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**REVIEW**

# Quality Decisions Based on Time between Events Data Analysis

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## ABSTRACT

Good decisions (Quality Decisions) depend on scientific analysis of data. Data are collected, generally, in two ways: 1) one sample of suitable size, 2) subsequent samples, at regular intervals of time. Often the data are considered normally distributed. This is wrong because the data must be analysed according to their distribution: Decisions are different. In several cases the data are exponentially distributed: we see how to scientifically deal with Control Charts (CC) to decide; this is opposite to what gives the T Charts that are claimed to be a good method for dealing with "rare events": The Minitab Software (19 & 20 & 21) for "T Charts" is considered. The author will compare some methods, found in the literature with the author's Theory RIT (Reliability Integral Theory): We will see various cases found in the literature. Classical Shewhart Control Charts and the TBE (Time Between Events) Control Charts have been considered: it appears that with RIT the future decisions will be both sounder and cheaper, for data is exponentially distributed. The novelty of the paper is in the scientific way of dealing with the Control Charts and their Control Limits, both with normally distributed data and with exponentially distributed data. In this way, a lot of wrong published papers on "Time Between Events" are to be discarded, even if their authors claim "We used Standard Statistical methods, typical in the vast literature of similar papers". The author had to self-cite because it seems the only one that has been fighting for years for "Papers Quality"; he humbly asked the readers to inform him if some people did the same.

***Keywords:*** Control Charts; Exponential distribution; TBE Box-plot method; Rare Event Charts; Minitab; RIT

## 1. Introduction

When the author was attending a post on Academia.edu (March 2021) he was invited to read the paper [1] "Boxplot-based Phase I Control Charts for Time Between Events" (BCCTBE) published in the

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magazine Quality and Reliability Engineering International. Soon after he read "Statistical design of ATS-unbiased charts with runs rules for monitoring exponential time between events", Communications in Statistics—Theory and Methods [2], where there is the same type of errors about the Control Limits as Dovoedo and Chakraborti [1] and the papers [3-23]. The author tried several times, to inform the "Scientific Community" about the problems of Control Charts for TBE (Time Between Event): Wrong Control Limits in them: He had no success.

In this paper I will use the Reliability Integral Theory (RIT) of Reliability Tests, for various cases found in the literature, when the data are exponentially distributed (Poisson Statistical Process).

On September 2, 2022, the author looked for 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) and of Journal wanting, from 15 $ to 60 $, to download a paper. 32 papers were Open Source and were downloaded.

Up to now, in September 2022, the author found a desperate situation: All the papers have the same problem, generated by Ignorance about the fundamental concepts of Confidence Limits, at a specified Confidence Level.

All the documents [1-24] have the same problem: Wrong formulae for the Control Limits (LCL and UCL). The author [25] and M. Sivo (in ResearchGate) raised the question about Control Limits and Confidence Limits. An answer was given in "Six Sigma_ Hoax against Quality_Professionals Ignorance and MINITAB WRONG T Charts" [25]. Looking at documents from 1 to 10 in the references, it came out that the "Box-plot" method was a competitor of another method that the author had asked (for discussion) in a post at site iSixSigma: https://www.isixsigma.com/topic /control-charts-non-normal-distribution related to control charts [25] by saying that the author was looking for a solution of Two cases for Master-Black-Belts-dec-2019", with data are exponentially distributed (see Figure 1). The first of the cases were taken from the book of D. C. Montgomery [26]; the author knew about that since 1996; Montgomery dealt with it in all the later editions of the book [26]. The iSixSigma "experts" were unable to provide a correct way to solve the cases and did not want to accept that Montgomery's solution was doubtful because he finds that the process is In Control (IC), while actually, the process is Out Of Control (OOC). To date, in September 2022, nobody (in iSixSigma, Academia.edu] and Research Gate) provided any good solution to the problem (see **Figure 1**).

Letters (not mentioned in the References) sent to the Editors of the Journals "*Quality Engineering, Quality Technology & Quantitative Management, Quality and Reliability Engineering International, Communications in Statistics - Theory and Methods, PLOS one, ...*" are not yet been published: the papers [1-24] are wrong and obviously the Editors cannot acknowledge that. In 2020 the author showed [25] the drawbacks of TBE Control charts in "Six Sigma_ Hoax against Quality_Professionals Ignorance and MINITAB WRONG T Charts", HAL Archives Ouvert.

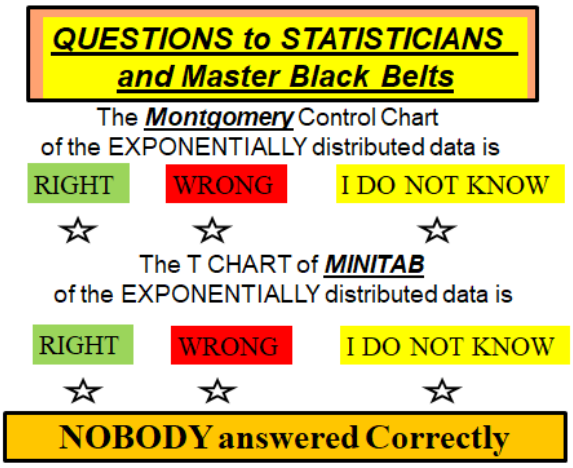


**Figure 1.** Question to MBB and Statisticians and Experts.

Control Charts are a statistical tool for monitoring the "measurable output" of a Process (Production or Service Process).

The "*Box-plot*" uses the data taken from Montgomery [26]; I will use the same data for comparison between the two methods, "*Box-plot*" and "*T Charts*" and the Reliability Integral Theory (RIT) of Reliability Tests, for various cases found in the literature, when the *data are exponentially distributed (Poisson*

*Statistical Process)*. Since T Charts are claimed to be a good method for dealing with "rare events", I consider, as well, the Minitab Software (19 & 20 & 21) for "*T Charts*".

The "measurable output" of the Process can be viewed as a "Stochastic Process X(t)", ruled by a probability density for any set of n "Random Variables RV" $X(t_1)$, $X(t_2)$, …, $X(t_n)$, considered at the "time instants" $t_1$, $t_2$, …, $t_n$, of the "Stochastic Process X(t)". X(t) can be multidimensional or unidimensional: generally in applications there is a single measured quality characteristic X(t); such control charts (CC) are routinely called univariate SPC (Statistical Process Control) charts in the literature.

The data plotted are the means $\bar{x}(t_i)$, determinations of the Random Variables $\overline{X}(t_i)$ , i=1, 2, ..., n (n=number of the samples) computed from the collected data $x_{ij}$, j=1, 2, ..., k (k=sample size); $x_{ij}$ are the determinations of $X(t_{ij})$ at *very close instants* $t_{ij}$, j=1, 2, ..., k; $\overline{X}(t_i)$ are normally distributed *because* they are the means of k data (usually k=5). The Random Variable $\overline{X}(t_i)$, is the mean, at time $t_i$, of the k RVs $X(t_{ij})$ j=1, 2, ..., k, sampled, at very near times $t_{ij}$; the distribution is $\overline{X}(t_i) \sim N(\mu_{\overline{X}(ti)}, \sigma^2_{\overline{X}(ti)})$ with mean $\mu_{\overline{X}(ti)}$ and variance $\sigma^2_{\overline{X}(ti)}$; a common assumption for Variable Control Charts is that the RVs (random variables) $X(t_{ij})$are independents and anybody can compute a grand mean $\overline{\overline{X}}$ [mean of all the RVs $X(t_{ij})$] distributed as $\overline{\overline{X}} \sim Nx(\mu_{\overline{\overline{X}}}, \sigma^2_{\overline{\overline{X}}})$. In **Figure 2** the determinations of the RVs $\overline{X}(t_i)$ and $\overline{\overline{X}}$ are shown.

An application in the papers [1-8] draws the author's attention: The papers considered Montgomery's case and did not solve it correctly.

Therefore the readers are confronted with the following situation: Several scholars, who published papers in "good and reputed" Journals, after "Peer Review" have been dealing wrongly with the way of using *Control Charts for Exponentially Distributed Data*. MINITAB, as well, with its T Charts, provides wrong Control Charts for Exponentially Distributed Data; the same for SAS.

The author for many years has been showing [25,27-41] the many drawbacks present in various books and papers: Wrong definitions of the term Quality, wrong control charts for Exponentially Distributed Data, wrong Design of Experiments cases…

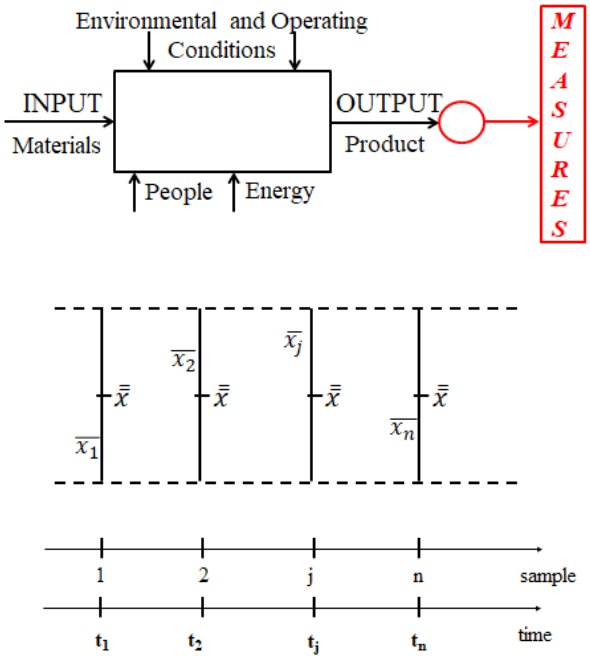


**Figure 2.** The process and the data "means" shown.

Suppose now that someone thinks that *"The problem of monitoring TBE that follows an exponential distribution is well-defined and solved"*. I do not agree that *"nobody could solve scientifically the cases"*.

He is wrong.

But, which chance has this paper been accepted? If the reader (PR, Editor) does not know RIT he would reject the paper.

Suppose, as well, that someone looks either more at the "style" of the paper or at the way of writing the references (or citing them) than to the scientific content for the solution of the problem of monitoring TBE that follows an exponential distribution, thinking that the paper sounds as a lecture: which chance has this paper to be accepted?

Suppose, finally, that someone writes *"We do not know this author and are not familiar with his work. His claim about our formulas being wrong is not justified by any facts or material evidence. Our limits are calculated using standard mathematical statistical results/methods as is typical in the vast literature of similar papers."* which chance has this

paper been accepted?

In my humble opinion, it is better a paper *"sounding like a lecture"* than several *"scientific (???, actually wrong) papers with the wrong theory."*

This paper has the following structure: First, I briefly present the Shewhart *Control Charts and the Individual Control Charts*; second, I analyse the method "(BCCTBE)"; third, the reader will see the Minitab calculations for the T Charts; finally I show the correct control limits of charts with exponentially distributed data, with the applications dealt in [1-24]. There is no specific "literature review" because I am only interested in showing the RIT ability to solve correctly the *Control Charts for Exponentially Distributed Data*. (Boxplot-based CCTBE and MINITAB T Charts): RIT was devised by the author in 1975 (47 years ago) well before the T Charts invention and BCCTBE.

The paper is important because all the papers [known by the author] on the TBE (Time Between Events) Control Charts are based on the same wrong formulae: *"limits calculated using **standard mathematical statistical** results/methods as is **typical in the vast literature of similar papers**". The two authors forgot that "many wrongs do not make a right"...*

Let's hope that the Peer Reviewers (of this paper) have better knowledge than those authors, referees, and Journals Editors.

## 2. The theory of Control Charts

I describe, very briefly, the Shewhart Control Charts (CC) [42,43]: I provide the formulae used and connect them to the concept of Confidence Interval (CI). I ask the readers to look at the books [42,43].

The technique was used extensively during World War II both in the UK and in the US. In the 1950s, the Shewhart ideas have been greatly appreciated by Deming [44,45] and Juran [46] who introduced them in Japan. The success in Japan spurred the interest in the West…

This section is important for the readers to understand the problems with the CCs for Normal and Exponentially Distributed Data.

The theory behind the (Shewhart) CC is very simple: the RV *means* $\overline{X}(t)$ of each sample, at time t, drawn from the "Stochastic Process" X(t) can be approximated as "*normally distributed*" (*Central Limit Theorem*); the Control Limits are derived accordingly. Several papers, two in the references [22,23] use the Normal distribution (for the np Control Charts).

In any Production or Service process (**Figure 2**), modelled by the "Stochastic Process" X(t), there is a "background noise", which generates a variable output: A certain amount of inherent natural variability always exists in any process output (it is called "due to chance causes of variability"); a process is declared "statistically In Control", IC. If a product (output of the process) has variability, in its quality characteristics, greater than the inherent natural variability we say that the process is an Out-Of-Control process (OOC) and operating in the presence of "*assignable causes of variation*". The Control Charts are a tool used to understand if a process is IC (In Control) or OOC [47-51].

The Theory of W. Shewhart, devised almost a century ago [42,43] in the 1920s, at Bell Telephone Laboratories, plots [the determinations of the "Stochastic Process" $\overline{X}(t_i)$ providing] the means $\bar{x}(t_i)$, i=1, 2, ..., n (n=number of the samples) computed from the collected data $x_{ij}$, j=1, 2, ..., k (k=sample size); $x_{ij}$ are the determinations of $X(t_{ij})$ at *very close instants* $t_{ij}$, j=1, 2, ..., k; $\bar{x}(t_i)$ follow a normal distribution. The RV mean (at time $t_i$) $\overline{X}(t_i)$ , of the (k sampled, at very near times $t_{ij}$), RVs $X(t_{ij})$ j=1, 2, ..., k, is distributed as $\overline{X}(t_i) \sim N(\mu_{\overline{X}(ti)}, \sigma^2_{\overline{X}(ti)})$ with mean $\mu_{\overline{X}(ti)}$ and variance $\sigma^2_{\overline{X}(ti)}$; a common assumption for Variable Control Charts is that the RVs (random variables) $X(t_{ij})$ are independents and we can compute a grand mean $\overline{\overline{X}}$ [mean of all the RVs $X(t_{ij})$] distributed [47] as $\overline{\overline{X}} \sim Nx(\mu_{\overline{\overline{X}}}, \sigma^2_{\overline{\overline{X}}})$; with this assumption we can draw two lines [see formula (1)] which have the probability $\pi=1-\alpha=0.9997$ of comprising the RVs $\overline{X}(t_i)$ , due to the Central Limit Theorem

$$\mathbf{L}=\mu_{\overline{\overline{x}}} - 3\sigma_{\overline{\overline{x}}}, \qquad \mathbf{U}=\mu_{\overline{\overline{x}}} + 3\sigma_{\overline{\overline{x}}} \tag{1}$$

Formulae (1) are true when the parameters $\mu_{\overline{\overline{X}}}$ and $\sigma_{\overline{\overline{X}}}$ are completely known: in such a case, the Probability $P\{L \leq \overline{X} \leq U\}$ is 0.997 because, for any

Normal distributed RV X, we have $P\{\mu - 3\sigma \le X \le + 3\sigma\}=0.997$. Unfortunately they are not known and we collect the data $x_{ij}$ from the process X(t) and estimate them: therefore we ***should not*** use (1) to compute the Control Limits LCL and UCL of the CC.

Consider (**Figure 3**) the Probability $P\{L \le \overline{X} \le U\}$; I can transform it into the following $P\{[(\mu_{\overline{X}} - 3\sigma_{\overline{X}}) - \mu_{\overline{X}}]/\sigma_{\overline{X}} \le (\overline{X} - \mu_{\overline{X}})/(\sigma_{\overline{X}}) \le [(\mu_{\overline{X}} + 3\sigma_{\overline{X}}) - \mu_{\overline{X}}]/\sigma_{\overline{X}}\}$ and, from that, I get the true Probability Statement $P\{-3 \le (\overline{X} - \mu_{\overline{X}})/\sigma_{\overline{X}} \le 3\}=0.997$.

I write the true Probability Statement $P\{-t_{1-a/2} \le (\overline{X} - \mu_{\overline{X}})/S_{\overline{X}} \le t_{1-a/2}\}=1-a$; from this I derive the other Probability Statement $P\{\mu_{\overline{X}} - t_{1-a/2}S_{\overline{x}} \le \overline{X} \le \mu_{\overline{X}} + t_{1-a/2}S_{\overline{x}}\}=1-a$; the two quantities RVs $L=\mu_{\overline{X}} - t_{1-a/2}S_{\overline{X}}$ and $U=\mu_{\overline{X}} + t_{1-a/2}S_{\overline{x}}$ are two random straight lines parallel to the bisector in the plane with abscissa the "true" mean μ and ordinate the grand mean $\overline{X}$.

When, from the collected data, we estimate the grand mean $\overline{\overline{x}}$ and the standard deviation $S_{\overline{X}}$ we have two lines (out of the infinite we can draw for any value of $S_{\overline{X}}$) as in **Figure 3**.

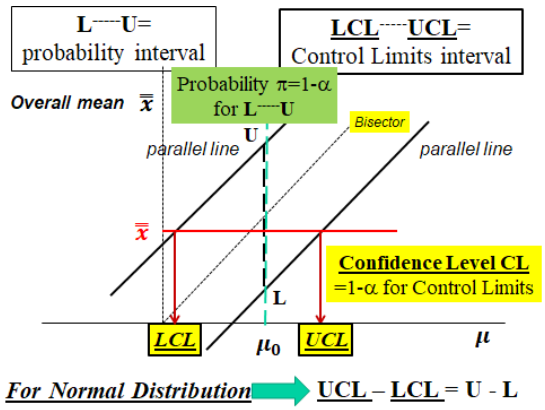


**Figure 3.** Probability interval L----U and Control Limits LCL----UCL, for Normal data

For a stated value $\mu_0$ we have the vertical probability segment L----U (one out of the infinite …): $L=\mu_0 - t_{1-a/2}S_{\overline{X}}$ and and $U=\mu_0 + t_{1-a/2}S_{\overline{X}}$.

From the estimate of the grand mean $\overline{\overline{x}}$ (on the vertical axis) we draw the Horizontal line intersection of the two above-mentioned parallel lines: we get the *Horizontal Confidence Interval* LCL----UCL segment: its abscissas are the limits of the *Confidence Interval* ***LCL*(*imit*)**$= \overline{\overline{x}} - t_{1-a/2}S_{\overline{X}}$ and ***UCL*(*imit*)**$= \overline{\overline{x}} - t_{1-a/2}S_{\overline{X}}$.

These two values are drawn as horizontal lines in **Figure 4**.

For Control Charts, since the parameters $\mu_{\overline{X}}$ and $\sigma_{\overline{X}}$ are *unknown*, we usually estimate them and write the Control Limits:

$$LCL_X = \overline{\overline{x}} - A_2\overline{R}, \qquad UCL_X = \overline{\overline{x}} + A_2\overline{R} \tag{2}$$

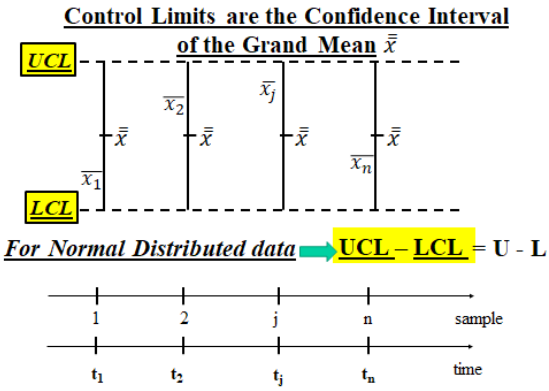


**Figure 4.** Control Limits LCL----UCL=L----U (Probability interval), for Normal data

It is clearly seen that the interval $LCL_X$------$UCL_X$ (Control Limits, on the horizontal axis, in **Figure 3** and on the vertical axis, in **Figure 4**) are the Lower Confidence Limit and Upper Confidence Limit [with "Confidence Level" 1-α=0.9997] of the unknown mean $\mu_{X(t)}$ of the Stochastic Process X(t); $\overline{R}$ is the "mean of the ranges $r_i$" [determination of the RV $\overline{R} = \sum r_i/n$], by putting $A_2\overline{R}=t_{1-a/2}S_{\overline{X}}$ . $r_i = \max(x_{ij}) - \min(x_{ij})$ of the i-th sample [determination of the RV $R_i$], and $A_2$ depending on the sample size k (as t depends on the degrees of freedom).

A similar control chart is drawn for the range by making a "**big** *mental leap*" [because the distribution of $\overline{R}$ is not normal.] and using the formulae (1) [which are probabilistically true] changing them into the statistical formulae (3) where we have the determinations of RVs (the coefficient $D_3$ and $D_4$ depend on the sample size k)

$$LCL_R = D_3\overline{R}, \quad CL_R = \overline{R}, \quad LCL_R = D_4\overline{R}, \tag{3}$$

The interval $LCL_R$------$UCL_R$ is the "Confidence Interval" with "Confidence Level" 1-α=0.9997 for the unknown Range of the Stochastic Process X(t).

*Notice* that **UCL-LCL=U-L** for normally distributed data, as a *consequence of the parallelism*. (**Figure 3**)

From the papers on CC it is clear that people (researchers, professors, practitioners) who use both the formulae (2) and (3) also for NON_normal data by transforming them in order to "produce Normal data" and to apply formulae (2) and (3) are failing.

This is especially dome when we use the so-called "*individual control charts*" I-CC (we have little data): in such a case we use the following figure.

## 3. Individual Control Charts (I-CC) and exponentially distributed data

Consider the data in **Table 1** [Example 7.6 in the Montgomery book [26] (7th edition, as reported in the paper [25])], where he writes "*A chemical engineer wants to set up a control chart for monitoring the occurrence of failures of an important valve. She has decided to use the number of hours between failures as the variable to monitor*". *Notice* that Minitab 19&20&21 show the same problems). Since the data are not normal I cannot use the ideas in **Figure 2**. The readers must be very careful.

The paper *Boxplot-based Phase I Control Charts for Time Between Events* [1] uses the same data (in **Table 1**). The authors (DC) [1] write "*As an illustration, consider the example in Montgomery in which a chemical engineer wishes to control the average time between failures of a valve. She observed 20 times between failures for this valve. JC uses these data, ..., as an illustration of their two-sided control chart. Note that the data with all 20 observations do not fail the Anderson–Darling test for the exponential distribution. From Minitab, the Anderson–Darling statistic is found to be 0.53 with a P-value = 0.44.*" Notice that JC is the authors of the paper [3].

The readers will see their (wrong) solution in the next session.

Formulae (2) and (3) should not be used because the data are few, 20, and exponentially distributed; **Figure 5** shows the Control Limits. Using [wrongly] those formulae one finds **Figures 6 and 7**. [25] *Notice that k=1 (sample size).*

See **Figure 6**: according to **Figure 6**, using the formulae (2), the "*process is OOC*" (Out Of Control): Two points are "above" UCL [25].

**Table 1**. Lifetime data (exponentially distributed, from Montgomery's book):*k=1 (sample size)*

| Failure # | lifetime | Failure # | lifetime | Failure # | lifetime |
|---|---|---|---|---|---|
| 1 | 286 | 8 | 143 | 15 | 603 |
| 2 | 948 | 9 | 431 | 16 | 492 |
| 3 | 536 | 10 | 8 | 17 | 1199 |
| 4 | 124 | 11 | 2837 | 18 | 1214 |
| 5 | 816 | 12 | 596 | 19 | 2831 |
| 6 | 729 | 13 | 81 | 20 | 96 |
| 7 | 4 | 14 | 227 | | |

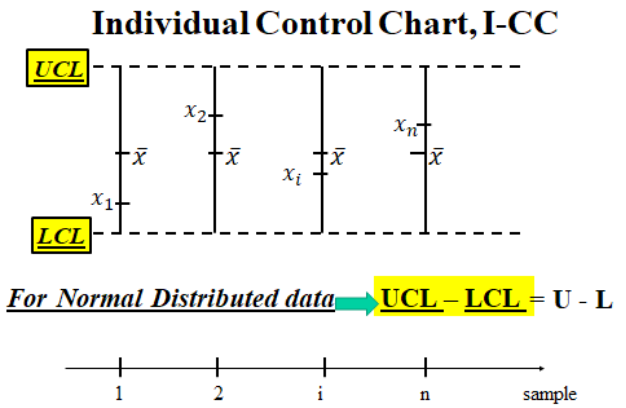


**Figure 5.** Individual Control Chart. *Notice that k=1 (sample size)*

Also the Moving Ranges CC shows two other points OOC.

All the software used provides the same picture of the process [25].

This is not the true picture of the process: these OOC depend on the formulae used [25].

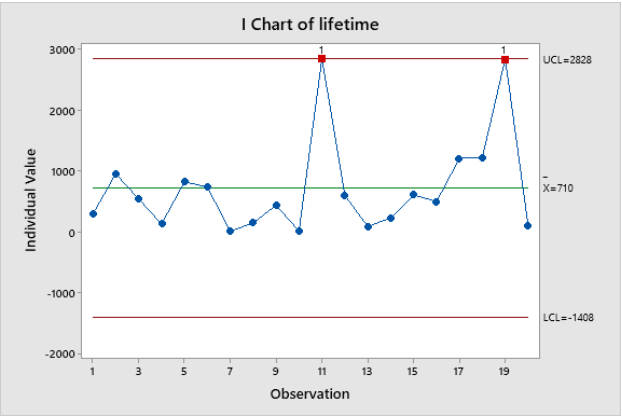


**Figure 6.** Individual chart lifetime. Minitab 19 & 20 & 21 used

Transforming the exponential data into Weibull data with shape parameter β=1/3.6 (the idea is due to Nelson) the original (exponential) data $y_i$ become $x_i=y_i^{1/3.6}$ (Weibull) data; Montgomery uses a I-MR

Chart (see **Figure 7**) and writes [26] "*Note that the control charts indicate* a state of control*, implying that ...*"

This is not the true picture of the process: These IC depends on the formulae used [25].

