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Discrete Probability Distributions_based methodology for measuring Software Usability

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Abstract— Software usability plays an important role as one of the main factors used to measure the software quality. This research focuses on studying the usability of an open source operating system "Linux". A new methodology to measure software usability using discrete random variables is presented. It was built on set of random variables. Population size, sampling size and methods of gathering samples were taken into consideration. The proposed technique was tested on one random variable: measurement of system comfortability (C). Results showed that Linux "3.9.2" is 63% comfortable.

Index Terms— Software Quality, Software Usability, Open-Source Operating System, Linux, Discrete Probability Distribution, Statistical Sampling, Basic Software.

1 Introduction

Software Quality is one of the terms that are simple but at the same time difficult to be defined exactly. The quality of the product means how well this product performs in its use. This includes all the characteristics of this product [1],[2].

According to the growth in demand of software systems and needs for high quality and efficient that which the software quality has also increased [3]. The quality of software can be measured as any product through its attributes. This attributes of software quality are usability, reliability, portability, and maintainability [4],[5].

Software usability can be defined as the ability to use software easily and effectively [6]. Usability is defined by 5 quality components (Learnability, Satisfaction, Efficiency and Effectiveness). Every one of these components is calculated by other sub-components [7],[8].

Learnability [6] is the capability of the software product to enable the user to learn its application. It contains sub-components (Memorability, Simplicity, and Self-Descriptiveness).

Satisfaction [6] refers to the fulfillment of all requirements by product as specified by the user. It contains (Ease of use and Preference).

Efficiency [6] refers to resources consumed in order that users achieve their goals. It contains (Resource Efficiency, Computability, Operability and Scalability).

Effectiveness [6] is the measurement of achieving the user goals when using the system. It contains (Speed, Accuracy, Understandability and Consistency).

Sanjay Kumar Dubey et al. [7] proposed a method for software usability quantification using the fuzzy multiple criteria weighted average approach. This approach has been chosen due to the highly unpredictable nature of the attributes on which usability depends. They applied method on Microsoft Word 2003. They built method based on a group of 10 users only. They used questionnaires which were filled by users. And apply the fuzzification criteria for all the characteristics and sub-attributes for analysis questionnaires.

Yuhanim Hani Yahaya, Normaiza Mohamad [8], presented the design of fuzzy set conjoint model in software usability measurement. Software Usability Measurement Through Web-based Evaluation (SUTWE) was developed as an online measurement tool. It is based on a questionnaire to assist developers and users in checking the usability and satisfaction level of a website. The questionnaire is evaluated based on 5 point liker scale. Despite the fuzziness and vague statements from the questionnaire respondents may have some uncertain choices of answers other than agree or disagree. Fuzzy set conjoint model is used to overcome the problems.

Arun Sharma et al. [9], proposed a fuzzy model to determine the usability of object-oriented software system. In this model, input variables are the usability sub-characteristics (effectiveness, efficiency, satisfaction, Learnability) on which usability of software depends. The sub-characteristics have been determined through extensive survey conducted on the experts of specified domains and were normalized on 0-1 scale. They have four main linguistic variables (Effectiveness "EFFEC", Efficiency "EFFIC", Satisfaction "SATIS" and Learnability "LEARN"). All these variables are different in nature and contribution in the usability of software system. To get usability, they have used fuzzy logic and defined the linguistic values of these variables into Low, Medium and High categories.

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Jeff Sauro and Erika Kindlund [10], presented a process to increase their meaning by adapting Six Sigma methods. Also define how common usability metrics can be evaluated in terms of a standardized defective rate or quality level and explore the benefits of this data transformation. They assume that usability variables are submitted under normal distribution.

Arpan Mittal et el. [11], proposed an extended ISO-9241 usability model. They investigate the application of fuzzy AHP technique to ISO-9241 model and the proposed enhanced ISO-9241 model. They evaluated the usability of software by using Fuzzy AHP. ISO 9241 was considered as a base model, new factor Learnability was added to this model to get model.

The main problem with the previous researches is that they did not take the population size, population characteristics, and population variance into consideration. They used very small samples. These samples did not represent the population.

The main contribution of this work is measuring software usability with considering population size, sampling size and population variance. As grown to our knowledge this is the first work that takes the previously mentioned aspects into account. Also a new methodology to measure software usability using discrete probability distribution for random variables is also presented.

The next sections of the research are organized as follows: A brief overview of statistical models (sample size, sample methods and discrete probability distributions) are described in section 2, followed by a new methodology for measuring software usability an explanation in section 3. Section 4 represents tested for the proposed methodology. Finally, conclusion is given in section 6.

