ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

INCREASING PORT OPERATIONAL EFFICIENCY THROUGH OPERATIONAL RELIABILITY ANALYSIS

M.Sc. THESIS

Fahriye Tuğba KURUM

Department of Maritime Transportation Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

OPERASYONEL GÜVENİLİRLİK ANALİZİ İLE LİMAN OPERASYONEL VERİMLİLİĞİNİN ARTIRILMASI

YÜKSEK LİSANS TEZİ

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OCAK 2024

Fahriye Tuğba KURUM, a M.Sc. student of ITU Graduate School of Science Engineering and Technology student ID 512201013, successfully defend the thesis entitled "INCREASING PORT OPERATIONAL EFFICIENCY THROUGH OPERATIONAL RELIABILITY ANALYSIS", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 05 January 2024
Date of Defense : 19 January 2024

To my daughter,

FOREWORD

In this study, I would like to express my gratitude to my thesis supervisor, Doç. Dr. Kadir ÇİÇEK for his constant guidance, support and advice. I would like to thank Mr. Levent ŞİNEL, who guided me with his knowledge and experience and supported me through all the difficult stages of my graduate education life. I would like to thank my colleagues whose moral support I feel in my work.

January 2024 | Fahriye Tuğba KURUM
(Port Operation Specialist)

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ABBREVIATIONS

12A : Multiple Vehicle Accumulation at Port Entry
13D : Vehicle Acceptance Error-Documentation (Ticket, Passport, Visa)
14B : Reservation Errors
14D : List Renewal Procedures Due To Overbooked
14E : Reservation Errors Made By The Agency
15 : Vehicle Loading Errors Or Vehicle Forget/ Mistake Of Port Operation
15B : Waited For Loading List To Start Loading
15E : Number Disclaimer / Mistake By Agent
15H : Total Number Of Cargo Not Be Closed By Agent Due To Waiting For Cargo
15J : Waiting For Cargo
17B : Late Arrival Of Provision Store
17F : Broken Provision Store Equipment
17G : Fresh Water Supply
18D : Vehicle Showing Red Light On Customs System
21B : Wrong Preparation Of Vessel Documents
21C : Document Control By Authority (Manifest Control)
21D : Preparing Late Document By The Company Authorized
21E : Late Preparation Of Vessel Documents
24C : Late Loading Operation Due To Fix Wrong Load
24D : Wrong Load Due To Wrong Declaration/Because Of Customers
31B : Make Some Arrangement To Fix Vessel Stability
32A : Wrong Load / Port Operation Mistake
32B : Wrong Load / Agent Mistake / Wrong Load Of Special Material
32E : Wait For Drivers Of Comple Units
32O : Load/Unload Defective Vehicle
32P : Organization Mistake
32R : Slow Loading/Unloading
32S : Vessel Waited For Feeder Ship To Load Cargo
33B : Lack Of Equipment (Mafi, Twist lock)
33C : Lack Of Equipment Operator
34A : Pilot Came Late On Arrival
34B : Pilot Came Late On Departure
34D : Delays Caused By The Procedure
34E : Waited For Departure Of The Other Ship In The Port
36B : Bunker Barge Came Late
36T : Waiting For Finish Operation Of Bunker & Sludge Barge
37A : Health Control Delays (Arrival)
37B : Health Control Delays (Departure)
38A : Extension/Delay Of Customs Control Of Special Cargo
41D : Vessel Stern Ramp Damage
41F : Waiting For Document After Technical Survey Approving

41M : Vessel Engine Breakdown
41O : Vessel Engine Faults In The Last Minute
42D : Insufficiency Of The Time Allocated For Maintenance, Wrong Planning
42E : Unexpected Failures Come Out On Planning Maintenance
43 : Special Controls
43A : Periodic External Maintenance
43C : Sea Trial
43D : Drill (Launching Freefall)
43E : Drill By Survey
43F : Waiting For Completion Of Survey
44C : Late Delivery Of Spare Equipments
55C : Customs System Failure
55D : Weighbridge Failure
64D : Planning Mistake By Crewmembers
65A : Starting Loading Operation Lately According To Master Order
65C : Refusing Cargo By Master
76A : Vessel Cannot Be Berthed Due To Heavy Weather
76B : Pilot Service Suspended Due To Heavy Weather At Departure Port
77A : No Berthing Operation Due To Heavy Weather
77B : Pilot Service Suspended Due To Heavy Weather At Arrival Port
87A : No Available Position To Berth
87D : Hitch Of Port Services
87E : Lack Of Parking Space
91 : Waiting For Intermodal Cargo
91A : Waiting For Equipment And Document
91C : Waiting For X-Ray
93A : Late Arrival Due To Late Departure From Last Departed Port
93B : Late Arrival Due To Several Reasons That Occurred During Sea Voyage
93C : Due To Weather Condition During Sea Voyage
93D : Late Arrival Due To The Technical Reasons
93F : Due To Late Entry Time Of Dardanelles Strait
93J : Route Change Due To Various Reasons
93G : Late Arrival Due To Joining Search And Rescue Operation
93H : Late Departure Due To Late Arrival
95A : Operational Control - Voyage Change
95C : Waiting For Voyage Material For Operational Needs
95F : Request Late Arrival Of Various Causes By Company
DFDS : Det Forenede Dampskibs-Selskab
MTBF: Mean Time Between Failure
Ro-Ro : Roll-on Roll-off
SOF : Statement of Facts
URLLC: Ultra Reliable Low Latency Communications

SYMBOLS

Φ	: Cumulative distribution function
e	: Euler
γ	: Location parameter
λ	: Parameters of distribution
R	: Reliability
η	: Scale parameter
β	: Shape parameter
σ	: Standard deviation
μ	: Statistical average
t	: Time

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SUMMARY

In order to meet the developing technology and increasing supply demand, the search for faster and safer transportation modules has begun. Maritime transportation, which allows the transportation of high tonnage loads, has been adopted, and Ro-Ro transportation, one of the transportation methods where speed is at the forefront, has gained great importance. In this study conducted on Ro-Ro transportation, where speed is at the forefront, operational activities disrupted due to delays were examined. For this purpose, delay data was collected, analyzed and improvement suggestions were made using qualitative methods. An actively operating Ro-Ro port was selected to collect data and the study was limited to this port only. These data were obtained by examining the reasons for the delay in the ship's planned departure and arrival times for 2 years. The collected data were divided into categories and delay code names were given. The most common delay codes were selected according to their frequency of occurrence. The examined delay codes were reduced to 18 delay codes. Reliability analysis was used to evaluate the consistency of the time frequency of occurrence of these delay codes. Different distribution methods were evaluated using the Minitab program. The Weibull distribution was found to be the most suitable distribution and the Weibull distribution was chosen for the calculations. Reliability function calculation was made in the Weibull distribution, and a graphical visualization of the reliability rate of the obtained data was made. It has been concluded that the right action must be taken at the right time to improve delays, otherwise the reliability of the system will decrease, and each delay will trigger each other. Based on the results obtained, improvement suggestions were made, and recommendations were made to reduce and/or completely eliminate these delays. This study was conducted to fill the gap in the literature.

Keywords: Delays, Maritime, Reliability analysis, Ro-Ro ships, Port operations

OPERASYONEL GÜVENİLİRLİK ANALİZİ İLE LİMAN OPERASYONEL VERİMLİLİĞİNİN ARTIRILMASI

ÖZET

Sürekli artan dünya nüfusu ve teknoloji alanındaki hızlı gelişmelerle birlikte artan arz talebi karşılamak amacı ile daha hızlı ve güvenli taşıma modüllerinin arayışı başlamıştır. Dünya ticaretinde farklı taşıma modları bulunmaktadır ve bu taşıma modlarının her birinin kendi alanında avantajları ve dezavantajları bulunmaktadır. Havayolu taşımacılığı hızlı olabilmekte ama yüksek tonajlı kargoların taşınmasında uygun bir yöntem olamamakla beraber çok maliyetli bir taşıma yöntemidir. Karayolu taşımacılığı ise özellikle uzak mesafeler için zaman kaybı yaratmakta ve yüksek tonajlı yüklerin taşınmasına elverişli bir taşıma sağlamamaktadır. Demiryolu taşımacılığı ise her bölgeye ulaşım sağlanamaması nedeni ile farklı taşıma modları ile bağlantı sağlamak zorundadır. Denizyolu taşımacılığa bakıldığında ise hem yüksek tonajlı yüklerin taşınmasına elverişli olması sebebi ile hemde daha az maliyetli bir ulaşım sağlaması sebebi ile tercih edilen bir yöntem olmuştur. Fakat denizcilik taşımacılığının nispeten daha yavaş olması ve yük tipine göre farklı tip ambarlara ihtiyacın olması sebebi ile, gemilerin kullanım amacı göz önüne alınmış ve talebe uygun farklı tip gemilerin inşası gerçekleştirilmiştir.

Hızın, emniyetin ve taşıyabildiği kargo tipindeki esnekliği sebebi ile deniz taşımacılığı yöntemlerinden biri olan Ro-Ro tipi gemilerle yapılan Ro-Ro taşımacılığı ise büyük önem kazanmıştır. Ro-Ro gemilerinin diğer kargo gemilere göre nispeten daha hızlı deniz seyri yapabilmesi ve taşıdığı yük tipleri sebebi ile farklı taşıma modlarıyla kolayca bağlantı sağlayabilmesi Ro-Ro taşımacılığının seçilmesine sebebiyet vermiştir. Fakat her taşımacılık modulünde olduğu gibi Ro-Ro taşımacılığında da bazı aksaklıklar yaşanmakta ve bu aksaklıklar operasyonel gecikmelere sebebiyet vermektedir. Bu tarz gemilerin esas tercih edilme sebeplerinden birinin hız olduğu göz önüne alındığında bu gecikmelerin incelenip, tolere edilebilir bir düzeye getirilmesi zorunluluğu oluşmuştur.

Bu çalışmada ise Ro-Ro taşımacılığında yaşanan gecikmeler sebebiyle yaşanan operasyonal aksaklıklar incelenmiş ve operasyonel hızlarının azalmasına neden olan faktörlerin azaltılması ve/veya ortadan kaldırılması hedeflenmiştir. Bu amaçla planlanan varış ve kalkışları sekteye uğratan gecikme nedenlerinin verileri toplanmış, analiz edilmiş ve iyileştirme önerilerinde bulunulmuştur.

Gecikme verileri toplamak amacı ile aktif olarak çalışmakta ve her gün en az bir gemi seferi olan bir Ro-Ro limanı seçilmiştir. Yapılmış olan çalışma sadece bu liman ile sınırlı tutulmuştur. Gecikme verileri 2020-2021 yıllarında toplam 2 yıl boyunca geminin planlanan kalkış ve varış zamanlarındaki yaşanan gecikmelerin sebepleri incelenerek yapılmıştır. Planlanan kalkış ve varış zamanlarında gecikmelere sebebiyet vermeyen fakat ortaya çıkan gecikme kodları ise değerlendirmeye alınmamıştır.

Toplanan veriler kategorilere ayrılmış, ve her gecikme için gecikmelere kod numaraları verilmiştir.

Gerçekleşme sıklığına göre gecikme kodları arasında en çok karşılaşılan gecikme kodlarının seçimi yapılmıştır. İncelenen gecikme kodları 18 adet gecikme koduna indirilmiştir. Bu gecikme kodlarının ortaya çıkış zaman sıklığının tutarlılığını değerlendirmek için güvenilirlik analizi kullanılmıştır. Genellikle istatiksel verilerin hesaplanması için kullanılan Minitab programı kullanılarak 5 farklı dağılım yöntemi değerlendirilmiştir. Bu dağılım yöntemleri; Weibull dağılımı, normal dağılım, lognormal dağılım, üstel dağılım, loglojistik dağılım yöntemleridir. Gecikme kodlarının dağılımları incelenmiştir; en uygun dağılım olarak Weibull dağılımı seçilmiştir ve hesaplamalarda Weibull dağılımı kullanılmıştır. Weibull dağılımında güvenilirlik fonksiyonu hesaplaması yapılmış, elde edilen verilerin güvenilirlik oranının grafiksel görselleştirilmesi yapılmıştır.

Gecikmelerde iyileştirme yapılması için doğru zamanda doğru aksiyonun alınması gerektiği, aksi halde sistemin güvenilirliğinin azalacağı ve her bir gecikmenin birbirini tetikleyeceği sonucuna ulaşılmıştır. Elde edilen sonuçlara iyileştirme önerilerinde bulunulmuştur, bu gecikmeleri azaltmak ve/veya ortadan tamamen kaldırmak için tavsiyelerde bulunulmuştur. Bu çalışma literatürdeki boşluğu doldurmak amacı ile yapılmıştır.

1. INTRODUCTION

Maritime transport has been the key to world trade for centuries. Throughout history, sea vessels have helped people go from one place to another and carry cargo. Maritime transportation has an important place in the world economy. Although it is not as fast as aviation, it is more economical and more profitable than aviation in terms of the tonnage it can carry. In addition, it can be faster than land transportation in certain areas and has the capacity to carry higher tonnage loads. Speed and reliability have a very important place in the maritime sector, as in the transportation sector. In order to meet the increasing demands in maritime transportation, it is aimed to use ships efficiently by staying in the port for less time and to obtain maximum profit by reducing transportation costs. Today, different branches of maritime transportation have been adopted in order to meet the increasing demand as soon as possible and to deliver cargo quickly and reliably. Especially businesses operating in the container and Ro-Ro sector, where speed is at the forefront, aim to deliver production volume quickly and safely. Container and Ro-Ro ships, which are structurally faster, are among the most preferred ship types with the variety and flexibility of the load they can carry. When container ships and Ro-Ro ships are compared, it can be seen that Ro-Ro ships can be more advantageous, especially in shorter distance voyages. Ro-Ro ships can reach higher speeds than container ships and are operationally faster due to the wheeled structure of the cargo. Through to the fact that the cargo carried on Ro-Ro ships is wheeled, the cargo can be loaded from the production facility and loaded directly onto the ship. In the next stage, multi-modal transportation can be provided by using the road and railway connections to which the port is connected.

Ro-Ro transportation stands out among the transportation types where speed and safety are at the forefront. Looking at the world in maritime transportation, it is seen that the interest in Ro-Ro transportation is increasing. Ro-Ro ships are a type of ship built to transport wheeled vehicles and its first use in the world was in 1851. The first Ro-Ro services in Turkey were started by DB Deniz Transport TAS in 1977, with 2 Ro-Ro ships on the Mersin-Izmir-Trieste line (Ozcan, 2012). Ro-Ro ship ports operating in the Eastern Mediterranean host 5 different core network corridors. Three of these are associated with ports on the Adriatic sea; Scandinavian-Mediterranean, Baltic-Adriatic, Mediterranean corridors. The Adriatic covers a dense Ro-Ro service network connecting the eastern coast of Italy with Croatia and neighboring Montenegro and Albania. These lines provide a means of land-based transfer of cargo from Western Europe to Greece and the Eastern-Eastern Mediterranean corridor (Izmir Development Agency, 2021). Ro-Ro Transportation in Turkey The Share of Maritime Trade in World Trade is 60 Percent with 11 Trillion Dollars. The most preferred type of transportation in the world in commercial transportation is maritime (Kocamis, 2014). It is currently actively operating from the ports of Istanbul, Yalova, Izmir and Mersin for the European region; Ro-Ro services are organized to Trieste, Bari, Patras and Sete.

Ro-Ro ship is a type of ship built for the transportation of cargo such as automobiles, trucks, trailers, and construction equipment that can move under its own power or can be towed by another vehicle. Cargoes such as non-wheeled containers can be transported on Ro-Ro ships by turning them into wheels with equipment such as roll-trailer. Ro-Ro ships can be built in different types according to different cargo types and different transportation areas. However, it is impossible to separate Ro-Ro types with clear boundaries. Because Ro-Ro ships are among the ships with the most load flexibility and the easiest revision features (Yesilbag, 1999).

In order for Ro-Ro ships to carry out their operations, the port must meet certain requirements. Although these requirements are less than those in a normal cargo port, they must be in a structure that can meet the flexibility of the incoming cargo. In addition to a pier where the port can dock, there must also be a ramp location that will allow the ship ramp to be opened and cargo operations to be carried out. In some ports, there is only an area where the ship can put its ramp, without a pier where it can dock. Although these types of structures are not very suitable for ships planned to stay in the port for a long time, they are generally specific to ports with short-term port operations. In addition, the port needs loading and unloading vehicles such as terminal tractors, container stackers and forklifts for loading and unloading operations. This is due to the fact that Ro-Ro ships are loaded not only with self-propelled wheeled vehicles but also with individual cargo such as trailers and containers. Equipment such as rotary locks and lashing bars are needed for container stacking and to secure the vehicles loaded on the ship. It also needs trailers to carry non-wheeled loads such as containers and yachts. Thus, loads without wheels are turned into wheels for loading and/or unloading. In addition, there should be designated parking areas for vehicles to wait before being loaded onto the ship or after being unloaded from the ship. The most common problem on Ro-Ro ships, which generally make fast and short voyages, is illegal immigrants. The port needs adequate infrastructure to detect these illegal immigrants more than ports where other types of ships dock.

1.1. Origin of the Study

In Ro-Ro transportation, reliability in timely delivery of the cargo is very important. Given the nature of Ro-Ro operations where vehicles and cargo can be driven on and off the vessel directly, efficiency in loading and discharging is paramount to ensure the smooth flow of operations and meet delivery schedules. Transportation of vehicles by Ro-Ro ships brings with it many advantages. The conveyance of road vehicles through Ro-Ro transportation yields a reduction in vehicular wear rates, concomitant with diminished maintenance and repair expenditures. Notably, the proclivity for delays inherent in traversing diverse border gates along highways is obviated Delays that may occur during passage through many different border gates on the highway are also prevented. The use of Ro-Ro transportation provides a cost advantage in transportation processes by reducing the amount of diesel consumed. Since the loading and unloading processes proceed quickly and without errors, it ensures regular delivery and facilitates planning. One of the biggest advantages of Ro-Ro transportation is that combined transportation can be used effectively. Ro-Ro transportation, which makes it possible to transport wheeled vehicles via sea, can connect road transportation and railway transportation with sea transportation.

In Ro-Ro transportation, where speed is at the forefront, arrivals and departures that do not occur at the planned time may also cause delays in other transportation modes. The occurrence of delays, if not mitigated promptly, holds the potential to precipitate a cascade of subsequent delays, thereby resulting in a chain of errors. This chain of errors detrimentally affects the confidence reposed by customers and diminishes the desirability of companies in the market. Consequently, it becomes imperative for enterprises to proactively undertake measures to forestall prospective delays. Instances of disruptions, whether encountered during the maritime voyage or arising from port operations, or the failure to execute operations within the scheduled timeframe, have the propensity to impart enduring economic challenges for businesses. Ensuring timely delivery necessitates rigorous examination of delay occurrences, followed by comprehensive analysis and the subsequent implementation of preventative strategies.

This study focuses on the failures that may occur during the operations carried out in order to increase the operational efficiency of a ro-ro port. In today's highly competitive environment, the operational efficiency of ports is of utmost importance. Several studies establish that port efficiency is not only crucial for individual port competitiveness but also exerts a significant influence on regional and national economic well-being In the face of intensifying competition in the port industry, exploring the impact of such competition on operational efficiency becomes increasingly important.

This research analyzes historical data of failures occurrences in a Ro-Ro port's loading and unloading activities. Through rigorous statistical analysis of the historical data, we derived the probability distributions specific to each failure mode. Building upon the failure probability distributions, a reliability-based analysis of the port's operational performance was carried out. This analysis focused on identifying and prioritizing potential disruptions in the loading and discharging process. Based on the findings in the study, we recommend proactive and preventive strategies to enhance the operational efficiency in Ro-Ro ports.

1.2. Objectives of the Study

In the age of globalization, ports have become indispensable arteries for international trade, playing a critical role in national and regional economic prosperity by facilitating efficient supply chains and fostering economic growth. Logistics services help import and export businesses located close to ports in terms of ease and efficiency. Seaports are viewed as drivers in the global trading system, acting as a catalyst for the growth of the maritime industry and a significant contribution to a nation’s worldwide competitiveness. Port operations are no longer limited to the handling of cargo. They have become a vital component of enterprises and economic markets internationally. Additionally, faced with the challenges of a rapidly evolving trade environment, increasing seaport operational efficiency through targeted interventions is critical for unlocking their role as engines of economic prosperity and catalysts for regional development. Within this direction, the primary objective of this paper is to conduct a thorough investigation into operational failures within Ro-Ro ports, with the overarching goal of presenting proactive and strategic solutions aimed at enhancing the operational efficiency of these ports. Through a comprehensive analysis of the identified operational failures, the study seeks to contribute valuable insights and recommendations to augment the operational efficiency of Ro-Ro ports. The paper endeavors to advance our understanding of the complex dynamics surrounding operational challenges in Ro-Ro ports and aims to provide actionable strategies for port authorities and stakeholders to fortify their operational resilience and efficiency.

1.3. Methodology

Data collection method was used to support the study. Delays to scheduled departure and/or arrival at the time of data collection; The SOF reports reported by the ships and the field reports prepared by the port were compared, evaluated, and analyzed. Delay situations were expressed with delay codes and reliability analysis was performed as a statistical method. The most common delay codes were evaluated and interpreted through reliability analysis. In order to prevent the causes of delay, suggestions have been made.

1.4. Report Organization

The first part of this study explains the place and importance of Ro-Ro ships in maritime transportation. Particular attention has been drawn to this form of transportation, where speed is at the forefront. In the second section, different studies that may be related to the study were evaluated. In these studies, the existence of analyses of operational delays was investigated. In the third section, the methods used to analyze the study are explained. In the last part, field work was carried out and the delays that reduce the performance of Ro-Ro ships were analyzed using the methods explained in the previous sections, and the measures that should be taken to prevent these delays were mentioned.

1.5. Limitations

The study was limited to a single Ro-Ro port in order to better investigate the delays in the research, to be more suitable for observation and data collection, and to carry out an objective process to find the right solutions to the delays. Only situations that cause delays are taken into consideration, and different problems that do not cause delays but occur are not addressed.

2. LITERATURE REVIEW

2.1. Literature Review

The studies on reliability analyses in the literature have increased over the years. As can be seen from here, the importance of reliability analyses is better understood with each passing day. Studies for reliability analysis have been largely carried out in the field of engineering. However, when the search is narrowed down to the maritime field, it can be seen that the number of studies conducted is limited. Considering the last 23 years of history, only 0.25 percent of the studies on reliability have been conducted on maritime. When the work done is classified only on a port basis, the number of work done decreases even more. Only 12.9 percent of maritime reliability analysis studies were conducted on ports (Figure 2.1.).

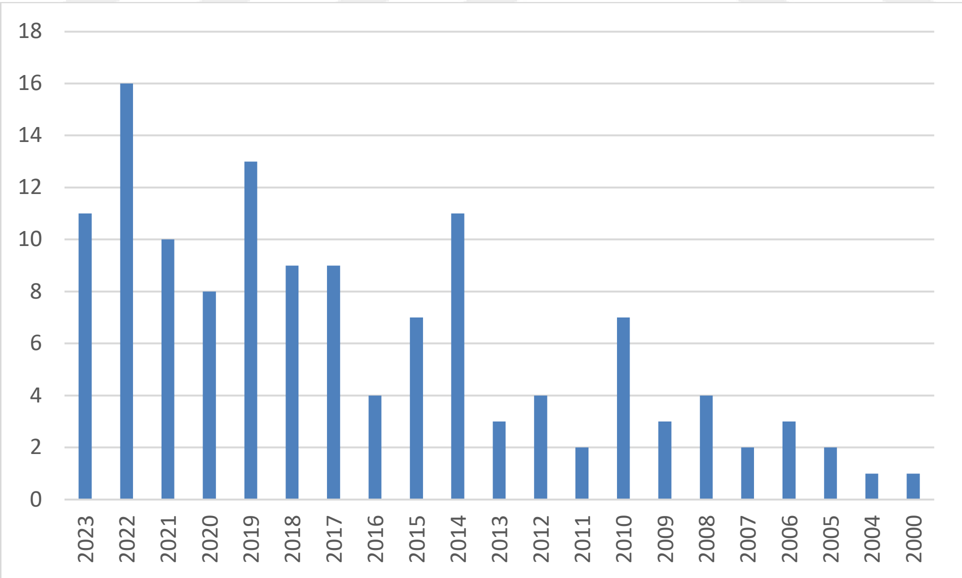

Figure 2.1.: Reliability analysis studies conducted in ports over the years.

Some of the reliability analyses carried out in ports were made based on risk assessment. Meriam Chaal, Eugen Roșca et al. and Alyami, H., et al. work on risk assessment stands out.

In Meriam Chaal (2023)’s study titled advancing safety in autonomous shipping through modern hazard analysis methods; it has explored the historical development of risk, safety and reliability issues in autonomous shipping through a bibliometric review and analyzed future research directions and potential risk assessment methods for autonomous ships. Reliability analysis based on risk factors in ports was made in the study of Alyami, H., et al. (2019). Considering that port performance can be increased by reducing risk factors, within the scope of this evaluation, the type of failure was taken into account and the impact was analyzed. Reliability analysis was performed to create a dynamic model that can cope with constantly changing operational conditions in ports. Eugen Rosca, et al. (2014) have researched the main risks in port logistics and measures to minimize their impact. Conducted a case study using computer simulation modeling by creating a risk management tree; investigates the behavior of the port logistics system under different risk scenarios and evaluates the reliability of the system. Calculated operational capacity and system performance measurements for different port subsystems.

Losada, M.A., and Benedicto, M.I., A.P. Teixeira, C. Guedes Soares, Samet Biçen, Lot Okanminiwei and Sunday Ayoola Oke’s works comes to the fore in studies on the operational reliability of a structure.

Losada, M.A., and Benedicto, M.I. (2005)'s study is limited to the maritime sector and confirms the requirements and target levels for reliability and functionality values throughout the life of a structure. Using reliability analysis, values and recommendations are given regarding the minimum service life of a structure, probability of failure according to main failure modes, minimum operationality, acceptable number of technical failures. A.P. Teixeira, C. Guedes Soares (2009)’s study, the reliability formulation and reliability analysis of a tanker hull girder exposed to combined sea states were carried out. The reliability calculations were carried out using the computer program COMREL, using a time independent first-order reliability formulation corresponding to one-year operation with the limit state function given by equation. In Samet Biçen (2019)’s study titled proposing a reliability availability maintainability analysis in shipboard machinery systems, reliability analyzes were made using the Minitab program for different distributions, and unlike this study, the reliability of ship machinery systems was analyzed. Additionally, no suggestions were made to increase reliability in the study. In the study, Lot Okanminiwei and Sunday Ayoola Oke (2021) developed statistically oriented predictions for the lifespan of gantry cranes of the container terminals company. Failure time, probability density function, cumulative density function, reliability and hazard rate were analyzed with Weibull distribution. Rayleigh and normal distribution functions were also used.

Asadabadi, A. and Miller-Hooks, E. and Dack, D., et al.'s works comes to the fore in studies on port operational reliability.

Asadabadi, A. and Miller-Hooks, E. (2020) touched upon the importance of port operational reliability and flexibility for the maritime industry in this article. For this purpose, game theoretical optimization models are presented. In the study of Dack, D., et al. (2017), mentioned the suitability of reliability assessment to look at the impact of changes in environmental conditions in the field. Reliability assessment methods, taking into account site-specific data and information on load and resistance parameters; It has been argued that it can be an effective way to accurately measure the risk of failure occurring and better inform the decision-making process. To this end, the article provides an overview of reliability assessment, a discussion of typical methodologies used to perform such an assessment, and examples comparing code-based and reliability assessment approaches.

Herrera Rodriguez, et al., Kilpi, Jorma and Kokkoniemi-Tarkkanen, Heli have carried out studies on increasing operational reliability and efficiency.

In the model he created, Herrera Rodriguez, et al. (2022) defines the Pareto optimal limit of cost, transportation time and CO_2 emissions in terms of generalized costs for the importer and the impact of potential delays. Considering the relationship between economical speeds and voyage and line cost reductions, it shows that the consequences of emission restrictions affect shippers in the form of longer delivery times. It shows that resolving the dispute between carriers and shippers will involve addressing difficult issues in the market, regulatory and technological development. Kilpi, Jorma and Kokkoniemi-Tarkkanen, Heli (2021) mentioned that it is possible to increase the automation of ports by using wireless communication services such as 5G URLLC. It has also worked to ensure efficient and safe maritime logistics by focusing on the automatic handling of containers in ports. It is mentioned that with the proposed method, highly reliable wireless control signals can be used for air and sea systems or other vertical systems.

Pennetti, Cody and Ünal Özdemir's work can be given as an example of reliability studies on carried cargo and freight costs.

In Pennetti, Cody (2023)'s study, a spatiotemporal mechanistic counting model was developed to evaluate the variability of round trips based on departure time, seasonality, and freight processing times. Based on the success criteria of completed round trips, the results were evaluated to investigate how operating conditions for an origin site and destination were affected by the natural variability of cargo handling. In this study, Ünal Özdemir (2021) aimed to determine freight demand forecasts based on the monthly number of containers based on twenty foot equivalent units handled in Turkish ports by comparing the forecast accuracy and reliability of artificial neural network models with various algorithms. Demand forecasts for the volume of containers to be handled in Turkish ports are made and a methodological approach for forecast models in different maritime industry areas is presented.

Siqi Wang, et al., Gillen, David and Hasheminia, Hamed and Konstantinos Kepaptsoglou, et al.'s works stands out in studies on the analysis of reliability that decreases due to unexpected situations or weather conditions.

Siqi Wang, et al. (2023)'s study proposes a new general port security framework to deal with recurring hazards and crisis events such as COVID-19 and improve the security of the Port Infrastructure System through a multi-state fault system. It offers feasible solutions for designing effective risk control measures to increase the durability and reliability of the General Port Infrastructure System. Gillen, David and Hasheminia, Hamed (2016) created an analytical framework based on discrete likelihood maximization techniques that provide predictions of queuing models and operational level data of transportation networks based on snapshots of data on the movements of goods in a network. By examining the intercontinental transportation network, the sources of variability in the network were identified and the reliability of the network against shocks was measured. In the article, Konstantinos Kepaptsoglou, et al. (2015) discusses the effects of weather conditions on container ship routing. A stochastic model was developed to determine the optimal routes for a homogeneous fleet performing the pickup and delivery of containers between a hub and several ports, taking into account travel time uncertainties due to weather conditions.

The study of Zeinab Elmi, et al., who has studied time management in transportation, is the closest study to the relevant thesis in the literature.

Zeinab Elmi, et al. (2023) touched upon the importance of time management in liner transportation services and the necessity of making necessary plans by making analyzes to eliminate the negative effects of disruptions. A full optimization algorithm based on the epsilon constraint was used to obtain the optimal Pareto Fronts.

2.2. Literature Gap

As can be seen from the literature review, different examinations and analyses have been carried out in terms of port operational reliability (Figure 2.2.). Although there is no study on the analysis of port operational delays and improvement suggestions in this study, it was conducted to fill the gap in the literature.

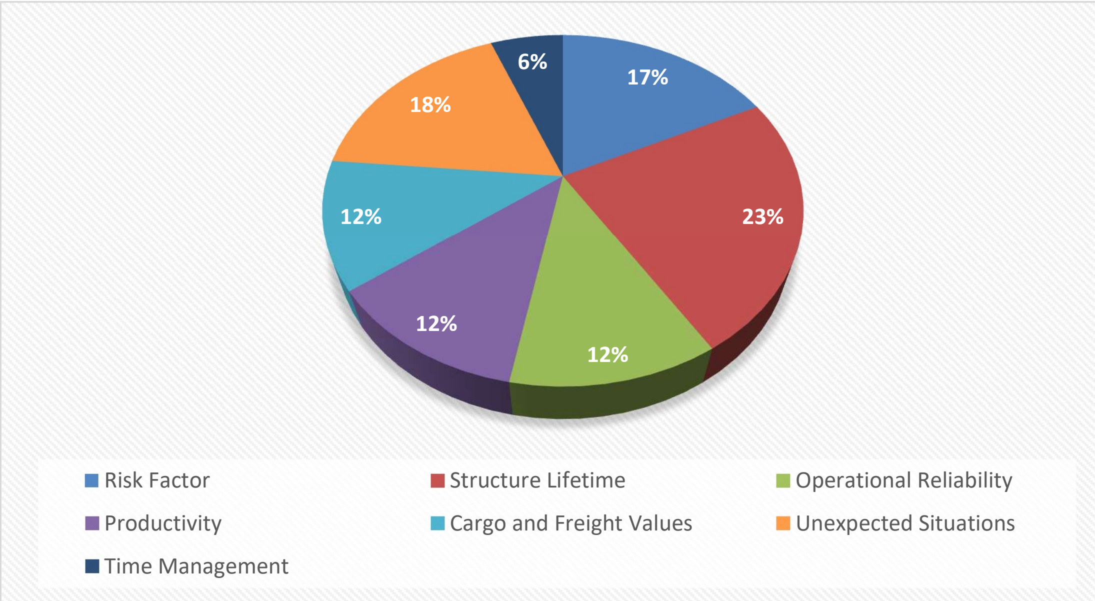

Figure 2.2. : Literature review categorization.

3. METHODOLOGY BACKGROUND

3.1. Failure Distributions

Failure rate is the frequency with which problems occur during operation. Delays, called malfunctions, may tend to increase as time goes by. Because any improvement not made in the delays may cause the delays to increase by affecting each other. Malfunctions can be handled on a time basis or on a day basis. Analysis of how often failures occur is directly related to the average time between failures. Mean time between failures is the average time between failures in a repairable product in a given unit of time (Elevli, 2020). The expression MTBF is used for systems that can be repaired. The average time between failures can be reached by dividing the total operating time by the total number of failures.

$$MTBF = \int t.\,f(t).\,dt = \int [1 - F(t)].\,dt = \int R(t).\,dt \qquad (3.1.)$$

3.2. Distributions in Reliability Analysis

Reliability analysis measures the consistency of the system. What is meant by consistency here is the consistency in which situations that occur at certain times occur again at the expected time. Reliability is the stability between independent measurements of a system. Reliability is a concept associated with obtaining related results each time when a feature is measured with the same instrument several times (Terzi, 2017).

3.2.1. Exponential distributions

The exponential distribution is a continuous probability distribution that specifies the time until a particular event or problem occurs. It refers to a process in which events occur continuously and independently. The reliability function calculation in the exponential distribution is made with the formula shown in 3.2.

$$R(t)= e^{-\lambda t} = e^{-t/\theta} \quad (3.2.)$$

3.2.2. Loglogistic distributions

The loglogistic distribution represents a probability distribution whose logarithm has the logistic distribution. This distribution is used in the lifetime analysis of systems to analyze events that initially experience an increase in speed and then a decrease in speed. A loglogistic distribution is a continuous distribution defined by η is the scale parameter and γ is the location parameter.

