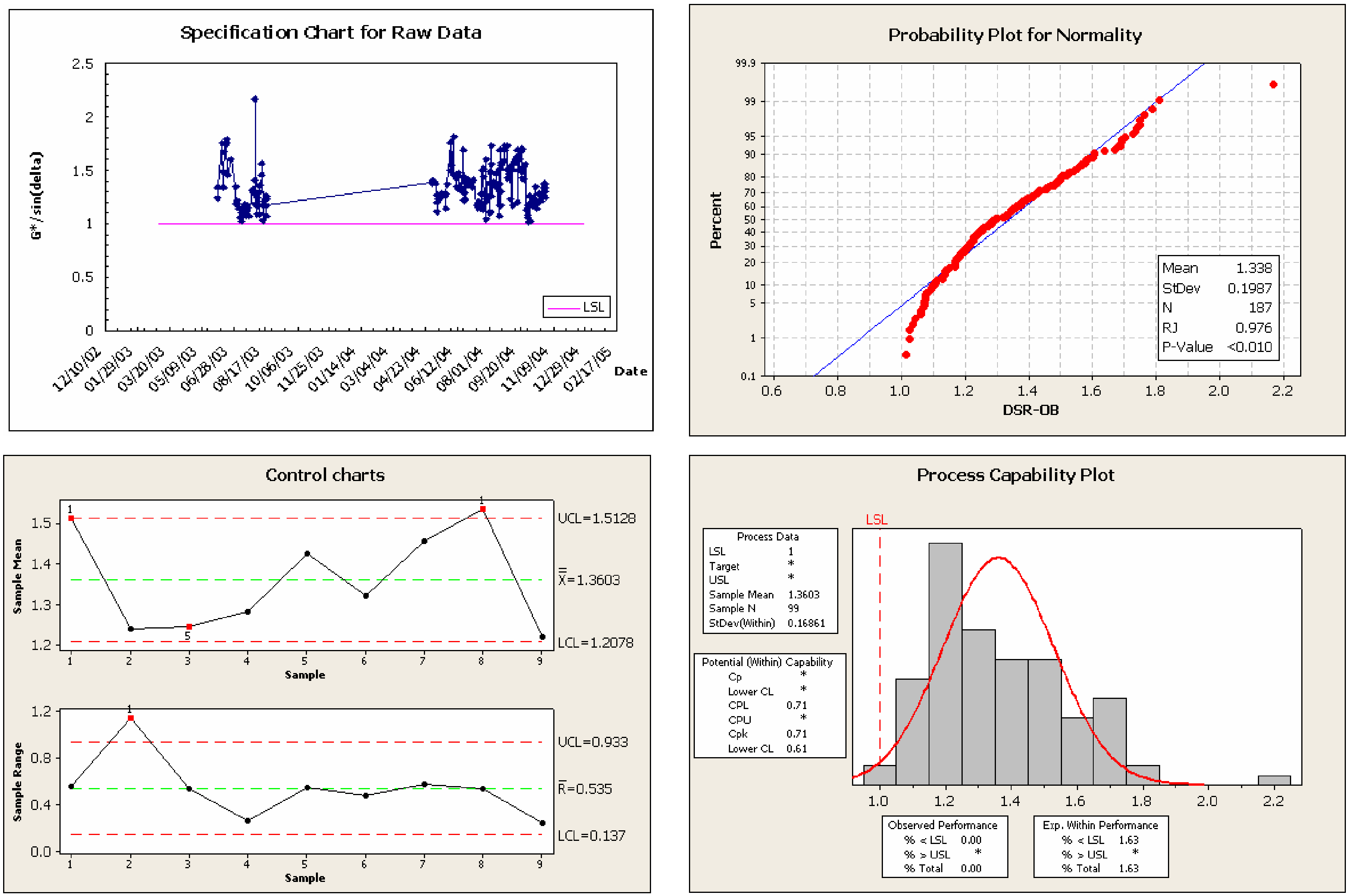


Figure G-72 Statistical Analysis Charts for Supplier: 0703 Grade: PG 70-28 Test: DSR-OB

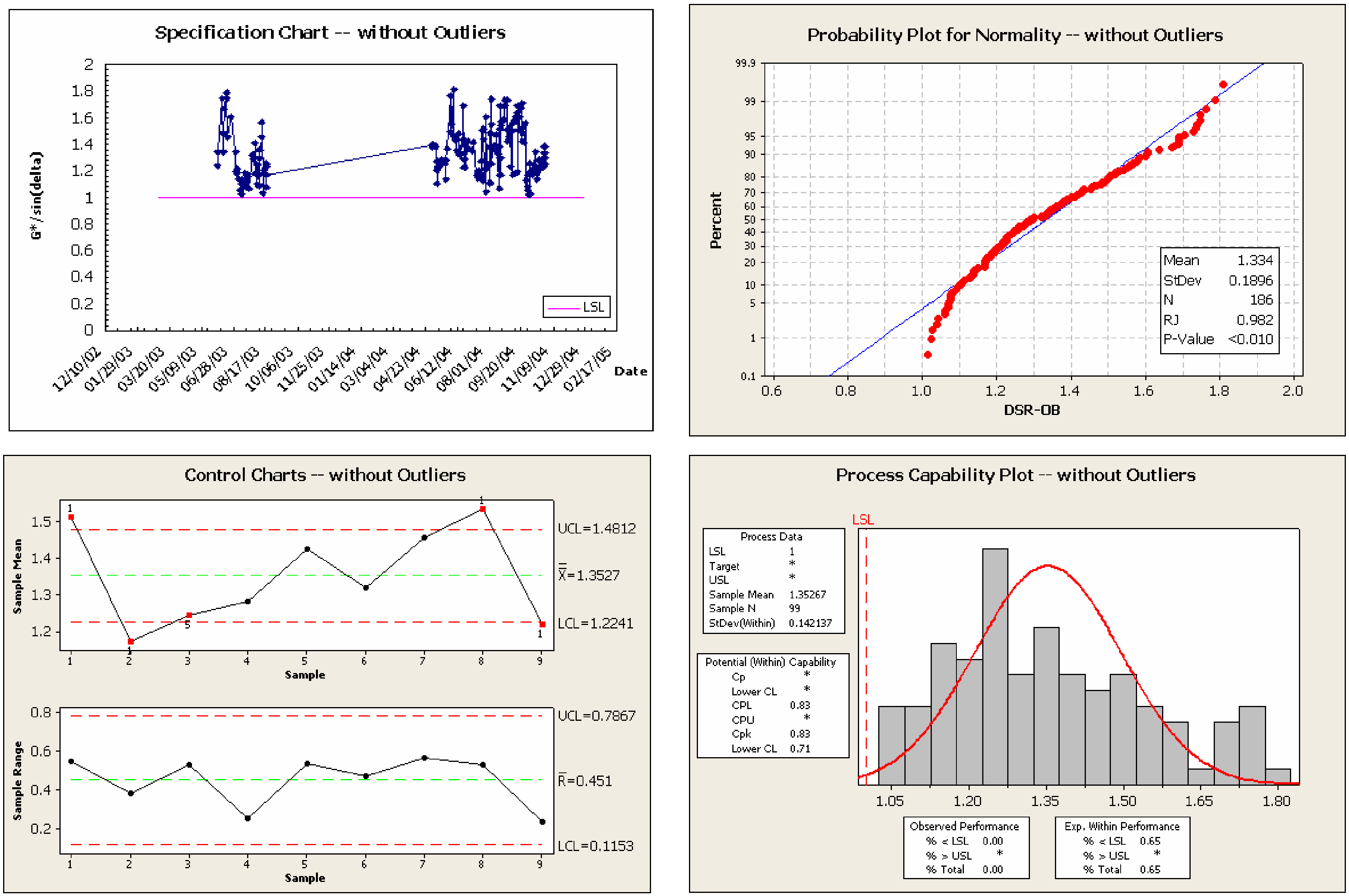


Figure G-73 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: PG 70-28 Test: DSR-OB

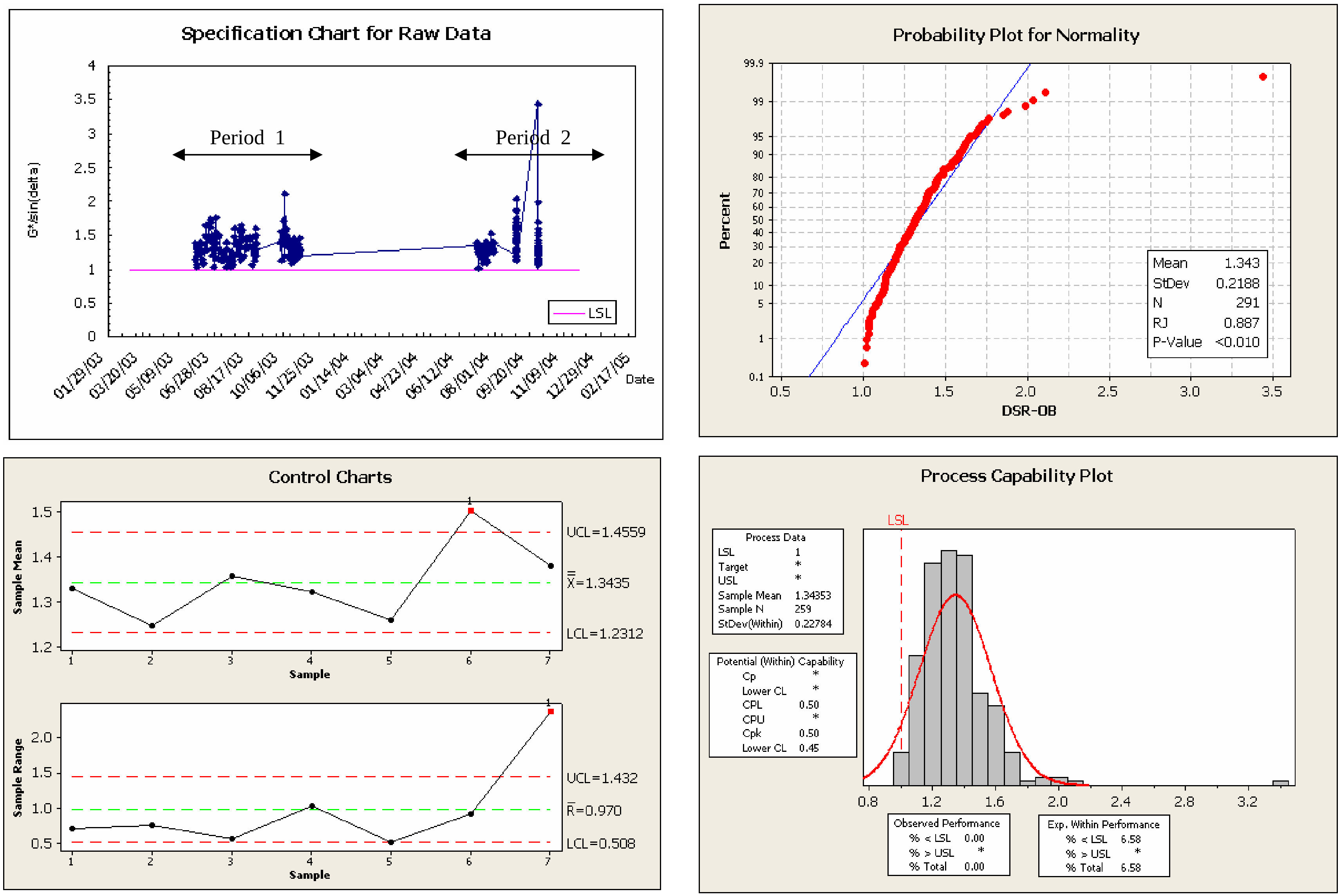


Figure G-74 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

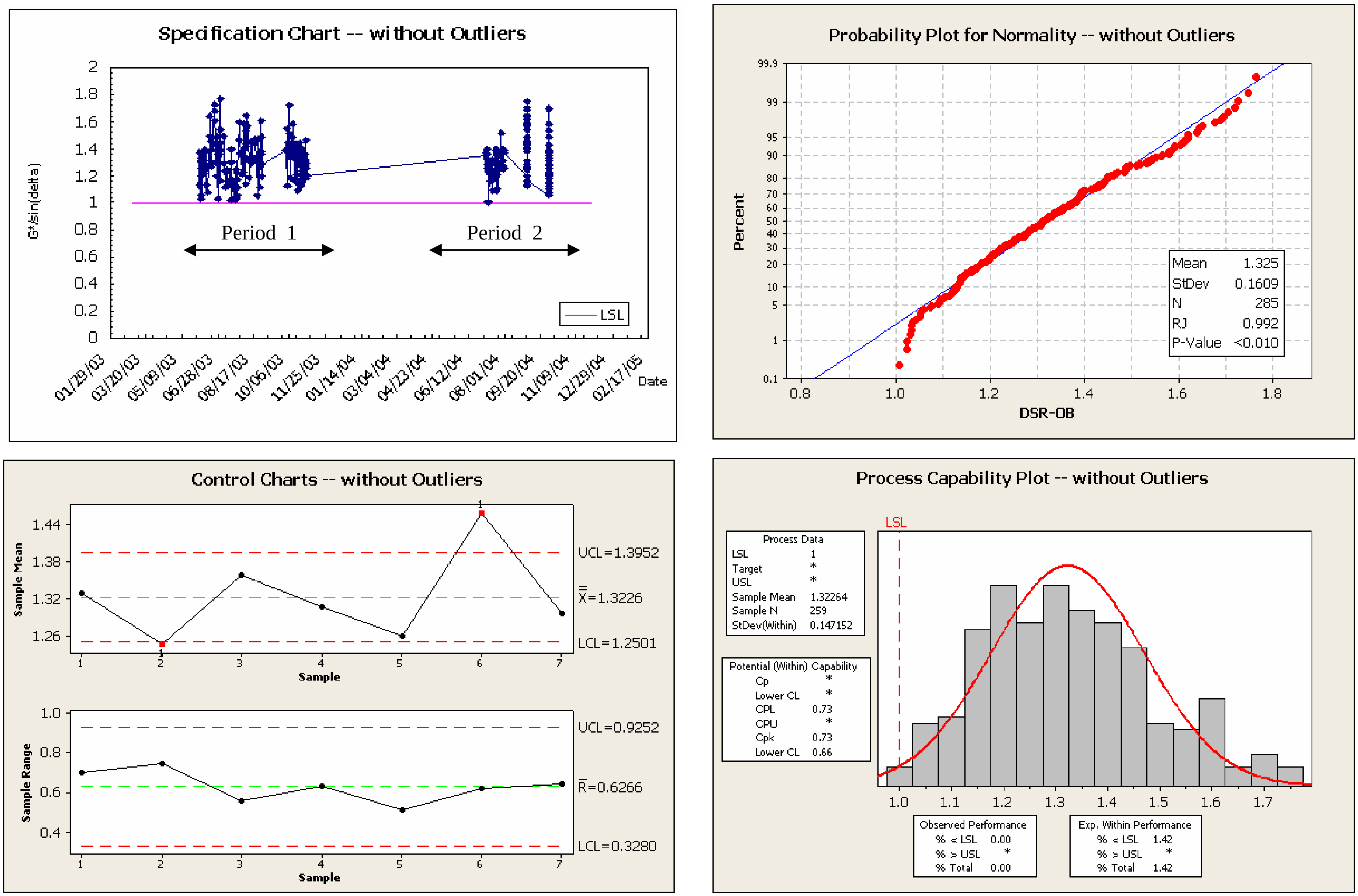


Figure G-75 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

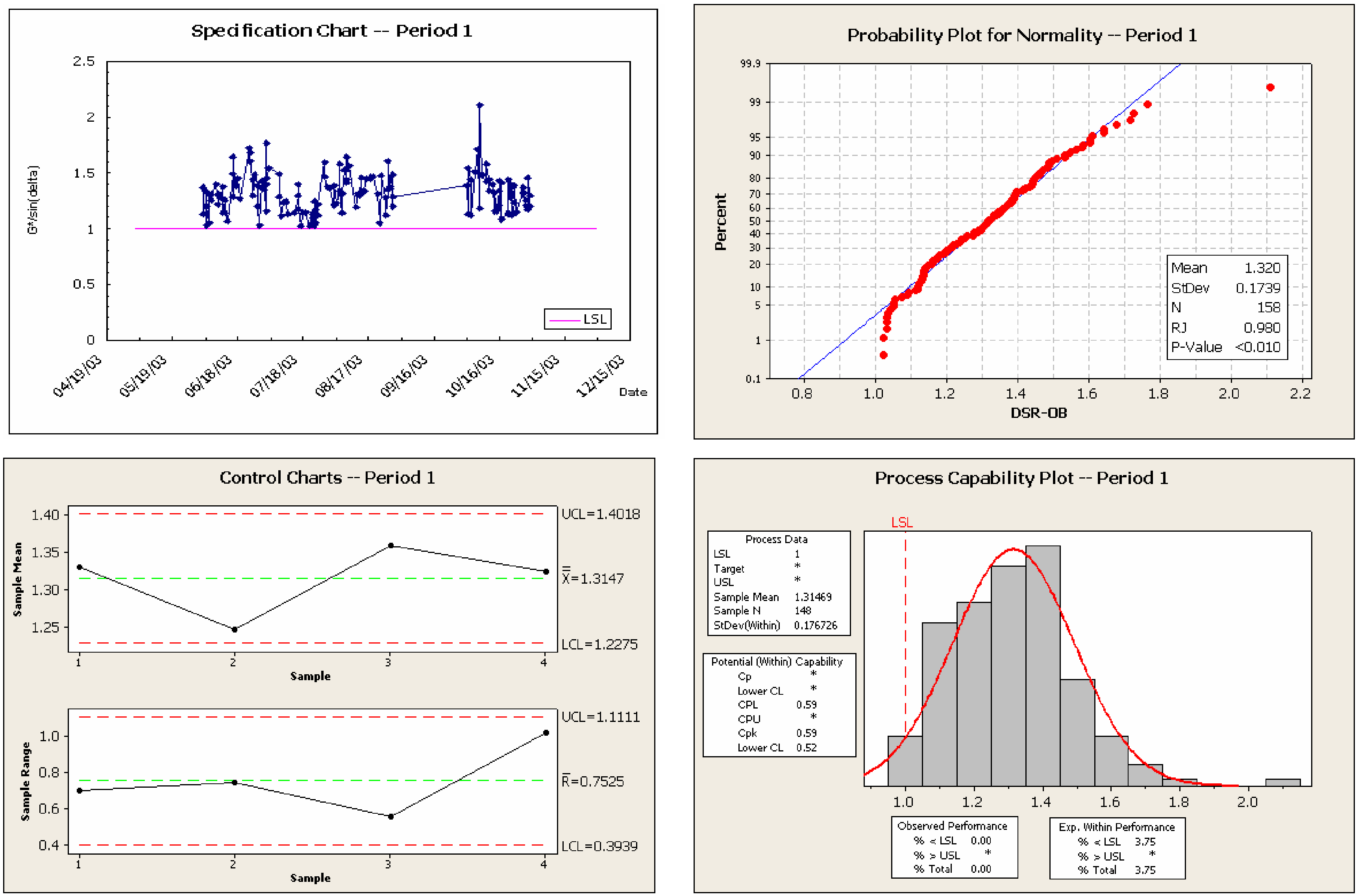


Figure G-76 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

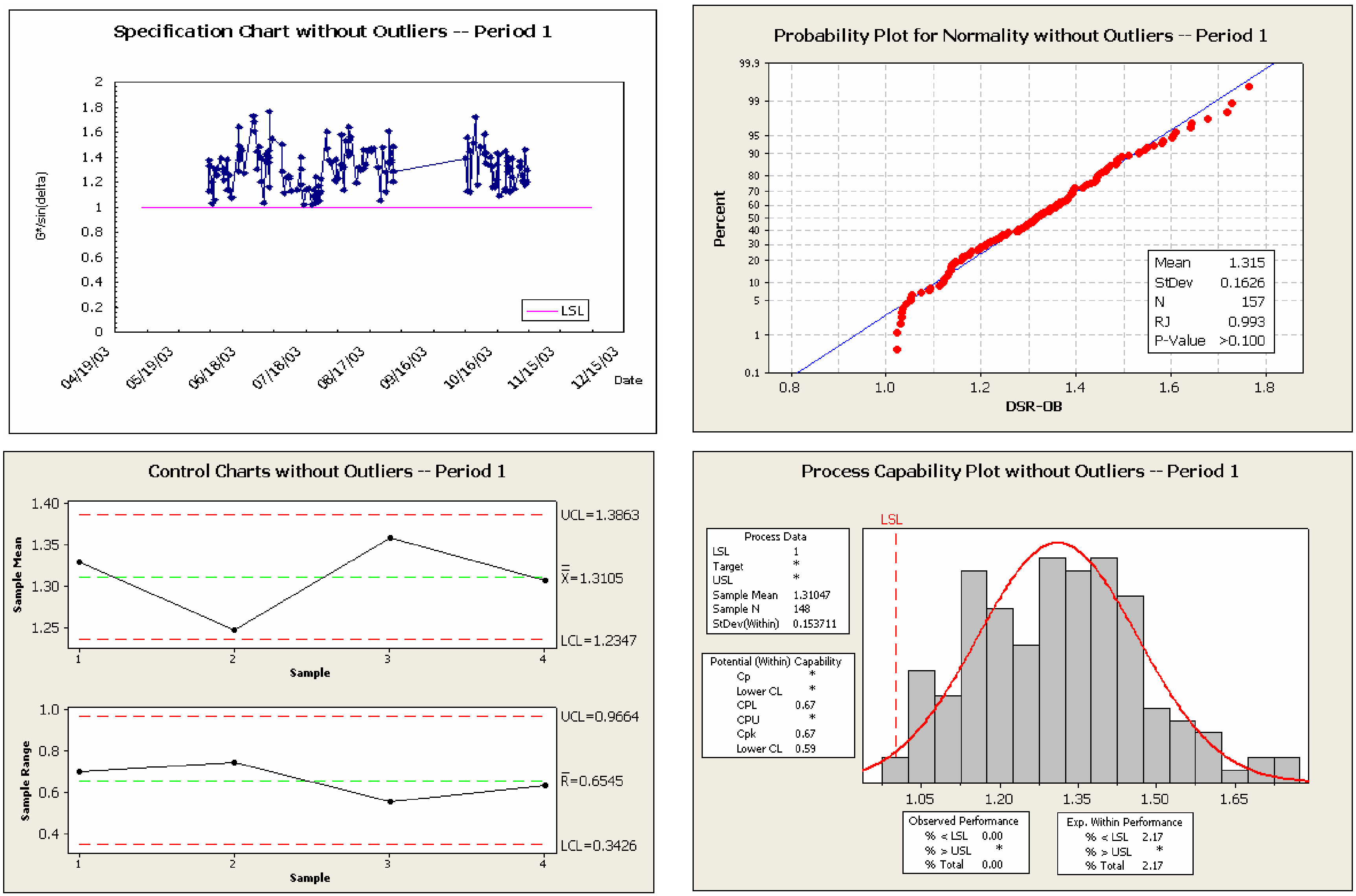


Figure G-77 Statistical Analysis Charts (without Outliers Period 1) for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

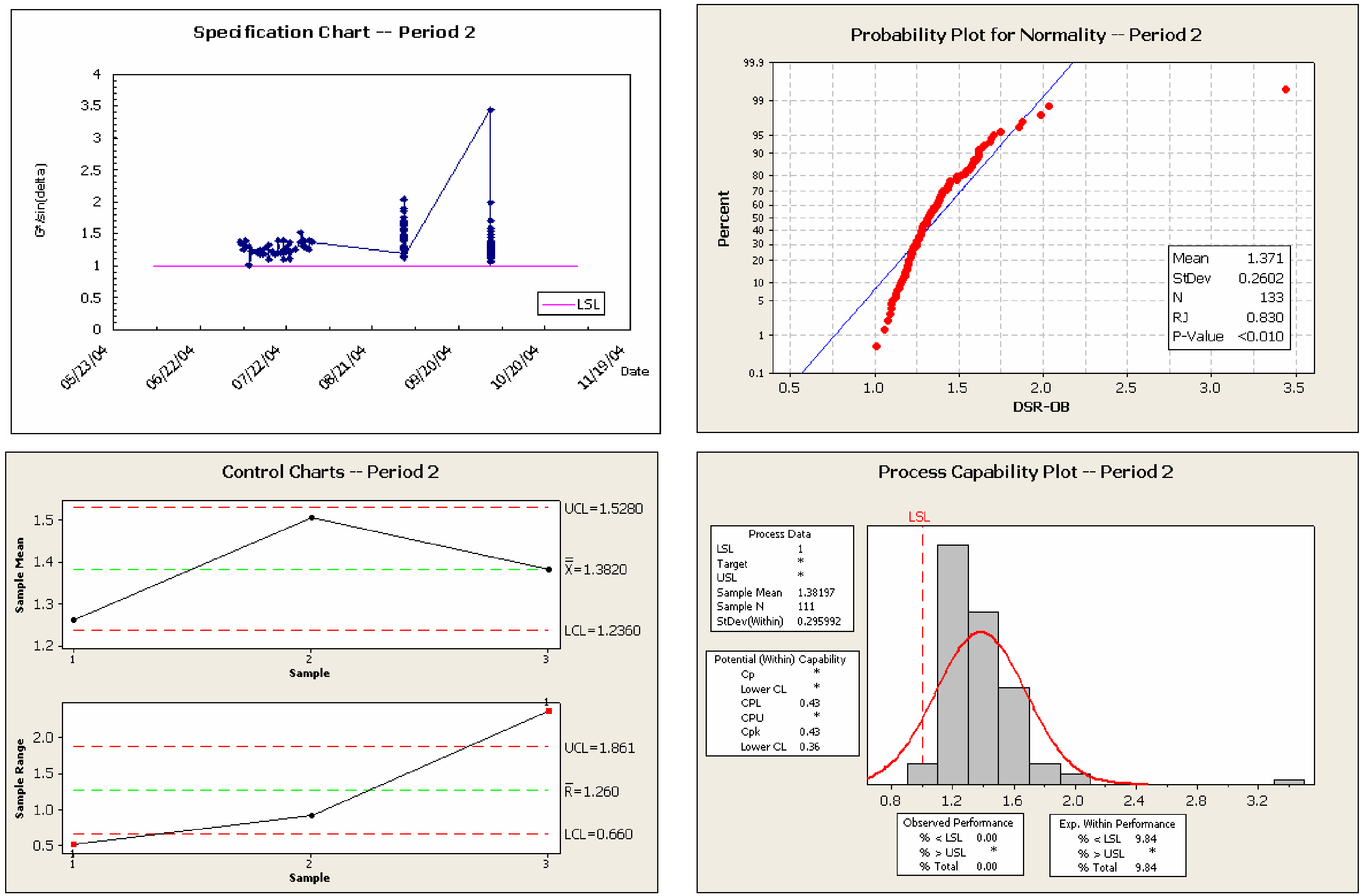


Figure G-78 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

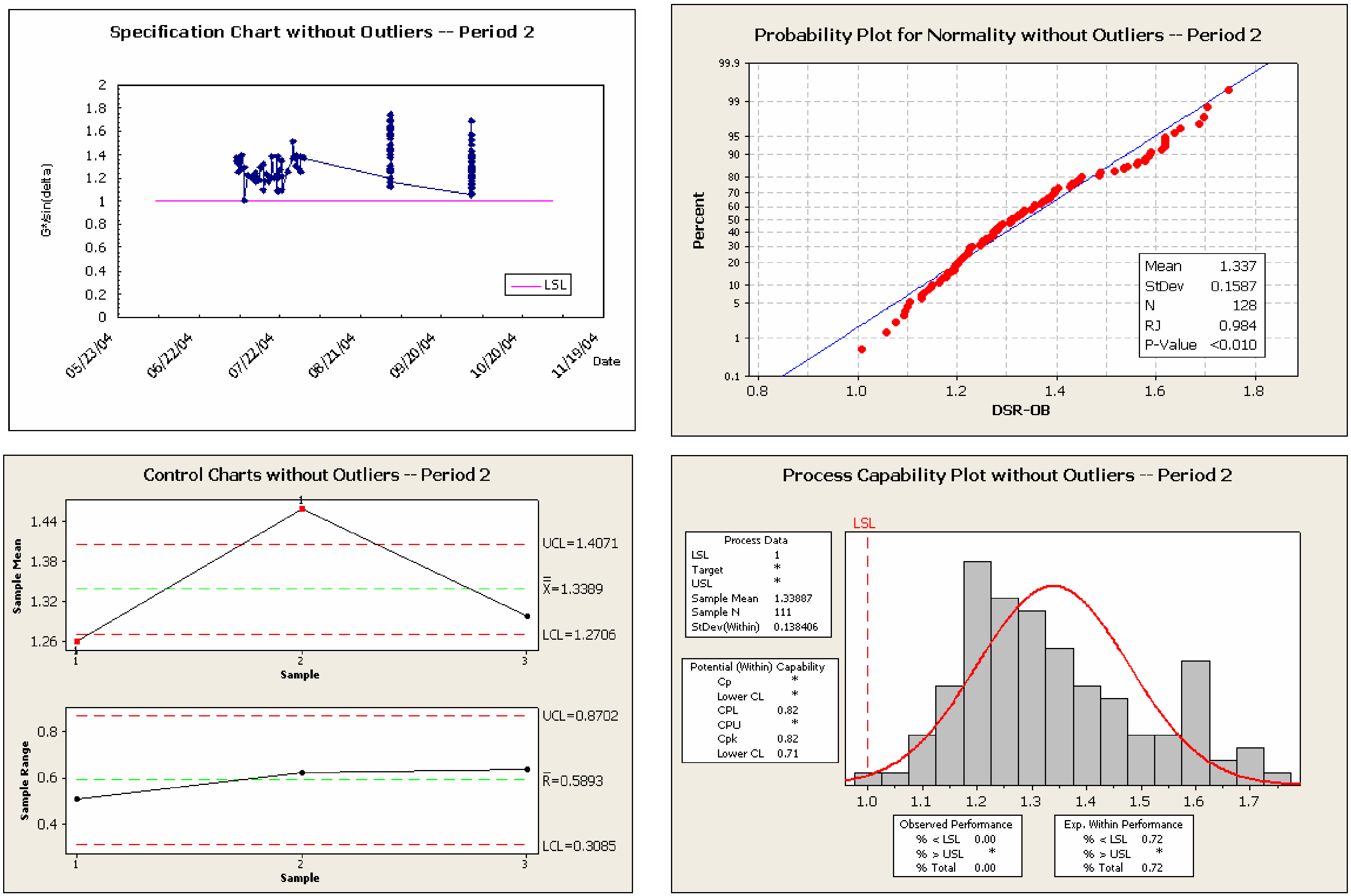


Figure G-79 Statistical Analysis Charts (without Outliers Period 2) for Supplier: 0703 Grade: PG 76-22 Test: DSR-OB