Before acting this way, any scholar should see if it is suitable, because, as said by Deming, "*Management need to grow-up their knowledge because experience alone, without theory, teaches nothing that to do to make Quality"* and "*The result is that hundreds of people are learning what is wrong. I make this statement on the basis of experience, seeing every day the devastating effects of incompetent teaching and faulty applications."* [Deming (1986)]

**Figures 6 and 7** provide *two contradictory conclusions*.

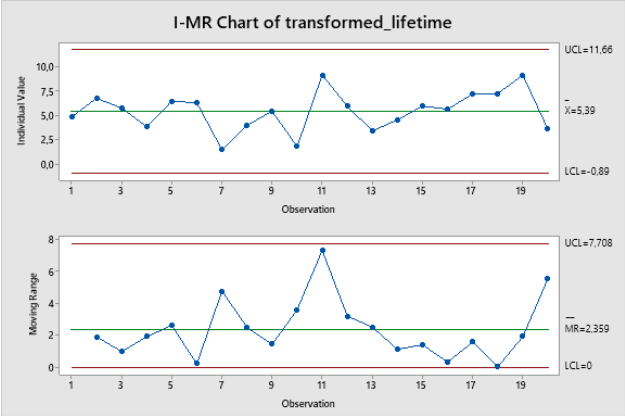


**Figure 7.** Chart of *"transformed"* lifetime (Nelson suggestion). Minitab 19&20&21 used (F. Galetto).

Assuming that T Charts are a good method to deal with "rare events" [25] (Minitab, JMP, SAS, …) one gets **Figure 8**; see *the paper* "Six Sigma_Hoax against Quality_Professionals Ignorance and MINITAB WRONG T Charts" [25]. The process is "In Control", again.

Actually, the process is Out Of Control.

The author found himself in such a situation during several International Conferences, Courses, Seminars and reading papers: wrong methods. Many times he invited scholars and professors to be scientific [27-41]. In particular see the paper [39], very useful for the next parts. The author had to self-cite because it seems he has been the only one that has been fighting for years for "Papers Quality"; he humbly asks the readers to inform him if some people did the same.

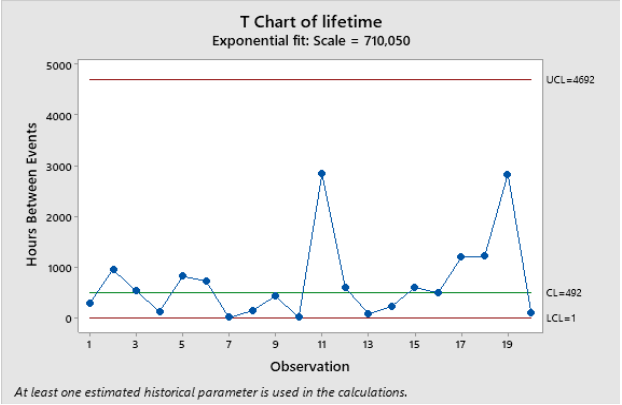


**Figure 8.** T Chart of Montgomery lifetime data. Minitab 19 & 20 & 21 used (F. Galetto).

## 4. Box-plot Control Charts (I-CC) for Time Between Events (TBE)

Now we see a bit of Theory in the papers [1,3,5] and the document [6]. The Box-plot based Control Charts (BpCC) are very similar to the Shewhart Control Charts. BpCC uses the median (instead of the mean) and the interquartile range (instead of the ranges) of the collected data.

Denoting as F(x) the [continuous] cumulative distribution of the RV X, one can find the abscissas $x_1$, $x_2$, $x_3$, so that $F(x_1)=1/4$, $F(x_2)=2/4$, $F(x_3)=3/4$; $x_2$ is the median and $x_3$-$x_1$ is the interquartile range.

For BpCC one estimate F(x) from the nk collected data; let $\hat{F}(x)$ [a step function with nk steps] the estimate of F(x): He then chooses the three abscissas $\hat{x}_1, \hat{x}_2, \hat{x}_3$ satisfying the relationships $\hat{F}(\hat{x}_1) \cong 0.25$ $\hat{F}(\hat{x}_2) \cong 0.5$ $\hat{F}(\hat{x}_3) \cong 0.75$

The two authors define the LCL and UCL.

$$LCL_X = \hat{x}_2 - k_L[\hat{x}_3 - \hat{x}_1] \quad CL_X = \hat{x}_2 \quad UCL_X = \hat{x}_2 - k_U[\hat{x}_3 - \hat{x}_1] \quad (2b)$$

where the coefficients, for a significance level $\alpha_0$=0.01 and sample size 20, are $k_L$=4.617 and $k_U$=15.56 (to be applied to Montgomery's case). The name "*nominal false alarm rate*" is the quantity $\alpha_0$. Notice that (2b) have the same structure as (2).

Therefore I do not understand their claim that "the proposed control charts are comparable to other charts, in their performance."

Those authors *consider the example in Montgomery* [data in our **Table 1**]; they find:

$UCL = q2 + k_U(q3 - q2) = X(10) + k_U(X(16) - X(10)) = 4341.552$

$LCL = q2 - k_L(q2 - q1) = X(10) - k_L(X(10) - X(5)) = -533.616$

They put LCL=0 because of LCL<0. They, wrongly, say that the process is IC. Note that JC's two-sided control chart leads to the same conclusion. Notice: JC is the author of the paper [3].

Their **Figure 1** (cited above) is the one called **Figure 9** [even if it is an Excerpt from the paper].

Compare **Figures 8 and 9**: *Both show no out-of-control.* The Process is considered *IC.*

The reader will see, on the contrary, that this is wrong.

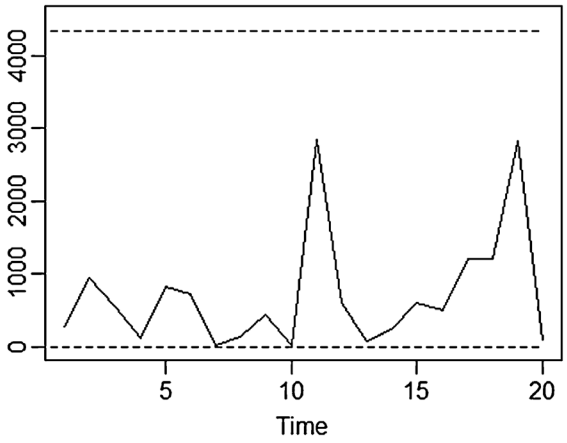


**Figure 9.** Chart of Montgomery lifetime data analysed by Dovoedo et al., "Boxplot-based … for TBE". *Quality and Reliability Engineering International* 2011.

## 5. T Charts and exponentially distributed data: Part 1

Now I give the ideas of two Minitab authors [21]: They provide "*0.00135 $\bar{t}$, 6.60773 $\bar{t}$, and log(2) $\bar{t}$*" [21] [(see formulae (4)]. The paper, "Peer Reviewed", has wrong formulae (4) [25]:$\bar{t}$ is the estimate of the parameter θ, determination of the Random Variable $\overline{T}$/m, the ratio of the "total time on a test" $\overline{T}$ and the number of failures m (m=20 in this case)] [25].

$LCL_T = 0.00135\ \bar{t}$ $CL_T = \ln(2)\ \bar{t}$ $UCL_T = 6.60773\ \bar{t}$ (4)

A lot of papers present formulae (4).

One of last papers I found is "A Comparative Study of Exponential Time Between Event Charts By Liu J., Xie M., Sharma P.", *Quality Technology & Quantitative Management*, 2006 [7]. **Figure 10** is made from an excerpt in the paper [7] (see) proving the author's attitude. The last 2022 is, "Statistical design of ATS-unbiased charts with runs rules for monitoring exponential time between events [by N. Kumar, A. C. Rakitzis, S. Chakraborti, T. Singh (2022)], *Communications in Statistics—Theory and Methods* [2]…

This proves the truth of Deming's statements mentioned above "*It is a hazard to copy",* etc…

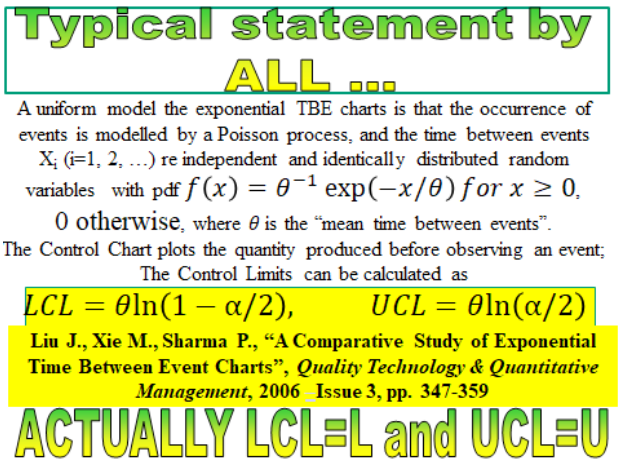


**Figure 10.** Typical statement about Individual Control Charts, with Exponential distributed data

Minitab, JMP, SAS "*T Charts*" are wrong: the Reliability Integral Theory (RIT) proves that. The readers are invited to read the author's books [47-56], "Six Sigma_Hoax against Quality_Professionals Ignorance and MINITAB WRONG T Charts", HAL Archives Ouvert, 2020 [25] and F. Galetto "Minitab T-Charts and Quality Decisions", Journal of Statistics and Management System, 2021.

## 6. Some basics of RIT (Reliability Integral Theory)

RIT was devised in 1977 by Fausto Galetto when he was working at FIAR (a division of General Electric); it is fully explained in the author's books [47-56]. Here I give only the formulae to solve the cases.

The System I consider starts in State 0, at time 0: All the units are reliable.

The general formula of the reliability of a g* units stand-by system [47-56] is given in the following matrix formula (5)

$$R(t) = \overline{W}(t) + \int_0^t B(s)R(t-s)ds \quad (5)$$

where R(t) is the vector of the reliabilities $R_i(t)$ of the Up-states, i=0, 1, …, g*-1, B(s) is the square matrix of the kernels $b_{ij}(s)$ [related to the transition probabilities $b_{ij}(s)ds$] between the Up-states and $\overline{W}(t)$ the diagonal matrix of the probabilities of remaining in each Up-state, for the time mission t. From (5) I get the EQUIVALENT matrix equation

$$R(t) = u + \int_0^t AR(t-s)ds \quad (6)$$

where u is the column vector $[1, 1, \ldots,1]^T$ and A the matrix of the *constant transition rates*.

When one considers the exponential kernels, formulae (5) [and (6)] provide the *fundamental system of the Reliability Integral Theory, for Markov processes*.

In F. Galetto's books [47-56] RIT is extended to Reliability Tests, for estimating parameters and testing hypotheses. Consider a system of (g* units); it has g* Up-states (0, 1, 2, …, g*-1) with transition rate λ, where λ=1/θ and θ is the MTTF of any units; one wants to estimate θ: It is the «*system associated to a reliability test*». This solves the *Time Between Events* Charts Problem.

The evolution (versus t) of the test is the same as the evolution of a standby system for the interval 0¨¨t. The reliability of any item [n are the items on test] determines the instants of the transitions of the "*system associated (to the reliability test)"*; the state g* is the "down-state", at which the test is over. One gets the following fundamental system of Integral Theory of Reliability Tests [F. Galetto, holding for any distribution of the time to failures of the units], for i=0, 1, …, g-1, where he assumes that r is the entrance time instant when he begins observing the system.

$$R_i(t|r) = \overline{W}_i(t|r) + \int_r^t b_{i,i+1}(s|r)R_{i+1}(t|s)ds \quad (7)$$

In matrix form it is

$$R(t|r) = \overline{W}(t|r) + \int_r^t B(s|r)R(t|s)ds \quad (8)$$

The component $R_0(t|0)$ is the probability that the physical sample does not experience the $g^{th}$ failure during the interval r=0¨¨t (t end of the test). At the end of the test, we have the empirical sample D={$t_1$, $t_2$, …, $t_{g-1}$, $t_g$, t}; so we get

$$R_j(t|t_j) = \overline{W}_j(t|t_j) + \int_{t_j}^t b_{j,j+1}(s|t_j)R_{j+1}(t|s)ds$$
$$\text{for i} = 0, 1, \ldots, g-1, \;\; R_g(t|t_g) = \overline{W}_g(t|t_g) \quad (9)$$

From (8) and (9) I compute the determinant **det-B(s|r)** [depending on λ]: λ is estimated, from

$$\det [B(s|r;\, \lambda, D) = \lambda^g \exp [-T(t)] \quad (10)$$

where $T(t) = \sum_1^g t_i + t(n-g)$ is the "Total Time on Test" generated by n items tested until the $g^{th}$ failure. At the end of the test of the equations (8) and (9) are constrained by D; deriving by λ, compute given the constraint D, I obtain exactly the same result as one can obtain with the Maximum Likelihood method.

From the documents [25,47-56] and F. Galetto "Minitab T-Charts and Quality Decisions", Journal of Statistics and Management System, 2021, anybody can obtain the Confidence Interval (symmetric) for the parameter θ [which is the MTTF of any unit] by finding the quantities $\theta_L$ and $\theta_U$ satisfying (11), with given $\boldsymbol{t_o}$ the "known (at the end of the test)" observed Total Time on Test *T*(*t*), and Confidence Level CL=1-α

$$R_0(t_O;\, \theta_L) = \frac{\alpha}{2},\; R_0(t_O;\, \theta_U) = 1 - \alpha/2 \quad (11)$$

## 7. T Charts and exponentially distributed data: Part 2

Let's apply RIT to the data in **Table 1**. The n=g*=20 lifetimes (exponentially distributed; $t_i$ "time to failure " from state i-1 to state i: They are the "*individuals*") are the "transition times" between states of a stand-by system of 20 units: The state 20 (g*) is the Down-state. The reliability $R_0(t|\theta)$ [the system reliability $R_0(t|\theta)$ given the parameter θ)] is, as well, the Operating Characteristic Curve of the reliability test, given t: The pdf (probability density function) of any transition ("*individual*") is $f(t;\, \mu, \sigma) = (1/\theta)\exp(-t/\theta)$; (**Figure 11**).

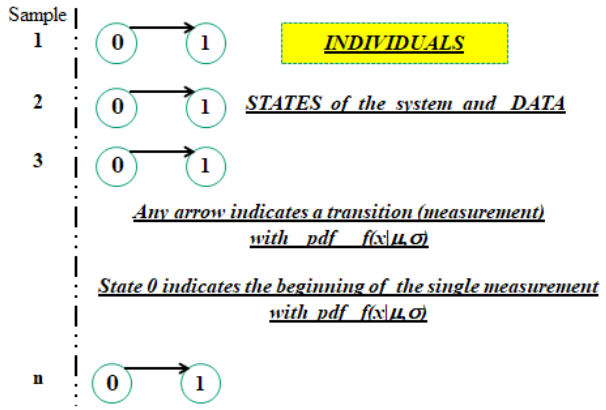


**Figure 11.** TBE States for the Individual Control Chart for Table 1 lifetime data.

Consider the Probability $P\{\boldsymbol{A} \le T(t) \le \boldsymbol{B}\} = 1-\alpha$ that the Random Variable "Total Time On Test $T(t)$", and g data, is comprised in the interval $\boldsymbol{A}^{---}\boldsymbol{B}$; one can transform it to the following $P\{2\boldsymbol{A}/\theta_0 \le 2T(t)/\theta_0 \le, 2\boldsymbol{B}/\theta_0\} = 1-\alpha$ with $\theta_0$ a known quantity. By RIT he gets the equivalent Probability Statement $P\left\{T(t)/\left[\chi^2_{1-\frac{\alpha}{2}}(2g)/2\right] \le \theta_0 \le T(t)/\left[\chi^2_{\frac{\alpha}{2}}(2g)/2\right]\right\} = 1-\alpha$.

When we have the "*individuals*" (**Figure 13**) we want to find the Probability $P\{\boldsymbol{L} \le T_0 = T(t)/n \le \boldsymbol{U}\} = 1-\alpha$ that we can transform into the following $P\{2\boldsymbol{L}/\theta_0 \le 2T_0/\theta_0 \le 2\boldsymbol{U}/\theta_0\} = 1-\alpha$. Since the reliability of any unit is exponential $R_0(t|\theta) = \exp(-t/\theta)$, (**Figures 5 and 13**) the function $t/\theta = K$ is a straight line $t = K\theta$, with angular coefficient $K$, related either to $\alpha/2$ or to $1-\alpha/2$, in the plane with abscissa $\theta$ and ordinate $t$: two lines intersecting in the origin (**Figure 13**); at $\theta=\theta_0$ we have the **vertical segment L$^{---}$U (probability interval)**, that has probability CL=1-α that the "time to failure", Random Variable T, of any single unit is in **L$^{---}$U**.

The result of this analysis [of **Table 1** lifetime data] is given in **Figure 12**, with logarithmic axes to see the values. See now **Figures 11, 12, 13.** The Control Limits LCL and UCL must be consistent with the single $t_i$ lifetimes ("*individuals*"): we want to assess if they are significantly different from the "*mean observed time to failure*" $\overline{t_o} = \boldsymbol{t_o}/n$. They are the values satisfying the two equations (12) for any single unit; so we have 20 Confidence Intervals [all equal, by solving formulae (12)], given $\overline{t_o}$ and CL=1-α [CL=0.997],

$$R_0(\overline{t_0};\ LCL) = \frac{\alpha}{2}, \quad R_0(\overline{t_0};\ UCL) = 1-\frac{\alpha}{2} \qquad (12)$$

*Remember that in this case k=1 (sample size) and* $\overline{t_o} = \boldsymbol{t_o}/n$: I-CC.

Formula (12) proves how wrong are all the authors in the first 21 referenced papers[1-21] and in many other you can find on the Web.

With the data from **Table 1 Figure 13** would be unreadable; then I made **Figure 12**. LCL and UCL are the abscissas of the points of interception with the horizontal line $\overline{t_o} = \boldsymbol{t_o}/n$: It is the ***Confidence interval***. (as in Figure 3, for the Normal Distribution: The same type of reasoning.)

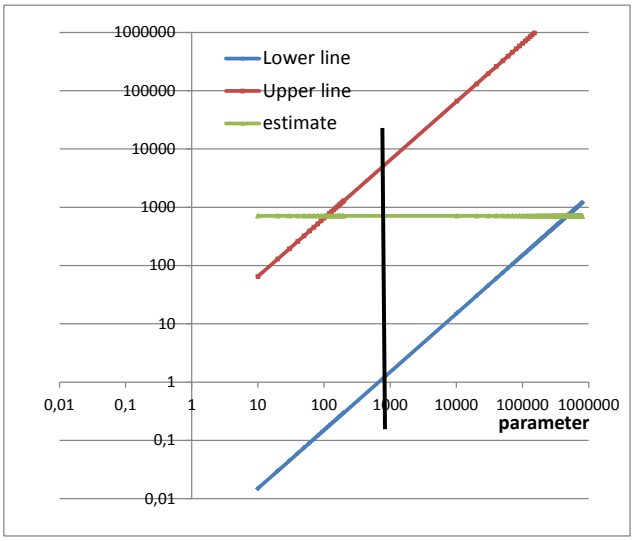


**Figure 12.** RIT LCL and UCL for the Individual Control Chart of Table 1 data [logarithmic scales].

Any intelligent person should realise that the two segments **L$^{---}$U** (vertical) and ***LCL$^{---}$UCL*** (horizontal) are two *different* intervals with clearly *different* meanings and obviously *different lengths* UCL-LCL ≠ U-L. All the documents, known to the author, make this BIG ERROR: they confound the vertical segment, which is a "**Probability segment**" with the horizontal segment, which is a "***Confidence segment***".

Formulae (4) and **Figure 10** made from "A Comparative Study of Exponential Time Between Event Charts", *Quality Technology & Quantitative Management* [7] (see **Figure 13**, as well), consider the segments **L$^{---}$U** (vertical) as though it were the Confidence Interval. This is completely WRONG.

*Simple example* with 2 data: $t_1$ and $t_2$, of a 2 units stand-by system. The matrix equation (5)

$R(t) = \overline{W}(t) + \int_0^t B(s)\ \ R(t-s)ds$ provides the solution $R_0(t) = \exp(-t/\theta)[1 + t/\theta]$, which allows us to find the Confidence Interval of the MTTF (considering g*=2). Formulae (12) $R_0(\bar{t}_o;\ LCL) = \alpha/2$ *and* $R_0(\bar{t}_o;\ UCL) = 1-\alpha/2$, for each sample, remembering that in this case k=1 (sample size), allow computing the Control Limits [that is the Confidence Interval for each sample, of size k=1. horizontal line], via the mean $\bar{t}_o$; = $(t_1 + t_2)$ and CL=1-α=0.997 [**Figure 13**]. Formulae (4), on the contrary, $LCL_T = 0.00135\ \bar{t}\ \ CL_T = \ln(2)\ \bar{t}$, $UCL_T = 6.60773\ \bar{t}$, with $\bar{t} = \bar{t}_o$ providing the vertical line **L----U**, at the **abscissa** $\bar{t} = \theta_0$ (**Figure 12**).

Look at **Figure 10**, as well; does the reader see that those formulae are the same as $LCL_T = 0.00135\ \bar{t}\ \ CL_T = \ln(2)\ \bar{t}$, $UCL_T = 6.60773\ \bar{t}$, with $\theta = \bar{t}$? The Authors, the Peer Reviewers and the Editors of the Journals *Quality Engineering, Quality Technology & Quantitative Management, Quality and Reliability Engineering International, Communications in Statistics - Theory and Methods, PLOS one, …* are wrong.

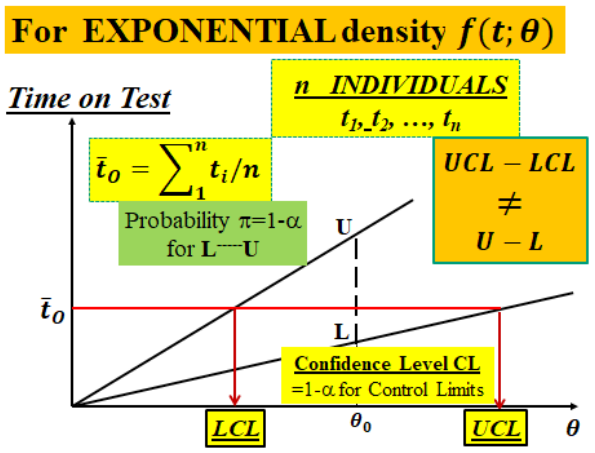


**Figure 13.** RIT LCL and UCL for the Individual Control Chart of Table 1 data.

All the authors do not realise that, *when the data are Normally distributed*, they have UCL-LCL=U-L (same length...) *notwithstanding* L----U and LCL----UCL are two *different* intervals with *different* meaning. Very likely for the users the error does not have any effect (see **Figures 3 and 4**)... The error is there, but it has no consequences, because for Normal data, formulae (12) $R_0(\bar{\bar{x}};\ LCL) = \alpha/2$ and $R_0(\bar{\bar{x}};\ UCL) = 1 - \alpha/2$, **for each sample**, of (sample size) k=5, with $\bar{t}_O = \bar{\bar{x}}$, provide formulae (2) above, here repeated $LCL_X = \bar{\bar{x}} - A_2(k=5)\bar{R}\ \ \ CL_X = \bar{\bar{x}}$ $UCL_X = \bar{\bar{x}} + A_2(k=5)\bar{R}$, the same result of the classical theory (assuming R known).

From **Figures 12 and 14**, it is very clear that, for the **Table 1** lifetime data, the TBE Control Charts tell us (the Theory shows the truth) that the process is OOC (Out Of Control). *Notice* the plural "TBE Control Charts" because also the differences $|t_i - t_{i+1}|$ are exponentially distributed, as well; see **Figure 15**.

This proves again the truth of Deming's statement "*…people are learning what is wrong.*", "*It is necessary to understand the theory…*"

There is a deep ignorance of "Professionals" about the Control Charts with Exponentially Distributed Data.

See both **Figures 8 and 14**: The reader can CLEARLY see both the wrong Control Limits of the Control Chart *and the right Lower Limit (the dotted line)*. Also the ranges are OOC (**Figure 15**).

**Figure 16** is very important: It shows the wrong Control Limits [LCL, UCL] derived from the formulae (2), which are valid when the data are normally distributed, and the *right correct LCL* (the dotted line for TBE) *computed with RIT*. The "original" Minitab 19 & 20 & 21 I-Chart shows two "wrong" Out Of Control points that do not actually exist; moreover it does not show the real OOC points below the dotted line: it shows them because the author forced the software to draw the *correct LCL* (the dotted line). The Minitab LCL is wrong, as well.

Anybody can transform the Exponential data into Weibull data, as suggested by D. C. Montgomery, who used the idea of Nelson.

He gets the wrong Control Charts, showing the Process IC (the opposite of the truth), as well…

The related I-Chart is in **Figure 17**: It shows the wrong Control Limits [LCL, UCL] derived from the formulae (2), now valid because the transformed data are normally distributed, and the *right correct LCL* (the dotted line) *computed with RIT*. Minitab 19 & 20 & 21 I-Chart does not show only the real Out Of Control points below the dotted line: It shows them because the author forced the software to show the dotted line.

The same happens with Johnson's transformation (**Figure 18**).

