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Article

G-Proc-2 Predictive Control Engineering Applications (RIT)

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Abstract

The stochastic processes [HMP (Homogeneous Markov), NHMP (Non-Homogeneous Markov), SMP (Semi-Markov), RP (Renewal), A&RP (Age and Repair)] used for reliability analyses and prediction (to the author knowledge) are particular cases of the G-Process. We present the basics of RIT (Reliability Integral Theory) a theory able to deal with the G-processes. It can be applied to Reliability, Availability, Maintenance and Statistical applications (Control Charts and Time Between Events Control Charts); its power allows the readers to prove that the T Charts and the reliability computations for repairable systems (e.g. the Duane method), used in Minitab 21 are wrong: various cases are considered, from published papers. due to lack of knowledge of RIT); moreover, with RIT anybody can prove that the T Charts and the reliability computations for repairable systems (e.g. the Duane method), used in Minitab 21 are wrong. We introduce the Stochastic G-Processes, via the Integral Equations, which rule the relationships between the reliabilities $R_i(t|s)$ related to the system states. We show the advantages of using RIT for Quality decisions (economics and business).

Keywords: reliability integral theory; G-Processes; exponential distribution; T Charts; Minitab; JMP; costs by wrong ideas

MSC:

1. Introduction

Our life is full of “systems” (arrangements of physical components, man-made or biological, connected in such a way as to form an entire unit or entity): e.g. our body, our telephone, our car, a man driving an automobile, a single home heating controller using a thermostat controlling a domestic boiler, an electric coffee maker, an electric oven, a refrigerator, a switch of an electric lamp, an automatic toaster, a washing machine, a tree, the leaves of a tree for chlorophyll synthesis, ...

In any system there is an *input*, taken from outside the system, used to produce a specified response, the *output*.

Many of them are “Control Systems” *able to* command, regulate themselves or other systems. To do that, they need *energy and information*, taken from other sources or from inside. A Control System, to command another system, needs two subsystems: an *open-loop* subsystem (generating the output depending on the input) and a *closed-loop* subsystem (generating the “*controlled*” output depending on the output itself and on the input).

To reveal the information content (in the input and in the output) the system needs to use data and discover the information hidden in observations; it is natural to think that nowadays *we live in the age of data*. We must “Let the data speak” [as R.E. Kalman (1930–2016) used to say].

An example clarify the previous concepts: driving our car. The driver’s eyes look at the road heading; its brain analyses the information and provides impulses to the hands to command the steering wheel (providing also impulses to the foots to command the accelerator and the brakes), causing the car heading. This is a *closed-loop* Control System. We filter the information of the eyes about the road and predict the trajectory generated by our actions: we estimate the temporal

evolution of the state (position and speed) of the car, that is, we deal with signal estimation. A typical situation where such a problem is encountered is also deep space navigation, where the position of a spacecraft has to be found in real time from available observations.

In any firm we find processes (production or services, such as the design, ...) and operations; to control them, *feedback* is necessary, so to compare the output with the goals set (specifications).

A typical industrial situation in the company life is the “Control of Processes (both production and services)”: it is carried out by an important tool, the Control Charts. We use them in this paper to control the two states of a process: the IC (In Control) state versus the OOC (Out Of Control) one. The Figure 1 shows a “Controlled System with Feedback” (CSF): the input is the “probability density” $f(x|\theta)$ [an hidden “probability” law (model) generating the data $D=(x_i; i= 1, ..., n)$, flowing into the Controlled System and providing an “inference function” $\tau(\theta)$, which rules the Feedback System, whose output is the state IC or OOC]; all the “subsystems” and the input are “disturbed” by possible unknown disturbances to be investigated through the data. θ is the set of the “parameters” characterising the probability model $f(x|\theta)$.

A typical problem in an industrial setting is to “predict” the possible behaviour of a product in service (a “system” when it is used) or of a process (a “system” when it is operated): we want that the “predicted behaviour” is, as much as possible, the “expected behaviour”; to do that we need feedback. Ideas about these points can be found in [1–7]. Generally, we assess the set of the “parameters” characterising the probability model $f(x|\theta)$. We do that by using the “Maximum Likelihood” method, depicted in the Figure 2.

To predict the system behaviour we will apply the G-Process to show the way to solve various cases of practical interest: analysis of repairable systems reliability and availability, statistical estimation (and Confidence Interval evaluation) of the parameters of distributions, correct computation of Control Limits of the Control Charts, especially for Individual CC with TBE exponentially distributed data and of the Douane method.

In 1999 the author met some managers of a “certified” company developing a new engine; he saw them using the “Duane Method” for predicting the in-service MTBF by elaborating the test reliability data. In 2022-25 he read various papers about Control Charts with wrong Control Limits. Between 1999 and 2023, the author read a lot of papers, of documents of Masters in RAMS (Reliability, Availability, Maintenance, Safety) and books on quality, reliability, fatigue tests, maintainability, maintenance, statistical tests for decision, Control charts, Six Sigma, Taguchi methods, ..., and unfortunately, he found many doubtful ideas on the basics of Quality, Probability and Statistics (QPS).

Due to that, he decided to show his views about such points.

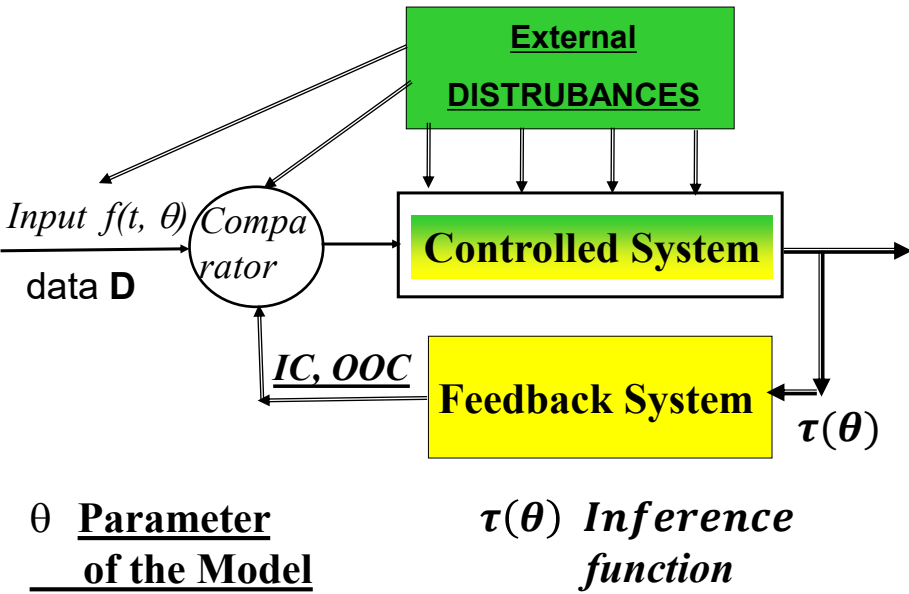


Figure 1. The “Controlled System with Feedback” for a Process (Stochastic Process).

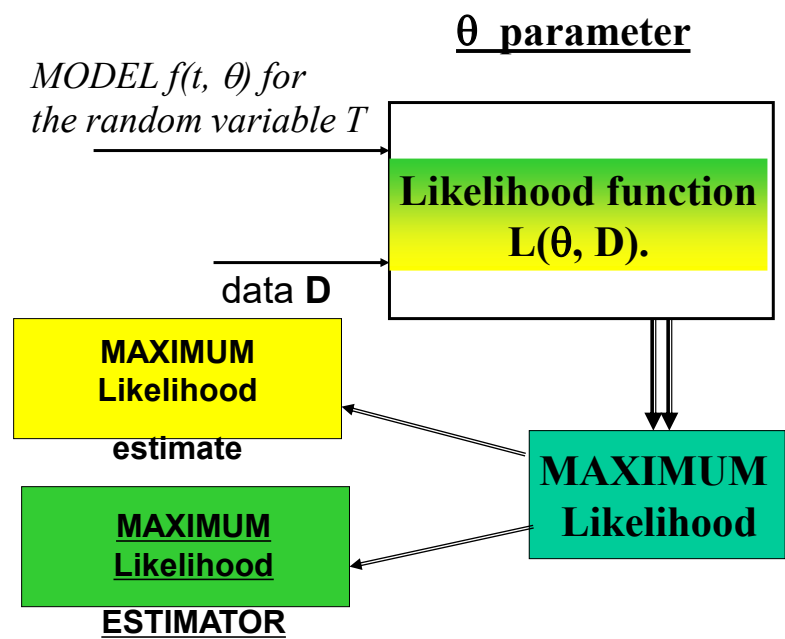


Figure 2. The way to predict the behaviour of a “Controlled System with Feedback” for a Process (Stochastic Process).

There are lots of papers providing wrong Control Limits in Control Charts (CCs) [8]: you can find them in Academia.edu and Research Gate; see also the letters written by the author to the Editors.

The Theory of “classical” CCs is shown in [9–33]; we shall consider it later.

These subjects can be dealt by Stochastic Processes: there are several documents about them; a sample is in the references [34–43]. Quality Methods, applied in industries, depends on Stochastic Processes, information provided and on Probability and Statistics. Their knowledge is fundamental for taking sound decisions: we will see the many wrong decisions taken by lack of knowledge.

Since we consider Engineering Applications of Stochastic Processes applied to physical systems in relation to the analysis of their Quality and Reliability/Availability and state of Control, we model the systems, by an engineering point of view, with a finite number of states (finite state space) and continuous time.

We begin [40–46, for in-depth study] by presenting it here through a quite simple example, a stand-by repairable system of two units, A and B, with reliabilities $R_A(t)$ and $R_B(t)$ for the “mission time” (interval) $0 \cdots t$. The system can be depicted as a three-state (Figure 3) process (representing the system with states 0 (unit A is working and B is in stand-by), 1 (unit A fails at some instant $s < t$ and B starts working), 2 (both units are failed)). The state space is denoted by $S = \{0, 1, 2\}$; it is partitioned into disjoint sets $S_1 = \{0, 1\}$, the set of the Up-states and $S_2 = \{2\}$, the set of the Down-states (only one in the Figure 1, yellow coloured). Forward transitions are related to failures of the units while backward transitions are related to repair of the units; the system fails if it enters the set S_2 ; any transition from S_2 to S_1 restores the system to a working condition; we did not depict the “inner transitions” $j \rightarrow j$, showing that the system remains in the same state j . The system is reliable as soon it makes transitions within S_1 : for each Up-state $j \in S_1$ we define a reliability function $R_j(t)$ which is the probability that the system does not fail (i.e. does not enter the set S_2), for the “mission time” (interval) $0 \cdots t$, while for each state $j \in S$ we define an availability function $A_j(t)$ which is the probability that the system is not failed (i.e. does not enter the set S_2), at the instant t .

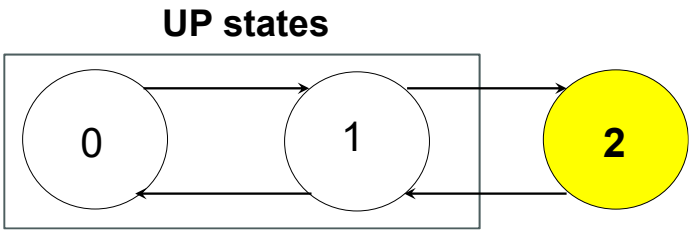


Figure 3. Transitions of a “very simple” Stochastic Process.

For a single unit we define the “failure rate” $h(t)=f(t)/R(t)$ which generally depends on t . IF and only IF $h(t)=\lambda$, a constant not depending on t , then $MTTF=1/\lambda$, and $\lambda=1/MTTF$ and $R(t)=\exp(-\lambda t)$: exponential reliability, the item is always “as good as new”. In any other case the failure rate is $h(t)\neq 1/MTTF$, and hence $MTTF\neq 1/h(t)$. For the Weibull distribution (η characteristic life, β shape parameter) $R(t)=\exp[-(t/\eta)^\beta]$, the failure rate $h(t)=(\beta/\eta)(t/\eta)^{\beta-1}$, and hence $MTTF\neq 1/h(t)$: many professionals do not know that [40–48].

Consider what we found on an EJTAG paper December 2023 “A New Approach for Effective Reliability Management of Biomedical Equipment” (3 Indian authors): there “Reliability is defined as the probability that an equipment or process performs its intended function adequately for a specified period of in a defined environment without failure.” What is wrong with the definition? The specified period is not the interval $0\text{---}t$. They add, later, “where ‘ μ ’ is mean of time between failure (MTBF), ‘ σ ’ is standard deviation of MTBF and ‘ x ’ is breakdown time”. This is misleading because they confuse MTBF with MTTF [a constant value equal to the area below $R(t)$] and confuse the “standard deviation of the RV T ” with the standard deviation of MTBF. We will see some their other problems later. They are in good company... See the Excerpt 1.

To be more general we define the *interval reliability* $R(t|r)$ as the probability that the system does not fail in the interval $r\text{---}t$, given that it did not fail before r .

For reliability analysis we have to consider (in Figure 3) $R_0(t|r)$ and $R_1(t|r)$ where r is the instant of entrance into the states 0 and 1, respectively.

«Birolini, A.: *Reliability Engineering – Theory and Practice*. Springer, Heidelberg, ISBN: 978-3-642-14951-1», «A. Regattieri, R. Manzini: *Ingegneria di Manutenzione*. Progetto Leonardo», «Manzini, A. Regattieri, H. Pham (Series Editor), E. Ferrari: *Maintenance of Industrial Systems* [4 professors (of 2 Universities)]. Springer Series in Reliability Engineering», «Reliability and Optimal Maintenance – Wang, H., Pham, H. (Author & Series Editor), (Springer 2006)», «Pham, H. (One of the Authors & Editor of the →) *Handbook of Engineering Statistics*, (Springer 2006)», «E. Ferrari, A. Pareschi, A. Regattieri, A. Persona: *Statistical Management and Modelling for Demand of Spare Parts*. [in the *Handbook of Engineering Statistics*, (Springer 2006)] (Pham, H. (One of the Authors & Editor of the ...)), «M. Lazzaroni, L. Cristaldi, L. Peretto, P. Rinaldi, M. Catelani: *Reliability Engineering* [5 professors (of 4 Universities)]. Springer 2003», «Zio, E.: *An introduction to the basics of Reliability and Risk Analysis*. World Scientific Publishing 2007», «Zio, E.: *The Monte Carlo Simulation Method for System Reliability and Risk Analysis*. Springer 2013 (Springer Series in Reliability Engineering, Pham, H. Editor of the ...)), «Rausand, M. and Hoyland, A., *System Reliability Theory*, Wiley, 2004», «Ushakov, I.A., *Handbook of Reliability Engineering*, Wiley, 1994», «Schneeweiss, W.G., *Reliability Modeling*, LiLoLe, Verlag, 2001», «Lewis, E.E., *Introduction to Reliability Engineering*, Wiley, 1996», «El-Damcese, M. *Reliability Equivalence Analysis of a Parallel-Series System Subject to Degradation Facility*, Science Journal of Applied Mathematics and Statistics. Vol. 3, No. 3, 2015», «El-Damcese, M. et al. *Semi-Markov Model of a Series-Parallel System Subject to Preventive Maintenance*, J. Stat. Appl. Pro. 2, No. 3, 307-318 (2013)», «Franceschini, F. et al., *The Qualitometro method, I, II, III*, Quality Engineering, 1997-2001», «Ficalora, P. et al *Quality Function Deployment and Six Sigma*, Pearson Education, 2010», «Franceschini, F. et al., *Advanced Quality Function Deployment*, St. Lucie (CRC Press), 2002», «Bossert, J., *Quality Function Deployment: a practitioner’s approach*, ASQC Quality Press, 1991», «Pyzdek, T., *The Six Sigma Handbook - The Complete Guide For Greenbelts, Blackbelts, And Managers At All Levels*, 2Nd Ed (2003), The McGraw-Hill Companies, 2003»

Excerpt 1. Some documents with several drawbacks.

For availability analysis we have to consider (in Figure 3) $A_0(t|r)$, $A_1(t|r)$ and $A_2(t|r)$ where r is the instant of entrance into the states 0, 1 and 2, respectively: $A_i(t|r)$ is the probability that the system is not failed at the instant t .

The functions $R_j(t|r)$ and $A_j(t|r)$ depend on the probabilities of the various transitions (failures or repair of the units).

Letting $S(t)$ the state occupied by the system at time t , we have that $S(t)$, at time t , is a Random Variable taking the values in the state space $S=S_1\cup S_2=\{0, 1, \dots, n_u, n_u+1, \dots, N\}$: $N+1$ is the number of states. The ("real") variable t is a parameter indexing the Stochastic Process $S(t)$.

Safety, Reliability, Maintainability, Conformity, Durability, Service, Process Control, Testing, are some of the most important dimensions of Quality; they must be taken into account during Product Development. To make Quality of products and services, knowledge of Quality ideas and Quality tools for achieving Quality are absolutely needed, for any person involved in any Company management (Universities, as well ...). To find and use the Quality tools for Quality achievement, education of Managers on Quality is essential. Unfortunately, too many managers [and not only managers ...] do not know much about Quality ideas and Methods; see Deming statements (in his exceptionally good books) [17,18]:

"Management need to grow-up their knowledge because experience alone, without theory, tea management nothing what to do to make Quality", "Experience alone, without theory, tea management nothing about what to do to improve quality and competitive position, nor how to do ... understanding of quality requires education. There is no substitute for knowledge.", "It is a haza copy. It is necessary to understand the theory of what one wishes to do or to make". ".... hundrea people are learning what is wrong. I make this statement on the basis of experience, seeing every the devastating effects of incompetent teaching and faulty applications". "Again, teaching of begin should be done by a master, not by a hack".

Excerpt 2. Some statements of Deming about Knowledge and Theory (Deming 1986, 1997).

In the author's opinion, the first step to Quality achievement, through **problem prevention**, is to define *logically* what Quality is. It is very important defining correctly what Quality means, because Quality is a serious and difficult business; to provide a practical and managerial definition, since 1985 F. Galetto was proposing the following one: *Quality is the set of characteristics of a system that makes it able to satisfy the NEEDS of the Customer, of the User and of the Society*. This definition highlights the importance of the *needs* of the three actors: **the Customer, the User and the Society**. *Prevention* is the fundamental idea present in this definition: you possibly satisfy the needs only by **preventing the occurrence** of any problem against the needs.

To measure and analyse the «*Characteristics*» of Quality during the total life of a product, from its design until its use in the field we NEED Probability Theory [9–51]: for this reason, we decided to write this paper on the Stochastic Processes and Predictions.

2. Materials and Methods

2.1. Reliability Integral Theory (RIT)

Let's now show how RIT manages the (Stochastic Processes) for reliability analysis and predictions of physical systems.

We use the Figure 4 (it is like the Figure 3, without the transition 2→1): if the system fails, enters the state 2, it remains there forever. In the model the transitions are ruled by some functions $b_{ij}(s|r)$ named *kernels*, related to the interval reliability $R_{unit}(t|r)$ of the units and by the probability of repair of the failed units.

The instant "r" is the time of entrance into a state, while "s" is the time instant of leaving a state.

$R_j(t|r)$ [*reliability associated to the state j*] is the probability that the system is working, at time t , i.e. $[S(t)=j] \in S_1=\{0, 1, \dots, n_u\}$, when it entered the state j at time r of the "mission time", $r \in 0-t$. The

functions $b_{i,j}(s|r)ds$ are the instantaneous probability of transition from state i to state j and $\bar{W}_i(t|r)$ are the probabilities of staying in the state i for the whole interval $r \rightarrow t$.

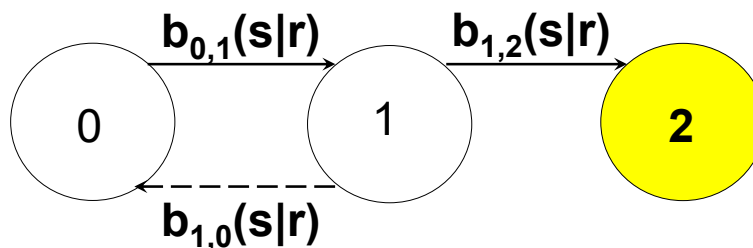


Figure 4. Transitions of a Reliability Stochastic Process.