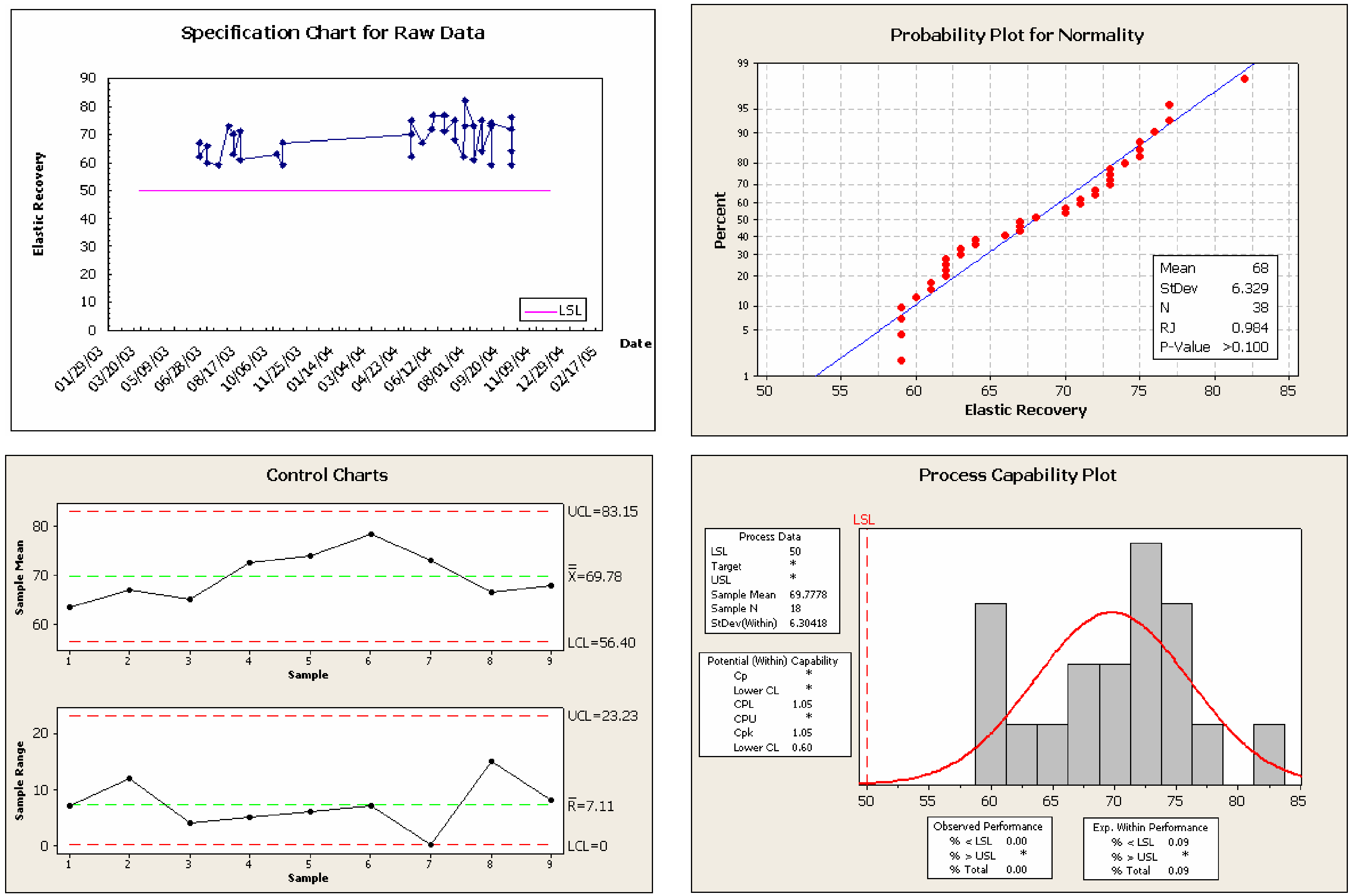


Figure G-80 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-22 Test: Elastic Recovery

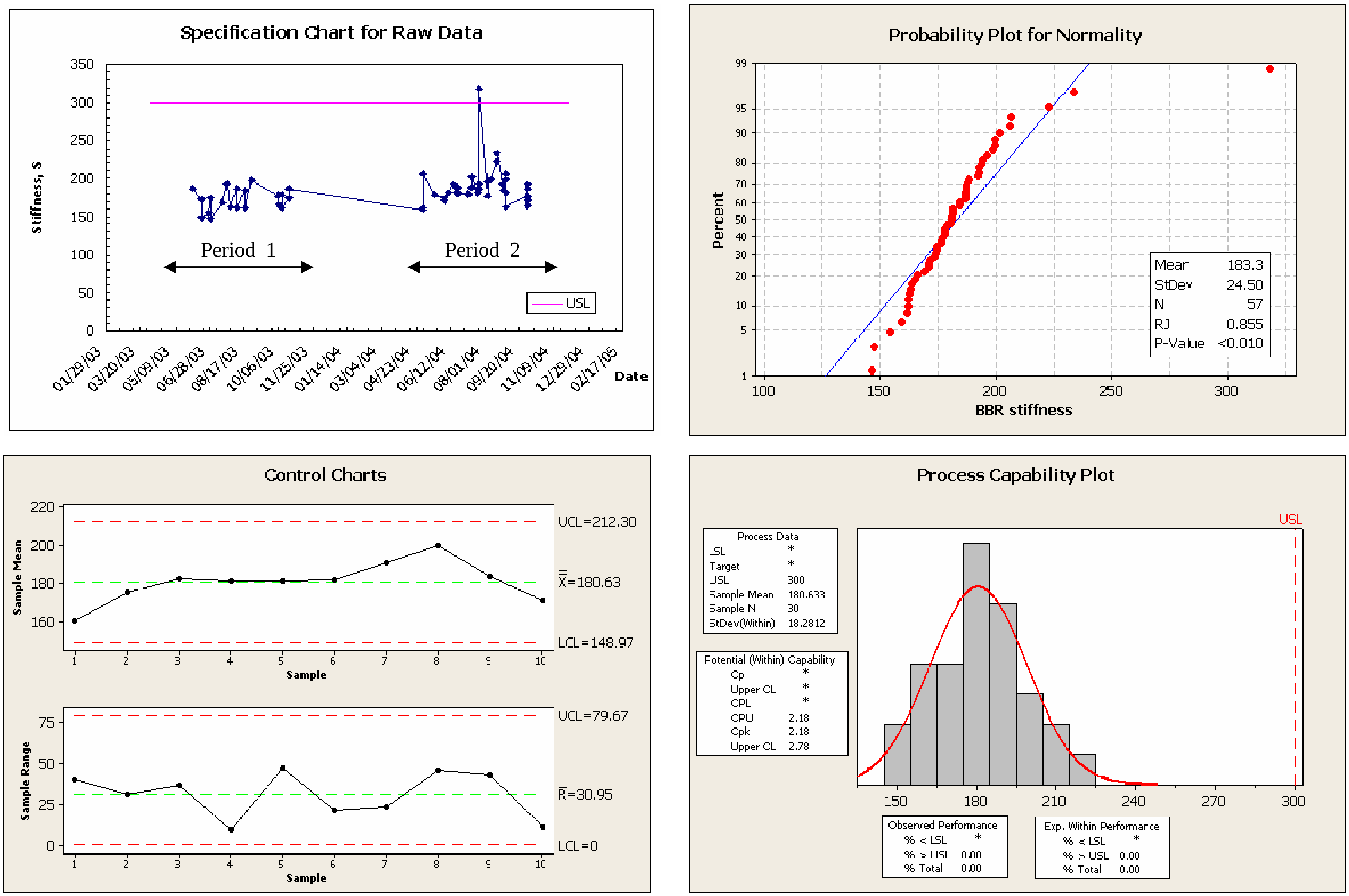


Figure G-81 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-22 Test: BBR-Stiffness

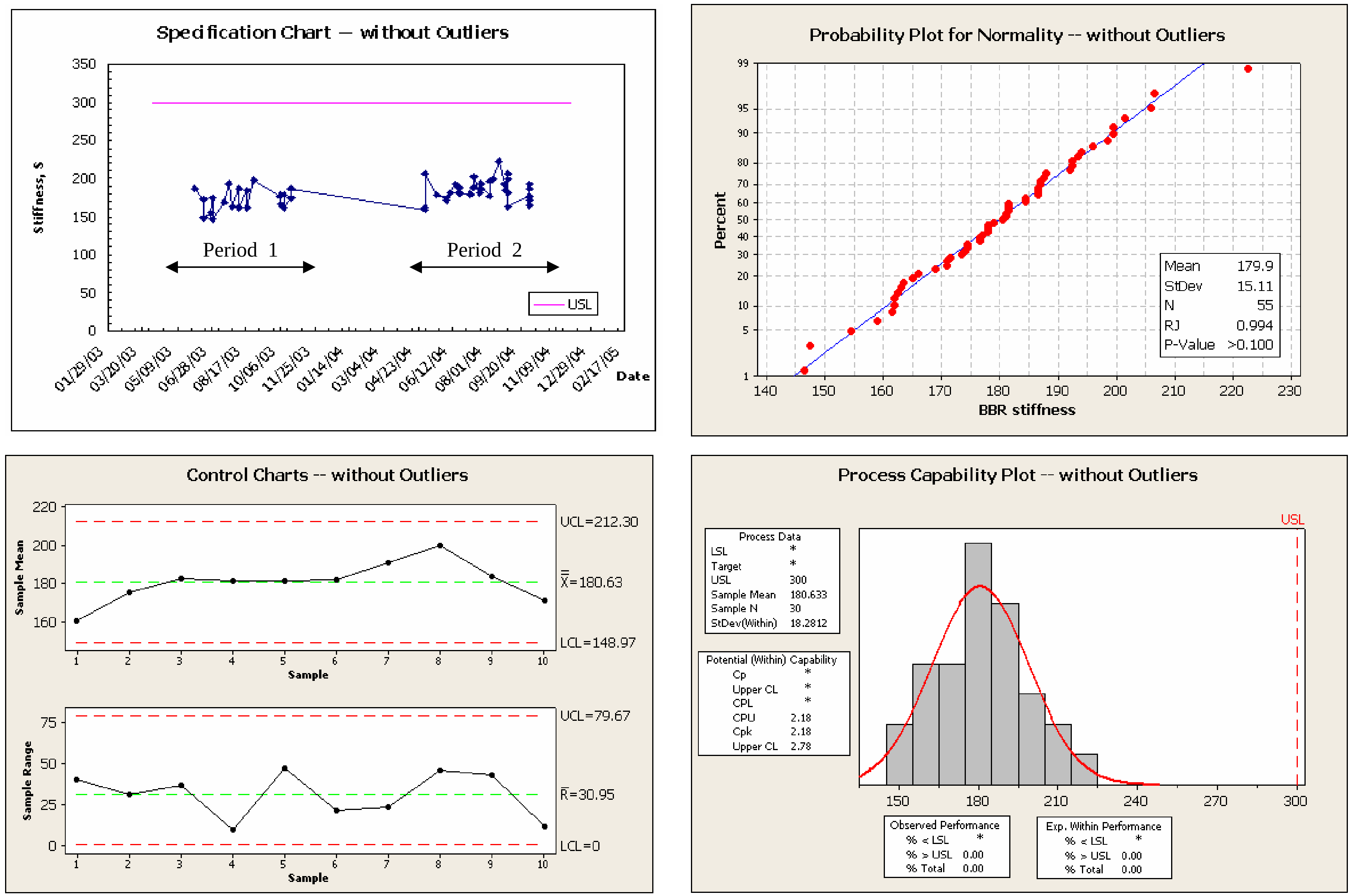


Figure G-82 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: PG 76-22 Test: BBR-Stiffness

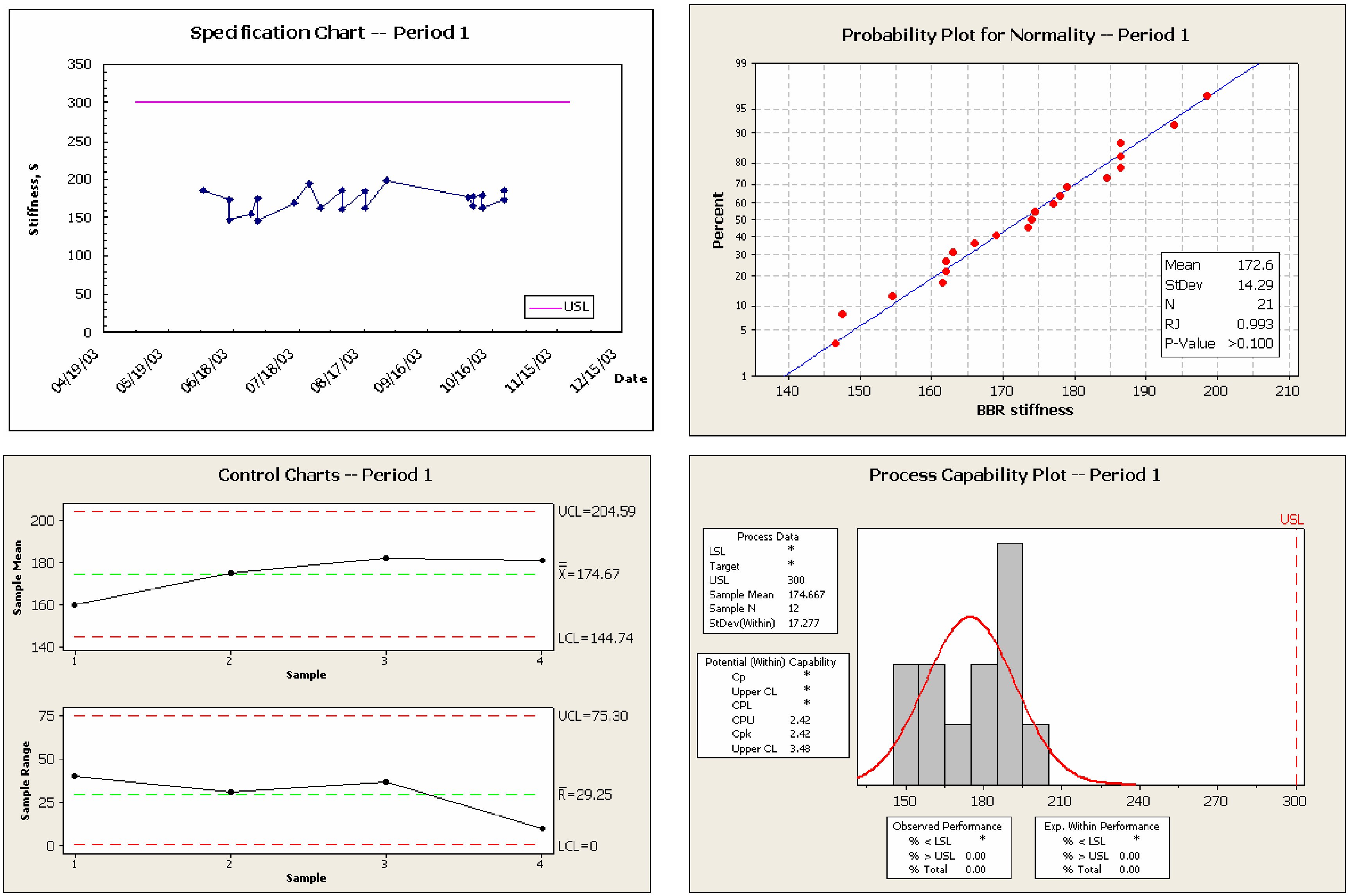


Figure G-83 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: PG 76-22 Test: BBR-Stiffness

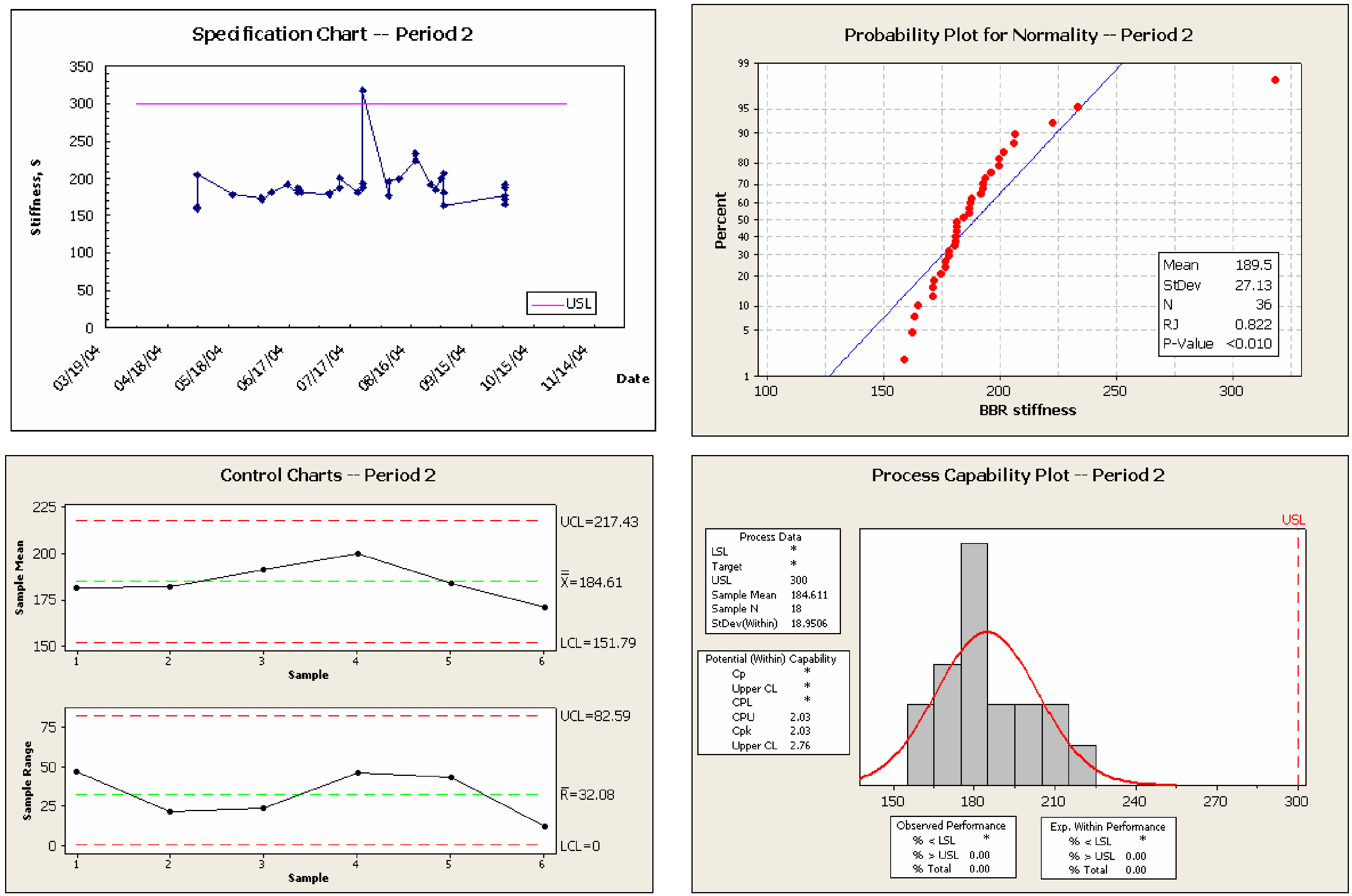


Figure G-84 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: PG 76-22 Test: BBR-Stiffness

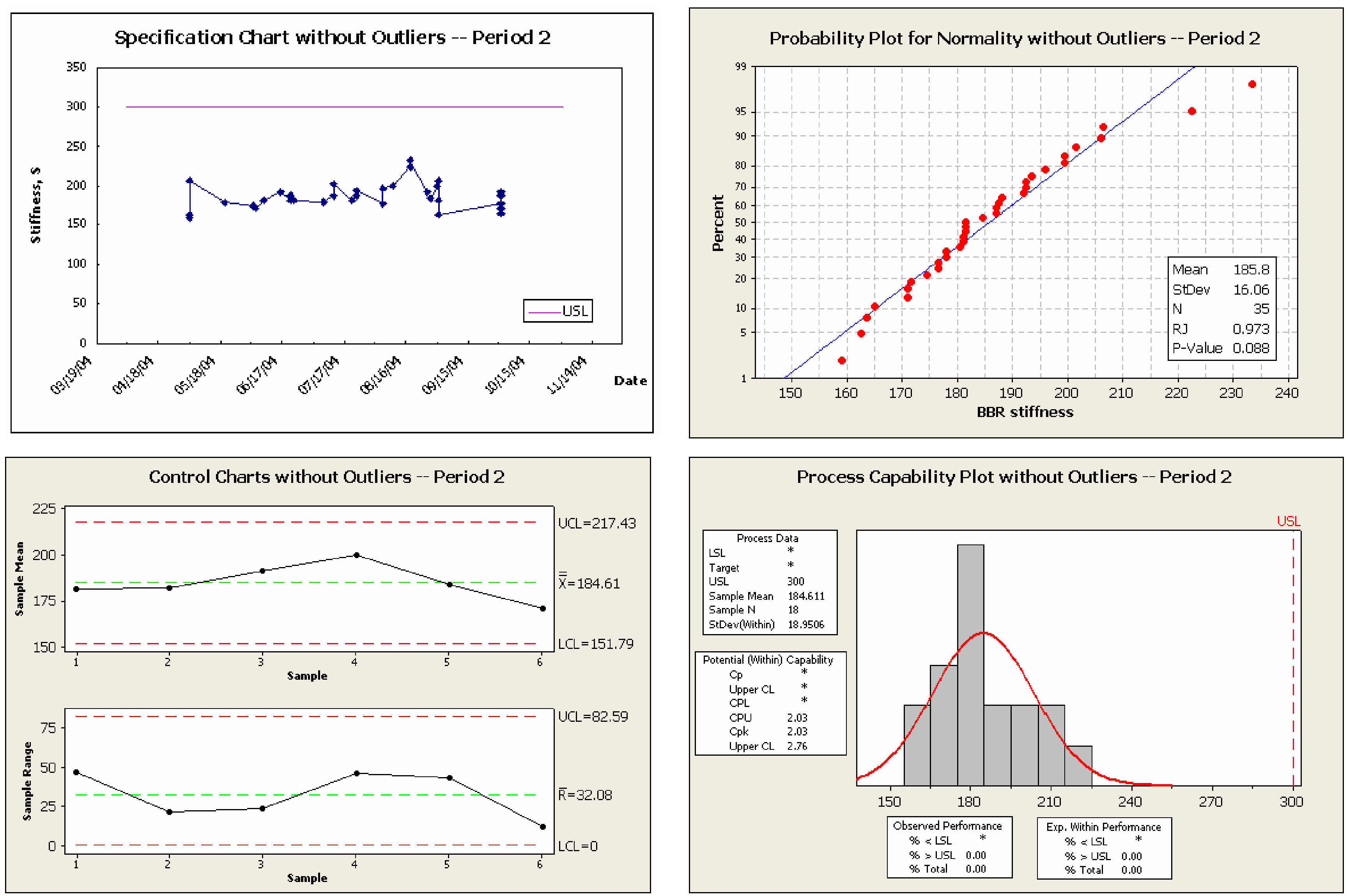


Figure G-85 Statistical Analysis Charts (without Outliers Period 2) for Supplier: 0703 Grade: PG 76-22 Test: BBR-Stiffness

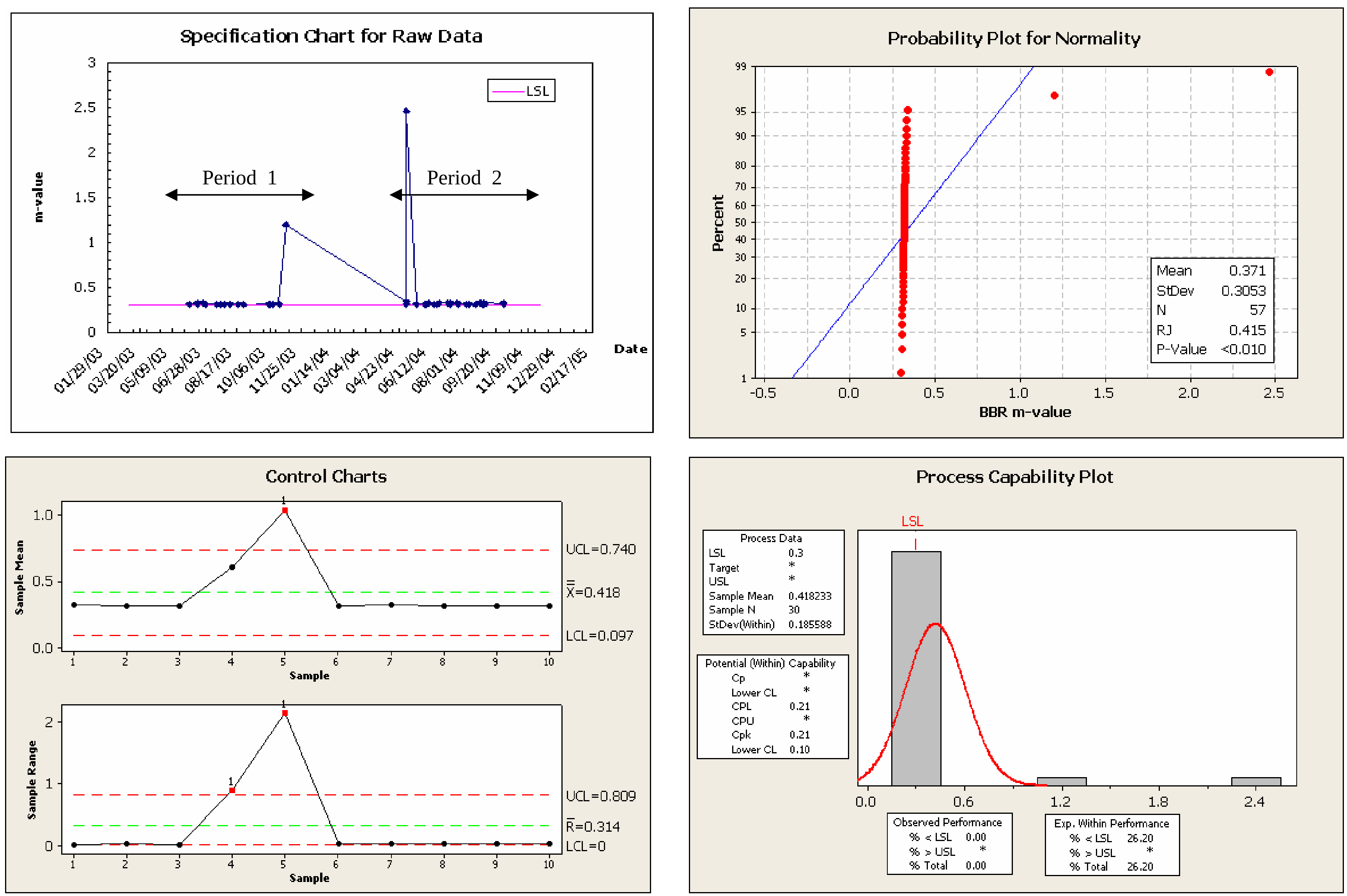


Figure G-86 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-22 Test: BBR-m-value

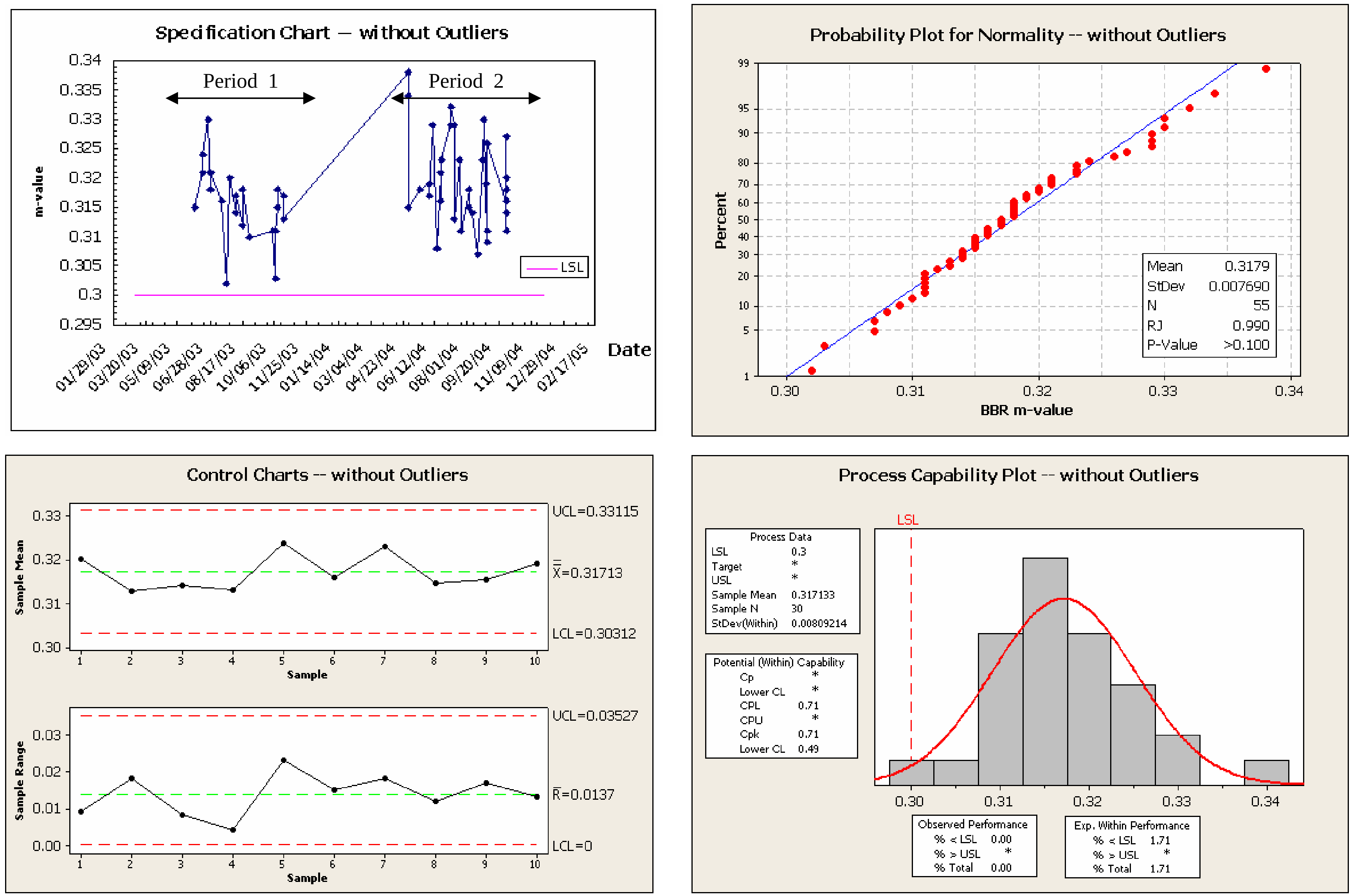


Figure G-87 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: PG 76-22 Test: BBR-m-value