2 Background

In this research we apply some statistical and probabilistic approaches due to the random nature of the variables that affects the quality metrics. It is obvious without proof that usability well depends on discrete probability distribution. So in the following a review for these concepts will be given.

For applying statistics on any problem it is necessary to begin with a population or process to be studied.

Population [12] is a complete set of items that share at least one property. A well-defined population size and population characteristics helps to define samples and random variables which are used in the studies.

The sample is a set or part of the population, selected to make a statistical analysis. It must cover all population characteristics. Sample size is an important feature of any empirical study. The largest sample generally leads to increased precision when estimating unknown parameters.To achieve sample objective, it is preferred to use the following factors together to determine sample size [13].

Population size [12],[13] is the total number of items in the population. It is important only when the sample size is greater than 5% of the population.

The population proportion [12],[13] the proportion of items in the population displaying the attributes that you are seeking to achieve.

Margin of error or precision [12],[13] a measure of the possible difference between the estimated sample and the actual population value

Variability in the population [12],[13] is how much the individual data points differ from each other in the whole population.

Confidence level [[12],[13] how certain you want to be that the population figure is within the sample estimate and its associated precision. Normally use 95% confidence to provide forceful conclusions, however, if you are only seeking an indication of likely population value a lower level such as 90% is acceptable.

There are many ways used for collecting sample such as (Cluster, Convenience, Quota, Simple random, Stratified and Systematic) [14].
Fig.1 represents these methods based on two questions.
Are there sub-groups for population?
What is needs accuracy for achieving best results?
Look for references to explain these methods.

Sampling size has a very important role to achieve accurate result. Two methods can be used to determine sample size [16]. The first one based on unknown population size.

$$\text{Sample size} = \frac{\left(\frac{\text{Range}}{2}\right)^2}{\left(\frac{\text{Accuracey Level}}{\text{Confidence Level}}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

Where

Accuracy Level Range x desired level of accuracy (expressed as a proportion)

The second one based on known population size.

$$\text{Sample Size} = \frac{\chi^2\ NP(1-P)}{d^2(N-1)+\chi^2\ P(1-P)} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where

$\chi^2 = \text{table value of Chi} - \text{Square degree of freedome}$
$= 1 \text{ for desired level}$
$N = \text{ population Size}$
$P = \text{population proportion (assumed to be .50 since this world provide the maximum sample size)}$
$d = \text{degree of accuracy (expressed as proportion)}$

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Discrete Probability Distributions [13] is a probability distribution characterized by a probability mass function.

Table 1, Represents discrete probability distribution types related to Parameters, support, probability Math Function (PMF) and Cumulative distribution Functions (CDF) [13],[14],[15].