Applying the probability theory, we can write the two general equations (1) [related to the model in Figure 4]

$$R_0(t|r) = \bar{W}_0(t|r) + \int_r^t b_{0,1}(s|r) R_1(t|s) ds \quad R_1(t|r) = \bar{W}_1(t|r) + \int_r^t b_{1,0}(s|r) R_0(t|s) ds \quad (1)$$

The two equations (1) are Integral Equations with unknown functions $R_j(t|r)$; we name the previous equations the fundamental system of the Reliability Integral Theory (RIT).

We name G-Processes the stochastic processes ruled by the Integral Equations (1).

For any type of system, we write

$$R(t|r) = \bar{W}(t|r) + \int_r^t B(s|r) R(t-s) ds \quad (2)$$

where $R(t|r)$ is the column vector of the reliabilities $R_j(t|r)$, $j \in S = \{0, 1, \dots, nu\}$, $B(s|r)$ is the kernel matrix and $\bar{W}(t|r)$, $j \in S = \{0, 1, \dots, nu\}$, is the diagonal matrix of the waiting functions in the up-states before any transition.

It is the fundamental system of the Reliability Integral Theory.

The unknown reliabilities $R_j(t|r)$ depends on the *kernels* $b_{i,j}(s|r)$, related to the failure rate and the repair rate of the units; if they assume some particular form then the *G-Processes* become known processes [29–33] (see Figure 5): Homogeneous Markov Processes (HMP), Non-Homogeneous Markov Processes (NHMP), Semi-Markov Processes (SMP), Poisson Processes (PP), Wiener Processes (WP), Branching Processes (BP), Birth and Death Processes (BDP), ...

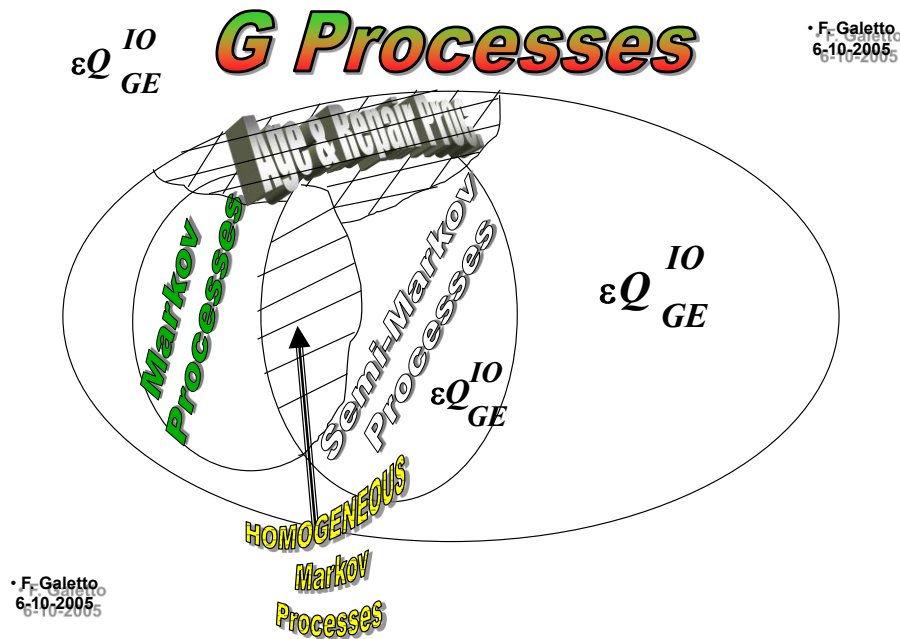


Figure 5. G-Processes comprise several Stochastic Processes (depending on the kernels).

To the author knowledge, there is no Theory (but RIT) able to deal the Age& Repair (A&R) processes, where the forward transitions depend on the age of the system, i.e. $b_{ij}(s|r)=b_{ij}(s)$, and the repair (backward transitions) depend on the time interval $r-s$ from the entrance r into a state, i.e. $b_{ij}(s|r)=b_{ij}(s-r)$. The transition rates are as in the Figure 6 (an example of a “parallel system of 2 identical units” with Weibull reliability and Erlang repair of the failed unit).

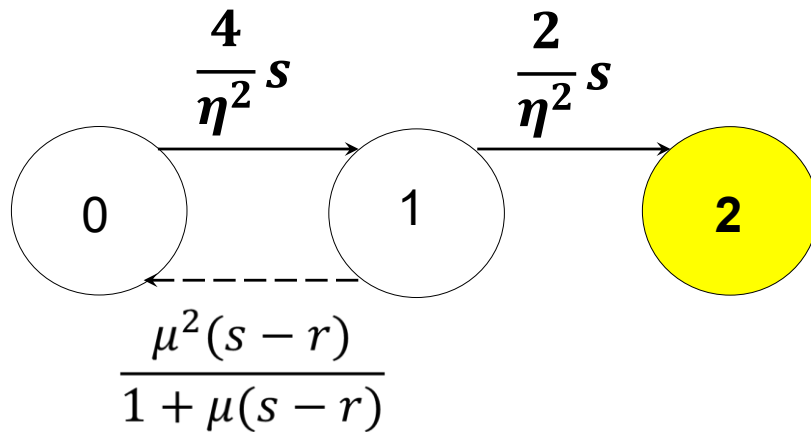


Figure 6. Transitions of an Age & Repair Stochastic Process (transition rates).

Generally, we are interested to the interval $0-t$ (mission time) and then we compute the two functions $R_0(t)=R_0(t|0)$ and $R_1(t)=R_1(t|0)$.

If both the kernels are exponential (no aging behaviour) we can draw a flow graph with the transition rates λ (failure rate) and μ (repair rate) and write the matrix equation where $R(t)$ is the column vector with entries $R_0(t)$ and $R_1(t)$ and A the “transition” matrix (see Figure 4 for the parallel, where there is no age)

$$R(t) = u + \int_0^t A R(s) ds \quad \text{with} \quad A = \begin{bmatrix} -2\lambda & 2\lambda \\ \mu & -(\lambda + \mu) \end{bmatrix} \quad (3)$$

(3) is the model of a Homogeneous Markov Processes (HMP).

For a renewable system we write

$$R(t) = \bar{W}(t) + \int_0^t B(s) R(t-s) ds \quad (4)$$

It is the fundamental system of the Reliability Integral Theory, for SEMI-Markov processes (SMP).

From the reliabilities we compute the two Mean Time To (system) Failure $MTTF_0$ and $MTTF_1$: (MTTF not MTBF...)

$$MTTF_0 = \int_0^\infty R_0(t) dt \quad MTTF_1 = \int_0^\infty R_1(t) dt \quad (5)$$

For HMP and SP we can get the MTTFs without actually computing $R_0(t)$ and $R_1(t)$, as follows

$$MTTF_0 = m_0 + p_{0,1} MTTF_1 \quad MTTF_1 = m_1 + p_{1,0} MTTF_0 \quad (6a)$$

where m_0 and m_1 are the mean holding time in the up-states 0 and 1, and $p_{0,1}$ and $p_{1,0}$ are the steady state transition probabilities from 0 to 1 and from 1 to 0.

It is very useful (Figure 7) to see the difference of the various reliabilities $R_0(t)$ and $R_1(t)$ dealt with the three stochastic processes: Homogeneous (red curves), Non-Homogeneous (blue curves), Age&Repair (green curves).

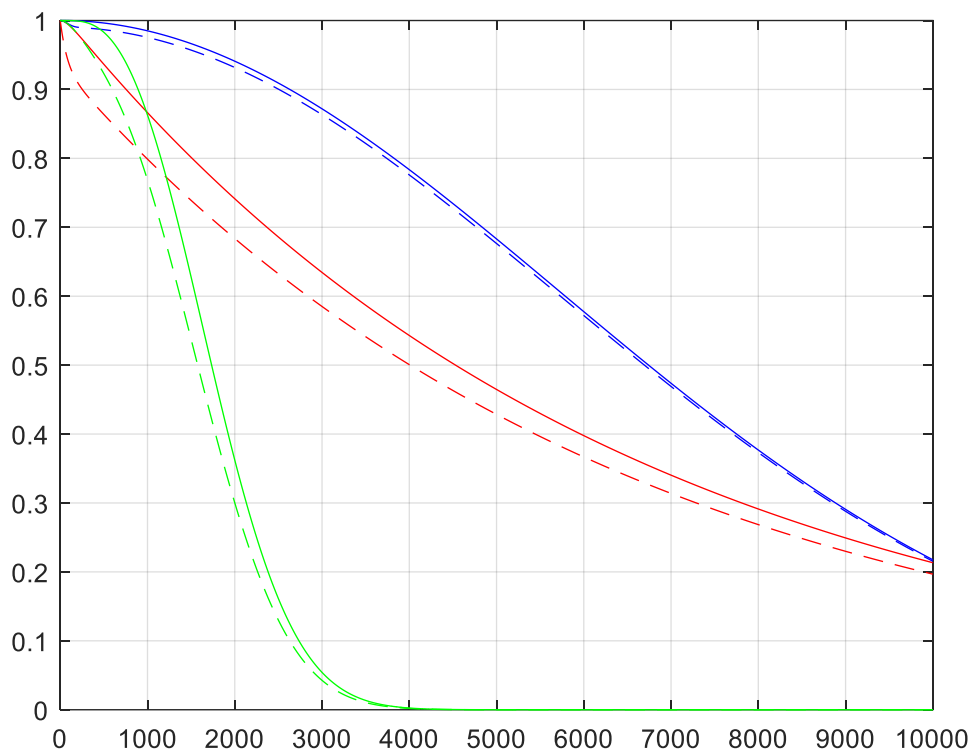


Figure 7. $R_0(t)$ and $R_1(t)$ for the HMP (red curves), for the NHMP (blue curves) and for the A&RP (green curves).

Notice that the reliabilities generated by the NHMP (with linear failure and repair rates) are the highest curves; that does not mean that they are the best curves: the linear repair rate is such that it depends on the age of the system (the older the system, the higher the repair rate: absurd!): this causes huge costs, due to wrong analyses and decisions.

It is clear that when the failure rate is increasing (due to wear out) we can benefit from "Preventive Maintenance": the units are replaced before they fail. Optimized Maintenance Actions (based on reliability, costs of repairs and cost of Preventive Maintenance, and Spare parts Availability) improve the earning of Systems.

To do that we need suitable Methods.

By integrating from 0 to ∞ the column vector $R(t)$ in the formula (4) we find the column vector of the system $MTTF_j, j \in S_1 = \{0, 1, \dots, nu\}$,

$$MTTF = \int_0^\infty R(t) dt = M + P * MTTF \quad (6)$$

where P is the matrix of the steady transition probabilities between the Up-states and M the diagonal matrix of the “Mean Holding Time m_j ” (the length of time in the state j , before transition).

So, we see that we can compute the MTTF, without actually computing the column vector $R(t)$; we need only M and P

$$MTTF = [I - P]^{-1}M \quad (7)$$

The matrix $[I - P]^{-1}$ provides the “Mean Number of Transitions Between the Up-states, before the system failure”.

Notice that we can use the formula (7) only for the Semi-Markov Processes; hence in the Figure 7 we must compute by numerical methods the area below the blue and green curves.

2.2. Availability Integral Theory (AIT)

If we (Figure 3) allow that the failed system, in the state 2, be repaired [transition from 2 to 1, with kernel $b_{2,1}(s|r)$] we can study the system Availability associated to the states $S=\{0, 1, 2\}$, $A_0(t|r)$, $A_1(t|r)$, $A_2(t|r)$; S is divided into two disjoint sets $S=S_1(\text{up states } \{0, 1\}) \cup S_2(\text{down states } \{2\})$; $A_i(t|r)$ [availability associated to state i], $[S(t)=i] \in S=\{0, 1, \dots, n_u, n_u+1, N\}$, is the probability that the system is working [in the up states, S_1], when it entered the state $i \in S$ at time r . Following the same lines, we can write the following *fundamental system of the Availability Integral Theory, AIT* [holding whichever is the distributions of the time to failures and times to repair of the various units]; the stochastic process ruling the transitions is named G-Process: all the quantities are computed using the kernels $b_{i,j}(s|r)$.

$$\begin{aligned} A_0(t|r) &= \bar{W}_0(t|r) + \int_r^t b_{0,1}(s|r) A_1(t|s) ds + \int_r^t b_{0,2}(s|r) A_2(t|s) ds \\ A_1(t|r) &= \bar{W}_1(t|r) + \int_r^t b_{1,0}(s|r) A_0(t|s) ds + \int_r^t b_{1,2}(s|r) A_2(t|s) ds \\ A_2(t|r) &= \int_r^t b_{2,1}(s|r) A_1(t|s) ds + \int_r^t b_{2,0}(s|r) A_0(t|s) ds \end{aligned} \quad (8)$$

When $t \rightarrow \infty$ all the availabilities $A_0(t)$, $A_1(t)$, $A_2(t)$ approach the same value $A_{ss} = \text{MUT}/\text{MTBF} = \text{MUT}/(\text{MUT} + \text{MDT})$, the steady state Availability (proved in the author's books).

Notice the differences with the EJTAS paper December 2023 “A New Approach... of Biomedical Equipment” where we find (... , excerpt 3)

Same problems are found in the Excerpt 1.

For a general SMP we can derive that

$$A_{ss} = \text{MUT}/\text{MTBF} = \text{MUT}/(\text{MUT} + \text{MDT}) \quad (9)$$

where MUT is the Mean Up Time, a suitable mean of the MTTF_i , from $i \in S_1 = \{0, 1, \dots, n_u\}$ to $S_2 = \{n_u+1, \dots, N\}$ in the steady state, and MDT is the Mean Down Time, a suitable mean of the MTTR_j , from $j \in S_2 = \{n_u+1, \dots, N\}$ to $S_1 = \{0, 1, \dots, n_u\}$ in the steady state [40–48].

Availability represents the probability that a device is capable of conducting its required function when it is not failed or undergoing a repair action and plays an important role for reliability analysis. Availability or inherent availability ‘ A_{in} ’ is depended on preventive or scheduled maintenance and is expressed (Leitch 1995) by Equation (9). $A_{in} = \text{MTBF}/(\text{MTBF} + \text{MTTR})$ (9). MTTR is mean time to repair and MTBF is mean time between failures.

Excerpt 3. From “A New Approach...”.

2.3. Statistics and RIT

RIT (G-Processes) can be used for parameters estimation and Confidence Intervals (CI), (Galletto 1981, 1982, 1995, 2010, 2015, 2016), in particular for Control Charts (Deming, 1986, 1997, Shewhart 1931, 1936, Galletto 2004, 2006, 2015). In fact, any Statistical (or Reliability) Test can be depicted by an “Associated Stand-by System” whose transitions are ruled by the kernels $b_{k,j}(s)$; we can write the *fundamental system of integral equations for the reliability tests*, whose duration t is related to interval $0 \cdots t$; the collected data t_j can be viewed as the times of the various failures (of the units comprising the System) [$t_0=0$ is the start of the test, t is the end of the test and g is the number of the data]

$$R_j(t|t_j) = \bar{W}_j(t|t_j) + \int_{t_j}^t b_{j,j+1}(s|t_j)R_{j+1}(t|s)ds \quad (10)$$

for $i = 0, 1, \dots, g-1$, $R_g(t|t_g) = \bar{W}_g(t|t_g)$

$R_j(t|t_j)$ is the probability that the stand-by system (statistical test or CC) does not enter the state g , at time t , when it starts in the state j at time t_j , $\bar{W}_j(t|t_j)$ is the probability that the system does not leave the state j , $b_{j,j+1}(s|t_j)ds$ is the probability that the system makes the transition $j \rightarrow j+1$.

The reliability system (10) can be written in matrix form,

$$R(t|r) = \bar{W}(t|r) + \int_r^t B(s|r)R(t|s)ds \quad (11)$$

At the end of the reliability test, at time t , we know the data (the times of the transitions t_i) and the empirical sample $D=\{x_1, x_2, \dots, x_g\}$, with $x_i=t_i - t_{i-1}$ is the length between the transitions; the transition instants are $t_i = t_{i-1} + x_i$ giving $D^*=\{t_1, t_2, \dots, t_{g-1}, t_g, t\}$; t is the duration of the test.

We consider now that we want to estimate the unknown $MTTF=\theta=1/\lambda$ of each item comprising the stand-by system: each datum is a measurement from the exponential pdf; we compute the determinant $\det B(s|r; \theta, D^*) = (1/\theta)^g \exp[-T(t)]$ of the integral system (11), where $T(t)$ is the "Total Time on Test" $T(t) = \sum_1^g x_i$. At the end time t , the integral equations, constrained by the constraint D^* , provide the equation

$$(\partial \ln \det B(s|r; \theta, D^*)) / \partial \theta = \theta/g - T(t) = 0 \quad (12)$$

In the case of exponential distribution, it is exactly the same result as the one provided by the MLM Maximum Likelihood Method [1–16].

If the data are normally distributed, $X \sim N(\mu_X, \sigma_X^2) = 1/(\sqrt{2\pi} \sigma_X) e^{-(x-\mu_X)^2/(2\sigma_X^2)}$, with sample size n , then we get the usual estimator $\bar{X} = \sum X_i/n$ such that $E(\bar{X}) = \mu_X$.

The same happens with any other distribution provided that we can write the kernel $b_{i,i+1}(s)$.

The reliability function $R_0(t|\theta)$, [formula (10)], with the parameter θ , of the "Associated Stand-by System" provides the *Operating Characteristic Curve* (OC Curve, reliability of the system) [8–23,30,35] and allows to find the Confidence Limits (θ_L Lower and θ_U Upper) of the "unknown" mean θ , to be estimated, for any type of distribution (Exponential, Weibull, Rayleigh, Normal, Gamma, ...); by solving, with unknown θ , the two equations $R_0(t_0|\theta) = 1 - \alpha/2$ and $R_0(t_0|\theta) = \alpha/2$ we get the two values (θ_L, θ_U) such that

$$R_0(t_0|\theta_L) = 1 - \alpha/2 \quad \text{and} \quad R_0(t_0|\theta_U) = \alpha/2 \quad (13),$$

where t_0 is the "total of the length of the transitions $x_i=t_i - t_{i-1}$ data of the empirical sample D " and $CL=1 - \alpha$ is the Confidence Level. $CI=\theta_L \dots \theta_U$ is the Confidence Interval of θ .

The same procedure can be used for normal data as those of the paper "The mixed CUSUM-EWMA (MCE) Control Chart as a new alternative in the Monitoring of a Manufacturing Process" published in the *Brazilian Journal of Operations & Production Management*, pp. 1-13, DOI: 10.14488/BJOPM.2019.v16.n1.a1, written by 6 authors.

Consider the 30 data and the authors' Control Chart

The 6 authors write: "The statistical analysis of this manufacturing process is obtained from 30 samples of size $n=1$. The first seven (7) samples of this process behaved according to a normal distribution with a mean of $\mu=70$ equivalent to the nominal value and standard deviation $\sigma=1$. i.e., $N(70,1)$, and the 23 remaining samples had a change of $0,5\sigma$ in the mean, or $N(70.5,1)$."

The authors wrongly stated that (verbatim): "... the EWMA (Figure 10, not reported here), CUSUM (Figure 11, not reported here) and Shewhart type (3σ) (Figure 12, given below as Figure 8) control charts cannot detect any situation out of control for the dataset provided."