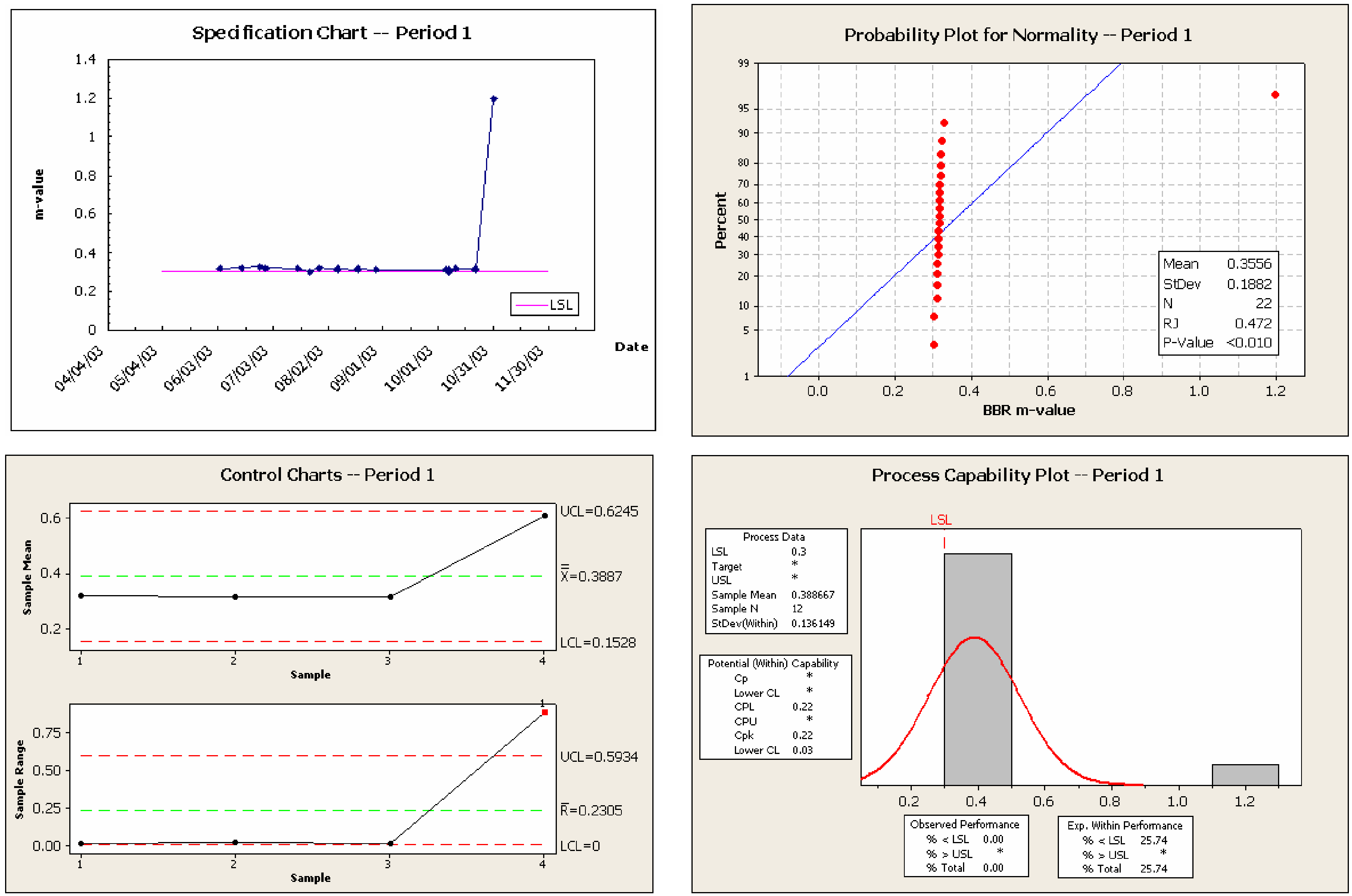


Figure G-88 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: PG 76-22 Test: BBR-m-value

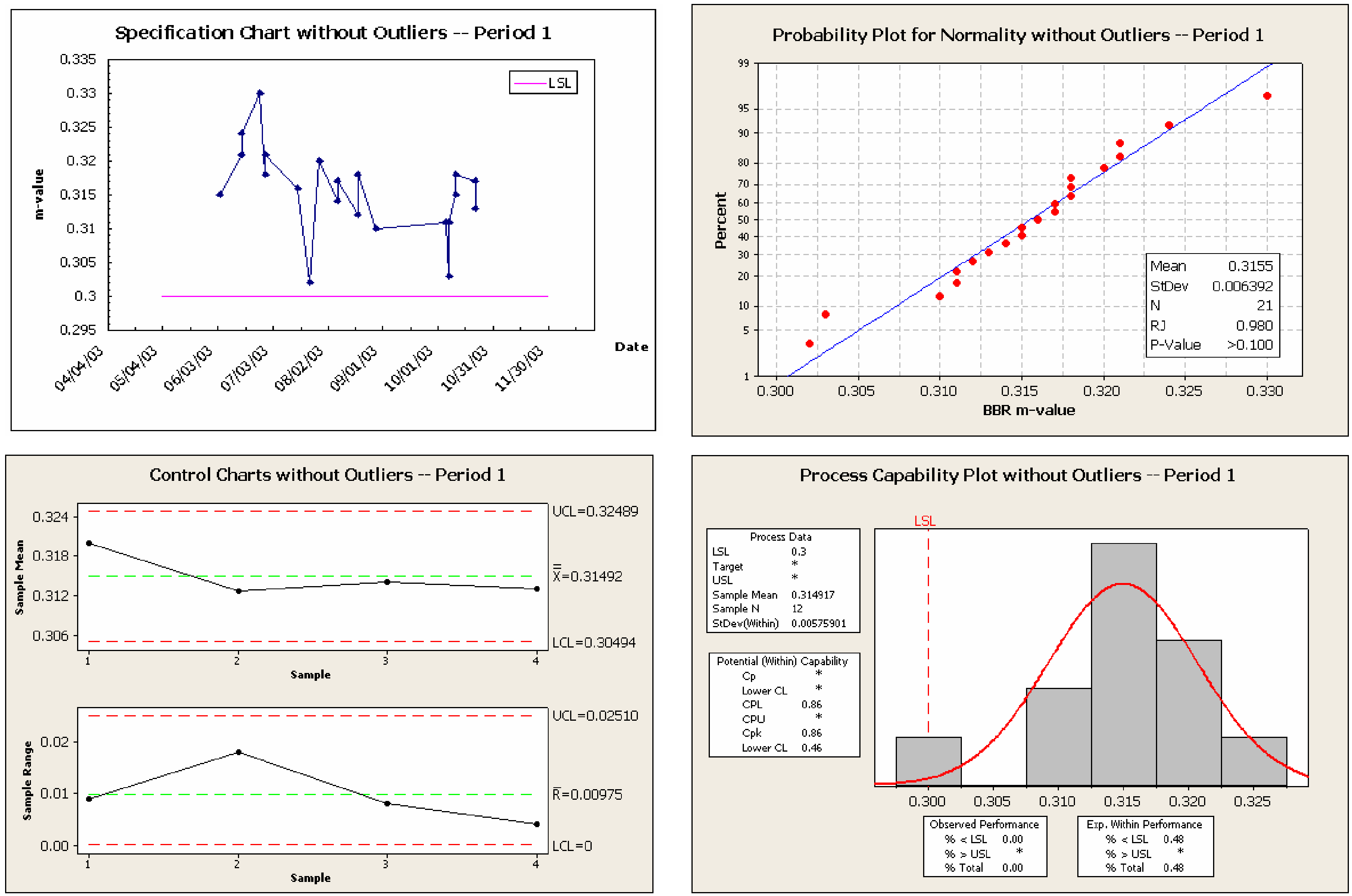


Figure G-89 Statistical Analysis Charts (without Outliers Period 1) for Supplier: 0703 Grade: PG 76-22 Test: BBR-m-value

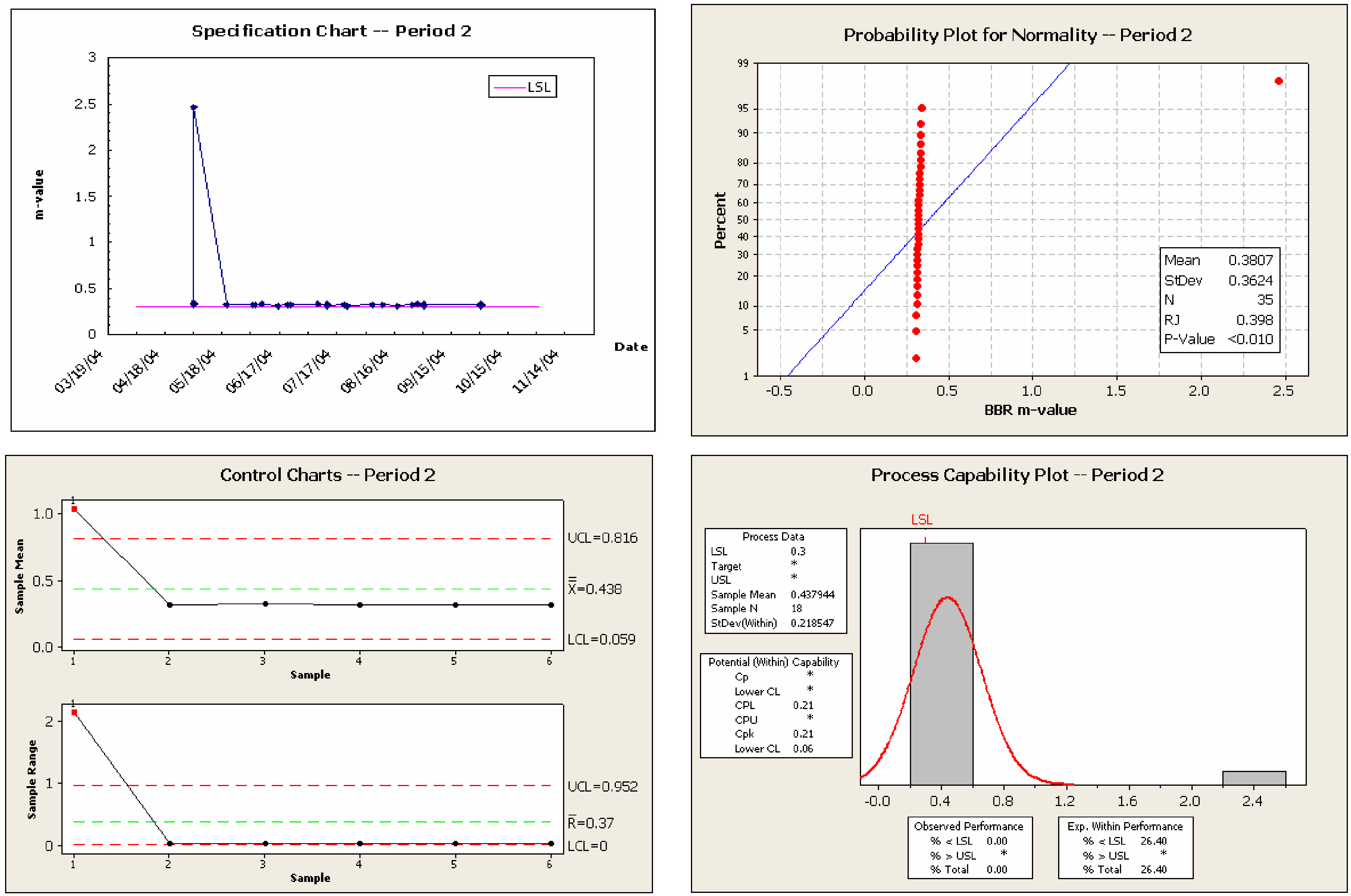


Figure G-90 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: PG 76-22 Test: BBR-m-value

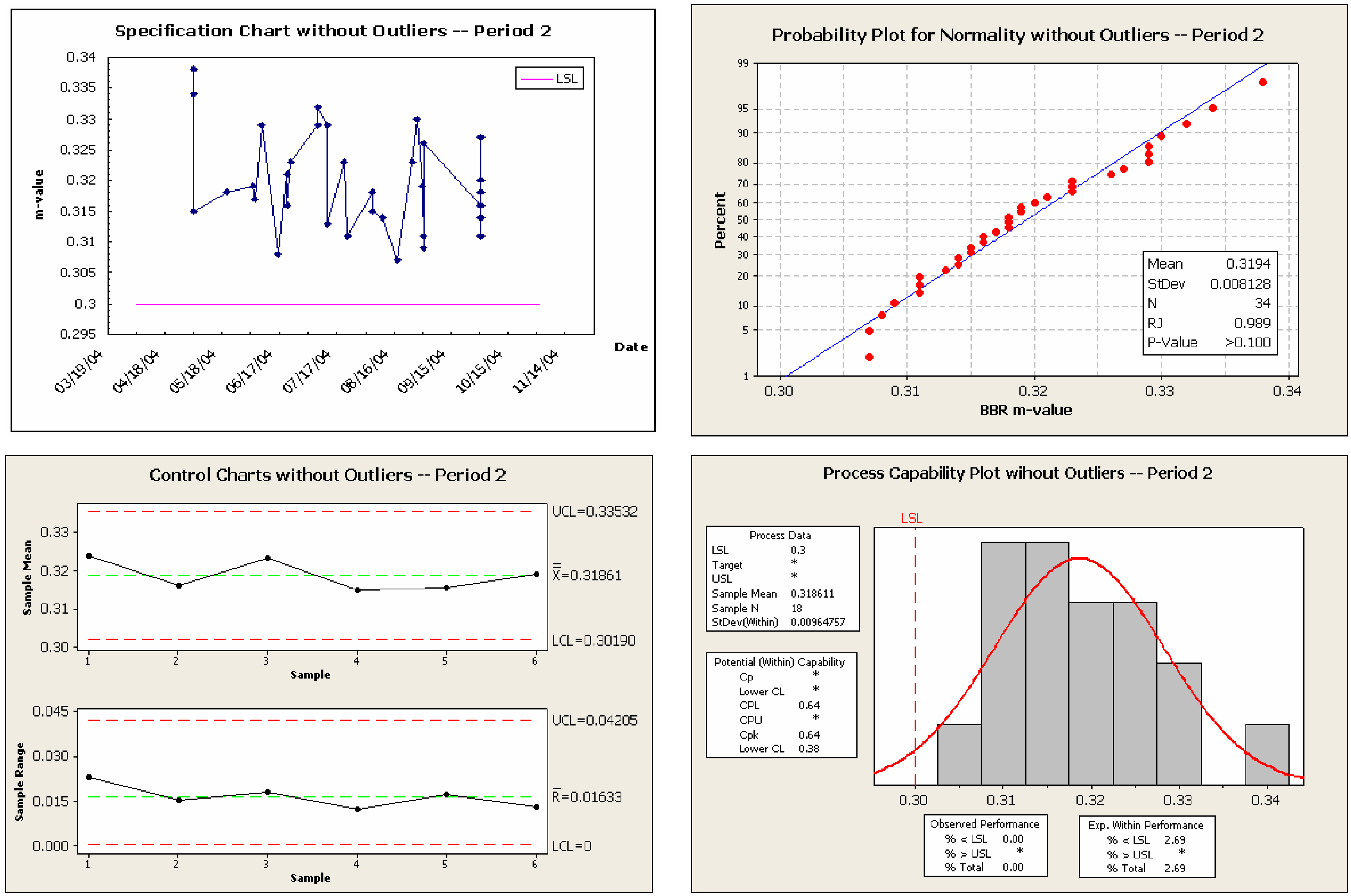


Figure G-91 Statistical Analysis Charts (without Outliers Period 2) for Supplier: 0703 Grade: PG 76-22 Test: BBR-m-value

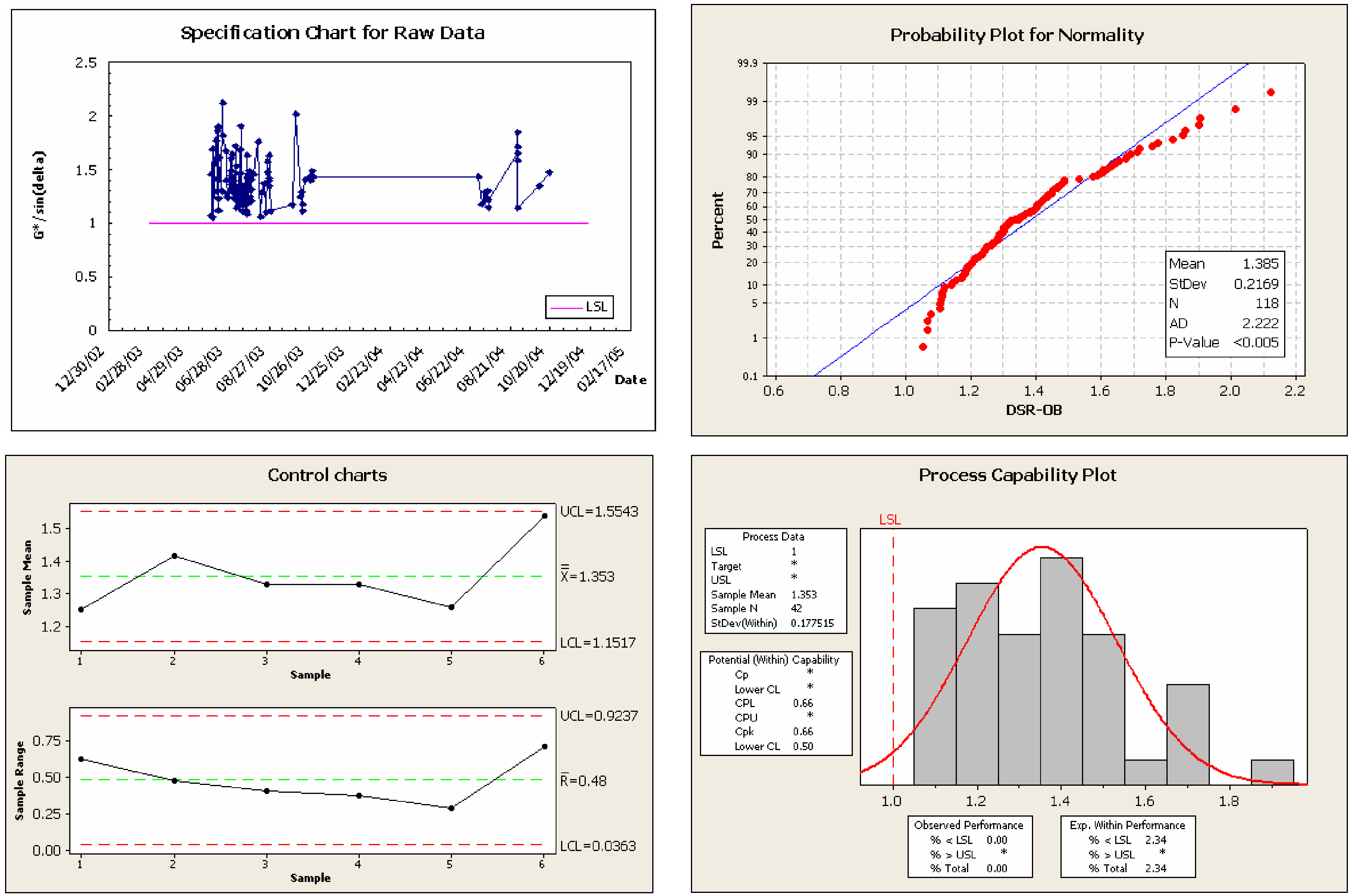


Figure G-92 Statistical Analysis Charts for Supplier: 0703 Grade: PG 76-28 Test: DSR-OB

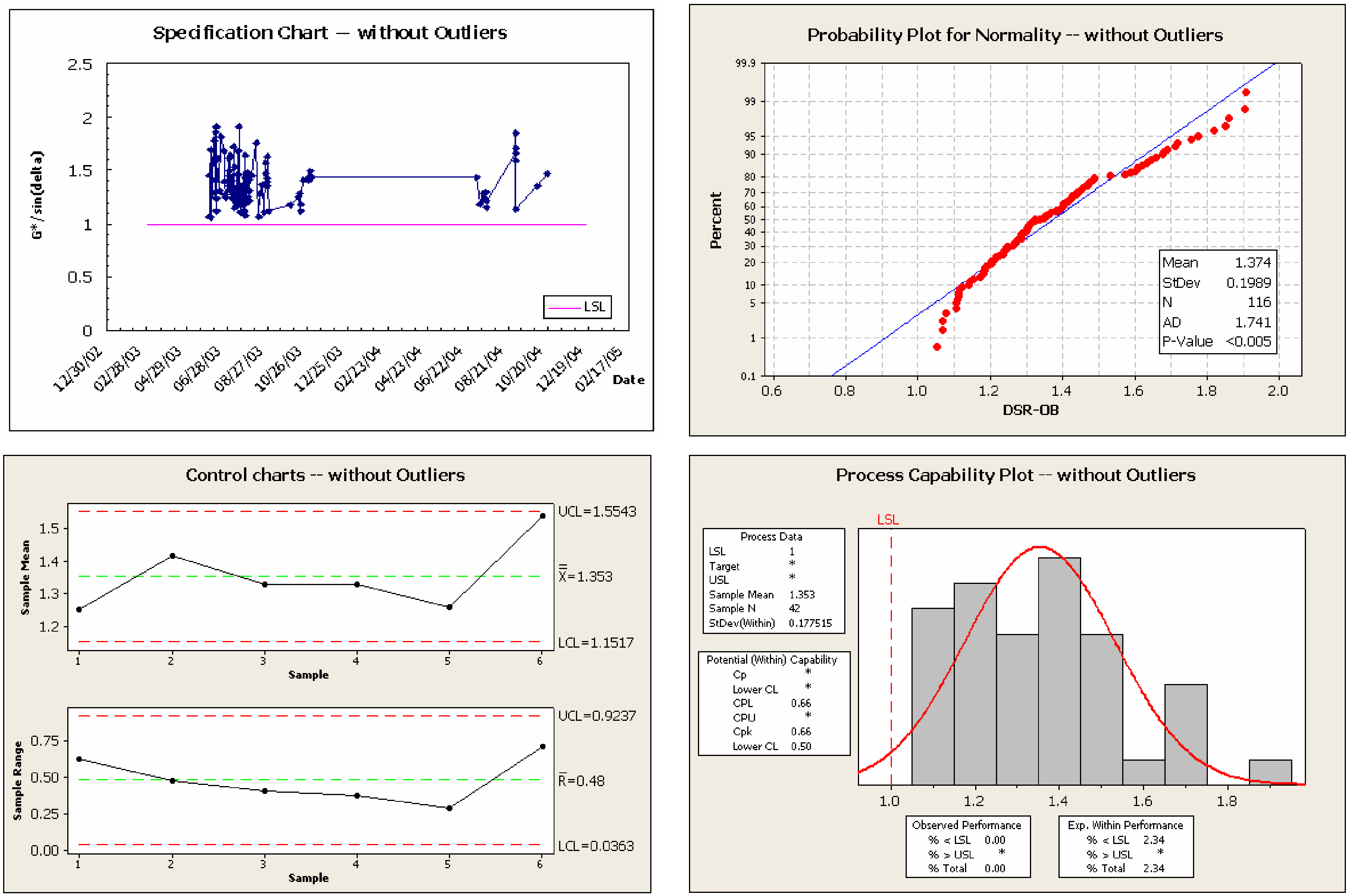


Figure G-93 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: PG 76-28 Test: DSR-OB

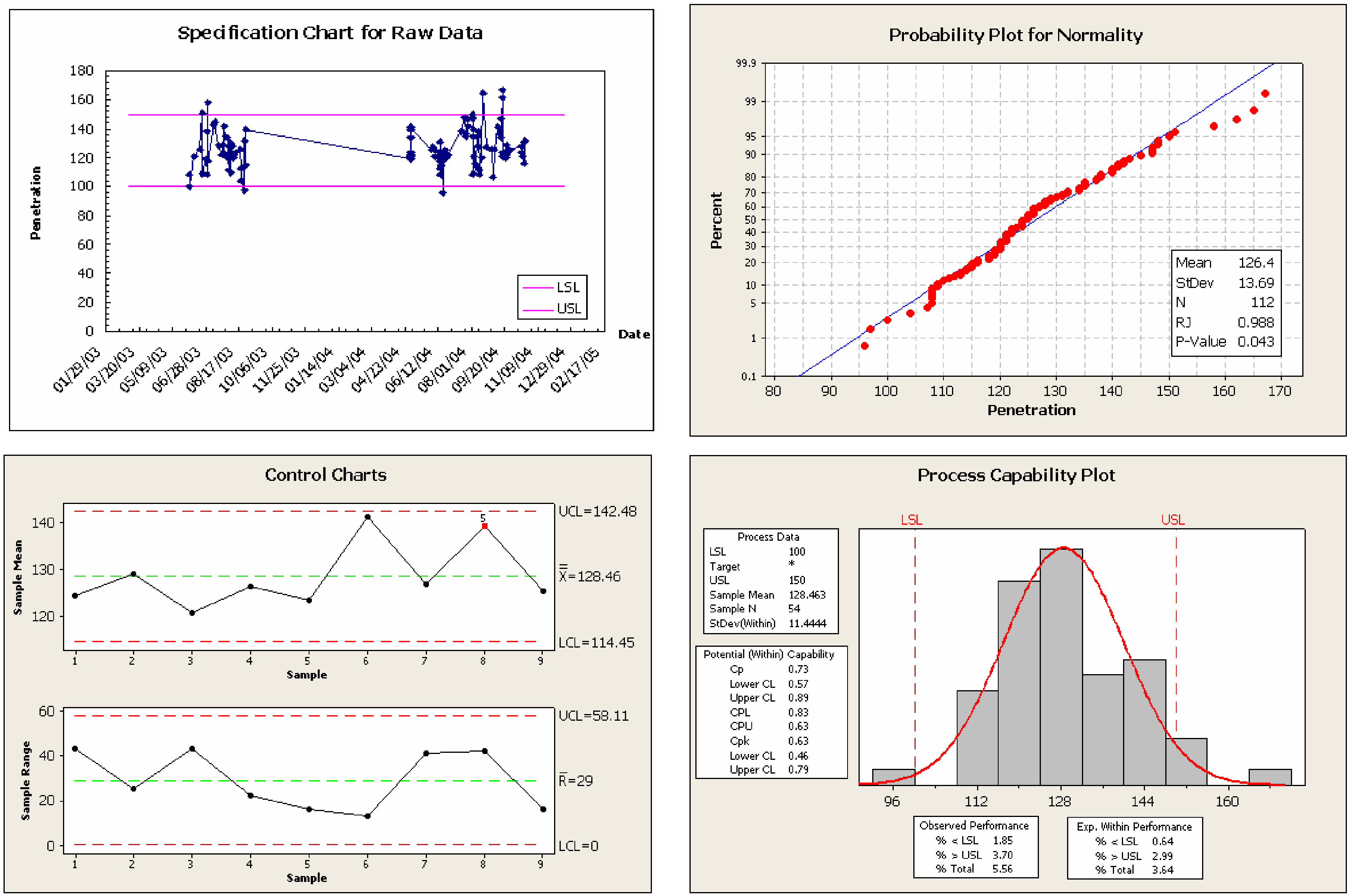


Figure G-94 Statistical Analysis Charts for Supplier: 0703 Grade: AC-15P Test: Penetration

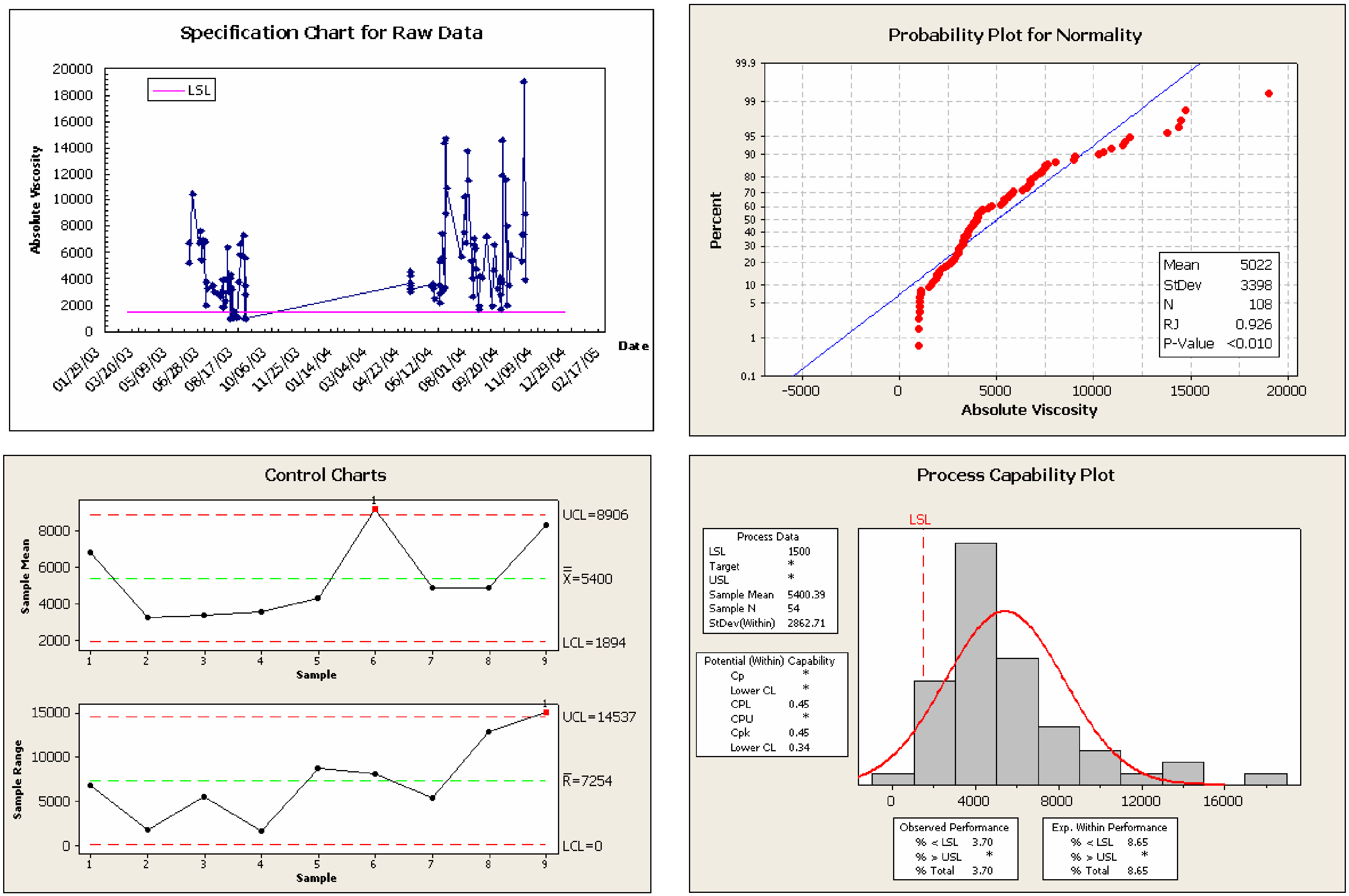


Figure G-95 Statistical Analysis Charts for Supplier: 0703 Grade: AC-15P Test: Absolute Viscosity