Any reader can clearly see that anybody needs the right and scientific method to analyse the data and derive the correct Control Charts: Data transformations can hide the truth.

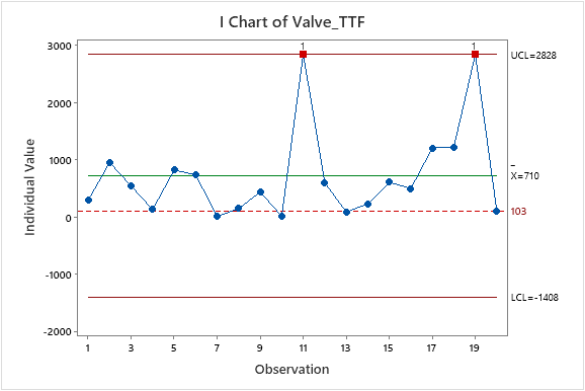


**Figure 16.** RIT I-Chart of Valve_TTF for Table 1 data . *The dotted line is the right correct LCL.*

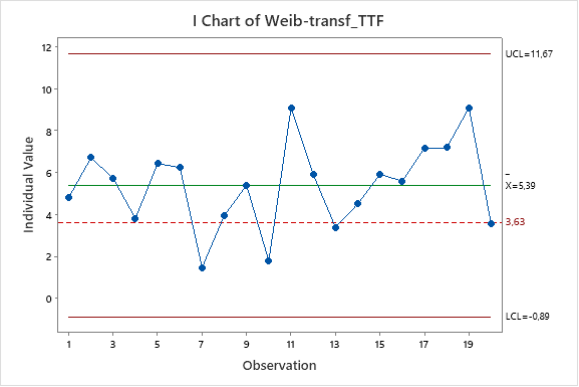


**Figure 17.** RIT I-Chart of Weib-transf_TTF for Table 1 data [transformed into Normal data, by Weibull transformation]. *The dotted line is the right correct LCL.*

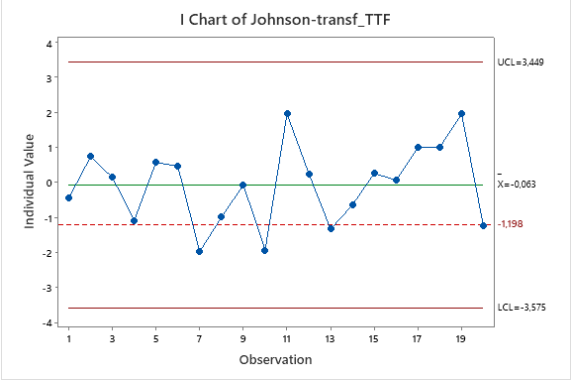


**Figure 18.** RIT I-Chart of Johnson-transf_TTF for Table 1 data [transformed into Normal data, by the Johnson's transformation]. *The dotted line is the right correct LCL.*

## 8. Time between events exponentially distributed data: From the paper "Improved Phase I Control Charts for Monitoring Times Between Events"

Now the readers can see how RIT can solve a case, found in a paper [5] published by *Quality and Reliability Engineering International* (whose editor is D.C. Montgomery). The two authors provide a wrong solution found neither by the Peer Reviewers nor by the Editor). Nevertheless, they "*thank D. Montgomery, Co-editor, for his interest and encouragement.*"

In their Abstract they claim that "their charts are ***more robust*** (i.e. less sensitive to unwanted OOC" than competitors).

The authors say that the data follow a Poisson Distribution with $\theta$=0.1; they find LCL=–53. (put to 0) and UCL=47.2; we see that the process is OOC because 52.32 plots above the UCL; they claim that for **Table 2** data "*neither the Dovoedo and Chakraborti, nor the Jones and Champ control chart indicates any OOC situation.*"

**Table 2**. Time between failures data ("Improved Phase… for Monitoring TBE".[5]).

| Failure # | TBE | Failure # | TBE | Failure # | TBE |
|---|---|---|---|---|---|
| 1 | 1.24 | 11 | 52.32 | 21 | 6.09 |
| 2 | 6.69 | 12 | 14.75 | 22 | 20.41 |
| 3 | 9.77 | 13 | 4.69 | 23 | 5.93 |
| 4 | 1.23 | 14 | 0.18 | 24 | 19.03 |
| 5 | 14.03 | 15 | 13.61 | 25 | 13.65 |
| 6 | 18.07 | 16 | 4.57 | 26 | 6.37 |
| 7 | 3.90 | 17 | 0.28 | 27 | 2.06 |
| 8 | 13.61 | 18 | 7.08 | 28 | 3.30 |
| 9 | 18.47 | 19 | 12.00 | 29 | 6.91 |
| 10 | 12.85 | 20 | 5.15 | 30 | 12.08 |

Their Control Charts is the **Figure 19**. Notice that the "wrong" Control chart shows an Out Of Control (OOC) situation that should not be there and various In Control (IC) that should not be there… Now I use RIT.

As done in the previous section, now n=g*=30 TBE

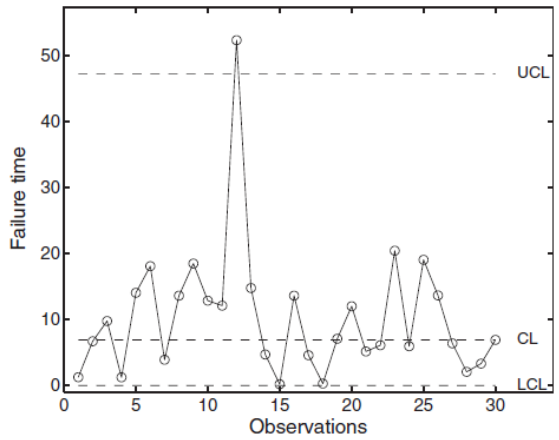


**Figure 19.** Control Chart from "Improved Phase… for Monitoring TBE". [5] *Remember that in this case k=1 (sample size).*

See the **Figure 19**. The Control Limits LCL and UCL must be consistent with the $t_i$ "Time between failures": We want to assess if they are significantly different from the "*mean observed time to failure*" $\bar{t}_o = \boldsymbol{t}_o/n$. They are the values satisfying the two equations (12) for any single unit; so we have 30 Confidence Intervals [all equal, by solving formulae (12)], given $\bar{t}_o$ and CL=1-α [CL=0.997], $R_0(\bar{t}_0;\ LCL) = \alpha/2, R_0(\bar{t}_0;\ UCL) = 1 - \alpha/2$

*Remember that in this case k=1 (sample size) and* $\bar{t}_o = \boldsymbol{t}_o/n$: I-CC.

Formula (12) proves how wrong all authors in the first referenced 21 papers [1-21].

Comparing **Figure 19** and **Figure 20**, it becomes very clear that the Control Chart from "Improved Phase… for Monitoring TBE" [5] presents 5 errors about OOC.

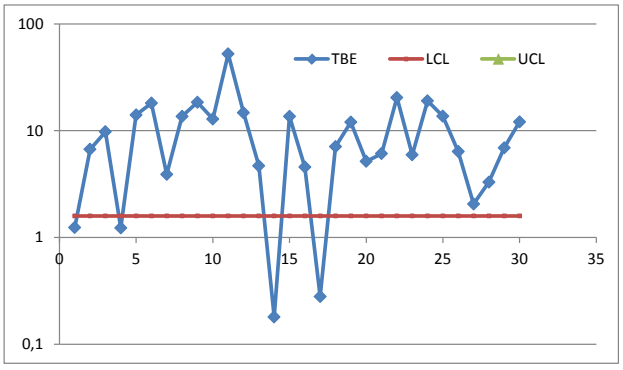


**Figure 20.** Control Chart of the data from "Improved Phase… for Monitoring TBE". [5]; vertical axe logarithmic; UCL is >100. RIT used (F. Galetto). Remember that in this case k=1 (sample size).

How can the Control Chart from "Improved Phase… for Monitoring TBE" [5] be good?

See their "absurd" Concluding remarks: "…IC robustness property …more than *Jones/Champ* and *Dovoedo/Chakraborti charts*".

Simulations made by F. Galetto (five million.) show that < 5% of the computations provide the correct decisions about IC and OOC…

I agree with those authors that "*Further work is necessary on the OOC performance of these charts*" [5]: The further Work must be to STUDY (see Deming.) to avoid "Huge costs of DIS-quality applications/decisions"…

## 9. Other cases from papers "Peer Reviewed"

The case presented before was taken from Peer Reviewed papers published in good and reputed Journals.

Now we see some other cases that show very clearly that the problem of Control Charts for TBE (Time Between Events) must be studied and solved using a sound Theory.

Consider the paper [21] and the good qualifications of both the authors [21]: Santiago/Smith both were (are now?) at Minitab, Inc.

The T Charts and the Box-plot methods *compute WRONG Control Limits.* And therefore the process is considered In Control, but it is not: **Figure 21**. The data are in **Table 3**.

F. Galetto analysis, with RIT, shows that the ***Process is OOC*** (Out of Control) ….

Consider also the paper of the "Qualified authors" Xie, M., Goh, T. N., Ranjan, P. (2002) "*Some effective control chart procedures for reliability monitoring*", Peer Reviewed by qualified Referees, published in Reliability Engineering & System Safety [16]. Again WRONG Control Limits.

Their data are in **Table 4**.

At least 10% of the data are Out Of Control: Xie et al. did not found that. Does the reader consider a very good result for a Peer Reviewed paper? See **Figures 10 and 22**.

**Table 3.** Urinary Tract Infection Data (from E. Santiago, J. Smith, Control charts based on the Exponential Distribution, *Quality Engineering* [21]).

| Datum # | UTI (days) | Datum # | UTI (days) | Datum # | UTI (days) |
|---|---|---|---|---|---|
| 1 | 0.57014 | 19 | 0.03819 | 37 | 0.12014 |
| 2 | 0.07431 | 20 | 0.24653 | 38 | 0.11458 |
| 3 | 0.15278 | 21 | 0.29514 | 39 | 0.00347 |
| 4 | 0.14583 | 22 | 0.11944 | 40 | 0.12014 |
| 5 | 0.13889 | 23 | 0.05208 | 41 | 0.04861 |
| 6 | 0.14931 | 24 | 0.12500 | 42 | 0.02778 |
| 7 | 0.03333 | 25 | 0.25000 | 43 | 0.32639 |
| 8 | 0.08681 | 26 | 0.40069 | 44 | 0.64931 |
| 9 | 0.33681 | 27 | 0.02500 | 45 | 0.14931 |
| 10 | 0.01389 | 28 | 0.27083 | 46 | 0.24653 |
| 11 | 0.03819 | 29 | 0.04514 | 47 | 0.04514 |
| 12 | 0.46806 | 30 | 0.13542 | 48 | 0.01736 |
| 13 | 0.22222 | 31 | 0.08681 | 49 | 1.08889 |
| 14 | 0.29514 | 32 | 0.40347 | 50 | 0.05208 |
| 15 | 0.53472 | 33 | 0.12639 | 51 | 0.02778 |
| 16 | 0.15139 | 34 | 0.18403 | 52 | 0.03472 |
| 17 | 0.52569 | 35 | 0.70833 | 53 | 0.23611 |
| 18 | 0.07986 | 36 | 0.15625 | 54 | 0.35972 |

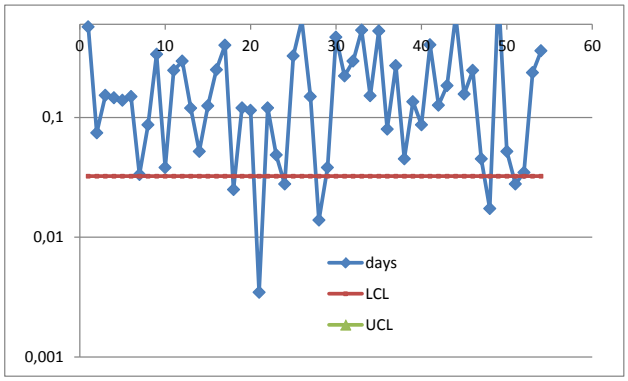


**Figure 21.** Table 3 Control Chart (of UTI); vertical axe logarithmic. (F. Galetto). *Remember that in this case k=1 (sample size).*

The two Peer Reviewers [16] should have known the Theory. "*It is necessary to understand the theory of what one wishes to do or to make.*" [Deming 1996]

It is clear that the shown methods (but RIT) compel their users to take wrong decisions, caused by the authors' qualifications….

**Table 4.** Time between failures (TBF) of a component. [16]

| Failure # | TBF | Failure # | TBF | Failure # | TBF |
|---|---|---|---|---|---|
| 1 | 30.02 | 11 | 0.47 | 21 | 70.47 |
| 2 | 1.44 | 12 | 6.23 | 22 | 17.07 |
| 3 | 22.47 | 13 | 3.39 | 23 | 3.99 |
| 4 | 1.36 | 14 | 9.11 | 24 | 176.06 |
| 5 | 3.43 | 15 | 2.18 | 25 | 81.07 |
| 6 | 13.2 | 16 | 15.53 | 26 | 2.27 |
| 7 | 5.15 | 17 | 25.72 | 27 | 15.63 |
| 8 | 3.83 | 18 | 2.79 | 28 | 120.78 |
| 9 | 21,00 | 19 | 1.92 | 29 | 30.81 |
| 10 | 12.97 | 20 | 4.13 | 30 | 34.19 |

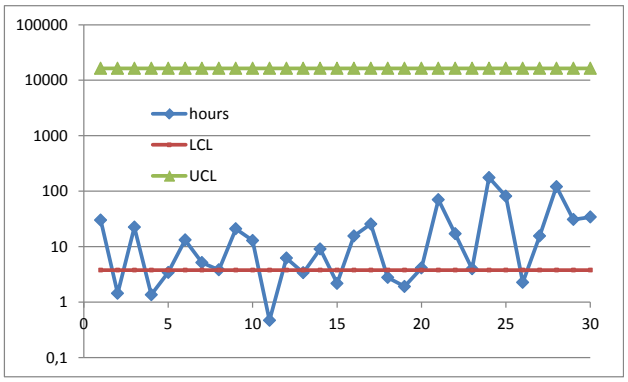


**Figure 22.** Control Chart of Xie et al. TBF data; vertical axe logarithmic. ***RIT used*** (F. Galetto). *Remember that in this case k=1 (sample size).*

From the paper [2] one finds a new wrong case copied from Santiago and Smith (2013) [21]. I do not report the data… Notice that the Control Limits are wrong (remember **Figure 10**).

Notice the "red and dashed lines" in **Figure 23**: They are "the control limits for the ATS-unbiased t1-chart with the {1/1,M:3/4} scheme…". Obviously, they are WRONG: **Table 5**.

The authors write [2]: "An example … *application of the proposed ATS-unbiased chart ... we consider the data provided in Table B2 in Santiago and Smith (2013). .... First, for r=1, we obtain the lower and upper control limits for the basic ATS-unbiased t1-chart, which are equal to LCL=0.63 and UCL=2093.69, respectively. In a similar manner,* "the values of the control limits for the ATS-unbiased t1-chart with the {1/1,M:3/4} scheme, are equal

to LCL=31.36 and UCL=1943.22, respectively"... *the **ATS-unbiased t1-chart** with and without the runs rule scheme **detects a signal at the 67th point**.*" "*Thus, we next investigate monitoring the process by considering the times to every 2nd event and using the ATS-unbiased t2-chart.* " OMISSIS….

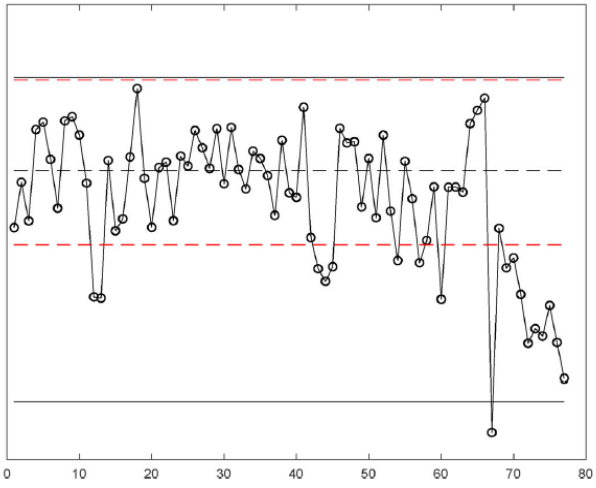


**Figure 23.** Control Chart from the paper [2] "Statistical design of ATS-unbiased charts with runs rules for monitoring exponential time between events", published in *Communications in Statistics - Theory and Methods*, DOI: 10.1080/03610926.2022.2092143 *k=1 (sample size)*.

It is interesting what I find with RIT. See **Table 5**.

**Table 5.** Comparison of results from the paper [2] and RIT.

| Type of Method | LCL | UCL | Comment |
|---|---|---|---|
| N. Kumar et al. "t1 Chart" | 0.63 | 2093.69 | Both LCL and UCL are lower than Scientific |
| N. Kumar et al. "ATS–unbiased t1 Chart…" | 31.36 | 1943.22 | LCL is 17 times higher than Scientific and UCL is 24% of Scientific |
| F. Galetto **RIT** | 1.835 | 7940.01 | Scientific |

Both the method from the paper [2] provide wrong Control Limits: The decision based on the process would be wrong, with the proposed methods.

## 10. Discussion

It should now be clear that several Journals published wrong papers on Control Charts (CC) for TBE (Time Between Events) data, exponentially distributed.

Does the reader think that the statement "*The problem of monitoring TBE that follow an exponential distribution is well-defined and solved"*. I do not agree that "nobody could solve scientifically the cases" has to be considered scientific?

Absolutely not. This is due to a lack of knowledge of the Sound Theory of the CC, generated by wrong knowledge of the basic concepts about Confidence Intervals.

It is a true disaster: It seems that nobody found the errors. Neither the Peer Reviews nor the Editors of the "good" Journals.

Many wrongs do not make a right.

Their "wrong formulae" are used by JMP, SAS, Minitab software.

The users of such software took and will take wrong decisions based on the "wrong formulae"…

Those Journals should, for future research about CC, accept the letters sent to their Editors.

I wrote letters to the Editors of *Quality Engineering*, *Quality and Reliability Engineering* and *Communications in Statistics_Theory and Methods* to inform them and the readers of the Journals about the errors on Control Limits for TBE Charts, to avoid costly errors and decisions. They have not been published yet…

*To publish them they must understand the problem…*

It is a big real problem: Big errors and nobody (known to the author), but F. Galetto, is taking care of teaching the students to use their own brains in order not to be poisoned by incompetents (**Figures 20 and 21**); for this reason the author self-cited himself (I ask the readers to signal him if other people have been sowing as many errors as he did).

The last document with errors [2] I found, published in 2022, uses the data on earthquakes that are shown (from the paper [21]): The Control Limits are again wrong.

The questions in Figure 1 give the readers some hints to think how many Statisticians, Certified MBB, …., *all over the world, are learning the wrong methods and will take the wrong decisions? And are teaching wrong methods…*

Writing this paper I think that I helped people (the readers, the Editors, the Peer Reviewers and other

Scholars) to avoid being cheated by the many wrong teachers running in the Disqualify Vicious Circle (**Figure 24**).

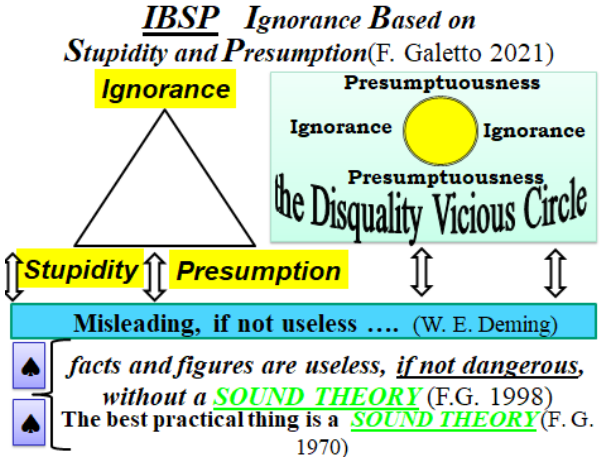


**Figure 24.** The Disquality Vicious Circle.

*The author hopes* that the Peer Reviewers of this paper have better knowledge than the discussants (in the various forums, iSixSigma, Research Gate, Quality Digest, Academia.edu and …), otherwise he risks being passed off…

In spite of all these proofs, the discussant who suggested the paper of J. Smith did not believe the evidence. He raised the problem that it could happen only by chance: He believed only in simulations ((like all who do not know Theory). After ten million simulations, F. Galetto got the result that T Charts (Minitab and in all wrong papers) were wrong 93.3% of the time.

I think that it should be enough…

But is it? No…, due to the ideas in **Figure 24**.

**Figure 25** shows the author's position in teaching [Qualitatem Docere]: The "epsilon Quality, driven by Intellectual hOnesty and by Gedanken Experimente".

**Figure 24** shows the real problem with the Minitab, JMP and SAS T Charts and the Box-plot based method.

The author many times (more than those you find in the references) tried to compel several scholars to be scientific [25,27-41,47-56]: He did not have success.

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 [28].


**Figure 25.** The "epsilon Quality, driven by Intellectual hOnesty and by Gedanken Experimente".

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 the author increased the h-index of authors publishing the wrong papers [1-24].

Since the basic rules for Control Charts are based on the "Central Limit Theorem", many "professionals" transform the data to make them "almost Normally Distributed"; this behaviour can be dangerous as I showed before.

If the reader considers that the author asked many [>>50] "Statisticians and Certified Master Black Belts and Minitab users (you can find them in various forums such as ReasearchGate, iSixSigma, Academia.edu, Quality Digest, … and in several Universities)" and *nobody* could solve scientifically the cases, he has the dimension of the problem.

The author hopes that the Peer Reviewers of this paper have better knowledge than the discussants (in the various forums, iSixSigma, Research Gate and …), otherwise he risks being passed off…

In spite of all these proofs, the discussant who suggested the paper of J. Smith did not believe the evidence. He raised the problem that it could happen only by chance: He believed only in simulations (as do all the people who do not know Theory). After ten million simulations F. Galetto got that T Charts (Minitab and in all wrong papers) were wrong 93.3% of the time.

I think that it should be enough…

**Figure 25** shows the author's position in his teaching at Turin Politecnico [Qualitatem Docere]: the "epsilon Quality, driven by Intellectual hOnesty

and by Gedanken Experimente".

## 11. Conclusions

Any scholar needs and must analyse data with suitable methods devised on the basis of Scientific Theory and not on methods in fashion [1-25], in order to generate the correct Control Charts, with correct Control Limits.

RIT is able to deal with many distributions (exponential included) and then is usable for many types of data [47-56] and makes Quality Decisions.

First, I briefly presented the Shewhart Control Charts and the Individual Control Charts; second, I analysed the method "(BCCTBE)"; third, I showed the Minitab calculations for the T Charts; I showed the correct control limits of charts with exponentially distributed data, with the applications dealt in the referenced papers. I showed the RIT ability to solve correctly the *Control Charts for Exponentially Distributed Data*. RIT was devised by the author in 1975 (47 years ago) well before the T Charts invention and BCCTBE.

I showed various cases (from books and papers) where errors were present due to the lack of knowledge of a Sound Theory of Control Charts and of RIT.

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

The truth sets you free.

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

In order to show the several wrong ideas and methods related to financial and business considerations about quality in several books (not given in the references) I would need at least 30 more pages in this paper: I, obviously, cannot do that. Therefore I ask the readers to look at some of the documents [27-56], including the "Several Papers and Documents in the Research Gate Database, 2014".

I end with the statements of two authors in one of the papers [1-25] who provided WRONG Control Charts, with WRONG Control Limits; they wrote, about F. Galetto comments:

"*We do not know this author and are not familiar with his work. His claim about our formulas being wrong is not justified by any facts or material evidence. Our limits are calculated using standard mathematical statistical results/methods as is typical in the vast literature of similar papers.*"

The complete document is available for any interested reader (write to F. Galetto).

The dramatic problem for TBE Control Charts is this: "*Limits are calculated using standard mathematical statistical results/methods as is* ***typical in the vast literature of similar papers***." This is the proof of how many "scholars" diffuse wrong ideas.

See **Figures 1, 9, 12, 20, 21** and **Table 5**.

As the last information, the readers must consider that the ARL (Average Run Length) for Individual Control Charts for TBE is quite different from the usual formula they can find in books: $ARL=1/\alpha$ [56].

The author had to self-cite because it seems the only one that has been fighting for years for "Papers Quality"; he humbly asks the readers to inform him if some people did the same.

## Conflict of Interest

There is no conflict of interest.

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**EDITORIAL**

# Analysis of Simple Additive Weighting Method (SAW) as a Multi-Attribute Decision-Making Technique: A Step-by-Step Guide

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## ABSTRACT

The simple additive weighting (SAW) method is one of the oldest and most widely used decision-making methods. It has a simple process that can be utilized in different subject areas such as engineering, environmental sciences, and energy. The main concepts of the SAW method are introduced in this paper and then a step-by-step guide to using SAW technique for decision-making and ranking purposes in multi-attribute cases is presented.

## 1. Introduction

The multi-attribute decision-making (MADM) methods are used for evaluating decision-making problems as selector models for choosing the best alternative [1]. These alternatives are evaluated by different attributes also considering the attributes' importance [2]. The SAW method also known as a weighted addition method is one of the simplest and the most widely-used decision-making methods. This method is the basis of most MADM methods such as the PROMETHEE and AHP methods. This method uses the concept of additive property for determining the ranks of the alternatives [3-5]. That is to say, the SAW as a classic version of the multi-attribute value method is "a value function is established based on a simple addition of scores that represent the goal achievement under each criterion, multiplied by the particular weights" [6].