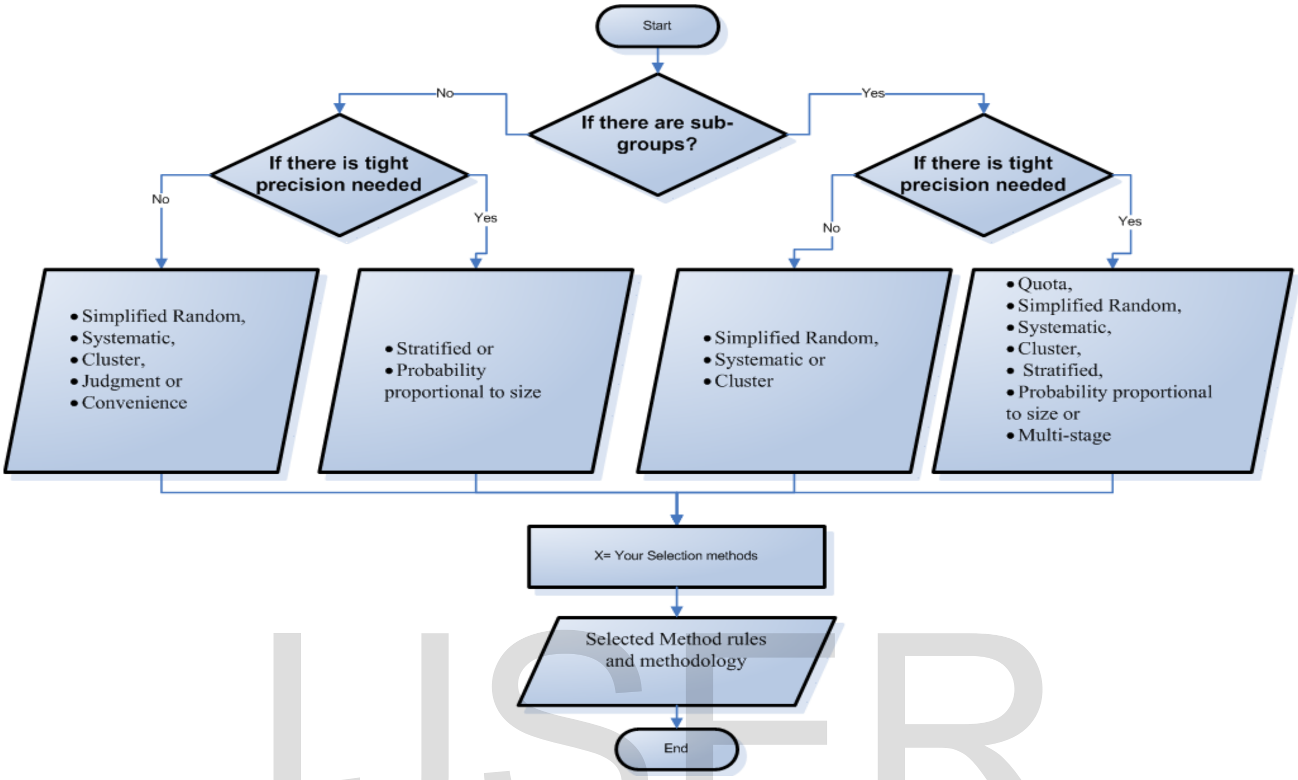

Fig.1 Methods for gathering samples

TABLE 1 DISCRETE PROBABLITY DESTRIBUTION (CONTINUED)

Discrete probability distributions	Parameters	Support	Probability Math Function (PMF)	Cumulative distribution Functions (CDF)
Bernoulli distribution	$0 < P < 1 , p \in R$	$k \in \{0,1\}$	$\begin{cases} q = (1-p) \text{for } k = 0 \\ p \quad \text{for } k = 1 \end{cases}$	$\begin{cases} 0 & \text{for } k < 0 \\ q \text{ for } & 0 \le k \le 1 \\ 1 & \text{for } k \ge 1 \end{cases}$
Binomial distribution	$n \in N_{0-\text{Number of trials}}$ $p \in [0,1]$ success probability in each trial	$k \in \{0, \dots, n\}$ Number of successes	$\binom{n}{k} p^k (1-p)^{n-k}$	$I_{1-p}(n-k, 1+k)$

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Discrete probability distributions	Parameters	Support	Probability Math Function (PMF)	Cumulative distribution Functions (CDF)
beta-binomial distribution	$n \in N_0$ number of trials $\alpha > 0$ (*real*) $\beta > 0$ (*real*)	$k \in \{0, \dots, n\}$	$\binom{n}{k}\frac{B(k+\alpha, n-k, +\beta}{B(\alpha,\beta)}$	$1-\frac{B(\beta+n-k-1, \alpha+k+1)\ {}_3F_2(\alpha, b; k)}{B(\alpha,\beta)B(n-k, k+2)(n+1)}$ Where $3^{F_2}(a, b, k)$ is the generalized hyper-geometric function $= 3F2(1,\ \alpha + k + 1,$ $-n + k + 1;$ $k + 2,\ -\beta - n + k + 2;\ 1)$
discrete uniform distribution	$a \in (\dots, -2, -1, 0, 1, 2, \dots)$ $b \in (\dots, -2, -1, 0, 1, 2, \dots), b \geq a$ $n = b - a + 1$	$k \in \{a, a+1, \dots b-1, b\}$	$\frac{1}{n}$	$\frac{\lfloor k \rfloor - a + 1}{n}$
Hyper-geometric distribution	$N \in \{0,1,2, \dots\}$ $K \in \{0,1,2, \dots, N\}$ $n \in \{0,1,2, \dots, N\}$	k $\in \{\max(0, n + K$ $- N), \min(K, n)\}$	$\frac{\binom{K}{k}\binom{N-K}{n-k}}{\binom{N}{n}}$	$1-\frac{\binom{n}{k+1}\binom{N-n}{K-k-1}}{\binom{N}{K}} 3F_2\left[\begin{matrix}1, k+1-K, k+1-n \\ k+2, N++2-K-n\end{matrix}; 1\right]$
Poisson binomial	$P \in [0,1]^n$ Success probabilities for each of the n trials	$k \in \{0, \dots. n\}$	$\sum_{A \in F_k} \prod_{i \in A} Pi \prod_{i \in A^c} (1 - p_j)$	$\sum_{i=1}^{k} \sum_{A \in F_t} \prod_{i \in A} Pi \prod_{i \in A^c} (1 - p_j)$

3 A METHODOLOGY FOR MEASURING SOFTWARE USABILITY

This research represents a new methodology to measure software usability. The following steps will describe this methodology:

1. Describe the population characteristics.
2. Define sampling characteristics.
3. Define sample size.
4. Test sampling distribution.
5. Define studies variables.
6. Define the distribution for each variable.