3.2.3. Lognormal distributions

A log-normal distribution is a continuous distribution of a random variable whose natural logarithm is normally distributed (Kissell, et al. 2017). The log-normal distribution has been used quite extensively in analysing lifetime data (Kundu, et al. 2017). The reliability function calculation in the lognormal distribution is made with the formula shown in 3.3.

$$R(t)=1- \Phi\ [(In(t)- \mu')/ \sigma'] \quad (3.3.)$$

3.2.4. Normal distributions

Normal distribution draws a symmetrical structure. In a normal distribution, the mean is considered to be zero and the standard deviation is 1. Many naturally occurring events tend to approach a normal distribution. The reliability function calculation in the normal distribution is made with the formula shown in 3.4.

$$R(t)=1- \Phi\ [(t- \mu)/ \sigma] \quad (3.4.)$$

3.2.5. Weibull distributions

Weibull distribution was first proposed by W. Weibull for modelling material properties (Weibull, 1938). Weibull distribution has the feature of providing a flexible reliability model as it can be used in all situations where the degradation rate is increasing, decreasing or constant (Lewis, 1996). There are two different weibull parameters. In the two-parameter Weibull distribution, β is the shape parameter and η is the scale parameter. If γ is the location parameter is present together with these two parameters, it is called a three-parameter distribution. The reliability function calculation in the Weibull distribution is made with the formula shown in 3.5.

$$R(t)=e^{-(t/\ \eta)\beta} \quad (3.5.)$$

4. FIELD STUDY

4.1. Scope

The scope of the paper encompasses the identification of failure modes responsible for delays or disruptions in the operational processes of the Ro-Ro ports. A central component of the study involves the statistical analysis of historical data pertaining to these failure modes. Subsequently, a comprehensive reliability analysis is conducted for each identified operational failures. By systematically scrutinizing the historical trends and patterns associated with these failure, the paper aims to provide a robust analytical foundation for understanding the reliability dynamics within Ro-Ro port operations. The outcomes of this analysis are anticipated to furnish valuable insights, enabling stakeholders to implement targeted strategies for mitigating the impact of operational failures and thereby fostering a more efficient operational environment in Ro-Ro ports.

In order to perform the reliability analysis of the port operation, the reliability of each of the elements affecting the reliability structure of the system should be analysed. In order to obtain element reliability values, scatter plot parameters of delay codes are needed.

In this study, reliability analysis was conducted based on delay data obtained from the DFDS Pendik Ro-Ro Port, which is currently in service. The total surface area of the coastal facility is 109,950 square meters and it has 2 piers. The length of these piers is 209 meters. There are 3 container reach stackers, 22 terminal tractors and 5 forklifts for handling operations in the port. Scheduled ship voyages are organized every day of the week, and 17 ships operated by the DFDS Company within the Mediterranean Business Unit are approaching the port in line with the planned voyages. Vehicle capacity of ships; 3 ships have 3.214 lane meters, 1 ship has 3.465 lane meters, 1 ship has 3.663 lane meters, 4 ships have 3.735 lane meters, 1 ship has 4.094 lane meters, 1 ship has 4.100 lane meters, 4 ships have 4.605 lane meters, 2 ships have 4.605 lane meters. It is 6.690 lane meters. An average of 81,342 vehicles and 23,676 containers are exported annually at the port, and 80,862 vehicles and 21,965 containers are imported. There are 365 voyages to the port on an annual basis. In addition, there are 100 permanent operations personnel, 50 permanent agency personnel, 65 permanent customs officers and 85 subcontracted security personnel at the port.

Delay code data was obtained during port and ship operations between 2020-2021 and It is anticipated that 199 different delay codes will be encountered. In the reliability analysis, the most common 18 delay codes were analysed.

4.2. Terminal Operations

In order to evaluate the problems caused by delays during port operations on port operations, the best method is to first understand the functioning of port operations. The port where the control was made was selected as DFDS Pendik Ro-Ro Terminal and the delay codes were also created based on this port.

The operation process, which seems to start from the port entrance gate, which is connected to the port by road, depends on a process that starts before the cargo reaches the port gate.

Before bringing their cargo to the port gate, customers are responsible for making reservations for their cargo through the relevant systems and bringing their cargo to the port gate on time. At this stage, we also encounter a delay code that is being evaluated. Waiting for registered loads also causes operational problems due to customers not bringing their vehicles on time. Looking at the time of observation, this delay code is encountered 15 times (Table 4.1).

After the cargo reaches the port gate, the next stage is started. The existence of the reservation of the cargo at the port gate is checked and it is checked whether the information of the driver who brought the cargo is matched in the system. During door entry, the surroundings and interior of the vehicle and/or cargo are checked with both physical and thermal cameras. This control is important in detecting stowaway passengers who are likely to come with the cargo, detecting materials that are dangerous to bring into the port area, and detecting undeclared cargo. In addition, these camera records are used to determine the damage to the vehicle and/or cargo. There is a scale at the port entrance gate, so the weight of the vehicle can be determined when entering the port. The check-in process is completed after the door staff notifies the driver of the location determined by the system.

The vehicle is checked at Gamma-ray just before going to the location specified by the system. After the vehicle reaches the determined location, field personnel routinely check the CO2 level in the vehicle. An unexpectedly high CO2 level creates suspicion that there is an illegal passenger inside the vehicle. In line with this suspicion, the interior of the vehicle is opened and checked in accordance with the customs smuggling request. Although these controls occasionally caused delays, they did not cause any significant delays during the examined period.

Companies have business followers in offices inside the port. These business followers are responsible for reporting registered cargo entering the port to customs. Customs personnel check the details of the loads in coordination with their own systems; any discrepancy, such as weight, may cause the vehicles to be opened and the loads to be counted. After this stage, the list of cargoes whose transactions have been completed and approved by the agency personnel are taken from the customs guard and transferred to the relevant ship. Since the ship on which the cargo is registered is not at full capacity, the agency may wait a while for new cargo to arrive. This reveals a delay code that is evaluated as the waiting period increases. The delay code, which occurred due to the agency not closing the number of loads and waiting for new cargoes, was detected 24 times (Table 4.1.) during the examined period.

The loading list created by the agency is shared with the yard supervisors and the work is distributed to the operators. The agency is also obliged to arrange the bill of lading of the cargo and the flight tickets of the drivers who will not be transported by ship. Drivers who will travel by ship also issue their ship tickets and share them with the port authority and maritime police. Cargoes whose customs procedures have been completed and approved begin to be loaded onto the ship.

Different delay codes occur during ship operations. These delays that disrupt the operation are of sufficient importance to be considered and calculated. Planned or unplanned repairs made on the ship, especially during loading and unloading operations, may disrupt the operation. Insufficient time allocated to maintenance and incorrect planning cause delays in operations and constitute the delay code on which studies have been carried out. For this reason, delays occurred 88 times (Table 4.1.) during the observation period. Another delay in maintenance and repair is due to non-periodic maintenance that is expected to last a long time. Failure to arrange a different ship for long-term maintenance and the same ship departing for the voyage may cause delays in operations. Another delay code that is related to ship management and disrupts operations is the late completion of the fuel operation by the bunker barge not arriving on time and/or being called late. In such a delay, although the ship's loading operation is completed, the ship has to wait for the bunker operation to be completed. This delay code occurred 15 times (Table 4.1.) during the observed period. This delay code occurred 28 times (Table 4.1.) during the observation period.

After completion of ship operation, a list is taken from the customs directorate and the number of vehicles loaded on the ship is checked and an agreement is reached. However, at this stage, in order to reach an agreement, customs enforcement must check and approve the cargo manifest. This control sometimes takes a long time and causes operational delays. This delay code, which occurred due to the prolonged manifest control of customs enforcement, was encountered 46 times (Table 4.1.) during the observation period.

The ship and the pilot are informed 1 hour before the ship loading is completed. After the loading is completed, the cargo decks are searched with a searching dog for stowaway. During the pilot phase, the ship may take off later than the specified departure time due to the pilot being on another manoeuvre or arriving late for other reasons. This delay code occurred 33 times (Table 4.1.) during the observation period.

Even though all the operations of the ship are completed quickly, the ship may depart later than the planned time because it arrives later than the planned time. This delay code is designated as late departure due to late arrival and appeared 215 times (Table 4.1.) during the observation period.

After the ship departs, the unloading and loading operation continues on the feeder ship. This ship operates between Ambarlı and Pendik and has a lower cargo capacity than other ships. Any delay in the operation of the ship embarking on a long voyage directly causes the delay of the feeder ship. This delay occurs 17 times (Table 4.1.) during the observation period.

Although the import section has similar features to export, it creates different delay codes within itself. Delays in the ship's departure from the opposite port directly cause its late arrival to Pendik port. This delay code is encountered 349 times (Table 4.1.) during the observation period. After the ship departs from the opposite port, the opposite port’s agency sends the total number to the Pendik agency. Pendik agency notifies the freight owners of the freight charges.

Some problems encountered by the ship during voyage may cause delays. Machinery malfunctions that occurred during the ship's voyage caused delays and occurred 32 times (Table 4.1.) during the observation period. Additionally, there may be delays in the ship's arrival due to weather conditions during the voyage. This delay code is encountered 94 times (Table 4.1.) during the observation period. Delays that may occur during the Dardanelles Strait passage may affect the arrival time at the port. The delay at the entrance of the Dardanelles Strait occurs 158 times (Table 4.1.) throughout the observation period. During ship arrival operations, multiple different delay codes are encountered. One of these can be called the pilot's boarding. This delay code was encountered 49 times (Table 4.1.) during the observation period due to the pilot being delayed for no particular reason. In addition, there were 35 delays (Table 4.1.) due to the pilotage service not being provided due to weather conditions. During the observation period, pre-arrival checks of the ships were also carried out due to the pandemic. For this reason, there are delays in the arrival of the ship, and delays were experienced 39 times (Table 4.1.) during the observation period. There are 2 piers in the port where observation is made. When these piers are not available, it causes delays in the arrival of ships. There were 12 delays (Table 4.1.) during the observation period for this reason.

After the ship arrives at the port, passport control of the ship crew and passengers is carried out before the discharge begins. After the inspection, the discharge begins with the approval of the police. Terminal tractors start to unload cargoes from the ship in line with the work orders assigned to them by the field supervisors. Before taking the cargo to the location determined by the system, the driver brings it to the import scale and performs the weighing process.

Since the port area where observation is carried out is not large enough, placing the vehicles in locations during evacuation becomes a problem. Import vehicles whose operations are completed within the port area must leave the port area as soon as possible, so that space can be made for new incoming cargo. However, if this does not happen, unloading and loading operations may be disrupted. There were 70 delays (Table 4.1.) during the observation period.

The business followers of the companies notify the customs of their cargo discharged from the ship and declare the necessary documents for them to exit. The drivers directed by the companies to receive their cargo enter the port with an ID check and declare which cargo they will pick up. After the declaration, agency officials calculate the storage fee of the cargoes and collect the port service fees. Authorized driver takes the cargo out of the port. Port exit procedures take less time than port entry procedures.

Table 4.1. : Total number of delays.

Delay Code	Number of Delay	Total Running Day
15H	24	732
15J	15	732
21C	46	732
32S	17	732
34A	49	732
34B	33	732
36T	15	732
37A	39	732
41M	32	732
42D	88	732
43A	28	732
77B	35	732
87A	12	732
87E	70	732
93A	349	732
93C	94	732
93F	158	732
93H	215	732

4.3. Data Collection

Port and ship operations were closely examined for 732 days and delays during arrival and departure during the ship's planned voyage were analysed. Delay codes that did not cause a delay in the planned voyage but occurred were not taken into account. Although it was expected to encounter 199 different delay codes, 78 different delay codes were encountered during the observation period (Appendix A). In addition, although it consists of 78 different delay codes, delay codes with low frequency of occurrence were ignored in the reliability analysis. Delay codes that occurred less than 10 times during the observation period were ignored, and the 18 most frequently encountered delay codes were included in the analysis (Table 4.1.).

4.4. Data Analysis

High frequency data collected between 2020-2021 were evaluated. The occurrence of delay codes was calculated on a daily basis. The frequency of occurrence of delay codes was analyzed using 'Minitab 21' statistical software and evaluated in terms of correlation coefficients. Weibull, lognormal, exponential, loglogistic and normal distribution methods were evaluated according to the correlation coefficient. The distribution correlation coefficients are as shown in the table (Table 4.2. to 4.19.). Correlation coefficients for Weibull, lognormal, exponential and loglogistic distributions were taken from the Minitab program as shown in Appendix B. The correlation coefficient for normal distribution was obtained from Appendix C. According to Appendix B and Appendix C, it was chosen to use the Weibull distribution to analyze the distributions of the occurrence of delays. Weibull method was chosen to analyze the reliability of delay codes, and the formulas in 3.5. were used for analysis calculation. Appendix D shows the probability plot of the Weibull distribution. Based on this graph, shape and scale values were reached. By entering these values into the formula specified formula in 3.5., visualization of the graphs of delay codes is provided as shown in Figure 4.1. to Figure 4.21.

In the last stage, improvement analyzes regarding delays were made and improvement parameters were created.

Table 4.2. : Delay Code 15H MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,942	423,195
Lognormal	0,92	435,214
Exponential	*	327,8
Loglogistic	0,91	442,105
Normal	0,953	425,417

Table 4.3. : Delay Code 15J MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,888	343,002
Lognormal	0,938	347,252
Exponential	*	252,381
Loglogistic	0,928	348,27
Normal	0,924	346,733

Table 4.4. : Delay Code 21C MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,973	454,09
Lognormal	0,955	459,605
Exponential	*	322,36
Loglogistic	0,946	461,801
Normal	0,974	455,652

Table 4.5. : Delay Code 32S MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,952	188,528
Lognormal	0,98	198,978
Exponential	*	180,353
Loglogistic	0,983	205,236
Normal	0,907	194,588

Table 4.6. : Delay Code 34A MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,94	424,359
Lognormal	0,859	469,616
Exponential	*	293,382
Loglogistic	0,861	562,271
Normal	0,95	375,429

Table 4.7. : Delay Code 34B MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,96	365,32
Lognormal	0,931	439,671
Exponential	*	312,129
Loglogistic	0,92	542,22
Normal	0,952	351,576

Table 4.8. : Delay Code 36T MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,97	422,352
Lognormal	0,921	447,915
Exponential	*	339,731
Loglogistic	0,919	479,62
Normal	0,967	402,933

Table 4.9. : Delay Code 37A MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,956	100,827
Lognormal	0,983	101,533
Exponential	*	67,565
Loglogistic	0,973	101,666
Normal	0,976	101,333

Table 4.10. : Delay Code 41M MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,986	435,952
Lognormal	0,966	442,993
Exponential	*	324,677
Loglogistic	0,964	447,218
Normal	0,979	435,906

Table 4.11. : Delay Code 42D MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,907	410,03
Lognormal	0,833	410,81
Exponential	*	282,085
Loglogistic	0,851	416,402
Normal	0,983	405,136

Table 4.12. : Delay Code 43A MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,983	435,374
Lognormal	0,957	439,59
Exponential	*	308,926
Loglogistic	0,955	442,173
Normal	0,982	435,429

Table 4.13. : Delay Code 77B MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,976	391,224
Lognormal	0,933	410,512
Exponential	*	306,624
Loglogistic	0,928	427,419
Normal	0,956	383,886

Table 4.14. : Delay Code 87A MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,922	410,55
Lognormal	0,923	444,84
Exponential	*	375,61
Loglogistic	0,912	469,72
Normal	0,909	418,83

Table 4.15. : Delay Code 87E MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,968	475,155
Lognormal	0,962	479,673
Exponential	*	327,897
Loglogistic	0,951	480,744
Normal	0,958	478,271

Table 4.16. : Delay Code 93A MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,971	436,376
Lognormal	0,898	442,389
Exponential	*	300,611
Loglogistic	0,9	449,26
Normal	0,981	426,567

Table 4.17. : Delay Code 93C MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,968	363,288
Lognormal	0,914	380,084
Exponential	*	278,764
Loglogistic	0,915	395,856
Normal	0,966	353,798

Table 4.18. : Delay Code 93F MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,96	422,264
Lognormal	0,896	447,662
Exponential	*	304,596
Loglogistic	0,89	470,593
Normal	0,956	406,259

Table 4.19. : Delay Code 93H MTBF and distribution correlation coefficient.

Distribution	Correlation Coefficient	Mean
Weibull	0,949	482,419
Lognormal	0,865	483,97
Exponential	*	319,359
Loglogistic	0,869	489,633
Normal	0,963	474,353

4.5. Visualization of Results

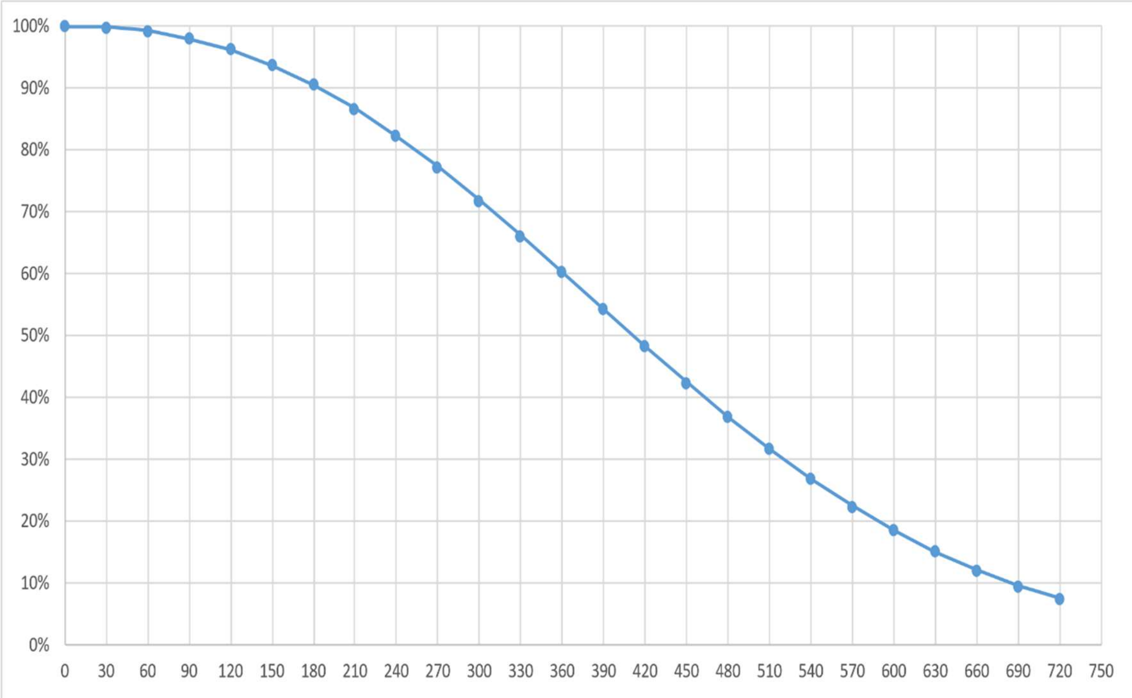

Figure Error! No text of specified style in document.**.1.:** Delay code 15H reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 423 days throughout the observed period.

As can be seen in the graph (Figure 4.1), reliability for the 15H delay code decreased as the operation time increased. While reliability was 100% on first 30 days, reliability decreased to 91% on the 180th day. After 360 days, reliability decreased to 60%. By the 540th day, the reliability of the system decreased to 27%.

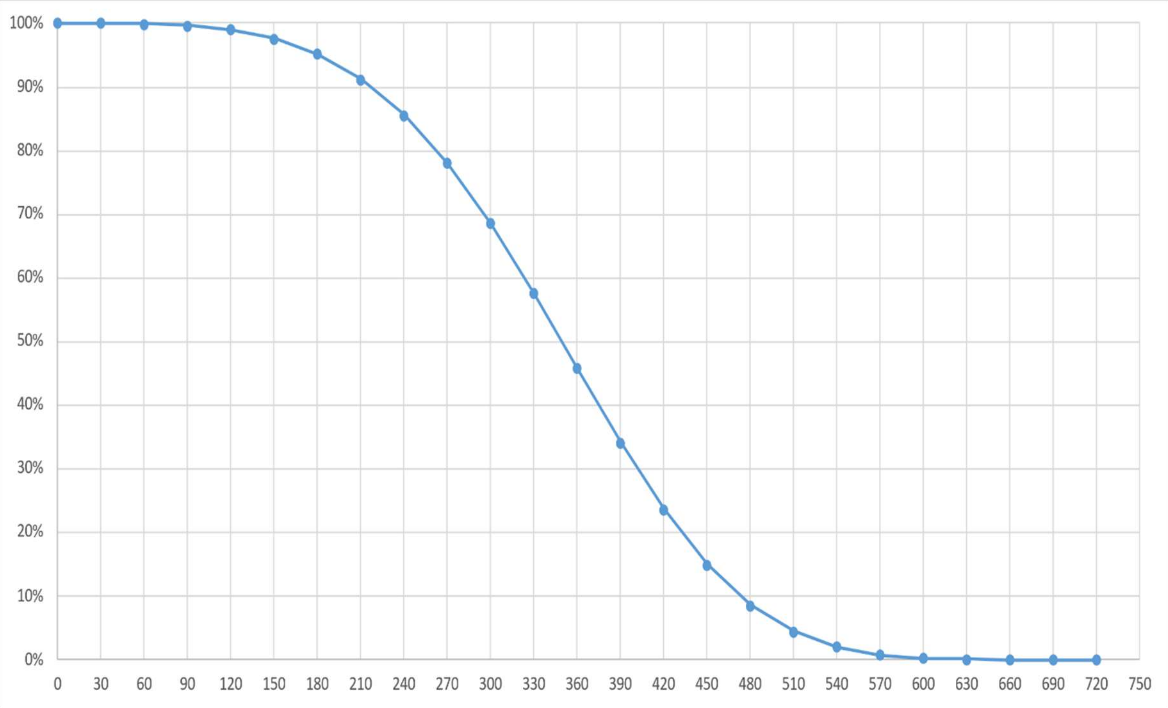

Figure 4.2.: Delay code 15J reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 343 days throughout the observed period.

As can be seen in the graph (Figure 4.2), reliability for the 15J delay code decreased as the operation time increased. While reliability was 100% on first 90 days, reliability decreased to 95% on the 180th day. After 360 days, reliability decreased to 46%. By the 540th day, the reliability of the system decreased to 2%. On the 600th day and after, the reliability dropped to 0%.

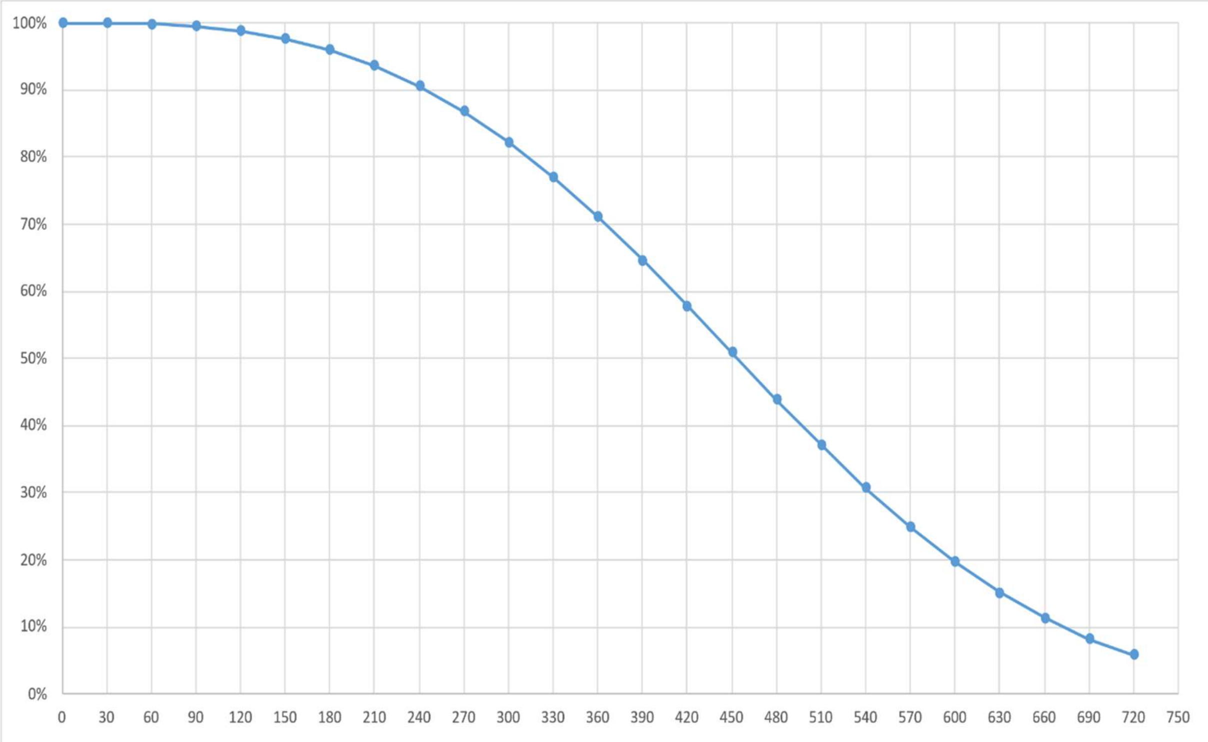

Figure 4.3.: Delay code 21C reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 454 days throughout the observed period.

As can be seen in the graph (Figure 4.3), reliability for the 21C delay code decreased as the operation time increased. While reliability was 100% on first 90 days, reliability decreased to 96% on the 180th day. After 360 days, reliability decreased to 71%. By the 540th day, the reliability of the system decreased to 31%.

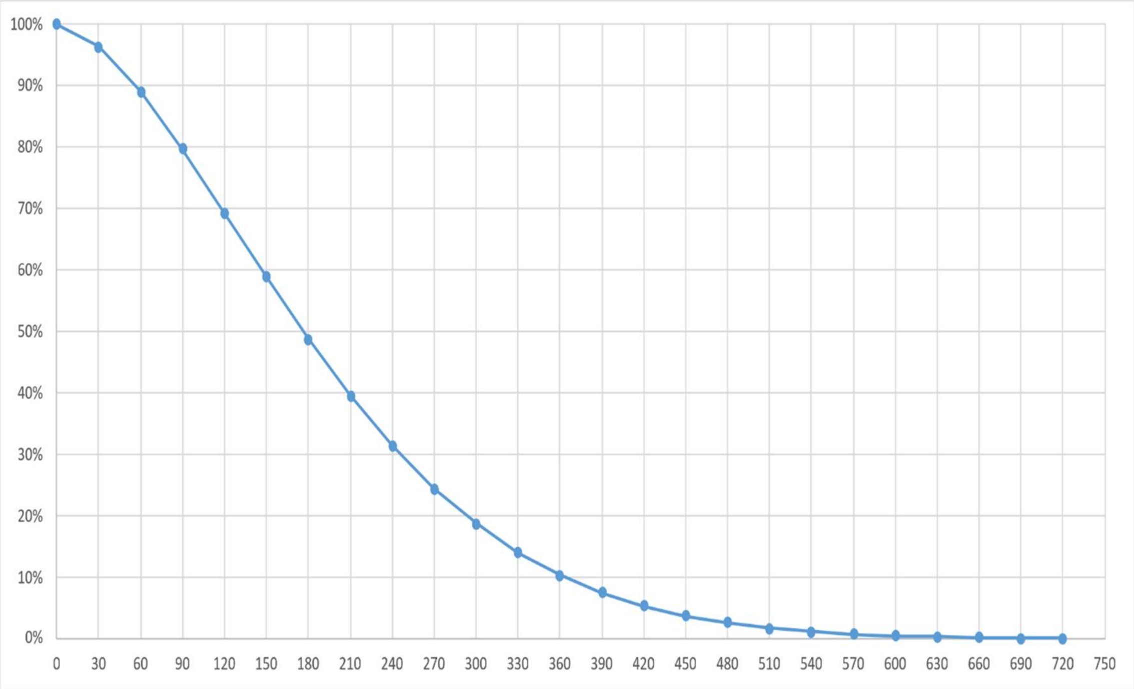

Figure 4.4.: Delay code 32S reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 189 days throughout the observed period.

As can be seen in the graph (Figure 4.4), reliability for the 32S delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 49% on the 180th day. After 360 days, reliability decreased to 10%. By the 540th day, the reliability of the system decreased to 1%. On the 600th day and after, the reliability dropped to 0%.

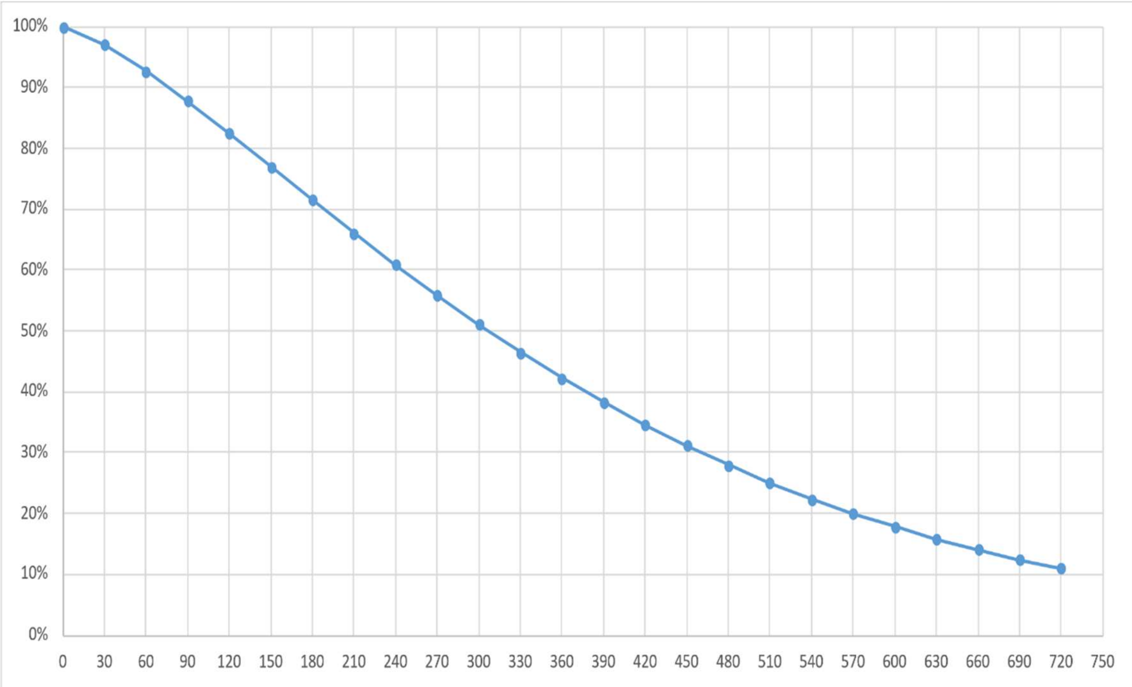

Figure 4.5.: Delay code 34A reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 424 days throughout the observed period.

As can be seen in the graph (Figure 4.5), reliability for the 34A delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 71% on the 180th day. After 360 days, reliability decreased to 42%. By the 540th day, the reliability of the system decreased to 22%.

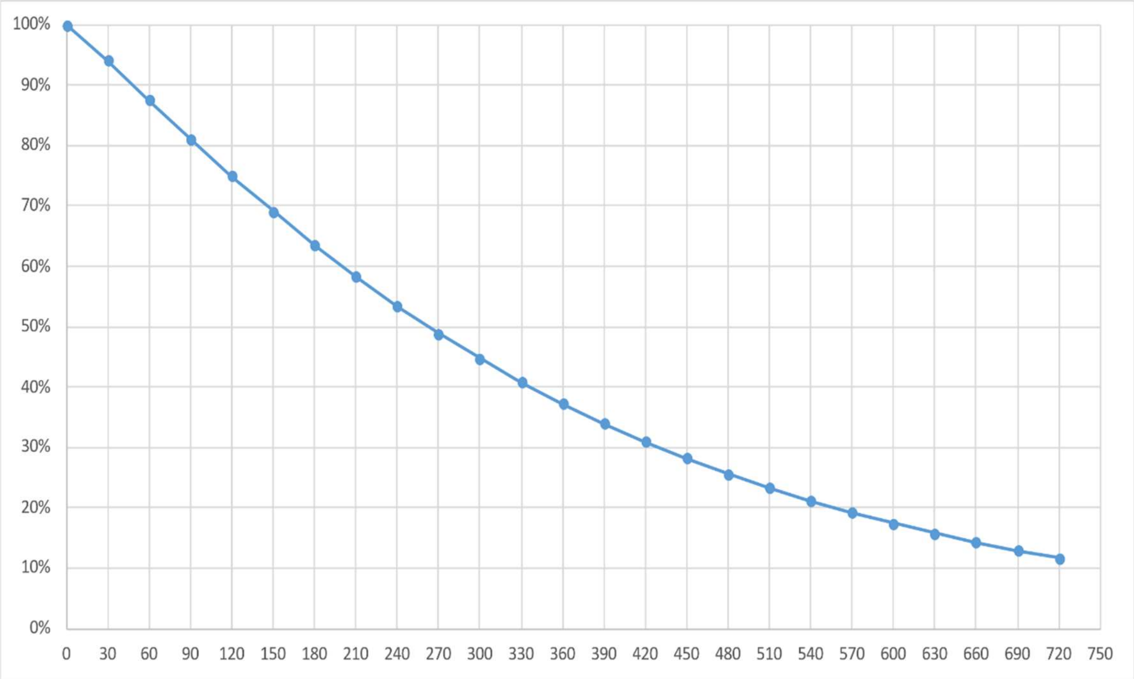

Figure 4.6.: Delay code 34B reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 365 days throughout the observed period.

As can be seen in the graph (Figure 4.6), reliability for the 34B delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 63% on the 180th day. After 360 days, reliability decreased to 37%. By the 540th day, the reliability of the system decreased to 21%.