The basis is to calculate the weighted sum of the performance ratings. This should be calculated for each alternative/object on all attributes/criteria. The decision-makers also should consider the weight of attributes in this process. Furthermore, a dimension-free rating for the attributes is obtained due to

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the normalization process in this method [7]. This method uses the idea of integrating the values of criteria and weights into a single value. The basis of the SAW method is only based on maximizing evaluation criteria, although the minimizing problems can be also converted into maximizing type by using specific formula (which will be discussed in the process steps) [5]. In this method, the minimizing and maximizing evaluation criteria/attributes are known as criteria of costs and benefits as well [8].

## 2. Application areas, merits, and demerits of the SAW

The SAW method possesses different application areas ranging from business to water management and financial studies [9]. Different studies are conducted based on utilizing the SAW method for ranking and selection purposes. This method can be also integrated with other MADM methods such as AHP, VIKOR, TOPSIS, and ELECTRE; some examples are as follows:

- Ranking the cloud render farm services
- Evaluating the quality of urban life;
- Risk assessment in public-private partnership projects;
- Selecting the most efficient devices;
- Studying available energy;
- Selecting sensors attached to the devices;
- Ranking the best resources at the local or lower level;
- Stock selection;
- Selecting Intercrop;
- Studying employee placement concept;
- etc. [10].

The main subject areas are shown in **Figure 1**. This figure is based on the "simple additive weighting" search term in the "ScienceDirect" database (conducted on 2022/06/2). The figure illustrates that according to the results this method is mostly used in the engineering, computer, environmental, and decision sciences subject areas.

As discussed, the SAW is one of the most widely-used MADM methods. This method has manifold advantages offered to the decision-makers, although the demerits are also negligible. The main positive and negative features are listed in this section in **Table 1**.

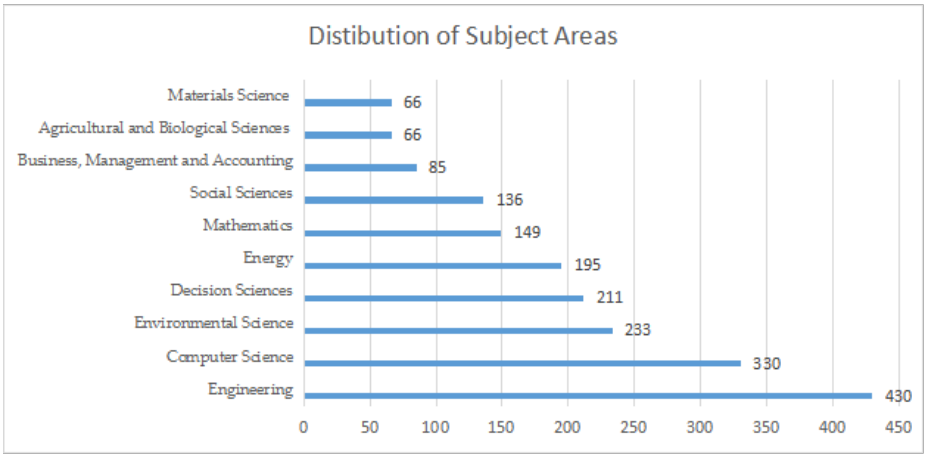


**Figure 1.** Distribution of subject areas used the SAW method.

**Table 1.** Merits and demerits of the SAW [5,8,9].

| Advantages | Disadvantages |
|---|---|
| ● The ability to compensate among criteria;<br>● Being intuitive to decision-makers;<br>● Simple calculation;<br>● No need for complex programming;<br>● Assisting to determine the differences between objects compared visually using the normalized values. | ● Transferring minimizing criteria to maximizing (or using the formula discussed later) in the main concept;<br>● Transferring negative values of $r_{ij}$ to positive ones (discussed in the final section);<br>● The obtained results are not always logical;<br>● Must provide the attributes' weights and the decision matrix. |

## 3. Process steps

The Simple Additive Weighting method is one of the most common multi-attribute decision-making (MADM) methods. Finding the weighted sum of the performance ratings for each alternative considering all attributes is the basic concept of the SAW method. For this, a normalized decision matrix must be prepared. This normalization process results in a scale that makes comparing with all alternative ratings possible [4]. The steps of the SAW method are presented in **Figure 2**.

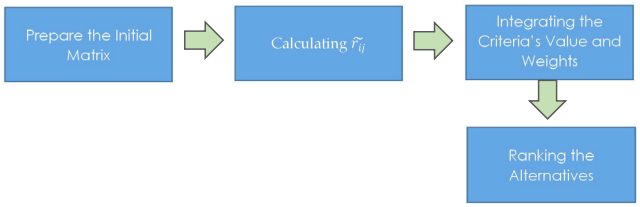


**Figure 2.** Steps of the SAW method.

**Step 1.** Prepare the Initial Matrix

This is an optional step that helps to conduct the following steps better. The initial matrix is prepared based on the values for $m$ criteria and $m$ alternatives/objects. There for, in this $m \times n$ matrix $r_{ij}$ is the value of the $i$ th criterion for $j$ th object where:

- $i = 1,2, ..., m$;
- $j = 1,2, ..., n$.

Another point is to determine the weights of the criteria ($w_i$) to show their importance. These weights can be considered as numbers between zero and one (or by percentages) and considering $\sum_{i=1}^{n} w_i = 1$.

**Step 2.** Normalizing the Value of $i$ th Criterion for the $j$ th Alternative (Calculating $\widetilde{r_{ij}}$)

The $\widetilde{r_{ij}}$ is known as the normalized $i$ th criterion's value for $j$ th alternative/object. This value must be calculated in this step considering whether the problem is a cost or benefit type. The difference is that in the cost problems the object is minimizing, on the other hand maximizing is the object of a benefit problem. These differences reflect in the $\widetilde{r_{ij}}$ calculation as follows:

$$\widetilde{r_{ij}} = \frac{\min_j r_{ij}}{r_{ij}}; \text{ if } j \text{ is a cost attribute.} \quad (1)$$

$$\widetilde{r_{ij}} = \frac{r_{ij}}{\max_j r_{ij}}; \text{ if } j \text{ is a benefit/profit attribute.} \quad (2)$$

where $r_{ij}$ is the value of the $i$ th criterion for $j$ th object. The $\min_j r_{ij}$ is the largest value of the $i$ th criterion when all alternatives are compared, and in contrast, $\min_j r_{ij}$ is the smallest value for it. Therefore, $\widetilde{r_{ij}}$ is a normalized value for the $i$ th criterion and $j$ th alternative.

**Step 3.** Integrating the Values of the Criteria and Weights

The integration of the criteria and weights helps to gain a single magnitude that is the final performance value for each alternative. For this, the following equation can be used for the $j$ th alternative/object:

$$S_j = \sum_{i=1}^{n} w_i \widetilde{r_{ij}} \quad (3)$$

**Step 4.** Ranking the Alternatives to Choose the Best One

In the final step, the best alternative is chosen based on the largest performance value of the $S_j$ maximizing criterion, and the smallest for the minimizing criterion [5,11-13]. Numerical examples are provided in the literature [8].

Finally, there is another important consideration for the SAW method that is beneficial to be noted here:

The $r_{ij}$ in this method should be positive. According to this requirement the negative values should be transferred to the positive ones ($\overline{r_{ij}}$) using different methods. For example, the following formula can be used:

$$\overline{r_{ij}} = r_{ij} + \left|\min_j r_{ij}\right| + 1 \quad (4)$$

Examples are provided in the literature [14].

## 4. Conclusions

The SAW method is one of the oldest and most common-used MADM methods. In this paper, the concept of SAW method, its advantages, disadvantages, and application areas were reviewed. Finally, the SAW process steps were explained in simple four steps. The process begins with

identifying the alternative and criteria's values and then continues to gain the final performance values for the alternatives used to rank them.

## Conflict of Interest

There is no conflict of interest.

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**ARTICLE**

# HIV Counseling and Testing Uptake, Knowledge and Attitude and Influencing Factors among Student Nurses and Midwives in The Gambia: An Institutional-based Cross-sectional Study

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## ABSTRACT

HIV counseling and testing (HCT) has become paramount in the prevention and control of HIV/AIDS worldwide. However, the uptake of HCT has been very slow globally, especially in sub-Saharan Africa. Student nurses formed the largest group undergoing health care training in the country compared to doctors and other health cadres. According to WHO, they are part of the most vulnerable group to HIV infection, judging by the fact that they interact more with patients/clients than other healthcare professionals. This study aimed to determine the prevalence of HCT uptake, knowledge, and attitude and evaluate influencing factors among student nurses and midwives in public nursing schools. An institutional-based cross-sectional study design was employed to collect data from 305 randomly selected nursing students and midwives using a validated and reliable self-administered questionnaire. Descriptive statistics (percentages, mean and standard deviation) and inferential statistics (chi square, logistics regression, one-way ANOVA and independent samples t-test) were used for data analysis using SPSS version 25.0. A p-value < 0.05 was considered for statistical significance. Out of the 305 students recruited for the study, 60.98% were females, with a mean age of 25.5 years old. About 58.4% of the participants had tested for HIV in the past. About 95.7% acknowledged the importance of HCT in the prevention and control of HIV/AIDS. HCT uptake among student nurses and midwives was influenced by factors ranging from an individual that are interpersonal challenges (such as concerns of friends), perceived susceptibility to the disease, lack of confidentiality, stigma and discrimination from health service providers. Therefore, these barriers can be addressed through an organized targeted health education intervention and advocacy programs across health training institutions in the Gambia and beyond.

***Keywords:*** Barriers; Facilitators; HIV testing and counseling; Student nurses; Uptake; Attitudes

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# 1. Introduction

Human immunodeficiency virus (HIV) infection is now predominantly seen as a controllable condition due to treatment advances and care. However, without appropriate strategy or intervention, HIV can lead to acquired immune deficiency syndrome (AIDS), which may bring about morbidity, health burden and mortality [1]. Mitigating the rapid transmission of HIV requires concerted efforts and commitment. This involves widespread screening and testing to isolate persons who may miss opportunities to seek treatment and thereby unknowingly transmit the virus to others. According to WHO and other health organizations, the key strategy or intervention in the battle against HIV is through HIV counseling and testing (HCT). HCT still remains crucial in the global fight to reach universal access to prevention and timely HIV treatment and health care [1]. This can only be realized if people modify their behaviour or attitude towards HCT, especially among vulnerable populations. Additionally and most importantly, a decrease in the uptake of HIV counseling and testing among undiagnosed people is a barrier encountered at the healthcare provider level [2]. Besides the importance of clear and vivid protocols for HCT and treatment, knowledge and attitudes towards the acceptability of HCT to potential recipients and health professionals who have to administer the services and willingness of health professionals to provide, manage and treat HIV-positive people are essential prerequisites [3]. Reviewed literature demonstrated that HIV/AIDS and HCT attitudes are particularly effective among health workers and pre-service nurses [4,5]. Therefore, student nurses and midwives with good attitudes toward HCT could serve as good role models for educating clients on HCT and HIV/AIDS services in their future work environments [6].

Nursing students and midwives, the primary focus of this article, are considered the risky or vulnerable group in The Gambia. Several studies have indicated that a high percentage of university students like nursing students, ages 17-24 years old are usually sexually active. This strong urge for sexual exploitation peaks in the first year and second years of study. This significantly correlates with an increased risk of HIV infection especially among young women especially. Therefore, nursing students are an important constituency in the interventions against HIV/AIDS as many might be entering nursing schools before they are sexually active and yet fall within the age bracket where HIV infection peaks. Globally, around half of the people who acquire HIV/AIDS become infected before they turn 25 years and HIV/AIDS is the second most common cause of death among 20-24 years old [7]. As mentioned in UN General Assembly Special Session (UNGASS) on HIV/AIDS, young people aged 15-24 are an important cohort to monitor for population-level reductions in HIV incidence. Student nurses fit well in this population cohort as they are usually fresh secondary school leavers with little guidance from their parents during the period of study. Student nurses and midwives are part of this vulnerable group that often contacts their peers. Also, student nurses formed the largest group undergoing healthcare training in the country compared to doctors and other health cadres. Also, student nurses are usually in their youthful age and according to WHO, they are part of the most vulnerable group to HIV infection. Student nurses are also expected to provide HIV services upon graduation, judging by the fact that they interact more with patients/clients than other healthcare professionals. Furthermore, the 2013 National Demographic Health Survey (DHS) found a significantly high HIV prevalence among youth aged 15-24 at 0.3% [8]. This figure includes student nurses. Hence, given this tendency, preventive interventions that can limit the epidemic among the cream of our society and the larger population are crucial.

Despite the acceptance of the HCT model by African governments, the level of acceptance and utilization of this model by citizens has been met with mixed attitudes [9], and many studies across the African continent have tried to ascertain the level of HCT coverage and general uptake of this prevention strategy. However, outcomes to date have been poor, with high efficacy acceptance [8]. A variety of models could be used for HCT such as provider-ini-

tiated counseling and testing (PICT) as part of medical care, and client-initiated counseling and testing (CICT), often dubbed voluntary counseling and testing (VCT/HCT). Provider-initiated testing occurs in hospital settings where the test would be performed unless patients/clients decline. In contrast, client-initiated testing and counseling could be performed at various service delivery points ranging from health facilities, specially designed stand-alone sites, mobile communities, and home settings. Voluntary counseling and testing (VCT), currently known as HIV counseling and testing (HCT), was developed in the mid-1980s as the norm for those desiring to know their infection status. These services are cost-effective treatments that offer chances to raise awareness of HIV and preventative practices and are key components of HIV prevention programs [9].

Knowledge about HCT is an important pre-requisite to HCT utilization especially in high prevalence settings where many individuals tend to develop feelings of hopelessness and helplessness and harbor the belief that behaviour change is late. However, learning one's HIV status with prevention, counseling can be an important prevention and care strategy [10]. In the aspect of HIV/AIDS, it is crucial that everyone has adequate knowledge about HIV counseling and testing as a preventive strategy. The focus should not be centered on one receiving HCT but also on the benefits associated with the test and it enhances the demand for the services. Some studies indicate that community awareness was associated with significant uptake of HCT among women who received pre-test counseling [11]. However, little is known about the level of knowledge of HCT among student nurses and midwives in the Gambia. Notwithstanding, the 2013 national demographical health survey revealed that knowledge of places for HIV testing is higher among urban women and men than in rural areas. Moreover, despite high knowledge of the sources of HIV testing, only 39% of women and 19% of men have ever been tested. Also, Multiple Indicator Cluster Survey (MICS-6) reports, 2018 indicated that 62.5% of men knew a place to get tested, only 23.3% were tested and 22.4% of men had been tested and knew the most recent test result, and 8.0% had been tested in the previous 12 months and knew the result [7].

The correlation between attitude and health behaviours has been analyzed in many studies and behavioral theories suggested that a change in attitude can result in behaviour change. It is one of the main factors of intention to change or utilize a behaviour (HIV testing). Despite it being a determinant of intention to perform a behavior, the intention is not altogether as utilizing the service. An individual may have the intention to perform a task like an HIV test but fail to carry out that intention due to other conflicting interests and pressures. In a particular study, participants who had not been tested held a significantly more negative attitude toward HIV tests than participants who had been tested [12].

HIV uptake among nursing students in the Gambia is unknown, although they are part of the vulnerable youth population. However, a study in Nigeria showed that, the acceptance rate of HCT among students of tertiary institutions ranged from 8.3% to less than 30% in reported studies. This finding has important implications for HIV preventive strategies in the Gambia and other developing countries in sub-Saharan with a huge HIV/AIDS burden. Therefore, nursing students and midwives demonstrating high HCT acceptability could serve as peer educators among youths in the communities. The HIV uptake among young people aged 15-24 years old in 2007 was about 1.2% and 2.9% in males and females respectively according to the national demographical health survey 2013 [13]. Young people are vulnerable to HIV/AIDS due to their low awareness of sexual health; poor translation of safe sex practices; and limited condom use, since parents do not discuss sexual health issues with their children [7]. This significantly correlates with an increased risk of HIV infection, especially among young women. As a result, the importance of this study cannot be overstated, and it is supported by empirical data on the need to assess HCT utilization or uptake among student nurses and midwives in the Gambia, as they are vulnerable young adults.

Globally, numerous studies have outlined many barriers and facilitators that can influence the uptake of HIV counselling and testing among different subset of the population. Barriers and facilitators may also differ across countries and groups of people with different characteristics. Findings from many studies also grouped barriers related to HCT into five main domains based on the socio-ecological model (intrapersonal, interpersonal, institutional, community and policy levels). In other studies, the barriers are phrased differently but mean the same. For example, the intent to seek HIV counselling and testing was attributed or related to five attitude subscales namely: people's concerns, individual concerns, friends' concerns, the value attached to testing, confidentiality, and perceived susceptibility [14]. Therefore, the magnitude of each independent domain may vary across countries or continents. However, the influencing factors associated with HCT uptake among student nurses and midwives in the Gambia are not known.

Undoubtedly, this study aimed to explore the influencing factors associated with HCT uptake among student nurses and midwives in the Gambia. The study also examined utilization rate or prevalence, knowledge and attitude toward HCT uptake. The findings identified in this study will help policymakers to revisit some of the laws, regulations, or policies on HIV/AIDS and HCT services in particular in the country. Hence, these findings may trigger a need to overhaul some policies or regulations that impedes HCT uptake in the country.

# 2. Methods

## 2.1 Design and setting

A cross-sectional study design was used across three public nursing schools in different regions. The three public nursing schools in the country are: The Registered School of Nursing and Midwifery in Banjul (capital city); the School of Enrolled Nursing and Midwifery (Bansang town) and the School of Community health and midwifery (Mansakonko town). The School of Enrolled Nursing and Midwifery is located in the Central River Region in the rural part of the country. It is about 300 km from the capital Banjul and it has a two years nursing program and one-year midwifery program with residence or accommodation available for students.

Similarly, the School of Community Health and Midwifery is located in the Lower River Region about 200 km from the capital. It also has a two-year program and a one-year midwifery program. Unlike the other two schools, graduates are usually posted to the community and less often to minor health centres where they engage in the community. Students in this school are not provided with residence or accommodation, hence are forced to rent within the vicinity of the school and sometimes very far away from the school where lectures are conducted.

The School of State Registered Nursing and Midwifery is located in Banjul under the Gambia College with a three-year registered nursing program and 18 months diploma midwifery program. It has a more comprehensive nursing curriculum compared to the other two schools. It also accommodates some of its students within the school campus while the majority stay outside.

## 2.2 Sample and eligibility criteria

In this study, the target population is student nurses and midwives currently studying in three public nursing schools in The Gambia. Student nurses formed the largest group undergoing health care training in the country compared to doctors and other health cadres. Also, they are usually at a youthful age and according to WHO, they are part of the most vulnerable group to HIV infection. They are also expected to provide HIV services upon graduation judging by the fact that they interact more with patients/clients compared to other healthcare professionals.

Student nurses and midwives presently studying in public nursing schools and willing to participate were recruited. However, the study excluded support staff, lecturers and practicing nurses.

## 2.3 Sample size determination

In other to determine the sample size for the study, we used Yamane (1967) formula to calculate the number of student nurses and midwives to participate in the study. The formula, assuming a confidence interval of 95% and an error of 5%, with a population of 651 students from all three schools, yielded a desired sample size of 248 participants. However, 10% was added to cover the non-response rate and erroneous questionnaires after completion. Hence, the final desired sample size was 273. However, a total of 305 students volunteered to participate surpassing the desired calculated sample size for the study. Below is a breakdown of how the researcher arrived at the sample size for the study.

$$n = \frac{N}{1 + N(e)^2}$$

where n= the sample size; N = the student population; e= the error of 5% points (0.05).

10% was added to cover for non-response rate and erroneous questionnaires after completion. Hence, the final desired sample size was 273.

## 2.4 Sampling technique

A stratified random sampling technique was used to select participants from the three schools. To achieve this, an enumerated list of all the regular students was secured from the heads of the nursing schools for each of the academic years and used as the sampling frame. Proportional allocation was done for each of the academic levels i.e. year 1, 2, 3 (RN school only) and midwifery class. Stratified random sampling using the lottery method was used to draw samples from each of the respective academic levels or classes. A total of 305 students volunteered to participate in the study (**Figure 1**).

## 2.5 Measurement

A self-administered questionnaire segmented into three parts was used to collect data from participants. The segments comprised of the following parts: Socio-demographic information such as age, sex, marital status, educational status of parents, religious affiliation, place of residence; ethnicity, school, academic level, marital status, educational level of parents, wealth quintile, and local government area (LGA) of the participants. The variables used herein are from previously published studies and also the demographic health survey of the Gambia, 2018.

The items on knowledge are a subset of items provided by the World Health Organization as part

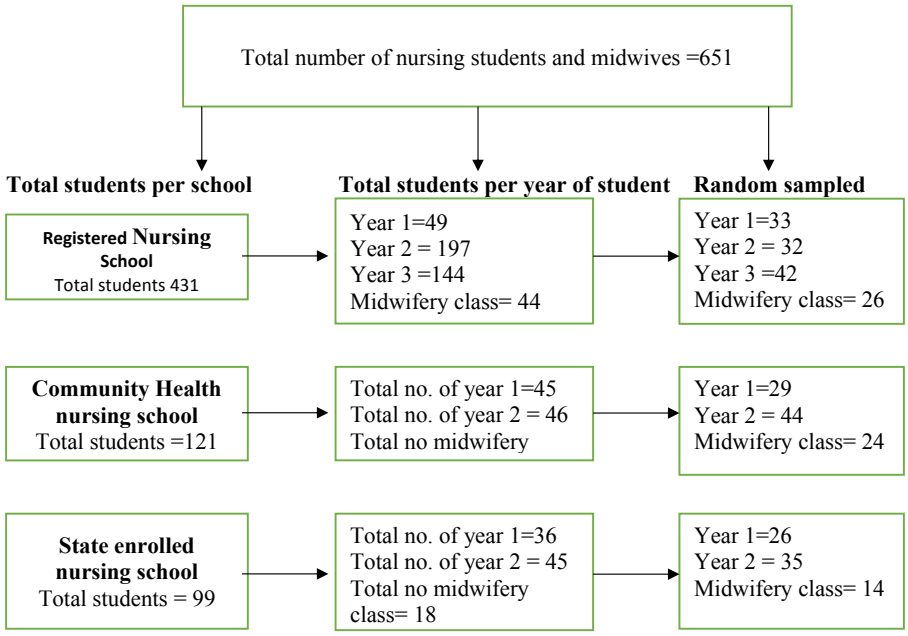


**Figure 1.** Schematic presentation of the sampling method.

of its research guidelines for studies related to HIV counseling and testing. This section contained questions about knowledge of HCT such as the source of information about HCT, perception of the benefits of HCT, the practice of HCT, satisfaction with HCT services, the reason for not taking HCT, willingness to HCT and preference of HCT method. The section contained 24 items with responses of yes/no and also multiple choices. Analysis was done based on the individual items mentioned above using descriptive analysis in the form of frequency, percentages and means.

For attitude, a 32-item HIV-Antibody Testing Scale was used (Boshamer CB, Bruce KE) [15]. This scale was validated and reliable as it was used in different previous studies in Africa and beyond with a Cronbach's alpha of 0.88. Responses were scored such that strong agreement with facilitator items was given 5 and strong disagreement was given 1. Reverse scoring was used for barrier items. Item scores were summed and high scores indicated a more favorable attitude toward HIV antibody testing. Participants' attitude was categorized as positive or negative attitude based on the total attitude score. An attitude score of more than or equal to the total mean score was regarded as a positive attitude and less than the total mean score was considered a negative attitude [16]. The test-retest reliability result for the HIV-Antibody Testing Scale showed good internal consistency with a Cronbach's alpha score of 0.813 for the present study. Equally, the knowledge questionnaire part had a good internal consistency with a Cronbach's alpha of 0.783.

## 2.6 Data collection

Data collection was carried out using the self-administered questionnaire with the assistance of data collectors in each school after permission was sought from the heads of schools. All the data collectors were trained prior to data collection. Data collectors in each school informed all students about the research prior to the data collection process. Student representatives were also used to inform their colleagues about the importance and benefits of the research. The time for data collection was communicated to all the lecturers and students in the three nursing institutions.

## 2.7 Statistical analysis

Data entry and analysis were done using Statistical Package of Social Sciences (SPSS) version 25 software. Descriptive and frequency analyses were used to analyze the socio-demographic characteristics of the participants, knowledge items and independent variables respectively. Categorical variables were presented as frequencies and percentages and chi square test was used to test for association. If the number of participants in one or more categories was less than five, Fisher's exact test was applied. Results were considered to be significant with a p-value $< 0.05$. Multivariate logistic regression was used to investigate the predictors or demographic variables associated with HCT uptake and the conditional method calculating odds ratio and 95% confidence interval was applied. One-way ANOVA and independent samples t-test were used to determine the mean difference between categories of the demographic variables and dependent outcomes for the attitude scale.

Factor analysis was also conducted to identify barriers and facilitators associated with HCT among student nurses and midwives using the 32 items on the HIV Antibody Testing Scale. A principal component analysis was used for facilitators and barriers using varimax rotation together with a scree plot for the extraction of factors. A cut-off point of 0.40 was applied for item inclusion in the interpretable factors and items with two or more loadings $> 0.30$ was considered cross-loading items and was assigned to a single factor with the highest loading [17]. Also, an eigenvalue of more than 1 point was considered for identifying factors using the scree plot. All the items loaded above the 0.40 cut-off.