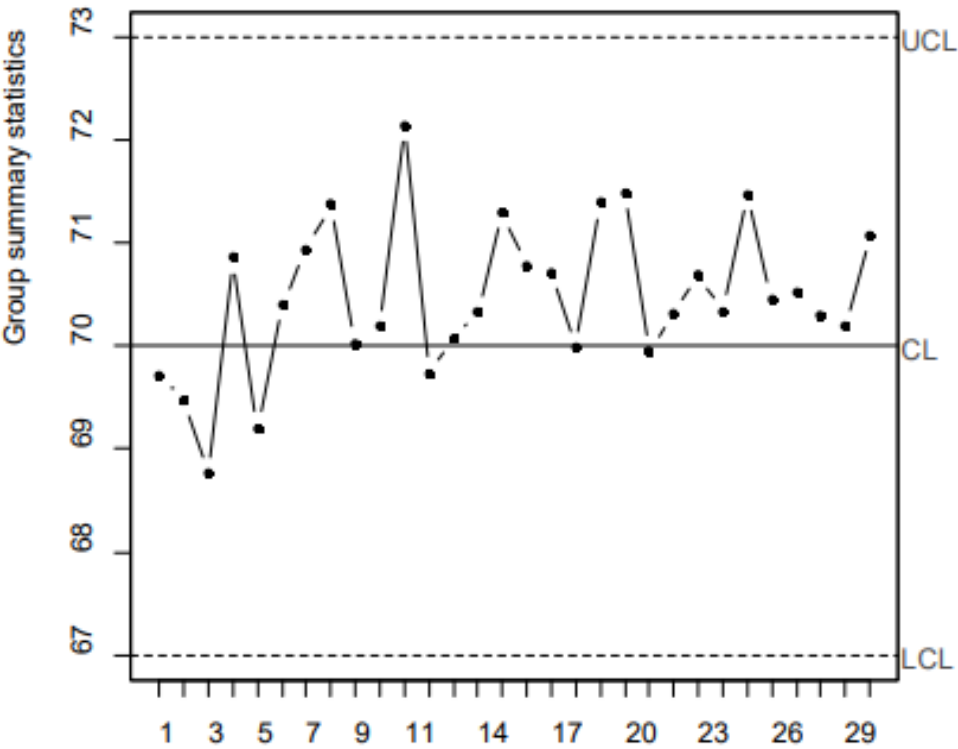


Figure 8. Shewhart I-CC from *Brazilian Journal of Op. & Prod. Management* (Figure 12 in their paper).

Notice: the process appears IC because in the Figure 8 the Control Limits do not depend on the collected data; actually, they are the Probability Limits of the Probability Interval.

See the Figure 9: the process is OOC! It is very clear that the Process is Out Of Control (OOC), due to two causes:

- a) Two points out of the Control Limits, and
- b) The points from 8 to 30 have a mean larger than the mean of the first seven points

Notice that the process is OOC in two ways: a) because one point is below LCL and one point is above UCL, b) because the mean of the last 23 points is statistically different form the mean of the first 7 points.

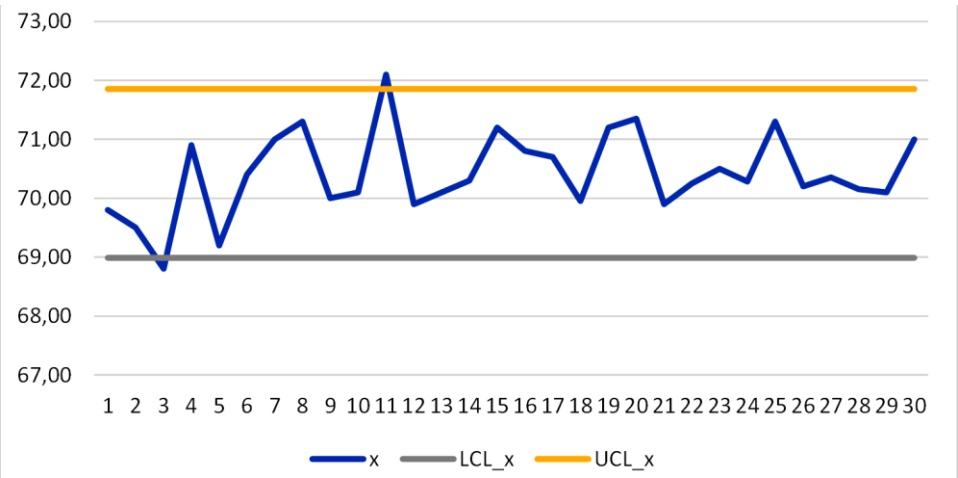


Figure 9. Shewhart I-CC computed by F. Galetto; notice the OOC points.

The Brazilian Journal ... Management, did not publish the letter to the Editors.

2.4. Control Charts for Process Management

Statistical Process Management (SPM) entails statistical Theory and tools used for monitoring any type of a process, industrial or not. The Control Charts are the tool used for monitoring a process, to assess two states: the first, when the process, named IC (In Control), operates under the common causes of variation (variation is always naturally present) and second, named OOC (Out Of Control), when the process operates under some assignable causes of variation. We do that by “predicting” (through the observed data) the route the process has to follow to be considered IC. The CCs, using the observed data, allow us to decide if the process is IC or OOC.

Control Charts were very considered by Deming (1986, 1997) and Juran (1988) after Shewhart invention (1931, 1936).

We start with Shewhart ideas (see the excerpt 4). He wrote on page 294, where $\bar{X}$ is the “Grand Mean”, computed from D, σ is “estimated standard of each sample” (with sample size n), $\bar{\sigma}$ is the “estimated mean standard deviation of all the samples”.

$$\bar{X} \pm 3 \frac{\sigma}{\sqrt{n}} = 13,540 \pm 3 \frac{440}{\sqrt{20}}$$

$$\bar{\sigma} \pm 3 \frac{\sigma}{\sqrt{2n}} = 423 \pm 3 \frac{440}{\sqrt{40}}$$

Excerpt 4. From Shewhart book (1931).

From Excerpt 4, we clearly see that Shewhart, the inventor of the CCs, used the “Normal Approximation (Central Limit Theorem)” [22,23] and the data to compute the Control Limits, LCL (Lower Control Limit) and UCL (Upper Control Limit) both for the mean μ_X (the 1st parameter of the Normal pdf) and for σ_X (the 2nd parameter of the Normal pdf). Similar ideas can be found in Dore, 1962, Belz, 1973, Ryan, 1989, Rao, 1965, Cramer, 1961, Mood, 1963, Rozanov, 1975 (where we see the idea that CCs can be viewed as a Stochastic Process). See also F. Galetto [36,37,41,42].

Compare Excerpt 4 (where LCL, UCL depend on the data) with Excerpt 5 (where LCL, UCL depend on the Random Variables) and appreciate the profound difference: this is the cause of the many errors in the CCs for TBE (Time Between Events (see the “Garden...” [52])). Notice that an author wrote several papers... Notice the wrong statement (with k=3) “The control limits of the standard Shewhart chart ($\bar{X}$ chart or the X chart) are given by $UCL_1 = \mu_Y + 3\sigma_Y$ and $LCL_1 = \mu_Y - 3\sigma_Y$ where μ_Y and σ_Y are the specified IC mean and standard deviation of the charting statistic Y_i ”. Notice that, as per Excerpt 5, $L = \mu_Y - 3\sigma_Y$ — $U = \mu_Y + 3\sigma_Y$ is not the CI (Confidence Interval) of the mean $\mu = \mu_Y$ (as in Excerpt 4) but the Probability Interval such that the RV Y

$$P[L = \mu_Y - 3\sigma_Y \leq Y \leq \mu_Y + 3\sigma_Y = U] = 0.9973 \quad (14).$$

The same error is in other books (e.g. Montgomery D., 1996-2019, page 192-3). The right ideas are in Galetto F. (2006, 2015, 2016). RIT will show clearly the drawbacks of those many authors (Galetto 1981, 2006, 2015, 2016).

Let X_{ij} , $i=1, 2, \dots, j=1, 2, \dots, n$ be independent and identically distributed (IID) normal $N(\mu_0, \sigma_0^2)$ r.v.’s, where μ_0 and σ_0^2 are the specified IC mean and variance, respectively. The X_{ij} represents the j th observation from the i th rational subgroup (sample) obtained at the i -th sampling stage, and Y_i denotes the i -th charting statistic based on the i -th sample. When $n \geq 2$, at sampling stage i , $Y_i = \bar{X}_i$ the subgroup mean, is typically used for monitoring the process mean, while in case of individual observations (i.e., $n=1$) $Y_i = X_{i1} = X_i$. The control limits of the standard Shewhart chart (X chart or the $\bar{X}$ chart) are given by $UCL_1 = \mu_Y + k\sigma_Y$ and $LCL_1 = \mu_Y - k\sigma_Y$ (1) where μ_Y and σ_Y are the specified IC mean and standard deviation of the charting statistic Y_i , and k denotes the distance of the control limits from the center line (CL) in the units of the standard deviation of the charting statistic. An OOC signal is triggered when for the first time $Y_i \notin [LCL_1, UCL_1]$. It should be mentioned that in the above setup, the control charts are used to monitor the process in real time, by comparing the value of the i -th charting statistic ($\bar{X}_i$ or X_i) to the control limits. Therefore, as long as an OOC signal is not triggered, samples are continued to be drawn from the process.

Excerpt 5. From Control Charts, Synthetic (2021), a paper in the “Garden...”. Notice that one of the authors wrote several papers....

Notice, in the Excerpt 5, the statement “... in case of individual observations (i.e. n=1)... the Control Limits...”.

It is very interesting that a Peer Reviewer chosen by the Editors of Quality and Reliability Engineering International (QREI) suggested (February 2024) the author to read the following paper in order to learn the way to compute the Control Limits for Individual Control Charts with Exponentially distributed data:

Khakifirooz, M., Tercero-Gómez, V. G. and Woodall, W. H. (2021). *The role of the normal distribution in statistical process monitoring*, Quality Engineering 33(3), 497–51

We anticipate our conclusion about the Excerpt 6 (below).

The 3 authors statement (in the Excerpt 6) “We can see from this chart that there are nine false alarms. (see the Figure 1, in the Excerpt 6)” **IS WRONG**.

The **TRUE** Control Limits (by **RIT!**) for the chart in Figure 1 (in the Excerpt 6) are actually:

LCL=0.103 and **UCL>>100**

From the Figure 1 (in the Excerpt 6) we cannot read the value of the data, BUT surely there are NO ... false alarms (above the TRUE UCL) (Figure 1, in the Excerpt 6).

IF we had the data, we could assess that there could be Out Of Control, BELOW the LCL...

The Peer Reviewer did not know the TRUE Theory, as did not the authors.

Notice the **wrong** LCL=1.022-2.06 and UCL=1.022+2.06 in the Figure 1 (in the Excerpt 6): they are computed with the wrong formula given in the Excerpt 5 (as though the Exponential data were Normal data!); Nonsense!

All the people involved did not know that also the differences $|x_{i+1}-x_i|$ are exponentially distributed.

The 3 authors write (authors’ statements):

Four examples involving transformations Example based on simulation. We can demonstrate through a simple example how the use of a power transformation can result in poor process monitoring performance. We generated a set of 100 independent exponential random variables which, without loss of generality, were assumed to have a mean of one. The X-chart is shown in Figure 1. We can see from this chart that there are nine false alarms. After the 0.2777 power transformation recommended by Nelson (1994) and others, we have the Xchart in Figure 2, for which there are no signals. If we transform the upper and lower control limits of Figure 2 back to the original units, then we have 7.456 and 0.0000192, respectively. The probability of exceeding this upper control limit for the exponential distribution with mean one is 0.00058, while the probability of falling below the lower control limit is very low, 0.0000192. This numerical example illustrates why the results of Santiago and Smith (2013) showed ...

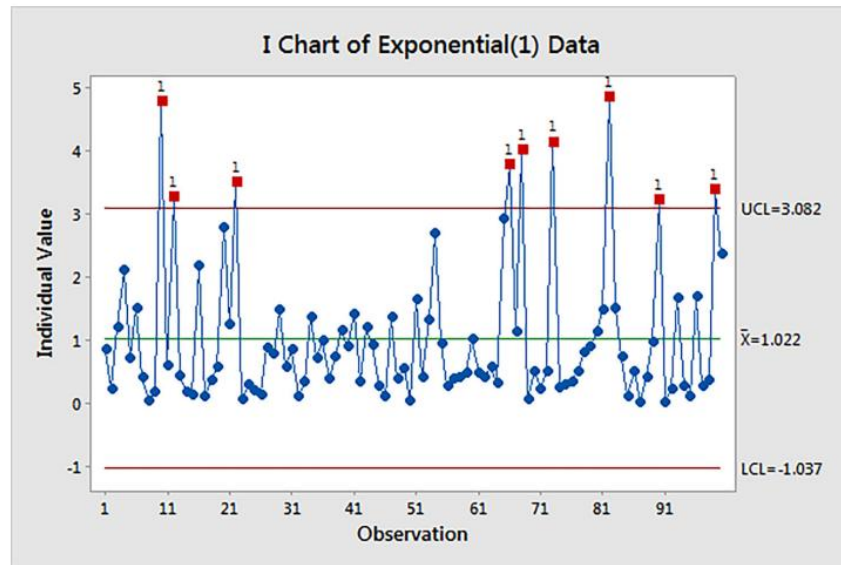


Figure 1. X-chart for exponential data with a mean of one.

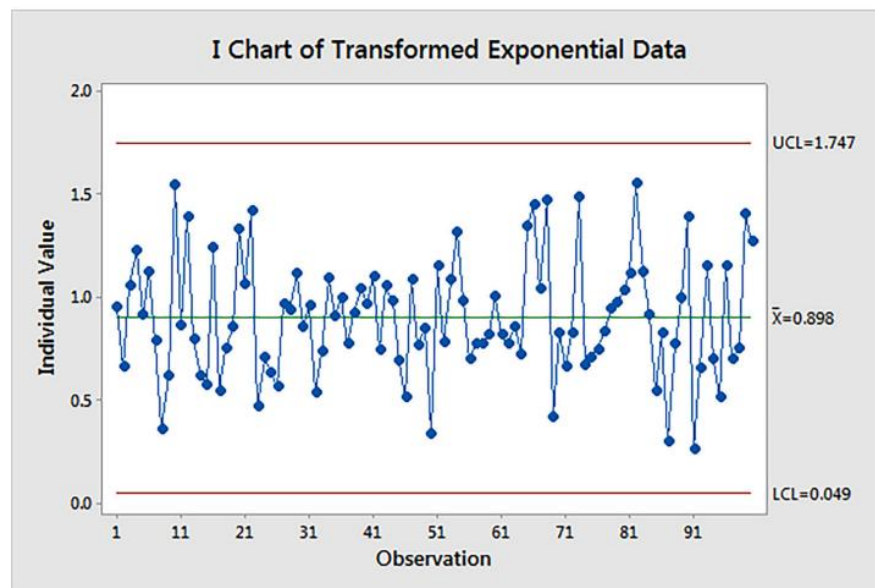


Figure 2. X-chart for exponential data after power transformation.

Excerpt 6. From the paper *The role of the normal distribution in statistical process monitoring*.

Generally, the data plotted are the means $\bar{x}(t_i)$, determinations of the Random Variables $\bar{X}(t_i)$, $i=1, 2, \dots, n$ (n =number of the samples) computed from the collected data x_{ij} , $j=1, 2, \dots, k$ (k =sample size), determinations of the RVs $X(t_{ij})$ at very close instants t_{ij} , $j=1, 2, \dots, k$. In other applications, the data plotted are the Individual Data $x(t_i)$, determinations of the Individual Random Variables $X(t_i)$, $i=1, 2, \dots, n$ (n =number of the collected data), modelling the measurement process of the “Quality Characteristic” of the product: this model is very general because it is able to consider every distribution of the Stochastic Process $X(t)$.

Shewhart on page 289 of his book (1931) writes “... we saw that, no matter what the nature of the distribution function of the quality is, the distribution of the arithmetic mean approaches normality rapidly with increase in n (his n is our k , the sample size), and in all cases the expected value of means of samples of n (our k) is the same as the expected value of the universe” (Central Limit Theorem in Excerpt 4). Let k be the sample size; the RVs $\bar{X}(t_i)$ are assumed to follow a normal distribution; $\bar{X}(t_i)$ [i^{th} rational subgroup] is the mean of RVs IID $X(t_{ij})$ $j=1, 2, \dots, k$, (k data sampled, at very near times t_{ij}), we

assume here that it is distributed as [probability density function (pdf) of “transitions from a state to the subsequent state” of a subsystem] $\bar{X}(t_i) \sim N(\mu_{\bar{X}(t_i)}, \sigma_{\bar{X}(t_i)}^2)$ [experimental mean $\bar{x}(t_i)$] with mean $\mu_{\bar{X}(t_i)}$ and variance $\sigma_{\bar{X}(t_i)}^2$. $\bar{X}$ is the “grand” mean and $\sigma_{\bar{X}}^2$ is the “grand” variance: $\bar{X} \sim N(\mu_{\bar{X}}, \sigma_{\bar{X}}^2)$ [experimental “grand” mean $\bar{\bar{x}}$]. In Figure 10 the distribution, the determinations of the RVs $\bar{X}(t_i)$ and $\bar{X}$ are shown. The function connecting the points x_{ij} is called a “sampled trajectory” of the stochastic process $X(t)$.

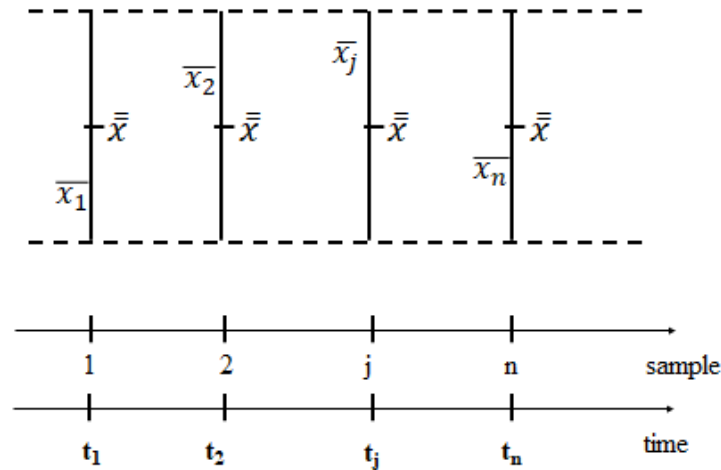


Figure 10. The Individuals x_{ij} , the “means” $\bar{x}_i$ of the process and the “grand mean” $\bar{\bar{x}}$.

When the process is OOC (Out Of Control, i.e. *assignable causes of variation*) some of the means $\mu_{\bar{X}(t_i)}$, estimated by the experimental means $\bar{x}_i = \bar{x}(t_i)$, are “statistically different” (Galetto 1981, 2006, 2015, 2016).

We said that (14) is a Probability Interval; IF we put $\bar{\bar{x}}$ in place of μ_Y and $\bar{s}/\sqrt{k}$ in place of σ_Y we get the CI of $\mu_{\bar{X}}$ when a sample size k is considered for each $\bar{X}(t_i)$, with $CL=0.9973$. The quantity $\bar{s}$ is the mean of the standard deviations of each sample. This allows us to compare each (subsystem) mean $\mu_{\bar{X}(t_q)}$, $q=1,2, \dots, n$, to any other (subsystem) mean $\mu_{\bar{X}(t_r)}$, $r=1,2, \dots, n$, and to the (Stand-by system) grand mean $\mu_{\bar{X}} = \mu$. If two of them are different the process is OOC. The quantities $LCL_X = \bar{\bar{x}} - 3\bar{s}/\sqrt{k}$ and $UCL_X = \bar{\bar{x}} + 3\bar{s}/\sqrt{k}$ are the limits of the Control Limits of the CC. When the Ranges $R_i = \max(x_{ij}) - \min(x_{ij})$ are considered for each sample we have $LCL_X = \bar{\bar{x}} - A_2\bar{R}$, $UCL_X = \bar{\bar{x}} + A_2\bar{R}$ and $LCL_R = D_3\bar{R}$, $UCL_R = D_4\bar{R}$, where the coefficients A_2 , D_3 , D_4 are tabulated and depend on the sample size k [9–27,34–52].

The interval LCL_X – UCL_X is the “Confidence Interval” with “Confidence Level” $1-\alpha=0.9973$ for the unknown mean $\mu_{X(t)}$ of the Stochastic Process $X(t)$ (Galetto 1981-2022).