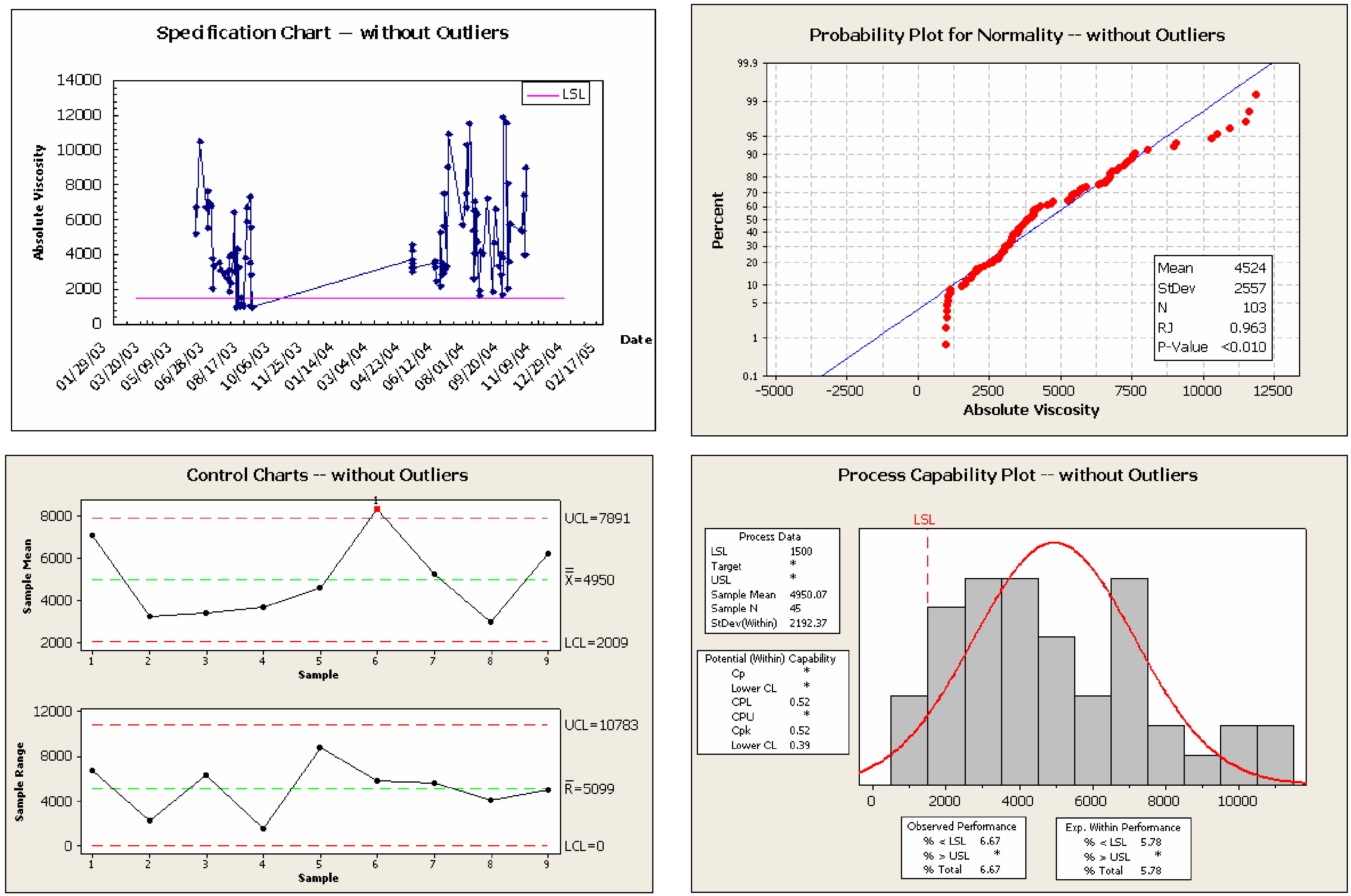


Figure G-96 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: AC-15P Test: Absolute Viscosity

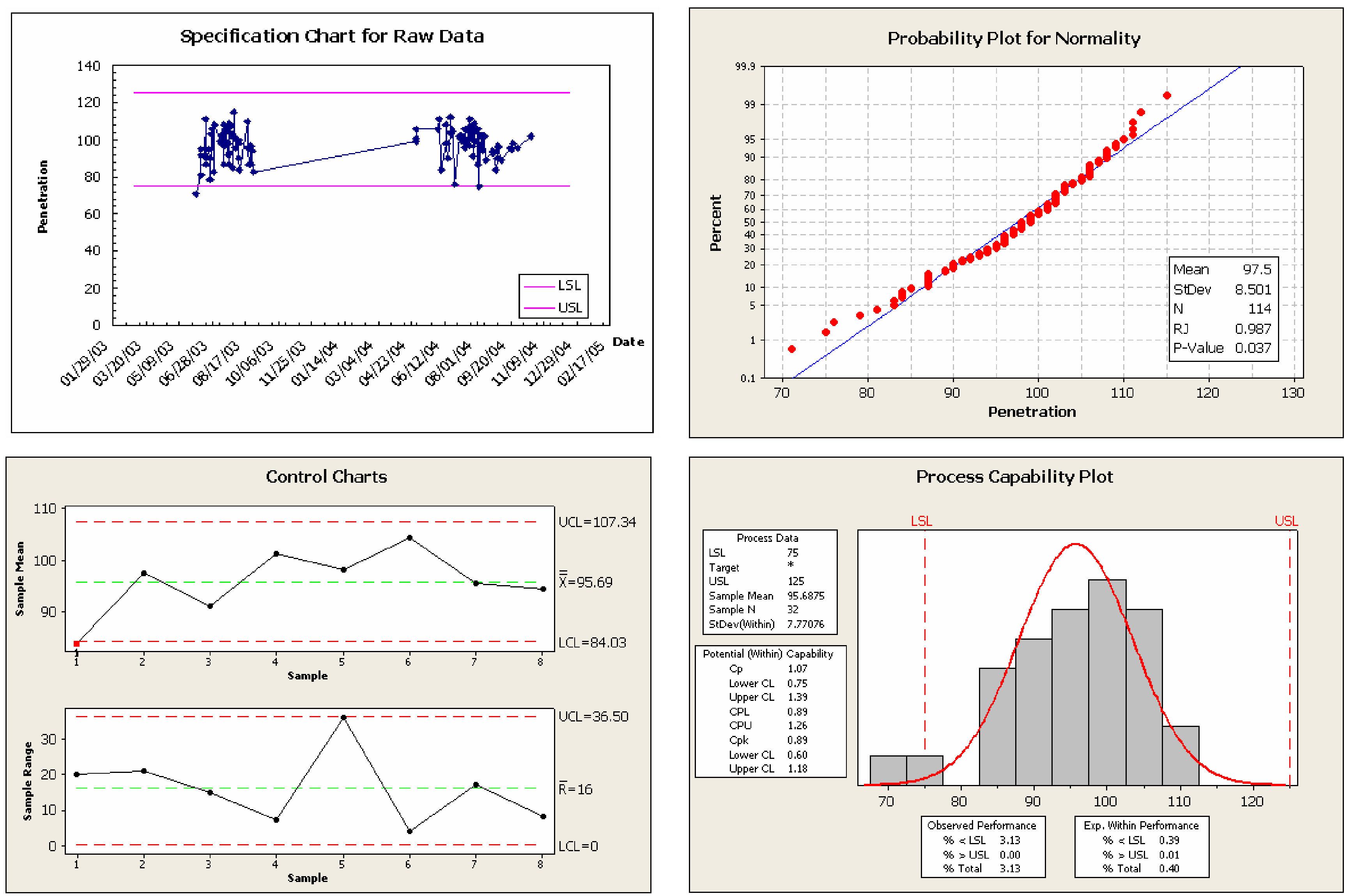


Figure G-97 Statistical Analysis Charts for Supplier: 0703 Grade: AC-15XP Test: Penetration

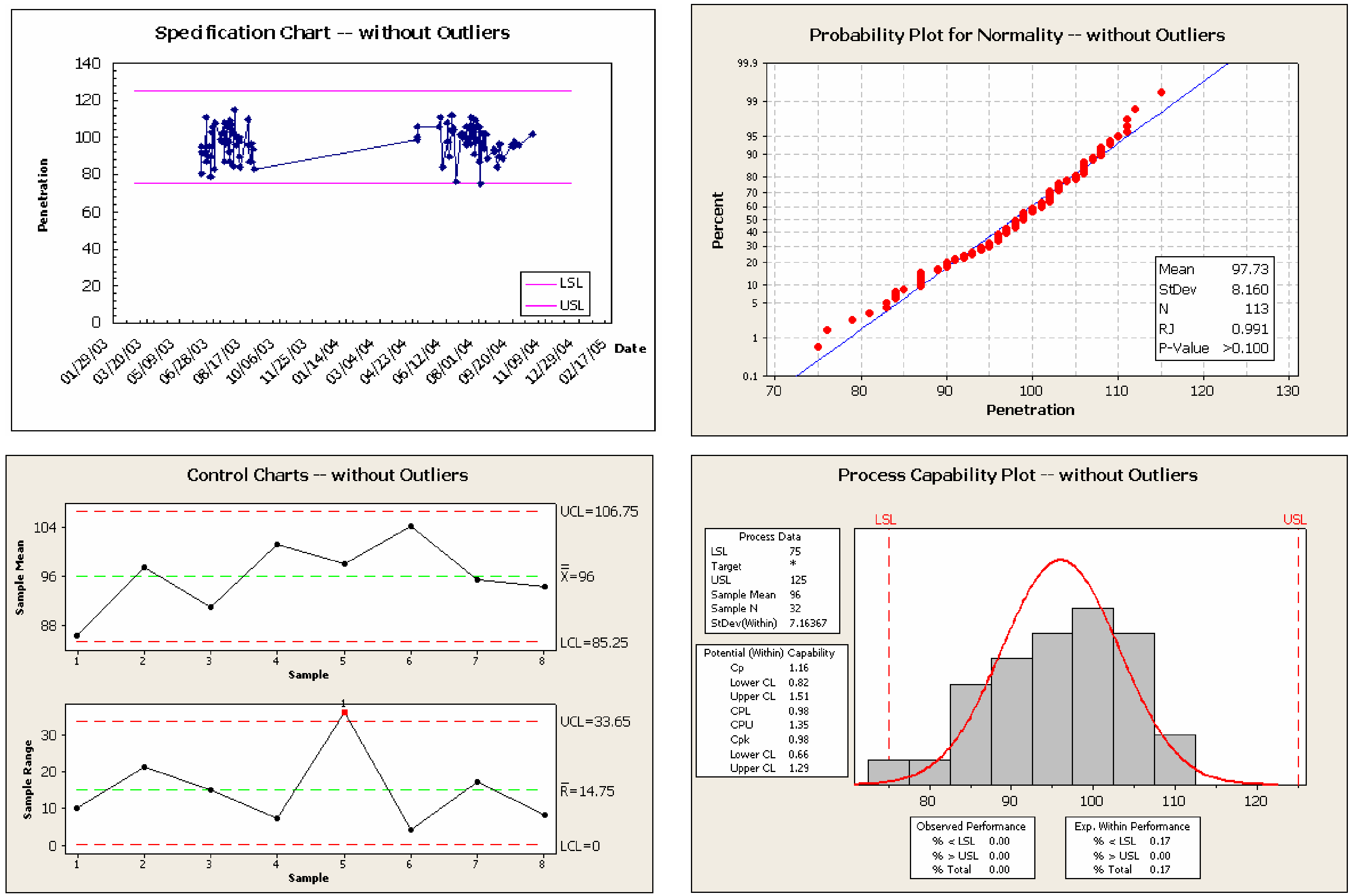


Figure G-98 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: AC-15XP Test: Penetration

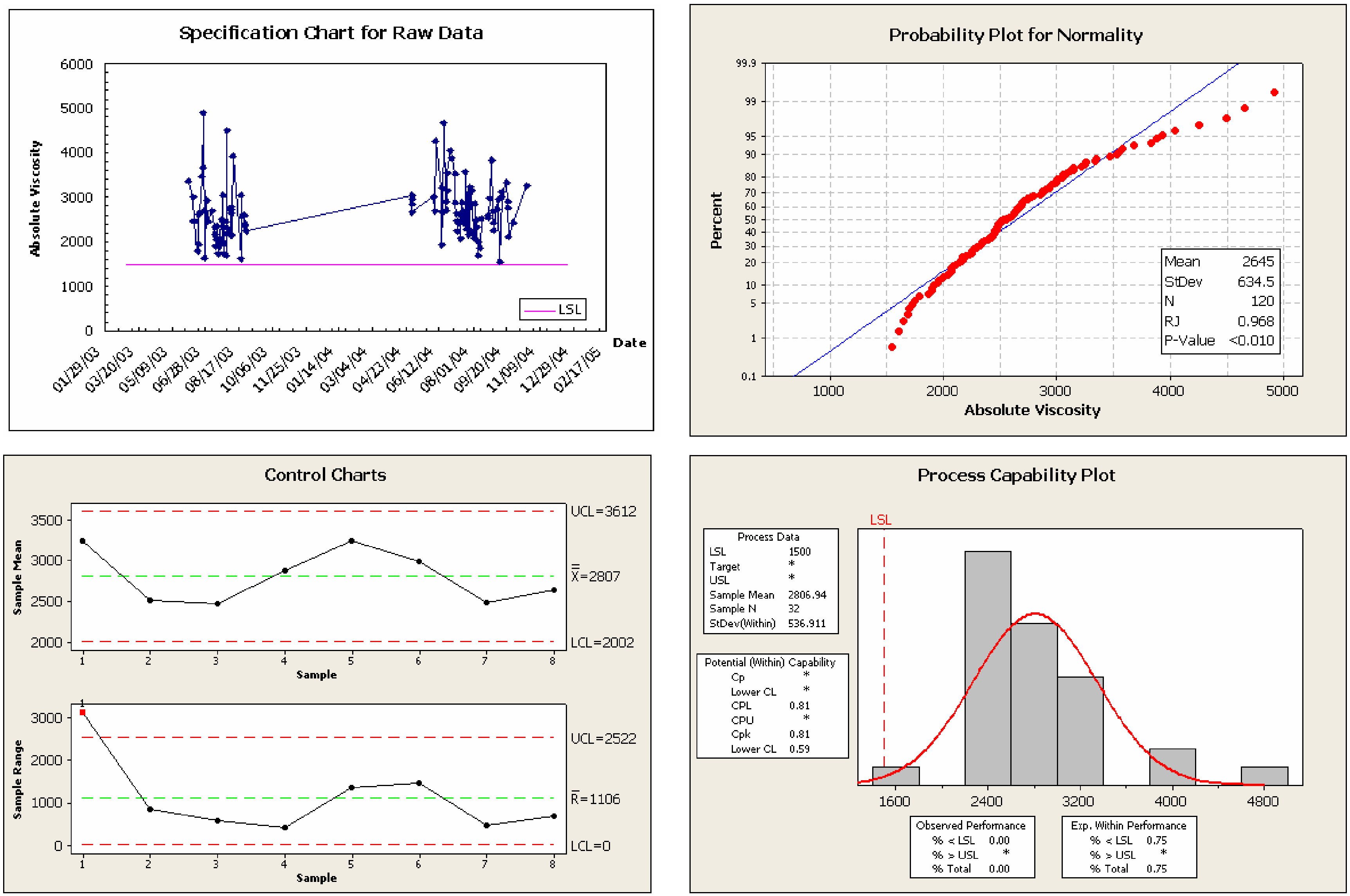


Figure G-99 Statistical Analysis Charts for Supplier: 0703 Grade: AC-15XP Test: Absolute Viscosity

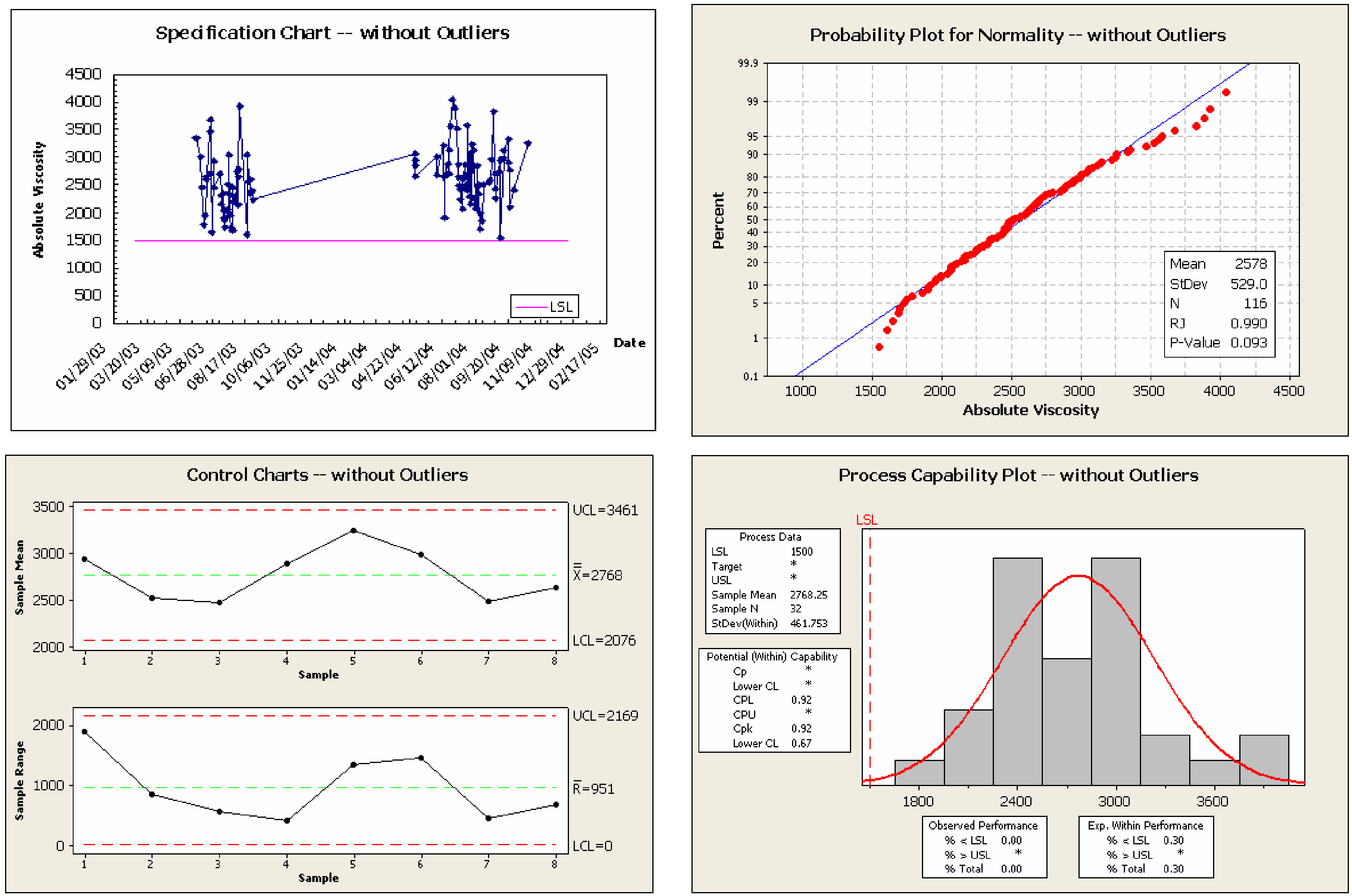
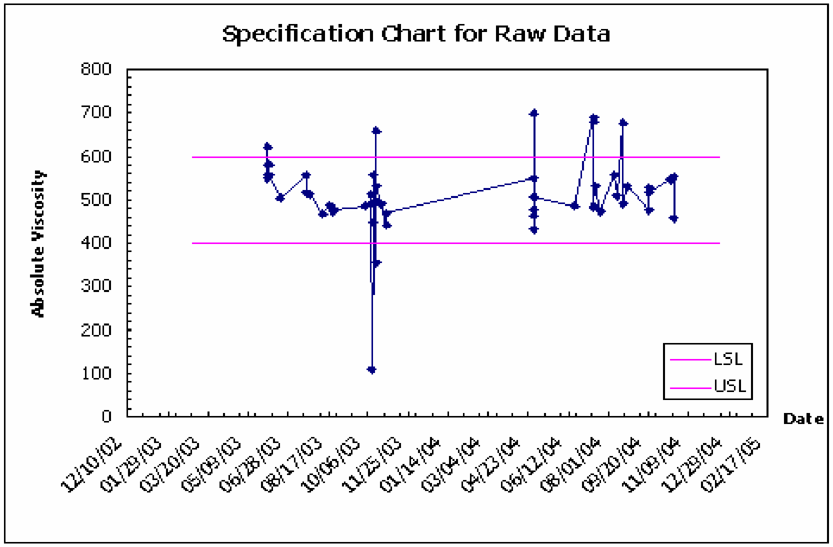
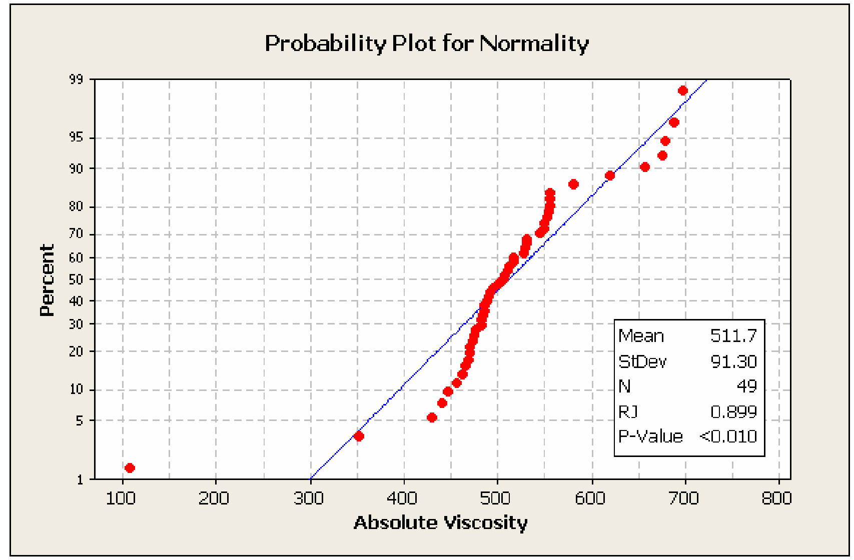
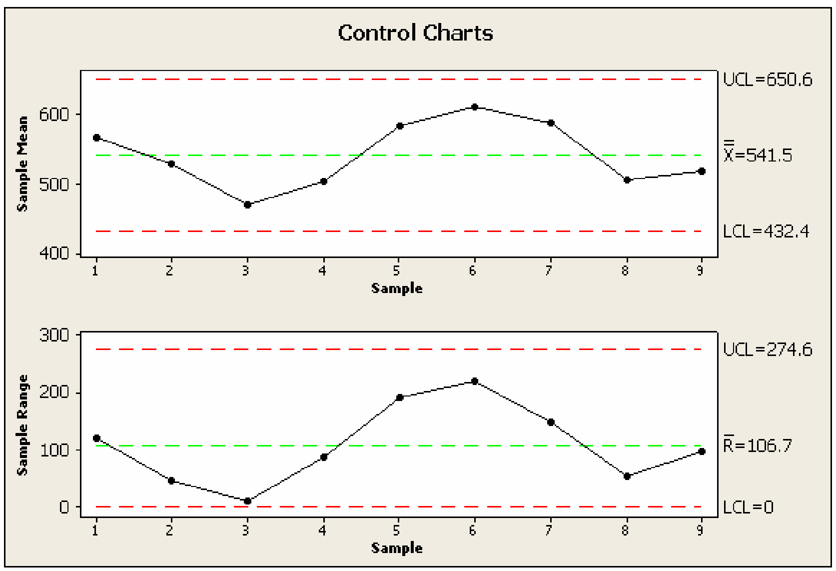


Figure G-100 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: AC-15XP Test: Absolute Viscosity







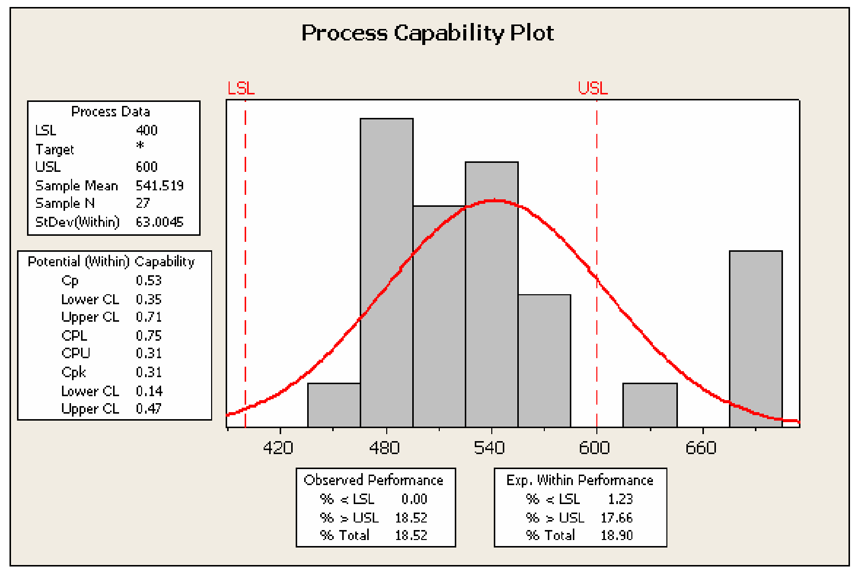


Figure G-101 Statistical Analysis Charts for Supplier: 0703 Grade: AC-5 Test: Absolute Viscosity

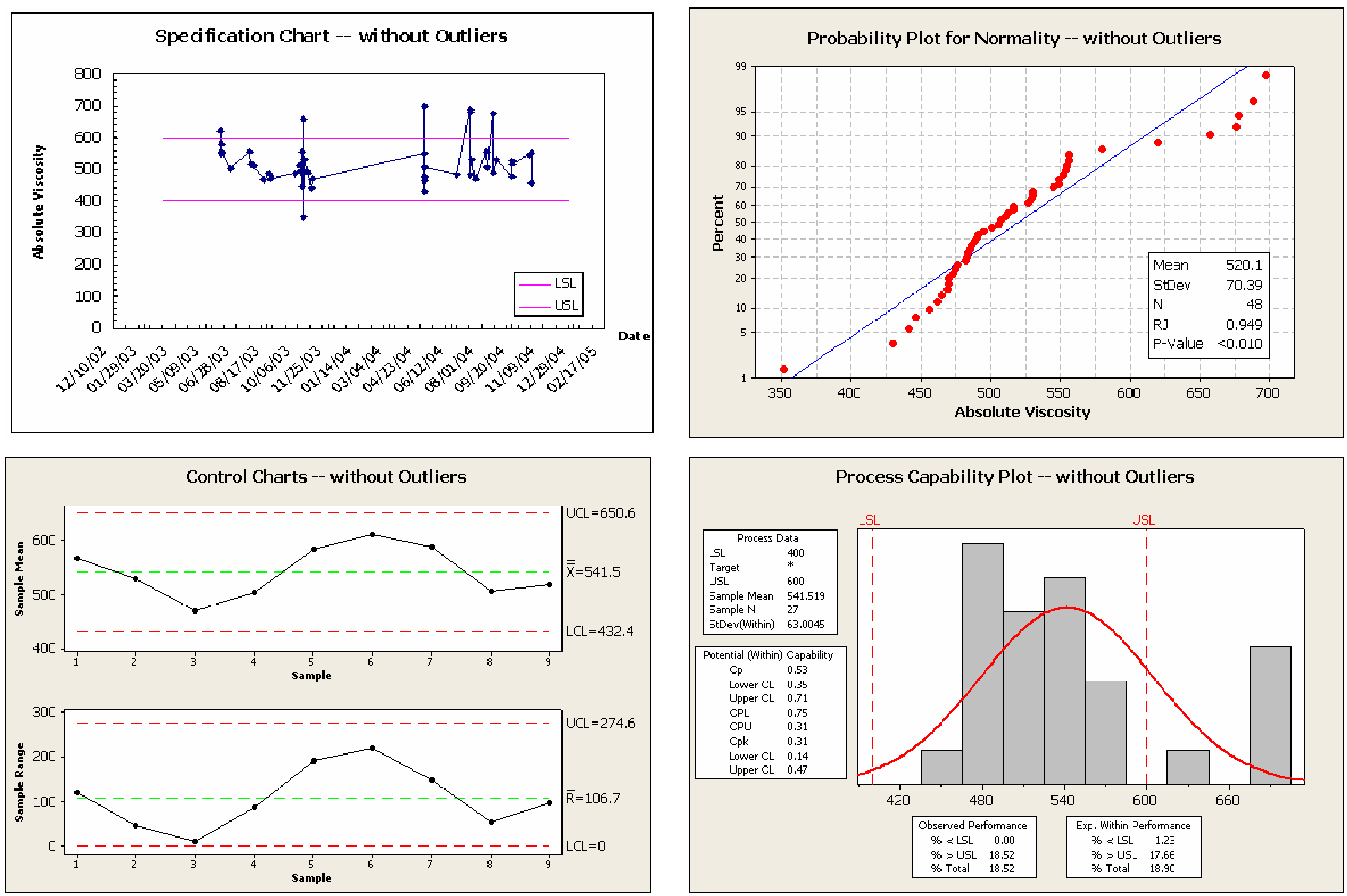


Figure G-102 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: AC-5 Test: Absolute Viscosity

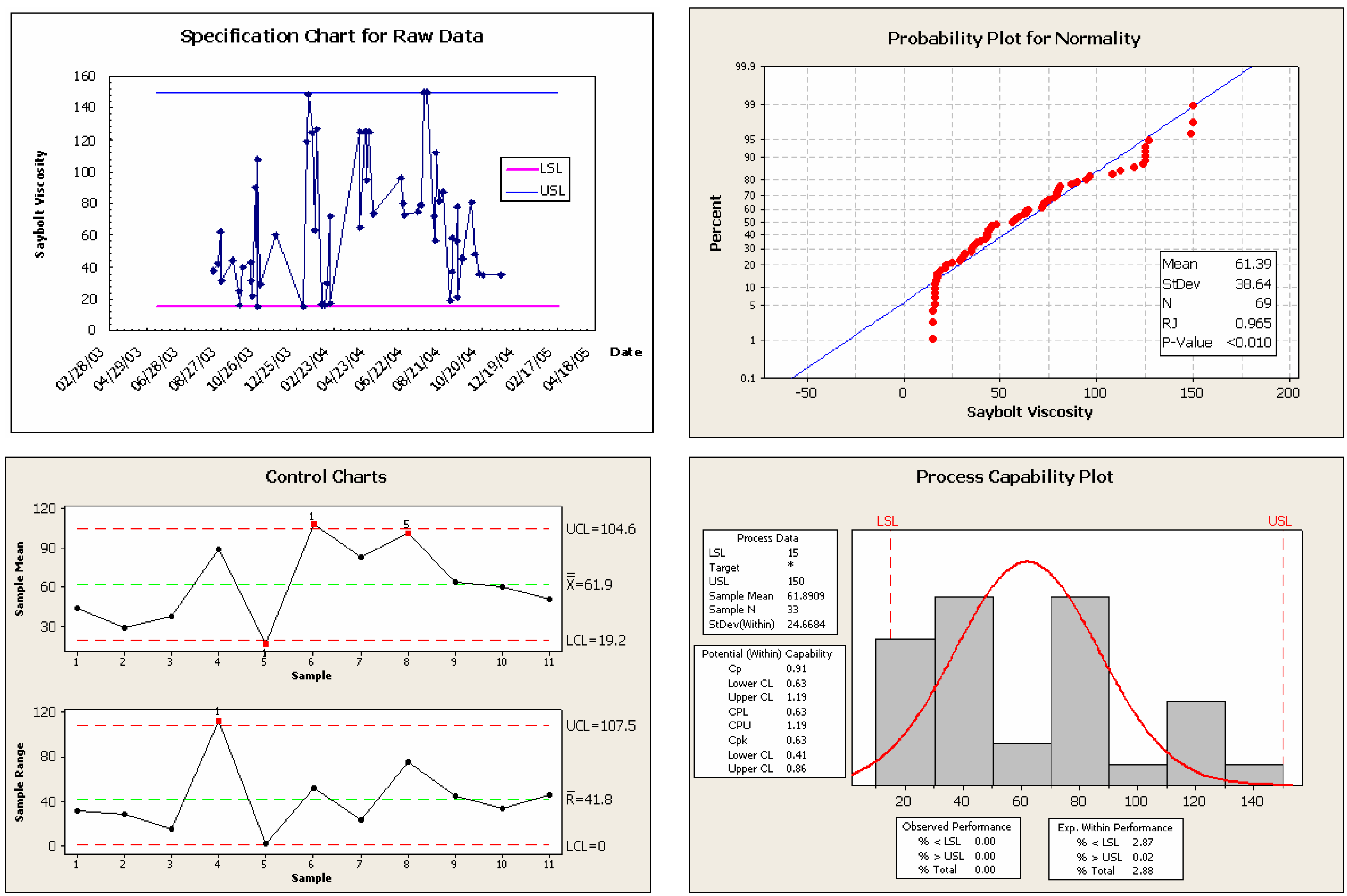


Figure G-103 Statistical Analysis Charts for Supplier: 0703 Grade: AE-P Test: Saybolt Viscosity