## 2.8 Ethical considerations

Before the study, ethical approval was obtained from the Institute Review Board at Central South

University, Xiangya School of Nursing, China (IRB Number: E202044). Similarly, approval to conduct the research in the nursing schools was sought and approved by the Gambia Scientific Coordination Committee (GSCC) of the University of the Gambia. Confidentiality was maintained and participation was voluntary, and no incentives were provided for participation. Participants could withdraw from the study at their will at any time or stage of the study. Also, respondents were issued with a detailed information sheet about the study and a consent form was signed by participants willing to participate. Confidentiality was maintained and participants were not required to write any information that may reveal their identity. Participation was voluntary, and no incentives were provided for participation. Apart from time, there were no other potential risks related to the study participants or the information they provided. Furthermore, this study was not invasive therefore, no harm was anticipated to the participants. There was no repercussion or punishment to be meted on the students for declining to participate in the study.

# 3. Results

## 3.1 Socio-demographic characteristics of the participants

In this study, the response rate was 91% (305 submitted questionnaires out of 335 were accepted for analysis) and out of the 305 participants, more than half (60.9%) were females. The mean age and standard deviation for nursing and midwife students were 25.5 years ± 5.4. However, by age range, more than half of the participants were within the age group of 19-24, at 58.3%. HCT use was more widespread within the age range of 31 & above years at 80.0% compared to 19-24 years at 43.5%. The HIV counseling and testing uptake among midwifery students was also higher by 81.5% compared to 58.8% second-year students. Students from Janjanbureh as well as Mansakonko LGA chose HIV counseling more than other LGAs in the study. These LGAs are located in rural areas of the country, which are frequently plagued by a lack of resources. The Mandingo tribe was the most common ethnic affiliation of the participants at 40.9%, while about 92.1% were Muslims. In terms of distribution of participants by school, about 43.6% were from the Registered Nursing School of Gambia College, 31.8% from Community Health Nursing School, Mansakonko and 24.6% from State Enrolled Nursing, Bansang. The majority of participants were single 65.3% while almost one in every four students was married at the time of the study. About 36.1% were in the second academic year as shown in **Table 1**. Regarding the educational status of participant parents, almost half of the participants' fathers and two-thirds of their mothers had no education. Our participants' wealth quintile was largely in the middle index class at 48.5%, followed by the second wealth index at 25.3%. Approximately about half of the participants reported living with both parents while about one-third reported having only one rent alive and one in five reported losing all their parents. According to participants' LGA local of origin, Brikama has the most residents while Kuntaur had the lowest participants at 1.7%. Overall, about 57.1% were from urban areas of the country.

## 3.2 HIV counselling and testing uptake

HIV counseling and testing uptake among nursing students and midwives was 58.4% as shown in **Figure 2**. HCT utilization was more prevalent within the age range of 31 & above years, 32 (80%) compared to the 19-24 years of age 77 (43.5%). Also, HIV counseling and testing utilization were higher among the midwifery students, 53 (81.54) compared to second-year students, 87 (58.78). Students who are from the Local Government Area (LGA) of Janjanbureh opted for HIV counseling more than other LGAs, 18 (81.82%) followed by Mansanko LGA, 19 (79.17). These LGAs are situated in the rural part of the country which are often plagued by limited resources (**Table 1**).

**Table 1.** Socio-demographic characteristics and utilization of HCT (n = 305).

| | | Ever had HIV test | | | |
|---|---|---|---|---|---|
| **Variable** | **Frequency n (%)** | **Yes n (%)** | **No n (%)** | **Chi-square test** | ***p*-value** |
| **Age** | | | | 38.342 | 0.001* |
| 19-24 years | 177(58.03) | 77(43.50) | 100(56.50) | | |
| 25-30 years | 88(28.85) | 69(78.41) | 19(21.59) | | |
| 30 & above | 40(13.11) | 32(80.00) | 8(20.00) | | |
| **Gender** | | | | 0.136 | 0.712 |
| Male | 119(39.02) | 71(59.66) | 48(40.34) | | |
| Female | 186(60.98) | 107(57.53) | 79(42.47) | | |
| **Religion** | | | | 9.136 | 0.003* |
| Islam | 281(92.13) | 171(60.85) | 110(39.15) | | |
| Christianity | 24(7.87) | 7(29.17) | 17(70.83) | | |
| **Ethnicity** | | | | 13.361† | 0.090 |
| Mandinka | 125(40.98) | 74(59.20) | 51(40.80) | | |
| Fula | 68(22.30) | 40(58.82) | 28(41.18) | | |
| Wollof | 30(9.84) | 19(63.33) | 11(36.67) | | |
| Jola | 36(11.80) | 23(63.89) | 13(36.11) | | |
| Manjago | 14(4.59) | 4(28.57) | 10(71.43) | | |
| Serere | 13(4.26) | 8(61.54) | 5(38.46) | | |
| Aku | 7(2.30) | 5(71.43) | 2(28.57) | | |
| Foreign | 5(1.64) | 0(0.00) | 5(100.00) | | |
| **Marital status** | | | | 42.110 | 0.001* |
| Married | 88(28.85) | 75(85.23) | 13(14.77) | | |
| Single | 199(65.25) | 94(47.24) | 105(52.76) | | |
| Divorced | 5(1.64) | 4(80.00) | 1(20.00) | | |
| Relationship | 13(4.26) | 5(38.46) | 8(61.54) | | |
| **Academic class** | | | | 21.628 | 0.001* |
| First year | 88(28.85) | 40(45.45) | 48(54.55) | | |
| Second year | 110(36.07) | 59(53.64) | 51(46.36) | | |
| Third year | 42(13.77) | 26(61.90) | 16(38.10) | | |
| Midwifery | 65(21.31) | 53(81.54) | 12(18.46) | | |
| **Year Study** | | | | 27.887 | 0.001* |
| 3rd Year RN | 42(13.8) | 16(38.1) | 26(61.9) | | |
| 2nd Year RN | 32(10.5) | 17(53.1) | 15(46.9) | | |
| 1st Year RN | 33(10.8) | 22(66.7) | 11(33.3) | | |
| 2nd Year CHN | 44(14.4) | 19(43.2) | 25(56.8) | | |
| Midwifery SEN | 14(4.6) | 1(7.1) | 13(92.9) | | |
| 1st Year SEN | 26(8.5) | 14(53.8) | 12(46.2) | | |
| 2nd Year SEN | 35(11.5) | 15(42.9) | 20(57.1) | | |
| Midwifery RN | 26(8.5) | 4(15.4) | 22(84.6) | | |
| 1st Year CHN | 29(9.5) | 12(41.4) | 17(58.6) | | |
| Midwifery CHN | 24(7.9) | 7(29.2) | 17(70.8) | | |
| **Residence** | | | | 0.693 | 0.405 |
| Urban | 174(57.05) | 80(45.98) | 51(29.31) | | |

Table 1 continued

| | | Ever had HIV test | | | |
|---|---|---|---|---|---|
| **Variable** | **Frequency n (%)** | **Yes n (%)** | **No n (%)** | **Chi-square test** | ***p*-value** |
| Rural | 131(42.95) | 98(74.81) | 76(58.02) | | |
| **Schools** | | | | 0.731 | 0.694 |
| SEN School | 75(24.59) | 45(60.00) | 30(40.00) | | |
| CHN School | 97(31.80) | 59(60.82) | 38(39.18) | | |
| RN School | 133(43.61) | 74(55.64) | 59(44.36) | | |
| **Parents alive** | | | | 3.162 | 0.367 |
| Yes | 154(50.49) | 94(61.04) | 60(38.96) | | |
| Divorced | 23(7.54) | 10(43.48) | 13(56.52) | | |
| One of them alive | 108(35.41) | 64(59.26) | 44(40.74) | | |
| Both of them not alive | 20(6.56) | 10(50.00) | 10(50.00) | | |
| **Family type** | | | | 0.143 | 0.705 |
| Nuclear | 157(51.48) | 90(57.32) | 67(42.68) | | |
| Extended | 148(48.52) | 88(59.46) | 60(40.54) | | |
| **Household wealth index** | | | | 2.741† | 0.611 |
| Lowest | 67(21.97) | 34(50.75) | 33(49.25) | | |
| Second | 77(25.25) | 49(63.64) | 28(36.36) | | |
| Middle | 148(48.52) | 87(58.78) | 61(41.22) | | |
| Fourth | 7(2.30) | 4(57.14) | 3(42.86) | | |
| Highest | 6(1.97) | 4(66.67) | 2(33.33) | | |
| **LGA of origin** | | | | 19.340† | 0.006* |
| Kanifing | 91(29.84) | 51(56.04) | 40(43.96) | | |
| Banjul | 18(5.90) | 7(38.89) | 11(61.11) | | |
| Brikama | 107(35.08) | 59(55.14) | 48(44.86) | | |
| Kuntaur | 6(1.97) | 6(100.00) | 0(0.00) | | |
| Janjanbureh | 22(7.21) | 18(81.82) | 4(18.18) | | |
| Mansankonko | 24(7.87) | 19(79.17) | 5(20.83) | | |
| Kerewan | 15(4.92) | 6(40.00) | 9(60.00) | | |
| Basse | 22(7.21) | 12(54.55) | 10(45.45) | | |

*Significant at $p < 0.05$, †Fisher's Exact test used

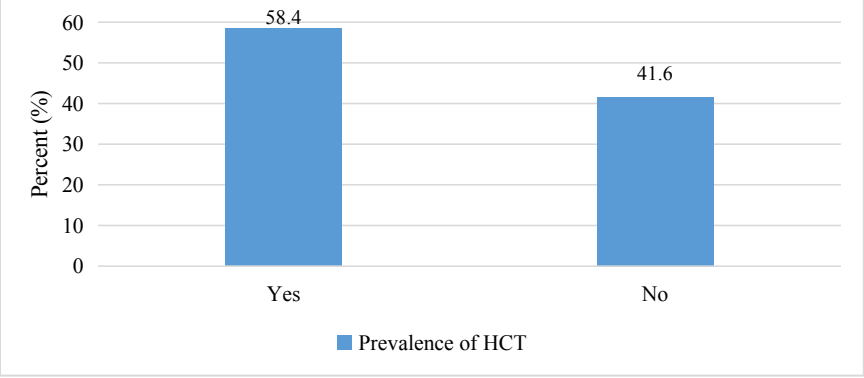


**Figure 2.** HIV counselling and testing uptake.

### 3.3 Knowledge on HCT

Regarding the source of information about HCT, the majority of the respondents heard of HCT before 290 (95.08%). The most common source of information was at school at 53.1% and followed by health facilities at 34.4% as shown in **Figure 3**. Of the 198 participants who had the HIV test, the most common reason for having the test was to know self-status at 65.3% and blood donation at 23.2%. 95.5% of those who underwent HCT mentioned that they were satisfied with the HCT services. Nearly all the participants (99.7%) agreed that HIV counseling and testing is important for the control of HIV/AIDS whilst 87.2% believed HCT is beneficial to both positive and negative persons. About 75.4% of the participant indicated that they will prefer the confidential-linked testing method compared to anonymous/self-testing. Participants were also asked as to who should go for HIV testing, 67.5% mentioned anyone at risk and 23.0% mentioned only those who are sexually active with multiple partners and about two-thirds preferred to receive counseling from a trained counselor compared to a nurse or doctor.

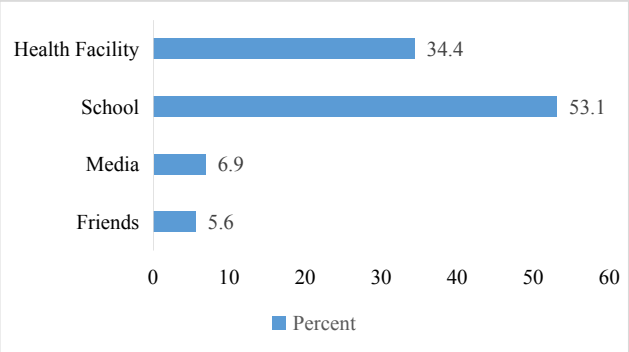


**Figure 3.** Source of information about HIV counseling and testing among respondents.

Despite many participants not having an HIV test in the past, 94.8% reported their desire to go for a test in the future. In terms of participants' health facility of preference to have an HIV test, 67.8% mentioned government health institutions having HCT services followed by a preference for private health facilities/clinics at 24.6%.

### 3.4 Attitude towards HCT

The mean attitude score was 113.94 ± 12.23. A total of 149 (48.9%) of the students showed a negative attitude towards HCT based on the overall mean attitude score. The results also showed that out of the students attending State Registered Nursing Schools, almost half (52.6%) of them showed a negative attitude towards HCT compared to community health nursing schools (46.6%) and state-enrolled nursing schools (43.3%).

The majority of the students agreed (94.1%) that it is very important to seek HIV and 86.9% rejected the statement: "HIV testing is unnecessary for me, as I feel healthy". However, about one-third of the participants assumed that everyone who is tested is infected with HIV, while 19.7% stayed neutral about this assumption (**Table 2**). Further analysis revealed the same trends in participants' opinions on HIV test information being kept very confidential by the medical staff who do the testing, the tendency to be judged or ignored by friends who knew they had done the test, and a very low proportion of neutral stands on this item. Additionally, more than half of the students disagree with the possibility of being positive for HIV/AIDS unknown to them, as well as having intercourse with a person who was at risk for HIV/AIDS.

### 3.5 Socio-demographic variables associated with HCT uptake

To explore the association between demographic variables and HCT uptake, chi square analysis was conducted. The analysis revealed a statistically significant association between six independent variables (age, religion, marital status, academic year of study, academic class by school and LGA) and HIV uptake as shown in **Table 1**. Age was statistically significant ($\chi^2 = 38.342$, $p < 0.001$), religion ($\chi^2 = 9.136$, $p = 0.003$), academic class of study participants ($\chi^2 = 21.628$, $p < 0.001$), marital status ($\chi^2 = 42.110$, $p < 0.001$) and year of study by a school

**Table 2.** Frequency analysis of items on attitude among nursing students (n = 305).

| Items | Strongly Agree/ Agree n(%) | Neutral n(%) | Strongly disagree/ Disagree n(%) |
|---|---|---|---|
| HIV-antibody testing is not really confidential | 67(22.0) | 54(17.7) | 184(60.3) |
| I would not want anyone to know if I got an HIV test. | 148(48.5) | 60(19.7) | 97(31.8) |
| HIV testing is unnecessary for me, as I feel healthy | 21(6.9) | 19(6.2) | 265(86.9) |
| I consider going for HIV counselling and testing extremely humiliating | 39(12.8) | 28(9.2) | 238(78.0) |
| People assume that everyone who is tested for HIV is infected with HIV. | 133(43.6) | 27(8.9) | 145(47.5) |
| Admitting that you should be tested for HIV means that you have engaged in immoral behavior | 27(8.9) | 17(5.6) | 261(85.6) |
| I am afraid that if I were tested for HIV, my name would go into public record | 67(22.0) | 31(10.2) | 207(67.9) |
| Anyone who is tested for HIV is dirty. | 8(2.6) | 6(2.0) | 291(95.4) |
| It would be embarrassing to get tested for HIV | 25(8.2) | 20(6.6) | 260(85.2) |
| People would assume I have HIV if I decided to get tested | 106(34.8) | 60(19.7) | 139(45.6) |
| I am afraid someone would find out I was tested for HIV | 85(27.9) | 53(17.4) | 167(54.8) |
| I would be embarrassed if my friends found out that I had decided to have HIV test. | 61(20.0) | 45(14.8) | 199(65.2) |
| I would not get tested for HIV because I would be asked information that was too personal | 41(13.4) | 35(11.5) | 229(75.1) |
| I do not have time to get an HIV test | 24(7.9) | 19(6.2) | 262(85.9) |
| My friends would treat me badly if I were tested for HIV | 59(19.3) | 69(22.6) | 177(58.0) |
| HIV test information is kept very confidential by the medical staff who do the testing. | 49(16.1) | 40(13.1) | 216(70.8) |
| My friends would not look down on me if I were tested for HIV | 135(44.3) | 54(17.7) | 116(38.0) |
| My friends would support my decision to get an HIV test | 37(12.1) | 69(22.6) | 199(65.2) |
| HIV tests give accurate results | 28(9.2) | 51(16.7) | 226(74.1) |
| It is extremely useful to test for HIV | 15(4.9) | 3(1.0) | 287(94.1) |
| I would be comfortable talking to an HIV counselor about personal behaviors that place me at risk for HIV infection | 31(10.2) | 18(5.9) | 256(83.9) |
| My friends would look down on me if I were tested for HIV | 113(37.0) | 69(22.6) | 123(40.3) |
| My friends would not treat me any differently if I were tested for HIV. | 121(39.7) | 80(26.2) | 104(34.1) |
| I would like to be alone when doing the test | 17(5.6) | 12(3.9) | 276(90.5) |
| I trust the HIV test counselors and 1s to keep my information confidential. | 27(8.9) | 39(12.8) | 239(78.4) |
| It would not bother me if someone I know sees me going to get an HIV test | 107(35.1) | 45(14.8) | 153(50.2) |
| I could easily discuss HIV-antibody testing with my family. | 49(16.1) | 35(11.5) | 221(72.5) |
| I consider going for HIV counselling and testing extremely frightening | 74(24.3) | 44(14.4) | 187(61.3) |
| Testing and counselling is a pleasant experience | 87(28.5) | 45(14.8) | 173(56.7) |
| There is a possibility that I have HIV and AIDS | 166(54.4) | 52(17.0) | 87(28.5) |
| I may have had sex with someone who was at risk for HIV and AIDS | 181(59.3) | 29(9.5) | 95(31.1) |
| I am at risk of HIV and AIDS | 99(32.5) | 38(12.5) | 168(55.1) |

($\chi^2$ = 27.887, $p$ = 0.001) and LGA ($\chi^2$ = 19.340, $p$ = 0.003) (**Table 1**). Other influencing factors associated with HIV counselling and testing were attitude ($\chi^2$ = 7.720, $p$ = 0.005), heard of HCT before ($\chi^2$ = 6.521, $p$ = 0.011), HCT availability ($\chi^2$ = 8.336, $p$ = 0.004) and knowing where to get HCT services ($\chi^2$ = 12.283, $p < 0.001$).

Four variables showed a statistically significant relationship with HCT uptake. The model was statistically significant using the forced entry method ($\chi^2$ = 71.219, $p < 0.001$) which clearly showed its capability of detecting between participants who utilized HCT and those who did not. The overall explanation of the model was 28% (Cox & Snell $R^2$) and 20.8% (NagelKerke $R^2$) of the variance in the utilization of HCT.

Comparing the determinants of HCT uptake among the participants, the analysis showed Christians were five times more likely not to utilize HCT services compared to Muslim participants [OR = 5.272, 95% CI (1.839-15.112), $p$ =0.002]. Similarly, participants who are single are four times more likely not to undergo HIV counselling compared to married participants [OR = 4.265, 95% CI (1.866-9.746), $p$ = 0.001]. Also, participants who are in a relationship were seven times more likely not to take an HIV test compared to married students [OR = 7.361, 95% CI (1.768-30.656), $p$ = 0.006]. Furthermore, participants within the age range of 25-30 years are more likely to undergo HIV testing than those within the age range of 19-24 years [OR = 0.282, 95% CI: (0.14-0.567), $p < 0.001$]. In academic class comparison, midwifery students were 2 times more likely to utilize HCT [OR = 2.718, 95% CI (1.124-6.575), $p$ = 0.027] compared to third-year students as shown in **Table 3**.

## 3.6 Influencing factors associated with HCT uptake

The HIV Testing Antibody Scale (HTAS) with 32 items was used to identify factors influencing HIV

**Table 3.** Logistic regression on socio-demographic factors influencing HCT uptake (n = 305).

| | | | 95% CI for aOR | | |
|---|---|---|---|---|---|
| **Predictors** | **B (regression coefficient)** | **aOR** | **Lower** | **Upper** | **P-value** |
| **Marital status** | | | | | |
| Married (Reference category) | 1 | | | | |
| Single | 1.45 | 4.265 | 1.866 | 9.746 | 0.001* |
| Relationship | 1.996 | 7.361 | 1.768 | 30.656 | 0.006* |
| Divorced | 0.137 | 1.147 | 0.096 | 13.75 | 0.914 |
| **Academic class** | | | | | |
| First year (Reference category) | | | | | |
| Second year | 1 | 2.718 | 1.124 | 6.575 | 0.027* |
| Third year | –0.014 | 0.986 | 0.332 | 2.925 | 0.979 |
| Midwifery | 0.472 | 1.604 | 0.537 | 4.788 | 0.397 |
| **Age of participants** | | | | | |
| 19-24 years (Reference category) | 1 | | | | |
| 25-30 years | –1.265 | 0.282 | 0.14 | 0.567 | 0.001* |
| 31-50 years | –0.493 | 0.611 | 0.171 | 2.184 | 0.448 |
| **Religion** | | | | | |
| Islam (Reference category) | 1 | | | | |
| Christian | 1.662 | 5.272 | 1.839 | 15.112 | 0.002* |
| Constant | –2.537 | 0.079 | | | 0.262 |

*Statistical significance p value < 0.05, aOR = adjusted Odds Ratio, CI = Confidence Interval.

counselling and testing uptake. The data was adequate for factor analysis with an overall Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) of 0.759 for the overall scale. The instrument was further sectioned into two subscales of facilitators and barriers associated with HIV counselling testing. The facilitators comprised 17 items and the barriers are 15 items in total. To identify facilitators and barriers associated with HIV counseling and testing among nursing students, factor analysis using principal component and Varimax rotation was used for the different subscales.

### 3.7 Facilitators to HIV counseling and testing

The items recommended as facilitators were feasible for factor analysis (KMO = 0.685). A total of five factors with an Eigenvalue more than 1 were recognized using the Scree test. These factors accounted for a total of 54.7% of the variance in scores. The identified factors and their loadings are tabulated in **Table 4**.

The factors were interpreted as relating to: 1 = support of friends/partners, 2 = positive perceived susceptibility, 3 =personal concerns about HCT, 4= assured confidentiality and support and 5 = fear about HCT, disclosure, stigma & discrimination. Items are assigned to the scale with highest loading (in bold).

Factor one (Eigenvalue = 3.09) accounted for an 18.2% variance in the responses, which is largely concerned with support from friends or partners in relation to HCT uptake. The factor comprised of items about the concerns of friends' feelings/reactions or support towards HIV counseling and testing. Items such as "my friends would not treat me any differently if I were tested for HIV" and "my friends

**Table 4.** Facilitator items and factor loadings for the HIV antibody testing scale (n = 305).

| **Items** | **Factors** | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| My friends would not treat me any differently if I were tested for HIV. | 0.787 | –0.03 | 0.122 | 0.041 | –0.161 |
| My friends would look down on me if I were tested for HIV | *–0.768* | –0.167 | 0.032 | 0.076 | –0.008 |
| My friends would not look down on me if I were tested for HIV | 0.653 | 0.006 | 0.006 | 0.258 | 0.146 |
| It would not bother me if someone I know sees me going to get an HIV test | 0.372 | –0.053 | 0.244 | 0.221 | –0.278 |
| My friends would support my decision to get an HIV test | 0.347 | –0.117 | 0.322 | 0.286 | –0.038 |
| I may have had sex with someone who was at risk for HIV and AIDS | –0.047 | 0.82 | –0.058 | –0.01 | –0.079 |
| There is a possibility that I have HIV and AIDS | 0.065 | 0.82 | –0.016 | 0.171 | –0.054 |
| I am at risk of HIV and AIDS | 0.061 | 0.742 | 0.136 | –0.069 | 0.065 |
| HIV tests give accurate results | –0.003 | 0.123 | 0.71 | –0.012 | –0.128 |
| I would be comfortable talking to an HIV counselor about personal behaviors that place me at risk for HIV infection | 0.032 | –0.074 | 0.689 | 0.097 | 0.245 |
| It is extremely useful to test for HIV | 0.075 | 0.088 | 0.678 | 0.063 | 0.228 |
| I could easily discuss HIV-antibody testing with my family. | 0.164 | –0.089 | 0.494 | 0.385 | –0.119 |
| I trust the HIV test counselors and nurses to keep my information confidential. | 0.232 | 0.044 | –0.002 | 0.746 | 0.222 |
| HIV test information is kept very confidential by the medical staff who do the testing. | 0.068 | 0.068 | 0.089 | 0.71 | 0.079 |
| Testing and counselling is a pleasant experience | –0.031 | 0.014 | 0.159 | 0.621 | –0.326 |
| I consider going for HIV counselling and testing extremely frightening | –0.006 | –0.023 | 0.048 | –0.108 | 0.764 |
| I would like to be alone when doing the test | –0.081 | –0.06 | 0.219 | 0.283 | 0.61 |

would not look down on me if I were tested for HIV" loaded highly in this factor (**Table 5**). A total of five items aligned under this factor accruing the majority of the items under this subscale. Support and positive attitude of friends is an important facilitators associated with HIV counselling and testing among nursing students. Therefore, the attitude of peers, partners or family members can immensely facilitate the uptake of HCT among nursing students.

The second factor (eigenvalue = 2.02) accounted for 11.86% of the variance and is associated with the intrapersonal level factors under the socio-ecological model. It is mainly concerned with the individual's perceived susceptibility to HIV/AIDS infection and the need for HCT. Self-evaluation is a crucial ingredient in promoting the utilization of HCT supported by cross-cutting factors like knowledge, motivation and ability to act or take a decision. The following items loaded highly: 'There is a possibility that I have HIV and AIDS', 'I may have had sex with someone who was at risk for HIV/AIDS' and 'I am at risk for HIV (**Table 4**).