Fig. 2 represents a context diagram for these steps.

In the first step determining the population characteristics and population size is required.

The second step is defining sample characteristics and defining the methods that will be used for collecting data taking into account the result accuracy and population sub-groups as shown in Fig.1.

The third step is determining the sample size. As mentioned before the way of determining the sample size depends on knowing or unknowing the population size.

Then the fourth step is to make sure if the sample will cover the population size. Using Chi-Square test for sampling, if it falls under normal distribution or not. Considering that, the best sampling is the one which falls under normal distribution.

For computing Chi square test, suppose two hypotheses H_0 as the null hypothesis and H_1 as the alternative hypothesis. [3][14][15][16].

The chi square test uses following formula

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \quad \dots\dots (3)$$

$$E = \frac{\sum_{i=1}^{n}(O_i)}{Count(O)} \quad \dots\dots (4)$$

Where:

n is the number of elements
χ^2 is chi square result
O is the Observed Frequency in each category
E is the Expected Frequency in the corresponding category.

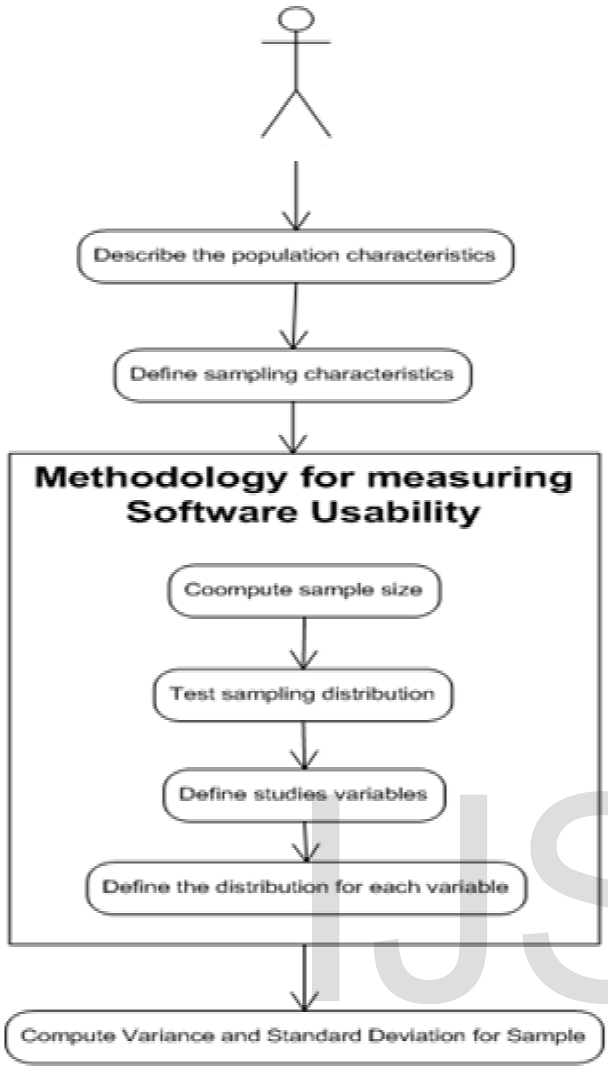

Fig. 2 Usability Measuerment Methodology

After calculating chi square for Observed Frequency, search for tabular chi square in freedom table after calculating freedom by the following equation [13],[14],[15]:

$$\mathrm{Df} = (\mathrm{Count}\,(O) - 1) \quad (5)$$

Where:

O is the same as before.

The last step is to compare the calculated chi square result vs. tabular chi square result, if the calculated result is greater than tabular result then H_1 hypothesis is approved else H_0 is approved [17],[18],[19].

In the fifth step define all the random variables that will be studied. The meaning and expected values for each variable should be known.

Finally the best discrete distribution for each variable is defined.

4 Research Experiement

Now we are going to apply methodology steps to measure software usability.

Population, There are a lot of users over the world using Linux operating system. So, it is difficult to determine the population size accurately.