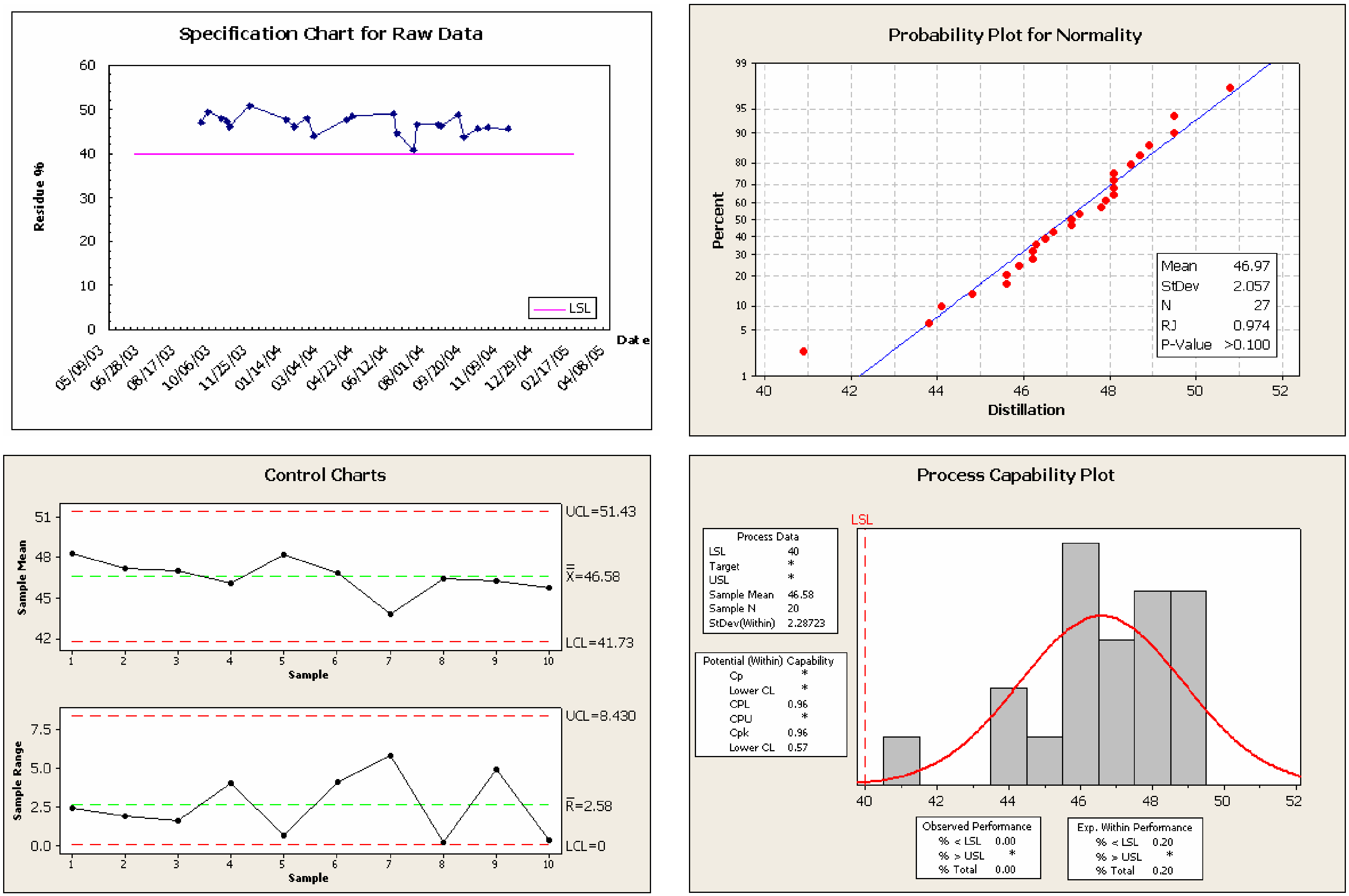


Figure G-104 Statistical Analysis Charts for Supplier: 0703 Grade: AE-P Test: Distillation

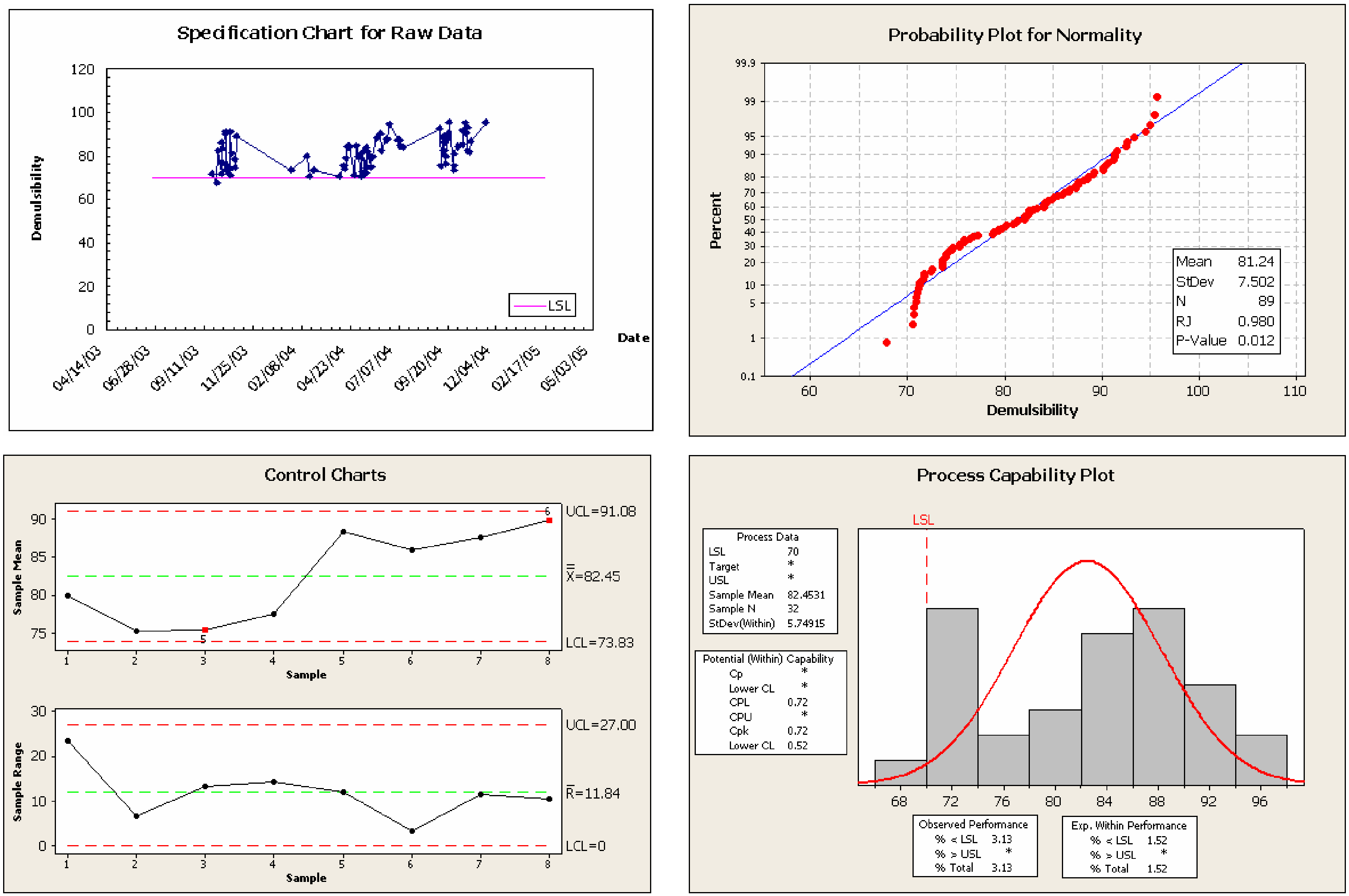


Figure G-105 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2 Test: Demulsibility

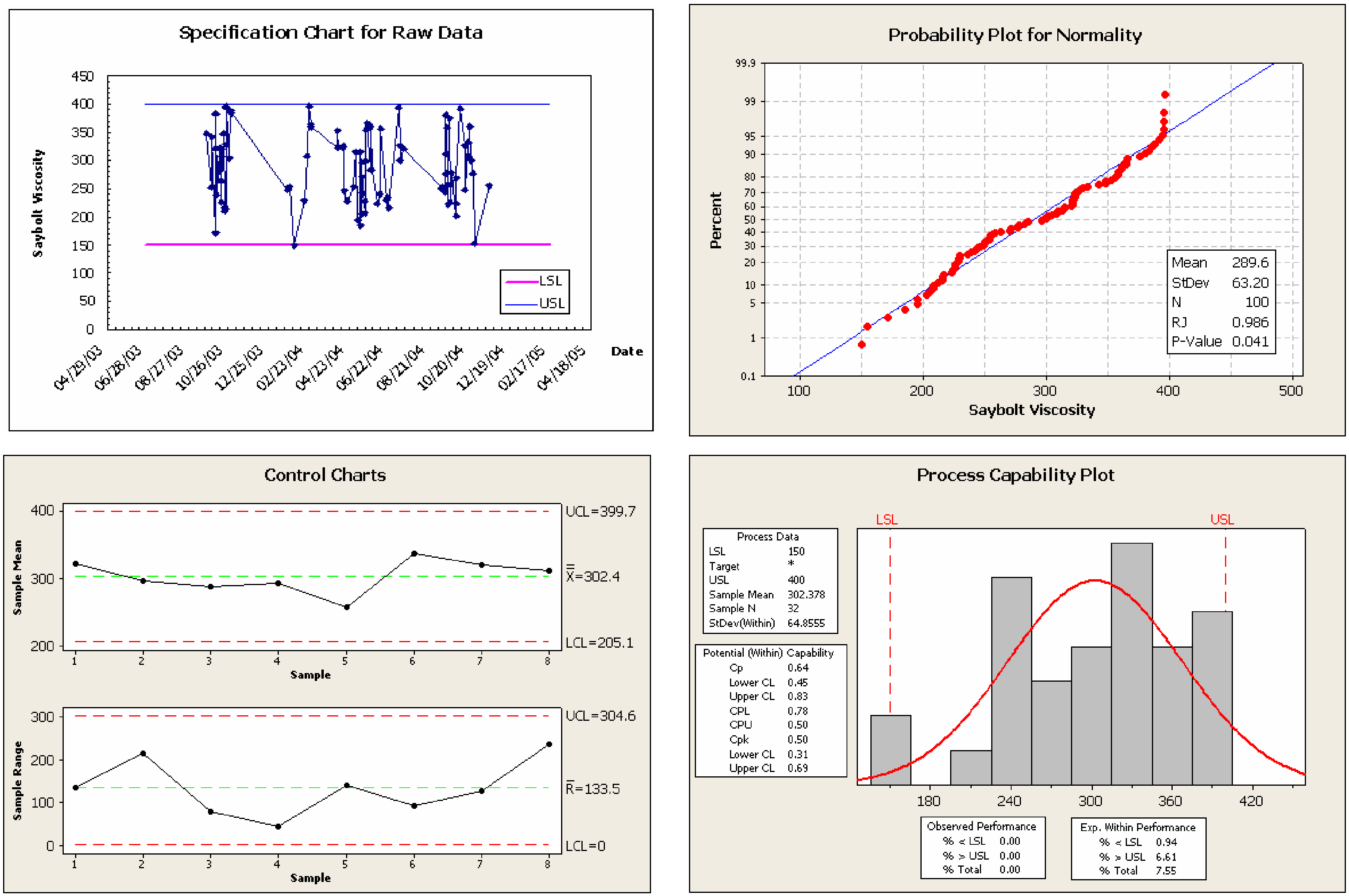


Figure G-106 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2 Test: Saybolt Viscosity

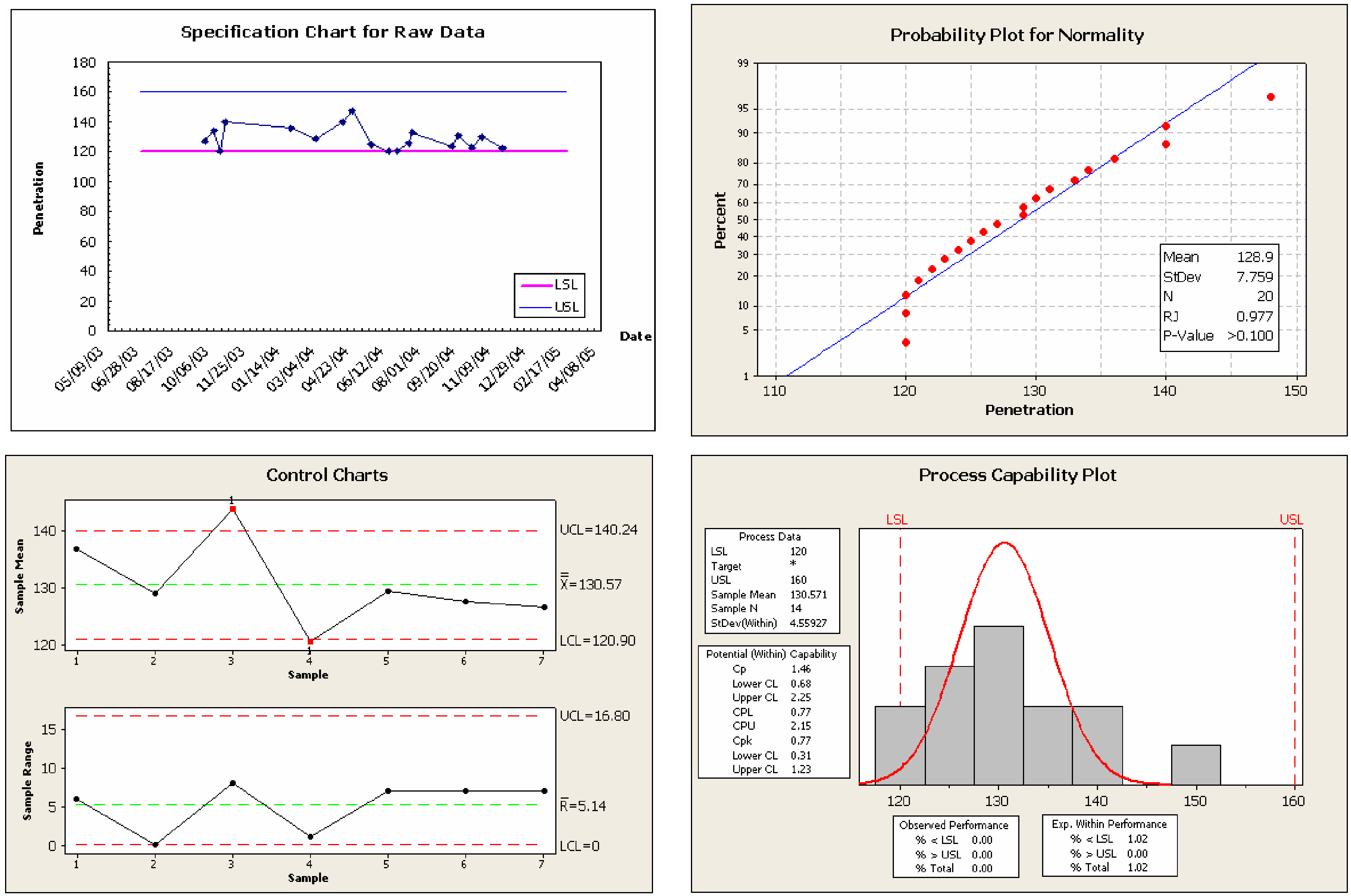


Figure G-107 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2 Test: Penetration

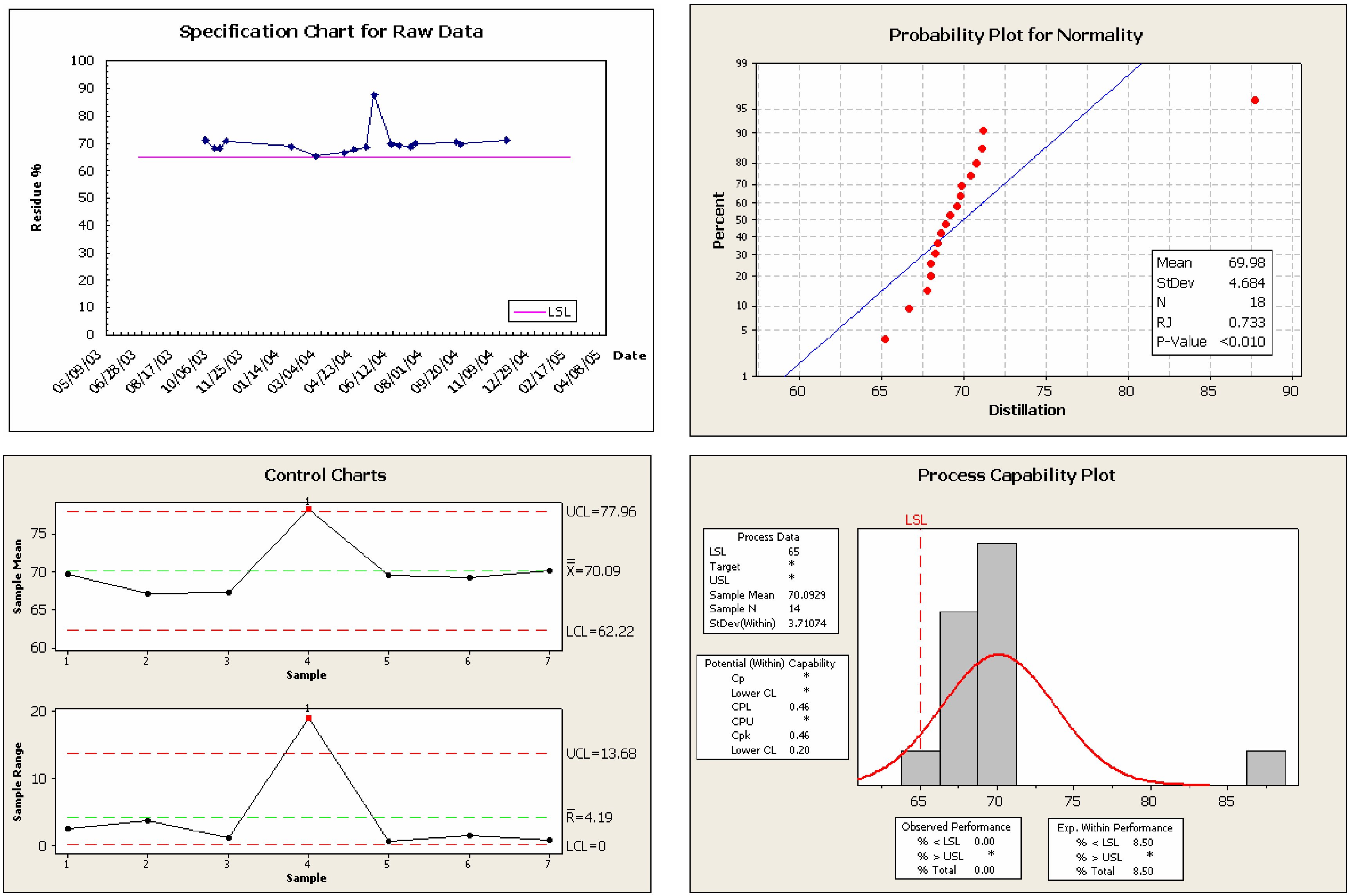


Figure G-108 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2 Test: Distillation

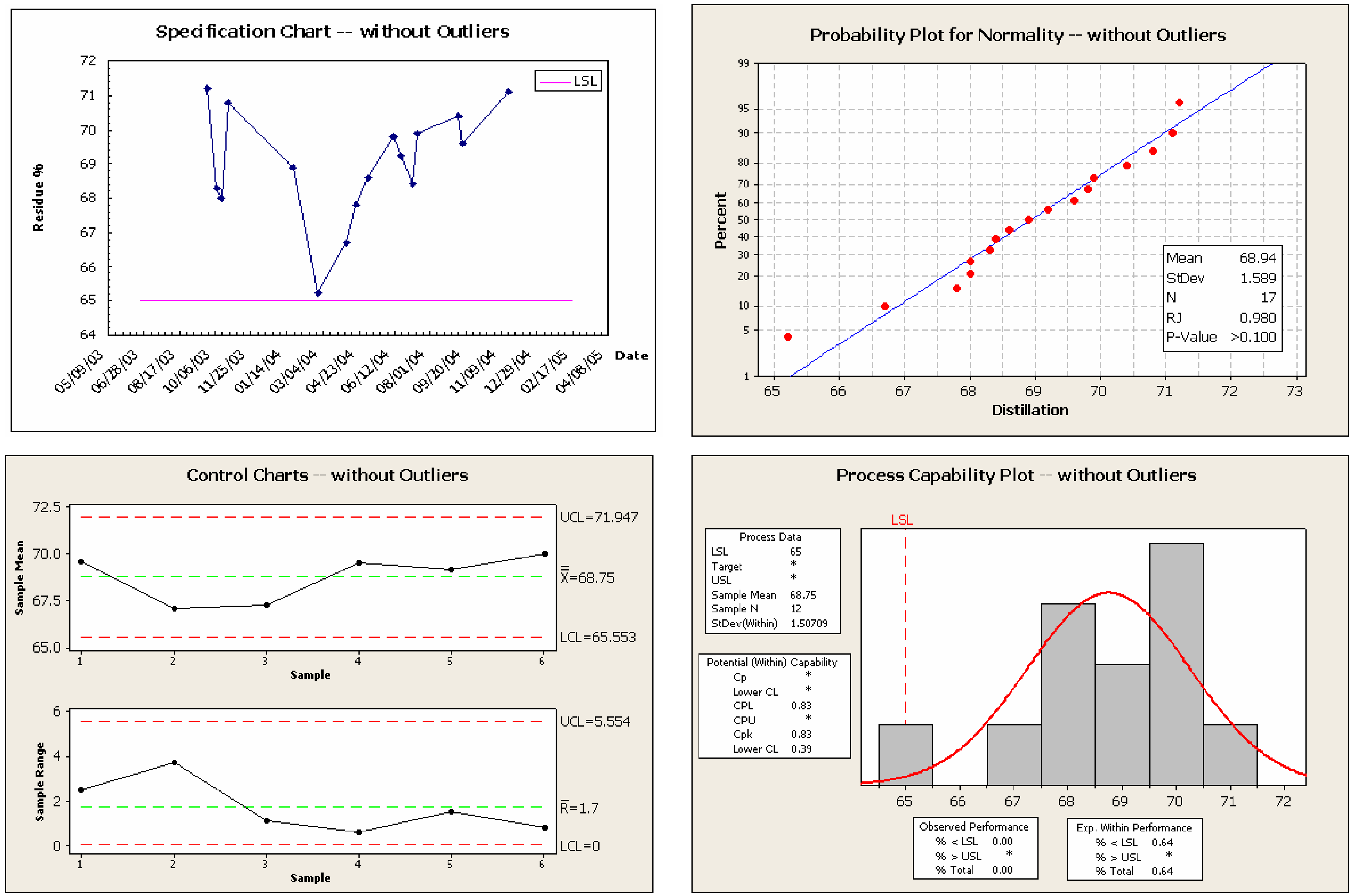


Figure G-109 Statistical Analysis Charts (without Outliers) for Supplier: 0703 Grade: CRS-2 Test: Distillation

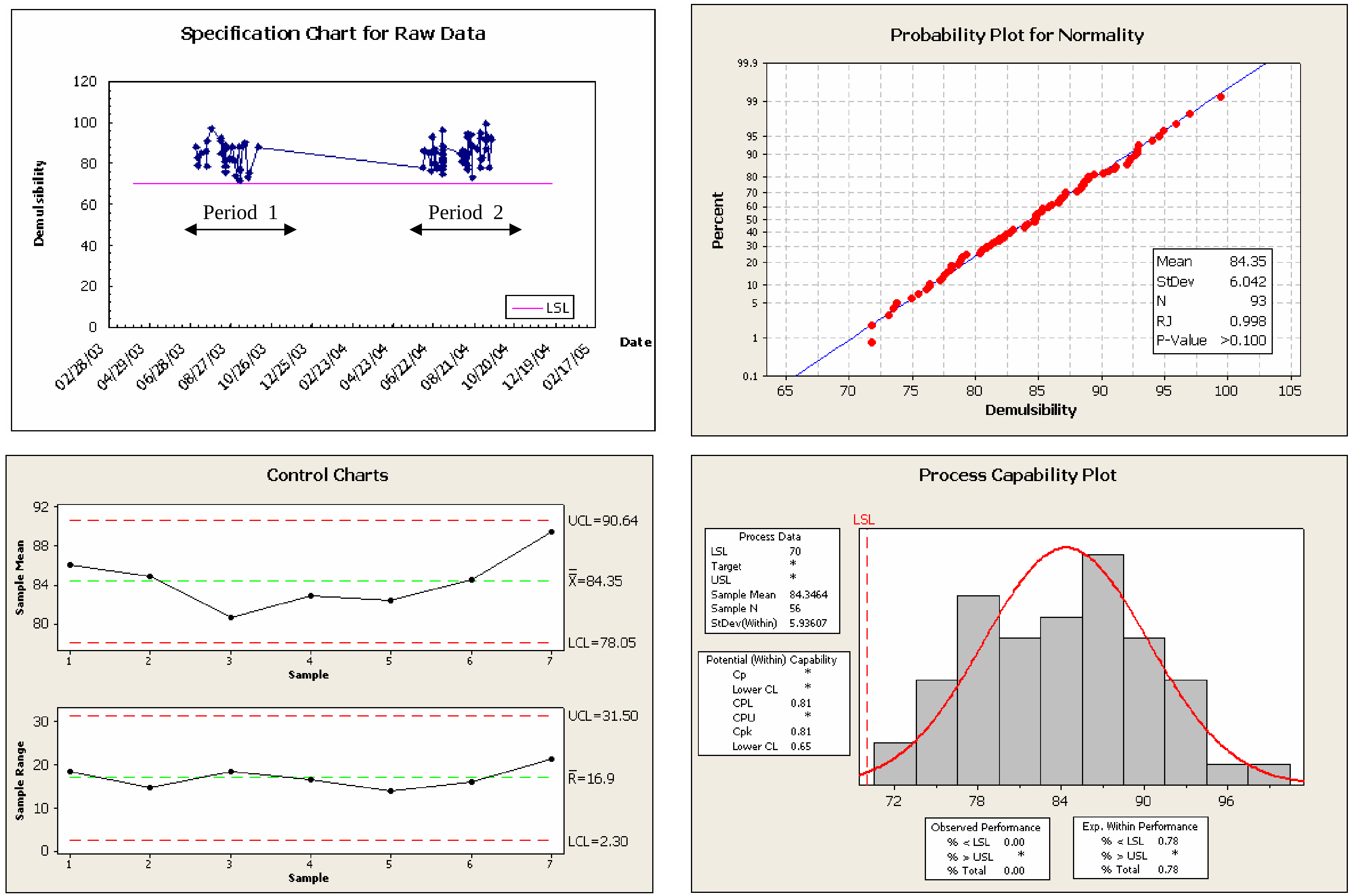


Figure G-110 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2H Test: Demulsibility

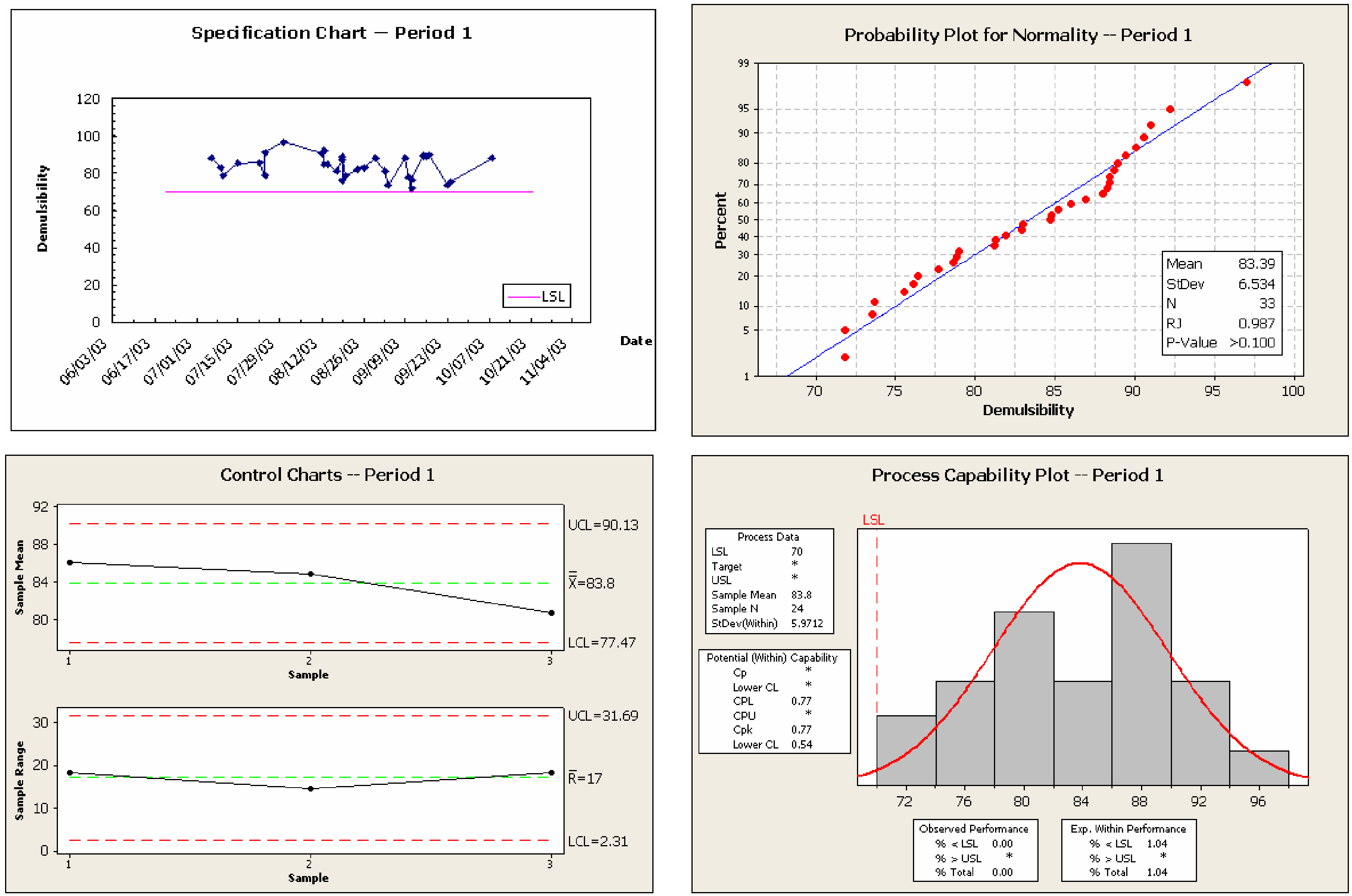


Figure G-111 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: CRS-2H Test: Demulsibility