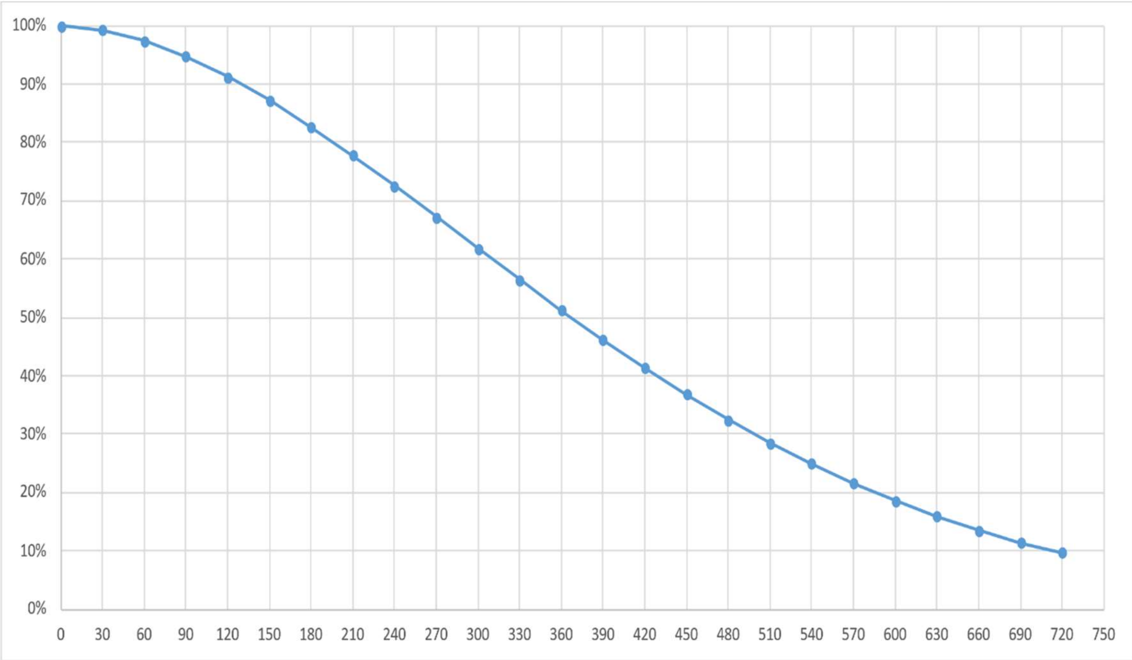

Figure 4.7.: Delay code 36T reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 422 days throughout the observed period. As can be seen in the graph (Figure 4.7), reliability for the 36T delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 83% on the 180th day. After 360 days, reliability decreased to 51%. By the 540th day, the reliability of the system decreased to 25%.

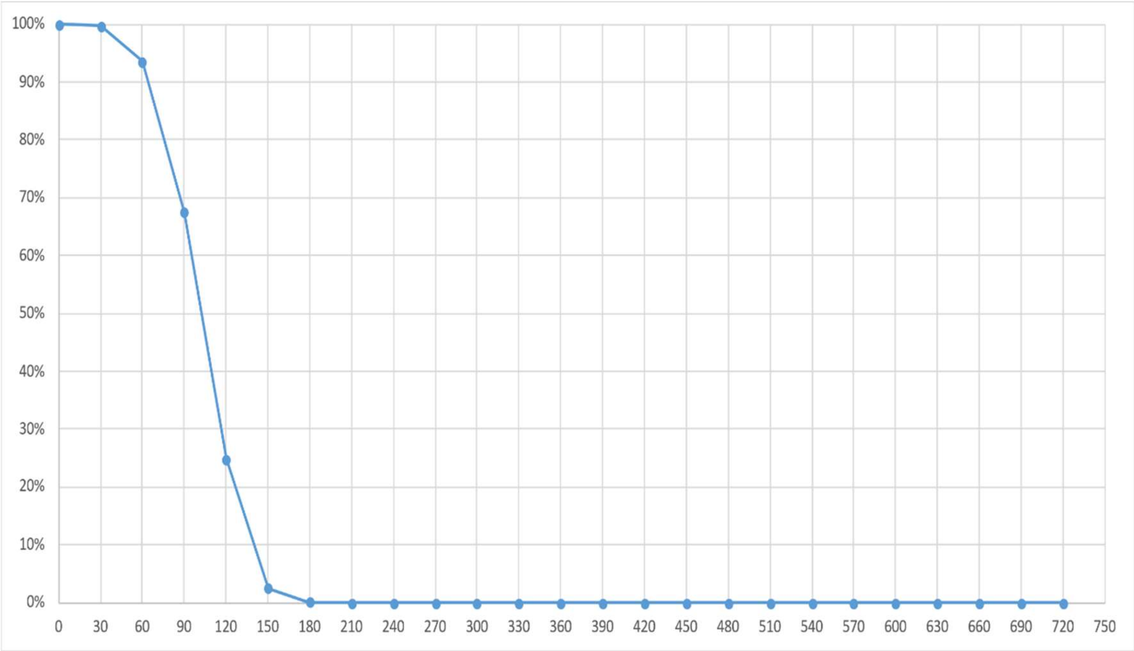

Figure 4.8.: Delay code 37A reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 101 days throughout the observed period. As can be seen in the graph (Figure 4.8), reliability for the 37A delay code decreased as the operation time increased. While reliability was 100% on first 30 days, reliability decreased to 94% on the 60th day. After 120 days, reliability decreased to 25%. By the 180th day, the reliability of the system decreased to 0%.

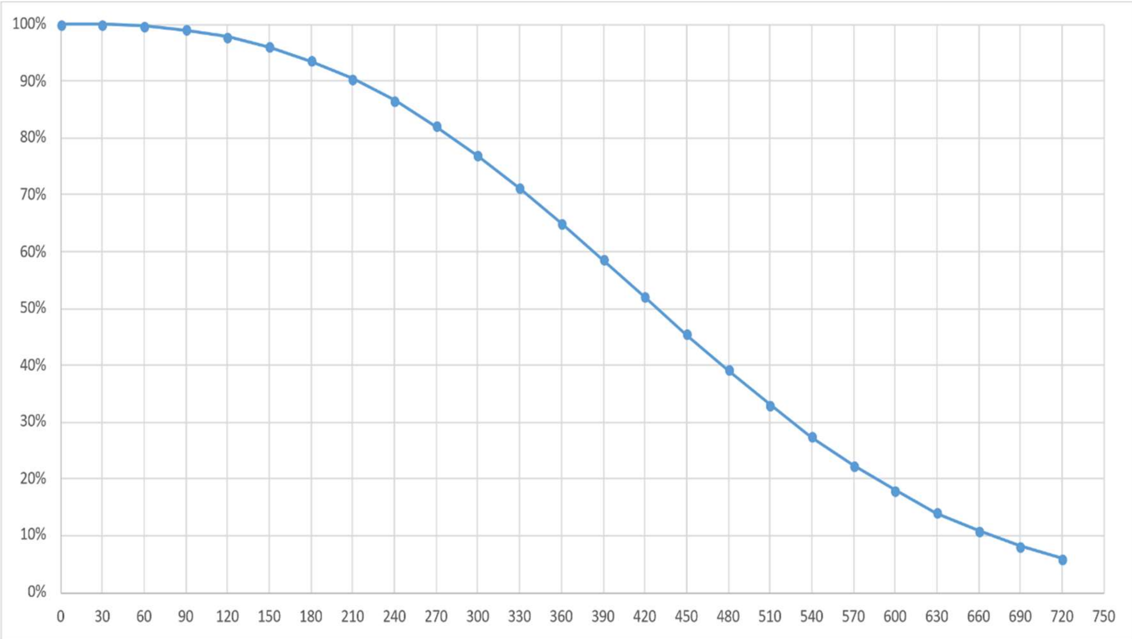

Figure 4.9.: Delay code 41M reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 436 days throughout the observed period.

As can be seen in the graph (Figure 4.9), reliability for the 41M delay code decreased as the operation time increased. While reliability was 100% on first 60 days, reliability decreased to 93% on the 180th day. After 360 days, reliability decreased to 65%. By the 540th day, the reliability of the system decreased to 27%.

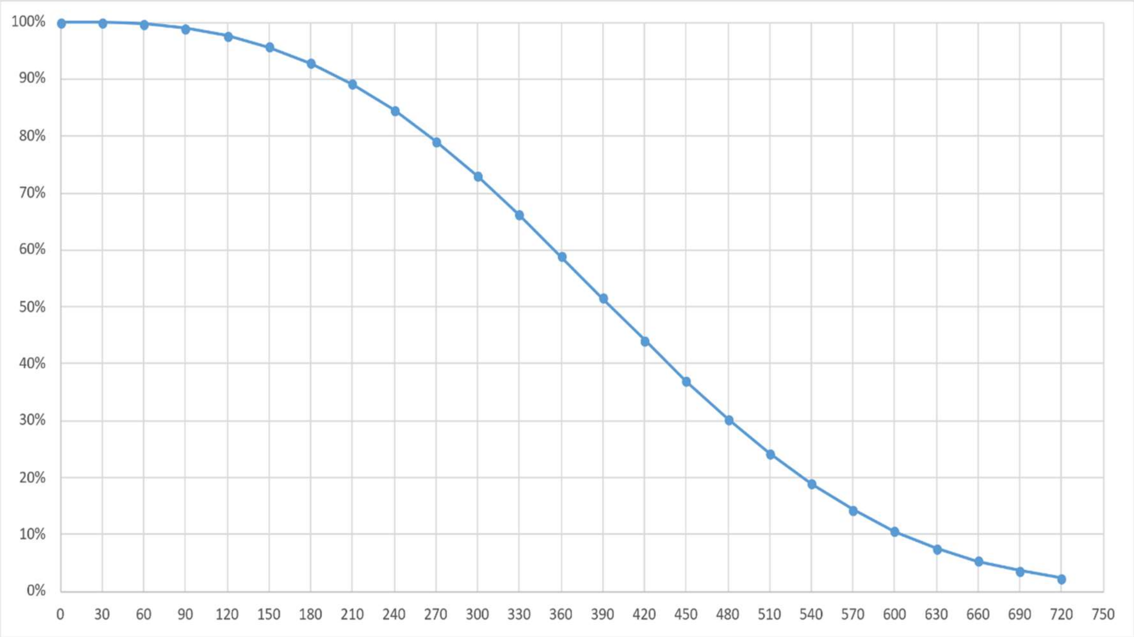

Figure 4.10.: Delay code 42D reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 410 days throughout the observed period.

As can be seen in the graph (Figure 4.10), reliability for the 42D delay code decreased as the operation time increased. While reliability was 100% on first 60 days, reliability decreased to 93% on the 180th day. After 360 days, reliability decreased to 59%. By the 540th day, the reliability of the system decreased to 19%.

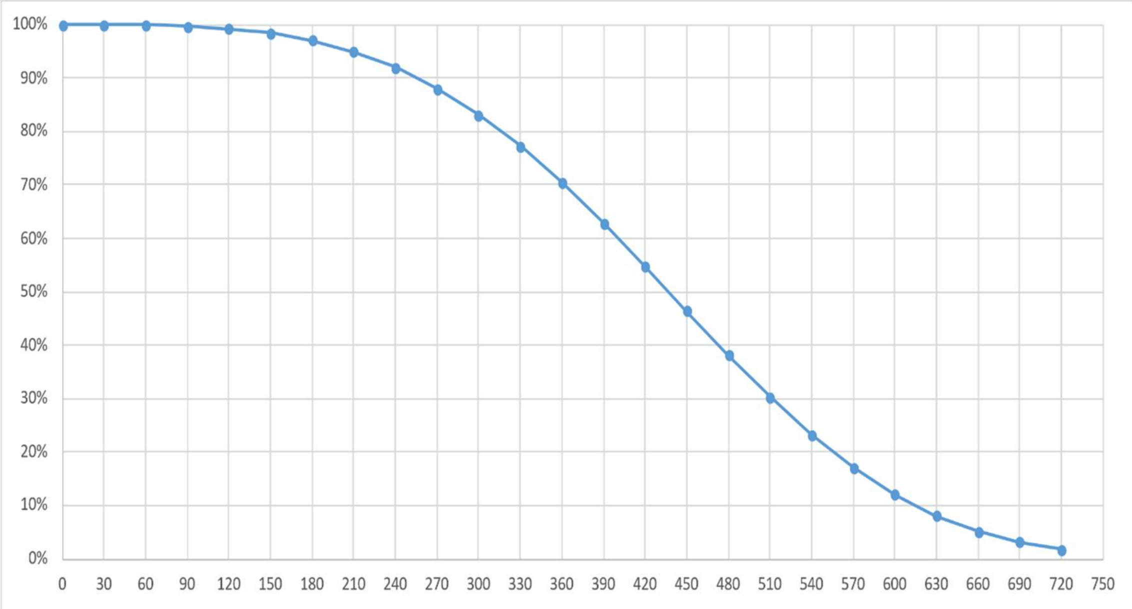

Figure 4.11.: Delay code 43A reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 435 days throughout the observed period.

As can be seen in the graph (Figure 4.11), reliability for the 43A delay code decreased as the operation time increased. While reliability was 100% on first 90 days, reliability decreased to 97% on the 180th day. After 360 days, reliability decreased to 70%. By the 540th day, the reliability of the system decreased to 23%.

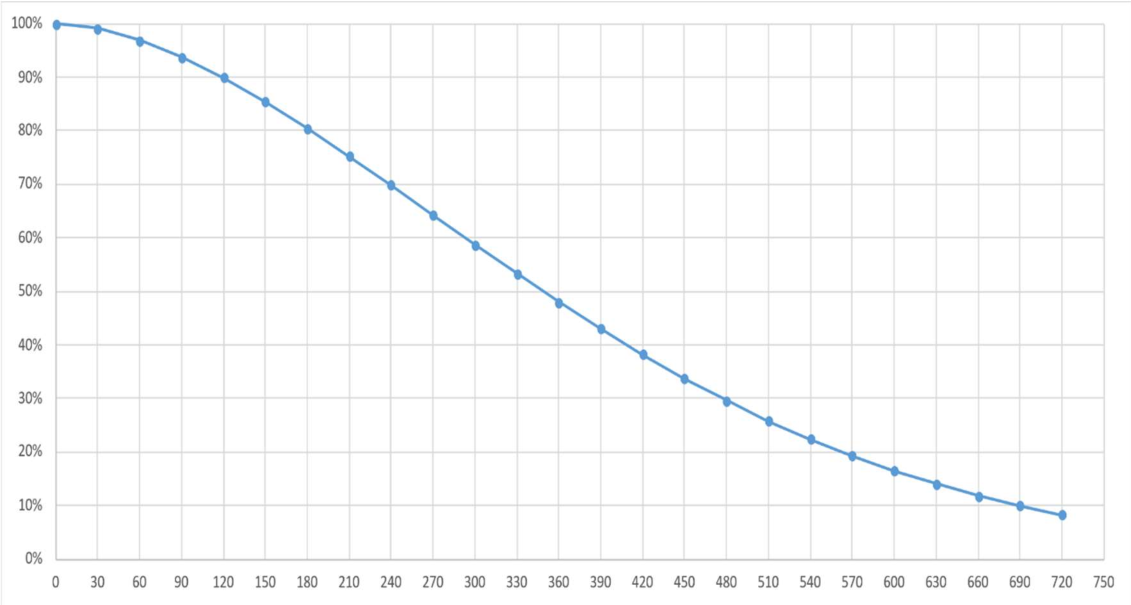

Figure 4.12.: Delay code 77B reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 391 days throughout the observed period.

As can be seen in the graph (Figure 4.12), reliability for the 77B delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 81% on the 180th day. After 360 days, reliability decreased to 48%. By the 540th day, the reliability of the system decreased to 22%.

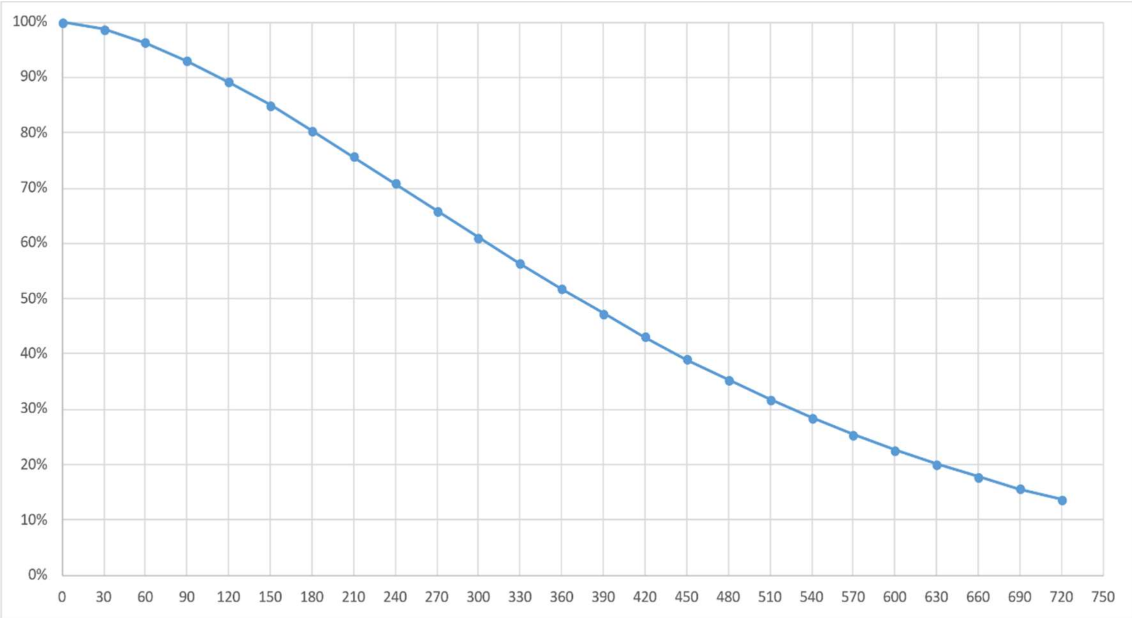

Figure 4.13.: Delay code 87A reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 411 days throughout the observed period.

As can be seen in the graph (Figure 4.13), reliability for the 87A delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 80% on the 180th day. After 360 days, reliability decreased to 52%. By the 540th day, the reliability of the system decreased to 25%.

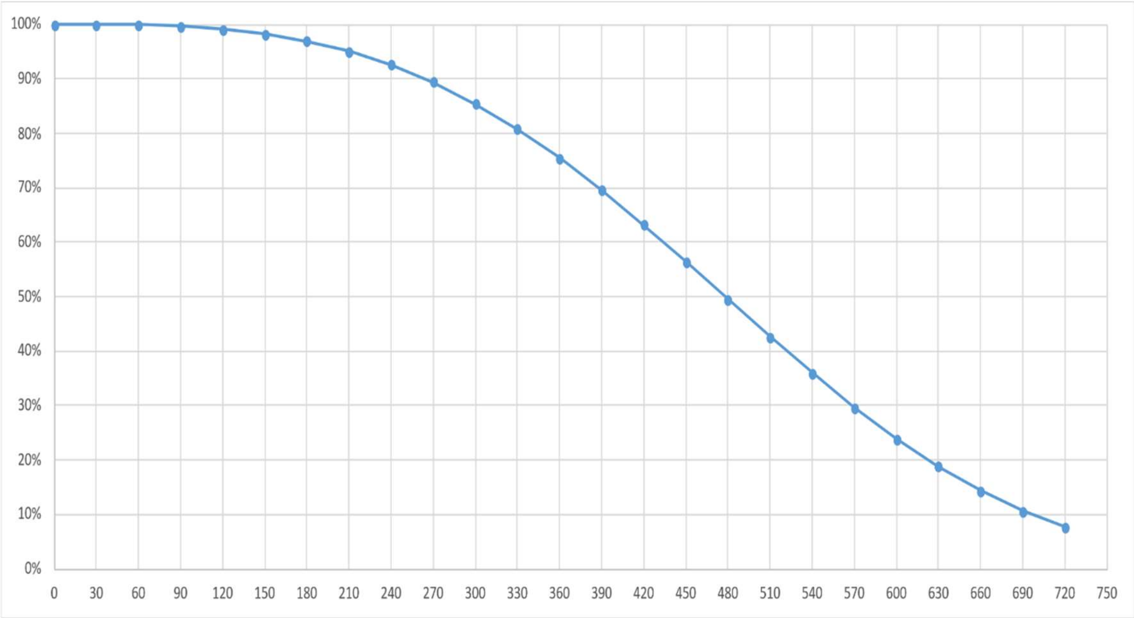

Figure 4.14.: Delay code 87E reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 475 days throughout the observed period.

As can be seen in the graph (Figure 4.14), reliability for the 87E delay code decreased as the operation time increased. While reliability was 100% on first 90 days, reliability decreased to 97% on the 180th day. After 360 days, reliability decreased to 76%. By the 540th day, the reliability of the system decreased to 36%.

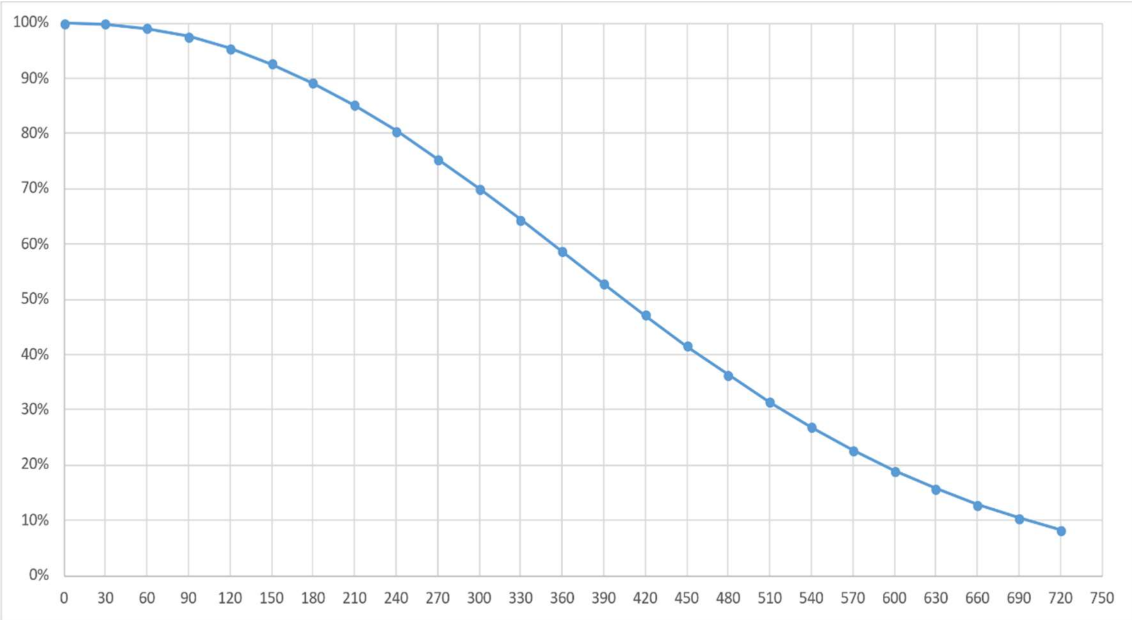

Figure 4.15.: Delay code 93A reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 436 days throughout the observed period.

As can be seen in the graph (Figure 4.15), reliability for the 93A delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 89% on the 180th day. After 360 days, reliability decreased to 59%. By the 540th day, the reliability of the system decreased to 27%.

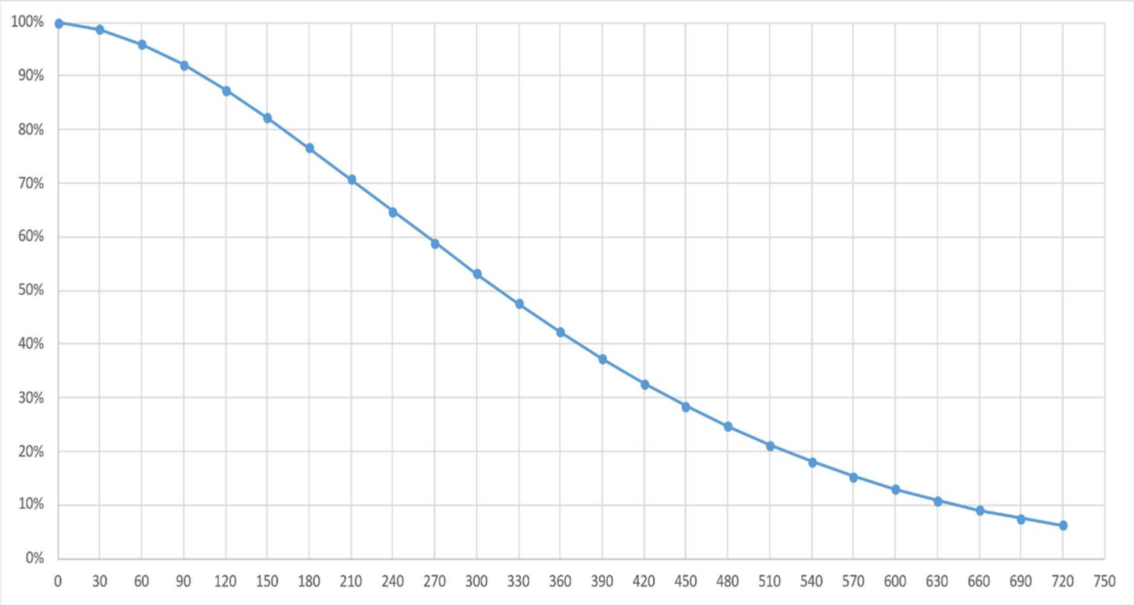

Figure 4.16.: Delay code 93C reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 363 days throughout the observed period.

As can be seen in the graph (Figure 4.16), reliability for the 93C delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 77% on the 180th day. After 360 days, reliability decreased to 42%. By the 540th day, the reliability of the system decreased to 18%.

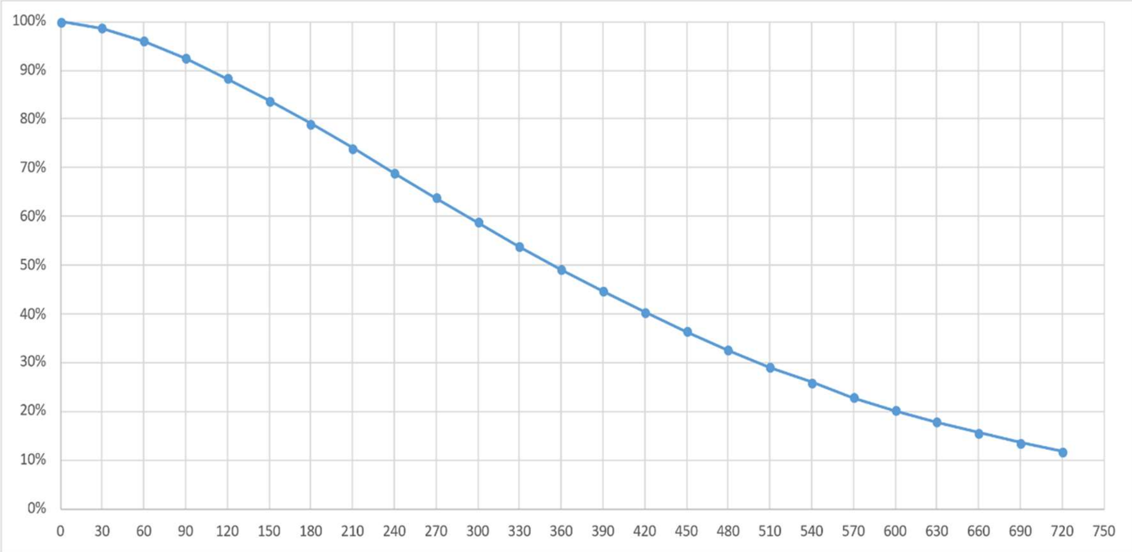

Figure 4.17.: Delay code 93F reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 422 days throughout the observed period.

As can be seen in the graph (Figure 4.17), reliability for the 93F delay code decreased as the operation time increased. While reliability was 100% on the first day, reliability decreased to 79% on the 180th day. After 360 days, reliability decreased to 49%. By the 540th day, the reliability of the system decreased to 26%.

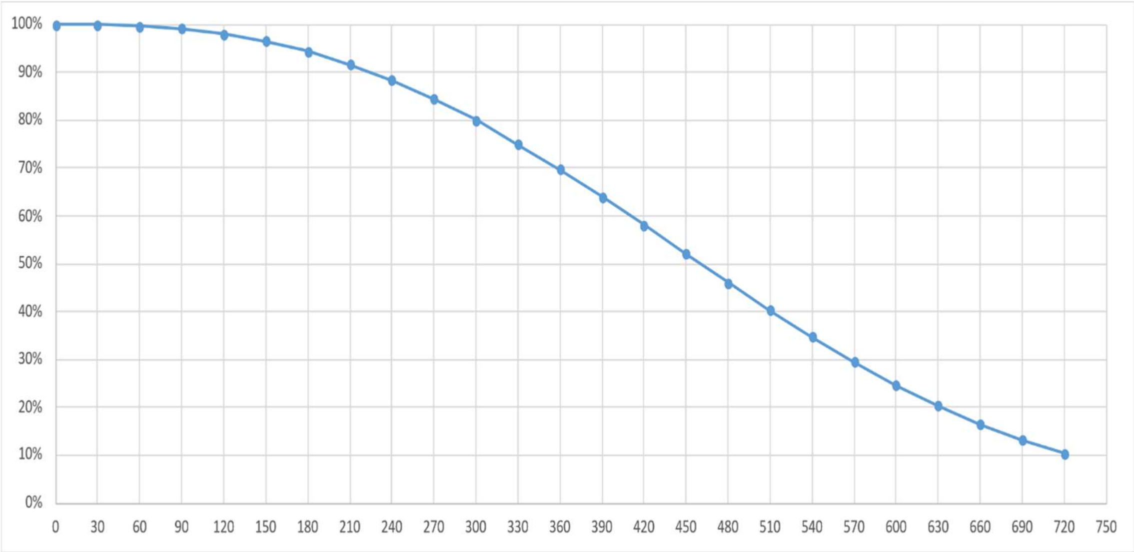

Figure 4.18.: Delay code 93H reliability ratio.

For reliability the correlation coefficient should approach +1.00. The reliability function was calculated using the Weibull distribution, because the correlation coefficient of the Weibull distribution was higher and/or acceptably higher than other distributions.

The mean time to delay was calculated as 482 days throughout the observed period.

As can be seen in the graph (Figure 4.18), reliability for the 93H delay code decreased as the operation time increased. While reliability was 100% on first 60 days, reliability decreased to 94% on the 180th day. After 360 days, reliability decreased to 70%. By the 540th day, the reliability of the system decreased to 35%.

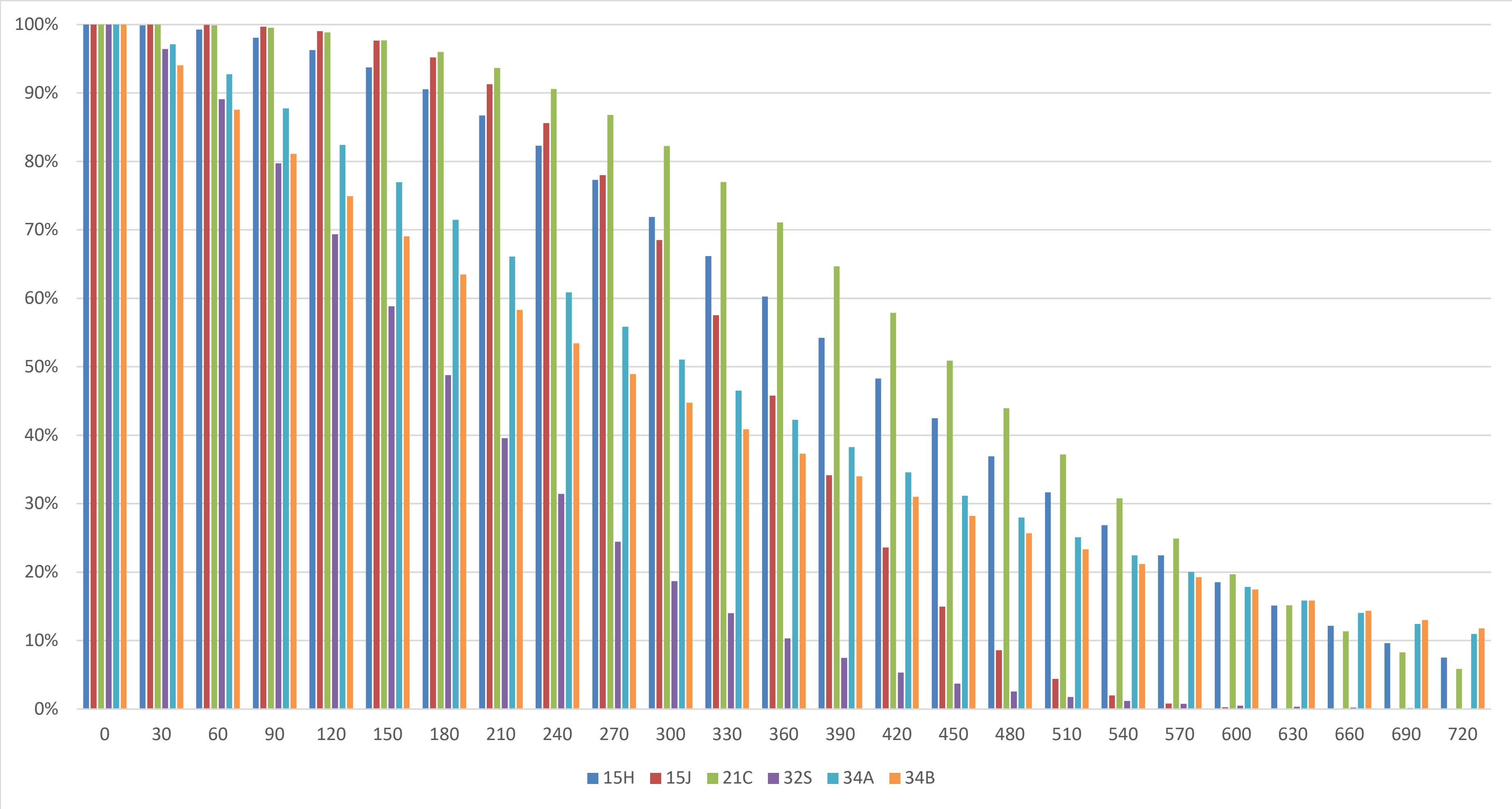

Figure 4.19.: Reliability ratio of delay codes 15H, 15J, 21C, 34A, 34B.