The third factor (eigenvalue = 1.69) with an overall variance of 9.96% is related to personal concerns about HCT as a whole. The value of HCT, the attitude of staff and family members are key to facilitating the uptake of HCT. The utilization of HCT will be enhanced if these sub-factors are addressed at our health facilities where services are rendered. Items that loaded high included 'HIV tests give accurate results', 'I would be comfortable talking to an HIV counselor about personal behaviors that place me at risk for HIV infection', 'It is extremely useful to test for HIV' and 'I could easily discuss HIV-antibody testing with my family'. They clearly demonstrated that if a good reception is accorded to clients at the health institution they will be more than willing to discuss further HCT with family members thereby

**Table 5.** Barrier items and factor loadings HCT uptake on HCT scale (n = 305).

| | **Factors** | | | | |
|---|---|---|---|---|---|
| Items | 1 | 2 | 3 | 4 | 5 |
| I would not get tested for HIV because I would be asked information that was too personal | 0.722 | 0.135 | 0.075 | 0.09 | 0.14 |
| I do not have time to get an HIV test | 0.69 | 0.315 | –0.22 | –0.057 | –0.085 |
| I would be embarrassed if my friends found out that I had decided to have an HIV test. | 0.675 | 0.099 | 0.328 | 0.206 | 0.108 |
| I am afraid someone would find out I was tested for HIV | 0.657 | 0.047 | 0.374 | 0.21 | 0.057 |
| My friends would treat me badly if I were tested for HIV | 0.417 | –0.041 | 0.389 | 0.255 | –0.117 |
| Anyone who is tested for HIV is dirty. | 0.077 | 0.759 | 0.068 | 0.039 | 0.043 |
| Admitting that you should be tested for HIV means that you have engaged in immoral behavior | 0.028 | 0.668 | 0.126 | 0.133 | –0.054 |
| HIV testing is unnecessary for me, as I feel healthy | 0.183 | 0.579 | 0.058 | –0.272 | 0.018 |
| I consider going for HIV counselling and testing extremely humiliating | 0.268 | 0.509 | –0.072 | 0.342 | 0.231 |
| People assume that everyone who is tested for HIV is infected with HIV. | –0.015 | 0.181 | 0.717 | –0.105 | 0.092 |
| People would assume I have HIV if I decided to get tested | 0.4 | –0.096 | 0.704 | –0.016 | –0.147 |
| I am afraid that if I were tested for HIV, my name would go into public record | 0.102 | 0.374 | 0.537 | 0.265 | 0.232 |
| I would not want anyone to know if I got an HIV test. | 0.221 | –0.058 | –0.088 | 0.784 | 0.036 |
| It would be embarrassing to get tested for HIV | 0.082 | 0.384 | 0.34 | 0.566 | –0.051 |
| HIV-antibody testing is not really confidential | 0.088 | 0.027 | 0.044 | 0.009 | 0.948 |

increasing the uptake as shown in **Table 4**.

Factor four (eigenvalue = 1.85) accounted for a 7.56% variance in the responses and mainly comprised items concerned with confidentiality and privacy. The items that loaded more with this factor are: 'I trust the HIV test counselors and nurses to keep my information confidential'. 'HIV test information is kept very confidential by the medical staff who do the testing'. 'Testing and counselling is a pleasant experience'. Clients would be motivated to utilize HCT if their privacy and confidentiality is assured by health staff and family members (**Table 4**).

The fifth factor (eigenvalue = 1.21) accounted for 7.13% of the variance in the response and is mainly concerned about the apprehension/fear and stigma associated with an HCT and a possible positive result. The items that loaded strongly with the factor are: 'I consider going for HIV counselling and testing extremely frightening' and 'I would like to be alone when doing the test' (**Table 5**). Demystifying the fear factor could be a great motivator for the uptake of HCT among nursing students and the general population at large.

### 3.8 Barriers to HIV counseling and testing

Similarly, the barrier items in the HIV testing Antibody scale were also applicable for factor analysis (KMO = 0.810) and five factors with an Eigenvalue more than 1 were identified using the Scree test. The factors accounted for a total of 59.21% of the variance in scores. The identified factors and their loadings are tabulated in **Table 5**.

The first barrier factor associated with HCT utilization had an Eigenvalue of 3.96 and accounted for 26.43% of the variance in the participants' responses. A total of five items aligned with this factor. The items contained in this factor are mostly about personal concerns and about peers/friends, partners' reactions to HIV counseling and testing. Five items loaded with this factor and item: 'I would not get tested for HIV because I would be asked information that was too personal' scored highly followed by the item "I do not have time to get an HIV test". Lack of support or negative stereotype from peers or friends can adversely deter individuals from HCT services as shown in **Table 5.** The second barrier factor with an eigenvalue of 1.58 and total response variance of 10.53% and a total of four items loaded strongly with this factor. The factor is mainly concerned with the value or perception attached to HCT by clients. Items such as: 'Anyone who is tested for HIV is dirty" and "admitting that you should be tested for HIV means that you have engaged in immoral behavior" scored highest followed by the item; 'HIV testing is unnecessary for me, as I feel healthy' as indicated in **Table 5**.

The third barrier factor (eigenvalue 1.28) had an overall response variance of 8.51% in which three items loaded strongly with the factor. The three items that aligned with this factor are mostly concerned about the concerns of people with regard to HCT. Items such as 'people assume that everyone who is tested for HIV is infected with HIV', 'people would assume I have HIV if I decided to get tested' and 'I am afraid that if I were tested for HIV, my name would go into public record'. The fourth barrier factor (eigenvalue = 1.06) had an overall response variance of 7.06% in which only two items loaded strongly. The two items that aligned with this factor are concerned "*privacy & stigma associated with HCT and attitude of staff".* The two items are: *"*I would not want anyone to know if I got an HIV test" and "It would be embarrassing to get tested for HIV".

The fifth barrier factor (eigenvalue = 1.002) had an overall response variance of 6.68% and only one item loaded strongly with the factor which is *concerned about confidentiality* (*HIV-antibody testing is not really confidential).*

## 4. Discussion

Our findings revealed that a majority (58.4%) of the students had been tested for HIV before. This figure is much higher than the 8% for males and the 14% for females reported nationally for reproductive-aged adults (ages 15-49) in the 2018 Multiple Indicator Cluster Survey (MICS) in The Gambia. Also, the proportion of those who tested was higher

than the 3% for males and the 9% for women reported for young adults (15-24 years) in the same national survey. The finding followed a similar trend among studies conducted in Ghana and also in Zambia [18,19] among nursing students. It also appears that even among would-be nursing professionals HCT uptake was not at hundred percent which signifies that there are some factors that hinder HCT uptake as observed in a study among university students in Nigeria. In that particular study results showed only about half (50.7%) of the participants had HCT [20].

The finding also showed that the majority of the students were aware of the importance of HCT in the prevention of HIV/AIDS and yet still the proportion of those who tested was not impressive. It was therefore evident that the student's knowledge of when and where to test for HIV did not again translate to the expected behaviour of seeking HCT services. This disparity has been reported in other studies [11] and also a study conducted in Zambia further showed that despite the majority of students who demonstrated a willingness to undergo HCT, few actually had the test unless there is an underlying illness [21]. All the nursing schools from where the participants are drawn have very close proximity to health facilities that offer HIV counseling and testing services yet still there was no hundred percent HCT utilization. The explanation for this scenario could be a result of self-perception of not being susceptible to the disease or that feeling of absolute well-being which is common among young adults.

The result showed that age, gender, marital status, religion, academic year, school of attendance and residence (LGA) were significantly associated with HIV uptake. Our observations seemed to show that HCT utilization increases with increasing years among students. This was clearly demonstrated in the results where participants between 25-30 years and 31 years and above were more likely to have HIV tests compared to participants between 19-24 years of students. However, these findings contradict other studies from sub-Saharan Africa that found younger adults more willing than older people to be tested for HIV [22,23]. The reason for the correlation between increasing age and HCT utilization could be due to the fact that as respondents grow in age, they engage into conjugal relationships that may predispose them or their partners to certain conditions that may increase their perceived susceptibility and vulnerability to HIV.

Our finding showed more male students testing for HIV compared to females. These results were the opposite or not in alignment with the national trend that males are less likely than females to have been tested for HIV in the Gambia and in other studies from across sub-Saharan Africa [24]. Also, this finding is non-congruent with findings from other studies done in Ghana and Kenya [25]. The utilization of HCT services among females as realized in most sentinel surveys or demographic health surveys could be due to the ongoing prevention of mother-to-child transmission program during antenatal services in The Gambia which requires every pregnant female who reports to the health facilities to undergo HIV testing as a protocol of the policy. Furthermore, gender inequity poses a great challenge to HCT uptake especially in sub-Sahara nations (Ghana, Gambia, Nigeria, Uganda, etc.) where the sole authority or power and responsibility of healthcare-seeking behaviours depend on men [26]. In the Gambia men may refuse HCT service as a show of strength or dominance or self-confidence which is very typical in many African homes. If the wife suggests HCT, this may be seen as undermining the role of the man as a decision-maker.

Furthermore, student nurses in the third year of study and midwifery class were two times more likely to utilize HCT services compared to those in academic years 1 and 2. These findings suggest that the higher the educational level of the student, the more likely that they will utilize HTC services. This finding was similar to a study done in Addis Ababa which predicts that the educational year is positively correlated with HCT uptake [27]. This finding could be interpreted as the more time students spent on the educational ladder the more likely they will utilize HCT services. In addition, our study showed that marital status was significantly associated with HTC

uptake. Our finding also showed that divorcees were equally more likely to undergo HIV counselling and testing than students who are single. This finding corroborated with other studies [28] across Africa among student nurses. In many parts of sub-Saharan Africa, the fear of divorce or broken marital relationships which may result in potential abandonment or even violence can serve as a potential deterrent to the uptake of HTC services [29]. Our findings are also aligned with findings from a Jamaican study which revealed that married persons were more likely to report previous HIV testing [30] than unmarried persons. The high figures among married and divorcees may be partially due to the parent-to-mother-child transmission program which offers routine HCT services to all pregnant mothers and partners. Yet still it could be related to the fact that young unmarried persons see themselves as less susceptible to HIV.

On HCT, the findings revealed that students who are aware were more likely to utilize HCT services compared to those who are not. This finding was similar to studies done in Nigeria and Uganda among youths [31,32]. This finding further emphasized the need to strengthen awareness campaigns about HCT services rather than concentrate solely on facts about HIV/AIDS. With regards to the preferred person for HCT, most of the participants preferred trained counselors to doctors and nurses. This finding was different from other similar studies in Ethiopia [33]. Our study also showed a majority of participants were willing to go for HCT in the future. This finding was similar to a study conducted in Mersa Town of Harbu district, Ethiopia [34]. This high proportion of students willing to undergo HCT was not parallel with the actual use of HCT services.

On attitude towards HCT, our findings showed a little over half of the student nurses and midwives had a positive attitude toward HCT uptake. The proportion of students with positive towards HCT was far lower compared to a study conducted in North West Ethiopia which revealed 73.3% of a student had a positive attitude toward HCT uptake [34]. This disparity between the current study and other studies with a high proportion of positive attitudes toward HCT could be a result of numerous factors. The explanation for the unimpressive proportion in this current study could be related to inadequate knowledge of HCT as demonstrated in our study. Our study also revealed that students with stigmatizing attitudes were less likely to utilize HCT than those who had a positive attitude toward HCT [35]. This is because stigma is seen as a barrier to HCT uptake which makes people less enthusiastic to seek HCT. The finding aligns with the finding from a study done in Mersa Town, Ethiopia among adults which indicated that persons with stigmatizing attitudes were less likely to utilize HCT services compared to those with positive attitudes [34]. Similarly, a study in South Africa also reported consistent findings [12].

On the socio-demographic variables associated with attitude towards HCT uptake, previous residence and marital status were significantly associated with attitude towards HCT. The finding showed that students who reside in rural areas showed more stigmatizing attitudes towards HCT compared to those from urban areas. Also, the result showed that married students showed a more positive attitude towards HCT compared to students who are single or in a relationship. This finding was similar to a study conducted among students at Addis Ababa University [36]. The plausible explanation for this observation could be related to the fact that students from rural areas lack good information about HCT due to adequate access to news outlets/media. Also, married students are mature and may have undergone HCT before.

Aside from the socio-demographic factors explored in this present study, we also sought to determine other influencing factors associated with HIV uptake. Results from factor analysis showed that HCT uptake was associated with five main barriers. These barriers are ranked as follows: Concerns about negative stereotyping from friends, concerns of people, personal concerns about HCT, privacy & attitude of health staff and lack of confidentiality and support. These findings were similar to a study conducted in Kenya by Rose Mwangi et al. [14]. In this study the most important barrier associated with HIV up-

take was personal concerns and concerns of friends which are strongly associated with stigma and discrimination. Therefore, stigma and discrimination are major barriers to HCT uptake among students. Therefore, when students have in mind that they will be stigmatized and discriminated against for having an HIV test, there is a strong likelihood that they will stay away from undertaking HIV services. The second barrier is related to a lack of adequate knowledge of the benefits of HCT. Hence participants see HCT as valueless and not worth undertaking, thus, it is crucial that youths are well educated on the importance and value of HCT so as to increase uptake. This was evident among those participants who did not undertake HCT in our current study who mentioned that self and partner mistrust was the main reason for not undertaking the HIV test. The third barrier observed in this study was peoples' concerns in which the major concern expressed was the risk of their status being exposed to sexual partners or other people within the community. These types of concerns are common throughout Africa [37,38]. Many studies showed that adults willing to be tested usually prefer to be counseled and tested by someone who does not know them hoping that their results will not be exposed [39]. Similarly, fear of rejection from partners or family members or friends is related to this particular barrier and very common in many settings in Africa including the Gambia. It is therefore imperative that testing is done in very secure health institutions where services are sought. The fourth factor or barrier is privacy and the attitude of staff at health facilities which can hinder the uptake of HCT. The barrier is also reported in a study conducted in Ghana among nurses [40]. Health staff is supposed to show a positive attitude towards clients and equally motivate and encourage them to seek for services to enhance good health. Negative attitudes towards patients/clients could hinder the uptake of services. Similarly, maintaining privacy during service delivery is paramount and can encourage more clients to seek services. Therefore, lack of privacy and negative attitude of staff can seriously hinder the uptake of HCT services across the different cohorts of the population especially the youths. Lack of confidentiality is another barrier reported in this current study. This barrier was also mentioned in a study conducted in Ghana among student nurses [40]. Lack of confidentiality can adversely decrease the uptake of HCT among trainee nurses and midwives. Clients generally feel insecure or worried that their private information may be shared with loved ones or exposed to the general public. This is very common especially in an African country where secure data storage is still a challenge. This is also coupled with the fact that those offering the service may be known to you or your family members or friends hence the fear that the vital information may be shared with them.

On the facilitators associated with HIV counseling and testing, our study revealed that support from friends/partners or family members can greatly increase the confidence of persons opting to undergo HIV counseling and testing. This was one of the main facilitators expressed by the students and it is paramount that more health education campaigns focus on the youths to change their misconceptions about HCT so as to offer more support or motivation to those willing to undergo HCT. In many studies, individuals fear undergoing HCT because of a lack of support from partners or friends who may taunt or stigmatize their actions [41]. Health care-seeking behaviour is strengthened or influenced by close partners especially in the African context especially among students in particular. Students tend to follow the footstep of their friends or family members in health-related activities, hence their support or encouragement is paramount. The second facilitator that can motivate people to undergo HCT was having that positive feeling of being susceptible to HIV infection. Based on the Health Belief Model, people tend to change their behavior if they felt susceptible to disease. Therefore people must be knowledgeable about the modes of HIV transmission and be able to assess their actions and take the appropriate measures to change positively. Many studies revealed that people who feel less susceptible do not undergo HIV testing [42]. Therefore, it is crucial that we discourage individuals from that false belief of low suscepti-

bility or the belief that 'they are healthy' and do not need an HIV test. The best way to assess your behavior in terms of HIV infection is to go for HCT therein you will be assisted by a trained counselor to assess your actions. As young adults who are active and with strong immune systems coupled with little or good knowledge of HIV/AIDS, students would tend to believe that they do not exhibit the signs of HIV hence there is no need for testing. Many may regard testing as a waste of time bearing in mind that there is no cure for a positive test. Our study also revealed that HCT uptake can increase if personal and other people's concerns are addressed. The finding showed that when an individual values the importance of HCT, there is a likelihood that they will undergo HIV testing. The finding is supported by the health belief model which states that if individuals appreciate the benefits of a particular behaviour they tend to adopt interventions recommended to bring about the change. Therefore, individual concerns with regard to HCT in a positive manner can promote or influence HCT uptake among student nurses and midwives. Many of the students are far away from the family home and are considered mature enough to make their own decision hence family influence may not play a major role. This finding was also supported by results from a study conducted among university students in four African countries which showed that going for HCT was related to: general concerns, trust and support, and fears. Additionally, in the same study, 'Friends concerns' were also associated with the intention to go for an HIV test [43].

The fourth facilitator which is related to assured confidentiality, support and privacy is paramount in the utilization of HCT services among young people like student nurses. This finding is aligned with the results of a study conducted in Ghana which acknowledged the importance of privacy and confidentiality in HCT uptake [40]. In this same study, results showed that many clients and potential users of services were uncomfortable with the quality of care given by some health workers, especially as they overtly and covertly breached confidentiality about their client's health status. This has compelled many patients and potential users of the services to adopt a modus vivendi that provides them access to some care services while protecting their identity. Therefore maintaining confidentiality is key to increase in the uptake of HCT among student nurses and other cohorts.

The fifth facilitator related to HCT counseling and testing was about privacy and fear of knowing their HIV status. Lack of privacy and fear of knowing one's HIV status can be deterrents to HIV counseling and testing among nursing students and others alike. Therefore, adequate privacy should be accorded to clients during service delivery. The mere presence of a person at the HIV counselling centre or clinic is enough for the person to be labelled as or suspected to be HIV patient. It demonstrates that stigmatization may occur not only in the community but also overtly or covertly, in the health facility itself.

### 4.1 Practical implications of the study

The findings of this study have some practical implications and therefore imperative that government/stakeholders consider nursing students and midwives as major players/stakeholders in the fight against HIV/AIDS. Nurses are key service providers who have regular and prolonged contact with individuals affected and infected with HIV/AIDS compared to other healthcare workers. Thus, the role or relevance of this sector of the health force cannot be left out in any effective HIV/AIDS programs. Therefore, nursing students should be regarded as key partners in the fight against HIV and AIDS and when developing an effective education strategy. Our current study showed that those who utilized HCT services showed better knowledge and positive attitude toward HCT than those that did not. It is therefore recommended that all key players in the fight against HIV/AIDS should be encouraged to regularly undergo HCT. This will definitely make them confident to give advice to others to seek HCT services. The unimpressive level of HCT uptake and moderate attitude towards HCT is a call for concern. Therefore, there is a great need to embark on extensive HIV/AIDS educational programs so that nurses

can be agents of change. Despite the limitations, the study provides useful information on education and strategic planning for future HIV programs. The study also provides insight into the prevalence of HIV counseling and testing uptake among nursing students and midwives which is crucial for future strategic planning.

### 4.2 Limitations of this study

The present study has some shortcomings that should be noted when interpreting the results such as the close-ended responses of the self-administered questionnaire did not give an opportunity for respondents to express their opinions about other influencing factors associated with HCT. Also information provided by the respondents may be biased due to misunderstanding of questions or as a result of dishonest answering.

## 5. Conclusions

The uptake of HCT services among student nurses and midwives in The Gambia is associated with a number of socio-demographic factors such as age, sex, the academic year of study, wealth index and marital status (in **Table A1**). Our findings further demonstrated that there are multifactorial barriers and facilitators that can adversely hinder the uptake of HCT services among nursing students and midwives. Negative stereotypes from friends or partners, personal concerns and concerns about other people, privacy, perceived susceptibility, stigma and discrimination, and confidentiality are key barriers to HCT uptake. Despite the majority of the students undergoing HCT, the utilization rate was not impressive as expected from would-be nurses. Similarly, knowledge of HCT was not significantly high as expected. However, students showed a positive attitude toward HCT.

Based on the findings of the study, we recommend that health education programs specific to the benefits of HCT and other relevant topics that are being undertaken by different stakeholders in the fight against HIV/AIDS through drama and entertainment should be strengthened. Also, HIV/AIDS educational programs should be incorporated into school curricula so as to increase knowledge of HCT among students and clear misconceptions regarding HIV/AIDS and HCT. Furthermore, HCT services should be provided in nursing schools to improve access and thus limit the stigma and discrimination that may prevail in some health institutions.

## Conflict of Interest

There is no conflict of interest.

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# Appendix

**Table A1.** Socio-demographic factors associated with attitude towards HCT (n = 305).

| Variable | N | Mean(SD) | Statistic value | *p* |
|---|---|---|---|---|
| **Age** | | | 0.411** | 0.663 |
| 19-24 years | 177 | 113.61(±11.54) | | |
| 25-30 years | 88 | 113.86(±13.653) | | |
| 31-50 years | 40 | 115.55(±12.098) | | |
| **Gender** | | | -0.33^ | 0.742 |
| Female | 186 | 113.75(±11.728) | | |
| Male | 119 | 114.23(±13.028) | | |
| **Family type** | | | 1.104^ | 0.271 |
| Nuclear Family | 157 | 114.69(±13.153) | | |
| Extended Family | 148 | 113.14(±11.162) | | |
| **Residence** | | | 0.885^ | 0.028* |
| Urban | 174 | 115.27(±12.034) | | |
| Rural | 131 | 112.17(±12.315) | | |
| **Ethnicity** | | | 1.111** | 0.355 |
| Mandinka | 125 | 113.24(±12.498) | | |
| Fula | 68 | 114.49(±11.475) | | |
| Wollof | 30 | 111.8(±14.414) | | |
| Jola | 36 | 118.19(±12.259) | | |
| Manjago | 14 | 116.5(±12.126) | | |
| Sarahuli | 7 | 107.29(±12.619) | | |
| Serere | 13 | 113.69(±7.398) | | |
| Aku | 7 | 111.71(±10.657) | | |
| Foreigner | 5 | 112(±10.954) | | |
| **Marital Status** | | | 3.543** | 0.015* |
| Married | 88 | 114.86(±12.381) | | |
| Single | 199 | 114.17(±11.842) | | |

Table A1 continued

| Variable | N | Mean(SD) | Statistic value | *p* |
|---|---|---|---|---|
| In a relationship | 13 | 103.38(±13.314) | | |
| Divorced | 5 | 115.8(±13.312) | | |
| **Year of Study** | | | 0.307** | 0.820 |
| 3rd Year Class | 42 | 113.88(±15.658) | | |
| 2nd Year Class | 110 | 113.09(±11.909) | | |
| 1st Year Class | 88 | 114.58(±8.907) | | |
| Midwifery Class | 65 | 114.54(±14.217) | | |
| **School** | | | 0.790** | 0.455 |
| RN School | 133 | 112.94(±12.82) | | |
| CHN School | 97 | 114.62(±10.919) | | |
| SEN School | 75 | 114.83(±12.793) | | |
| **Parent alive** | | | 0.355** | 0.786 |
| One alive | 108 | 114.51(±12.344) | | |
| Yes | 154 | 113.36(±12.558) | | |
| Both alive | 20 | 115.8(±9.266) | | |
| Divorced | 23 | 113.48(±12.176) | | |
| **Education father** | | | 1.380** | 0.249 |
| Tertiary | 97 | 113.3(±13.718) | | |
| None | 145 | 113.73(±11.689) | | |
| Primary | 30 | 112.63(±9.357) | | |
| Secondary | 33 | 117.91(±11.977) | | |
| **Education Mother** | | | 0.502** | 0.681 |
| Tertiary | 37 | 112.59(±15.179) | | |
| None | 176 | 113.78(±12.19) | | |
| Primary | 49 | 113.86(±11.079) | | |
| Secondary | 43 | 115.84(±10.987) | | |
| **Wealth index** | | | 1.225** | 0.300 |
| Middle | 148 | 113.35(±11.795) | | |
| Lowest | 67 | 112.19(±12.828) | | |
| Second | 77 | 116.23(±11.343) | | |
| Fourth | 7 | 115(±12.138) | | |
| Highest | 6 | 117.17(±23.6) | | |
| **LGA** | | | 0.431** | 0.882 |
| Brikama | 107 | 113.81(±12.709 | | |
| Kanifing | 91 | 114.43(±11.611 | | |
| Kerewan | 15 | 113.67(±14.171 | | |
| Basse | 22 | 110.05(±15.126 | | |
| Janjanbureh | 22 | 115.82(±12.006 | | |
| Banjul | 18 | 115.06(±7.008 | | |
| Mansakonko | 24 | 113.79(±13.012 | | |
| Kuntaur | 6 | 114(±8.944 | | |

^ = independent samples t-test, ** = one-way ANOVA, SD = standard deviation *statistical significance p-value < 0.05

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**CASE STUDY**

# Evaluating the Impact of Workshop Management on the Progress of Road Construction Projects (Case Study: Road Construction Projects of Tehran Province)

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## ABSTRACT

Construction projects, including road construction, are very important. Therefore, a lot of money is spent on these projects every year. So, the lack of proper planning will increase the cost and cause irreparable damage to the country. The role of workshop management is one of the most important factors in increasing the cost of these types of projects. Generally, workshop management plays a very important role in improving the quality and quantity of projects and has an important place in the project implementation process. Therefore, this study evaluated the impact of workshop management on the progress of road construction projects on a case-by-case basis in road construction projects in Tehran province. According to the purpose of the research, this study was a descriptive-survey type. In addition, the tool used in this research was a questionnaire. The statistical population of this research included all experts and specialists in road construction projects, among whom 65 people were selected by snowball method. Then the collected data were analyzed using SPSS software. The results of this study showed that the management of the workshop and its role in the control and implementation of projects is a complex process, which can be implemented at high levels and effectively by combining scientific and experimental training. And a very important point in the discussion of workshop management is applying scientific management to the use of valuable experiences from others. Because management knowledge not only does not negate the use of these experiences, but also emphasizes the necessity of using them. In other words, improving the knowledge of workshop management is one of the requirements for the implementation of value engineering in construction projects, especially road construction, and it is very important.