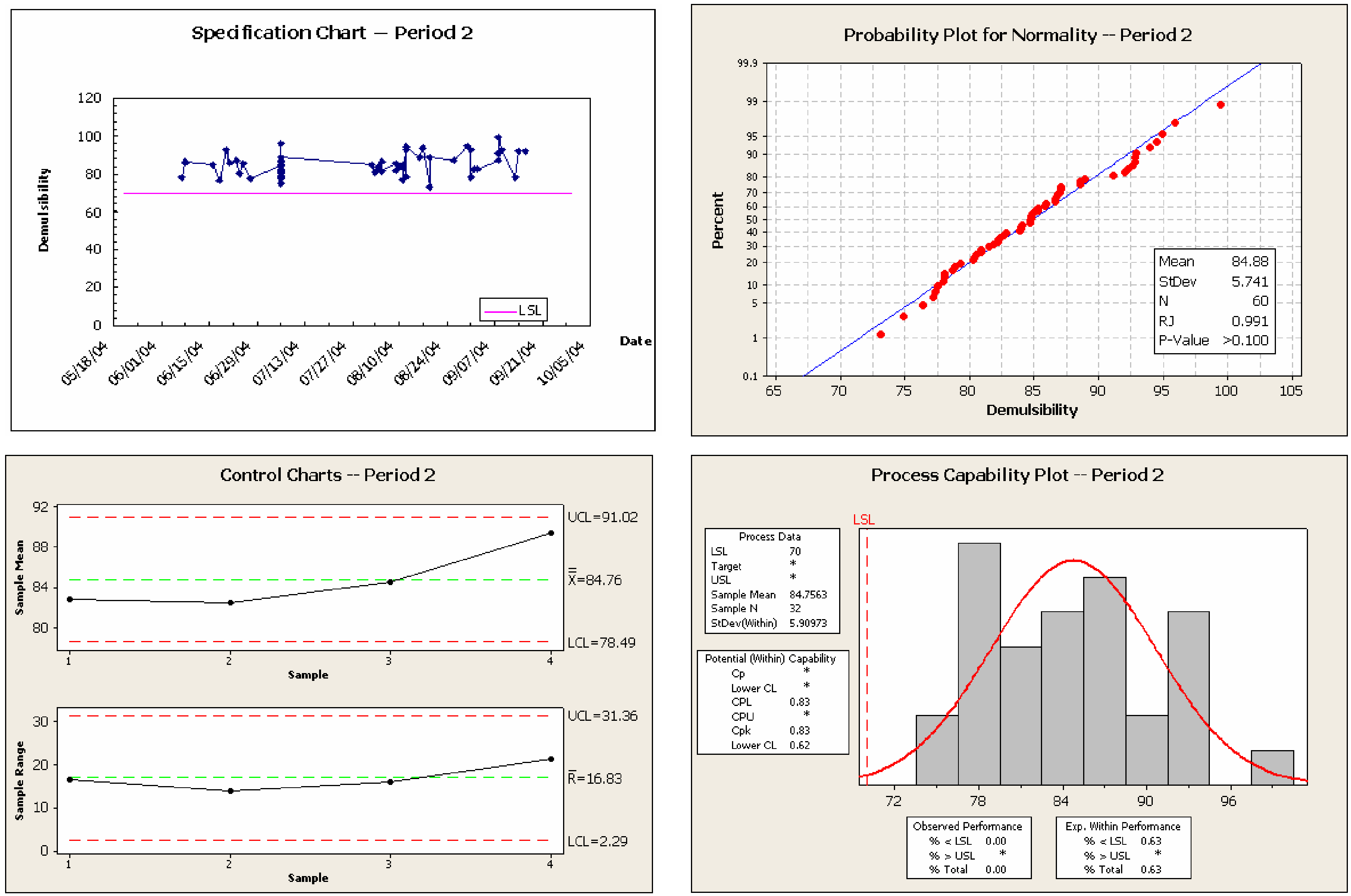


Figure G-112 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: CRS-2H Test: Demulsibility

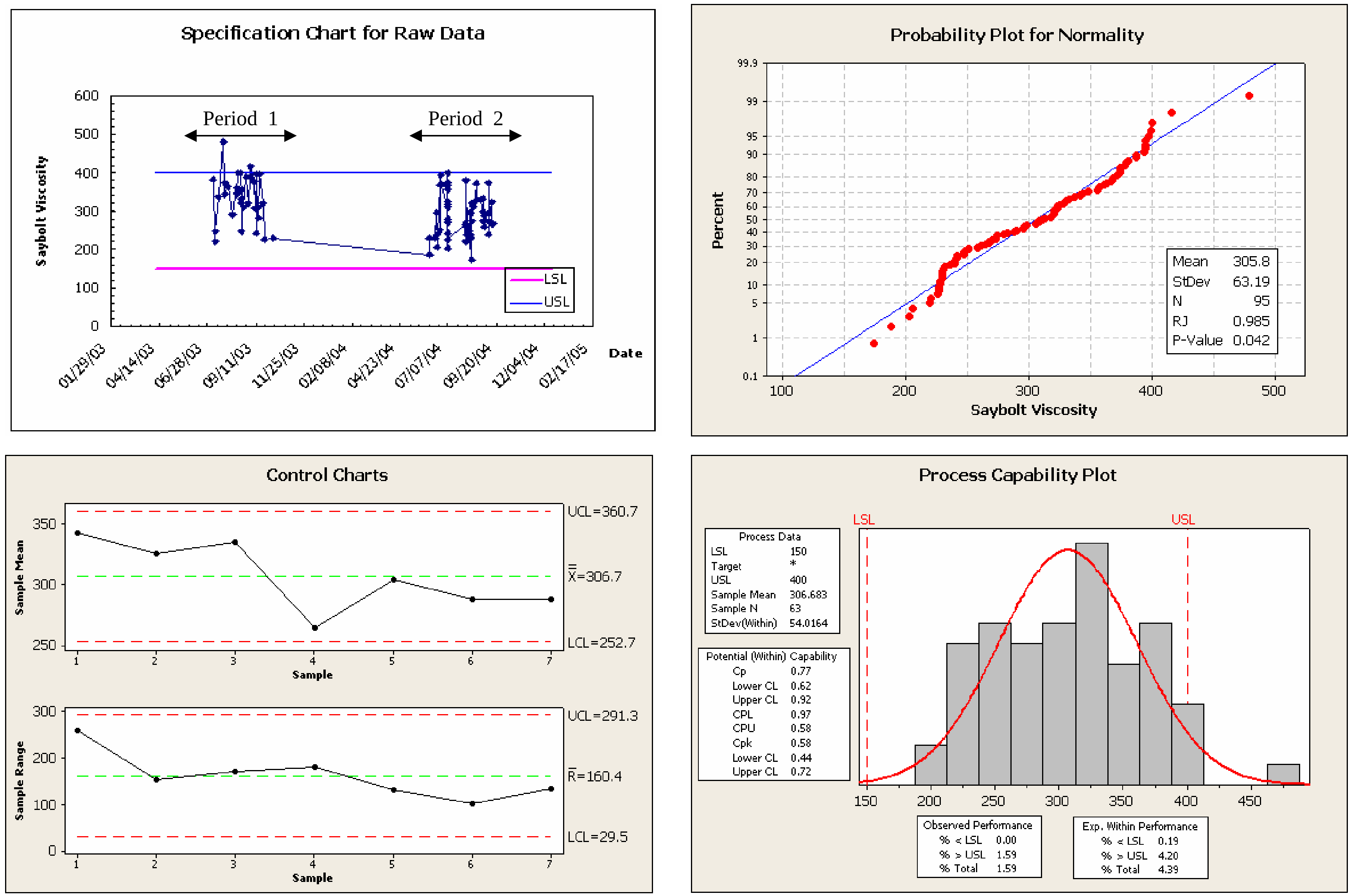


Figure G-113 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2H Test: Saybolt Viscosity

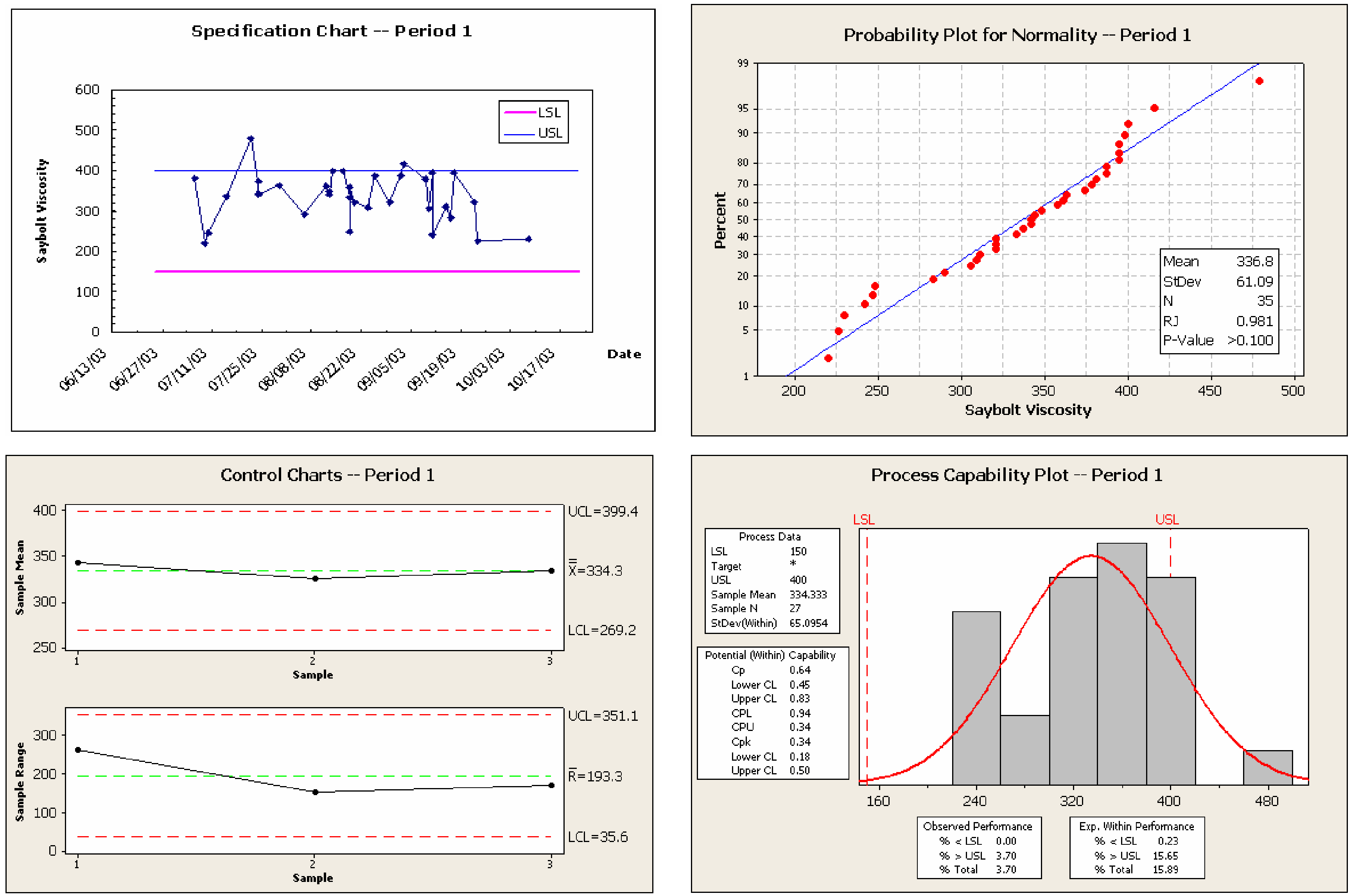


Figure G-114 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: CRS-2H Test: Saybolt Viscosity

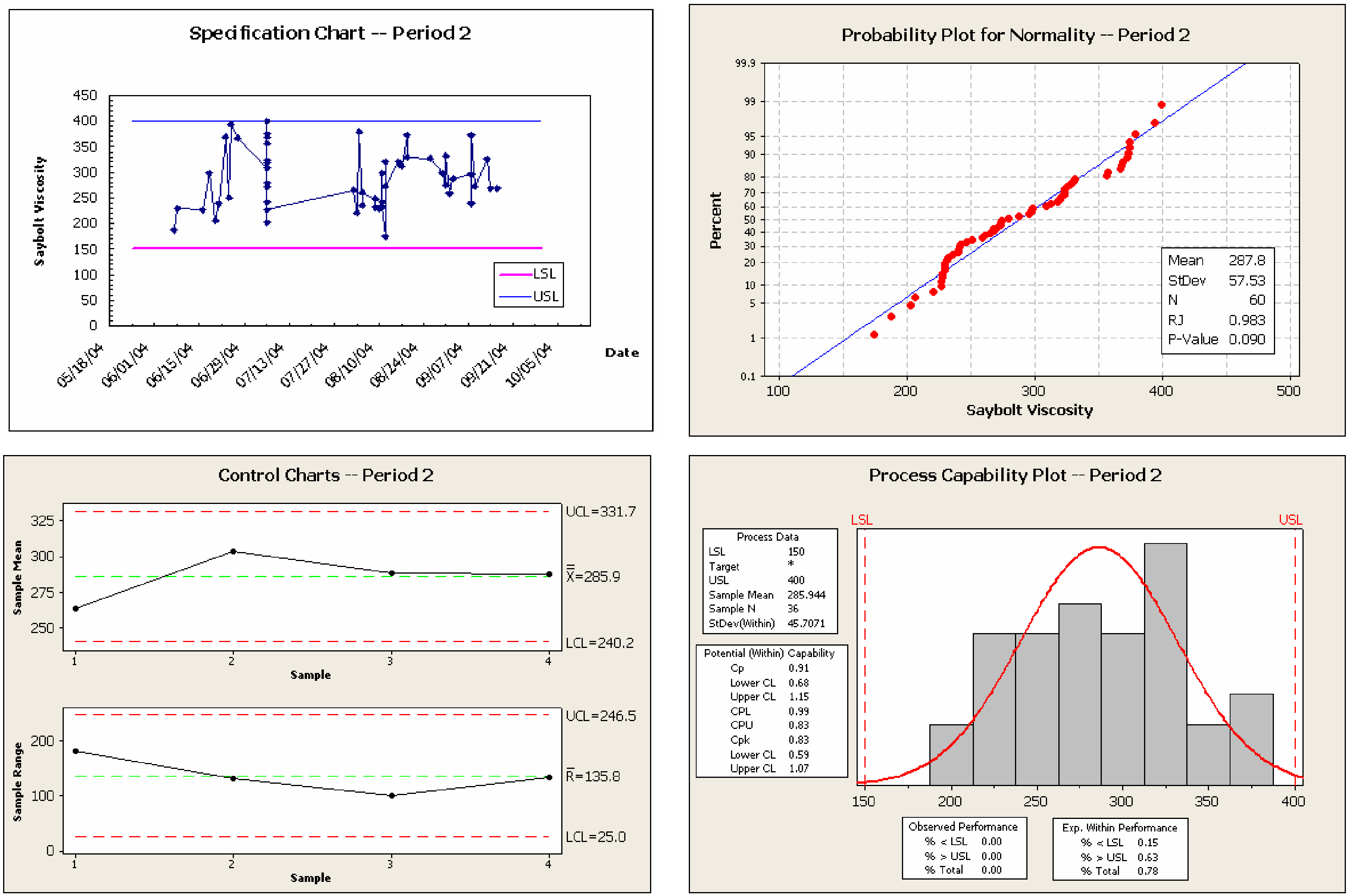


Figure G-115 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: CRS-2H Test: Saybolt Viscosity

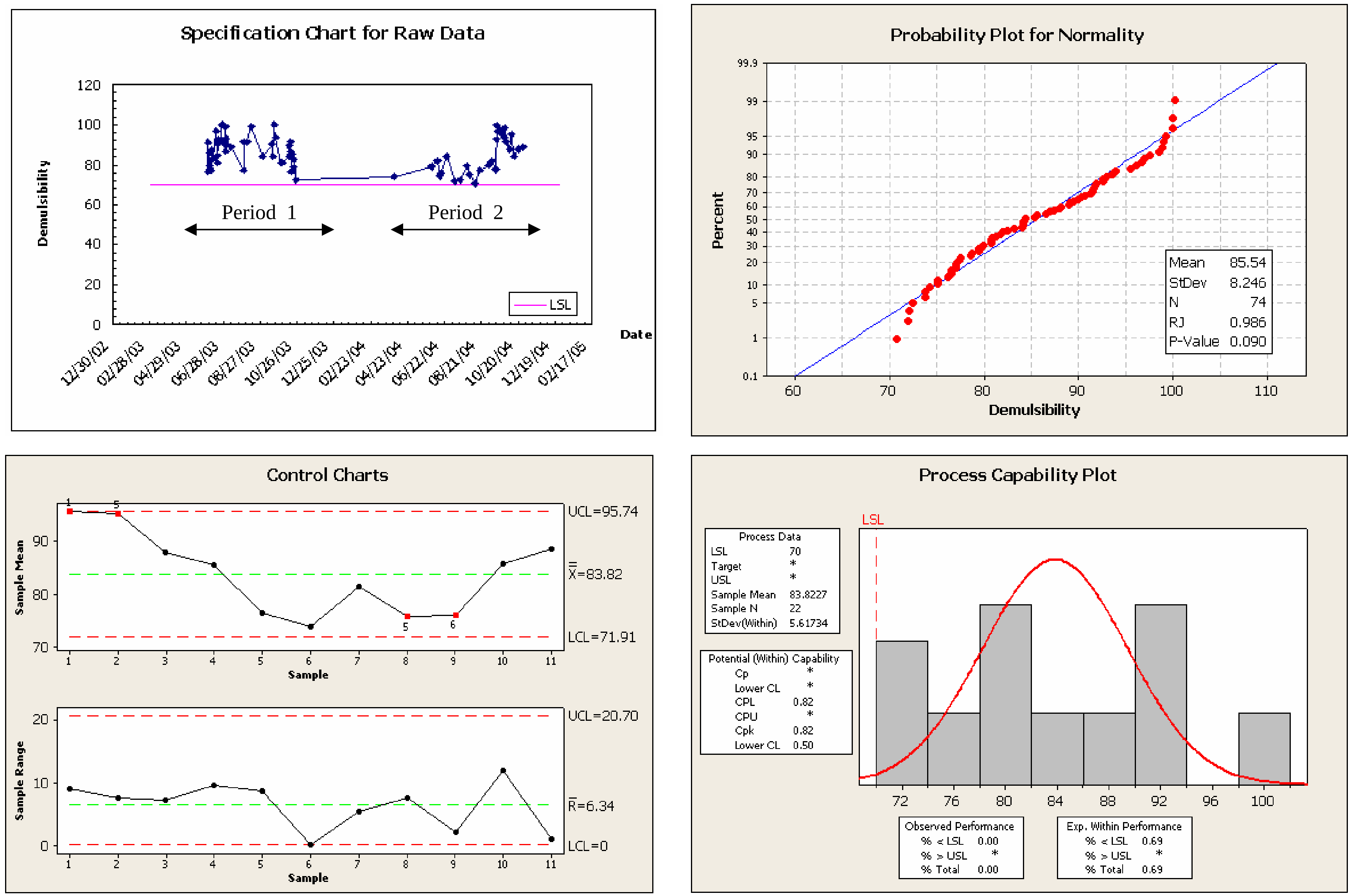


Figure G-116 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2P Test: Demulsibility

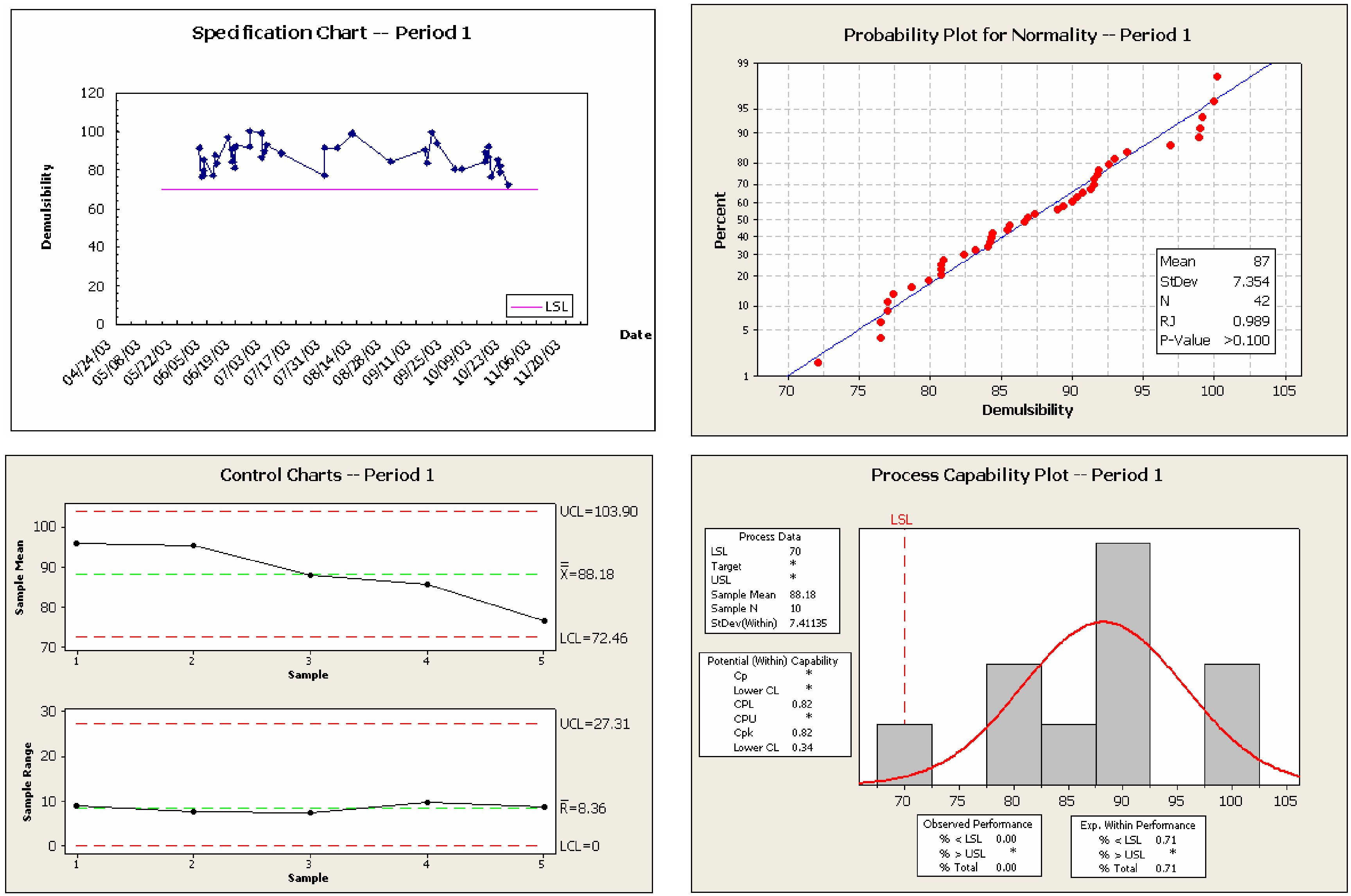


Figure G-117 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: CRS-2P Test: Demulsibility

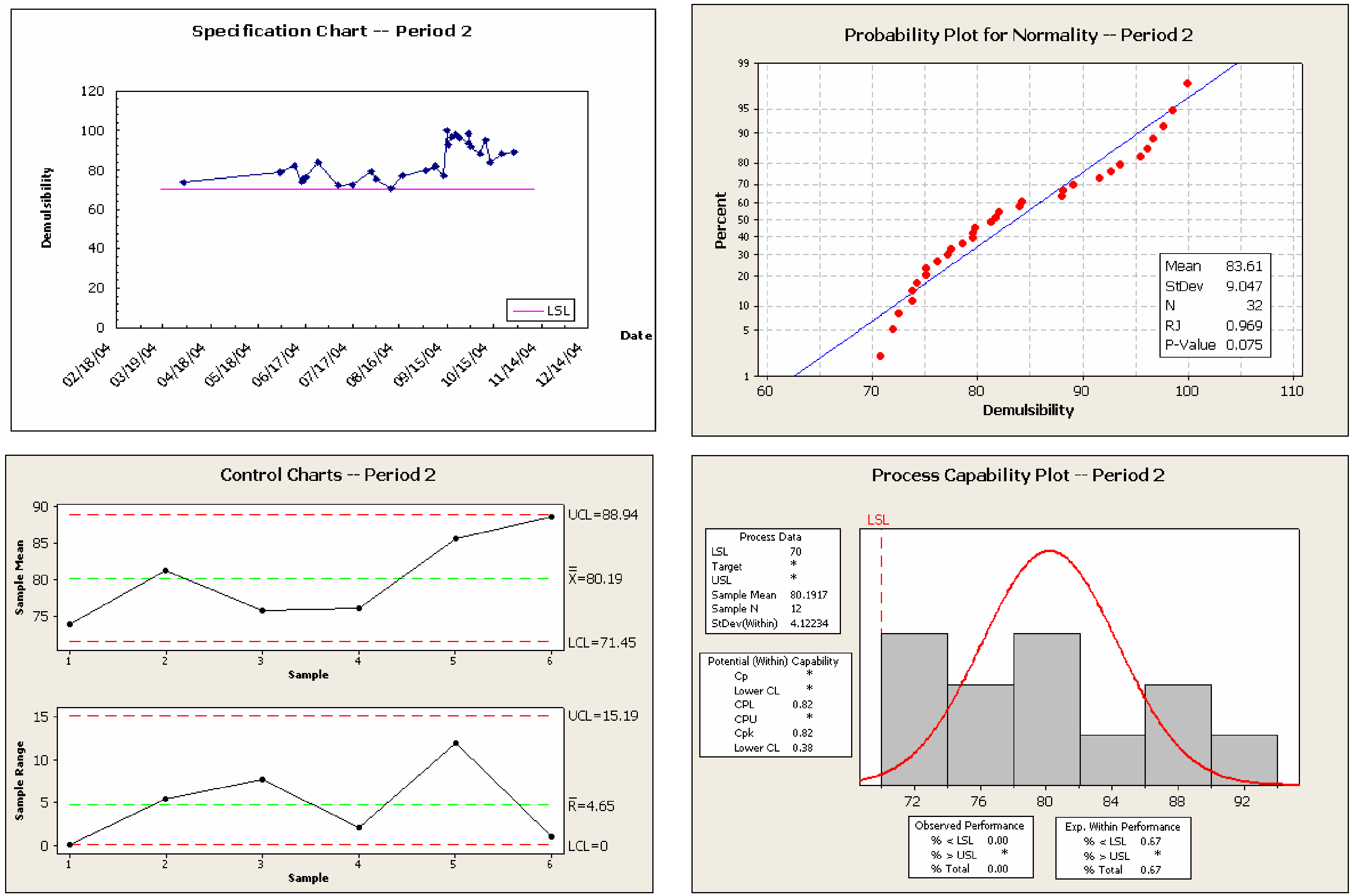


Figure G-118 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: CRS-2P Test: Demulsibility

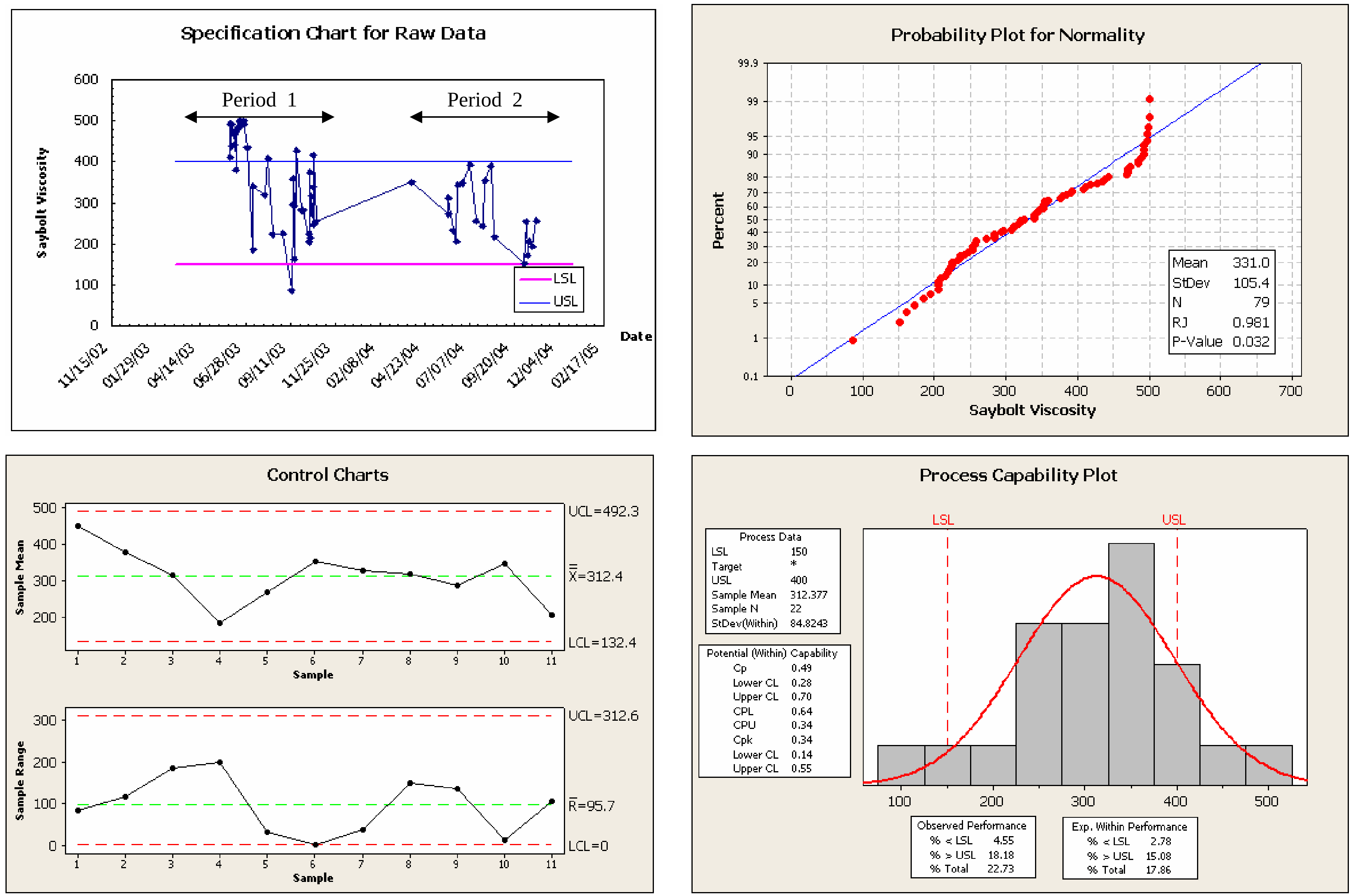


Figure G-119 Statistical Analysis Charts for Supplier: 0703 Grade: CRS-2P Test: Saybolt Viscosity