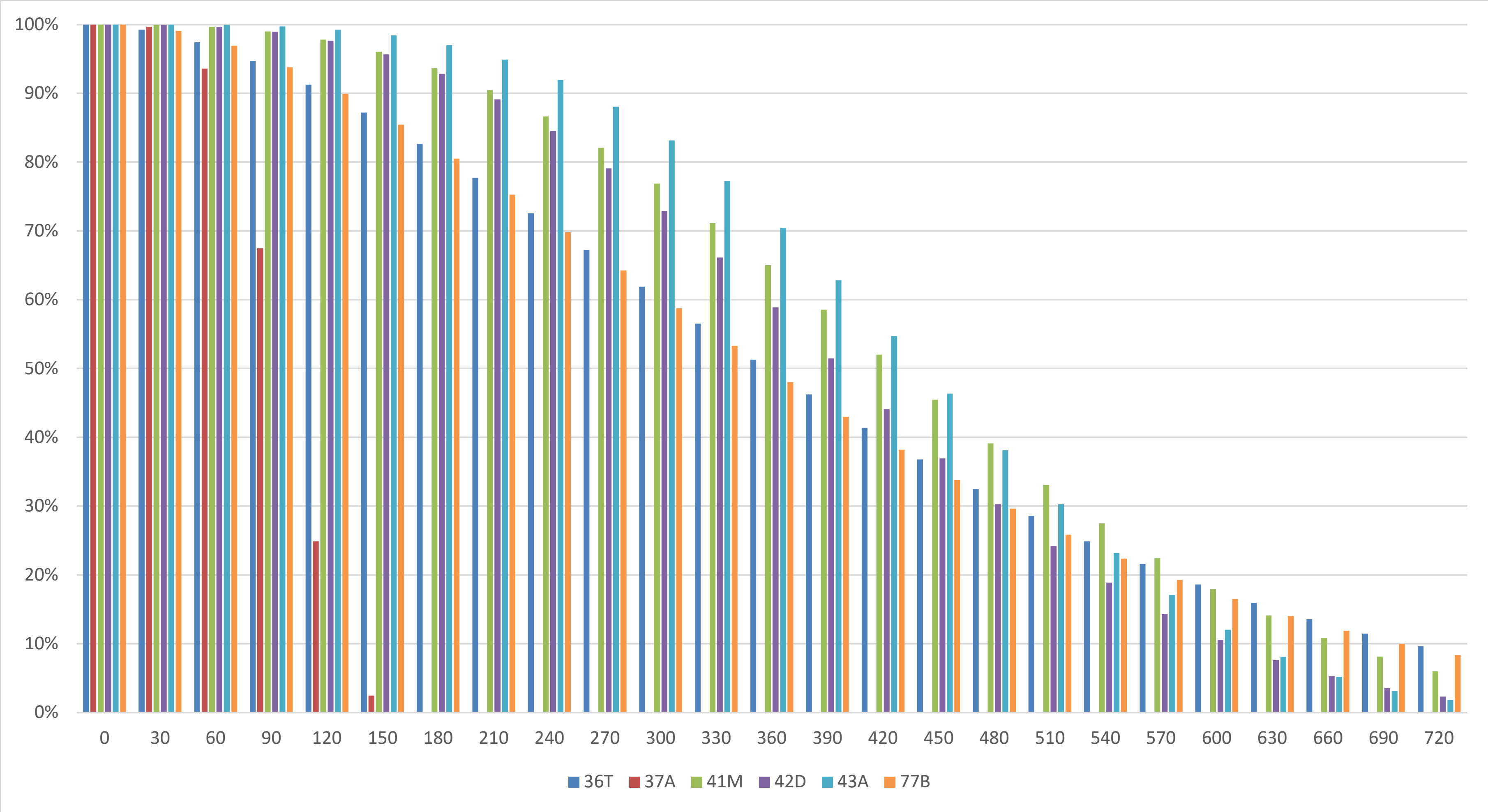

Figure 4.20.: Reliability ratio of delay codes 36T, 37A, 41M, 42D, 43A, 77B.

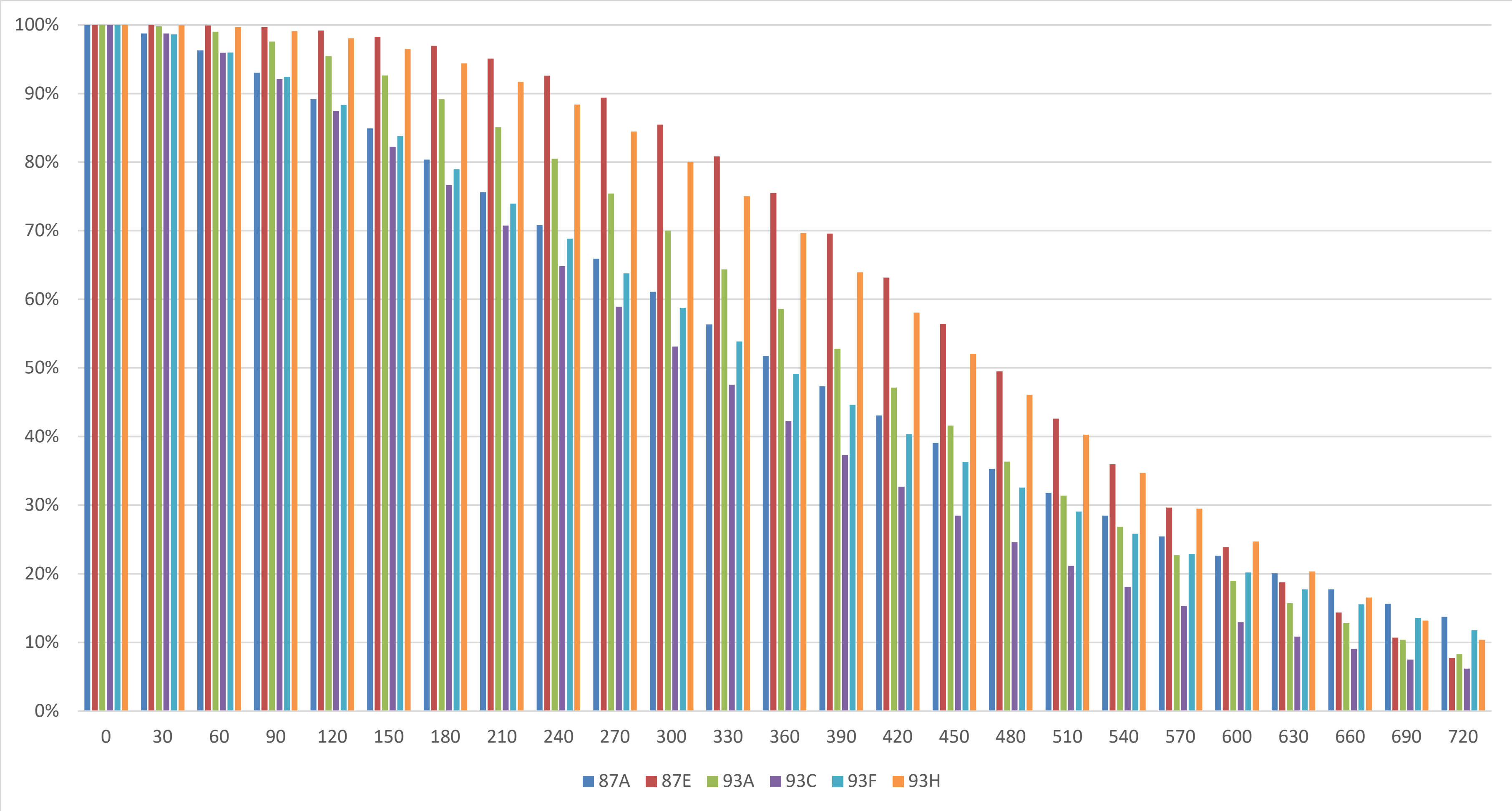

Figure 4.21.: Reliability ratio of delay codes 87A, 87E, 93A, 93C, 93F, 93H.

The reliability ratio relationship of 18 delay codes with each other can be seen in 3 separate graphs.

When the reliability rates were examined, it was seen that the initial reliability was 100% for all delay codes. It was observed that the reliability reached 0% at 3 delay codes. When we ignore these delay codes and do not include them in the average calculation, the reliability of other delay codes varies between 63% and 97% after 180 days. The reliability average of the 180th day was found to be 86%. After 360 days, reliability ranges from 37% to 76%. The reliability average of the 360th day dropped to 57%. After 540 days, reliability varies between 18% and 36%. The reliability average of the 540th day decreased to 26%.

5. FINDINGS AND RECOMMENDATIONS

Each delay brings with it different delays if not corrected. It is therefore very important that delays are corrected in a timely manner. When looking at the research framework, it can be seen that reliability decreases over time. Especially when the reliability of the system reaches around 37%, precautions must be taken. In fact, in some delay codes, this percentage is much higher, requiring earlier precautions to be taken.

Delays can be grouped under 7 main headings based on departments. The first of these is the delays experienced due to the agency, these delay codes are shown with 15H. There are delays in the planned departure time due to the fact that the agency does not cover the number of loads and therefore the ship's departure is postponed. Different measures can be taken regarding this situation. As examples of these, If the planned cargo does not arrive on a particular ship, it can be shifted to the next voyage. This may cause problems with the customer in the short term, but in the long term, it ensures that the cargo reaches the customer at the planned time by avoiding delays. Another reason why the number of loads does not close may be due to the ship not being fully loaded. On an operational basis, it is more costly for the ship to go empty than for the ship to be delayed. For this reason, a profit and loss evaluation should be made, taking into account whether the delay will cause different problems in the future.

Another category of delay can be said as customer. The ship may have to wait for a certain load because the cargo planned for the ship does not leave the loading facility on time or is delayed for various reasons during its arrival. In order to prevent this, the port gate should be closed after a certain time according to the planned ship departure time and the operation should be prevented from being delayed for a different vehicle coming from outside. However, since this situation may cause problems with the customer, progress in the operation should be made by re-evaluating the profit and loss. Waiting for the cargo to arrive on the ship is expressed with the delay code 15J. In addition, another delay code that causes delays, although it does not directly affect the customer, is 87E. This code indicates the lack of parking space in the port area. However, import vehicles whose operations are completed are not removed from the port area and occupy the parking areas, which prevents the port from operating at full capacity and causes delays. In this regard, customers are charged a storage fee and a storage fee is charged for vehicles that sit for more than two days. It is necessary to shorten the two-day free parking right by increasing the storage fee or in case the import vehicles whose transactions have been completed remain at the port. By introducing the priority customer concept, customers can be encouraged to pay attention to timing by charging discounted port fees to customers who enter and exit the port on time. Grimaldi Lines Türkiye Commercial Operations Manager Francesco Olivieri said; Ports need to standardize their processes and service quality. It is very important to be organized according to customer needs (Olivieri, 2018) .

In another category of grouping delay codes includes customs procedures. Along with the exit notification, the manifest information is sent to the customs administration via computer data processing technique. Original manifests and bills of lading are kept for the document retention period specified in Article 13 of the Law to be submitted to the customs administration when deemed necessary within the scope of customs controls. Necessary procedures and checks are carried out within twenty-four hours after the departure of the sea vessel, within the framework of the procedures and principles to be determined by the Ministry, based on the exit notification and the declaration and manifest information subject to the exit notification (Customs Regulation, 2017). Delays due to manifest control specified in 21C cause serious problems on an operational basis. The necessary equipment support should be provided by contacting the customs personnel. If deemed necessary, personnel support should be provided and extra customs personnel should be present during shifts.

There are many different delay topics regarding ship operations. One of these is the delays caused by periodic maintenance with code 43A. The delay code occurs when periodic maintenance is planned but these are not shared with the port operation and the planned ship departure time is not changed. Delays can be improved if the port operation is aware of the situation and can plan the area where it will work, the number of shift personnel and the amount of equipment. Additionally, the departure time of a ship with planned maintenance can be changed by stating this in the schedule. Another suggestion is to arrange the ship's arrival earlier than planned. Proceeding at maximum safe speed during the voyage allows the ship to arrive early. However, this may cause extra fuel to be burned and should be considered as a loss or profit. Another delay code due to ship operations is 42D. This delay code refers to delays that occur due to unexpected problems encountered during repair and the repair time being extended. In such cases, the port operation should be informed about the issue and operational planning should be made in this context. Another delay due to ship operations is due to the fuel and sludge barge specified with code 36T not being called on time. During the cruise, the ship transmits its fuel and sludge request to the ship operations department, and the fuel and sludge barge must be ready for the arrival of the ship. Communication disruptions, late calls to the fuel and sludge barge, and failure to notify the barge of the ship's arrival earlier or later than the scheduled time cause operational delays. Communication with the fuel and sludge barge must be established continuously and possible delays and disruptions must be reported to the barge personnel. It should not be forgotten that the ship operation is a whole and any problem can affect the entire operation.

Another delay code is the delays due to the feeder ship, indicated by 32S. Delays caused by vehicles expected to be evacuated from the Feeder ship have been added to this code. A chain of errors that trigger each other occurs due to incorrect planning of the operations of the feeder ship, not departing from the opposite port on time, approaching the destination port late, or not completing the operation for various reasons even though it docks on time. These delays are caused by port operations and occur due to incorrect planning by the port operation. In this case, the port operation must carry out its operations by ensuring the ship arrives on time or early, taking into account the delays that may occur in the next step.

When the grouped delay categories are examined, another item is the limits on port facilities. Three main points stand out about the capacity of the Ro-Ro terminal; How many ships can be handled at the same time, how long it will take to load or unload from a ship, possible loading area capacity at the terminal for Truck/Trailer type vehicles (Izmir Development Agency, 2021). Since the port indicated with 87A does not have enough piers and more than two ships cannot dock at the port, it is necessary to wait for the departure manoeuvre of a ship in the port for a third ship to dock.

Although usually one ship is scheduled for every day of the week; The departures of some ships may be postponed for various reasons; their planned voyages may be changed, or they may need to stay in the port for longer than expected in case of a malfunction. In these cases, the number of ships may exceed the port's capabilities. In such cases, the current problem must be resolved as soon as possible and/or the ship that is not planned to depart immediately should not cause a delay in the operation of the other ship and should drop anchor. Another delay code, shown as 87E, is due to insufficient port parking area. Although it can accommodate an average of 800 vehicles, it is a relatively small port compared to other ports. In some cases, due to the density in the port area, it is used as a parking area if there is a different ship that is not planned to depart from the port. This situation causes unnecessary fuel consumption and extra manpower. Although it is not possible to expand the port parking area due to environmental factors, different ways can be followed to reduce the density in the port. By renting a parking area close to the port area, export cargo can be prevented from being kept waiting in the port. In this way, a large part of the documentation and customs procedures can be completed and the export vehicles in their turn can be quickly arrived at the port and loaded onto the ship. In addition, by taking steps to encourage customers regarding import cargo waiting at the port, the density within the port area can be reduced.

Another heading in the delay category is others that cannot be categorized. In this category, unexpected machinery malfunction occurs with code 41M during the ship's sea voyage. Depending on the time it takes to resolve the fault, there are delays in the planned arrival time of the port. In this case, the port operation must be informed. Operation planning must be done well and the operation of the ship arriving with a delay must be completed quickly. If the malfunction takes too long to be resolved, the planned voyage of a different ship should be changed and it should be ensured that it joins the voyage. This study was carried out during the pandemic period, and during this period, every ship approaching the port was checked by the General Directorate of Border and Coastal Health. There were delays during the pandemic period because the ship was waiting for medical personnel and the ship personnel were undergoing health checks, which were time-consuming procedures. These delays are expressed with code 37A. The way to tolerate delays is to ensure that the ship arrives at the maximum safe speed during the sea voyage and/or port operations are planned correctly and are as quick and effective as possible. Another delay code is the delays that will occur at the entrance of the Dardanelles Strait, indicated by 93F. The Dardanelles Strait may be closed for various reasons or only one-way passages may be allowed. According to the Turkish Straits Maritime Traffic Order Regulation, passenger ships, Ro/Ro ships, refrigerated ships are priority ships at the entrance of the strait. In cases where the administration deems it appropriate, although the strait traffic is closed or can only operate in one direction, pilot service is provided to these priority ships and strait passage is provided. Despite the priority given at the entrance to the Dardanelles Strait, delays may occur in the planned arrival time. In order to prevent this situation, delays at the entrance of the Dardanelles Strait can be reported to the port operation so that the operation planning can be carried out correctly. Another delay code is delays due to bad weather conditions during the sea voyage specified with 93C. Precautions that can be taken regarding this delay are to monitor the weather conditions on the ship's route in advance and analyze the availability of different routes. If this is not possible and the ship's delay is inevitable, a different ship's loading operation can be performed instead of the ship. Thus, it will be ensured that exports are not disrupted. Delays should be reduced as much as possible and prevented from causing different delay codes later. Weather can also cause disruption to pilot services. This delay is indicated by code 77B. When the overall delays due to weather conditions in both arrival and departure of the ship are analyzed, it is seen that the delay in pilot arrival is greater, especially during the departure of the ship. The weather should be closely monitored throughout the stay in the port. If the weather conditions are expected to worsen at the time of the ship's planned departure, the departure time may be moved earlier. However, in this case, a profit and loss evaluation should be made, such as how long the delay will be and how much of the export cargo cannot be loaded. Delay codes 34A and 34B occur due to the pilot's late arrival to the ship during the ship's arrival and departure. In order to reduce the frequency of this situation, the pilot should be notified of the ship's arrival and departure times in a timely and accurate manner. Although not all possible delays can be prevented, these delays can be reduced. Another delay code is 93A, which represents a late arrival due to a late departure from the opposite port. It should be closely examined whether the ship departs at the planned time and the operation at the destination port is planned correctly. The planned operation may not completely eliminate the delay, depending on the magnitude of the delay. In this case, 93H delay code occurs, that is, late port departure due to late port arrival. The operation should be as fast and effective as possible. Thus, the size of the delay can be reduced. In addition, the ship should proceed at maximum safe speed during the sea voyage and delays should be reduced as much as possible.

6. CONCLUSIONS AND IMPLICATIONS

Maritime transportation is one of the world's indispensable trade and transportation methods. In line with the increasing demands and needs over time, the need for faster and safer trade has increased. The structures of ships that enable them to carry large tonnage loads put maritime transportation one step ahead of other transportation modes. Ro-Ro ships, which allow carrying both fast and high tonnage loads, have become more important than other ship types engaged in maritime transportation. Another major advantage is that these ships allow carrying wheeled vehicles, ensuring faster operational times during both the loading and unloading phases. It also allows easier handling of cargo at road and railway connection points. Thanks to today's developing technologies, faster and larger Ro-Ro ships have been built. Despite the various improvements made, some operational problems occur and affect the full performance of this type of ships. Different measures need to be taken in order to eliminate these shortcomings. In particular, disruptions that may occur in port operations, malfunctions and delays that may occur during sea navigation, inadequacy of port facilities, straits crossings, sea navigation in bad weather conditions, customs and/or customer-related delays disrupt ship operations and cause operational delays. For this reason, necessary precautions should be taken before delays occur to ensure that the operation is not disrupted as much as possible. It is necessary to evaluate whether delays can be prevented by taking the right actions at the right time. In the study, the reliability analysis of the system was made and the frequency of the delays was evaluated. During the reliability analysis, 5 different distributions were used and calculations were made with the Weibull distribution as the most appropriate distribution selection for the delay codes. When the results of the study are evaluated, the importance of timely measures has become evident, as each delay code that cannot be corrected in the system or for which action is taken late results in another delay code. By using operational planning effectively in order to increase communication and effectiveness, delays in the system can be reduced to a tolerable level or completely eliminated. Taking the right actions at the right time is a very critical point in being prepared for expected or unexpected situations.

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APPENDICES

APPENDIX A

Delay Code	Number of Delay	Total Running Day
12A	1	732
13D	1	732
14B	1	732
14D	1	732
14E	2	732
15	1	732
15B	4	732
15E	3	732
15H	24	732
15J	15	732
17B	2	732
17F	2	732
17G	1	732
18D	8	732
21B	1	732
21C	46	732
21D	1	732
21E	7	732
24C	2	732
24D	1	732
31B	2	732
32A	7	732
32B	3	732
32E	1	732
32O	2	732
32P	1	732
32R	1	732
32S	17	732
33B	7	732
33C	1	732
34A	49	732
34B	33	732
34D	1	732
34E	2	732
36B	1	732
36T	15	732
37A	39	732
37B	2	732
38A	1	732
41D	2	732
41F	6	732
41M	32	732

Table A.1.: Total number of all observed delays

Delay Code	Number of Delay	Total Running Day
41O	7	732
42E	2	732
43	1	732
43A	28	732
43C	1	732
43D	5	732
43E	1	732
43F	3	732
44C	1	732
55C	9	732
55D	2	732
64D	1	732
65A	1	732
65C	2	732
76A	2	732
76B	9	732
77A	3	732
77B	35	732
87A	12	732
87D	2	732
87E	70	732
91	1	732
91A	2	732
91C	8	732
93A	349	732
93B	1	732
93C	94	732
93D	1	732
93F	158	732
93J	1	732
93G	2	732
93H	215	732
95A	3	732
95C	1	732
95F	4	732

Table A.1. (continued): Total number of all observed delays

APPENDIX B

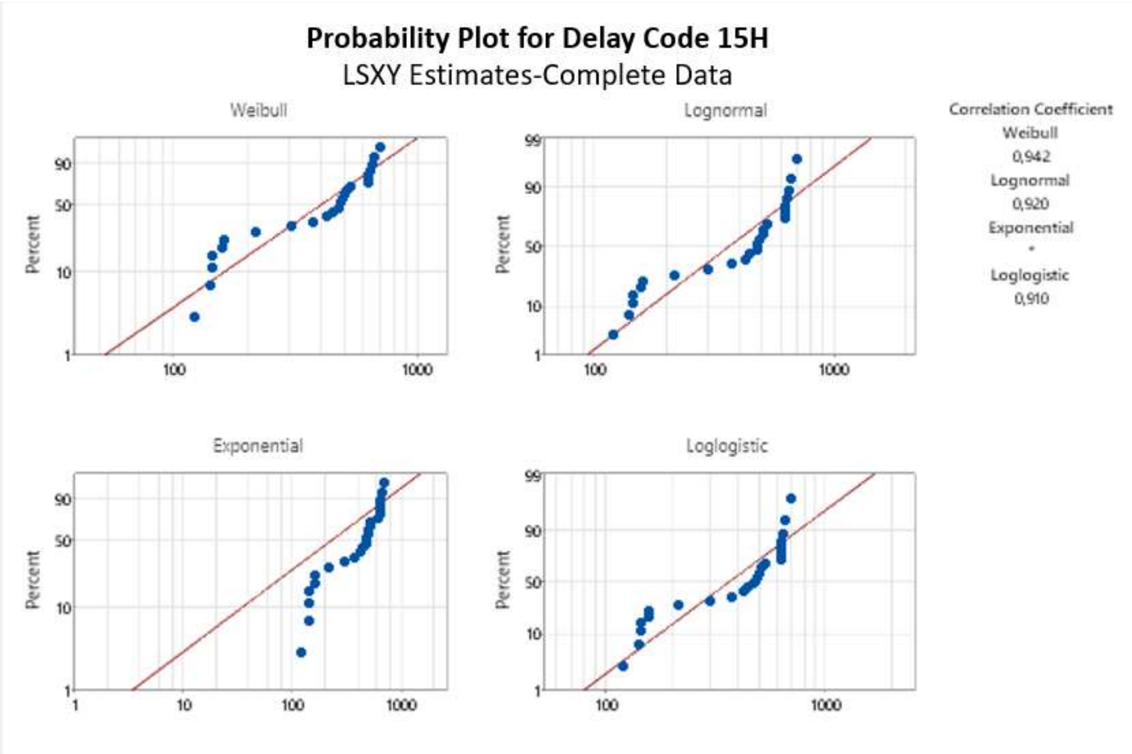

Figure B.1.: Delay code 15H – Correlation coefficient between delay times.

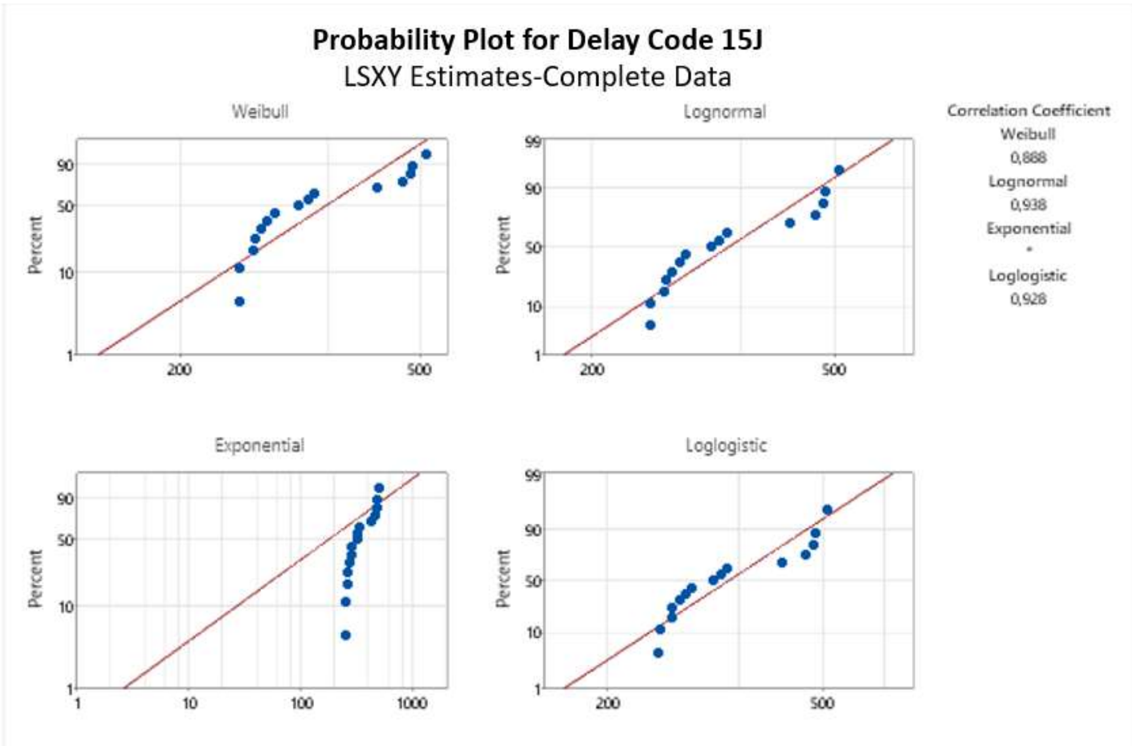

Figure B.2.: Delay code 15J – Correlation coefficient between delay times.

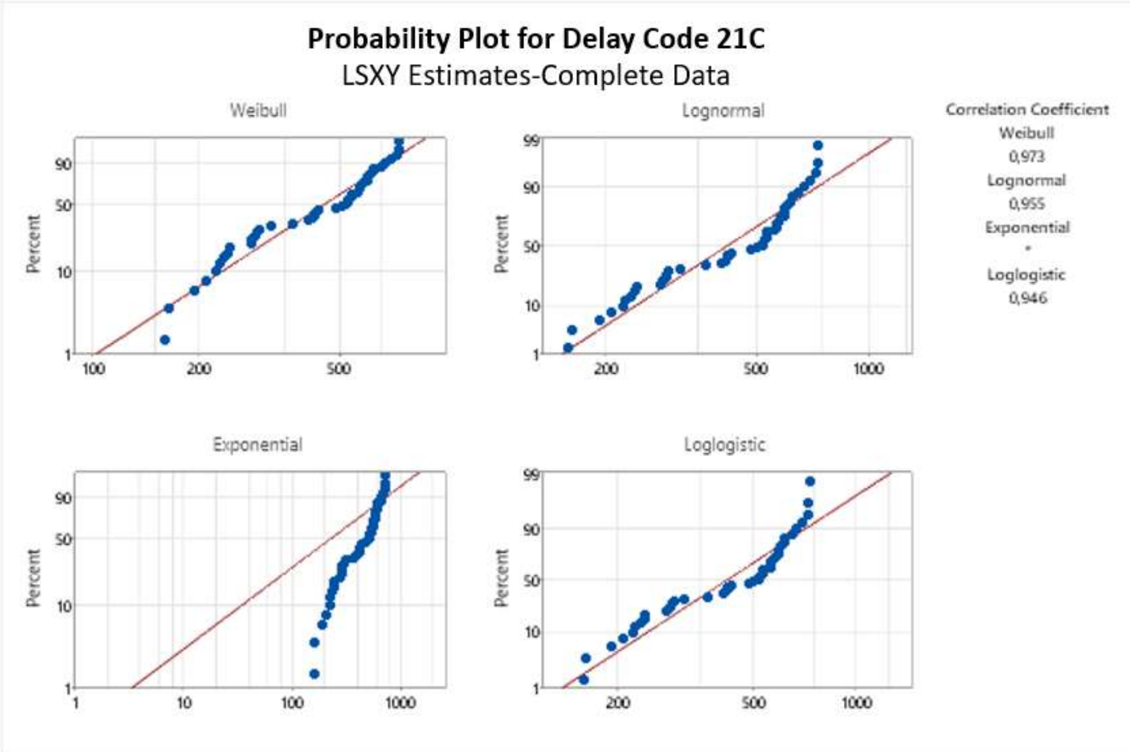

Figure B.3.: Delay code 21C – Correlation coefficient between delay times.

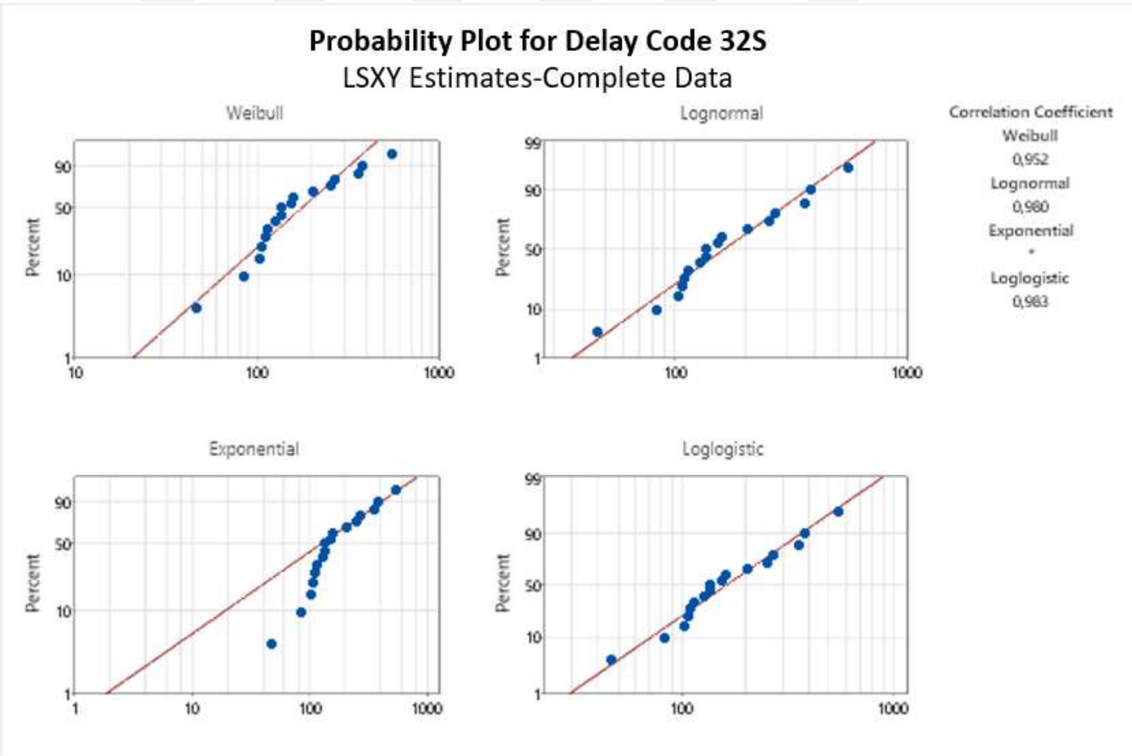

Figure B.4.: Delay code 32S – Correlation coefficient between delay times.

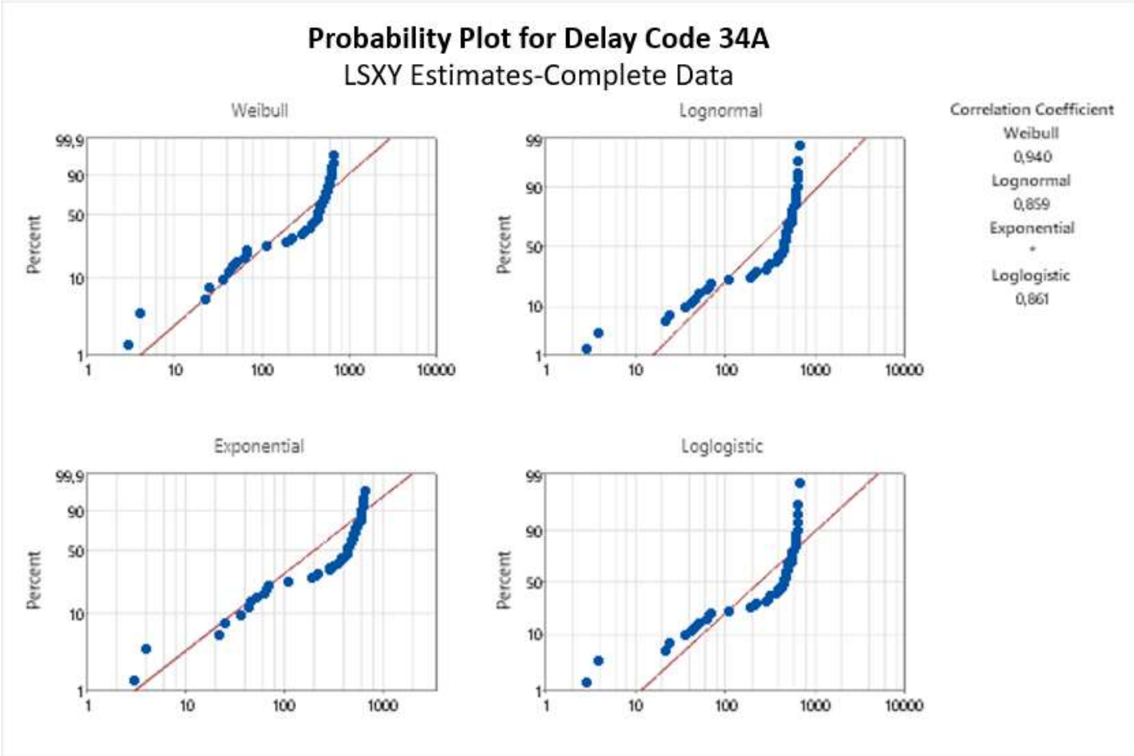

Figure B.5.: Delay code 34A – Correlation coefficient between delay times.