***Keywords:*** Construction projects; Workshop management; Snowball; Road construction

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# 1. Introduction

Generally, no society without an advanced and planned management system will not be able to witness progress in various fields and will not be able to compete with other societies. On the other hand, construction projects are one of the most important economic sectors in the countries of the world, and the success of these projects largely depends on the definition and implementation of the project management system and its effectiveness. And the characteristic of the economic development of every country is construction projects, especially road-building and bridge-building, which are considered as a major criterion and index in the economic prosperity of that country [1]. Therefore, the progress and prosperity of a nation depend on the success of its country's construction projects, and success in the implementation of construction projects requires mechanisms and factors to end the cycle of affairs in a favorable way with the least cost and the most profit. Therefore, the ultimate goal of implementing any project is to create beneficial change and transformation [2]. In general, the amount of investment that has been made in the construction of large construction projects such as road and bridge construction is very large and significant [3]. Therefore, regardless of scientific issues and correct planning, the return of these funds is insignificant due to defects, excessive time wasting, loss of project efficiency in a period much shorter than the useful life, and causes loss of public property [4]. Different models have been presented to define the elements of a project. The commonality between all of them is the formation of a project organization that deals with managing the important limitations of the project including time, quality and cost. Therefore, in each project, according to the type of work, the volume of work, the extent of work, and the power of permanent forces, a suitable organization should be predicted to carry out the work [5]. On the other hand, the lack of proper management without a plan and the lack of continuity of proper management will prolong the duration of the operation and, as a result, increase the costs. The results and statistics from the studies conducted in American road construction operations also show that at least 45% of the total duration of the operation is lost due to various factors and if the management is not done properly, the figure of wastage will reach 80%. In other words, in correct management, the amount of useful work is 55% and in incorrect management, the amount of useful work is 20% of the total work, and these statistics also show the importance of correct management [6]. Therefore, according to the statistics and studies, the lack of proper management without a plan and the lack of continuity of proper management causes the duration of the operation to increase and as a result the costs increase. On the other hand, the ultimate goal of implementing a project is to create useful and beneficial changes and transformations, and various models have been presented to define the elements of a project. The common denominator of all of them, with minor differences, is the formation of a project organization that manages the important limitations of the project, including time, quality, and cost [7,8]. In order to carry out project activities, project resources such as machines, manpower, materials and a sufficient budget are needed.

Generally, civil infrastructures are undeniable in order to realize the economic and social development plans of the country, and the continuation and growth of constructions and the economic and social development of the country requires the creation and development of infrastructure facilities, including roads and bridges [6]. On the other hand, roads and bridges are one of the main criteria for the development of any country [9,10]. Today, in IRAN, many construction projects, including road construction, are being implemented, the credit of these projects is billions of Rials, and many human resources are working on these projects [11]. Road construction projects are among the country's infrastructure projects, which usually require spending heavy budgets and a long period of time [12]. In many road and bridge construction projects, the lack of proper planning in the implementation of the projects causes additional costs. These costs are due to the idleness of part of the machines during the project implementation period and the waste of useful time of human labor. This

causes the prices to increase due to the lengthening of the project implementation period and ultimately the increase without the logic of investments [1,13]. Therefore, proper and efficient planning and management in road and bridge construction projects is very necessary so that they can be put into operation in the estimated time, expected cost and appropriate quality [10,13]. But unfortunately, the lack of proper planning in the implementation of these projects causes additional costs in many of these projects. These costs are due to the idleness of part of the machines during the project implementation period and the waste of useful time of human labor. This causes the prices to increase due to the lengthening of the project implementation period and ultimately the increase without the logic of investments [2].

Basically, road construction projects are implemented with a delay in the schedule, and finally, with the delay in the start of operation of the road construction projects, in Iran, Sometimes the economic justification of the projects is lost [12]. So that in the last decade, some freeways have been invested by banks, but due to the significant increase in the implementation time and the delay in exploitation, irreparable losses have been inflicted on the investor. Currently, banks are no longer willing to invest in road construction projects. Therefore, it is necessary to find the root of these problems [2]. In examining the causes of delays in construction projects such as road and bridge construction, most of the mentioned cases are related to credit problems. In the second stage, it is caused by the weakness of the executive bodies in performing the tasks of the site, and in the third place, these delays are attributed to the weakness of the contractor [5].

Therefore, according to the mentioned contents, the success of a project depends to a great extent on the definition and implementation of its management and its effectiveness [13,14]. Management is a combination of science, experience, talent and art, and by combining these elements, it is possible to guide the desired collections in the best way in order to achieve the set goals. Many studies have shown that management is responsible for most delays and inefficiencies in the workplace [8]. Workshop management and equipment is an activity that is performed before the start of any project and has a very important role in the cost, safety and quality of the project [13,14]. Meanwhile, the role of workshop management is very important in order to achieve the goals of the project, and workshop management plays a very important role in the amount of cost, safety and quality of the project. The role of workshop management in order to create a logical interaction with the important limitations of the project and their components. improving the quality and quantity of the project is very unique in order to achieve the predetermined goals of the project [15]. On the other hand, the role of workshop management in shaping the project organization as well as the strategic orientation of the project management processes is very clear and decisive, and the weakness of workshop management will ultimately cause the failure of the project [16,17]. Therefore, considering the very high importance of the role of workshop management in the control and implementation of road and bridge construction projects in order to improve project quality and reduce costs and considering that no study has been done in Iran in this field. So, in this research, for the first time, the role of workshop management in the control and implementation of road construction projects located in Tehran province will be evaluated.

## 2. Materials and method

### 2.1 Case study

Road construction projects of Tehran province are a case study of this research. Tehran city is the center of Tehran province and the capital of Iran. This city is between the cities of Tehran, Ray and Shemiran. It is connected to the Alborz mountain range from the north and the desert from the south. The height of Tehran city starts from about 900 meters above sea level in the south and reaches about 1800 meters in the north. Geographically, in 51 degrees and 17 minutes to 51 degrees and 33 minutes of east longitude and 35 degrees and 36 minutes to 35 degrees and 44 minutes north latitude. The area of Tehran is an

area with approximate area of 615 square kilometers with 22 municipal districts and it has been done to meet the needs of urban services of the resident and working population (daily population), based on a population equivalent to 9.1 million people. Housing capacity, based on about 20 percent excess of the above population forecast and in order to develop construction and prevent housing market stagnation, for about 10.5 million people have been prepared up to the horizon of the plan. (Tehran Comprehensive Plan, 2016). According to the comprehensive plan document of the spatial organization of the city of Tehran, the "grid structure of the city of Tehran" is coordinated with the natural and historical structures and movement, performance and activity systems, consisting of five north-south axes and three east-west axes, which facilitates the possibility of movement. And better movement at the city level and reduction of travel demand, organizing large-scale elements with urban and extra-urban functions of Tehran provides. Also, the first comprehensive plan of this city was prepared in 1970 and until today this plan has been prepared only once for Tehran which corresponds to December 2016 with a horizon of 20 years, the spatial organization of Tehran is shown in the map below.

**Figure 1.** Tehran province map.

## 2.2 Scope of research

The subject area of this research is the impact of workshop management in the implementation of road construction projects. The spatial territory of Tehran province and the temporal territory is 1401.

## 2.3 Population and statistical sample

Since the criteria presented in this research include a wide range of variables in the field of examining the role of workshop management in the implementation and control of the project. Therefore, the selected statistical population includes employers, consulting engineers and contractors in the field of road and transportation in Tehran province who have expertise, skills and work related to the research flow. In the selection of the statistical population, samples were asked who mostly have a history related to the implementation of various types of roads in Tehran province. Then, 65 people were selected as a statistical sample using the snowball method.

## 2.4 Type of research method

Considering that the purpose of this research is to collect information from road construction workshops in Tehran province, the survey method is used. Therefore, the current research method is descriptive-survey type.

## 2.5 Method of collecting information

Considering the survey-analytical research in the completion of this thesis, in order to provide the information needed to complete the research, survey methods and statistical methods have been used. And in order to collect research data, various methods such as the use of available information and documents, interviews with experts and experts, as well as face-to-face and electronic questionnaires have been used. For this purpose, at first, the data and information were collected using the library method, and then the selection criteria were evaluated based on interviews with specialized and experienced people in this field and finally, to check the importance and weights of each of the criteria, a survey is done through a questionnaire. Therefore, in general, the method of conducting this research is to collect data and information in the field and in the library. In

the library method, in addition to studying available sources and books as well as authentic articles, an effort was made to collect and categorize the required information related to the role of workshop management in controlling road construction projects. A questionnaire tool was used in the field method. The questionnaire is considered as one of the most common tools of data collection in survey research. In order to prepare the questions of the questionnaire, experts and experts in this field were asked for their opinions, and after considering the sum of their opinions, the final questionnaire was prepared and distributed among the sample people. It should be noted that the measurement scale of this research was a 5-point Likert scale, and Cronbach's alpha method was used for the reliability coefficient of the measurement tool and the validity of the questionnaire.

### 2.6 Information analysis method

After collecting the completed questionnaires, the information obtained from the answer sheets will be entered into the computer and then analyzed using SPSS software. In order to analyze the data, descriptive statistics such as arithmetic mean, median, standard deviation, significance level will be used first, and then it will be done in order to obtain demographic information from the statistical sample. Then correlation tests such as Pearson's correlation coefficient were used.

## 3. Results

**Table 1** shows the frequency distribution of respondents according to education, work experience, specialized work experience in works related to road construction and service location. **Table 1** shows that most of the respondents have a bachelor's degree, which is a total of 27 participants in the research (42%). Also, this graph shows that the lowest frequency is related to people with doctorate degrees, who made up 7 of the participants (11%). Also, **Table 1** shows that most of the participants in the research have 6 to 10 years of work experience, which is a total of 25 respondents (38%) and the least number have more than 16 years of work experience, which is a total of 5 of the participants in the research (8%). In addition, **Table 1** shows that most of the participants in the research have specialized work experience in works related to road construction and bridge construction 1 to 5, which made up a total of 40 respondents (62%) and the least number have specialized work experience in road construction and bridge construction for more than 16 years, which constituted only 1 of the participants in the research (1%) and **Table 1** shows that most of the participants in the research are contractors, who made up a total of 28 respondents (43%) and the number of employers (18 people) and consultants (19 people) was almost equal.

**Table 1.** The frequency distribution of respondents according to education, work experience, specialized work experience in works related to road construction and service location.

| **Education** | **Frequency** | **Percent (%)** |
|---|---|---|
| PhD | 7 | 10.76923 |
| Master | 19 | 29.23077 |
| Bachelor | 27 | 41.53846 |
| Associate | 12 | 18.46154 |
| Work experience (year) | Frequency | Percent (%) |
| 1-5 | 22 | 33.84615 |
| 6-10 | 25 | 38.46154 |
| 11-16 | 13 | 20 |
| >16 | 5 | 7.692308 |
| Specialized work experience (year) | Frequency | Percent (%) |
| 1-5 | 7 | 17.5 |
| 6-10 | 7 | 17.5 |
| 11-16 | 12 | 30 |
| >16 | 14 | 35 |
| Place of service | Frequency | Percent (%) |
| Employer | 18 | 27.69231 |
| Consultant | 19 | 29.23077 |
| Contractors | 28 | 43.07692 |

**Figure 2** shows the frequency chart, which shows the horizontal axis of the given answers (1-5) and the vertical axis shows the frequency of samples in each

answer. According to **Figure 2**, the highest frequency is related to index 5, which shows that 31 people strongly agree with this question. And after that, most response is related to index 4, which shows that 23 people agree with this question. In fact, according to **Figure 2**, 47.7% of the respondents agree very much and 7.7%, 9.2%, and 35.4% disagree, somewhat agree and agree respectively.

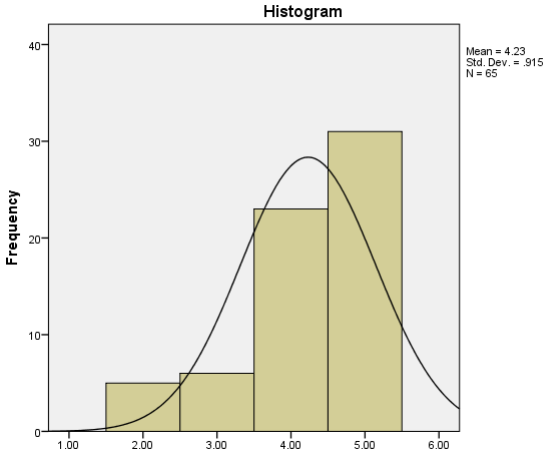


**Figure 2.** The graph of the frequency of respondents to hold periodic meetings and at different times in order to review the status of work.

**Table 2** shows the results of the One-Sample Test related to the question of holding meetings alternately and at different times in order to review the status of the work, which the statistical test is in accordance with the null hypothesis and the opposite hypothesis that is mentioned in the section. The previous ones have been said and done. The test statistic value is 37.29 and the degree of freedom is 64. Due to the large probability value (p-value) displayed in SPSS with Sig and comparing it with the probability of arbitrary first-type error α (which is considered (0.05) It can be seen that the null hypothesis was rejected with 95% confidence because the value of 0.00 is less than 0.05. As a result, according to the positive value of the Mean Difference, holding intermittent meetings at different times in order to review the status of works has been recognized as one of the effective factors in the control and implementation of road and bridge construction projects.

**Figure 3** shows the frequency chart related to the project plan update variable, which shows that the desired answers are normal. According to this figure, the highest frequency is related to index 4, which shows that 35 people agree with this question, and after that, the highest response is related to index 5, which shows that 20 people agree with this question. So, they agree with the question. In fact, according to this figure, 53.8 percent of respondents agree, and 4.6, 10.8, and 30.8 percent disagree, somewhat agree, and completely agree.

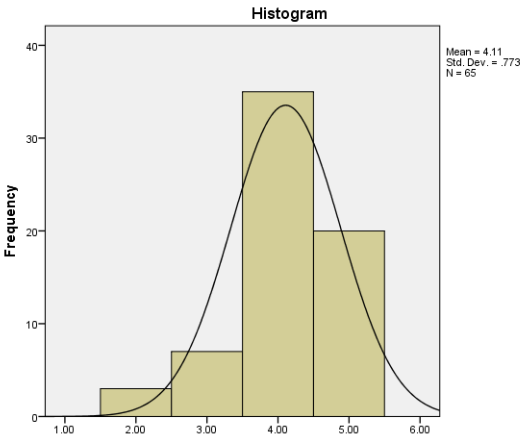


**Figure 3.** Frequency diagram related to the project plan update variable.

**Table 3** shows the results of the One-Sample Test related to the variable of updating the project plan. The test statistic value is 11.55 and the degree of

**Table 2.** The results of the average test of a single sample related to the question of holding meetings alternately and at different times in order to review the state of affairs.

| One-Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| | Test Value =3 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| meetings | 37.293 | 64 | 0.000 | 4.23077 | 4.0041 | 4.4574 |

**Table 3.** The results of the single sample mean test related to the variable of updating the project plan.

| One-Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| | Test Value = 3 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| updating | 11.552 | 64 | 0.000 | 1.10769 | 0.9161 | 1.2992 |

freedom is 64. Considering the large probability value (p-Value) and comparing it with the error probability of 0.05, we can conclude that the null hypothesis was rejected with 95% confidence, because the value of 0.00 is less than 0.05. As a result, according to the positive value of the Mean, updating the project plan has been recognized as one of the effective factors in the control and implementation of road construction projects.

**Figure 4** shows the variable frequency table of corrective measures in technical specifications. According to this figure, the highest frequency is related to index 3, which shows that 36 people agree with this question to a certain extent, and after that, the highest response is related to index 2, which shows that 15 people agree with this question. They disagree with this question. Therefore, according to **Figure 4**, 55.4% agree to some extent.

**Table 4** shows the results of the One-Sample Test related to the variable of corrective measures in technical specifications. The test statistic value is –3.76 and the degree of freedom is also 64. Considering the large probability value (p-value) and comparing it with the error probability of 0.05, it can be concluded that the null hypothesis was rejected with 95% confidence. Because the value of 0.00 is less than 0.05. As mentioned, in this case, the average value and the Mean Difference should be checked. Considering that the average score obtained by the respondents for the target index is less than 3. According to **Table 4**, the value of Mean Difference is negative, so it can be concluded that the average obtained for the variable of corrective measures in technical specifications is less than 3, and it can be concluded that the respondents disagree with this proposal or question, that is, in fact, the respondents have not recognized the variable corrective measures in technical specifications as one of the effective factors in the control and implementation of road and bridge construction projects.

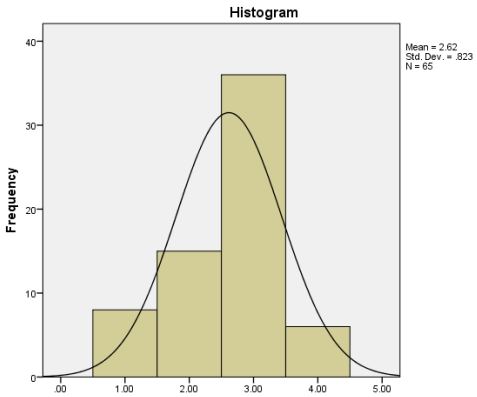


**Figure 4.** Frequency chart related to the variable of corrective actions in technical specifications.

**Figure 5** shows the variable frequency table of documentation of learning in the project by the contractor, according to this figure, the highest frequency is related to indicators 2 and 3, which are equal to each other, and shows the number of 18 people. They disagree with this variable and 18 agree with

**Table 4.** The results of the average test of a single sample related to the variable of corrective measures in technical specifications.

| One-Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| | Test Value = 3 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| measures | –3.766 | 64 | 0.000 | –0.38462 | –0.5886 | –0.1806 |

this variable to some extent.

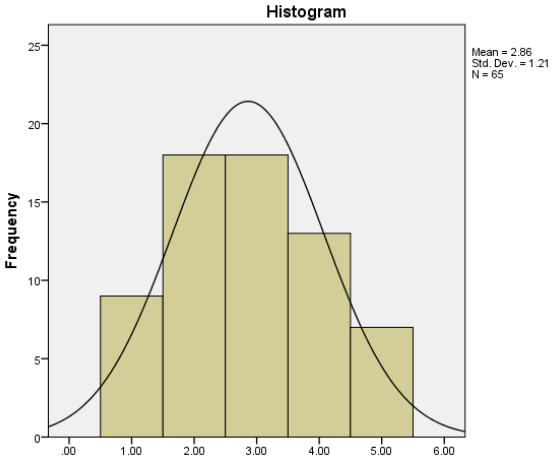


**Figure 5.** Frequency chart related to the variable of documenting the learnings in the project by the contractor.

**Table 5** shows the results of the One-Sample Test related to the variable of documenting what has been learned in the project by the contractor. According to **Table 5**, the value of the test statistic is –0.92 and the degree of freedom is also 64. Considering the large probability value (p-value) and comparing it with the error probability of 0.05, it can be concluded that the null hypothesis is confirmed with 95% certainty. Because the value of 0.36 is higher than 0.05, as a result, the respondents to the variable of documenting the lessons learned in the project by the contractor did not recognize it as one of the effective factors in the control and implementation of road and bridge construction projects. And as a result, the null hypothesis cannot be rejected.

**Figure 6** shows the frequency table of the speed of action variable in the appointment of the project manager or head. According to this figure, the highest frequency is related to index 4, which shows that 29 people, equal to 44.6%, agree with this variable.

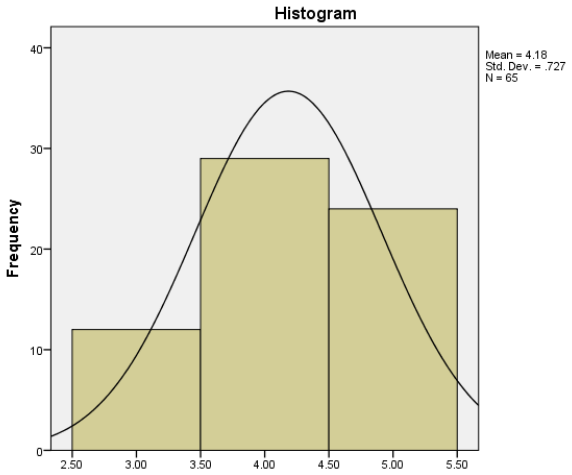


**Figure 6.** Frequency diagram related to the speed of action variable in the appointment of the project manager or head.

**Table 6** shows the results of the One-Sample Test related to the variable of the speed of action in the appointment of the project manager or head. According to **Table 6**, the test statistic value is 13.14 and the degree of freedom is 4.6. Considering the smallness of the probability value (p-Value) and comparing it with the error probability of 0.05, it can be conclud-

**Table 5.** The results of the average test of the single sample related to the variable of documenting the learnings in the project by the contractor.

| One-Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| | Test Value = 3 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| documenting | –0.922 | 64 | 0.360 | –0.13846 | –0.4384 | 0.1614 |

**Table 6.** The results of the single sample mean test related to the speed of action variable in the appointment of a project manager or president.

| One-Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| | Test Value = 3 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| appointment | 13.145 | 64 | 0.000 | 1.18462 | 1.0046 | 1.3646 |

ed that the null hypothesis is rejected with 95% certainty. Because the value of 0.00 is less than 0.05. As a result, the respondents have recognized the speed of action variable in the appointment of the project manager or chief as one of the effective factors in the control and implementation of road and bridge construction projects.

**Figure 7** shows the frequency chart related to the variable of the contractor benefiting from sufficient knowledge and experience and doing things similar to the ongoing project. According to **Figure 7**, the highest frequency is related to index 5, which shows that 26 people completely agree with this question and after that, the most response is related to index 4, which shows that 25 people agree with this question. In fact, according to **Figure 7**, 40% of the respondents completely agree and 38.5% of the respondents agree.

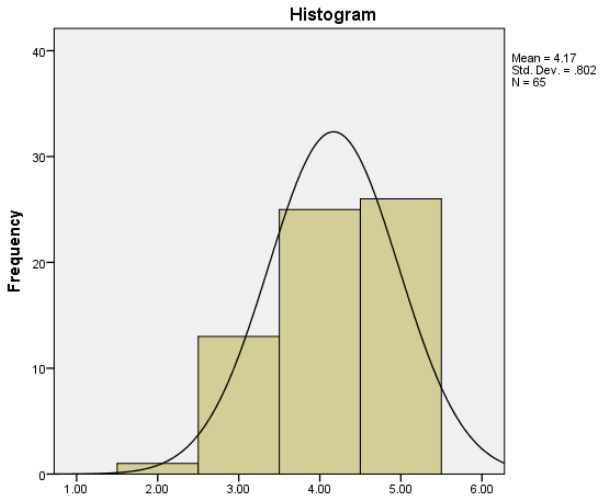


**Figure 7.** Frequency chart related to the variable of the contractor benefiting from sufficient knowledge and experience and performing similar tasks with the ongoing project.

**Table 7** shows the results of the One-Sample Test related to the variable of the contractor benefiting from sufficient knowledge and experience and doing similar things with the ongoing project. The statistical test has been performed according to the null hypothesis and the opposite hypothesis that was mentioned in the previous sections. The test statistic value is 41.92 and the degree of freedom is 64. Due to the large probability value (p-value) displayed in SPSS with Sig and comparing it with the probability of arbitrary first type error α (which is considered 0.05). It can be seen that the null hypothesis was rejected with 95% confidence, because the value of 0.00 is less than 0.05. As a result, considering the positive value of Mean Difference, the variable of the extent of benefiting the contractor from sufficient knowledge and experience and doing similar things with the ongoing project has been identified as one of the effective factors in the control and implementation of road and bridge construction projects.

## 4. Discussion

According to the purpose of the research, a descriptive-survey method was used in this research, and in order to collect the necessary information in this research, online and face-to-face questionnaires were used. Therefore, at first, using the library method of collecting data and information, then the selection criteria were evaluated based on interviews with specialized and experienced people in this field, and to check the importance and weights of each of the criteria, a survey was done through a questionnaire. In the next step, after collecting the completed questionnaires, the information from the answer sheets was entered into the computer and analyzed using SPSS software. According to the obtained results, it can be said that workshop management plays a very important role in road construction projects and improves the quality of project implementation. On

**Table 7.** The results of the average test of a single sample related to the variable of the extent of the contractor benefiting from sufficient knowledge and experience and performing similar tasks with the ongoing project.

| One-Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| | Test Value = 0 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| knowledge | 41.926 | 64 | 0.000 | 4.16923 | 3.9706 | 4.3679 |

the other hand, the lack of optimal implementation of road construction projects in terms of resources, time and cost has an effective relationship with compliance and non-compliance with management standards in the implementation of such projects. According to the results obtained from this research and the opinions of the respondents and the conducted studies, it is necessary to pay attention to some points in playing the role of management as best as possible in the control and implementation of road construction projects. One of these variables is the processes related to project procurement management. These processes include issues related to the communication and interactions of the workshop management with subcontractors and the process of dealing with the status of subcontractors on behalf of the main contractor as well as the consultant and presentation to the employer, etc. According to the opinion of the respondents, the importance of this component was more than 79%, and in general, indirect communication between the contractor and the employer is foreseen in most types of contracts, but for some reason, it is recommended to communicate directly with the employer. One of the reasons for proposing direct contact between the contractor and the client is the possibility of making changes in the technical specifications and managing the integrity of the project. Sometimes, due to problems such as the expensiveness of the implementation method, the existence of more suitable alternatives and possible mistakes in the design, etc., there is a need to change the option and the implementation method according to the change applied. In case of no response from the consultant and interaction with the employer, it will not be possible to apply the desired change. Another factor to propose interactions is the possibility of changing contract items such as project cost management and corrective measures. These factors exist in most road construction projects that are ignored in the list of costs, in which it is easier to apply new figures and volumes through the employer, and considering that this responsibility is taken from the consultant, it is easier for the consultant to accept it. Another thing that emphasizes this proposal is the possibility of improving the situation review meetings and changing the control system. In this case, the possibility of things such as the necessity of helping the contractor, compensating part of the losses, facing unforeseen cases, etc. shows the necessity of the employer's intervention. Also, the interaction between the employer and the consultant improves project communication management and communication skills. In other words, the contractor may be harassed by the placement consultant while doing the work for some reason, and effective communication with the employer can be very useful.