The interval LCL_R – UCL_R is the “Confidence Interval” with “Confidence Level” $CL=1-\alpha=0.9973$ for the unknown Range of the Stochastic Process $X(t)$ (Galetto 1981-2022). Notice that the Control Interval [Confidence Interval] $UCL_X-LCL_X=U-L$ [Probability Interval, formula (14)] for normally distributed data and that LCL_X can be obtained from L by substituting μ with $\bar{\bar{x}}$; the same for UCL_X and U .

The error highlighted, the confusion between the Probability Interval and the Control Limits (Confidence Interval!) has NO consequences for decisions WHEN the data are Normally distributed, as hypothesised by Shewhart. On the contrary, it has BIG consequences for decisions WHEN the data are Non-Normally distributed as in the Excerpt 6. **Notice!**

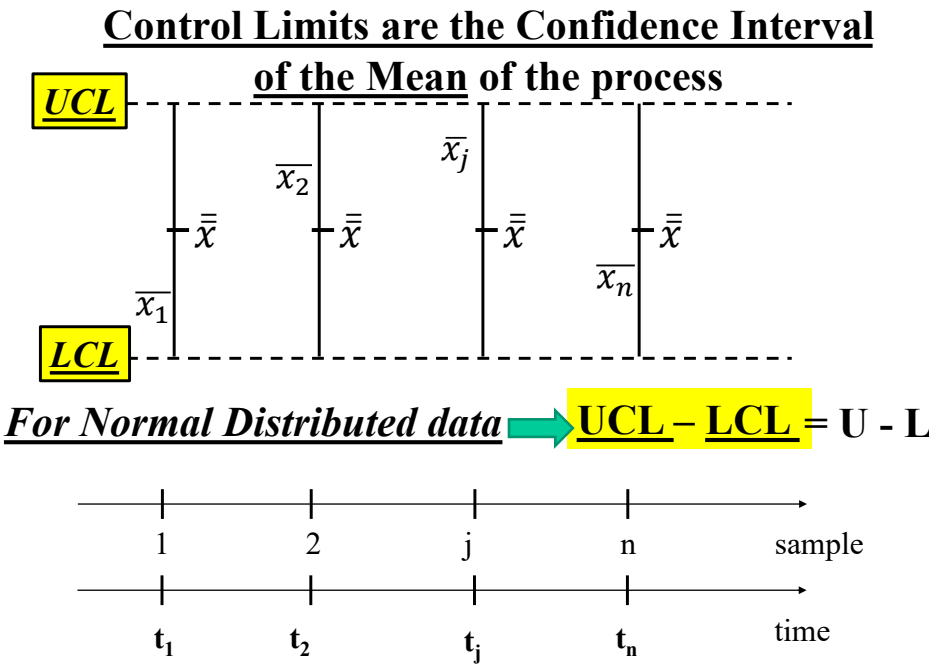


Figure 11. Control Limits $LCL_{\bar{x}} \sim UCL_{\bar{x}} = L \sim U$ (=Probability interval), for Normal data.

2.5. Control Charts for TBE Data

We consider now, again, TBE (Time Between Event) data, *exponentially or Weibull distributed*. Quite a lot of authors (see Appendix A, “Garden ...” [52]) *compute wrongly the Control Limits*.

The previous section formulae are used also for NON_normal data (see Excerpt 6): for that, the NON_normal data are transformed “with suitable transformations” in order to “produce Normal data” (see Excerpt 6) and to apply those formulae (above).

Sometimes we have few data and then we use the so called “individual control charts” I-CC. The I-CC are very much used for exponentially distributed data: they are named “rare events Control Charts for TBE (Time Between Events) data”, I-CC_TBE (see Excerpt 6).

The author (FG) knew about the wrong way of dealing with I-CC_TBE since 1996 by reading the Montgomery book where he transformed the into Weibull data (approximately normal) following Nelson L. S. (*J. Qual. Techn.*, 1994): he acted wrongly in all the later editions of the book. Any scholar who wants to learn Control Charts both with normal distribution and TBE can usefully read the book “Statistical Process Management” [42].

Several authors did the same as Montgomery did. See the Journal *Operation Research and Decisions* where the 3 authors, in their paper “An EWMA Control Chart for the exponential distribution” made the same error transforming the data into Weibull with $\beta=1.36$; the data are the “Urinary Tract Infection” (UTI) taken from a paper of two Minitab authors (Santiago & Smith) in their “Control charts based on the Exponential Distribution”, *Quality Engineering*; their T Chart (Figure 13) shows the process IC: wrong decision; making the transformation we could draw the I-CC as in Figure 14 where the Control Interval= $UCL-LCL=U-L$ =the Probability Interval. The process is again IC: wrong decision. It is NOT so if we analyse directly the TBE (Figure 13).

Using RIT (the Reliability Integral Theory of F. Galetto) we get the Figure 13 (vertical axis logarithmic, to let the OOC points evident). The process is OOC.

The problem with the authors in the “Garden... [52]” is that they do not care of Theory: they do not consider that THEORY MATTERS, in every field!

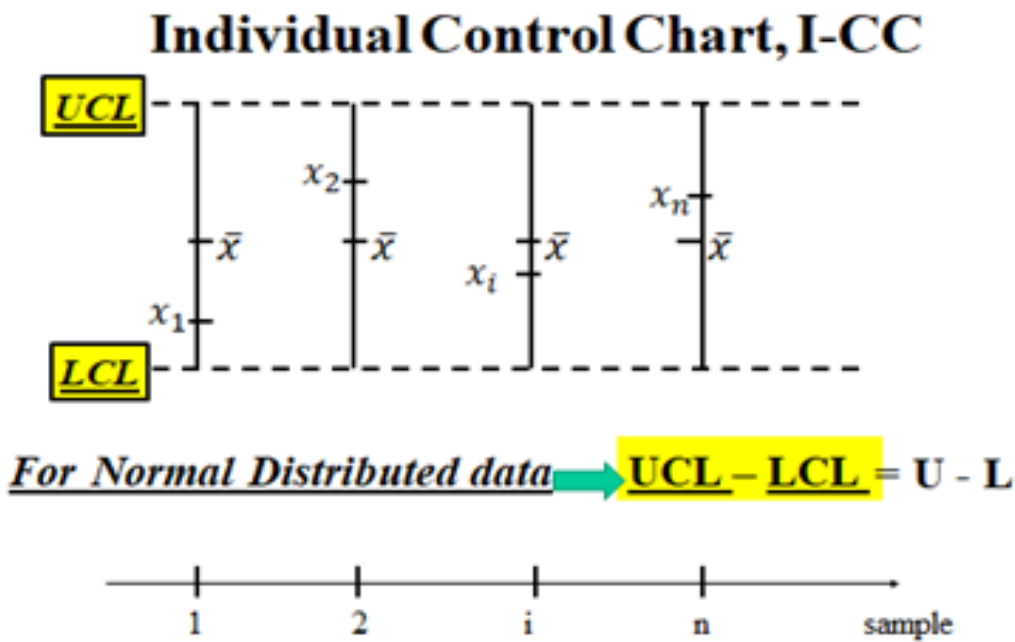


Figure 12. Individual Control Chart (sample size $k=1$). Control Limits $\text{LCL} \cdots \text{UCL} = L \cdots U$ (Probability interval), for Normal data.

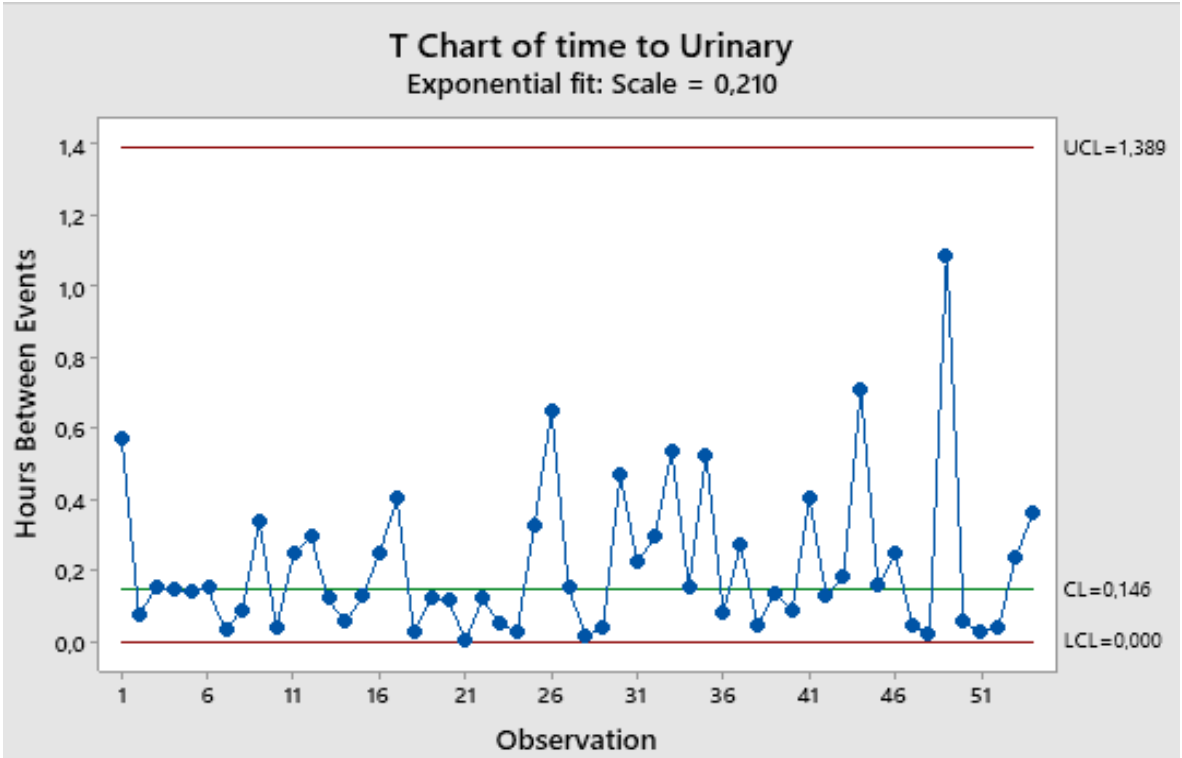


Figure 13. Chart of Minitab authors’ paper data (Urinary), Minitab 19 used.

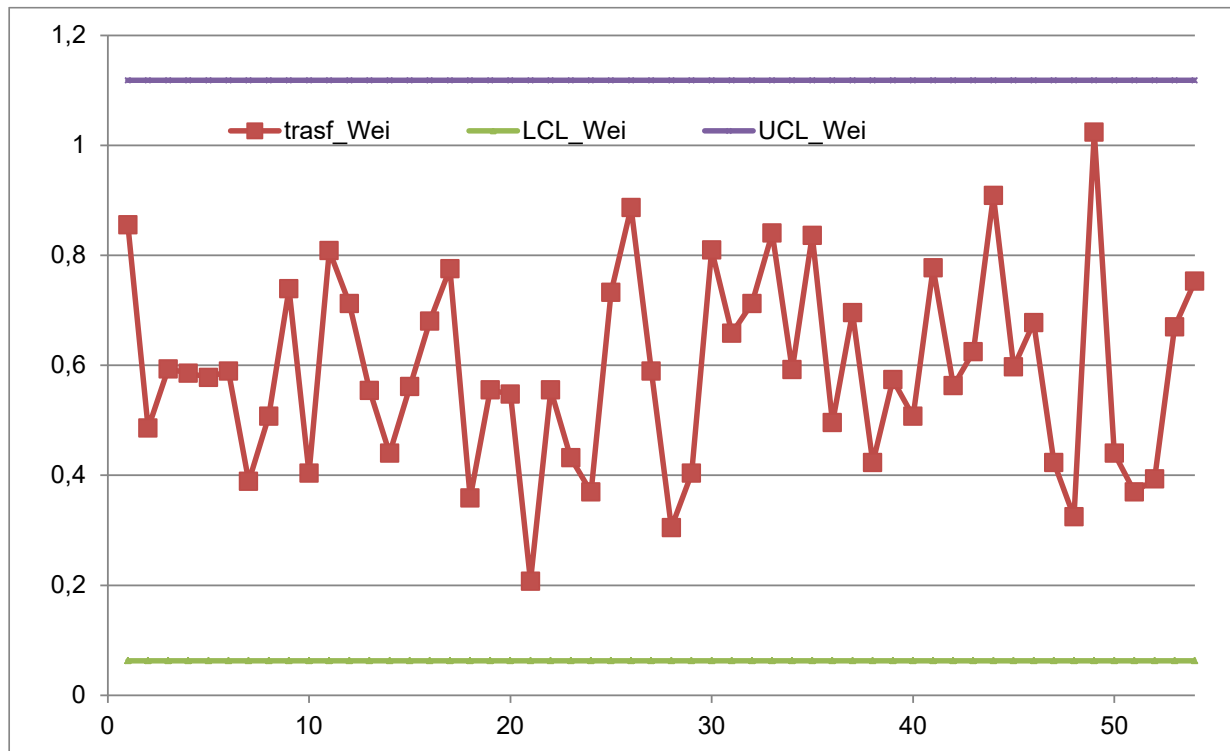


Figure 14. I-CC of the UTI, transformed into Weibull data.

On the contrary, making the same error as Montgomery, the 3 authors transform the data into Weibull with $\beta=1.36$ and then they make an EWMA Chart with “double Control Limits” with the formulae $LCL_1 = \theta_0^* c_{L1}$ $LCU_1 = \theta_0^* c_{U1}$ $LCL_2 = \theta_0^* c_{L2}$ $LCU_2 = \theta_0^* c_{U2}$, where $\theta_0^* = \theta_0^{1/3.6}$ with θ_0 the “target of an IC process”:

$$c_{L1} = \Gamma\left(1 + \frac{1}{3.6}\right) - k_1 \sqrt{\frac{\lambda}{2-\lambda} \{1 - (1-\lambda)\}^{2t}} \sqrt{\Gamma\left(1 + \frac{2}{3.6}\right) - \Gamma\left(1 + \frac{1}{3.6}\right)^2}$$

$$c_{U1} = \Gamma\left(1 + \frac{1}{3.6}\right) + k_1 \sqrt{\frac{\lambda}{2-\lambda} \{1 - (1-\lambda)\}^{2t}} \sqrt{\Gamma\left(1 + \frac{2}{3.6}\right) - \Gamma\left(1 + \frac{1}{3.6}\right)^2}$$

$$c_{L2} = \Gamma\left(1 + \frac{1}{3.6}\right) - k_2 \sqrt{\frac{\lambda}{2-\lambda} \{1 - (1-\lambda)\}^{2t}} \sqrt{\Gamma\left(1 + \frac{2}{3.6}\right) - \Gamma\left(1 + \frac{1}{3.6}\right)^2}$$

$$c_{U2} = \Gamma\left(1 + \frac{1}{3.6}\right) - k_2 \sqrt{\frac{\lambda}{2-\lambda} \{1 - (1-\lambda)\}^{2t}} \sqrt{\Gamma\left(1 + \frac{2}{3.6}\right) - \Gamma\left(1 + \frac{1}{3.6}\right)^2}$$

Excerpt 7. From the paper “An EWMA Control Chart ...” (the k coefficients are to be suitably found...). **Notice** the errors in the formulae.

See now the wrong I-CC in the Figures 13, 14, 16; only the CC in the Figure 15 is right.

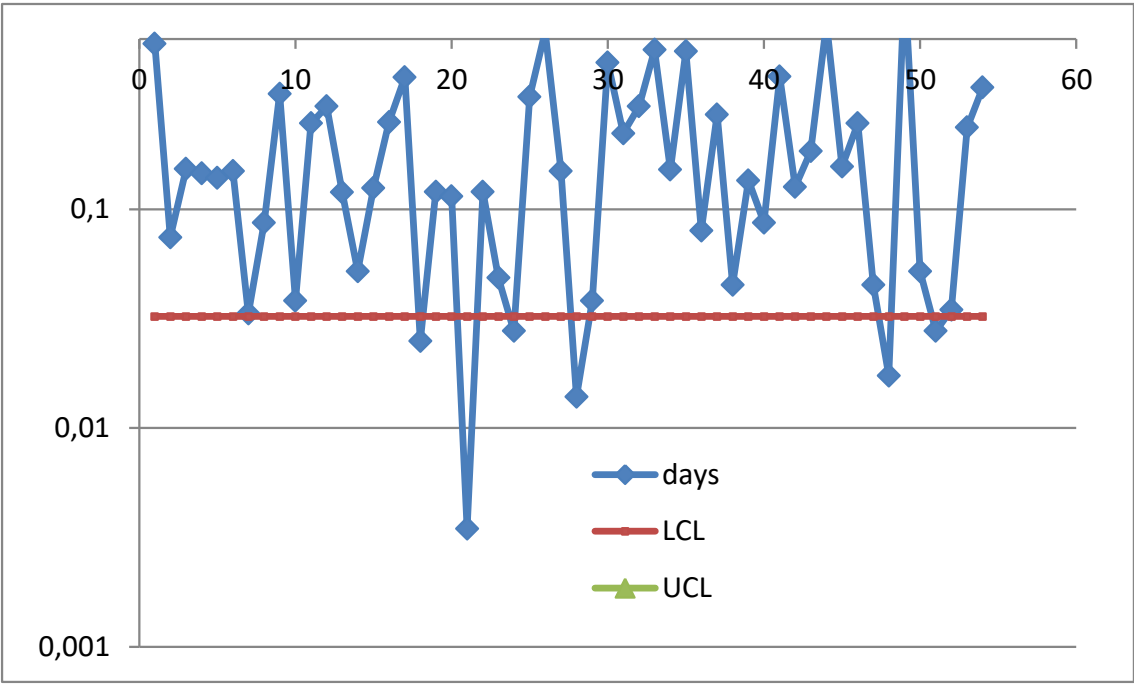


Figure 15. I-CC of the UTI, y-axis logarithm mic. RIT used (F. Galetto).

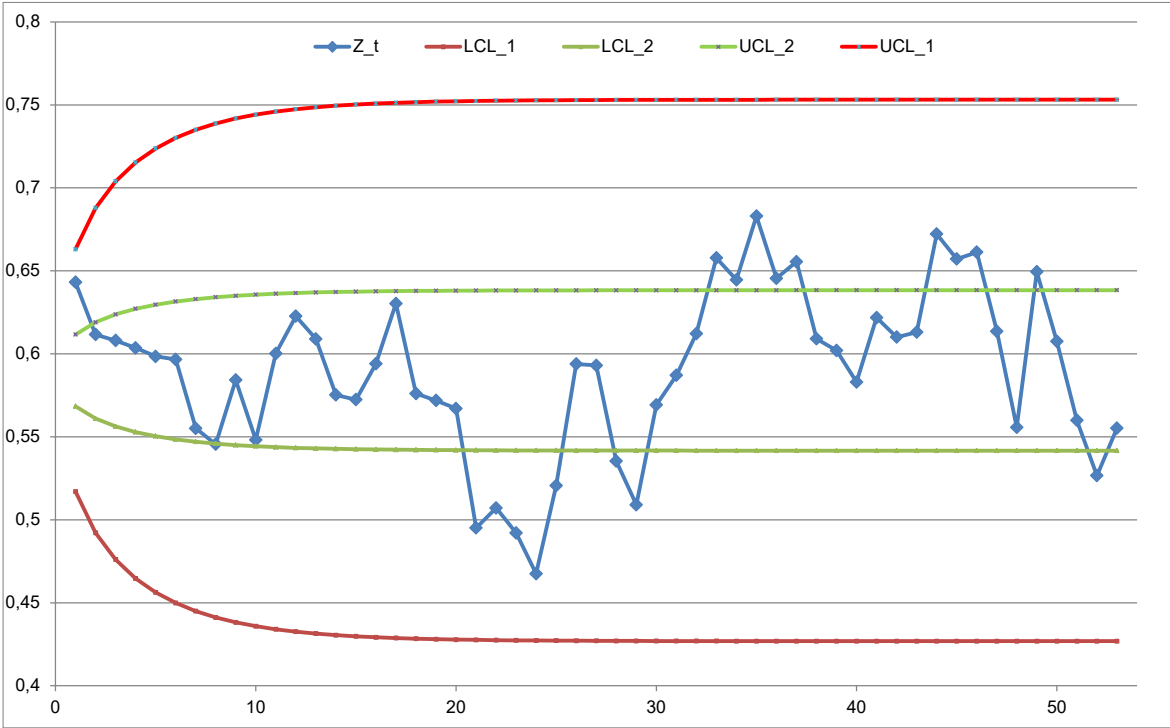


Figure 16. EWMA (F. Galetto) of the UTI.