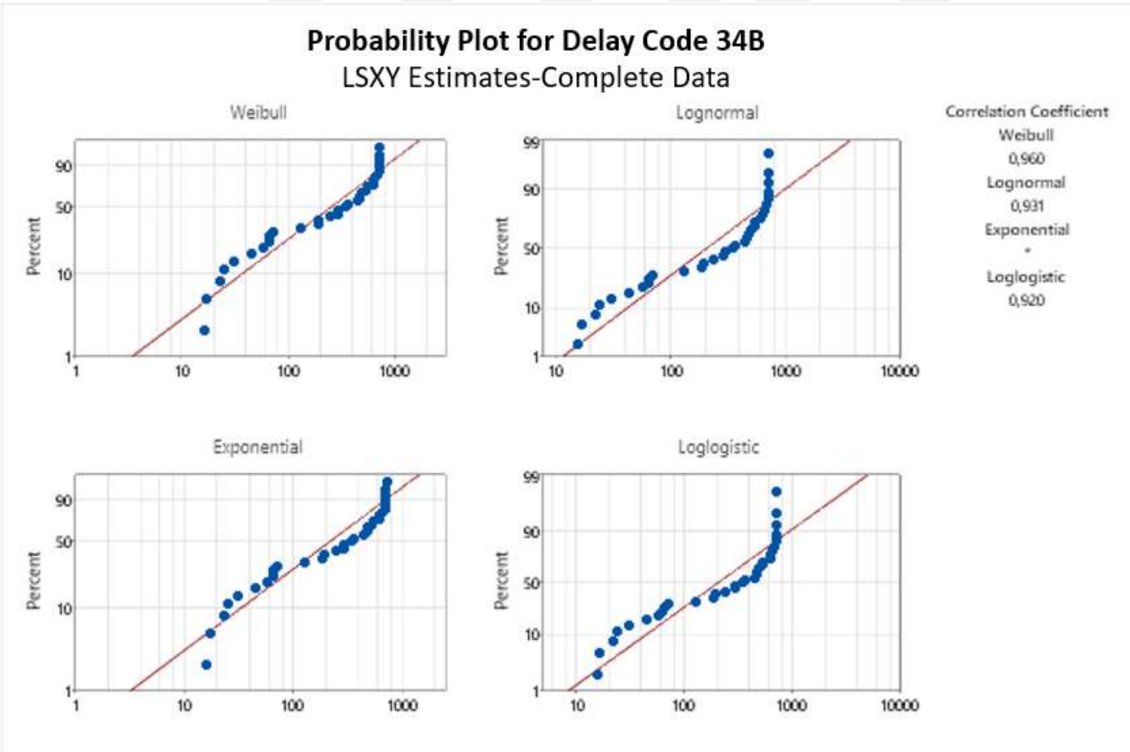

Figure B.6.: Delay code 34B – Correlation coefficient between delay times.

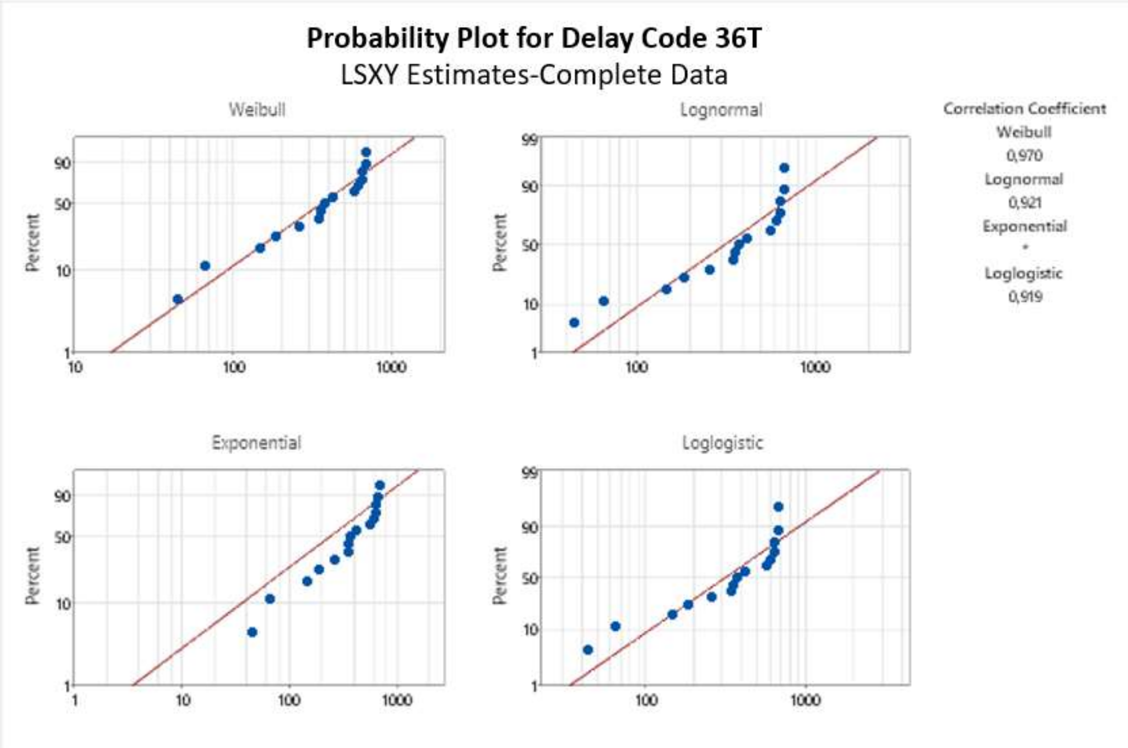

Figure B.7.: Delay code 36T – Correlation coefficient between delay times.

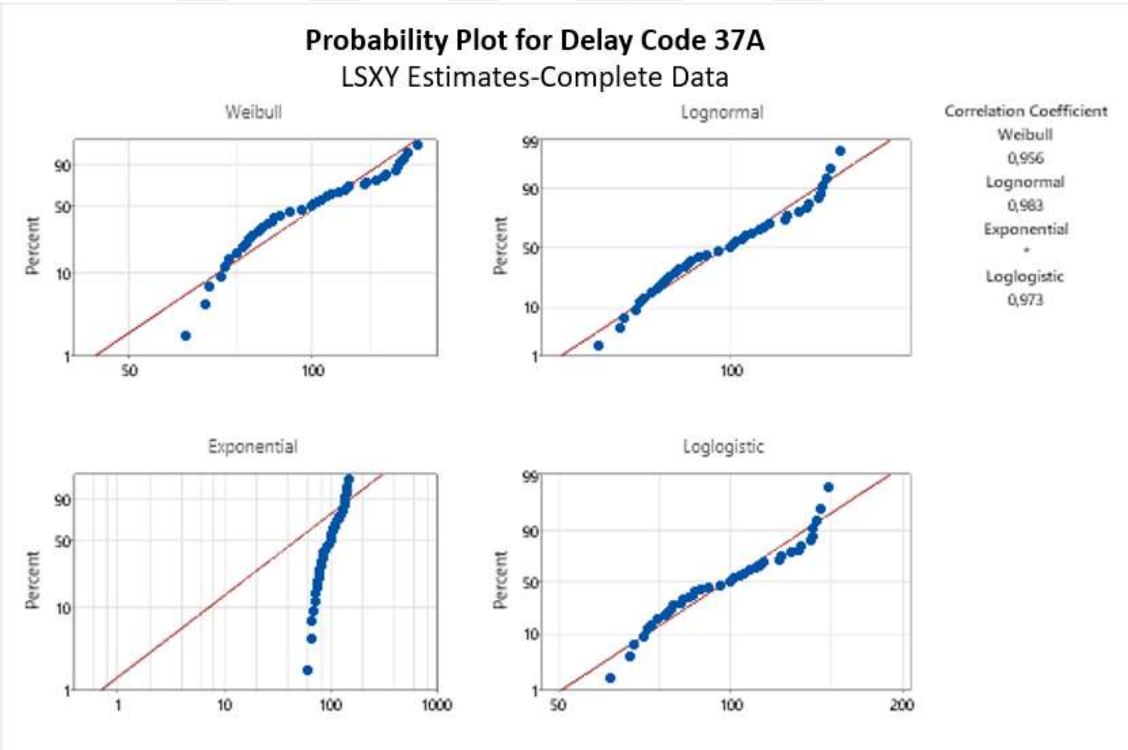

Figure B.8.: Delay code 37A – Correlation coefficient between delay times.

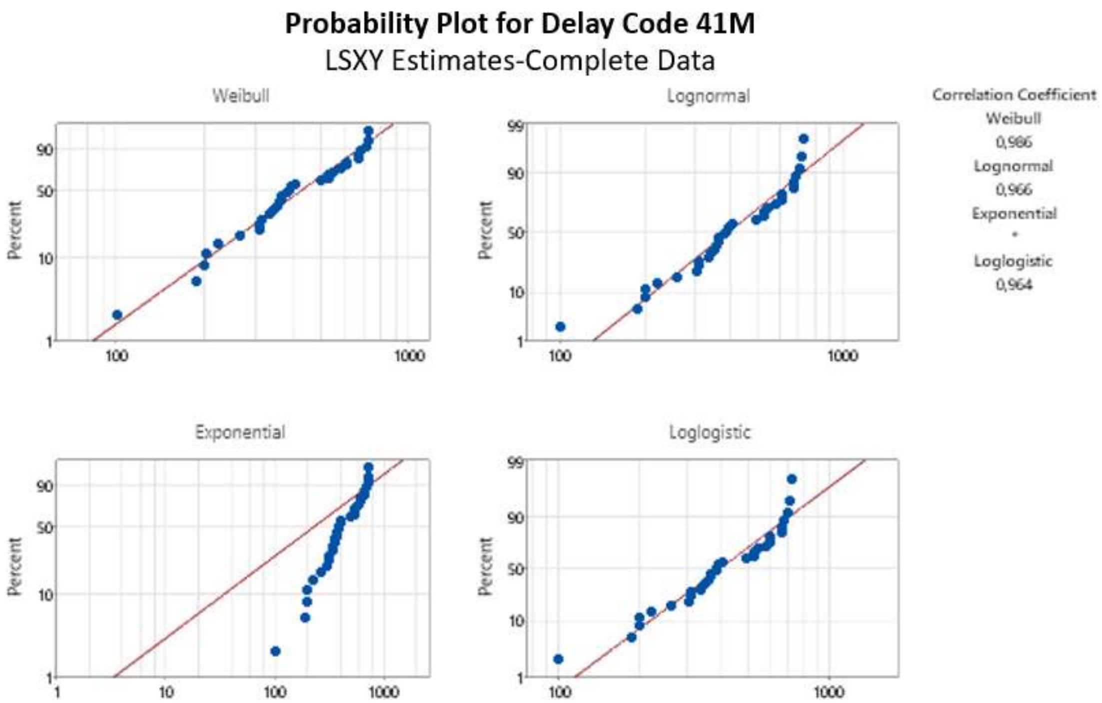

Figure B.9.: Delay code 41M – Correlation coefficient between delay times.

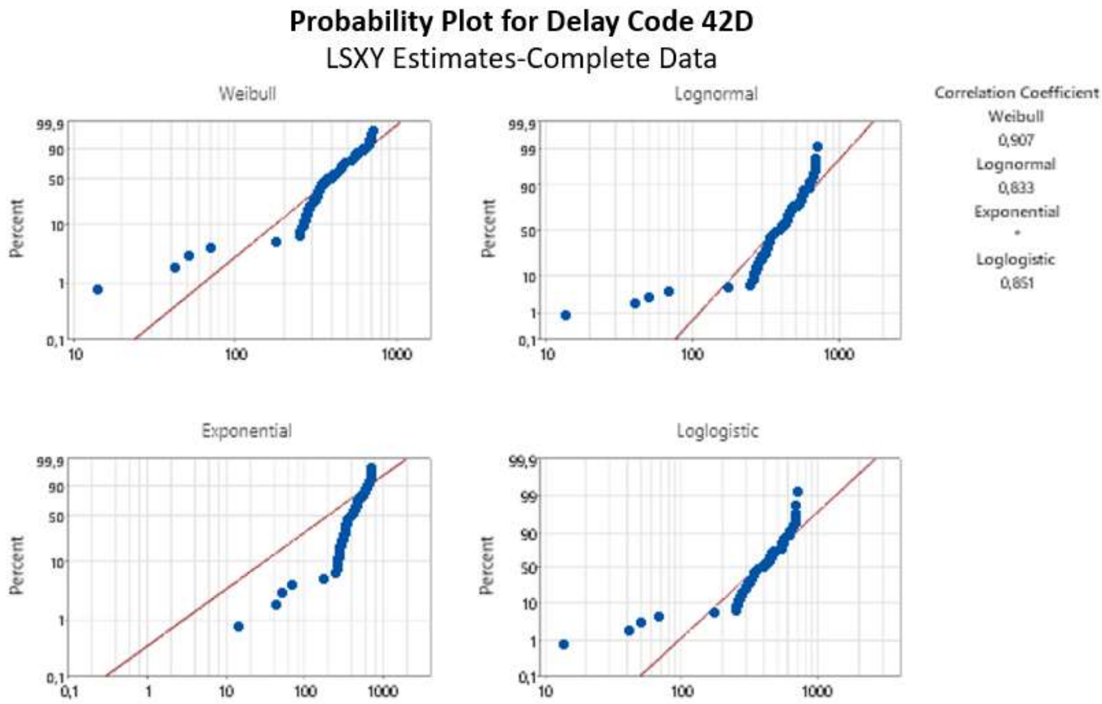

Figure B.10.: Delay code 42D – Correlation coefficient between delay times.

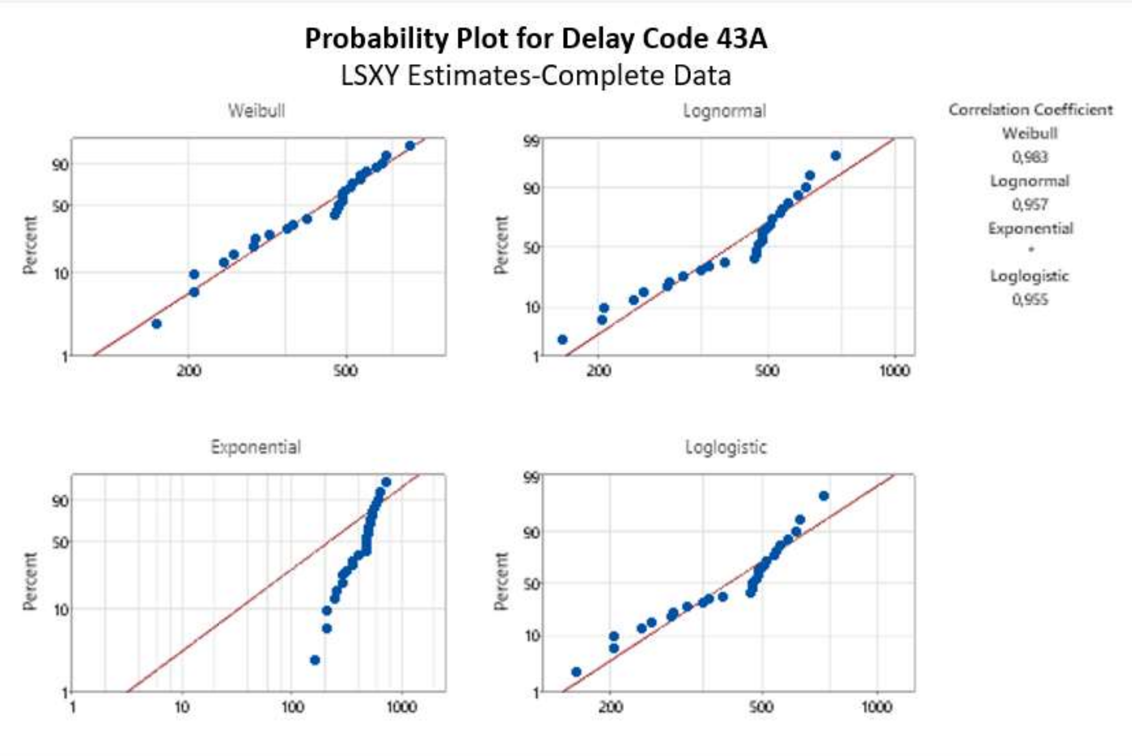

Figure B.11.: Delay code 43A – Correlation coefficient between delay times.

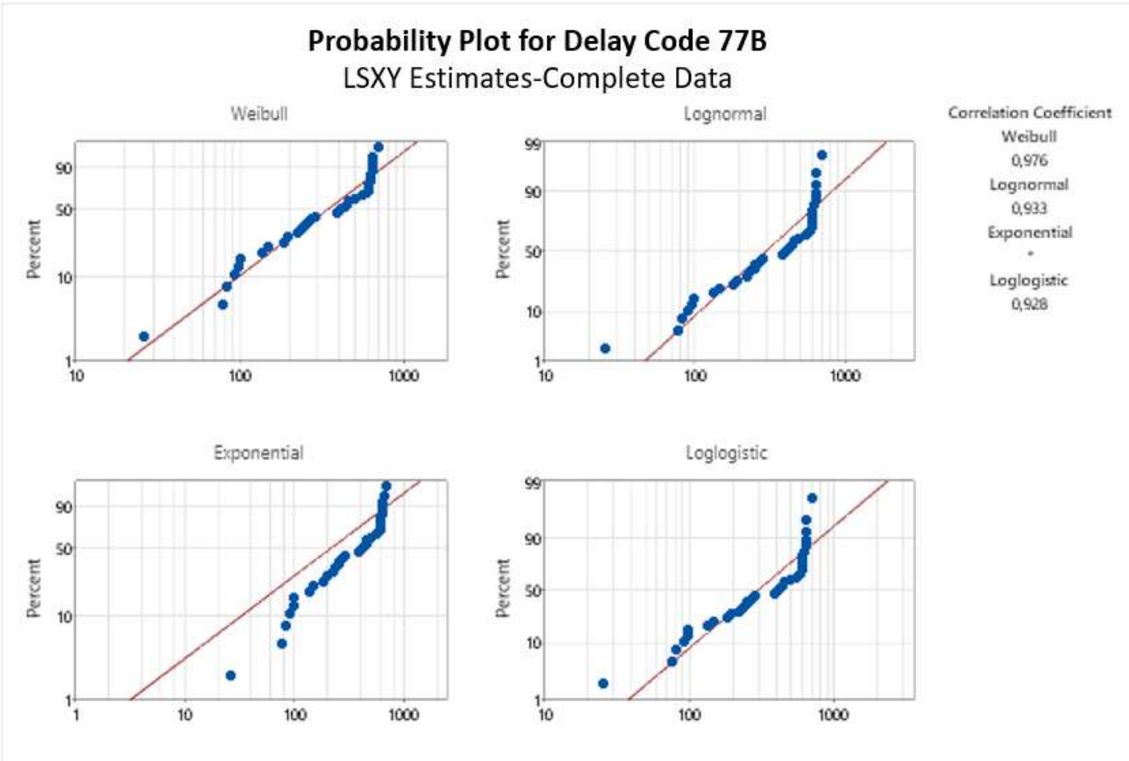

Figure B.12.: Delay code 77B – Correlation coefficient between delay times.

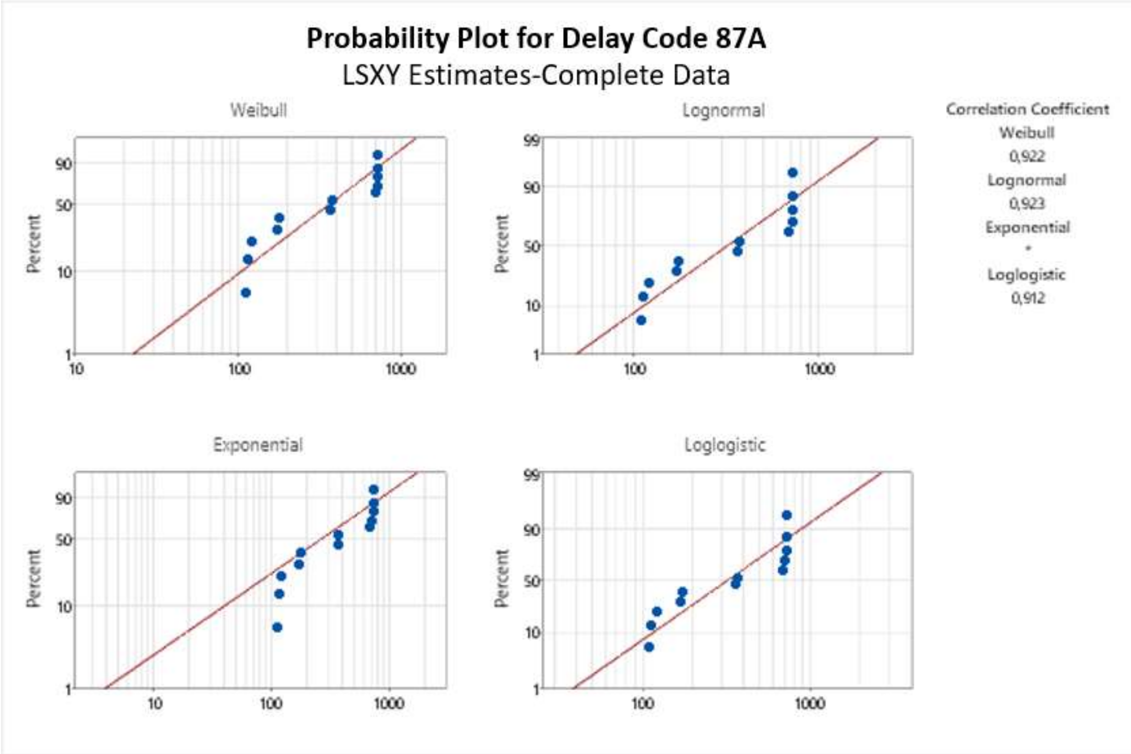

Figure B.13.: Delay code 87A – Correlation coefficient between delay times.

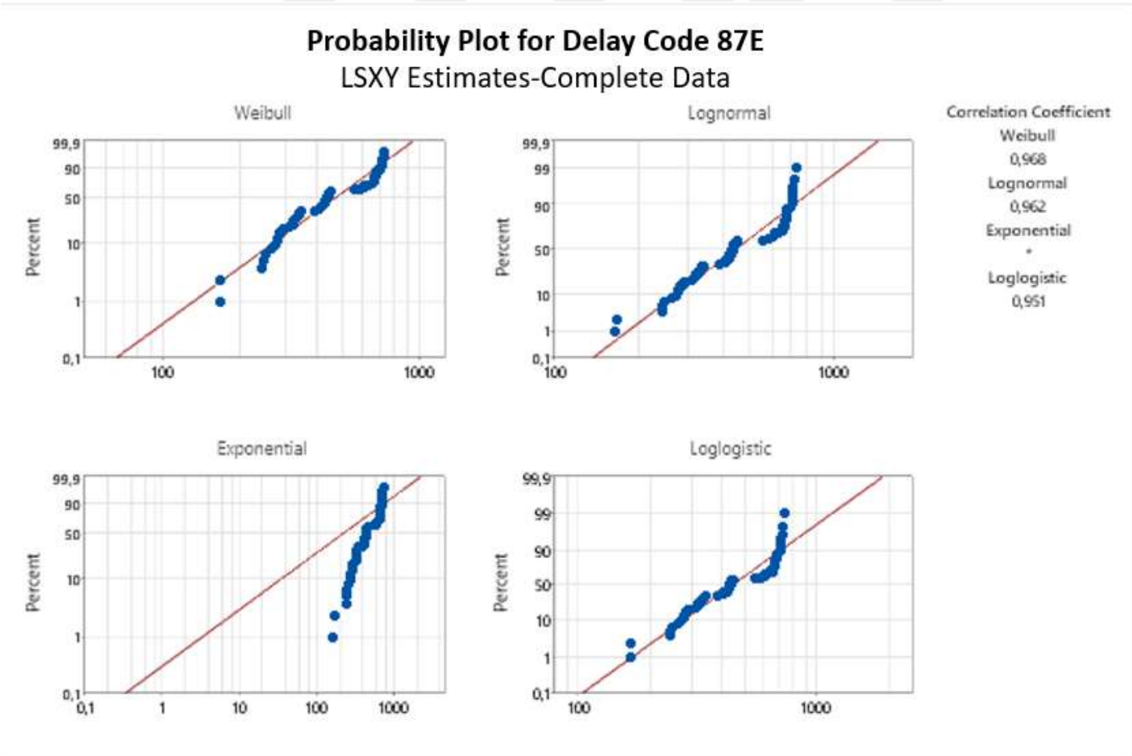

Figure B.14.: Delay code 87E – Correlation coefficient between delay times.

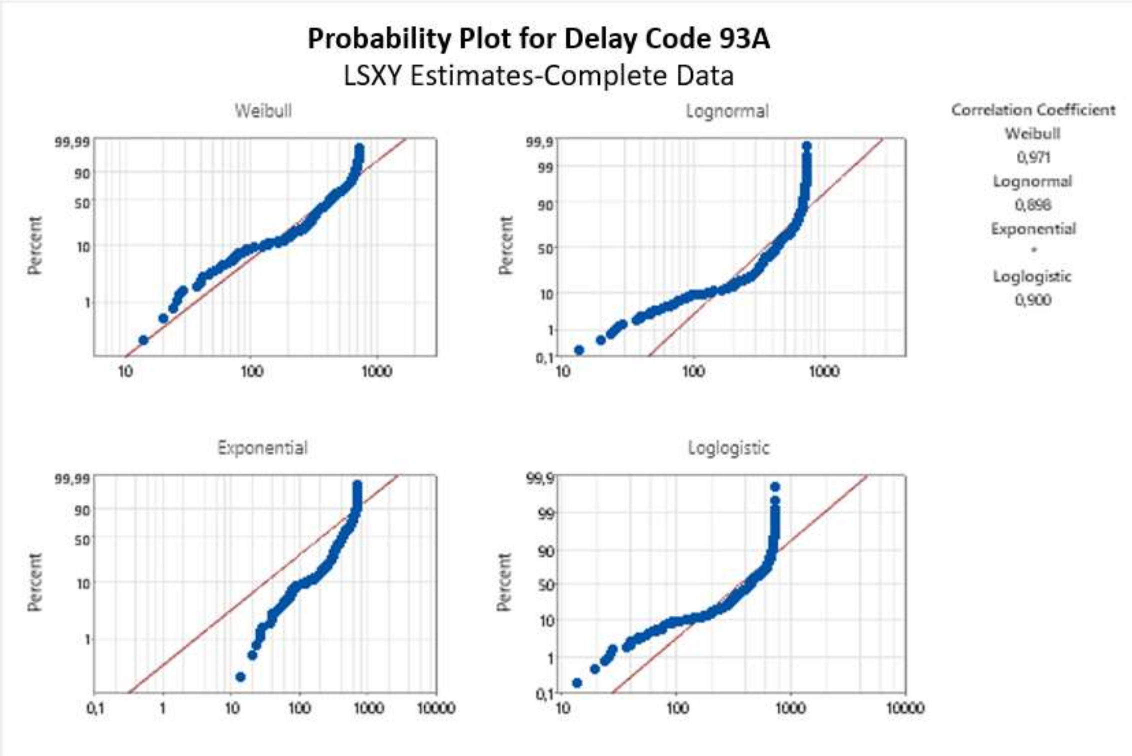

Figure B.15.: Delay code 93A – Correlation coefficient between delay times.

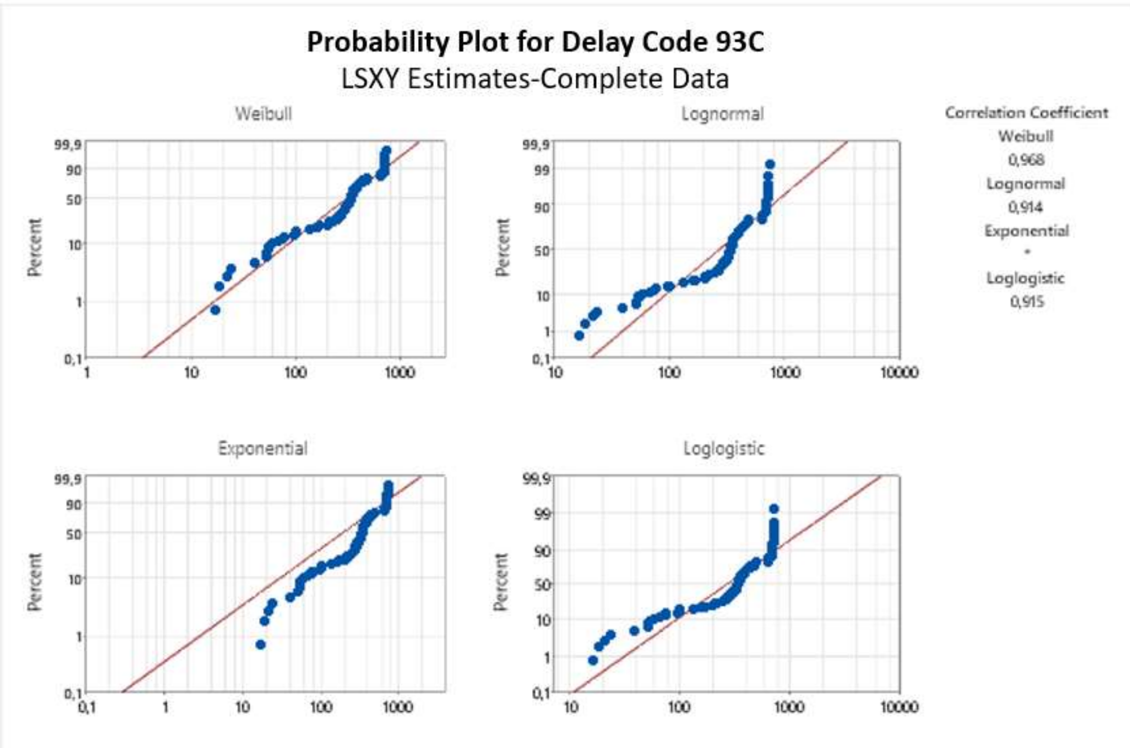

Figure B.16.: Delay code 93C – Correlation coefficient between delay times.

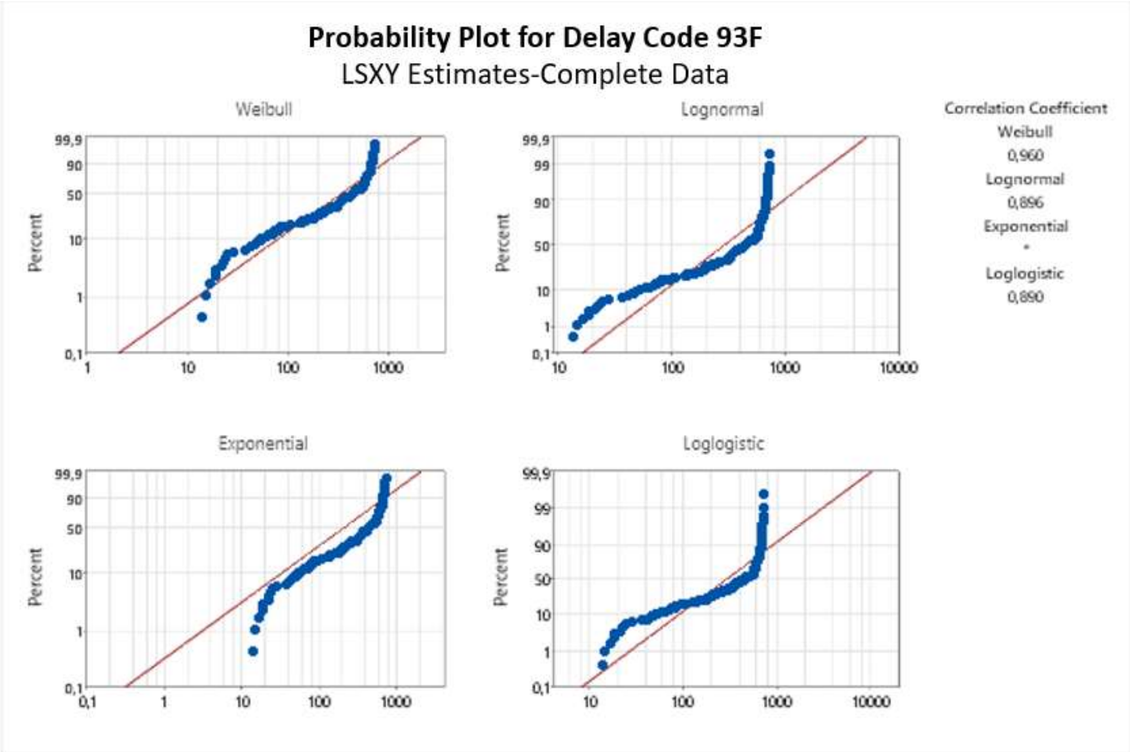

Figure B.17.: Delay code 93F – Correlation coefficient between delay times.

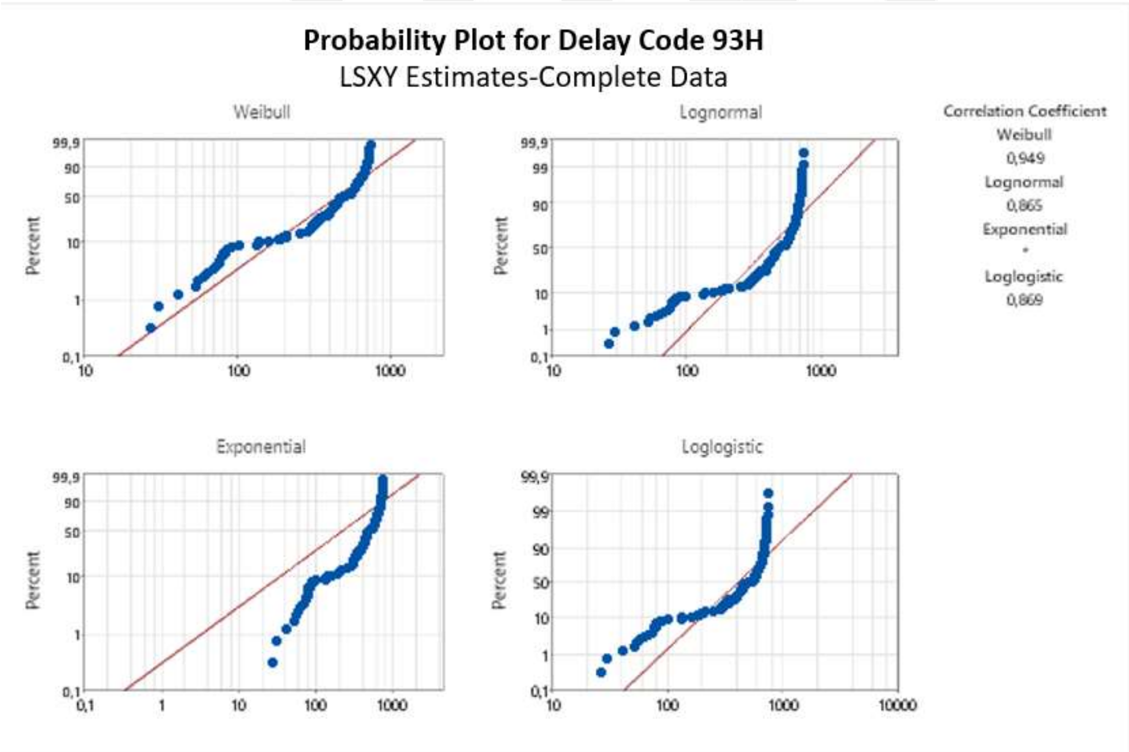

Figure B.18.: Delay code 93H – Correlation coefficient between delay times.