## 5. Conclusions

Since one of the important causes of the increase in the implementation costs of road construction projects is the correct consideration of the role of workshop management. The lack of proper planning in terms of organizational structure and planning in road and bridge construction projects increases costs and reduces efficiency, and on the other hand creates differences among different executive units. Therefore, every workshop needs the correct role of workshop management. Therefore, in this research, the role of workshop management in the control and implementation of road construction projects was investigated, and the study scope of this research is road construction projects in Tehran province. In general, according to the obtained results, workshop management and its role in controlling and implementing projects is a complex process that can be implemented at high levels and efficiently by combining scientific and experimental teachings. A very important point in the discussion of workshop management is not to neglect the application of scientific management to the use of valuable experiences from others, because these experiences are not easily obtained and management knowledge not only does not negate the use of these experiences but also emphasizes the necessity of using them. In other words, improving the knowledge of workshop management is one of the requirements for the implementation of value engineering in construction projects and especially road construction, and in the meantime, the

existence of sufficient self-confidence of the head of the workshop due to mastering the knowledge of workshop management leads to quantitative and qualitative improvement.

## Conflict of Interest

There is no conflict of interest.

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**ARTICLE**

# The Economic Analysis of Law as a Reference for the Grounds of Judicial Decisions

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## ABSTRACT

The present article aimed to analyze the application of the economic analysis of Law as a reference for the reasoning of judicial decisions. To that end, an analysis was carried out on the definitions of what is hermeneutics and economic analysis of law, based on the construction of the matrix rule of conduct for public administration. The method of the approach followed was empirical-dialectical, using bibliographic, legislative and jurisprudential research, having a reference to the Law and Economics.

***Keywords:*** Economic analysis of law; Hermeneutics; Matrix rule

## 1. Introduction

In the scope of civil law, the legal system is formed based on written texts, in order to allow different interpretations, considering that, through the use of the most varied hermeneutic techniques, the student of Law can proceed in different ways when applying the same law to the specific case.

However, despite the diversity of ways of interpreting the law, the Judge State, when judging a concrete case, must observe the principles of legality, impersonality, morality, publicity and efficiency. In this context, it is up to the Judiciary, when applying the law, to obey the aforementioned principles, so that the analysis of the legal text must use the tech-

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nique that is closest to their observance.

Faced with this reality, the following question arises: Observing the principles of legality, impersonality, morality, publicity and efficiency, can the economic analysis of Law be used as a reference for the interpretation of the Brazilian legal system, guiding the decisions of the Judiciary Power applicable to specific cases?

In this context, the validity and consequences of using the economic analysis of law [1], as a reference before the legal system, gains special importance, since it provides new directions for legal thinking, seeking to achieve ethical consequences that result in social well-being, a reflection of the direction of judicial decisions to pursue their social functions, orienting them to a context that provides the best conditions for the community, offering legal certainty, which is why it becomes the objective of this study.

To carry out this analysis, Law and Economics were used as a theoretical framework, in order to verify the validity of applying the economic analysis of law in judicial decisions.

In this way, legal hermeneutics was first approached, clarifying what it consists of and its applicability, then weaving brief considerations in relation to the economic analysis of Law, the concepts of externality, rationality and transaction costs, in order to provide an adequate cut methodology for further study.

## 2. Methodology

To carry out this research, the deductive approach method was adopted, based on bibliographic research.

In the Brazilian legal system, more specifically in the Brazilian Civil Code, there is a provision that the State Judge, when judging a concrete case, must apply the law through an interpretation of the positive norm based on the principles of legality, impersonality, morality, publicity and efficiency.

In this context, it is up to the Judiciary, when applying the law in the concrete case, to obey the aforementioned principles, so the analysis of the legal text must use the interpretation technique that is closest to the observance of these principles.

In this way, the following research problem arises: The economic analysis of the Law can reveal itself as an interpretation technique capable of guiding the Judge in the application of the Law to a concrete case, observing the principles of legality, impersonality, morality, publicity and efficiency?

In this sense, from the deductive method, the following research premises can be arrived at: a) in the application of the positive law, the Brazilian State Judge must observe the principles of legality, impersonality, morality, publicity and efficiency; b) for the application of the positive law, the State Judge must use one of the several existing techniques of interpretation of the Law; c) the economic analysis of the Law can reveal itself as a technique of interpretation of the Law that allows the Judiciary to apply the Law to the concrete case with observance of the principles of legality, impersonality, morality, publicity and efficiency.

Thus, major works were analyzed in order to, from knowledge already studied, seek to answer the problem that is the focus of the present research, in order to provide new knowledge about the researched subject.

Through the use of the theoretical framework studied from the literature related to this research, it is intended to verify the possibility of using the economic analysis of Law, as a reference for the interpretation of the Brazilian legal system, guiding the decisions of the Judiciary Power applicable to cases concrete.

In this methodological context, the concepts covered, of a founding nature, are presented in the investigation, linked to legal hermeneutics and the economic analysis of law.

The punctual analysis of such concepts only gave way when they were united to the present interpretative proposal, the vital nucleus of this study.

The teleological reasoning, therefore, progresses towards the mixture of these institutes of paramount importance to verify the validity of the application of the economic analysis of Law in judicial decisions, before the Brazilian legal system.

# 3. Related literature

## 3.1 Essay on legal hermeneutics

Since the emergence of the word, hermeneutics has been understood as the science and, respectively, the art of interpretation, taking the form of a doctrine that presents the rules of competent interpretation.

Its intention was predominantly technical and normative, providing the openly interpretive sciences with some methodological indications, in order to prevent, in the best possible way, arbitrariness in the field of interpretation of texts or signs [2]. Hans-Georg Gadamer [3] states that, through hermeneutics, when interpreting a text, understanding has a productive and not merely reproductive character, because: "The meaning of a text goes beyond its author not only occasionally, but also but ever". Thus: "One understands differently, when one understands effectively" (our own translation).

The hermeneutics consists of the understanding of re-experiencing the text construction process from the author's perspective. The author is the protagonist of a linguistic attitude according to a time, a perception that is alien, so that it can be given meaning, but never reconstituted. "The task of hermeneutics is essentially to understand the text, not the author" [4]. It is a true art, and because of that, it only builds a set of guidelines for interpreting a text that is neither fixed nor rigid.

Because it is an art, it requires a creative spirit, which is characterized by a free process, whose source is the interaction of faculties unique to each artist. Thus, his product is a unique and inimitable achievement, like all art and interpretation. The interpreter follows his own inspiration, leaving mechanical rules out of the question, so that the encounter between reader and text is an event that cannot be predicted or defined, two worlds that merge in a way that creates another world, which overcomes even the author's expectation, so that the text takes on a life of its own [5].

With regard to legal studies, it can be said that hermeneutics is an auxiliary science of law that aims to establish principles and rules aimed at making possible the interpretation and explanation not only of laws, but also of law as a system [6].

The hermeneutics "is the scientific theory of the art of interpreting", that is, "of determining the meaning and scope of the expressions of Law". It is thus a legal science that "has as its object the study and systematization of the application processes to determine the meaning and scope of the expressions of Law Direito" [7]. That is, it is the science that studies the methods and techniques of interpretation of law, seeking to systematize them in order to make the exegete's work easier and more efficient.

Thus, because the laws are formulated in general terms, which do not present specificities, hermeneutics is used to establish the relationship between the abstract text and the concrete case, in order to interpret and apply the law correctly.

Hermeneutics cannot be confused with interpretation, since the concept of hermeneutics is more comprehensive, as it concerns the systematization of applicable processes to determine the meaning and scope of legal expressions.

The identification and application of Law involve numerous argumentative and interpretative aspects of the normative context and the reality of a given society, and the interpretative aspect is essential to demonstrate how legal discourse cannot be reduced to the mere subsumption of a fact to the norm [8].

In this context, the importance of the interpretive dimension is certain, and it is pertinent to identify which of the possible interpretations allows for a better justification of decisions from the point of view of morality, which pursues an ideal acceptable to society [9].

Thus, legal interpretation must be understood within an argumentative framework [10]. It is in this context that the present study proposes the economic analysis of Law as an argumentative framework to promote the subsumption of facts to the norms, in the way that best meets the principles to which it is subject, providing the most adequate justification of decisions, with the objective of to reach the ideal solution for society.

### 3.2 Economic analysis of the law: An understanding

The economic analysis of law (AED) consists of applying theoretical contributions from the economic sciences to the law, enabling the understanding of the legal system as a structure of incentives for human behavior and the clarification of the consequences of legal and judicial commands, assuming relevance in the process itself of elaboration of these. According to Ivo Gico Júnior [11], the economic analysis of Law consists of:

> *The application of analytical and empirical instruments of economics, especially microeconomics and social welfare economics, to try to understand, explain and predict the factual implications of the legal system, as well as the logic (rationality) of the own legal system. In other words, AED is the use of the economic approach to try to understand the law in the world and the world in law (our own translation).*

In its approach, the economic analysis of Law assumes methodological individualism, consistent with the assumption that collective behaviors are a product of the set of actions of all members of the collectivity. Individual choices are therefore the "fundamental unit of analysis" [12].

Thus, through the economic analysis of Law and the need for its observance, a realistic view of legal phenomena (legal realism) will be demonstrated, moving away from a merely formal analysis [13], taking into account that, for this purpose, the relationships between individuals in society are examined from an economic perspective. The dialogue between law and economics is essential to offer the best solutions for society at any time, especially in the current one, in which these sciences are increasingly related [14]. The usefulness of the economic analysis of Law lies in finding the rationality of each and every decision, regardless of whether it is inside or outside the market, considering that all non-instinctive human activity is included in this concept and can, therefore, be economically analyzed [15].

Thus, the method that takes economics into account for the analysis and application of Law, considering the interaction between economic thought and Law, began to gain strength and was consolidated through the studies carried out by Richard Allen Posner [16] for whom Law must be interpreted and thought from the principles of Economics. Starting with pragmatic logic, the author defends a consequentialist method of interpretation of Law, transforming it into an instrument guided by the effects of legal decisions. In this context, it clarifies that judicial decisions must be guided by the standard of cost-benefit analysis, which is called wealth maximization, which represents a true behavioral ethical principle. Following his reasoning, Posner argues that the Judiciary must be predictable and stable to provide the market with security for the free flow of resources. Judicial decisions must, therefore, be free from evaluative subjectivities arising from the legal logic of principles and be guided by the guideline of efficiency in the allocation of resources.

The loss of resources/efforts represents a social cost, which is undesirable from any perspective, so the use of law in the production and application of norms must aim at achieving the best economic result with the minimum of errors or losses, which will result in obtaining better performance and achieving goals in a more productive way, making clear the need to consider the existing relationship between Law and Economics.

In this way, it can be said that the Law is an open system that influences and is influenced by the existing social institutions in the community in which it is applied. For this reason, defenders of the evolutionary theory of societies admit that the set of socially predisposed rules serves to organize intersubjective relations and, at a given moment, is consecrated as established Law. Thus, economic factors will be involved in the process of creation and application of norms [17].

Furthermore, when it comes to the application of norms by an institution, an essential point to be highlighted is the teaching of Douglas North [18], who clarifies that institutions have the vocation of inducing or restraining conduct from an evaluative

judgment. In this sense, when economics is taken as a science that is directly related to the study of human behavior, its instruments prove to be powerful for prospecting the behavior of agents in the face of the various prescriptions of the legal system [19]. It should also be noted that economic analysis is applicable to all branches of law [20].

It is from this perspective, considering externalities, rational choice and transaction costs, that it will be demonstrated how the economic analysis of Law composes the material criterion of the matrix rule of public administration conduct in the Brazilian legal system.

### *Externalities in the economic analysis of law*

The notion of externality proposed by the economic analysis of law has its origins in the work of Ronald Coase, for whom, despite having based his discussions on externalities on Arthur Cecil Pigou's discussions on divergences [21], externalities could be resolved if the people affected by them and the people who created them could easily come together and bargain, that is, externalities, positive or negative, could be resolved within a strictly private relationship, without the need for any state intervention. On the other hand, Arthur Cecil Pigou, when dealing with divergences[s] asserted that they are reflected in "imposed costs or benefits conferred on others that are not taken into account by the person taking the action" and that their existence would be "sufficient justification for government intervention", imposing taxes on those that generate a negative externality and subsidies on those that generate positive externalities [22].

Thus, Ronald Harry Coase [23] proposes to analyze the externality from the notion of opportunity cost, a comparative analysis between the revenue obtained from a given combination of factors and the possibilities of revenue that would be obtained with alternative arrangements. Thus, instead of treating factors of production as things, he proposes to consider them as rights. In this sense, the right to do something that harms others can also be seen as a factor of production, that is, the cost of exercising. This right (to use a factor of production) is always a loss for those who suffer the effects. In this way, Coase inverted the terms in which the issue was traditionally considered, giving it a dual approach. According to him:

> *The traditional approach has tended to obscure the nature of the choice that has to be made. The question is commonly thought of as one in which A inflicts harm on B and what has to be decided is: how should we restrain A? But this is wrong. We are dealing with a problem of a reciprocal nature. To avoid harm to B would inflict harm on A. The real question that has to be decided is: should A be allowed to harm B or should B be allowed to harm A? The problem is to avoid the more serious harm.*

There is then a problem of a reciprocal nature, whose solution is not as obvious as the traditional analyzes pointed out, given that, from this perspective, in order to achieve the lowest social cost, the ideal is to search for the outcome that provides the least harm, regardless of who the reason in the conflict is. Coase follows in his reasoning, exemplifying as follows:

> *The problem of straying cattle which destroys crops on neighbouring land. If it is inevitable that some cattle will stray, an increase in the supply of meat can only be obtained at the expense of a decrease in the supply of crops. The nature of the choice is clear: meat or crops. What answer should be given is, of course, not clear unless we know the value of what is obtained as well as the value of what is sacrificed to obtain it.*

The problem is not simply avoiding damage, but avoiding the greater damage. What must be evaluated is whether it is feasible, from the point of view of society, to allow or inhibit the action of "A", and the answer is not obvious, unless the values of gains and losses involved in the question are known.

This situation arises from the fact that decision-making at the time of law enforcement must take into account all the values involved in the issue under analysis, directly and indirectly, and all externalities must be considered.

### *Rational choice*

Once the concepts of externalities are addressed, to complement the understanding of the economic analysis of law and its application to the national legal system, it is necessary to understand the assumption of rationality of human conduct.

Based on the teachings of Coase [24], rationality consists of the possibility of the individual, whenever faced with a diversity of choices, to evaluate which option offers him the greatest benefit, analyzing the losses and choosing the situation that is best for him. That is, the individual, faced with various possibilities of choice in everyday life, does so according to what is best for him, always aiming at his own interests, opting for what brings him greater satisfaction [25].

Thus, through economic analysis, individual makes decisions based on their individual interests, without considering whether that decision is the best thing to be done for society. This is the thesis of natural selfishness, which:

> *Finds support in Western thought in two distinct traditions: The tradition of Leviathan (Hobbes) and that of the invisible hand (Adam Smith). The first leads to an emphasis on state and bureaucratic control of social antagonisms; the second trusts that, unchecked, private vices result in public benefits. These distinct conceptions are expressed in the analysis of public policies in the pendular oscillation between state intervention and privatization. Both disregard the collaborative vocation of human beings as the basis of collective action [26].*

Paula Forgioni [27] highlights that "the individual decisions of economic agents are marked by the selfish desire to satisfy their needs" (our own translation), which is why, in pursuit of their own interests, they choose the conduct that best meets their objectives. Adam Smith [28] exemplifies stating that "It is not from the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest".

### *Behavior induction*

Taking into account the economic analysis, the human being's choice will depend on the advantages and disadvantages related to compliance with and non-compliance with the norm, always prevailing that which presents the best benefit from the point of view of the individual who practices it. As demonstrated through rational choice, it is clear that the legal system can influence the conduct of individuals in society, since legal norms are about incentives or not incentives for human beings to act or not act in a certain way. The sanction or reward is simply a price that will be valued by the economic agent according to the cost/benefit logic of their possible behaviors.

Thus, institutions, including legal ones, form the rules of the game, which will serve as a parameter for the choices made on a day-to-day basis by economic agents. Therefore, the law exerts influence on the conduct of individuals, using instruments of sanction and reward.

Thus, through rationality, taking into account the current legal system, the individual will analyze the individual costs and benefits to make the best decision for himself. In this scenario, the relationship between Law and Economics is not merely financial, but has implications of rational choice, resulting in the effects of legislation on the behavior of individuals, so that it will take into account all externalities arising from their conduct [29].

In view of these considerations, it can be said that the Law is a powerful inducer of conduct, capable of leading individuals to reflect on their acts and their respective consequences, which, based on economic analysis, directly or indirectly, can inhibit or encourage behavior in society.

### *Transaction costs*

The analysis of transaction costs is also essential to verify the applicability of the economic analysis of Law to the legal system. Transaction costs are those related to the establishment of a commercial relationship, which does not involve the manufacture of the transacted object.

These costs can be defined, for example, as the costs of negotiating, drafting and enforcing a contract. Transaction costs are those related to the movement of the economic system, differing from produc-

tion costs, which are related to other factors such as raw material and labor [30].

Transaction costs are those related to (i) the search for interested parties in the business; (ii) expenses for negotiation and formalization of transactions; and (iii) the costs to inspect and take the appropriate measures, in the event of a breach of contract [31].

Thus, faced with the impossibility of eliminating transaction costs, individuals will always pursue their reduction, taking into account the legal system to which they are subject and the form of action of legal institutions.

In this sense, the reduction of transaction costs is related to the search for greater efficiency in the economic sphere, as previously discussed with regard to externalities. Thus, in the present study, the scenario in which there is a reduction in transaction costs will be considered efficient.

## 4. Results

Through the use of the theoretical framework studied from the literature related to this research, it is intended to verify the possibility of using the economic analysis of Law, as a reference for the interpretation of the Brazilian legal system, guiding the decisions of the Judiciary Power applicable to cases concrete.

As verified, the economic analysis of Law, both prescriptive and descriptive, allows the students of Law to evaluate the best solutions to be adopted, in view of the rationality that is inherent to the human being, who pursues his well-being within society.

In the present study, the validity of the use of the economic analysis of Law as a theoretical reference for the reasoning of judicial decisions is approached. Therefore, it uses the economic analysis of Law as a way of adequately fulfilling the material criterion of the Judiciary's conduct, which is done based on its principles.

As already discussed, the material criterion of the Judiciary's conduct is obedience to the principles of legality, impersonality, morality, publicity and efficiency. Therefore, as a verb of the material criterion, we have to obey; and as a complement, the principles of legality, impersonality, morality, publicity and efficiency. In this way, the Judiciary, when applying the laws, must obey the aforementioned principles. Obedience to the principles is what gives validity to the conduct of the Judiciary before the legal system.

However, as demonstrated, through hermeneutic techniques, there are several ways of thinking about the consequences of applying a certain law to concrete cases, so, when judicial decisions are made, the way that best provides obedience to the principles of legality, impersonality, morality, publicity and efficiency.

When faced with specific cases, magistrates can use the most varied hermeneutic techniques to apply the law, which will lead to countless possibilities. Once the possibilities have been raised in the face of the various possible interpretations, the magistrate will carry out prognostic exercises in order to consider, among the possibilities, which one will provide the best result for society, taking into account the material aspect of obedience to the principles of legality, impersonality, morality, publicity and efficiency.

The economic analysis of Law allows the magistrate, when applying the rule, to do so in the most pertinent way, taking into account all these principles. This is because, (i) it will always seek the best interpretation observing the set of the current legal system, thus obeying the principle of legality; (ii) through the study of rationality, which is inherent to the human being, as well as the externalities and transaction costs potentially caused, it will identify the best interpretation to promote the well-being of society, and not of certain classes or individuals, thus enforcing the principle of impersonality; (iii) the economic analysis of Law pursues ethical consequences within society, so that, among the various possibilities of interpretation for the application of laws, it will recommend the one that is morally more beneficial for the achievement of social well-being; (iv) its recommendations are aimed at promoting greater efficiency for society, so that, when applying the law, it will take into account which of the pos-

sible options will lead to greater efficiency, in view of the social cost/benefit to be produced, for means of analyzing potential externalities and transaction costs, also taking into account the rationality of individuals; and (v) it is always publicity, which is essential to provide an efficient dialogue between Law and Economics.

In order to better elucidate, a real case that occurred in Brazil and addressed by Luciano Benetti Timm [32] is presented:

> *In 1994, the advent of the Real Plan provided parity of the national currency in relation to the dollar. As a result, many consumers, in search of lower interest rates offered by the North American market, assumed the exchange rate risk and contracted vehicle leasing operations with readjustments linked to the price of the North American currency. In 1999, due to the government policy of the Brazilian State, the national currency (the Real) suffered a great devaluation, resulting in increases of more than 150% in the installments of these operations. This situation reached the Judiciary, before which, the Superior Court of Justice (STJ), when interpreting the law, divided the damage caused by the exchange variation between consumers and financial institutions (our own translation).*

Is this interpretation given to the law by the Brazilian court the one that best meets social aspirations in terms of applying the economic analysis of law to judicial decisions?

The economic analysis of law shows that it is not. This is because the decision was efficient only for the few consumers involved, to the detriment of society as a whole. After that decision, even though it was legally permitted, this type of leasing contract disappeared from the market, which currently prevents all other consumers, who are willing to assume the risks of exchange variation, to contract leasing operations with very low-interest rates.

In this context, the decision of the Brazilian court in the present case did not seek the greatest efficiency for society nor was it impersonal, as it was conferred in the privilege of a minority. Likewise, it was not coated with morality, completely at odds with the material criterion of the matrix rule of public administration conduct.

It is in this scenario that, through the analysis of the externalities involved, as well as the inherent rationality of individuals and the cost/benefit in relation to society, the economic analysis of Law is valid in relation to the reference system adopted in this research.

## 5. Conclusions

Legal hermeneutics is the scientific theory of the art of interpreting, in a way that determines the meaning and scope of the expressions of Law.

It is a legal science whose object is the study and systematization of applicable processes to determine the meaning and scope of legal norms.

Thus, it is a science that provides scholars with methods and techniques for interpreting Law, seeking to systematize them in order to make the exegete's work easier and more efficient.

Economic analysis, one of the methods of interpreting the law, provides theoretical contributions from the economic sciences, enabling the understanding of the legal system as a structure of incentives for human behavior and the clarification of the consequences of judicial commands, assuming, therefore, relevance in the process of enforcement of laws.

The economic analysis is applicable to all branches of law, given that, even if it falls under rules with extra-economic reasons and regulates activities with extra-economic purposes, such rules will have economic effects that can be described and analyzed.

Through the analysis of the externalities involved, as well as the rationality and cost/benefit in relation to society, the economic analysis of Law provides new directions for legal thinking, in order to identify the ethical consequences that may result in social well-being, thus directing judicial decisions to pursue their social functions, orienting them to a context that provides the best conditions for the community, offering legal certainty, through compliance with the

principles of legality, impersonality, morality, publicity and efficiency.

Thus, regarding the initial premises of this research, it is possible to conclude that, within the scope of the Brazilian State, for the application of the positive law to the concrete case placed for trial, the State Judge must observe the general principles of Law, pursuant to art. 4 of Decree-Law No. 4,657, of September 4, 1942, amended by Law No. 12,376, of December 30, 2010, including the principles of legality, impersonality, morality, publicity and efficiency.

In order to interpret the positive law and apply the Law to concrete cases placed for judgment, the State Judge must make use of one of the various interpretation techniques existing within the scope of legal hermeneutics.

The economic analysis of the Law allows, as a technique for interpreting the Law, the Judiciary to apply the Law to the concrete case in compliance with the principles of legality, impersonality, morality, publicity and efficiency, since, based on the analysis of the externalities involved, then a judge can identify the legal and ethical consequences of a particular judicial decision for society and, thus, can decide more efficiently, providing legal certainty for society and generating a consequent increase in social well-being.

The present research was limited to analyzing the economic analysis of the Law as a technique of interpretation of the Law to be used as a reference for the application of the law approved by the Judiciary Power when judging concrete cases.

This study demonstrates that the use of economic analysis of law, as a technique for interpreting the law, can contribute to the legal certainty of judicial decisions in Brazil, in order to increase social well-being based on the security generated by the efficiency and effectiveness of what decided by the Judiciary in concrete cases placed for trial.

## Conflict of Interest

There is no conflict of interest.

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