In the paper mentioned there is a figure: we did not find the data used for the target θ_0 and the coefficients k . Hence, we used the target $\theta_0=0.59$, coefficients $k=-2.7, -0.8, 0.8, 2.7$ and $\lambda=0.2$; we got the Figure 16.

Those authors made a mess; the Peer Reviewers did not analyse correctly the paper, and the Editors did not do their Job. The same as for all the papers in the “Garden ...[52]”. Remember Juran who mentioned the FG paper, at the Plenary Session of the EOQC Conference ... [43]

3. Results

Now it is time to see the wrong formulae used by the “Garden ...” authors [52]. A small sample in in the Excerpt 8.

Typical statement by ALL ...

A uniform model the exponential TBE charts is that the occurrence of events is modelled by a Poisson process, and the time between events X_i ($i=1, 2, \dots$) re independent and identically distributed random variables with pdf $f(x) = \theta^{-1} \exp(-x/\theta)$ for $x \geq 0$, 0 otherwise, where θ is the “mean time between events”. The Control Chart plots the quantity produced before observing an event; The Control Limits can be calculated as

$LCL = \theta \ln(1 - \alpha/2), \qquad UCL = \theta \ln(\alpha/2)$

Liu J., Xie M., Sharma P., “A Comparative Study of Exponential Time Between Event Charts”, *Quality Technology & Quantitative Management*, 2006 –Issue 3, pp. 347-359

ACTUALLY LCL=L and UCL=U

Suppose LCL and UCL denote the lower and upper control limits of the Phase II t_r -chart respectively. Then for a given false alarm rate (FAR) α_0 , they can be obtained from $P(T_r < LCL|IC) = P(T_r > UCL|IC) = \alpha_0/2$ according to the equal tail probabilities approach. Thus, we have (see also Kumar and Baranwal (2019))

$$LCL = \frac{\chi^2_{2r, \alpha_0/2}}{2\lambda_0} = \frac{A_1}{\lambda_0} \text{ and } UCL = \frac{\chi^2_{2r, 1-\alpha_0/2}}{2\lambda_0} = \frac{A_2}{\lambda_0} \tag{1}$$

where $A_1 = \frac{\chi^2_{2r, \alpha_0/2}}{2}$, $A_2 = \frac{\chi^2_{2r, 1-\alpha_0/2}}{2}$ are the design constants and λ_0 is the known or specified IC rate parameter value. The $\chi^2_{2r, a}$ denotes the a -th quantile of the chi-square distribution with $2r$ degrees of freedom. The center line (CL) of the t_r -chart can be considered as the median of the IC distribution of T_r and it is given by $CL = \frac{\chi^2_{2r, 0.5}}{2\lambda_0}$.

TBE data (exponential distribution, r=1)

ACTUALLY LCL=L and UCL=U

Chakraborti et. al. (with several papers...)

Another statement by INCOMPETENTS

To construct a t chart, we determine the control limits based on a false alarm rate (α) of 0.0027, equaling that of an individual chart of normal data, and use the median as the centreline”. Whenever historical estimates are not available, the scale parameter θ can be estimated using maximum likelihood. because both control limits and the centerline are functions of solely θ , by the invariance property of MLEs the estimates are $0.00135 \bar{t}$, $6.60773 \bar{t}$, and $\log(2) \bar{t}$.”.

$LCL_T = 0.00135 \bar{t}$, $UCL_T = 6.60773 \bar{t}$
E. Santiago, J. Smith, Control charts based on the Exponential Distribution, Quality Engineering, Vol. 25, Issue 2, 85-96

ACTUALLY $LCL=L$ and $UCL=U$

Excerpt 8. Typical statements in the “Garden full of errors ... [52]” where the authors name LCL, UCL what actually are the Probability Limits L and U.

All the authors in the “Garden ... [52]” make the same error: they confuse the Probability Interval with the Control Interval in CCs (Confidence Interval!). The same happens for MINITAB, JMP, SAS, ... software.

Now we see how RIT solves the I-CC_TBE with exponentially distributed data. Before we computed the Confidence Interval is $CI=\theta_L-----\theta_U$ of the parameter θ , using all the data with t_o the “total of the data of the empirical sample D (n=20)” and Confidence Level $CL=1-\alpha$. When we deal with a I-CC_TBE we have to consider the Figure 10 and compute the LCL and UCL through the empirical mean $\bar{t}_o$ (mean observed time to failure $\bar{t}_o = t_o/n$) we only have to solve the two following equations with unknown LCL and UCL

$$R_0(\bar{t}_o|LCL) = 1 - \alpha/2, \quad R_0(\bar{t}_o|LCL) = \alpha/2 \tag{15}$$

similar to (13). For exponentially distributed data (15) become

$$\exp[-\bar{t}_o/LCL] = 1 - \alpha/2 \quad \text{and} \quad \exp[-\bar{t}_o/LCL] = \alpha/2 \tag{16}$$

The two equations (16) show clearly the errors of the authors in the “Garden ... [52]”. See on the left.

See the case by the Peer Reviewer chosen by the Editors of Quality and Reliability Engineering International about the Control Limits for Individual Control Charts with Exponentially distributed data and compare the results:

Khakifirooz, M., Tercero-Gómez, V. G. and Woodall, W. H. (2021). *The role of the normal distribution in statistical process monitoring*, Quality Engineering 33(3), 497–51

3.1. Some Papers from the “Garden ... [52]”

Let’s see some other few cases from the “Garden ... [52]”.

Consider the paper *Box-plot based Control Charts* [by Chakraborti (same author in excerpt 5.) et al.), Quality and Reliability Engineering International, 2011.

Notice [QREI again], where the lifetime data (“valves TTF”) the same as in Montgomery, 2013, page 334) are analysed; the authors use the median (instead of the mean) and the interquartile range

(instead of the ranges). The two authors define the control limits with a form similar to Shewhart (but significance level $\alpha=0.01$): the process (Figure 17) is found IC, as did Montgomery.

Using the T Chart of *Minitab* (which makes use of the *wrong formulae*, *devised by Santiago & Smith*) we can find the Figure 18: the process is found IC (as in Figure 17, Chakraborti, and as Montgomery).

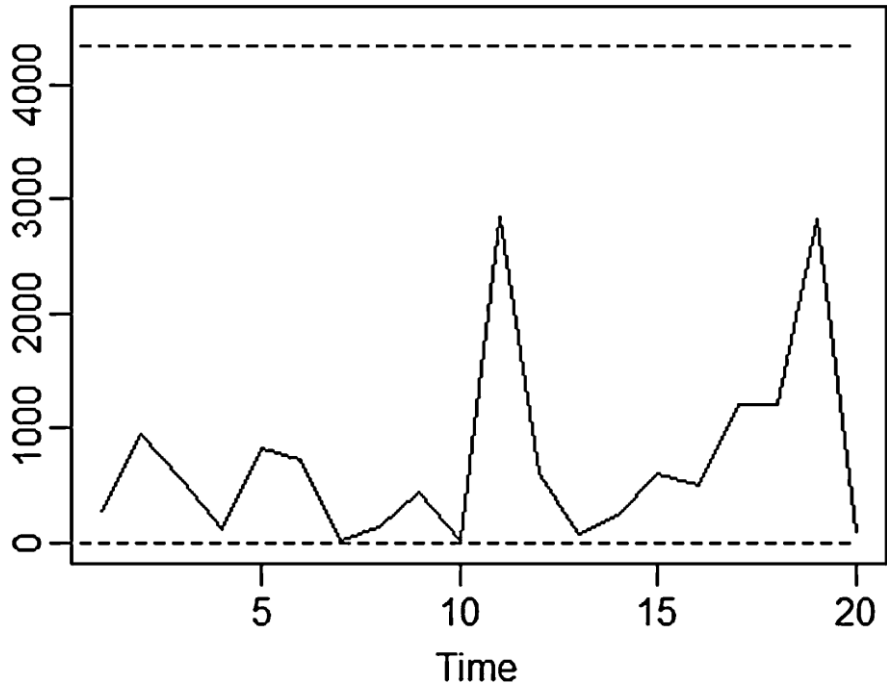


Figure 17. I-CC of Montgomery data analysed by Chakraborti (with $\alpha=0.01$).

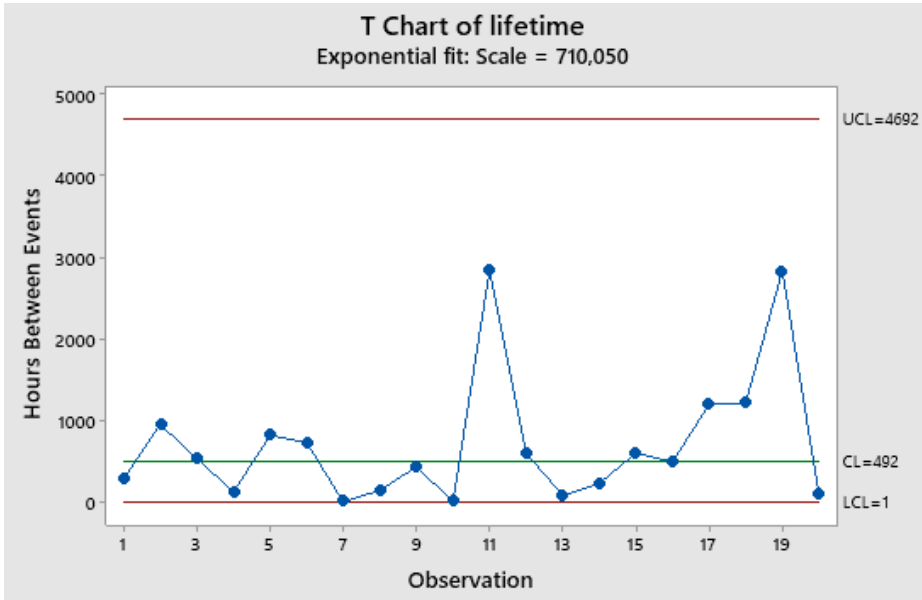


Figure 18. T Chart of Table 1 data. Minitab 19&20&21 used (F. Galetto).

Table 1. Data from *Brazilian Journal of Op. & Prod. Management*.

69.80	69.50	68.80	70.90	69.20	70.40	71.00	71.30	70.00	70.10
72.10	69.90	70.10	70.30	71.20	70.80	70.70	69.95	71.20	71.35
71.35	69.90	70.25	70.50	70.28	71.30	70.20	70.35	70.15	70.10

By using Minitab , one finds the Figure 19 (with wrong OOC as in the Excerpt 8, as happened in the Excerpt 6): UCL and LCL are wrong, while the dotted line (found with RIT) is the correct LCL.

Compare figures 18 and 19: only the dotted line is the right correct LCL, allowing taking correct decisions: huge costs of DIS-quality applications/decisions by Minitab Clients, caused by Minitab wrong methods.

The process is OOC. The reader can see easily from figures 17, 18. The ranges too are OOC.

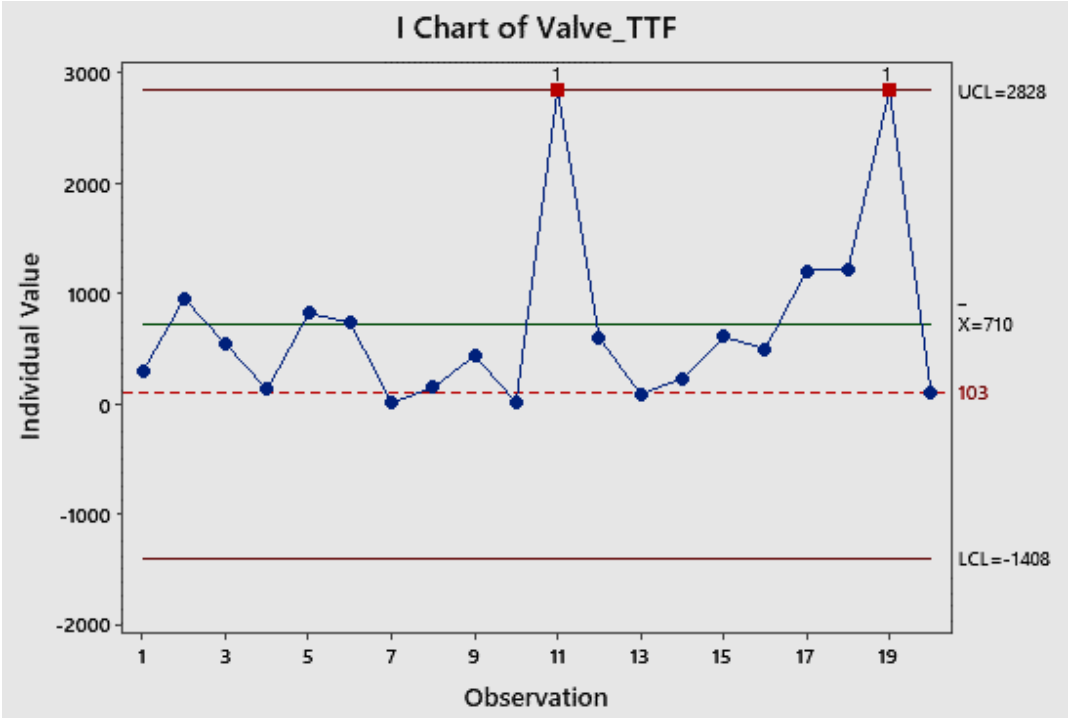


Figure 19. (F. Galetto) I Chart (Control charts) for valves data (Minitab 19&20&21 used). *The dotted line is the right correct LCL when RIT is used; the UCL is wrong.*

It should be clear that Managers, Professors and Scholars must use the Theory. The author, for many years, has been showing the many drawbacks present in various books and papers: unfortunately, he had little success; only few understood (one was Juran at 1989 EOQC Conference, Vienna).

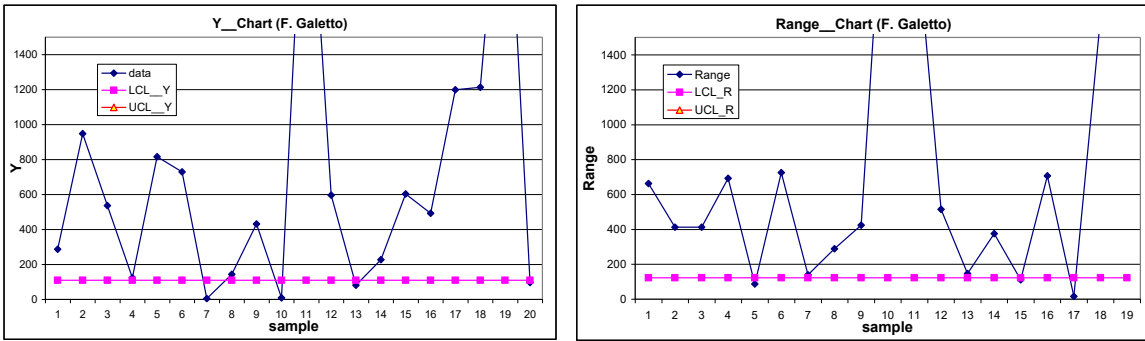


Figure 20. (F. Galetto) Scientific Control Charts for valves data [related to the data and control charts in Montgomery books]. *RIT is used.*

Now we see another paper in the "Garden... [52]" (found online, 2021) "Improved Phase... for Monitoring TBE" [Chakraborti (same author above et al.) published by QREI (again). The two authors provide a wrong solution (found neither by the Peer Reviewers nor by the Editor!). Nevertheless, they write in their Acknowledgements: ... *The authors would like to thank Dr. Douglas Montgomery, Co-editor, for his interest and encouragement.* In the authors' Abstract, we read

... In this paper, phase I control charts are considered for the observations from an exponential distribution with an and out-of-control performance of the proposed chart. It is seen that **the proposed charts are considerably more in-control robust than two competing charts and have comparable out-of control properties.** Copyright © 2014 John Wiley & Sons, Ltd.

and

Table ... shows a set of 30 failure time data generated from a Poisson distribution with a mean of 0.1. For these data, $n = 30, l=8, m= 15,$ and $u = 23.$... The center line for the proposed two-sided control chart is $CL=X(15)=6.91,$ and the lower and UCL are given by $LCL=-53.9213$ and $UCL=47.2320.$... we set the LCL as $LCL=0.$ It can be seen from Figure (our 20) that **the eleventh observation 52.32 plots outside the UCL,** which indicates an OOC situation that needs further investigation. Note that for these data, neither the Dovoedo and Chakraborti, nor the Jones and Champ control chart indicates any OOC situation.

See 21. shows a “false” OOC situation and various “false” IC...

Using RIT as done previously the $n=g^*=30$ TBE can be considered as the “transition times” between states of a stand-by system of 30 units: the Up-states are 0, 1, ..., 29, and 30 is the Down-state; t_i is the “time to failure “ from state $i-1$ to state $i.$ $R_0(t|\theta)$ is the system reliability for the interval $0\text{---}t,$ given $\theta,$ and it is, as well, the Operating Characteristic Curve of the reliability test, given $t.$ At the end of the test, we know *to* the observed Total Time on Test.

We want to analyse if the “individual” TBE are significantly different from the “mean observed time to failure” $\bar{t}_o = t_o/n.$ The Control Limits are the values satisfying the two equations (13) with *to* replaced by $\bar{t}_o = t_o/n,$ that is two equations (15 and 16) for any single unit; so, we have 30 Confidence Intervals [all equal, by solving formulae (16)], given $\bar{t}_o$ and $CL=1-\alpha.$

Compare the figures 21 and 22: it is clear that the I-CC_TBE from “Improved Phase... TBE” presents **5 errors** about OOC; the paper is wrong.

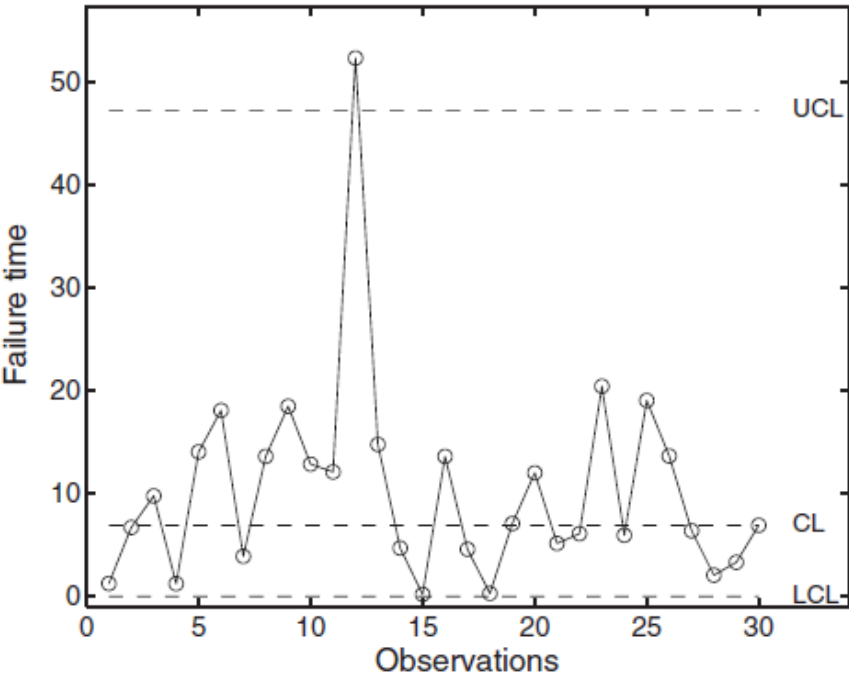


Figure 21. Control Chart from “Improved Phase... for Monitoring TBE”.