APPENDIX C

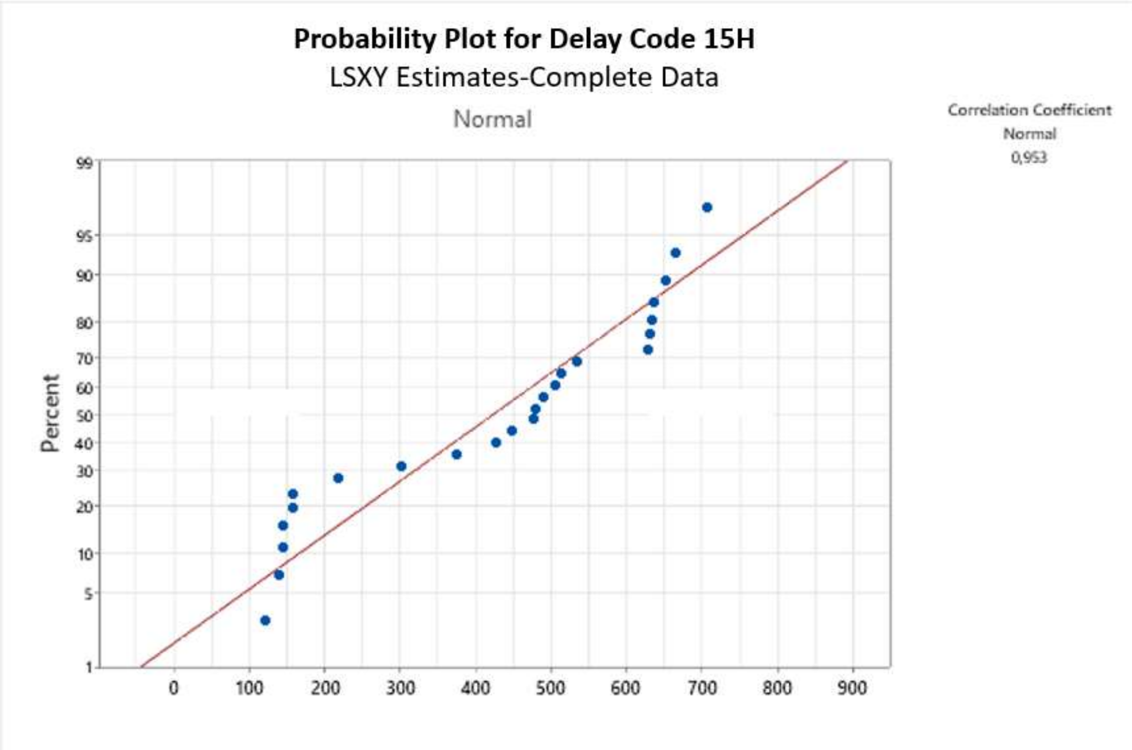

Figure C.1.: Delay code 15H – Correlation coefficient between delay times (Normal)

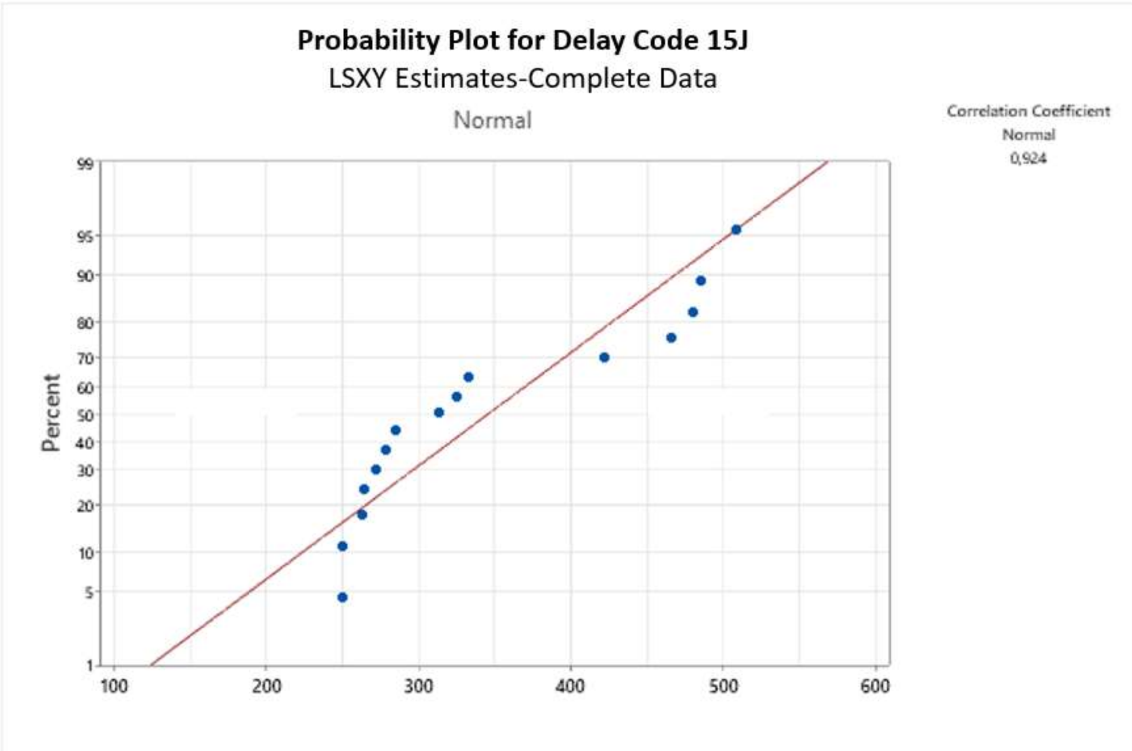

Figure C.2.: Delay code 15J – Correlation coefficient between delay times (Normal)

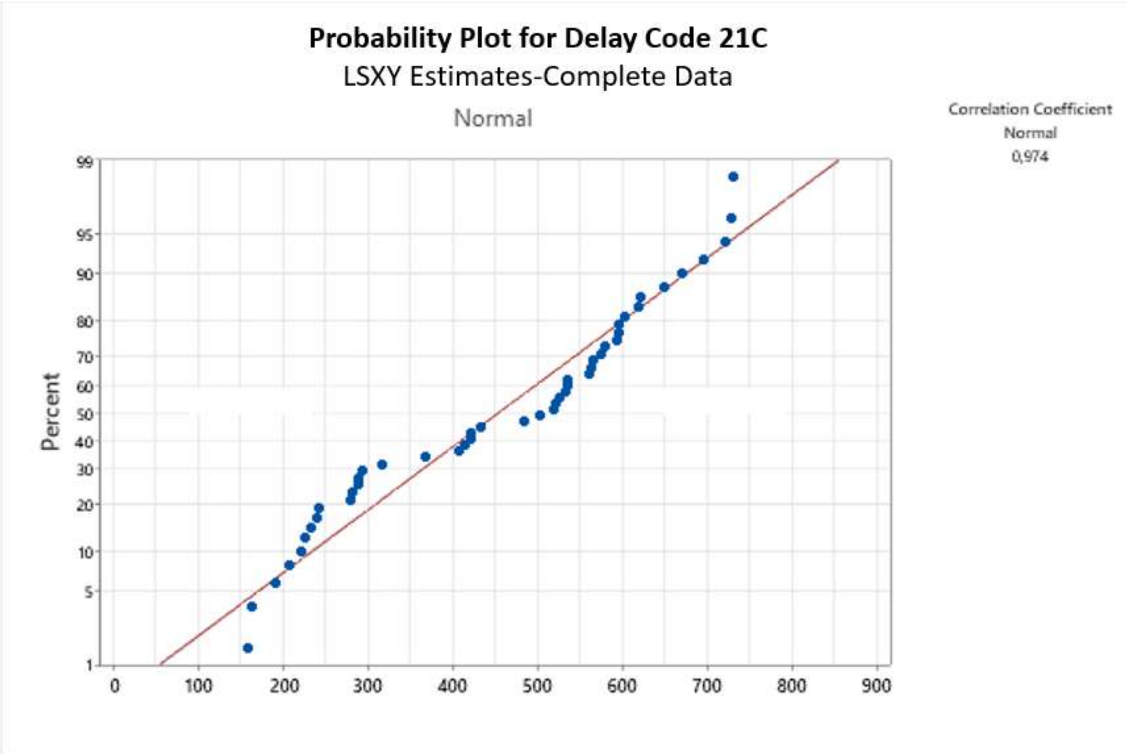

Figure C.3.: Delay code 21C – Correlation coefficient between delay times (Normal)

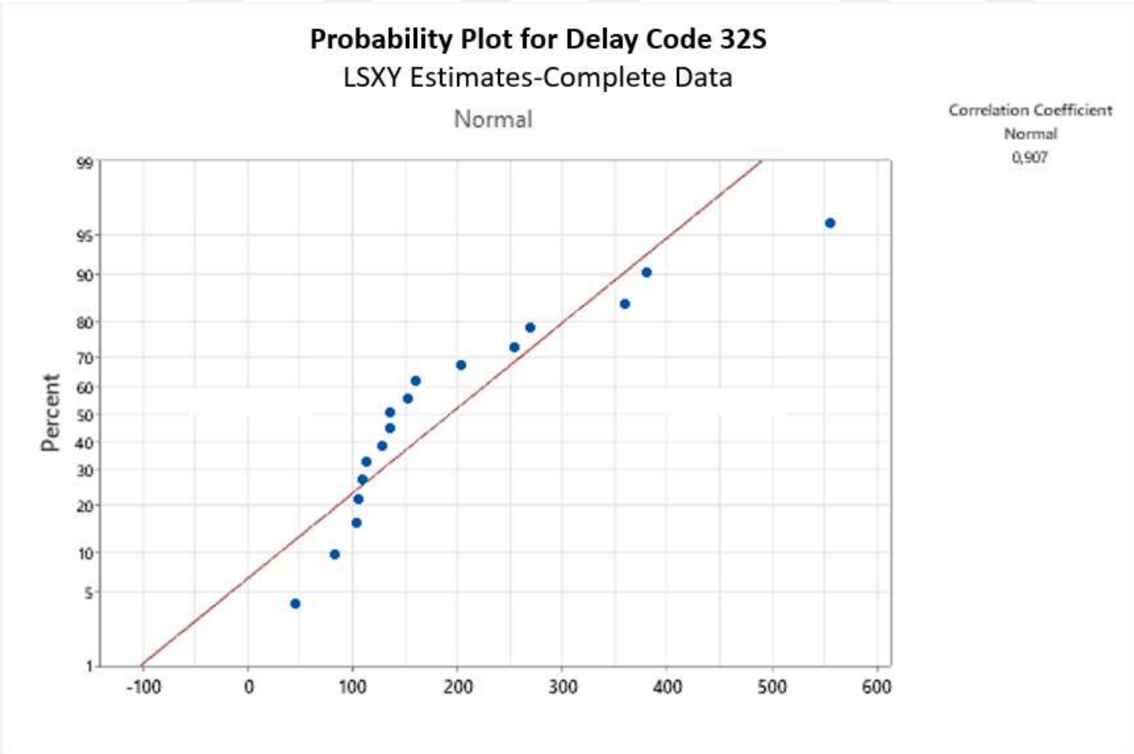

Figure C.4.: Delay code 32S – Correlation coefficient between delay times (Normal)

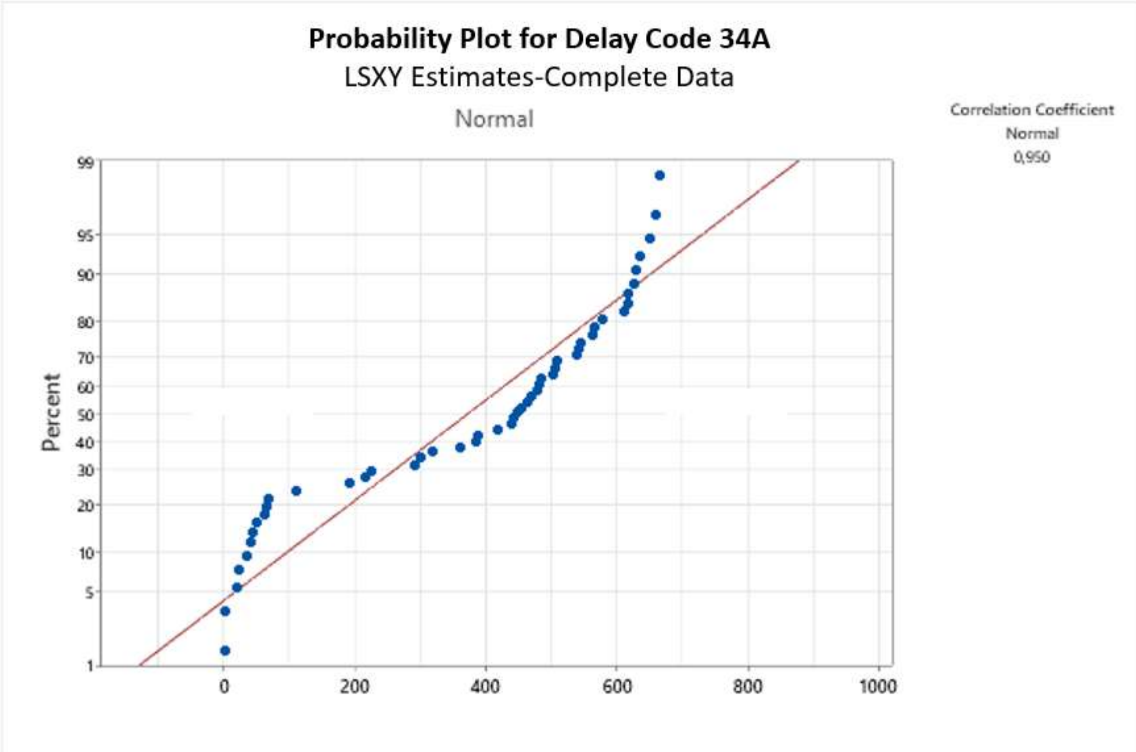

Figure C.5.: Delay code 34A – Correlation coefficient between delay times (Normal)

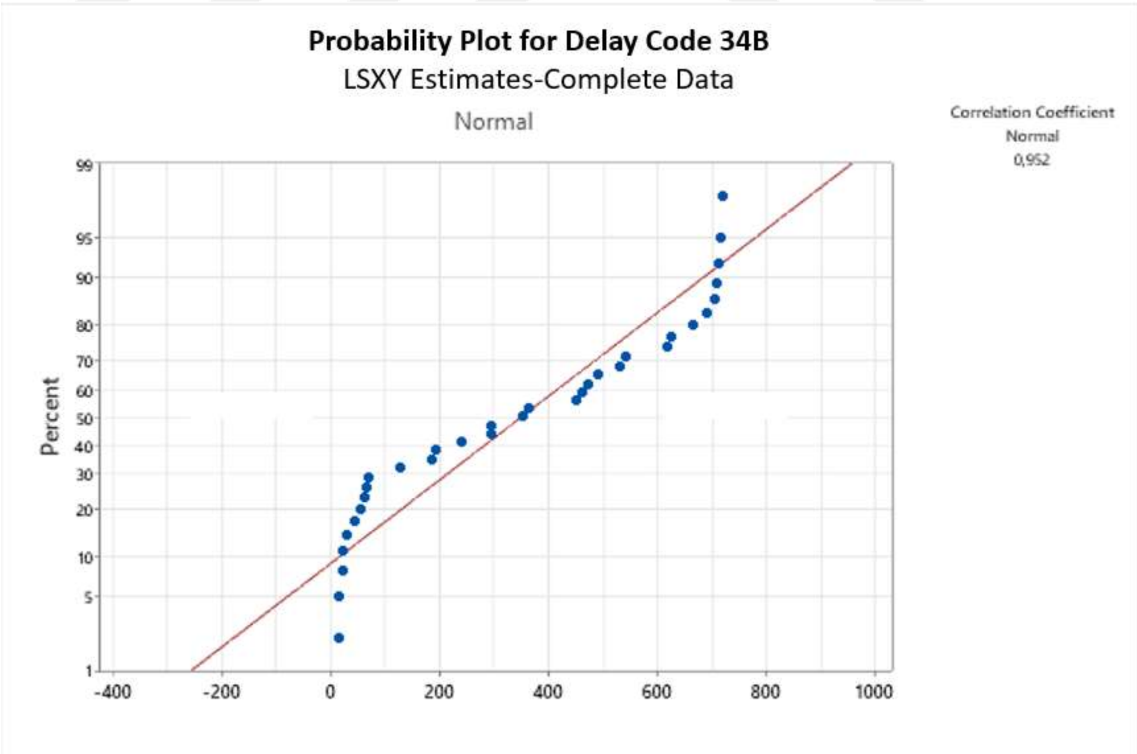

Figure C.6.: Delay code 34B – Correlation coefficient between delay times (Normal)

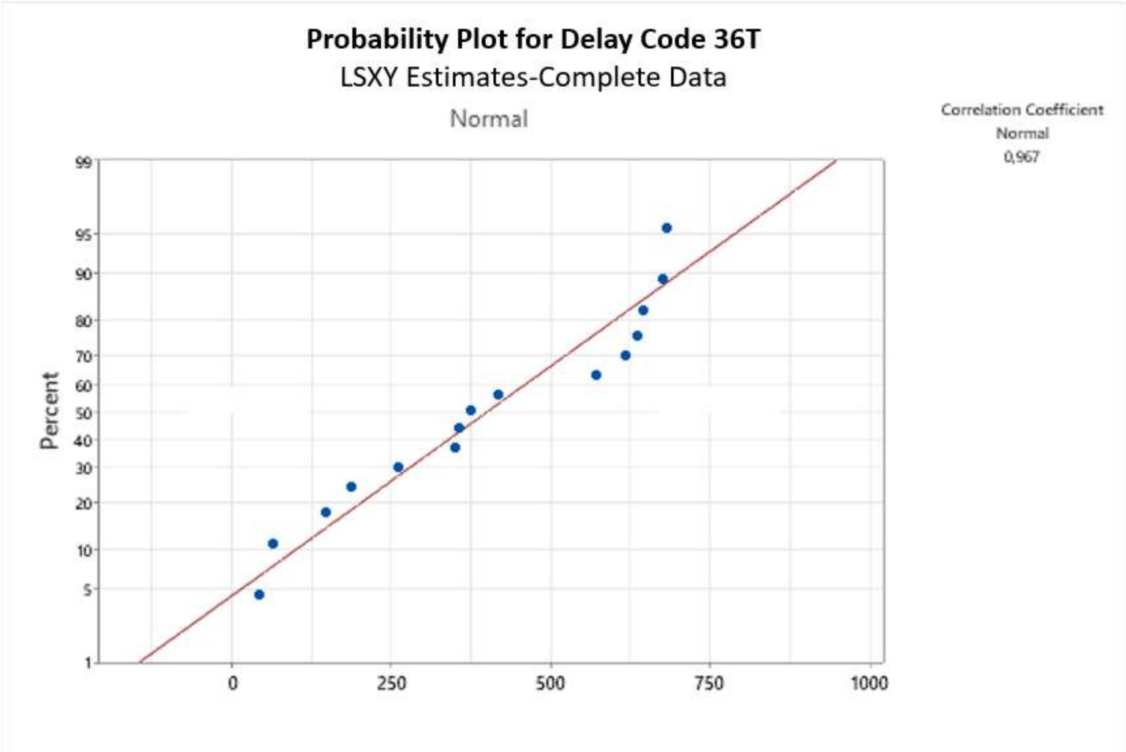

Figure C.7.: Delay code 36T – Correlation coefficient between delay times (Normal)

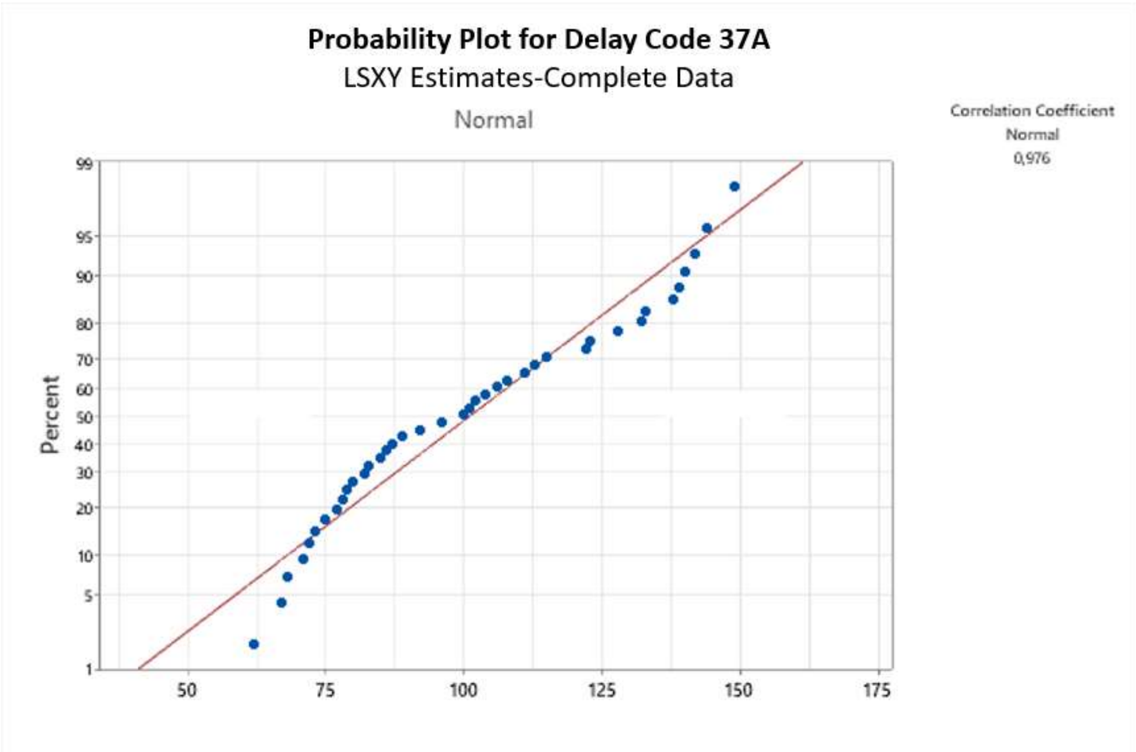

Figure C.8.: Delay code 37A – Correlation coefficient between delay times (Normal)

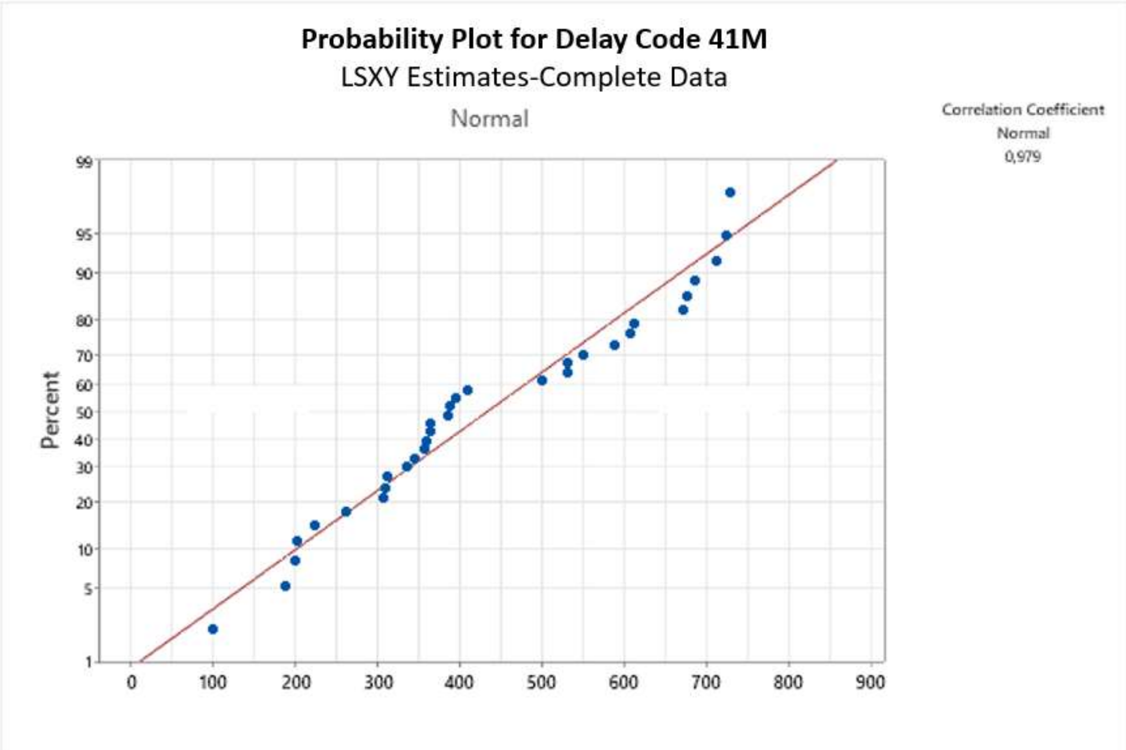

Figure C.9.: Delay code 41M – Correlation coefficient between delay times (Normal)

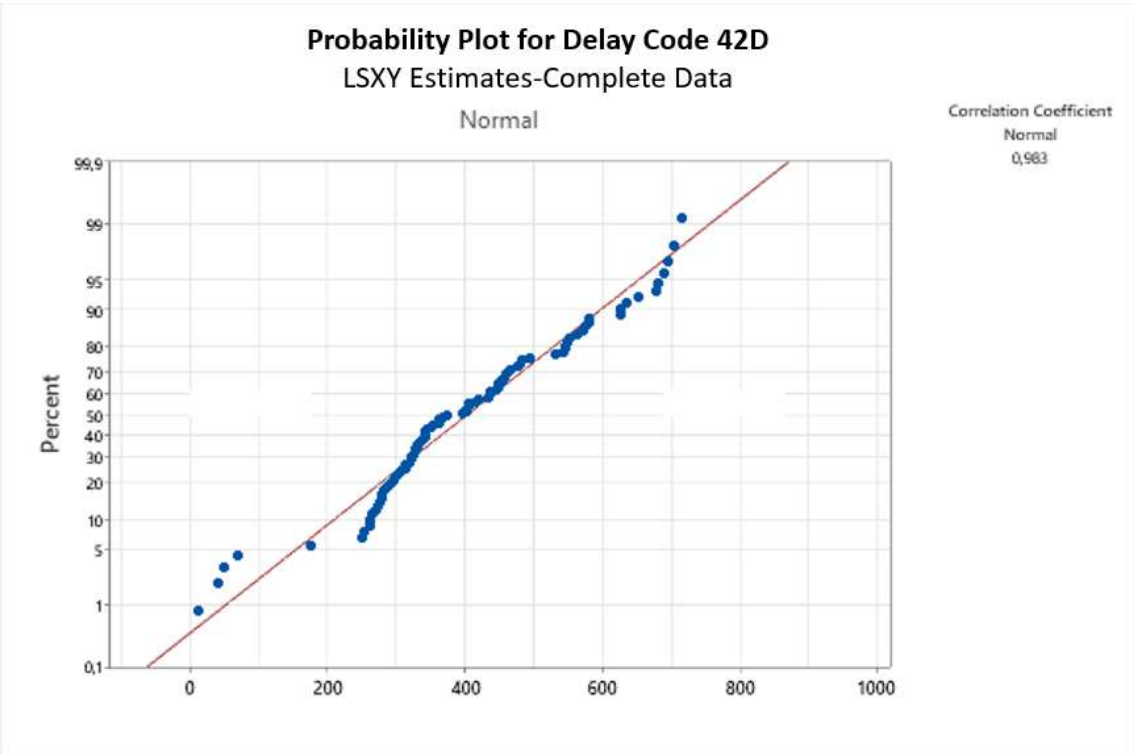

Figure C.10.: Delay code 42D – Correlation coefficient between delay times (Normal)

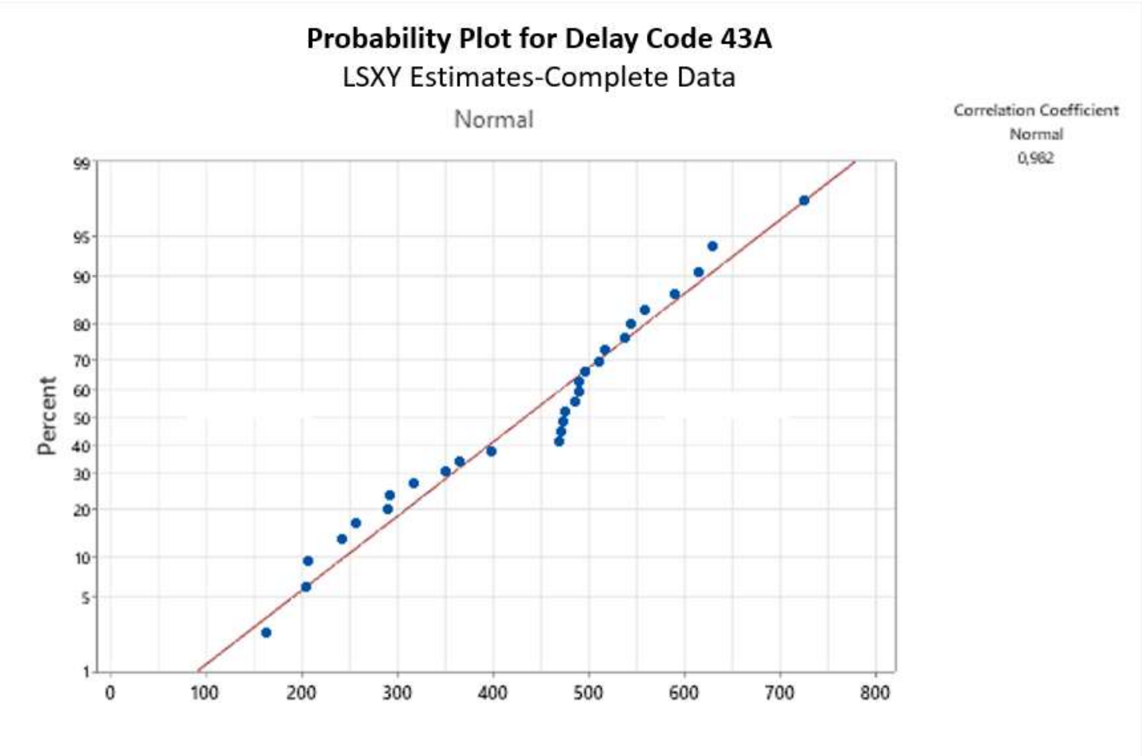

Figure C.11.: Delay code 43A – Correlation coefficient between delay times (Normal)

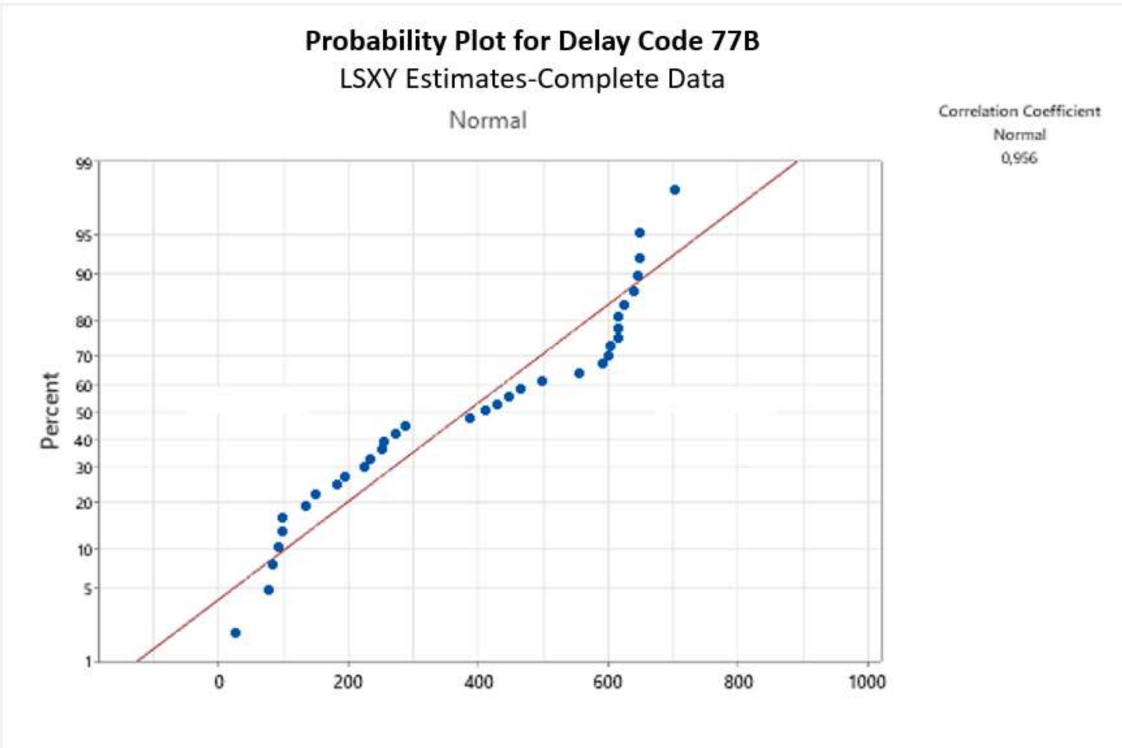

Figure C.12.: Delay code 77B – Correlation coefficient between delay times (Normal)

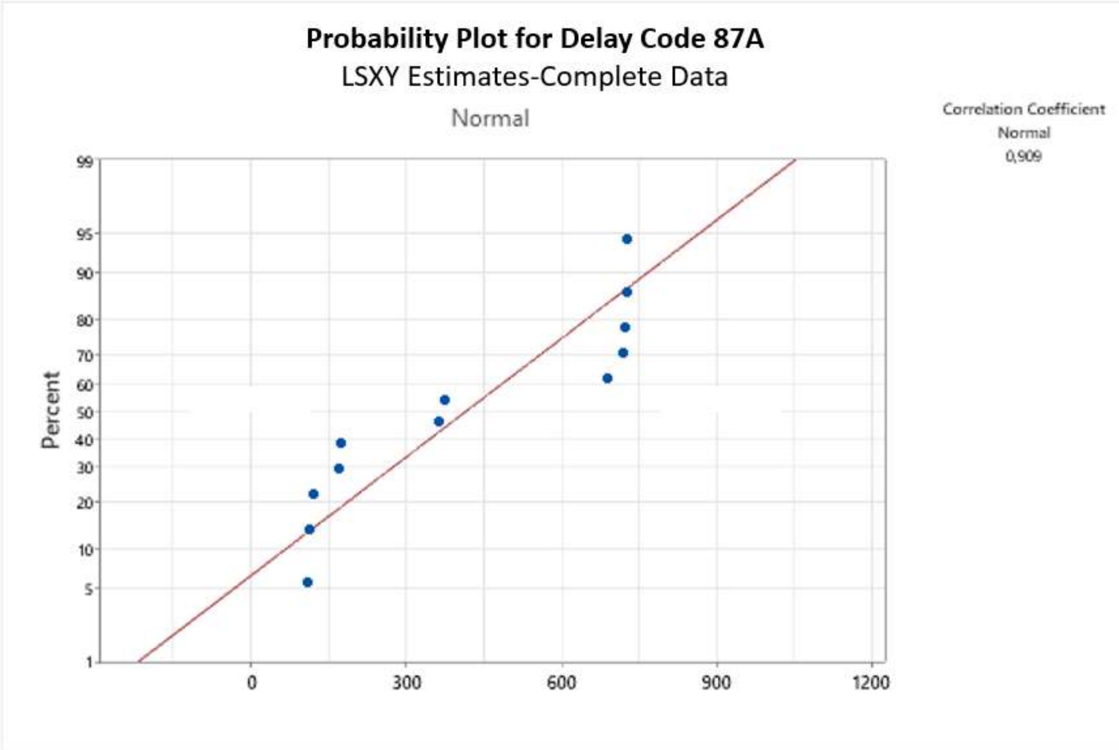

Figure C.13.: Delay code 87A – Correlation coefficient between delay times (Normal)