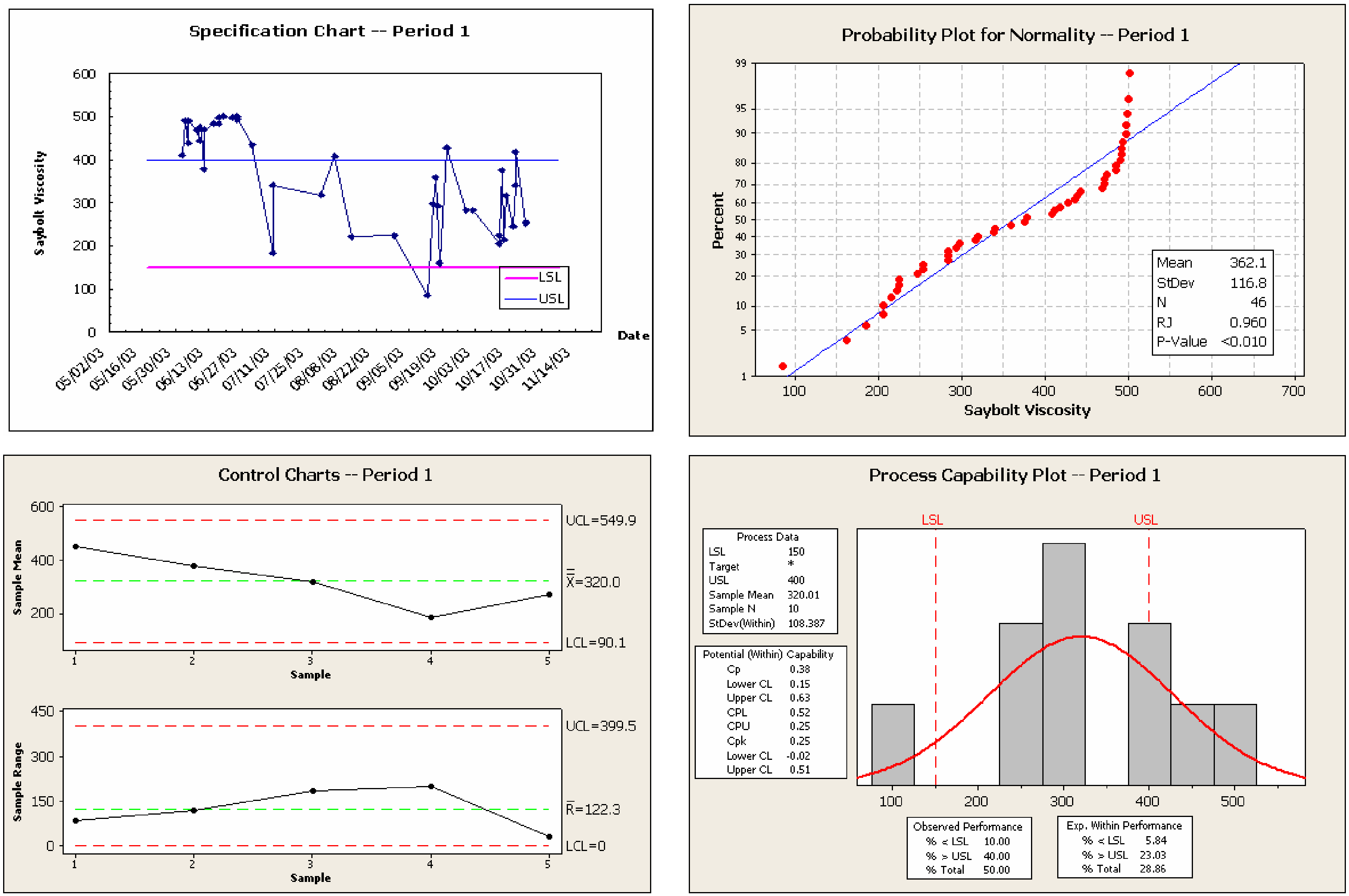


Figure G-120 Statistical Analysis Charts (Period 1) for Supplier: 0703 Grade: CRS-2P Test: Saybolt Viscosity

Figure G-121 Statistical Analysis Charts (Period 2) for Supplier: 0703 Grade: CRS-2P Test: Saybolt Viscosity

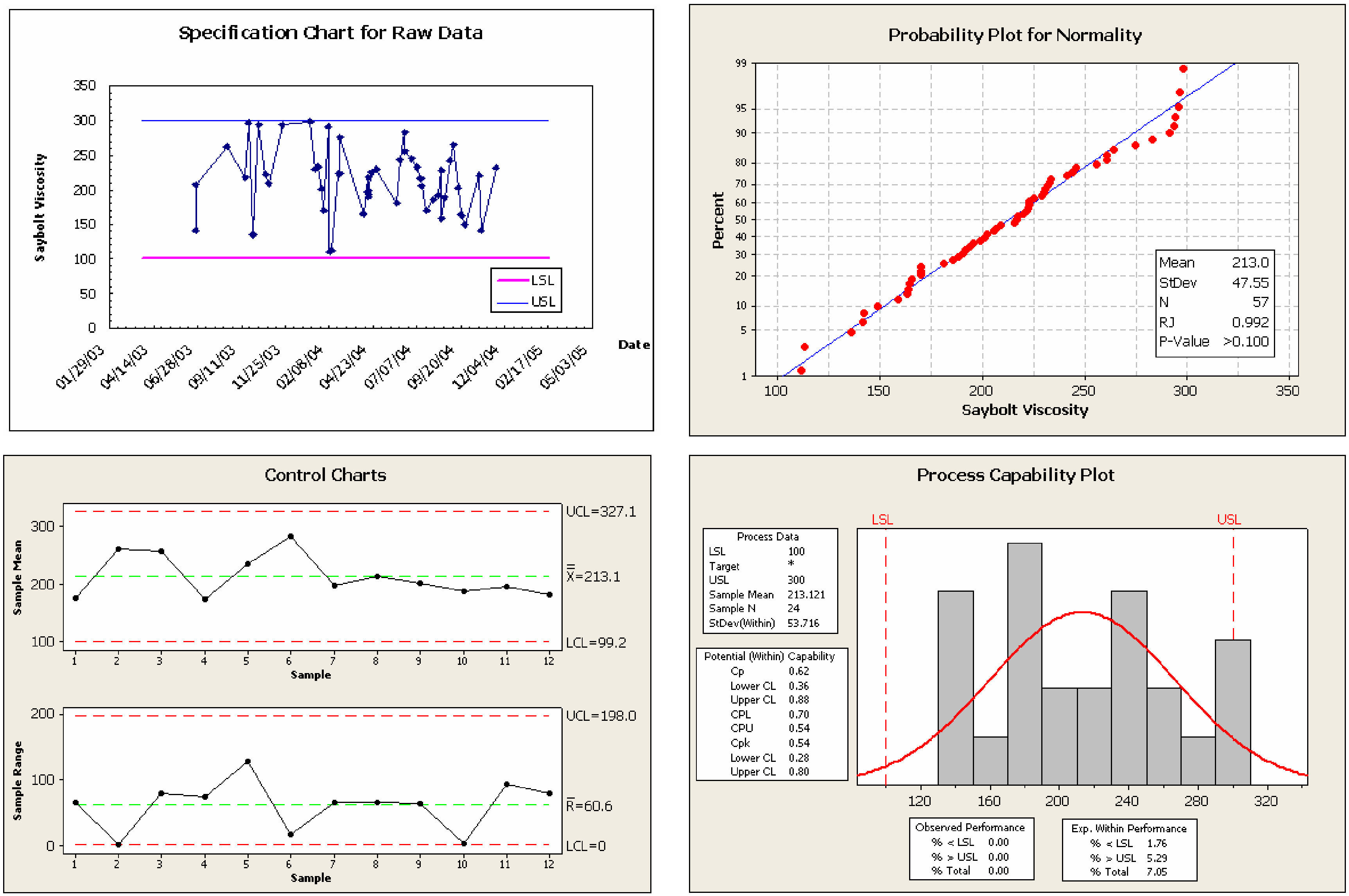


Figure G-122 Statistical Analysis Charts for Supplier: 0703 Grade: MS-2 Test: Saybolt Viscosity

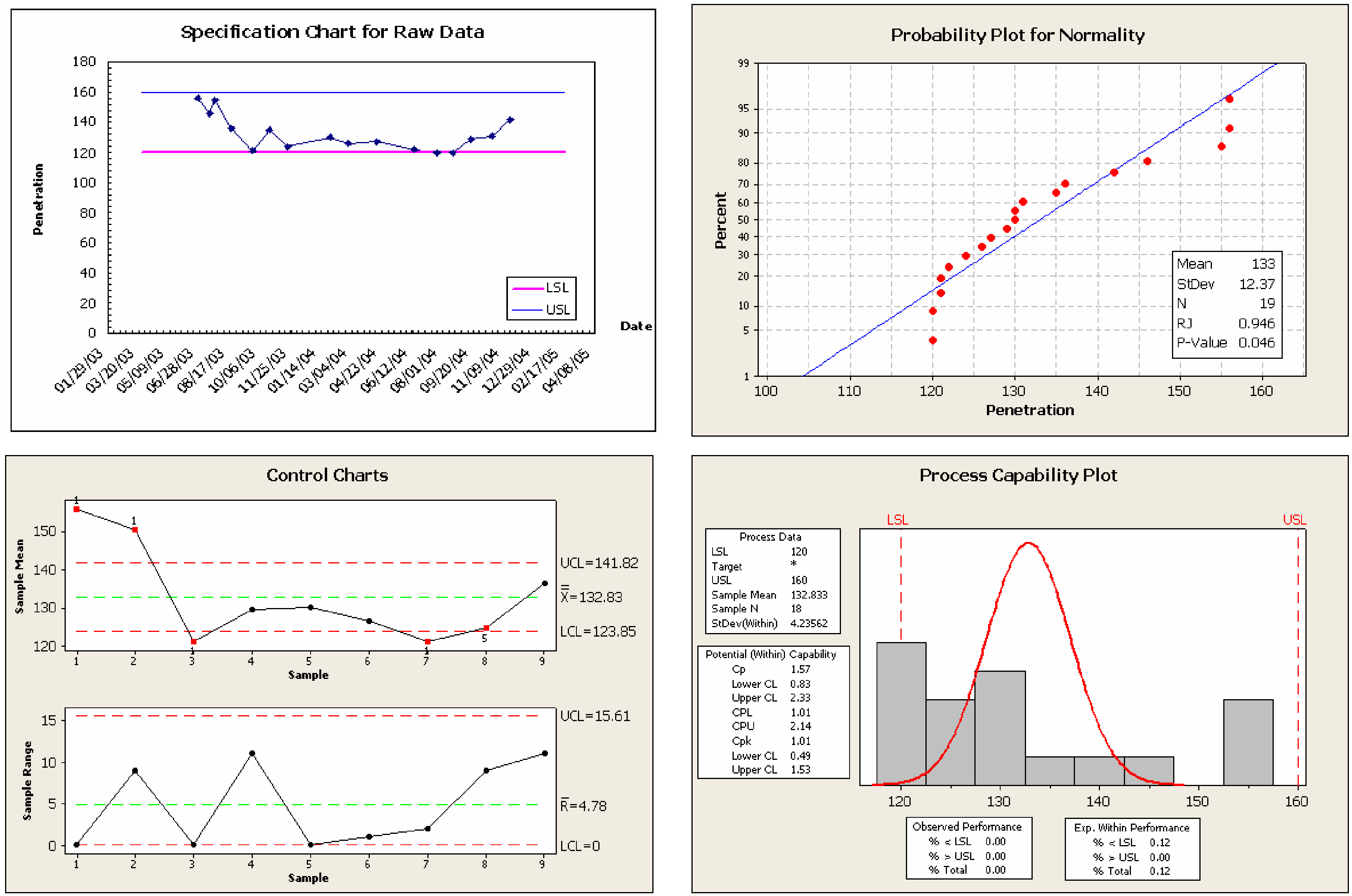


Figure G-123 Statistical Analysis Charts for Supplier: 0703 Grade: MS-2 Test: Penetration

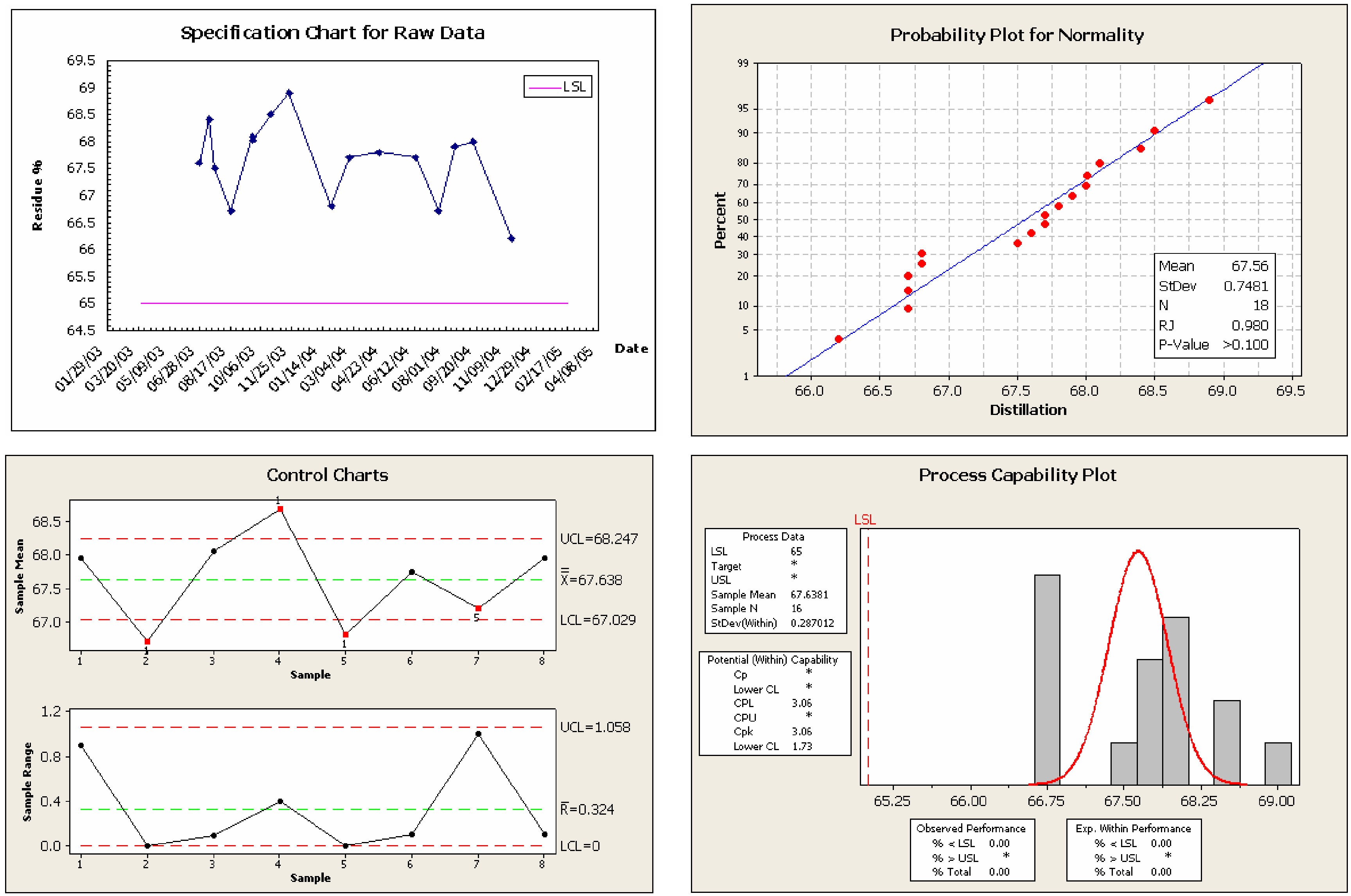


Figure G-124 Statistical Analysis Charts for Supplier: 0703 Grade: MS-2 Test: Distillation

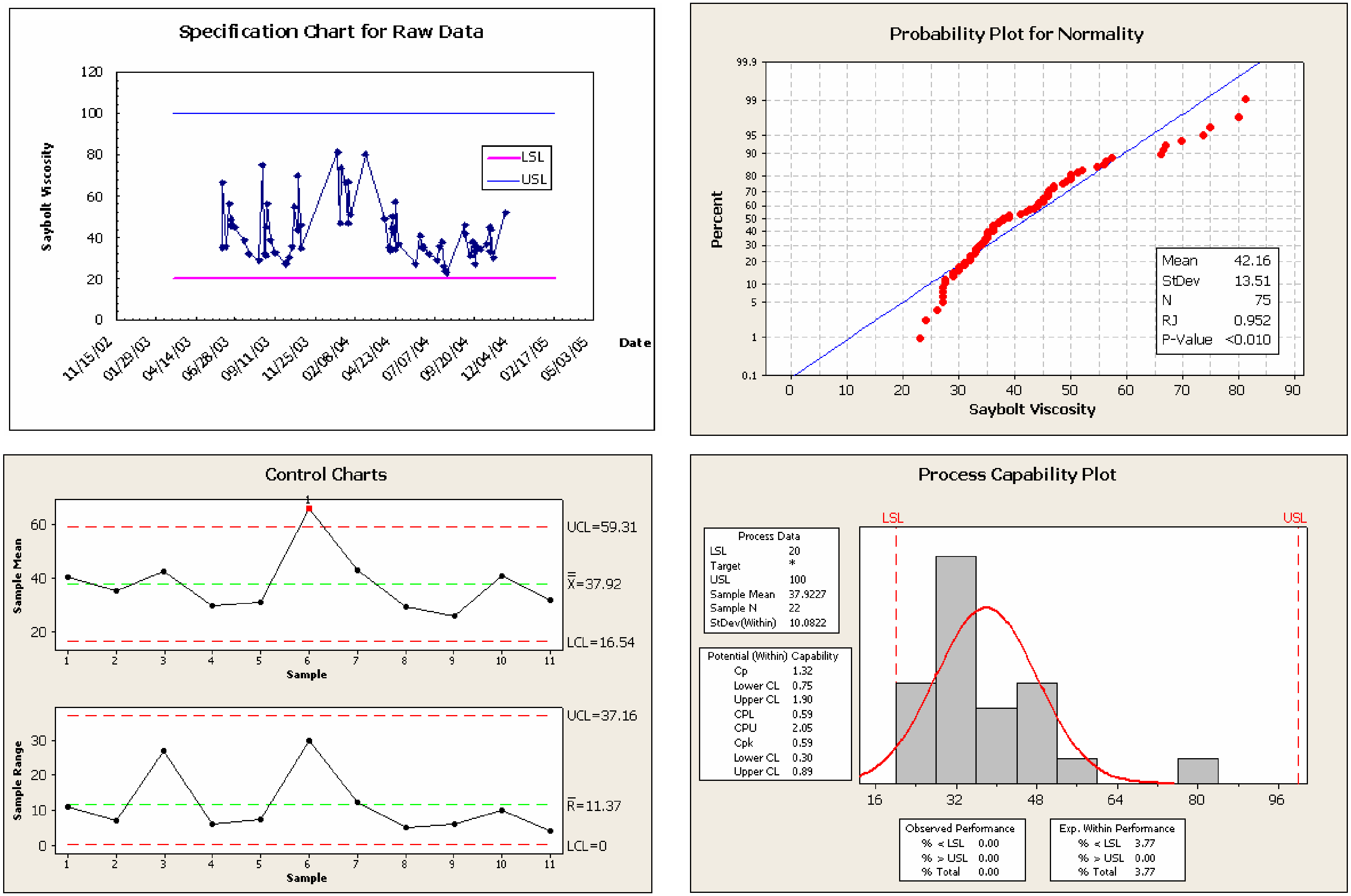
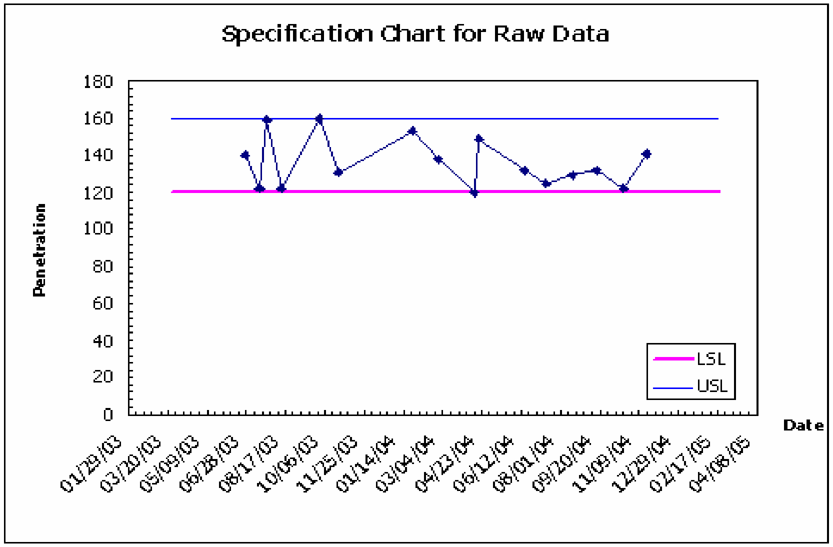
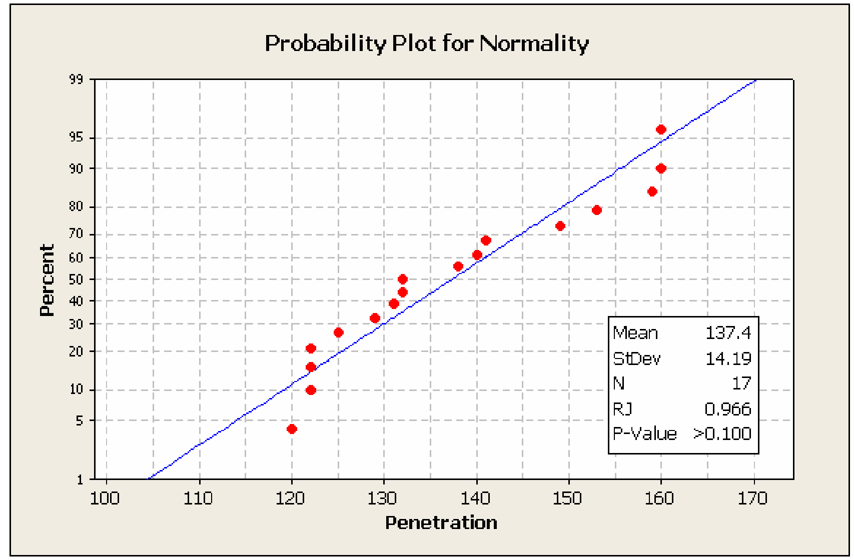
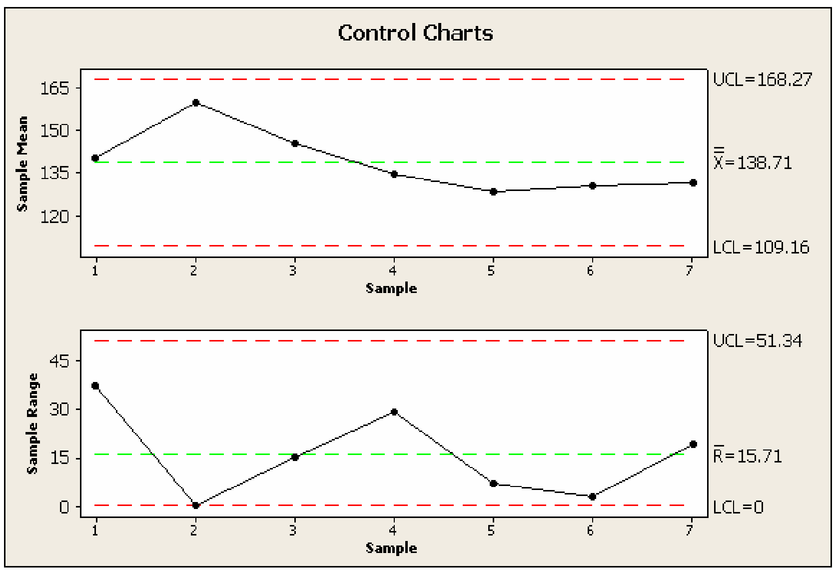


Figure G-125 Statistical Analysis Charts for Supplier: 0703 Grade: SS-1 Test: Saybolt Viscosity







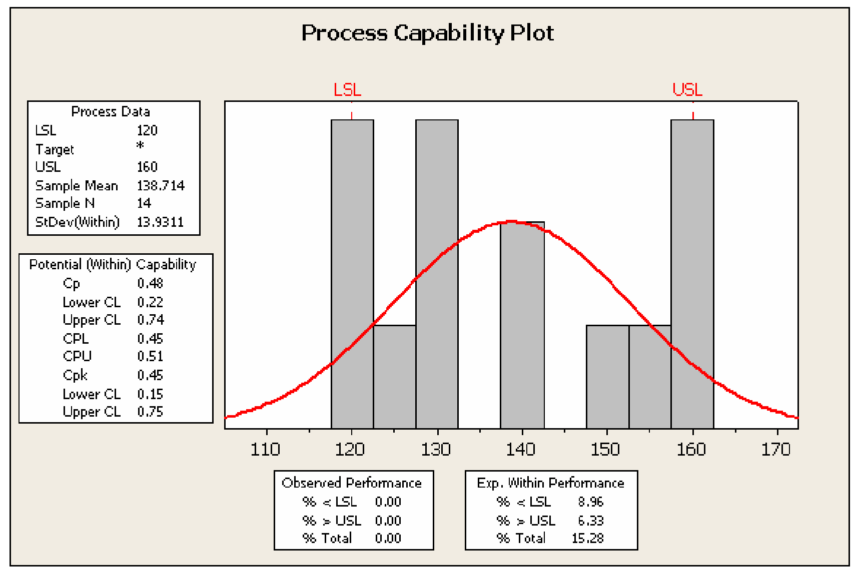


Figure G-126 Statistical Analysis Charts for Supplier: 0703 Grade: SS-1 Test: Penetration

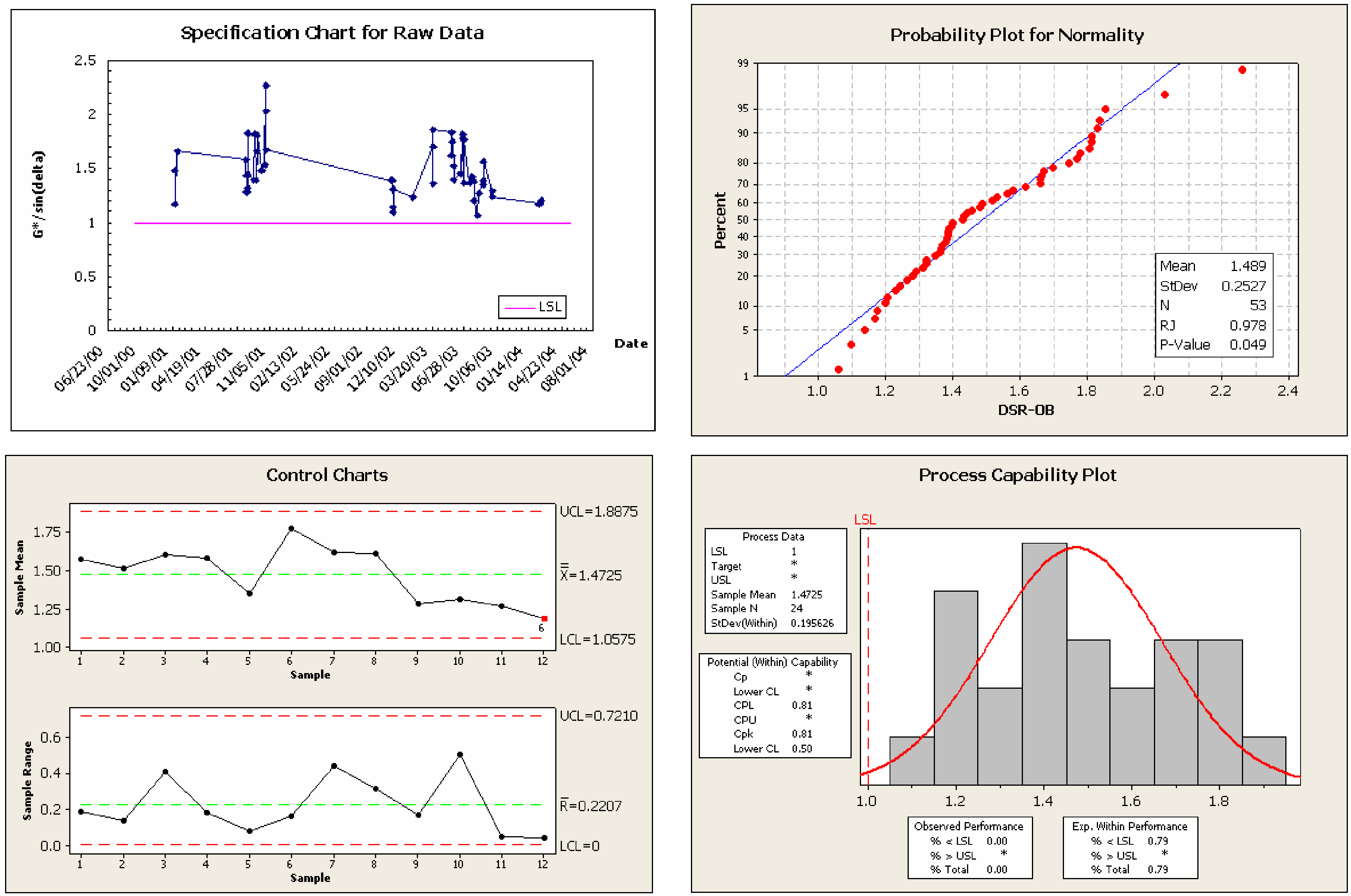


Figure G-127 Statistical Analysis Charts for   Supplier: 0802   Grade: PG 76-22   Test: DSR-OB