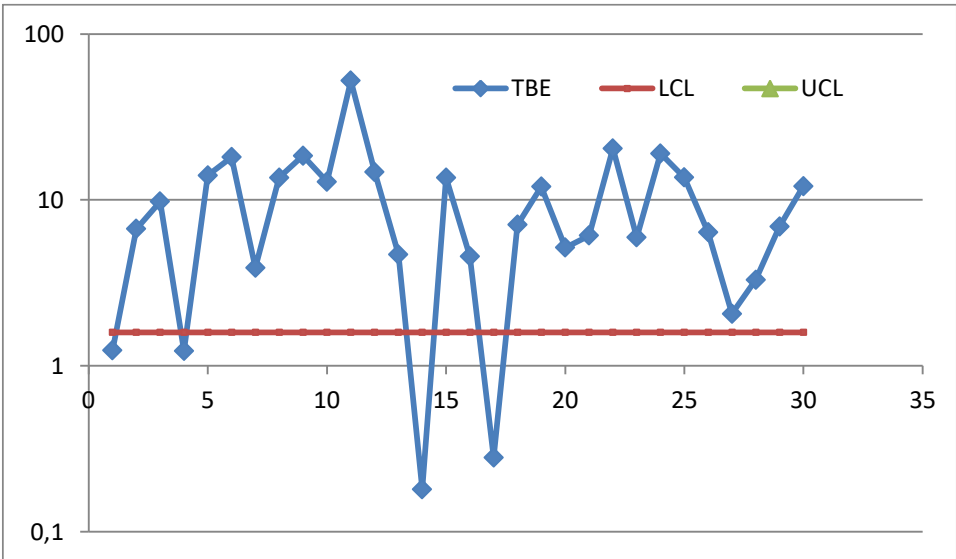


Figure 22. Control Chart of the data from “Improved Phase... for Monitoring TBE”; vertical axis logarithmic; UCL is >100. *RIT used* (F. Galetto).

Also consider the paper *Some effective control chart procedures for reliability monitoring* published in *Reliability Engineering & System Safety*. Again, WRONG Control Limits! The authors Xie et al. the “Time between failures of a component”. They do not realise that at least 20% of the data are OOC (Figure 23), a very good result for a PR paper! All the people involved did not know the Theory. “It is necessary to understand the theory of what one wishes to do or to make.” (Deming 1996) T Charts and the “Garden... [52]” methods make the users to take wrong decisions...

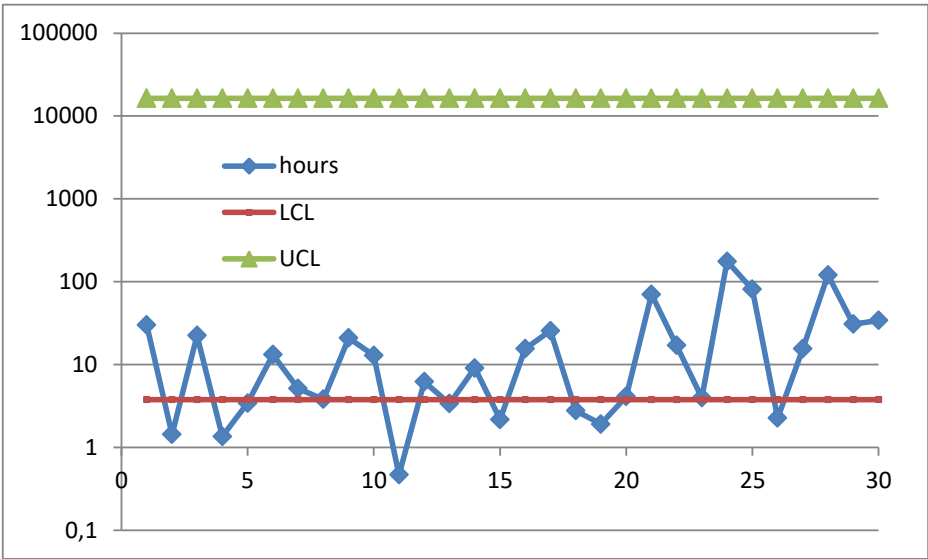


Figure 23. I-CC_TBE of Xie TBF data in “Some effective ... for reliability Monitoring”; vertical axis logarithmic; *RIT used* (F. Galetto).

Also, see a paper in (Multidisciplinary Open Access) IEES Access 2017, “EWMA Control Chart For Rayleigh Process With Engineering Applications (Alduais, Khan)”. At the end of the Abstract, we read the fantastic statements

“An application of the REWMA chart on simulated data also reveals that the proposed chart is highly sensitive to smaller and persistent shifts in the scaling parameter of Rayleigh distribution. Finally, an example from real-life has been presented to illustrate the importance of the suggested chart.”

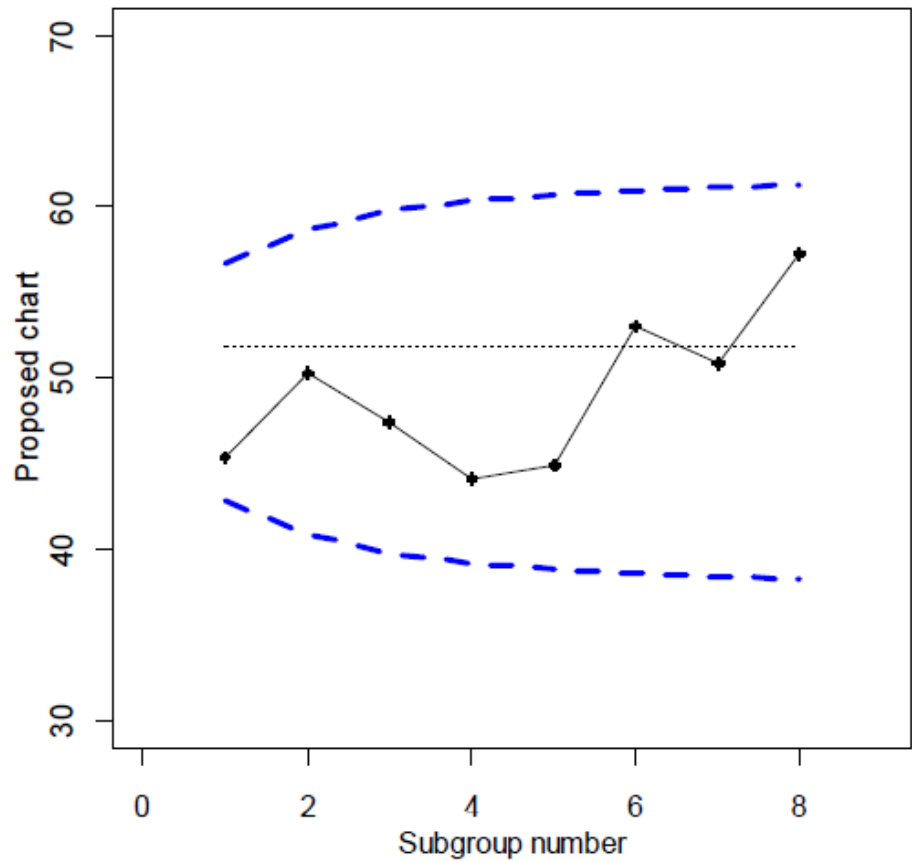


Figure 24. Proposed CC, ball bearing data [EWMA of $\hat{V}_{SQR}(i) = \sqrt{x_{ij}^2/6}$ of 8 samples, size 3)].

They consider the TTF (Time to failure, Rayleigh distributed) of 24 bearings (8 samples of size 3). The process of the 8 samples is IC (Figure 26) by their “theory”. On the contrary, the process is OOC [using RIT], both for the 24 Individuals (Figure 25) and the 8 samples (Figure 26).

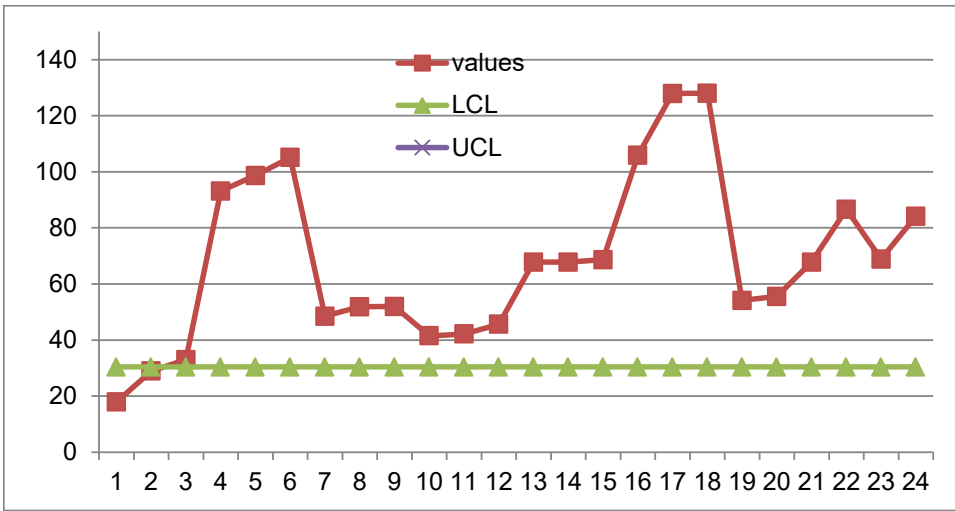


Figure 25. CC of the 24 Individuals TTF, RIT used.

The two authors claim in their Conclusions: “Simulation analysis also indicates the considerable improvement of the REWMA chart over the existing procedure in detecting shifts of smaller sizes in the study parameter”.

We think that the readers agree will not agree on that, by seeing the application (real) on the Ball Bearing failure data: the authors “detect shifts” but do not detect OOC... (figures 25, 26).

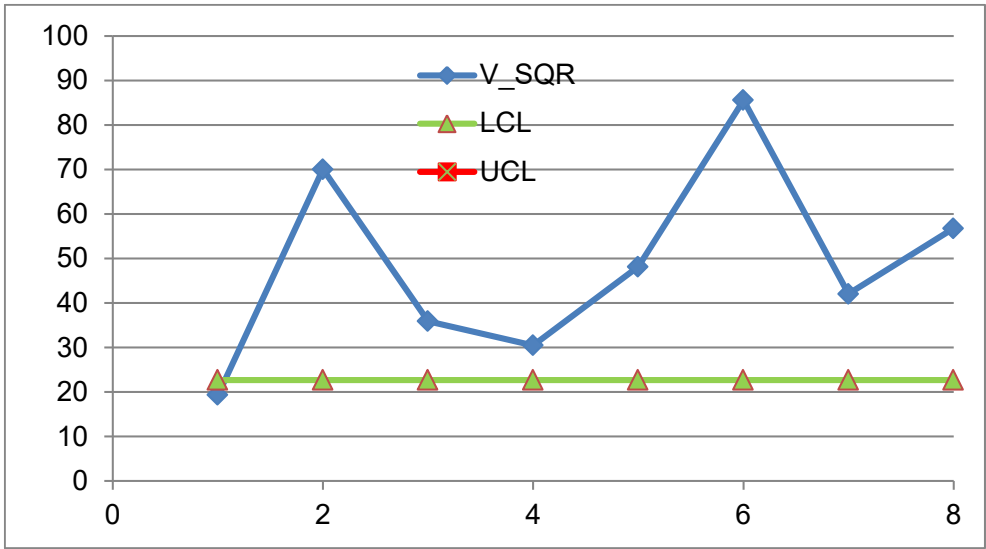


Figure 26. CC for ball bearing data [$\hat{V}_{SQR}(i)$ of the 8 samples], RIT used.

Last case: two papers (*The length-biased weighted exponentiated inverted Weibull distribution*, Cogent Mathematics, 2016, *The Weighted Exponentiated Inverted Weibull Distribution*, Journal of Informatics and Mathematical Sciences, 2017),

Distance between cracks in a pipe data-set							
30.94	18.51	16.62	51.56	22.85	22.38	19.08	49.56
17.12	10.67	25.43	10.24	27.47	14.70	14.10	29.93
27.98	36.02	19.40	14.97	22.57	12.26	18.14	18.84

Goodness of fit summary of distance between cracks in a pipe data set.

Fitting models:	WEIW	EIW	LBEIW	LBIW	Weibull
Parameter	$\beta^{\wedge} = 2.8639$	$\beta^{\wedge} = 2.7347$	$\beta^{\wedge} = 3.3891$	$\beta^{\wedge} = 1.3484$	$\beta^{\wedge} = 2.3089$
Estimates:	$\theta^{\wedge} = 394.0386$	$\theta^{\wedge} = 2384.5601$	$\theta^{\wedge} = 9508.9505$	$\theta^{\wedge} = 26.0230$	$c^{\wedge} = 0.4815$
K.S statistic	0.0865	0.0891	0.1031	0.5129	0.1436
P-value	0.9850	0.9822	0.9376	0.0000	0.6532

the estimates are wrongly written for Weibull $\beta^{\wedge}=2.3089$, $\theta^{\wedge}=26.0230$ and $c^{\wedge}=0$

Excerpt 9. From the paper “The length-biased weighted exponentiated inverted ...”.

The papers deal with the same data, on the “*distance of cracks in a pipe data-set*”: same subject and the same real data as an application: they are in Excerpt 9, with the estimates of the density $g(x; \beta, \theta, c) = \frac{\beta \theta^{(1+c-1/\beta)}}{\Gamma(1+c-1/\beta)} x^{-(1+c)\beta} \left\{ e^{-x^{-\beta}} \right\}^{\theta}$. The estimates of the parameters are (by the authors): $\hat{\beta}=1.4256$, $\hat{\theta}=100.7943$ and $\hat{c}=1.4857$. Notice that there is NO Confidence Interval... The authors do not provide any way to do that... When $c=0$ we get Length-Biased Exponentiated Inverted Weibull pdf (LBEIW), with estimates of the parameters (by the authors): $\hat{\beta}=3.3891$, $\hat{\theta}=9508.9505$, $\hat{c}=0$. NO Confidence Interval and not any way to find it...

A question arises: do the data of Excerpt 9 show a process In Control? In the papers there is no way to assess that. Using RIT, we find that the process is OOC for the 24 Individuals (Figure 27). Again, Authors, Peer Reviewers and Editors were wrong!

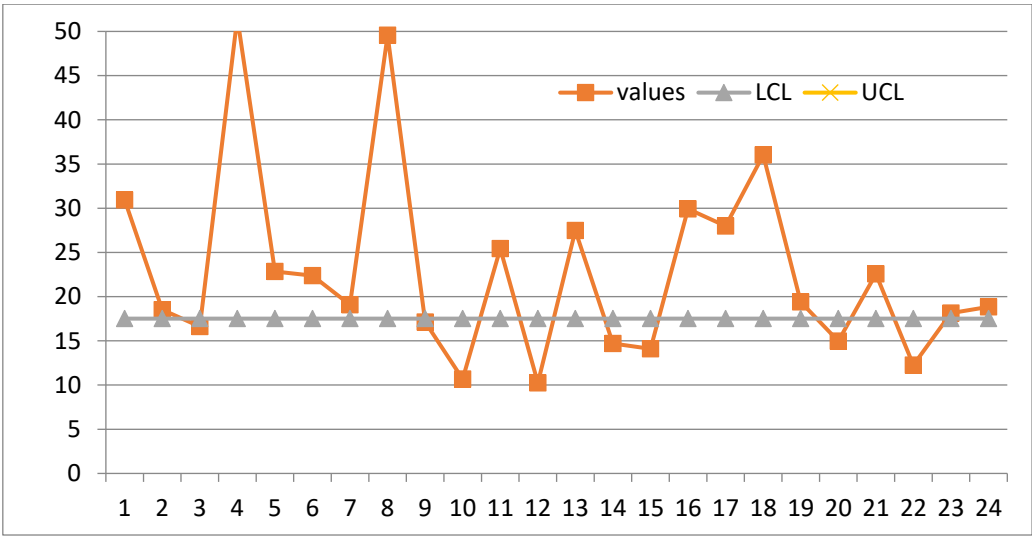


Figure 27. CC of the Individuals (from the paper “The length-biased weighted exponentiated inverted ...”), RIT used.

Also consider the paper *On designing a new control chart for Rayleigh distributed processes with an application to monitor glass fiber strength* published in *Communication in Statistics- Simulation and Computation*, January 2020. Again, WRONG Control Limits! The authors M. Pear Hossain et al. consider the “data on strength of 15 cm glass fibers”. They write:

8. Illustrative example (section 8)

To illustrate the developed VR chart we use the data on strength of 15cm glass fibers. This data has been collected from the National Physical Laboratory in England (Smith and Naylor 1987). For illustration purpose, first, we check that the data follows Rayleigh distribution or not using Kolmogorov-Smirnov test. We fail to reject the null hypothesis that data follows Rayleigh distribution at 5% level of significance with p-value 0.144.

The arrangement of the sample batches is given in Table 6 (see our Excerpt 10). They use $\alpha=0.0027$...

Table 6. Strength of 15 cm glass fiber.

Sample Number	Observation				
	1 st	2 nd	3 rd	4 th	5 th
1	1.2	1.1	0.7	1.51	1.25
2	1.2	1.1	0.75	1.28	0.4
3	1.17	1.3	0.8	1.42	1.35
4	1.38	1.22	0.94	1.43	1.28
5	1.4	1.21	1.37	0.81	1.29
6	1.4	0.92	1.37	1.06	1.29
7	1.09	0.92	1.35	1.13	0.95
8	1.08	0.86	1.61	1.14	0.98
9	1.06	0.83	1.53	1.15	1.03

Excerpt 10. From the paper “On designing a new control chart ... to monitor glass fiber strength.”.

Notice the authors’ statement “We fail to reject the null hypothesis that data follows Rayleigh distribution at 5% level of significance with p-value 0.144.”

According [36] the Rayleigh distribution can be considered a Weibull distribution with $\beta=2$ (shape parameter). Analysing the data in Excerpt 10, we find that $\beta=5.59$, with a Confidence Interval $CI=[3.81, 8.86]$ at $CL=99.5\%$; the value 2 is not comprised in the CI: hence the distribution is not the Rayleigh distribution (also for $CL=95\%$).

All the authors’ considerations are not valid for their *Illustrative example* (section 8), that is our Excerpt 10; *they find* that the “process is IC”.

Analysing the data with RIT we get the Figure 28: *the process is OOC*, using the correct distribution and directly the data in our Excerpt 10.

Analysing the data with the Normal distribution (a Weibull with $\beta=5.59$ can be approximated by the Normal) we get the Figure 29: *now the process is IC ...* as it was found by the authors with the *Rayleigh distribution!*

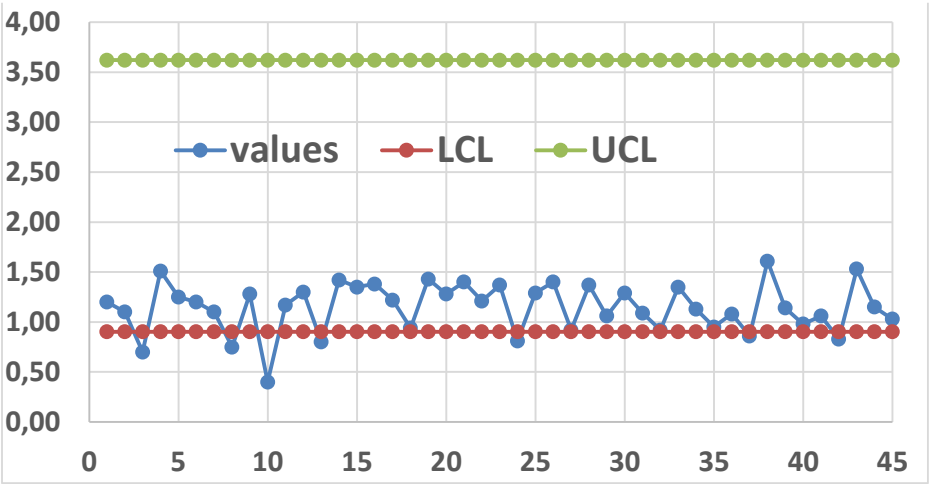


Figure 28. CC of the Individuals (from the paper “On designing a new control chart ... to monitor glass fiber strength”), RIT used.