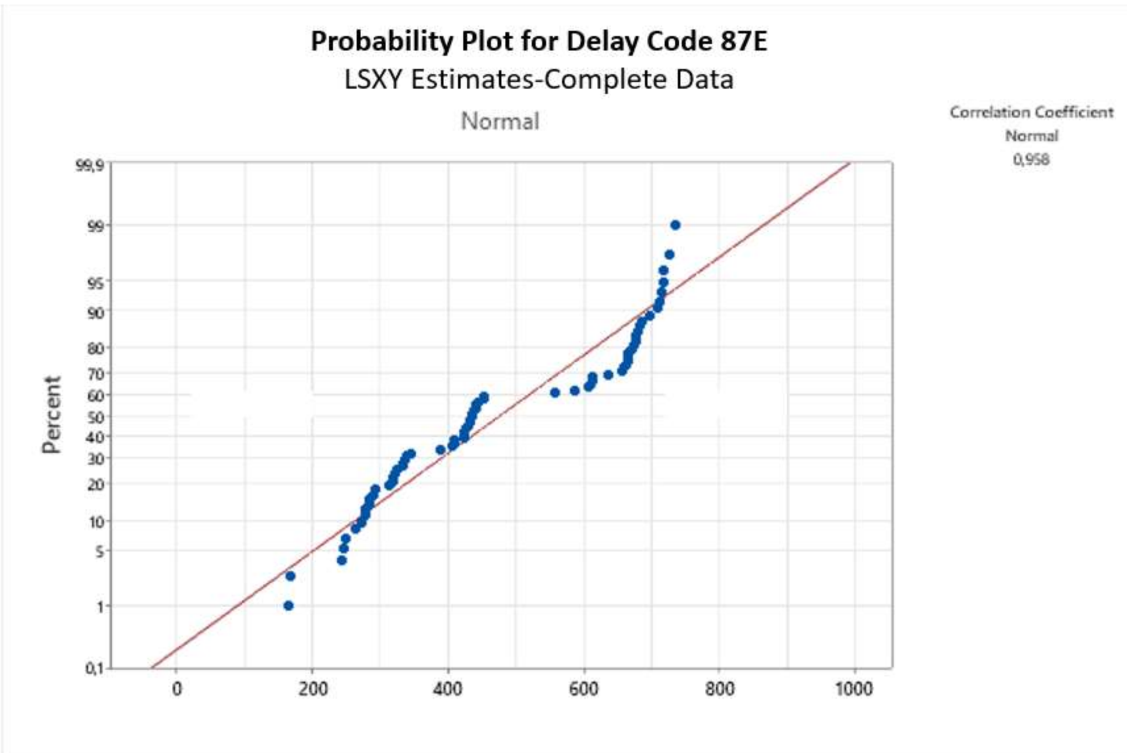

Figure C.14.: Delay code 87E – Correlation coefficient between delay times (Normal)

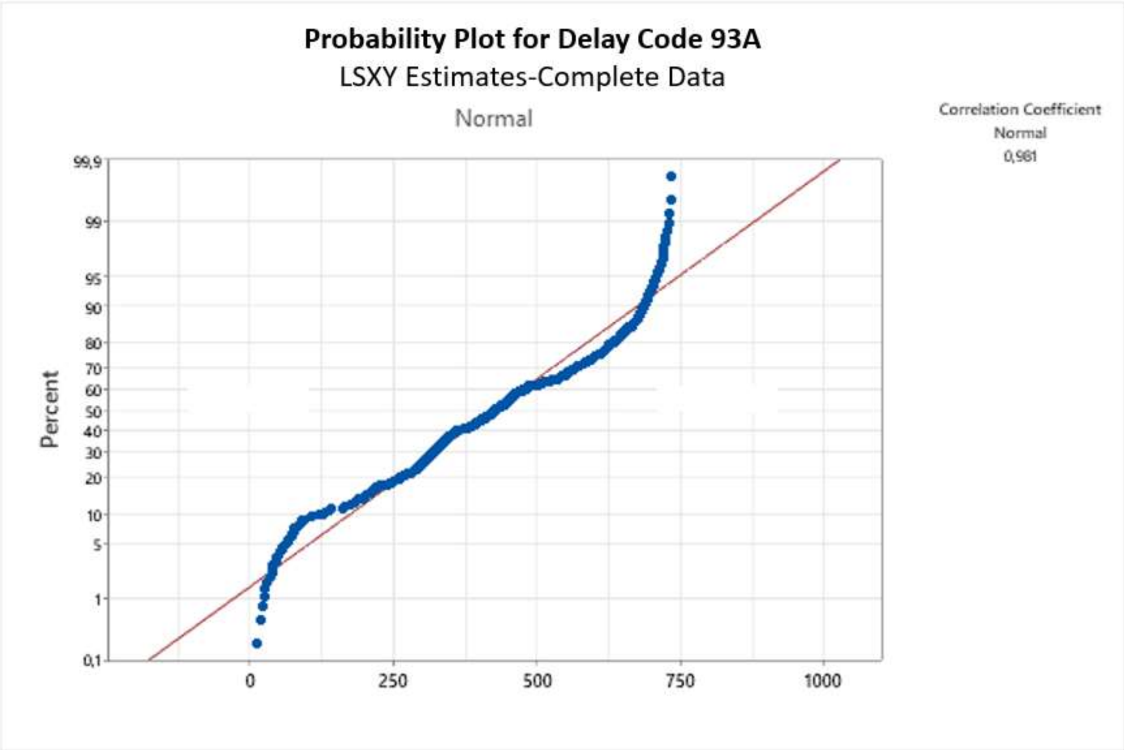

Figure C.15.: Delay code 93A – Correlation coefficient between delay times (Normal)

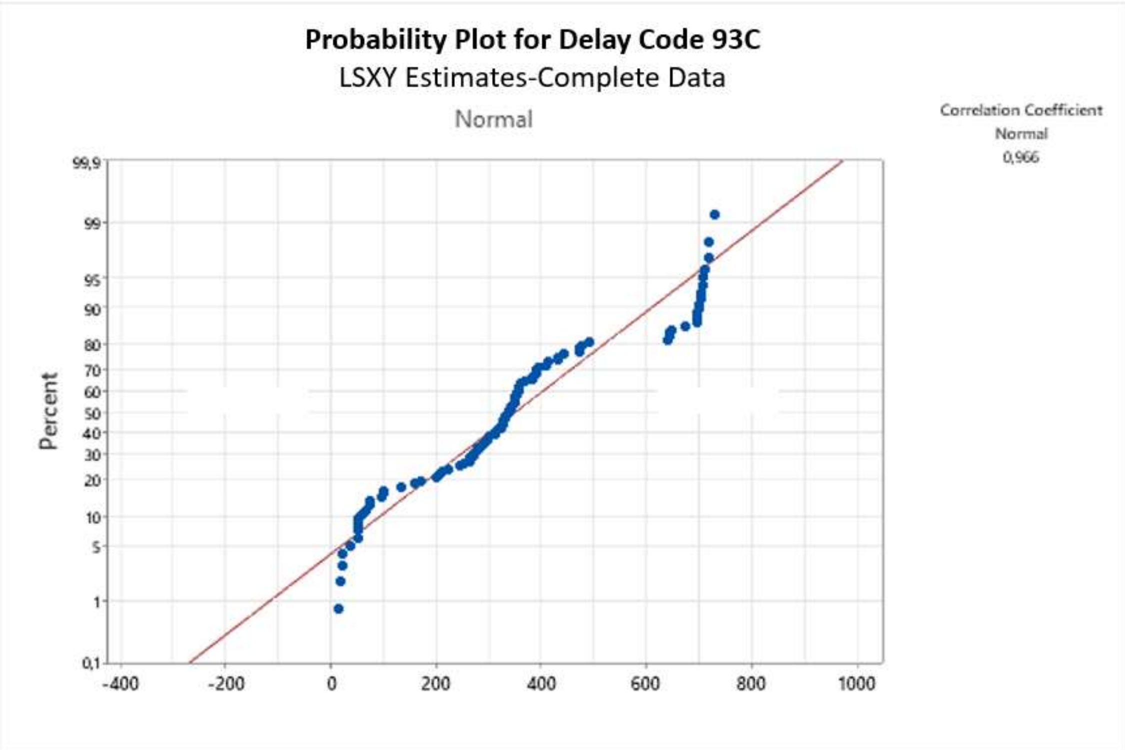

Figure C.16.: Delay Code 93C – Correlation coefficient between delay times (Normal)

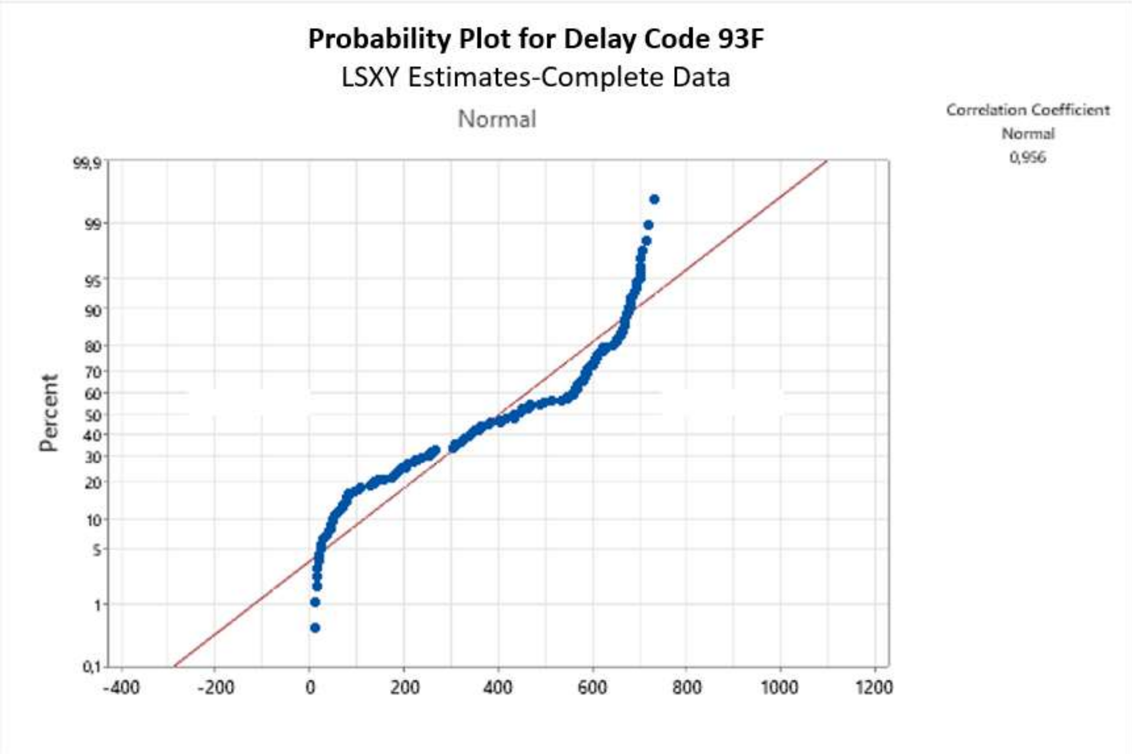

Figure C.17.: Delay Code 93F – Correlation coefficient between delay times (Normal)

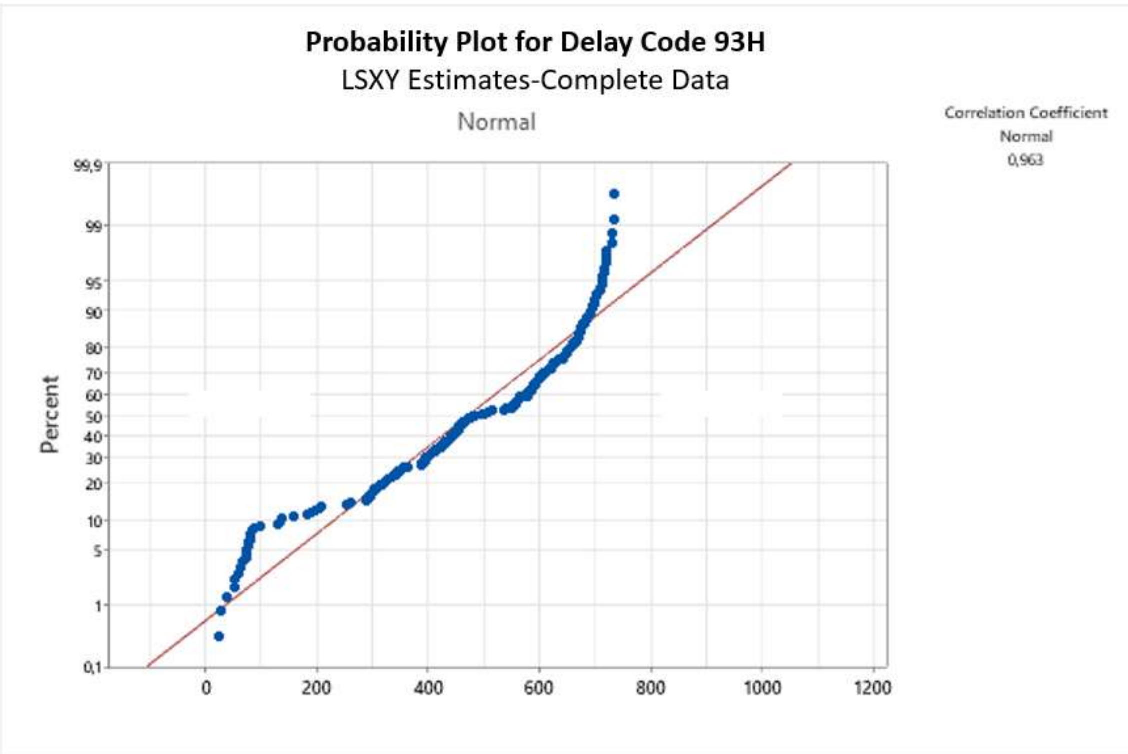

Figure C.18.: Delay Code 93H – Correlation coefficient between delay times (Normal)

APPENDIX D

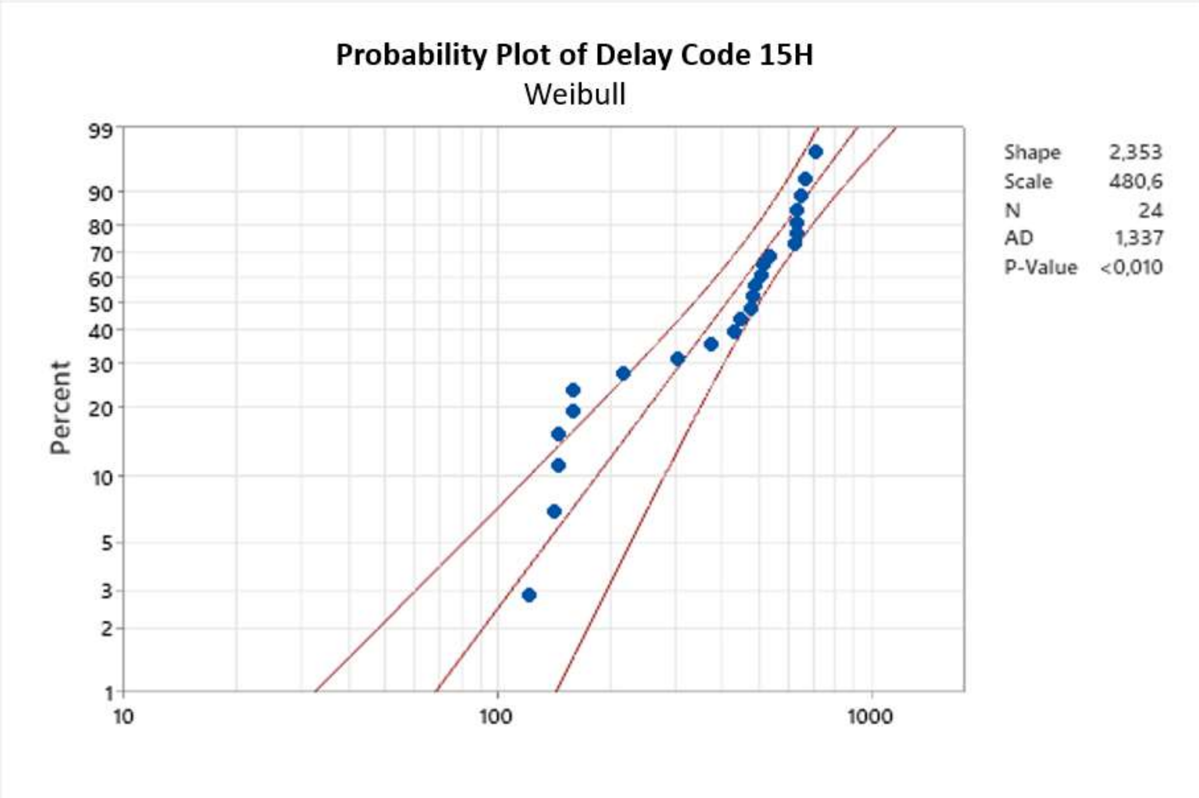

Figure D.1.: Delay code 15H - Weibull distribution plotting.

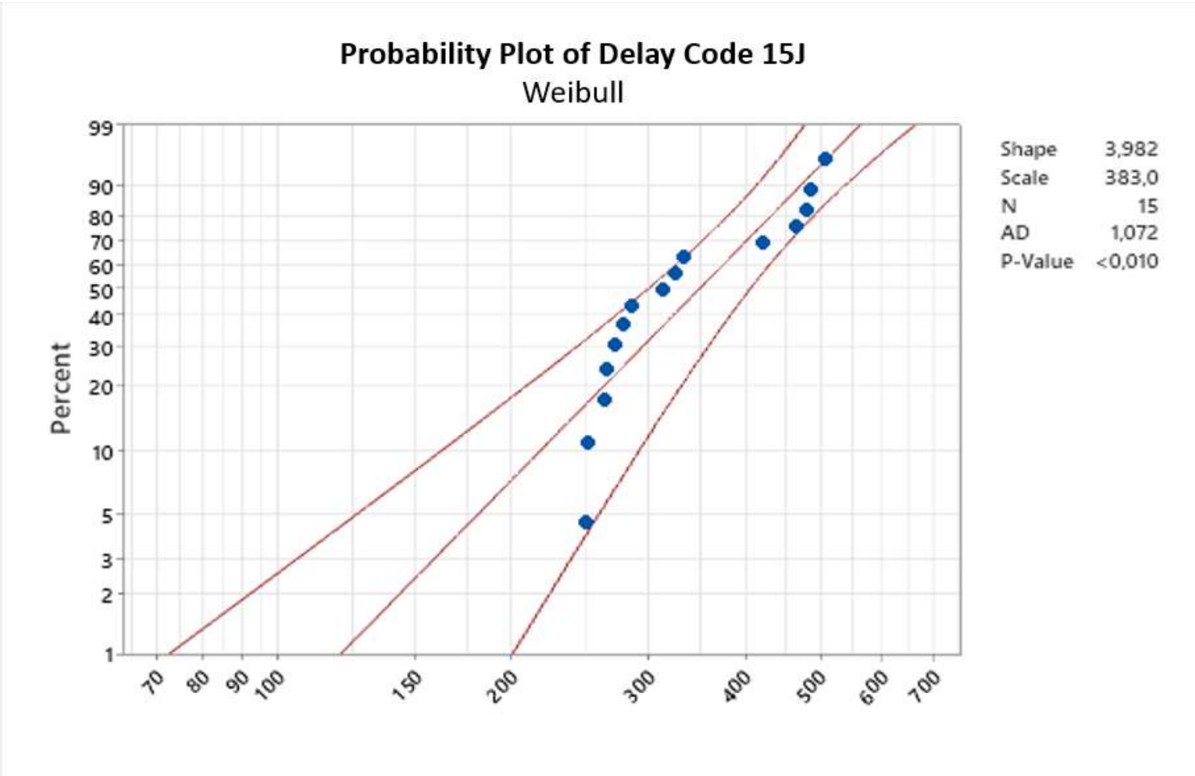

Figure D.2.: Delay Code 15J - Weibull distribution plotting.

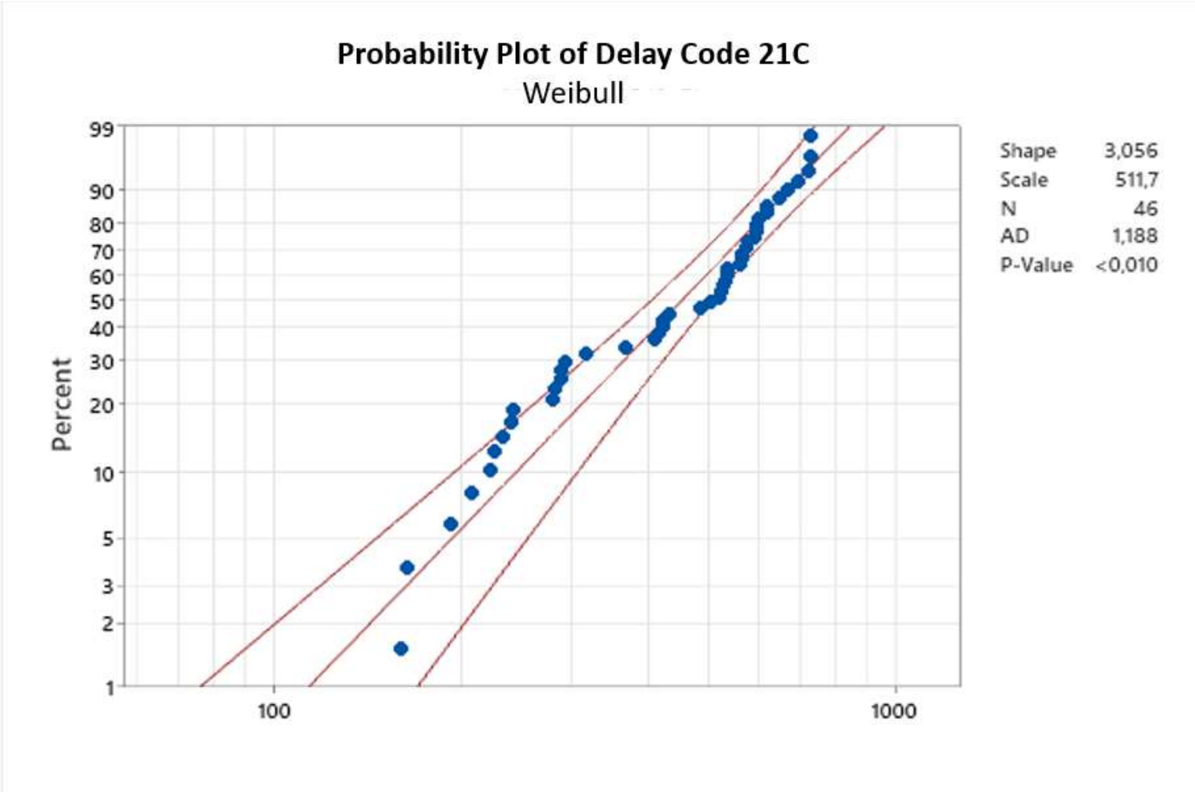

Figure D.3.: Delay code 21C - Weibull distribution plotting.

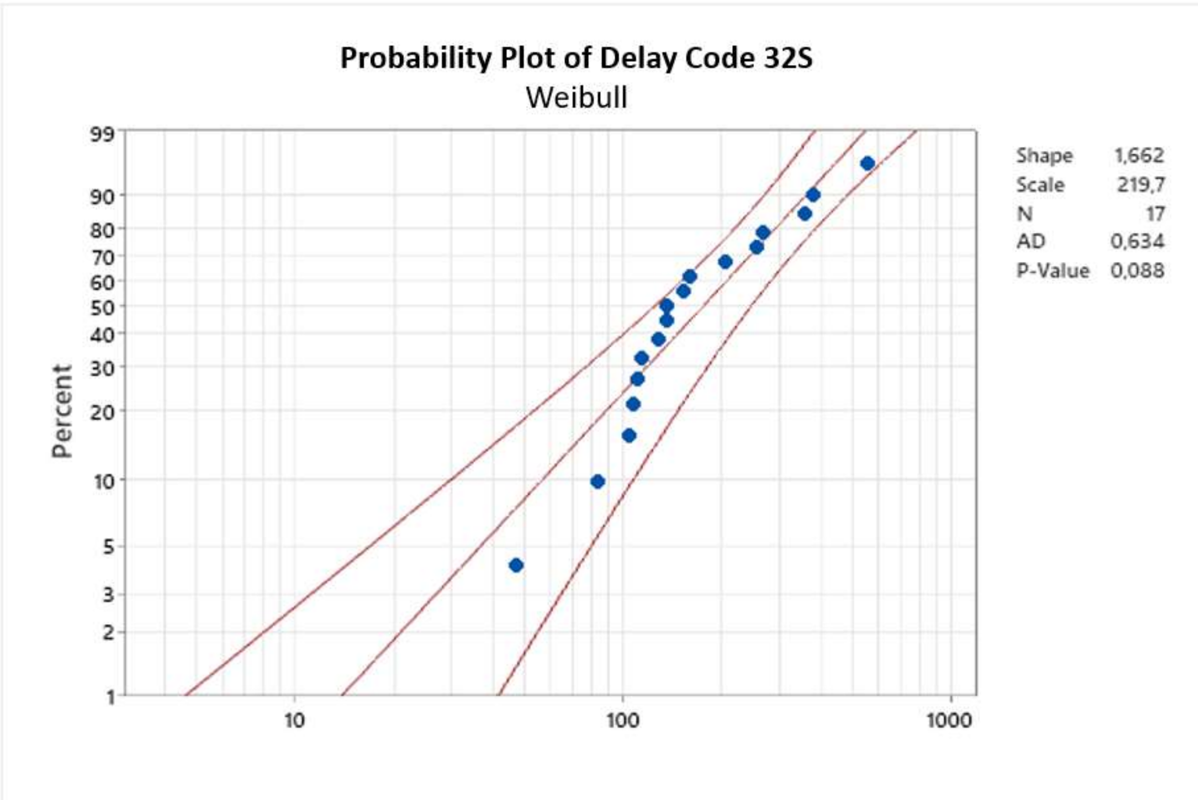

Figure D.4.: Delay code 32S - Weibull distribution plotting.

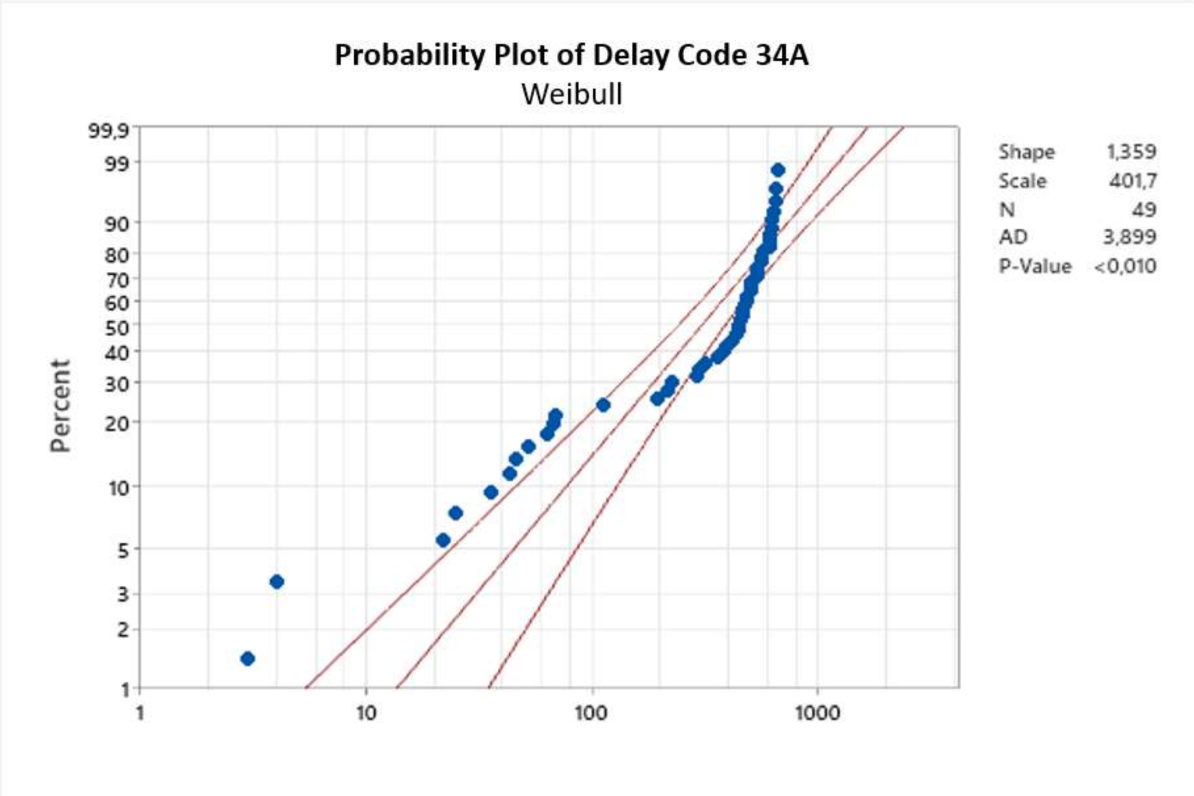

Figure D.5.: Delay code 34A - Weibull distribution plotting.

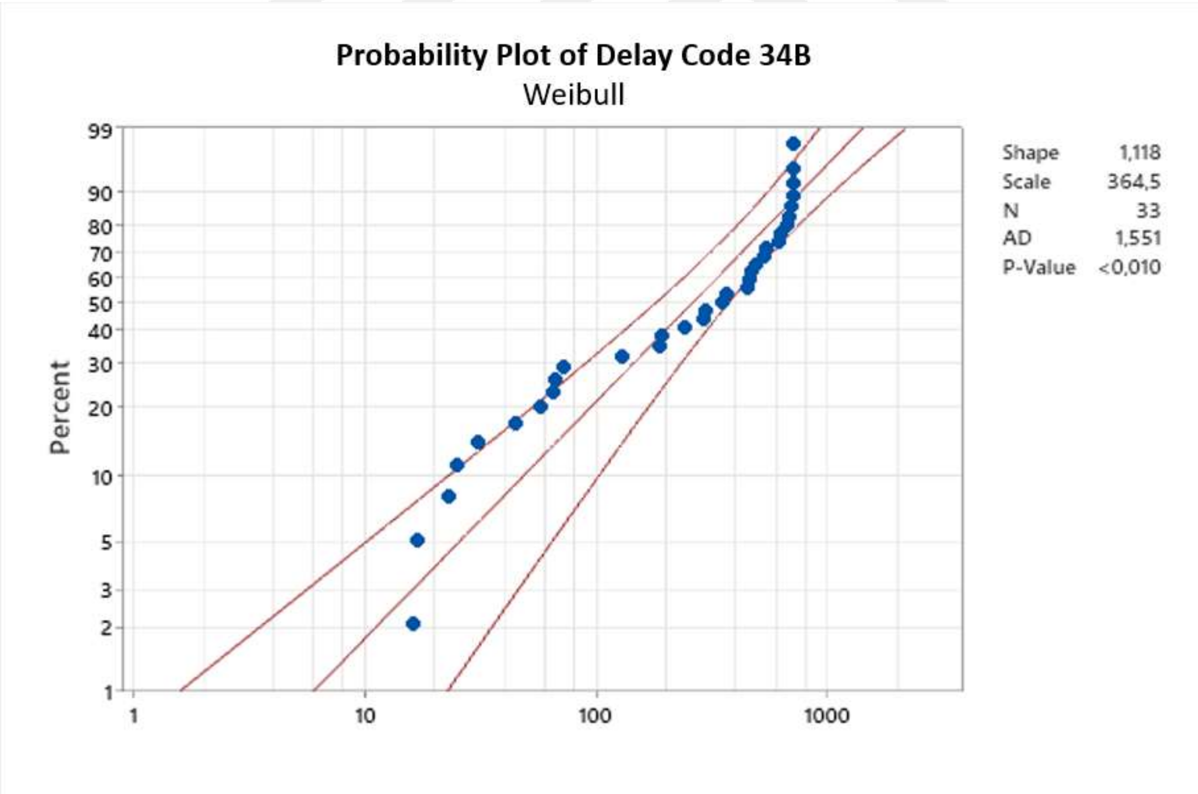

Figure D.6.: Delay code 34B - Weibull distribution plotting.

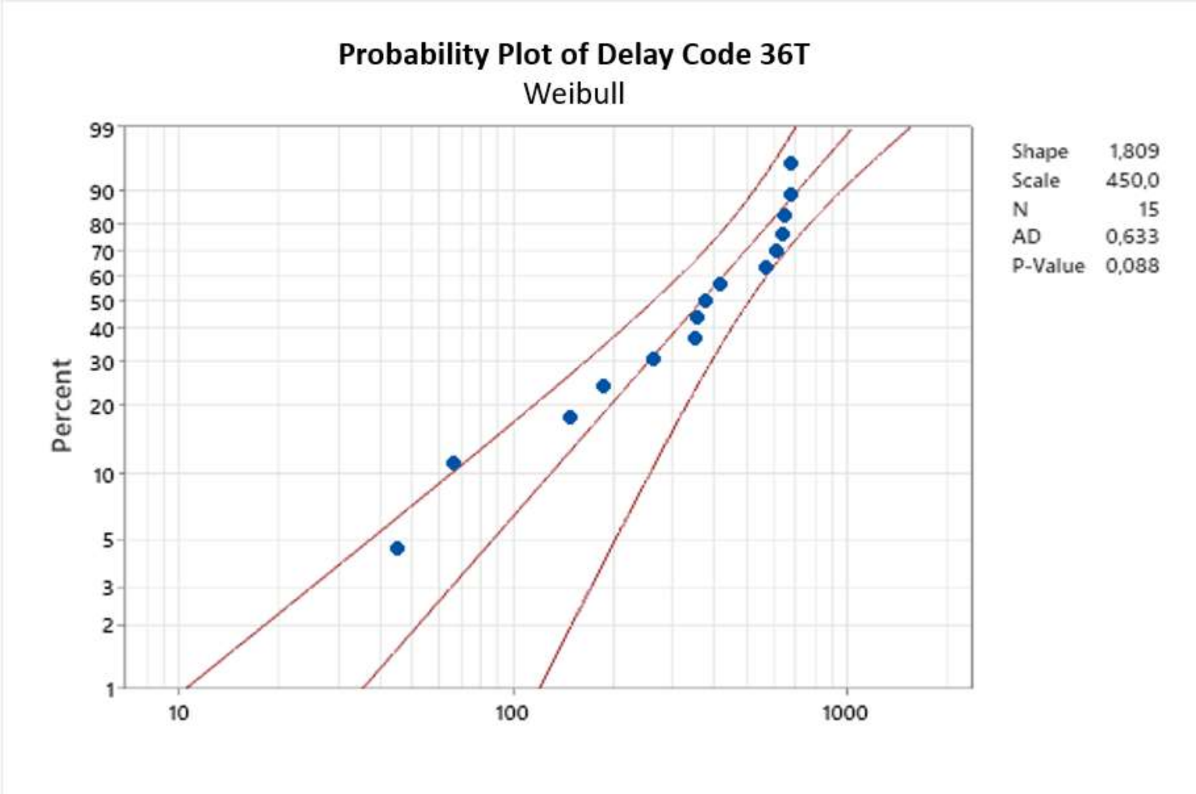

Figure D.7.: Delay code 36T - Weibull distribution plotting.