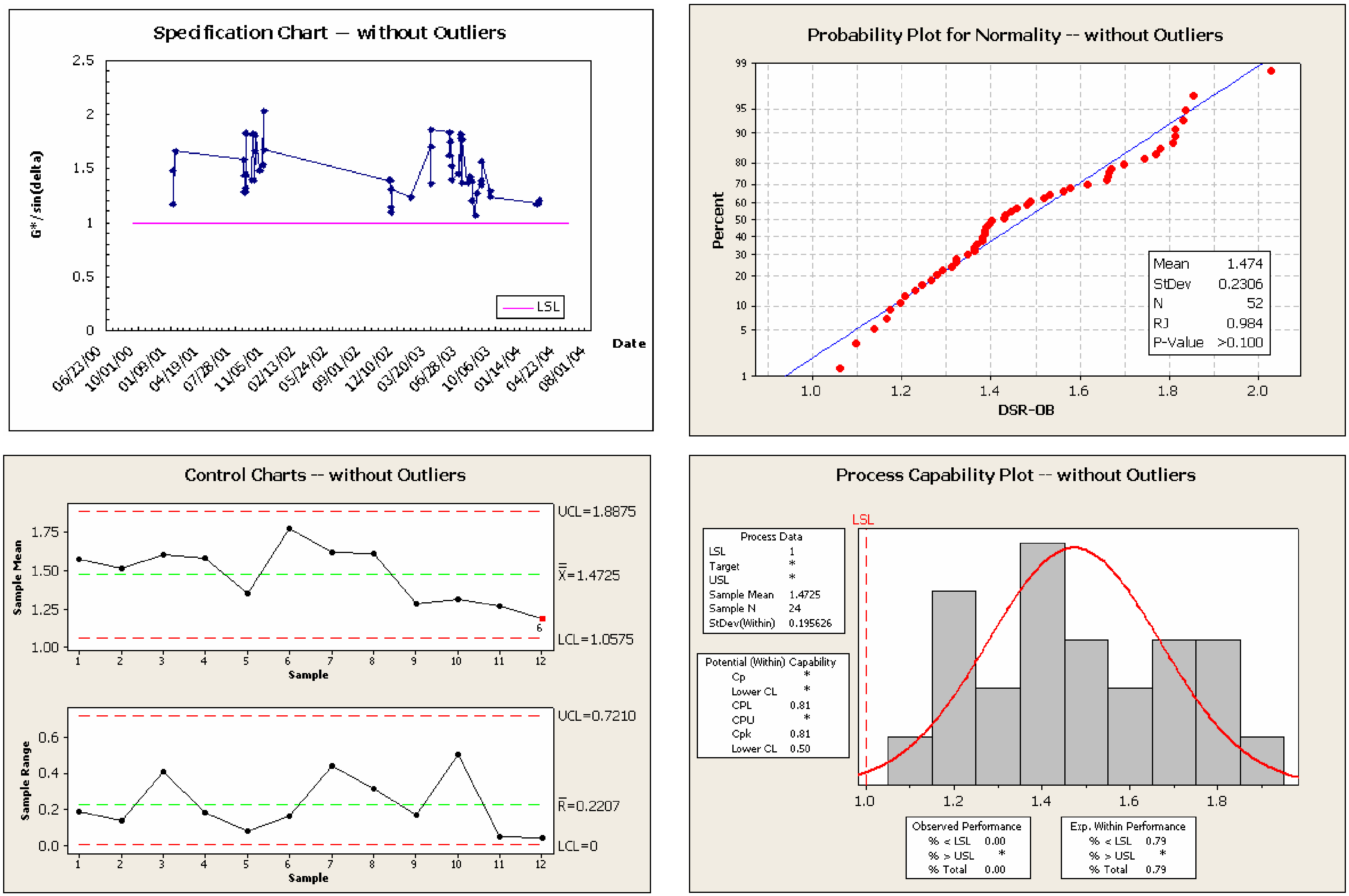


Figure G-128 Statistical Analysis Charts (without Outliers) for Supplier: 0802 Grade: PG 76-22 Test: DSR-OB

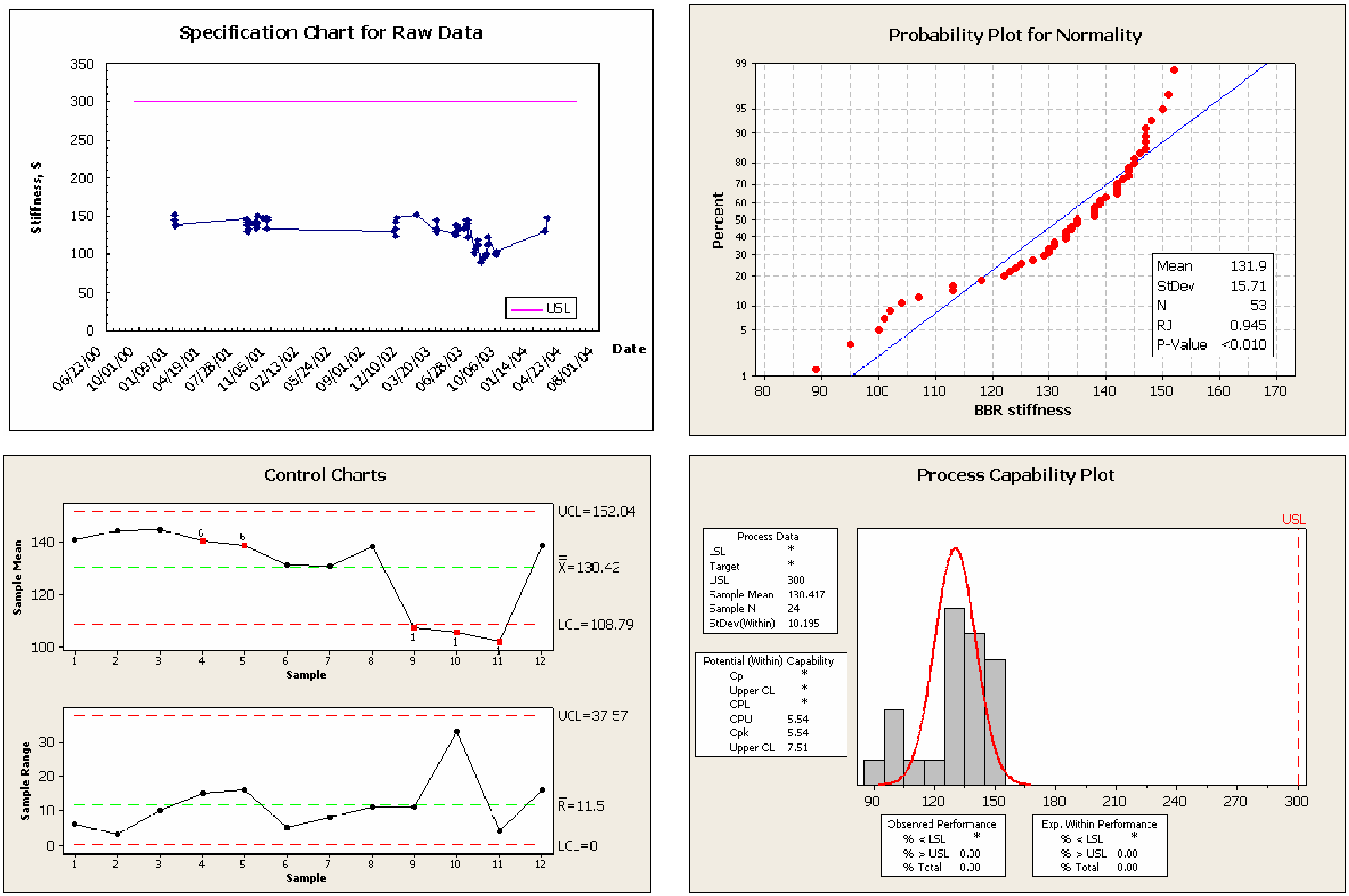


Figure G-129 Statistical Analysis Charts for Supplier: 0802 Grade: PG 76-22 Test: BBR-Stiffness

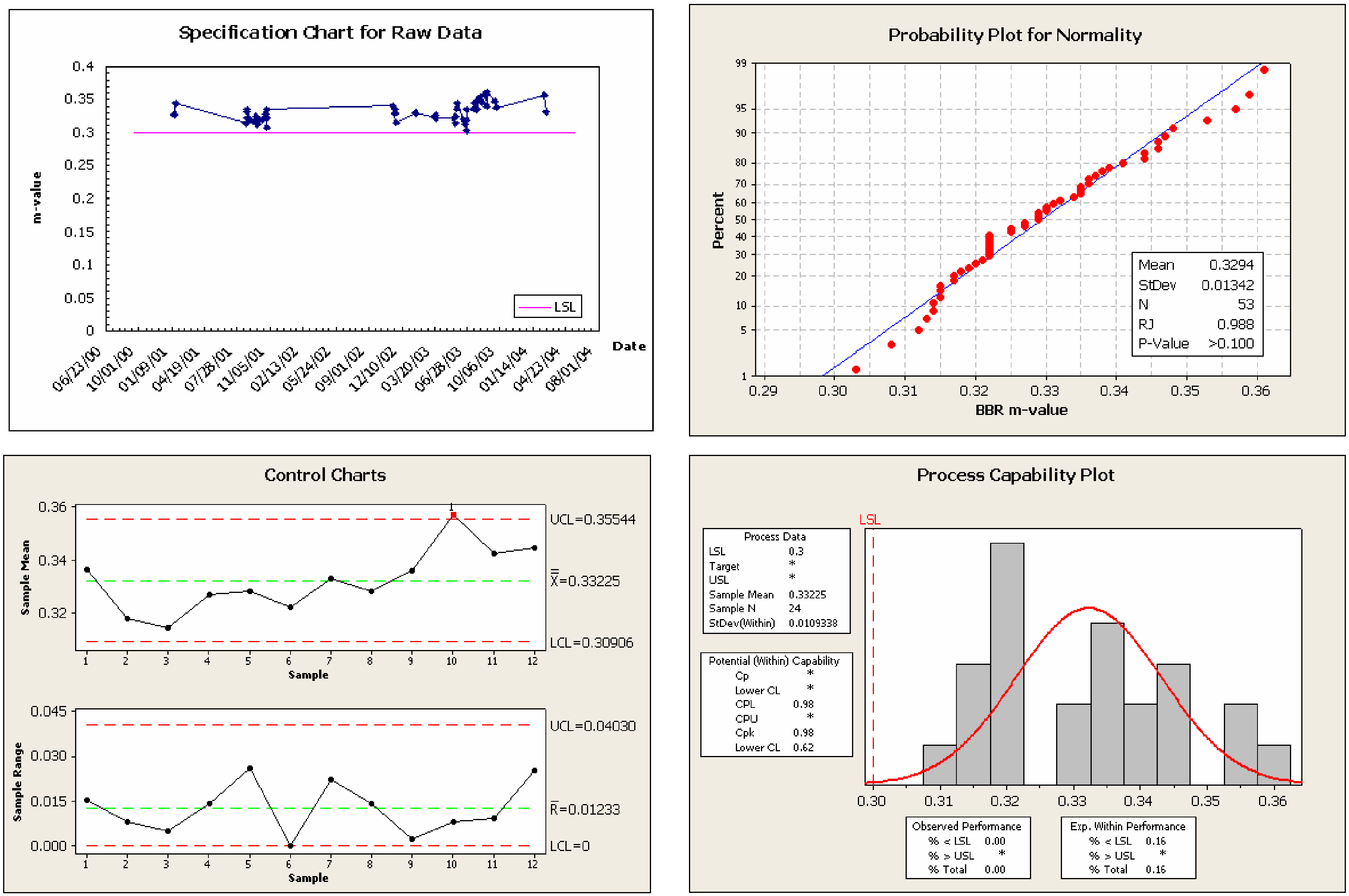


Figure G-130 Statistical Analysis Charts for Supplier: 0802 Grade: PG 76-22 Test: BBR-m-value

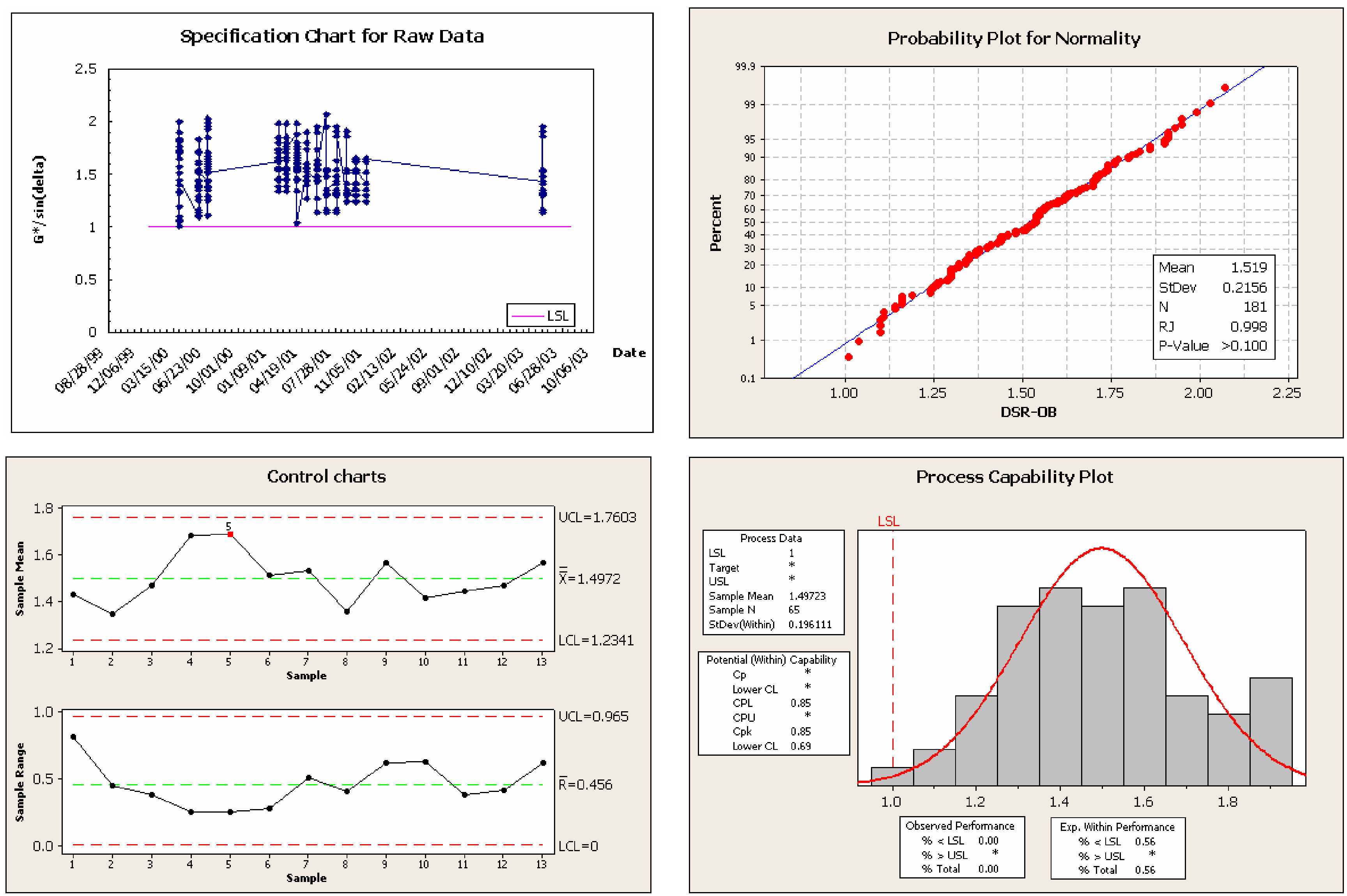


Figure G-131 Statistical Analysis Charts for Supplier: 1201 Grade: PG 64-22 Test: DSR-OB

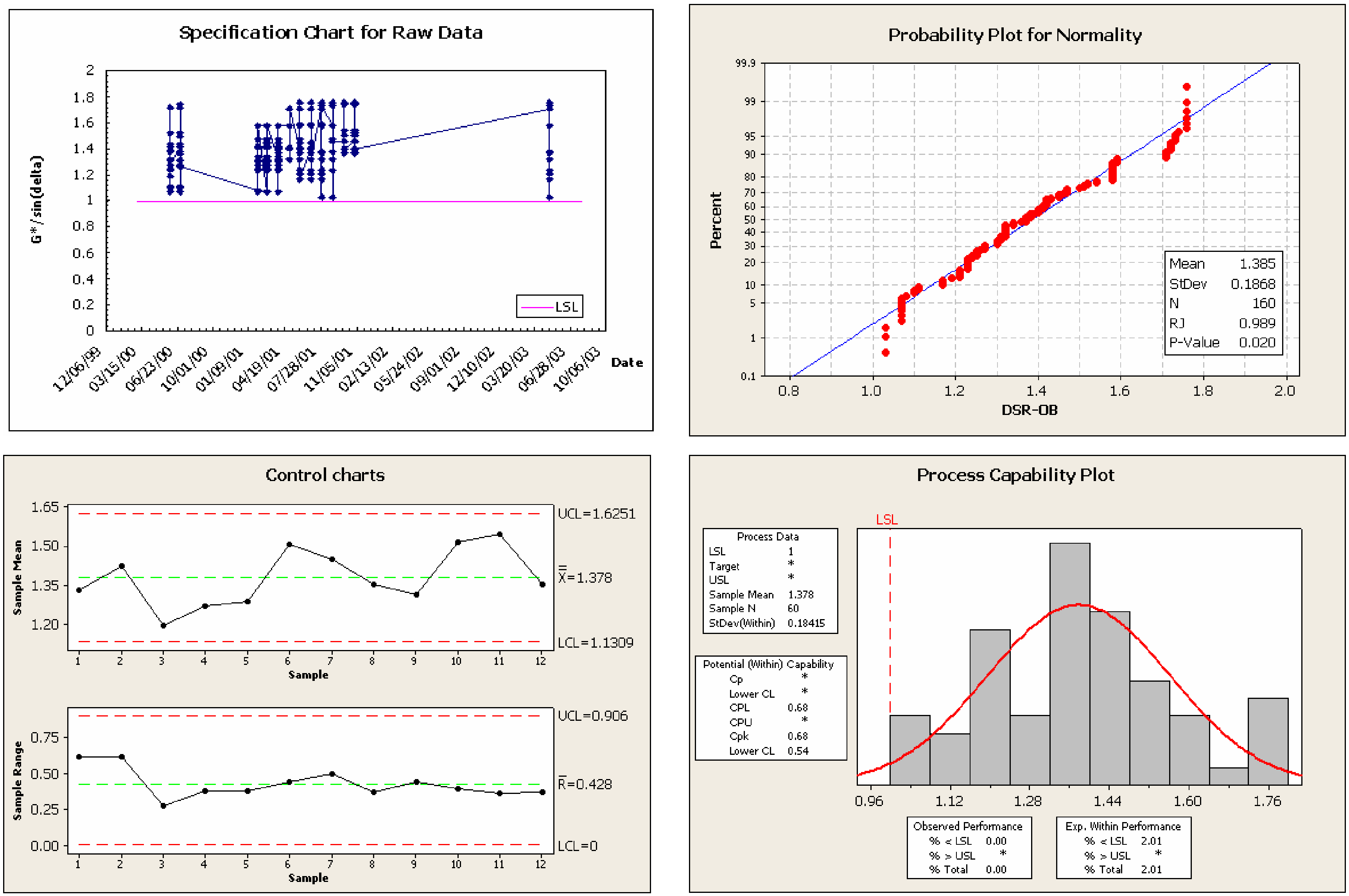


Figure G-132 Statistical Analysis Charts for Supplier: 1201 Grade: PG 70-22S Test: DSR-OB

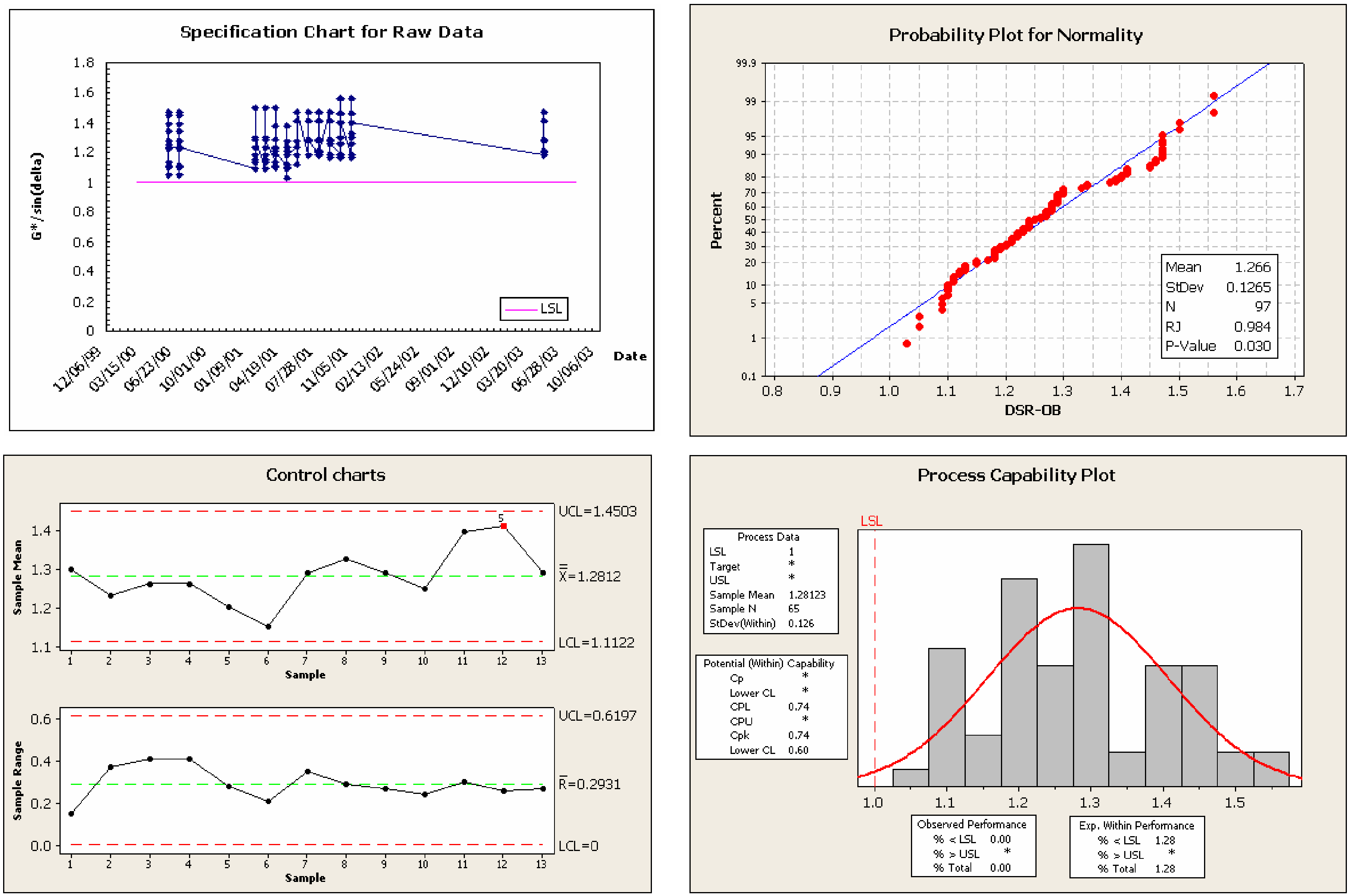


Figure G-133 Statistical Analysis Charts for Supplier: 1201 Grade: PG 76-22S Test: DSR-OB

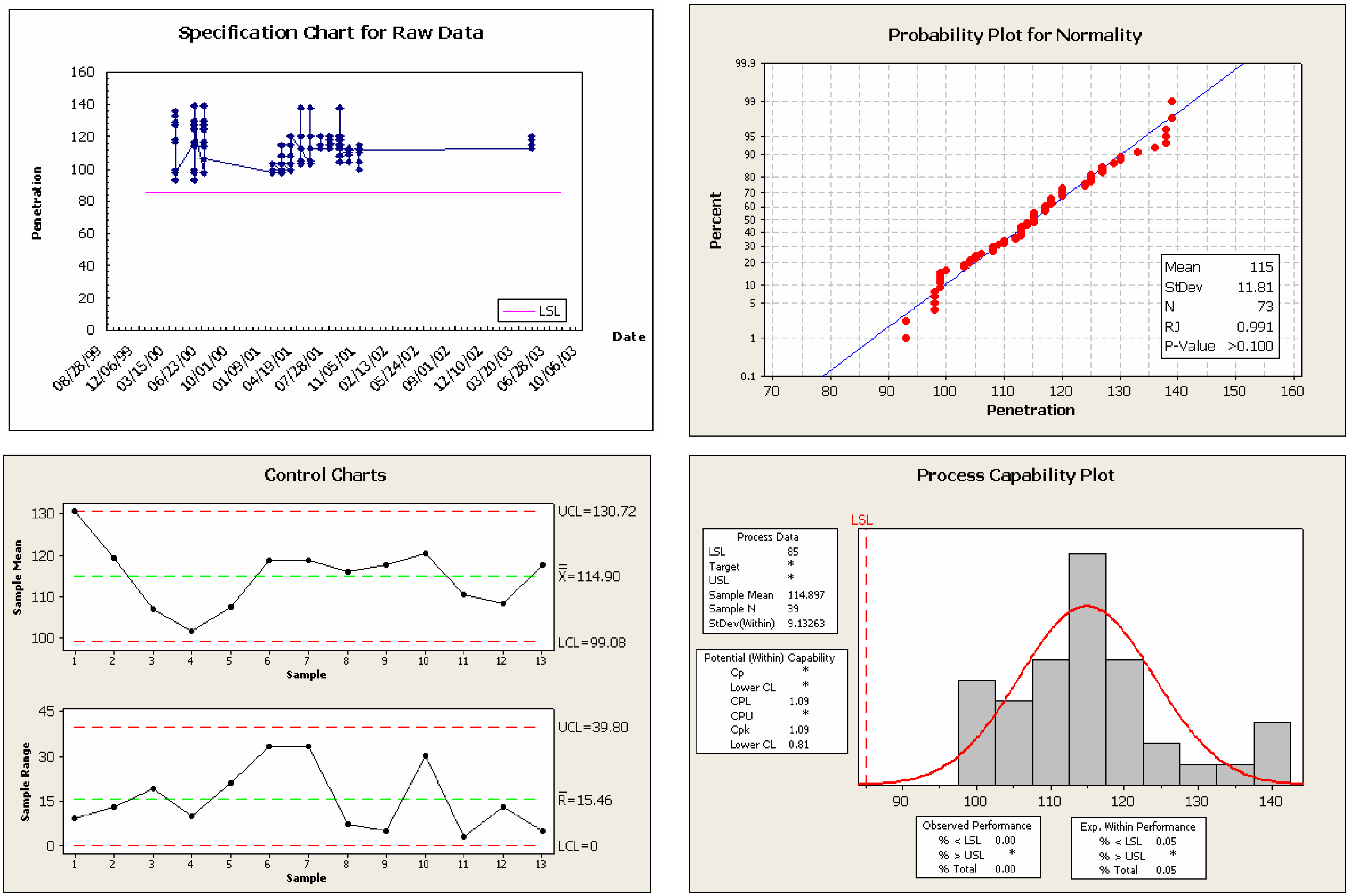


Figure G-134 Statistical Analysis Charts for Supplier: 1201 Grade: AC-10 Test: Penetration

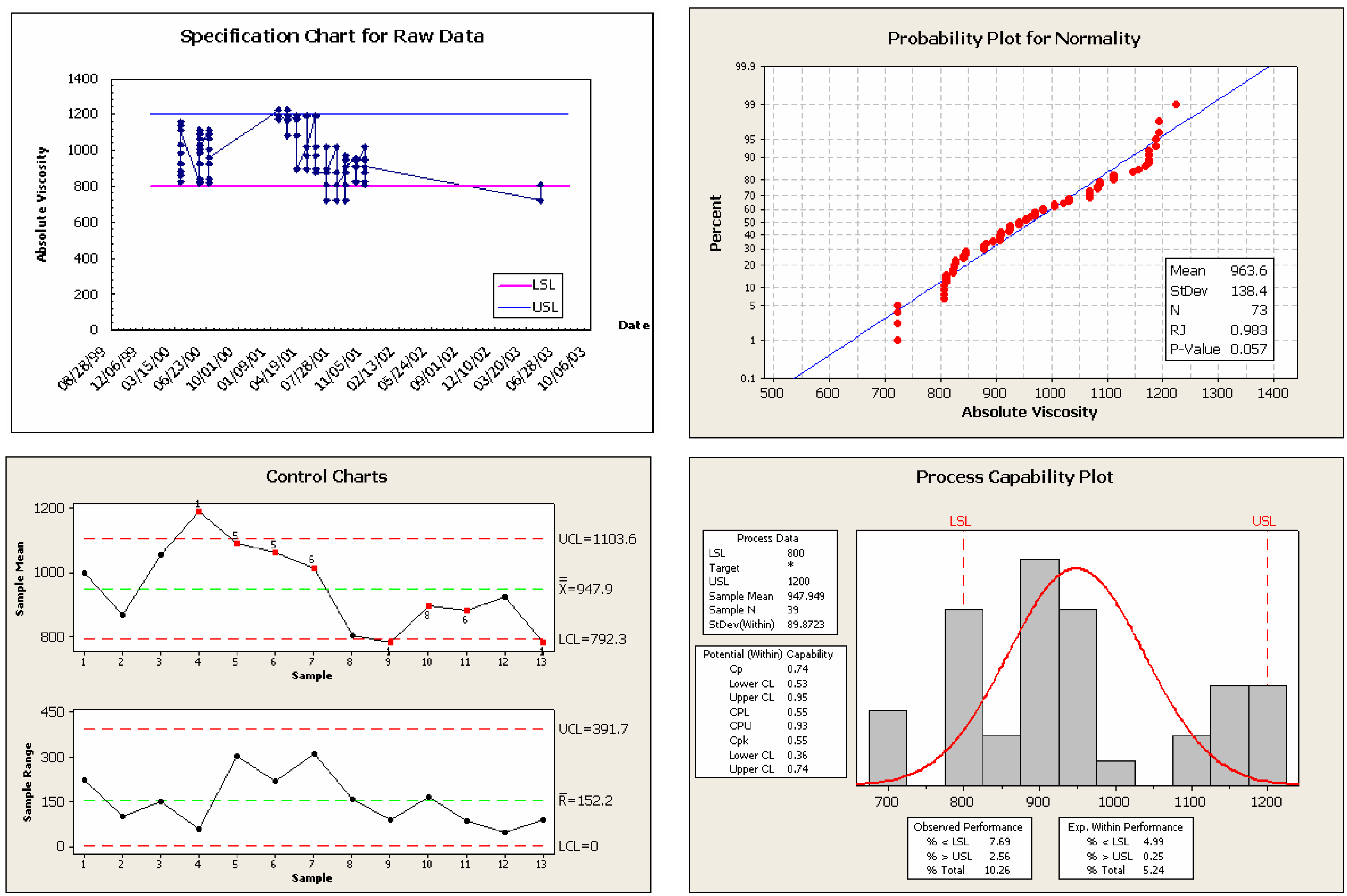


Figure G-135 Statistical Analysis Charts for Supplier: 1201 Grade: AC-10 Test: Absolute Viscosity