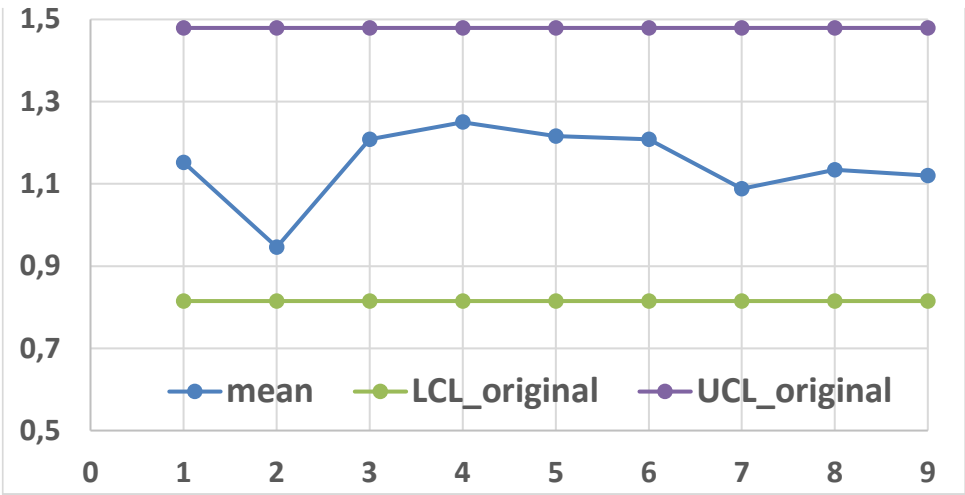


Figure 29. CC of the samples with sample size 5 (from the paper “On designing a new control chart ... to monitor glass fiber strength”), Normal distribution used.

3.2. RIT and the Duane Method (Prediction of the “Future Failure Rate”)

We found this method in the software Minitab 19&20&21.

Minitab provides the data on “reparable air-conditioners” and a graphical picture of them [see Figure 30], and computes, the mean number of failures up to time t [$M(t)$ function], of the 13 reparable systems: $M(t)=E[N(t)]$; Minitab does not give any “theory” to interpret the results; they only inform us that (1) $M(t)$ is interpolated by a model named “power law” $(t/\eta)^\beta$, with β =shape parameter and η =scale parameter, and (2) the MLM (Maximum Likelihood Method) is used. No “Reliability Theory” is provided by Minitab: this is extremely dangerous and costing.

They say (with figures):

The methods used in Minitab Statistical Software are based on established statistical practice and theory, referenced guidelines in the literature, and in some cases, simulation studies performed by statisticians in Minitab's Research and Development department. The following papers describe the research conducted to develop the methods and data checks used in the Assistant and the methodology and supporting research.... Minitab has spent the past 50 years helping companies and organizations drive cost containment, enhance product and service quality and boost customer satisfaction with our comprehensive, easy-to-use, best-in-class suite of data analysis and process improvement tools. Thousands of businesses and institutions worldwide work with Minitab because of our unique and integrated approach of solutions analytics, empowering you to make better decisions that drive business excellence.

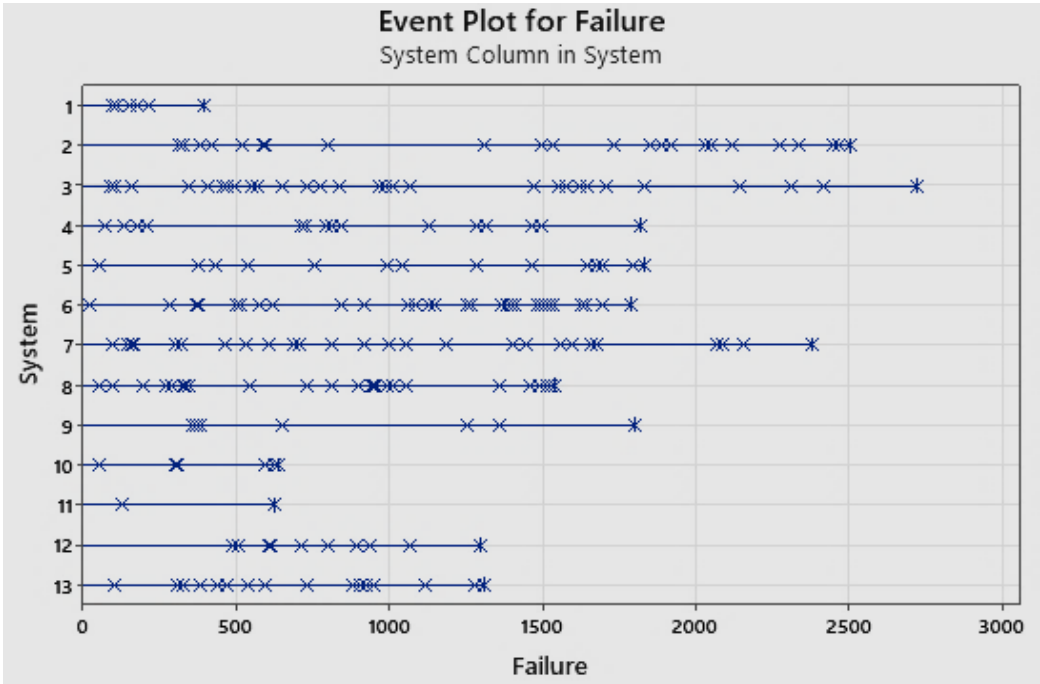


Figure 30. 13 repairable air-conditioners.

We can compare the Figure 32 [the $M(t)$] with the 33 one [the “cumulative failure rate”]; how it is related to “our” failure rate, as defined in our theory? Think about that ... See the figures 31, 32. The Figure 33 is the Duane Model!

AIRCONDITIONERRELIABILITY.MTW Parametric Growth Curve: Failure				
Model: Power-Law Process, Estimation Method: Maximum Likelihood, Parameter Estimates				
95% Normal CI				
Parameter	Estimate	StandardError	Lower	Upper
Shape	1.10803	0.067	0.984256	1.24738
Scale	128.763	22.489	91.4369	181.325
Test for Equal Shape Parameters Bartlett's Modified Likelihood Ratio Chi-Square				
	Test Statistic	10.88		
	P-Value	0.539		
	Df	12		

Figure 31. Statistical Output for 13 repairable air-conditioners (Minitab 21 used).

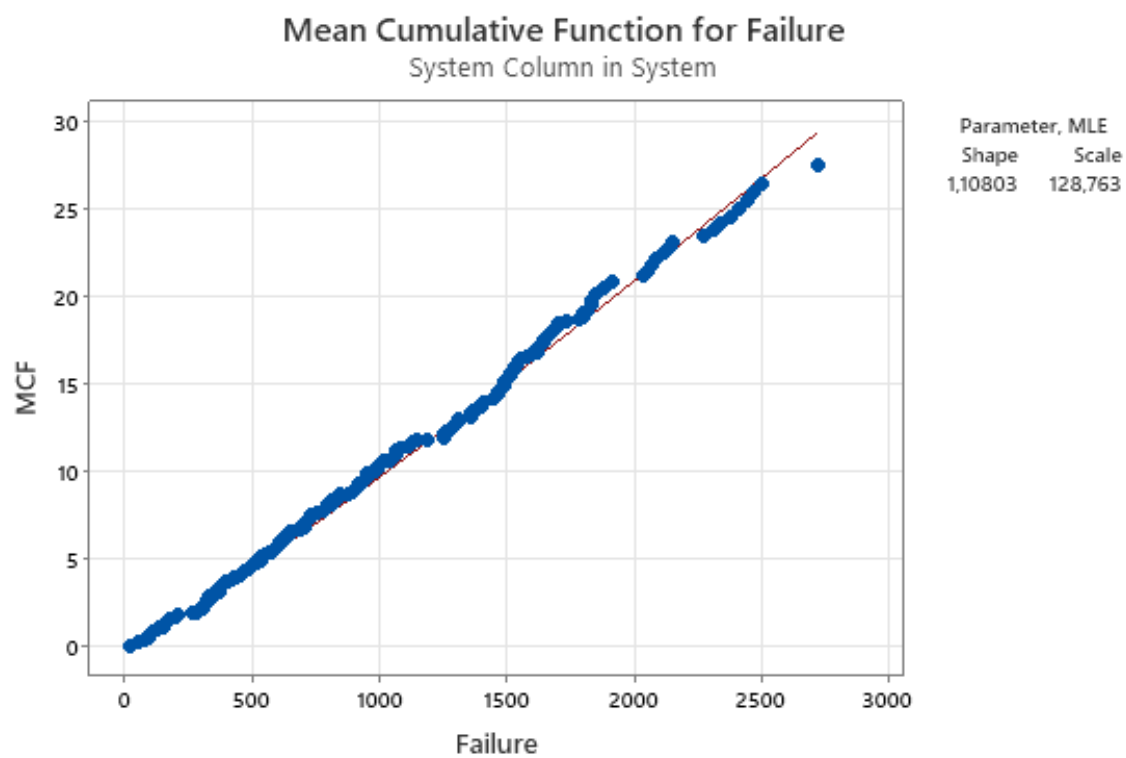


Figure 32. Graphical Output for 13 repairable air-conditioners data (Minitab 21 used).

The figures 34 and 35 show the distribution of times t_{ij} , and their differences d_{ij} , respectively.

From the figures 32, 33, 34 we see that the shape parameter β of $M(t)$ is estimated by Minitab as $\beta_{PL}=1.10803$, where PL stands for “Power Law”. Notice that this estimate tells us that “there is no aging”; moreover, the figures 34 and 35 describe a completely different aging process of the air-conditioners! $\beta_W=1.532$ (aging) and $\beta_a=0.9219$ (no aging). Where is the TRUTH?

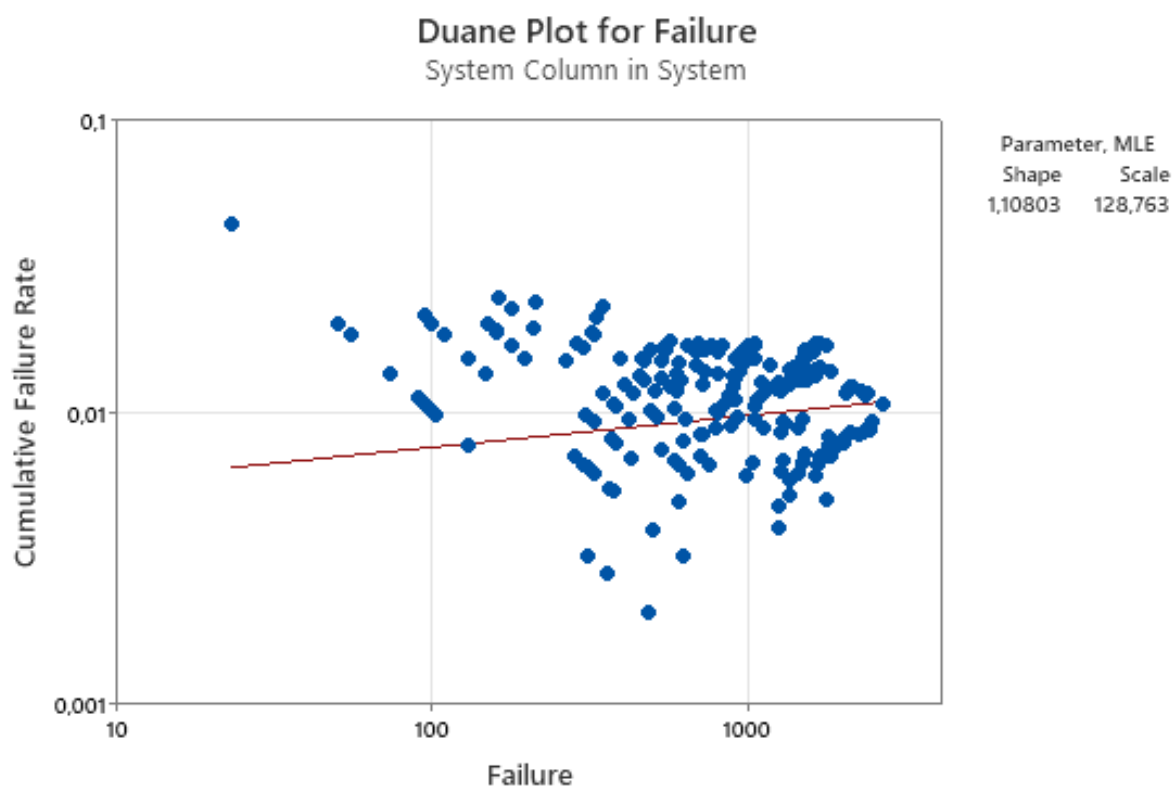
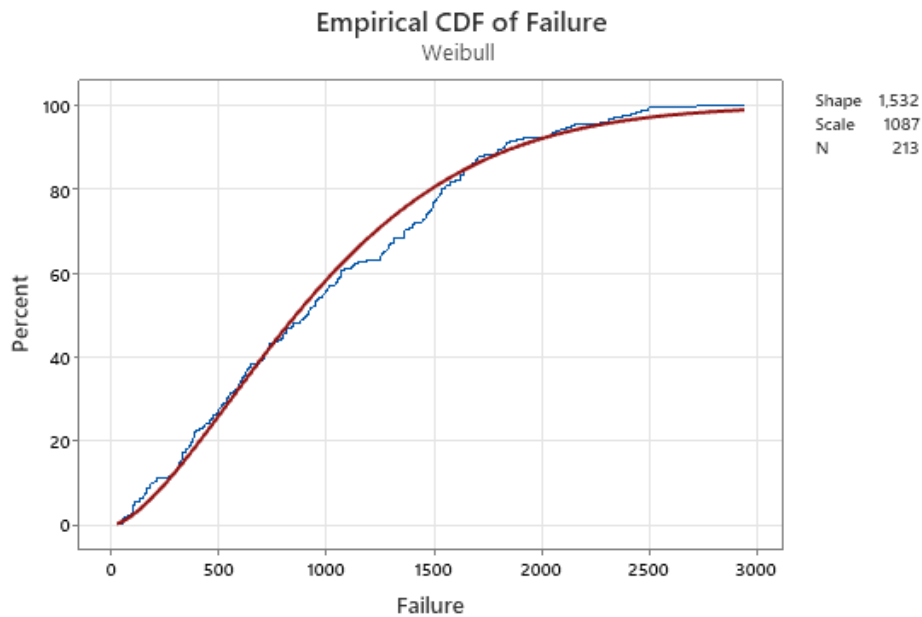
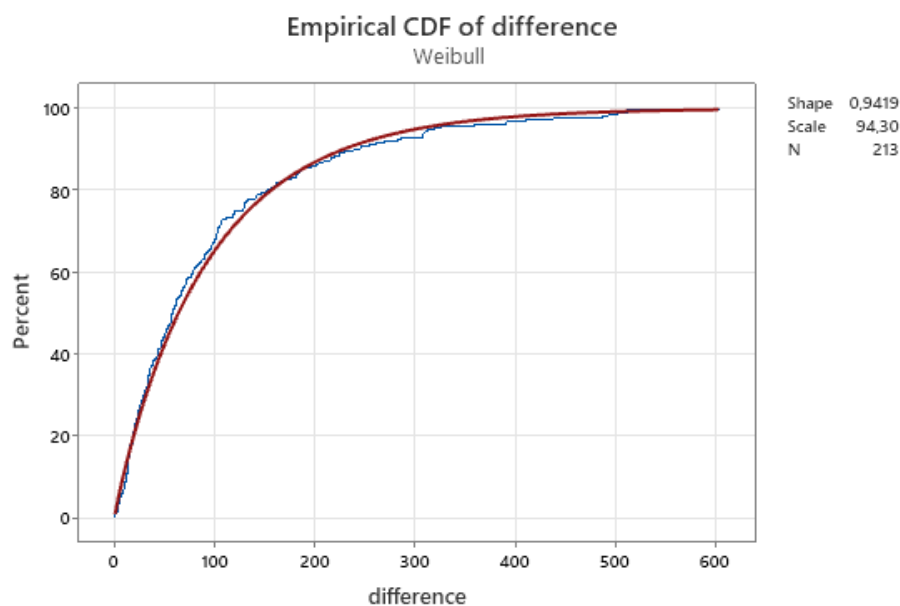


Figure 33. Duane plot for 13 repairable air-conditioners data (Minitab 21 used).**Figure 34.** Distribution of repairable air-conditioners data t_{ij} (Minitab 21 used).**Figure 35.** Distribution of repairable air-conditioners differences d_{ij} (Minitab 21 used).

It is in the given Theory, RIT.

The fundamental system (integral equations) for reliability tests (duration $0 \leq t$) [$t=0$ is the start of the test and t is the end of the test], with t_j times of failures is given in (10), with the kernels of Figure 36; at the end t of the reliability test, we know the *empirical sample* $D=\{t_1, t_2, \dots, t_{g-1}, t_g, t\}$; t_g is the last failure. To estimate the parameters β and η , from the equations we compute the determinant of the integral system (in matrix form) $\det B(s|r)$ [depending on β and η]. We have, for the system (air-conditioner) 1, with failures time t_{1j} , and g_1 failures, the formula (identical to the Likelihood)

$$\det [B(; \beta_1, \eta_1, D) = \frac{\beta_1^{g_1} e^{-\left(\frac{t_1 g_1}{\eta_1}\right) \beta_1} [t_{11} t_{12} t_{13} \dots t_{1g_1}]^{\beta_1 - 1}}{\eta_1^{\beta_1 g_1}}$$

The values maximising $\det [B(; \beta_1, \eta_1, D)]$, for the item 1, are

$$\beta_1 = \frac{g_1}{\sum_1^{g_1} \ln(t_{1g1}/t_{1j})} \quad \text{and} \quad \eta_1 = \frac{t_{1g1}}{g_1^{1/\beta_1}}$$

Similar results are found for all the 13, identical and repaired, air conditioners.

Same results can be found with the MLM.

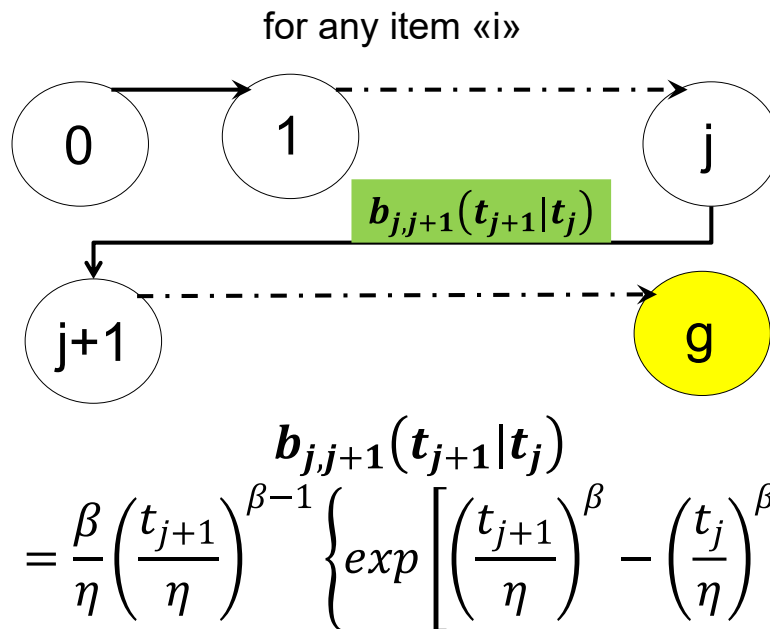


Figure 36. Transition Diagram of a repairable unit (BAO) and probability density of transitions.

From the reliability system of 13 items, we get the estimations β_{all} and η_{all} of the parameters β and η :

$$\beta_{all} = 0.99 \quad \text{and} \quad \eta_{all} = 92.38$$

The CI of β_{all} is 0.858—1.121, with CL=95%.

Notice: $\beta_{all}=0.99$ is slightly in the (Minitab) CI of β (0.984256—1.24738, with CL=95%), AND the (Minitab) $\beta_{PL}=1.10803$ is slightly in the CI of β_{all} (0.858—1.121, with CL=95%). The contrary would happen by choosing CL=90%!

We cannot have “enough confidence” that the (Minitab) $\beta_{PL}=1.10803$ AND $\beta_{all}=0.99$ are “equivalent”!