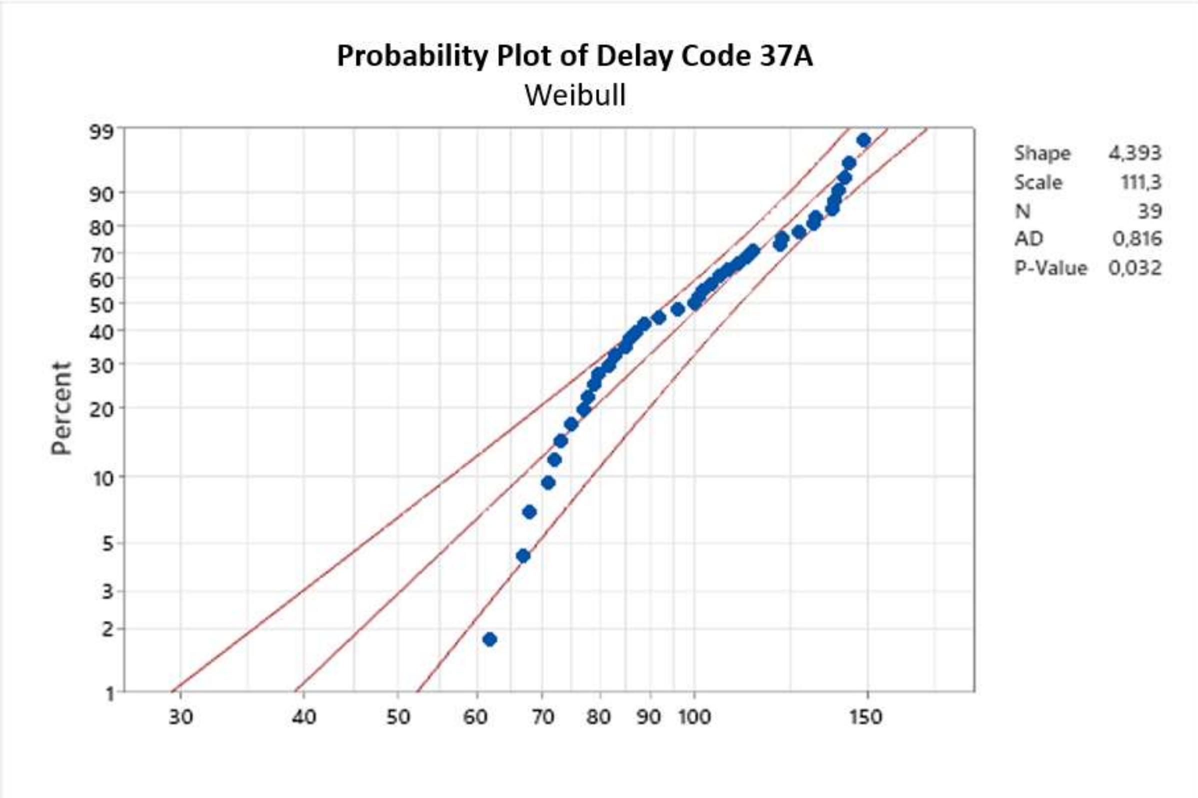

Figure D.8.: Delay code 37A - Weibull distribution plotting.

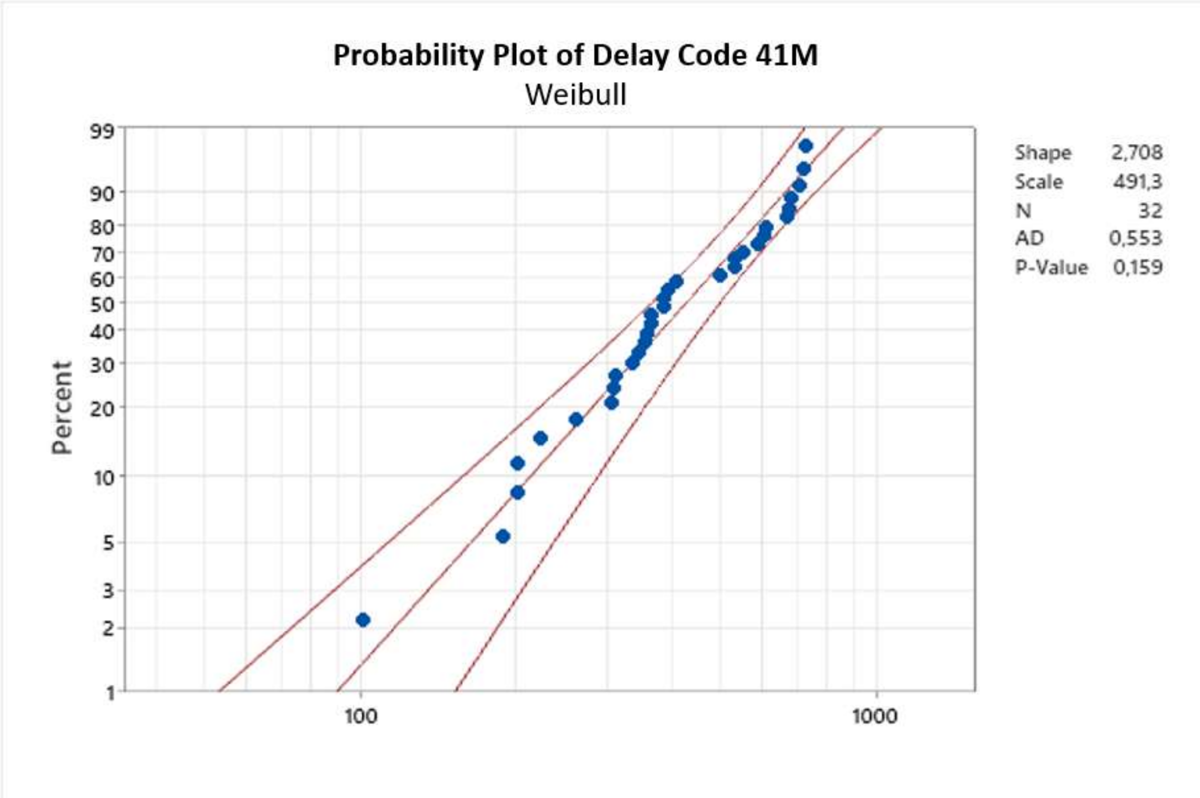

Figure D.9.: Delay code 41M - Weibull distribution plotting.

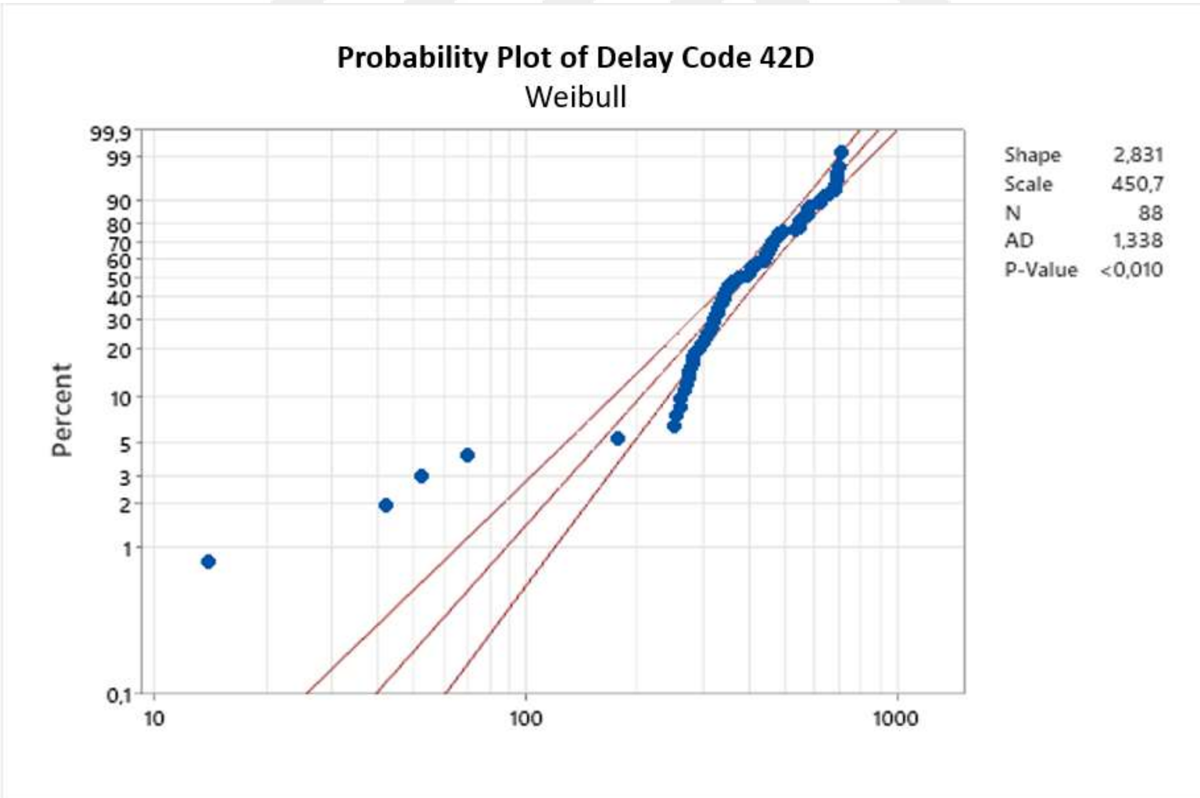

Figure D.10.: Delay code 42D - Weibull distribution plotting.

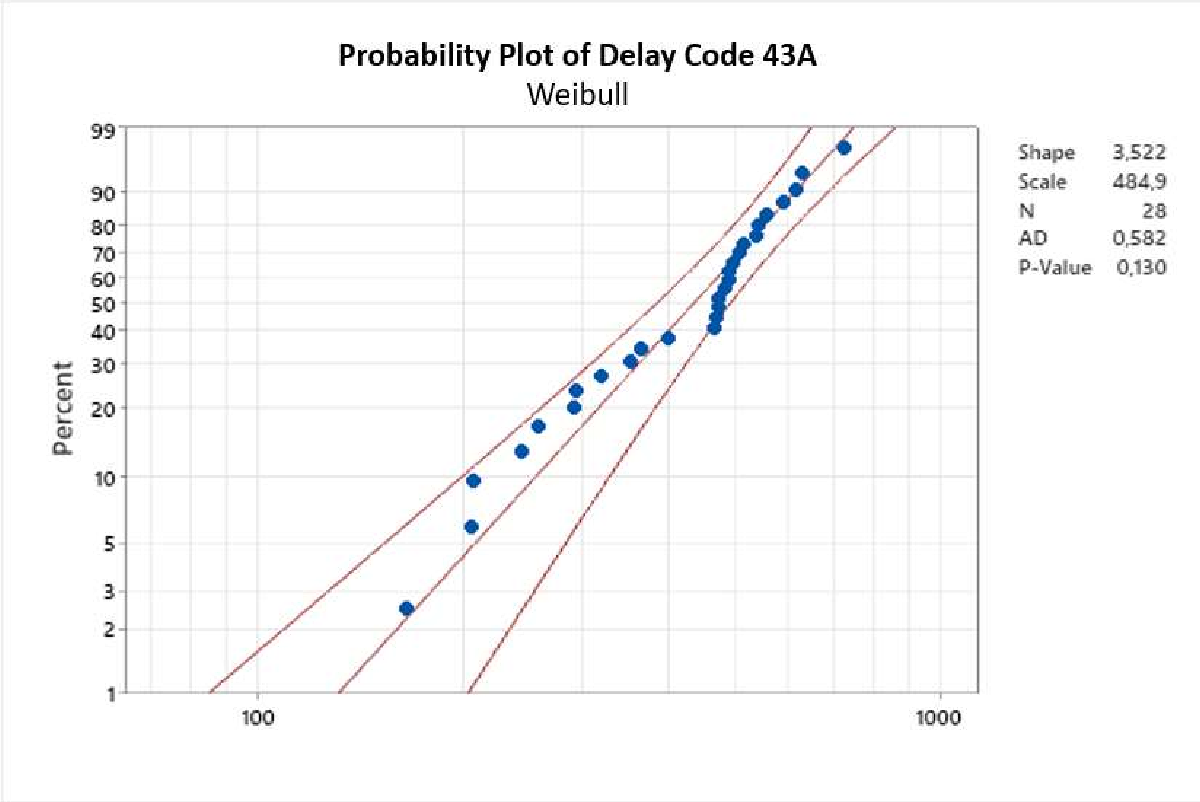

Figure D.11.: Delay code 43A - Weibull distribution plotting.

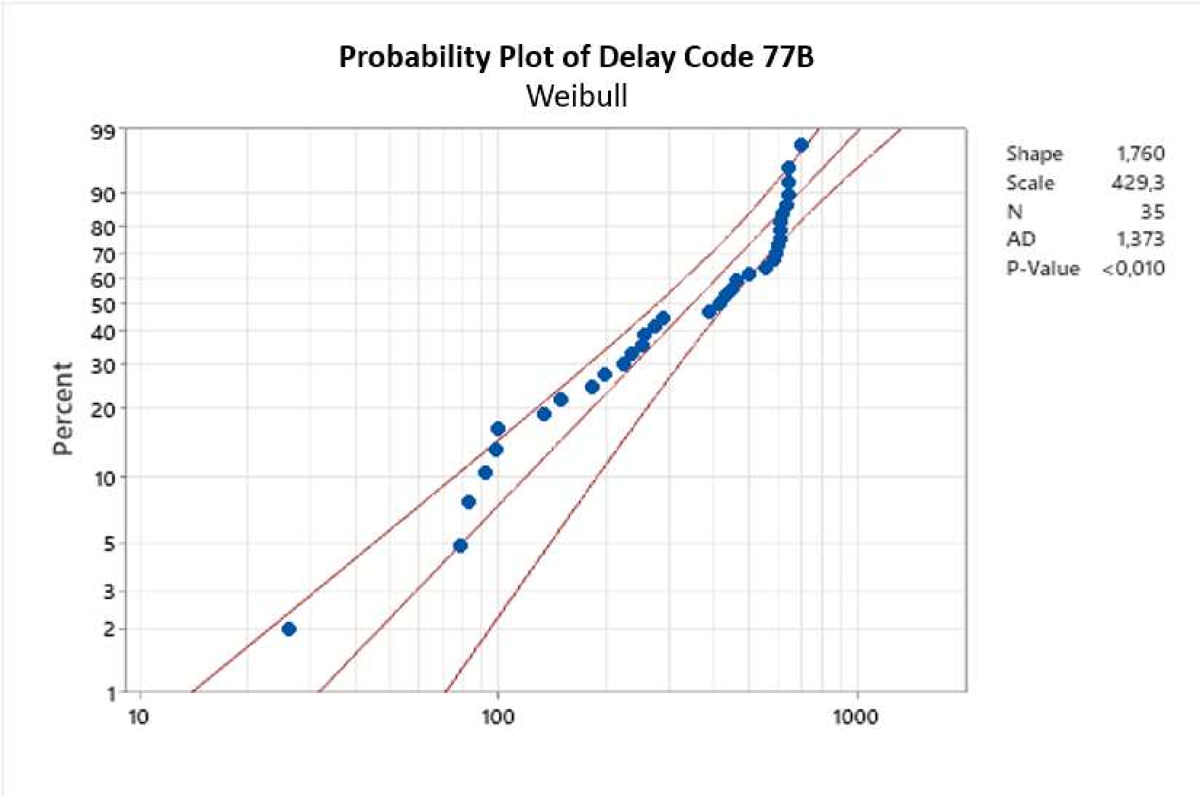

Figure D.12.: Delay code 77B - Weibull distribution plotting.

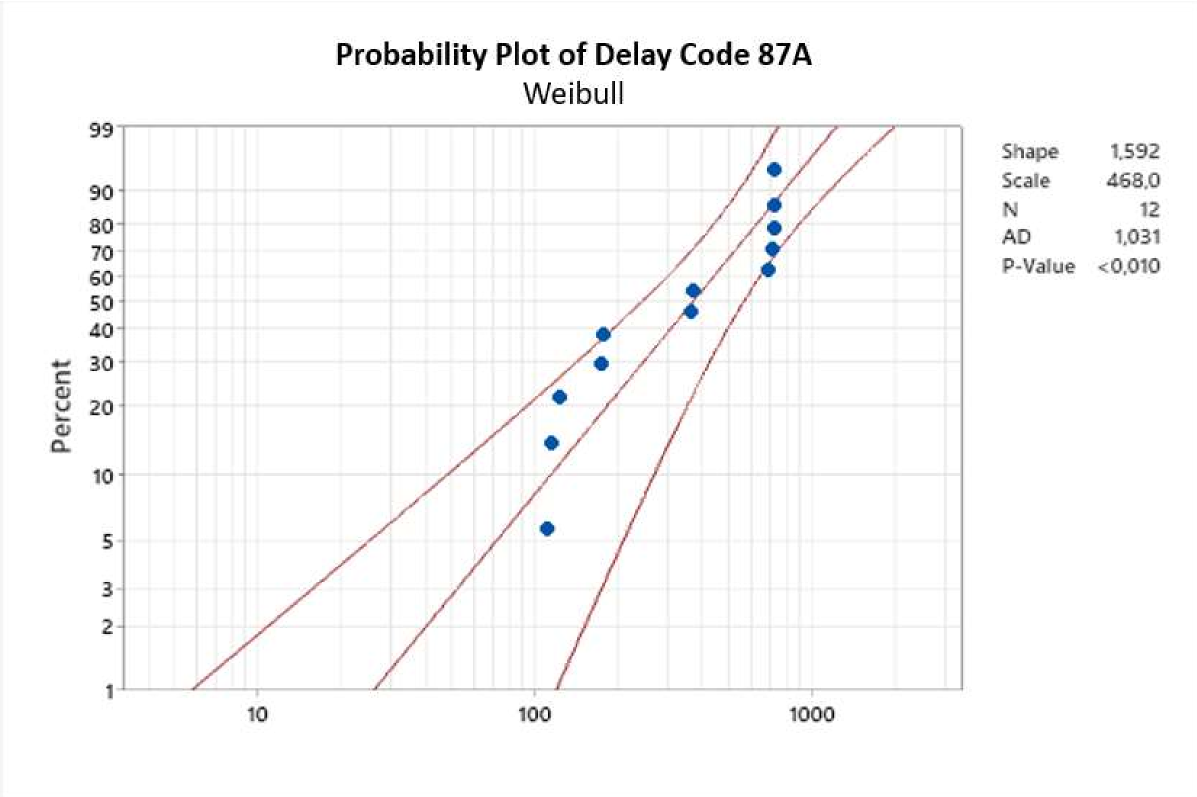

Figure D.13.: Delay code 87A - Weibull distribution plotting.

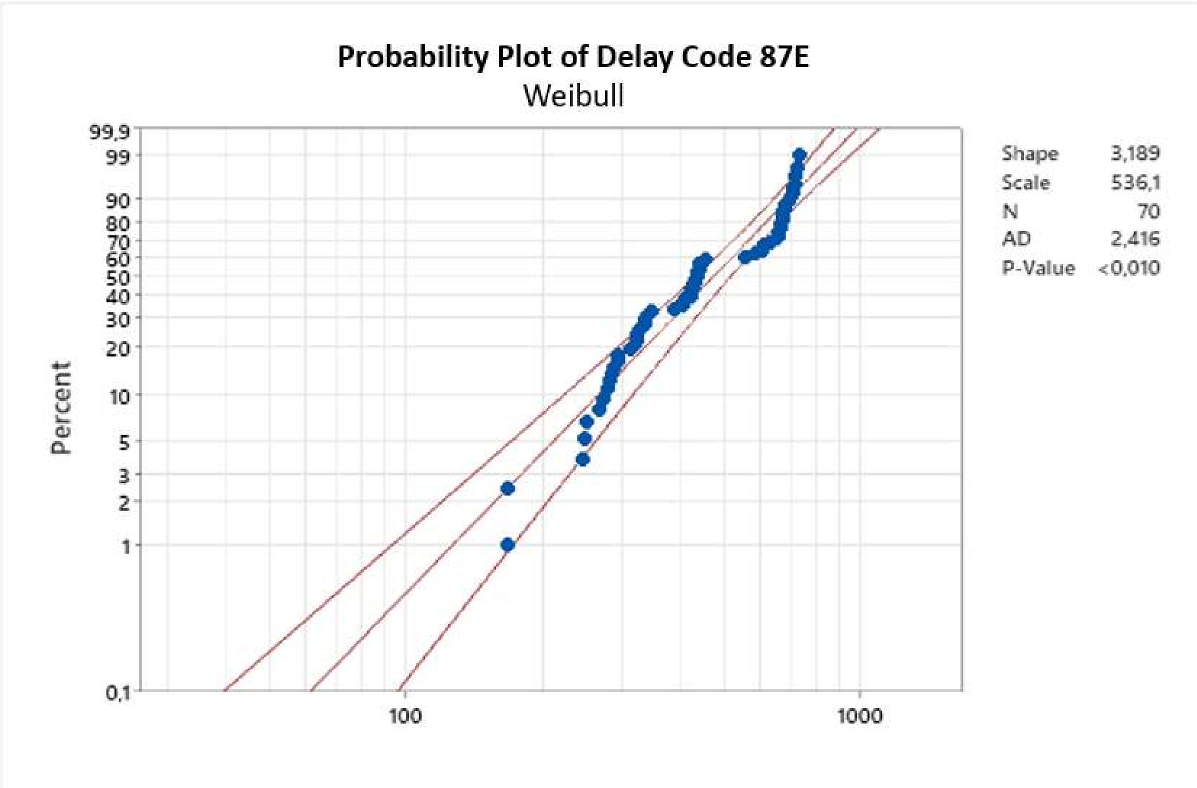

Figure D.14.: Delay code 87E - Weibull distribution plotting.

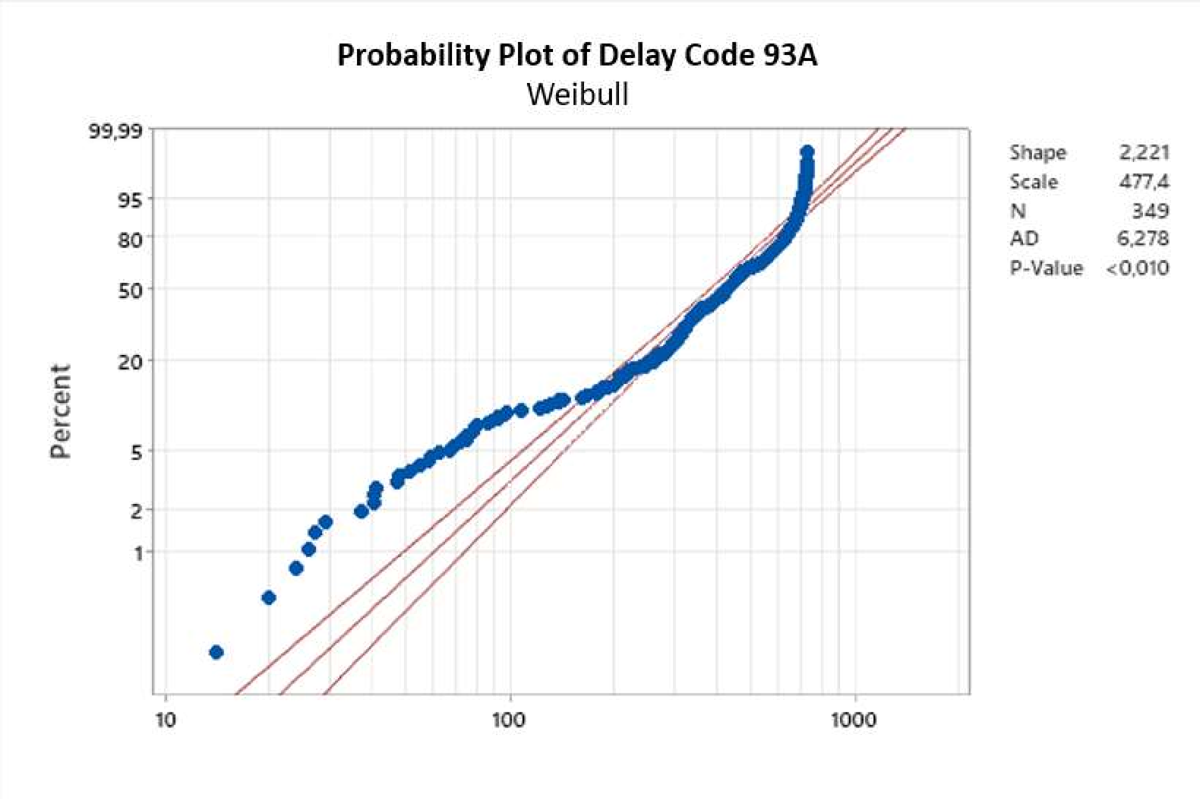

Figure D.15.: Delay code 93A - Weibull distribution plotting.

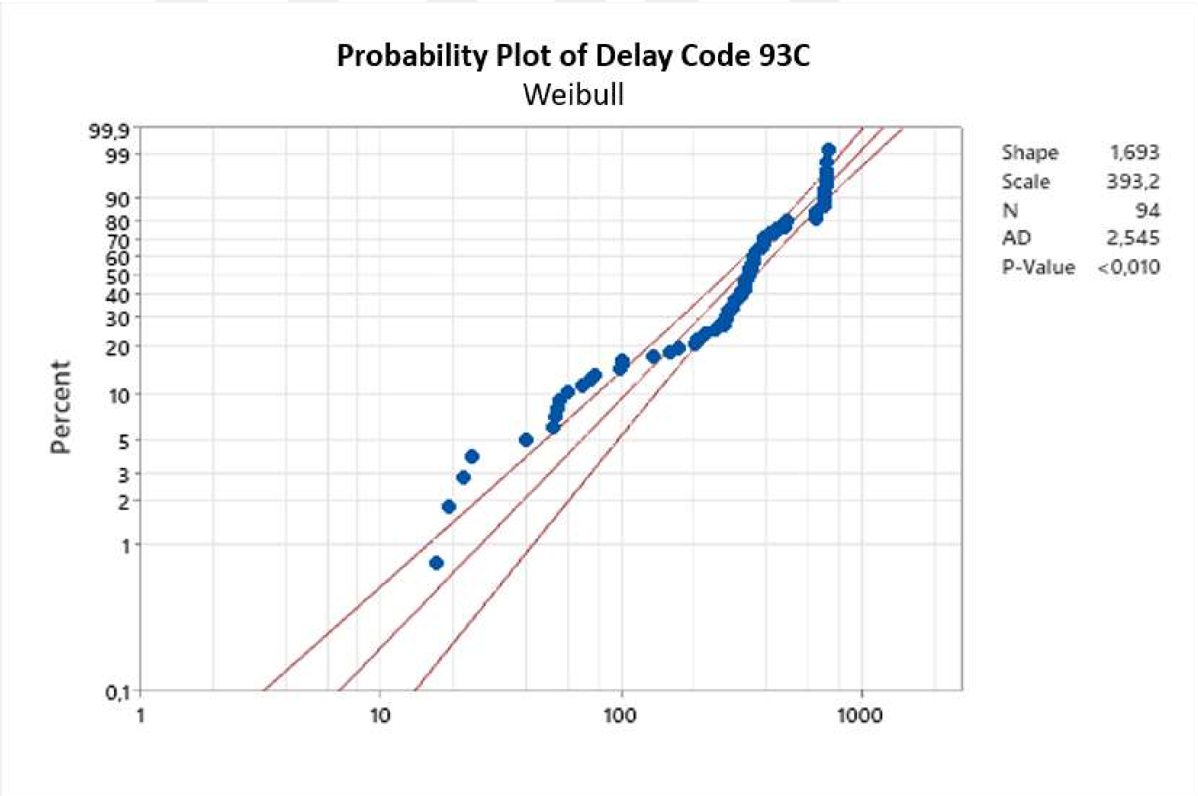

Figure D.16.: Delay code 93C - Weibull distribution plotting.

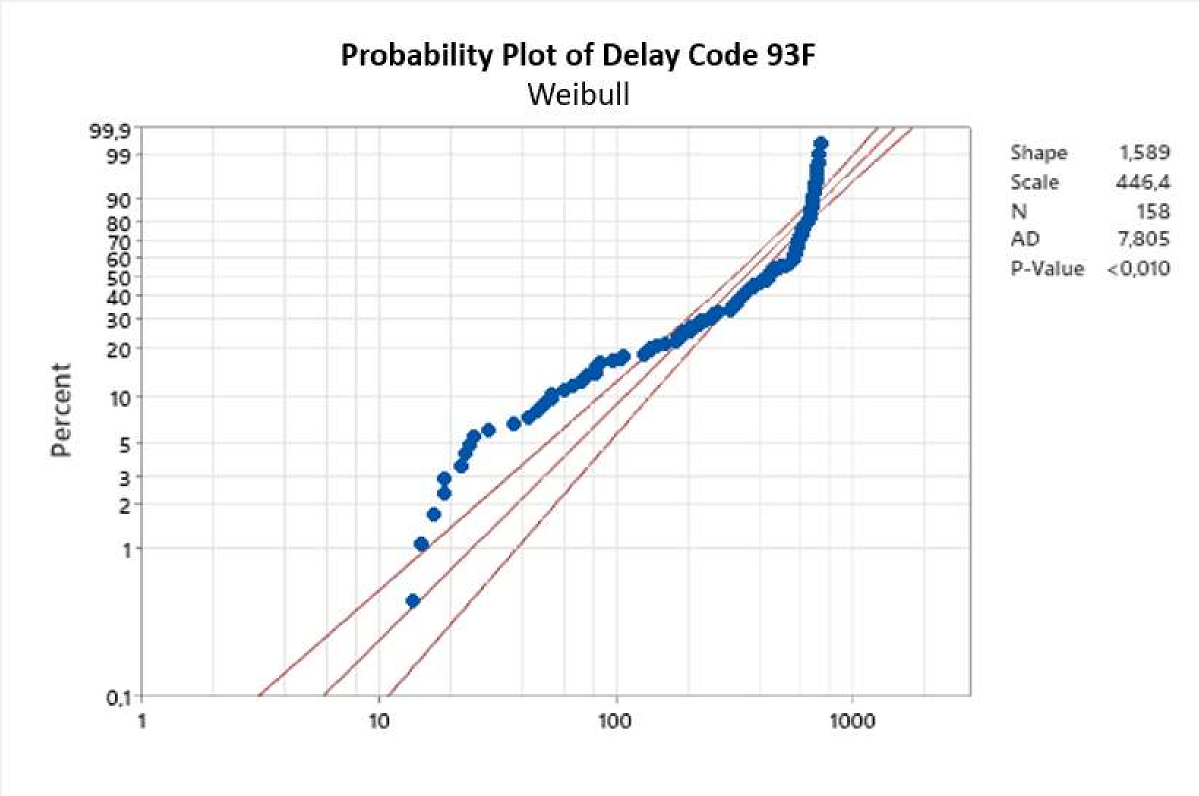

Figure D.17.: Delay code 93F - Weibull distribution plotting.

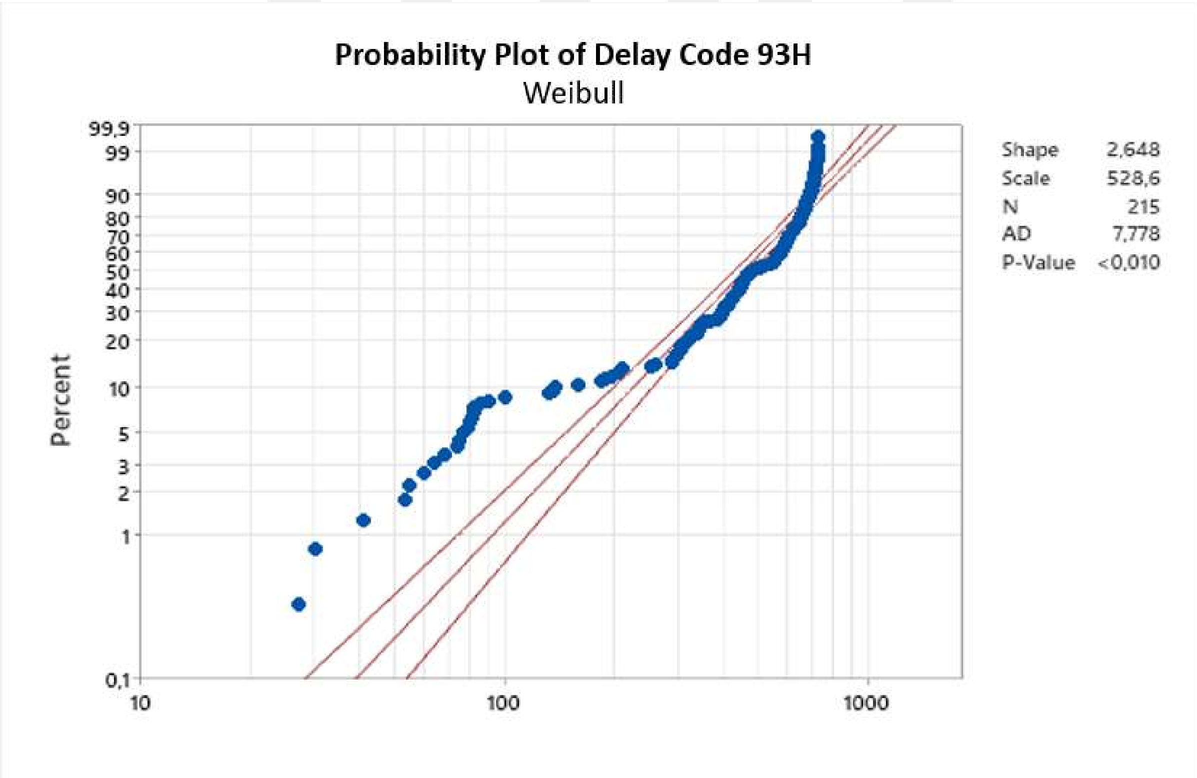

Figure D.18.: Delay code 93H - Weibull distribution plotting.

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