Minitab provides wrong results for repairable systems and Duane analysis: Minitab lacks scientificity and generates huge costs for Companies using them, due to their wrong analyses.

The wrong “Duane method” is based on the wrong “Duane Axiom”: “the $MTBF_c$ (the Mean Time Between Failures, instantaneous cumulated) is the ratio of the total cumulated time by the tested items, t_c , to the total number of failures $M(t_c)$ experienced in the total time test interval t_0 — t_c ”. So, they write with $\alpha=0.2 \div 0.4$, and t_0 the “total time cumulated at the beginning of the total time test interval t_0 — t_c ” where $MTBF=MTBF_0$

$$MTBF_c = MTBF_0 (t_c / t_0)^\alpha$$

For the Weibull distribution, we have $h(t)=(\beta/\eta)(t/\eta)^{\beta-1}$ and (by the absurd “Duane Axiom”) $MTBF=1/h(t)=t^{1-\beta} \eta^\beta/\beta$, $\alpha=1-\beta$ with $MTBF_0/t_0^{1-\beta}=\text{constant}$.

The position $MTBF=1/h(t)$ is an absolute NONSENSE, as shown before.

The same nonsense can be found in the paper “Using the non-homogenous Poisson Process (Duane’s model) to analyze the number of failures in Industrial Equipment” by 6 authors! (E. Junior Borges et al.) as you see in the Excerpts 11 and 12 (Abstract...).



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Excerpt 11. From the paper “Using the non-homogenous Poisson Process (Duane’s model) to ...”.

ABSTRACT

Objective: The aim of this paper is to show the application of Duane's Chart to analyze the time between failures in a company in the South of Rio de Janeiro.

Theoretical framework: A Duane chart is a scatter plot of the cumulative failure rate versus time. Use a Duane chart to do the following: •Assess whether the data follows a power-law process or a homogeneous Poisson process. •Determine whether a repairable system is improving, getting worse or remaining stable. The fitted line on the Duane chart plots the best fitted line when the power-law process assumption is valid and the shape and scale are estimated using the least squares method. The Duane plot should be approximately linear if the power law process or homogeneous Poisson process is appropriate. A negative slope shows an improvement in reliability, a positive slope shows a deterioration in reliability and no slope (a horizontal line) shows a stable system (Zanin et al., 2010).

Method: Data was taken from a company in the South of Rio de Janeiro and a case study was carried out using Duane's Chart.

Final Considerations: This result indicates that Duane's Model is a very viable option when the aim is to monitor the failure rate as a function of time to check whether a system is improving or not. In this specific Case Study, it is clear that there is a significant improvement in the system over time and that the work carried out in this company is being very effective in reducing and even eliminating failures in the long term. Implications of the research: The use cases of Duane’s Chart are multiplying in scientific literature and are proving to be highly effective for interpreting data in the area of reliability.

Originality/value: Despite being a well-known Statistical Tool, Duane's Chart has a specific application in monitoring the number of failures over time in a system.

Keywords: Duane's Chart, Faults, Cumulative Average versus Time, Mathematical Model.

Excerpt 12. From the paper “Using the non-homogenous Poisson Process (Duane’s model) to ...”.

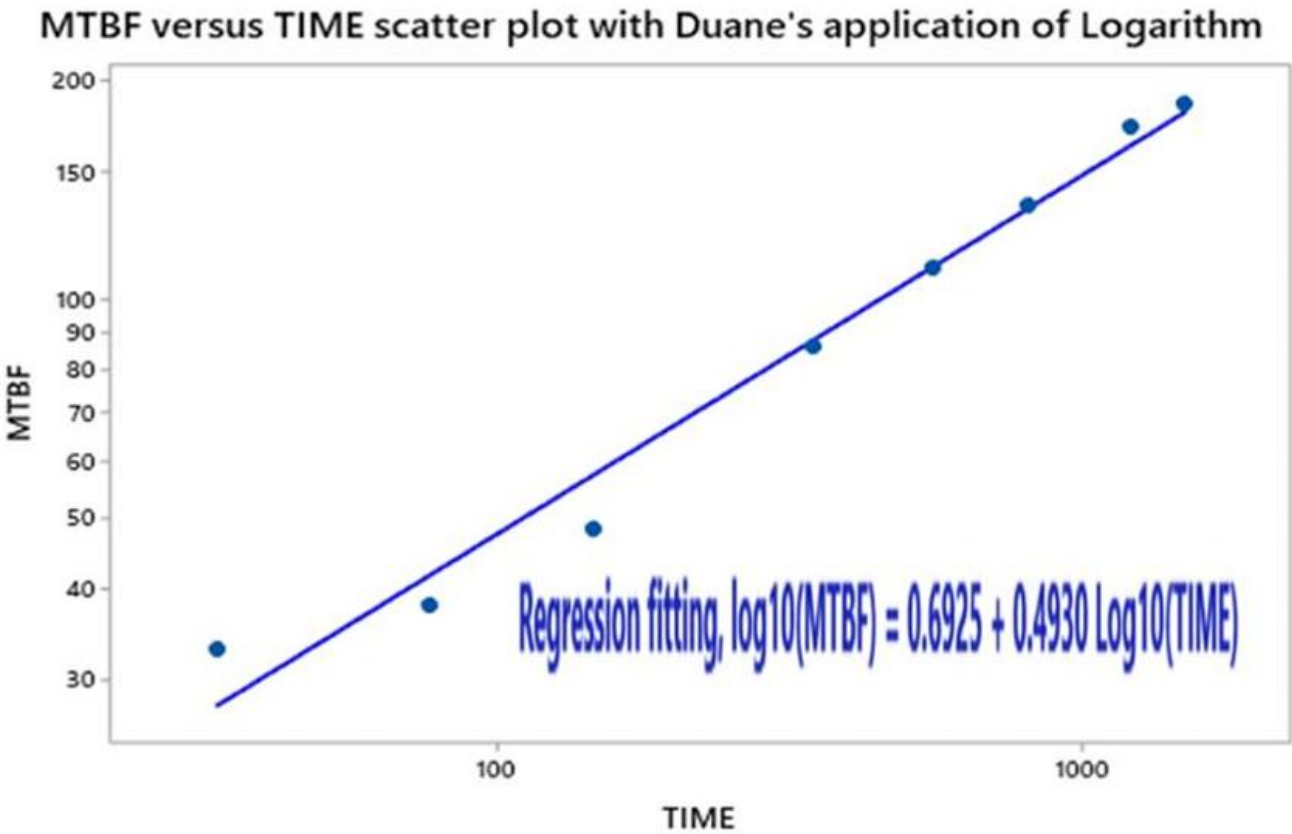
Notice the statements “*The use cases of Duane’s Chart are multiplying in scientific literature and are proving to be highly effective for interpreting data in the area of reliability*” and “*well-known Statistical Tool*” ... We will see that are nonsense, by using their case study!

The data of the case study are in the Table 2.

Table 2. Case study: Data from *Revista de Gestao Social e ambiental*.

failure	1	2	3	4	5	6	7	8
time_cum (s)	33	76	145	347	555	811	1212	1499

From the Table 2 the 6 authors compute the Cumulative Average Function (CAF)= $(t/\eta)^\beta$, which is the M(t), the mean number of failures in the interval 0-----t [34–40]; taking the logarithm with base 10 they find the linear regression of the excerpt 12, and derive the estimates $\beta=0.507$ and $\eta=23.237$; they do not provide any Confidence Interval (CI) for the estimates, because they do not have any theory for that!



Excerpt 13. From the paper “Using the non-homogenous Poisson Process (Duane’s model) to ...”.

From the reliability system related to Table 2 (and RIT with the Figure 36), we get the estimates $\beta=0.6442$ and $\eta=59.437$ for the parameters β and η : these estimates are quite different from the “Brazilian” ones.

By the Theory (RIT), we can compute the CI of β ; $CI_{FG}=0.227\text{---}1.052$, with $CL=95\%$.

Notice: the value 1 is slightly in the CI_{FG} of β (with $CL=95\%$); therefore we can conclude, with $CL=95\%$, that the data are exponentially distributed. To investigate this point we consider the “time between failures (TBF)” 33, 43, 69, 202, 208, 256, 401, 287 and estimate the parameters β and η of the Weibull density $f(t; \beta, \eta)$; we find $\beta=1.481$ and $\eta=206.791$ for the parameters: quite different results from the previous ones!

However, by the Theory (RIT), we can compute the “new” CI of β ; $CI'_{FG}=0.821\text{---}3.430$, with $CL=95\%$. Again, the value 1 is in the CI'_{FG} of β (with $CL=95\%$); therefore we can conclude, with $CL=95\%$, that the data are exponentially distributed: same decision as before.

Therefore we can conclude, with $CL=95\%$, that the data are exponentially distributed and there is “no improvement in the “time between failures (TBF)””: the Duane method is nonsense!

Using JMP18 we found that the “exponential distribution provides the best fit of the TBF data”.
The position $MTBF=1/h(t)$ is an absolute NONSENSE, as shown before.

4. Discussion and Conclusions

We consider first some statements found in the paper “On 100 Years of Quality Control Charts” by Muhammad Waqas, University of WAH, Pakistan

"Journal of Quality Technology" and "Quality and Reliability Engineering International" are top sources due to their high citation counts and strong h-indices, showing sustained and considerable scholarly influence. These journals and others on the list balance research quantity and quality to increase chart literature's local influence. Despite lower h-indices, "Computers and Industrial Engineering," "IIE Transactions," and "Quality Engineering" have significant influence and citation counts, demonstrating their persistent contributions to the subject. This technique helps chart researchers evaluate journals and choose venues.

Overall Growth The number of chart articles published in all journals has increased over time, demonstrating greater interest and participation. Production has increased steadily due to the growing understanding and continued significance of research. Prominent Journals "Quality and Reliability Engineering International" consistently leads article production and is gradually expanding. "Journal of Quality Technology" is also steadily increasing, confirming its industry leadership. "Quality Engineering," "International Journal of Production Research," and "Computers and Industrial Engineering" all contribute significantly and steadily.

These statements show clearly that a real "probability, statistical and stochastic processes" education of authors, Peer Reviewers and Editors is absolutely needed: the case we presented are a "very small" clear indication [1–78]: see the appendix.

Applying the G-Processes we could show the way to solve various cases of practical interest: analysis and prediction of repairable systems reliability and availability, statistical estimation (and Confidence Interval evaluation) of the parameters of distributions, correct computation (prediction) of Control Limits of the Control Charts, especially for Individual CC with TBE exponentially distributed and of the Duane method (prediction of future MTBF).

We introduced the Stochastic G-Processes which rule the relationships between the reliabilities $R_i(t|s)$. The stochastic processes [HMP, NHMP, SMP, RP, A&RP] used for reliability analyses (to the author knowledge) are particular cases of the G-Process. We showed various cases (from papers) where errors were present due to the lack of knowledge of RIT.

The author many times tried to compel several scholars to be scientific: he did not have success (Galletto 1981-2025). Only Juran appreciated the author's ideas when he mentioned the paper "Quality of methods for quality is important" at the plenary session of EOQC Conference, Vienna [43].

For the control charts, it came out that RIT proved that the T Charts, for rare events and TBE (Time Between Events), used in the software Minitab, SixPack, JMP or SAS are wrong. So doing the author increased the h-index of the mentioned authors publishing wrong papers. See Appendix A.

We suggest the readers to consider the various excerpts, especially those related to CCs: many authors have been diffusing wrong concepts for years and years...

RIT allows the scholars (managers, students, professors) to find sound methods also for the ideas shown by Wheeler in Quality Digest documents [24–27].

We proved also that Minitab software provides wrong analysis repairable systems Reliability (Minitab says "the items are aging", while they are actually GAN after any failure). A recent article has the same problem: authors are incompetent.

We informed the authors and the Journals who published wrong papers by writing various letters to the Editors...: no "Corrective Action", a basic activity for Quality, was caried out. The same happened for Minitab: so, people continue taking wrong decisions...

Deficiencies in products and methods generate huge cost of DIS-quality (poor quality) as highlighted by Deming and Juran. Any book and paper are a product (providing methods). The books present financial considerations about reliability: their wrong ideas and methods generate huge cost for the Companies using them. The methods given here provide the way to avoid such costs, especially when RIT gives the right way to deal with Preventive Maintenance (risks and costs), Spare Parts Management (prediction of cost of unavailability of systems and production losses), Inventory Management, prediction of cost of wrong analyses and decisions.

We think that we provided the readers with the belief that Quality of Methods for Quality is important [43] and with several ideas and methods to be meditated in view of the applications, generating wealth for the companies using them.

There is no “free lunch”: metanoia and study are needed and necessary.
“He came unto his own, and his own received him not.” (Gospel of John)
“Acta, non verba”.

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Data Availability Statement: “MDPI Research Data Policies” at <https://www.mdpi.com/ethics>.

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Abbreviations

The following abbreviations are used in this manuscript:

LCL, UCL	Control Limits of the Control Charts (CCs)
L, U	Probability Limits related to a probability 1-α
θ	Parameter of the Exponential Distribution
θL-----θu	Confidence Interval of the parameter θ
RIT	Reliability Integral Theory
Prediction	Result of application of RIT, both for Reliability, Availability, Mean Number of Failures M(t), Duane method (proving its nonsense), ...

Appendix A

The “Garden of flowers” (anthology, florilegium)
Ali, Pievatolo, Göb, (2016), “An Overview of Control Charts for High-quality Processes”, <i>Quality and Reliability Engineering International</i> , Khakifirooz, Tercero-Gómez, Woodall, (2021), “The role of the normal distribution in statistical process monitoring”, <i>Quality Engineering</i> , Alduais, Khan, (2023), “EWMA Control Chart For Rayleigh Process With Engineering Applications”, <i>IEEE Access</i> , Zhang, Xie, Goh (2006) “Design of exponential control charts using a sequential scheme”, <i>IIE Transactions</i> , Di Bucchianico, Mooiweer and Moonen1 (2005) “Monitoring infrequent failures of high-volume production processes”, <i>Quality and Reliability Engineering International</i> , Jiang and Wong (2012) “Interval Estimations of the Two-Parameter exponential”, <i>Journal of Probability and Statistics</i> , Mukherjee, McCracken, S. Chakraborti, “Control Charts for Simultaneous Monitoring the Parameters of a Shifted Exponential Distribution” (<i>found online</i> , 2023, December), Zhang, Megahedb, Woodall, (2013), “Exponential CUSUM Charts with Estimated Control Limits”, <i>Quality and Reliability Engineering International</i> , Alqurashi, Chakraborti, Holcombe, (2023), “Exact tolerance interval with specified tail probabilities and a control chart for the sample variance”, <i>Quality and Reliability Engineering International</i> , Shah, Azam, Aslam, Sherazi, (2020) “Time between events control charts for gamma distribution”, Wiley, Adeoti, (2019) “On control chart for monitoring exponentially distributed quality characteristic”, <i>Transactions of the Institute of Measurement and Control</i> , Aslam, Arif, Jun (2016) “A Control Chart for Gamma Distribution using Multiple Dependent State Sampling”, <i>Industrial Engineering & Management Systems</i> , Khilare (2021) “A synthetic control chart for generalized exponential distribution”, <i>Research Journal of Mathematical and Statistical Sciences</i> , Khilare, Shirke

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On September 2022, the author looked (in the web) for other TBE (Time Between Event) papers and books to see their way of dealing with "Rare Events" Control Charts; he copied 77 pages of documents (several from Consultants); he downloaded 32 papers (Open Source). Several Journals asked from 15 \$ to 60 \$, to download a paper. The Open Source are: "Control Chart: Charts for monitoring and adjusting industrial processes", "TOOL #6 - XBar & R Charts", "Integrating Quality Control Charts with Maintenance", "A Brief Literature Review", "Paper SAS4040-2016, "Improving Health Care Quality with the RAREEVENTS Procedure Bucky Ransdell, SAS Institute Inc.", "Performance Criteria for Evaluation of Control Chart for Phase II Monitoring", "(Thesis) A Comparative Study of Control Charts for Monitoring Rare Events in Health Systems Using Monte Carlo Simulation", "A study on the application of control chart in healthcare", "Control Charts for Monitoring the Reliability of Multi-State Systems", "Part 7: Variables Control Charts2, "A Control Chart for Gamma Distribution using Multiple Dependent State Sampling", "A Variable Control Chart under the Truncated Life Test for a Weibull Distribution", "Plotting basic control charts: tutorial notes for healthcare practitioners", "Appendix 1: Control Charts for Variables Data – classical Shewhart control chart",

TRUNCATED ZERO INFLATED BINOMIAL CONTROL CHART FOR MONITORING RARE HEALTH EVENTS", "Comparison of control charts for monitoring clinical performance using binary data", "A number-between-events control chart for monitoring finite horizon production processes", "Rare event research: is it worth it?", "Quality Improvement Charts: An implementation of statistical process control charts for R", "Control Chart Overview", "Statistical Process Control Monitoring Quality in Healthcare", "A Control Chart for Exponentially Distributed Characteristics Using Modified Multiple Dependent State Sampling", "Synthetic-Type Control Charts for Time-Between-Events Monitoring", "A systematic study on time between events control charts", "Lifestyle Management through System Analysis Monitor Progress", "Multivariate Time-Between-Events Monitoring – An overview and some (overlooked) underlying complexities", "A Comparison of Shewhart-Type Time-Between-Events Control Charts Based on the Renewal Process", "Control Charts for Monitoring Time-Between-Events-and-Amplitude Data", "How to Measure Customer Satisfaction Seven metrics you need to use in your research".

Later, new papers were downloaded (notice the same authors as before!, published wrong ideas for many years): Supharakonsakun, Y. "Bayesian Control Chart for Number of Defects in Production Quality Control", MDPI (2024), Chakraborti, S. et al., "Properties and performance of the c-chart for attributes data", Journal of Applied Statistics (2008), Chakraborti, S. et al., "Exact two-sided statistical tolerance limits for sample variances", Quality and Reliability Engineering International (2018), Baocai G. et al., "Exact two-sided tolerance interval controlling tail proportions for sample variances", Quality and Reliability Engineering International (2020), Chakraborti, S. et al., "Tolerance interval for the exponential distribution with a specified ratio of the tail probabilities and generalizations", Quality Engineering (2022), Rakitzis, A. et al., "The Unconditional Performance of Control Charts for Zero-Inflated Processes with Estimated Parameters", Statistical Methods and Applications in Systems Assurance & Quality (2024), Chakraborti, S. et al., "Dynamic Risk-Adjusted Monitoring of Time Between Events :Applications of NHPP in Pipeline Accident Surveillance", Quality and Reliability Engineering International (2025), E. Mamzeridou & A. Rakitzis (2024) "On the design and performance of upper one-sided Shewhart charts for zero-inflated Poisson processes with estimated parameters", Quality Technology & Quantitative Management (2024), Mukherjee, A., "Distribution-free Phase II CUSUM Control Chart for Joint Monitoring of Location and Scale", Quality and Reliability Engineering International (2015), Chakraborti, S. et al., "ARL-Unbiased Exponential Control Charts With Estimated Parameters: Statistical Design and Implementation", Quality and Reliability Engineering International (2025), Chakraborti, S. et al., "Robustness of the EWMA control chart for individual observations", Journal of Applied Statistics (2011), Chakraborti, S. et al., "Run Length Distribution and Percentiles: The Shewhart Chart with Unknown Parameters", Quality Engineering (2007), Chakraborti, S. Kumar, N., "Phase II Shewhart-type Control Charts for Monitoring Times Between Events and Effects of Parameter Estimation", Quality and Reliability Engineering International (2014), Chakraborti, S. Kumar, N., A. Rakitzis, et al., "Improved Shewhart-Type Charts for Monitoring Times Between Events", Journal of Quality Technology (2016), Mukherjee, A., et al., "Some two-sample tests for simultaneously comparing both parameters of the shifted exponential models", Communications in Statistics Theory and Methods (2022), Mukherjee, A., et al., "Simultaneous Location and Scale Monitoring of Key Performance Indicators", Quality and Reliability

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The "Garden of flowers" (anthology, florilegium)

There is no "free lunch": metanoia and study are needed and necessary.

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