So we assumed that:

- Population is ultra set of users .
- The percentage of population is unknown.
- The confidence Level is 95%.

Sample characteristics, there is a huge number of users over the world using open source operating system “Linux”. So we can separate the population into groups such as (age, geographic region, system usage, the scientific level and educational type.

Sample size, as we assumed before:

If we assume that, the population size is up to 6 million users over the world.

Percentage of population = 50%.

Confidence level = 95% then Degree of freedom = 0.05 so $\boldsymbol{\chi^2 = 3.841}$

Using equation (2)

$$\mathbf{S} = \frac{\mathbf{3.841 \times 6000000 \times 0.5(1-0.5)}}{\mathbf{0.05^2(6000000-1)+3.841(1-0.5)}} = \mathbf{730\ sample}$$

The sample size is 730 for each group (age, geographic region, system usage, the scientific level and educational type)

Using Chi square test

$\mathbf{H_0}$ = distribution of sample under normal distribution

$\mathbf{H_1}$ = distribution of sample is not under normal distribution

Table 2 Chi square test for sample distribution

E	614.812
Degree of freedom	24
Calculated χ^2	1314643744

From freedom degree table, under degree of freedom 24 and Confidence level 0.95 got chi square results is 36.415 By comparing calculated ($\boldsymbol{\chi^2}$) resulted that existing in Table 2 and tabular result for Chi square, found that the calculated value is greater than tabular value; so accept $\mathbf{H_0}$ assumption. That means, we distributed sample based on age according normal distribution.

From usability definition, usability is qualitative measure. So, we need methods to convert from qualitative to quantitative measure. Table 3 represent assumed the following random variables cover all the usability factors and its sub factors.

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TABLE 3 RANDOM VARIABLES FOR USABILITY FACTORS

Variable	Meaning	Definition
E	Easiness	How easy the system?
S	Satisfaction	The extent of user satisfaction for the system?
EF	Efficiency	The efficiency of the system?
SP	Speediness	How fast system response?
C	Comfort	Is the system comfortable?
L	Learner	What is the extent Learnability of system?
P	Productivity	Is the system productive?
MC	Messages Clearness	Is the system error messages clarity?
DC	Documentation Clearness	Is the system help documentations clarity?
IC	Interface Clearness	Is the system interface clarity?
U	Usage	Is the system recommended to be used?

From the meaning of each variable we can expect results as shown in Table 4

TABLE 4- POSSIBLE VALUES FOR RANDOM VARIABLE

Variable	Expected result
E	1,2,3,….n
S	1,2,3,….n
EF	1,2,3,….n
SP	1,2,3,….n
C	Yes or No
L	1,2,3,….n
P	Yes or No
MC	Yes or No
DC	Yes or No
IC	Yes or No
U	Yes or No

Table 5 shows the discrete probability distribution of each random variable according to the previous assumptions.

TABLE 5 POSSIBLE DISTRIBUTIONS FOR EACH RANDOM VARIABLE (CONTINUED)

distributions / Random Variables	Bernoulli	binomial	beta-binomial	discrete uniform	Hyper-geometric	Poisson binomial
E			√	√	√	√
S			√	√	√	√
EF			√	√	√	√
SP			√	√	√	√
C	√	√				√
L			√		√	√
P	√	√		√		√
MC	√	√				√
DC	√	√				√
IC	√	√				√
U	√	√				√

Based on easiness distribution, we can focused the distribution for each random variable based as represent in Table **6**

TABLE 6 PROPOSED DISTRIBUTIONS FOR EACH VARIABLE BASED ON COMPUTATIONAL COMPLEXITY

Random Variables	Discrete Probability Distribution
E	Beta-binomial or Discrete Uniform
S	Beta-binomial or Discrete Uniform
EF	Beta-binomial or Discrete Uniform
SP	Beta-binomial or Discrete Uniform
C	Binomial or Poisson binomial
L	Beta-binomial or Discrete Uniform
P	Binomial or Poisson binomial
MC	Binomial or Poisson binomial
DC	Binomial or Poisson binomial
IC	Binomial or Poisson binomial
U	Binomial or Poisson binomial

Now using Binomial distribution, we are going to estimate the random variable "C" which measures system comfortability.

Applying the last methodology on 800 uses we found that:

$\mathbf{n = Number\ of\ selectect\ item\ (\ the\ sample\ )}$

$\mathbf{X = number\ of\ succsess\ times\ in\ n\ \{1, 2, 3, \ldots\ldots n\}}$

$$\mathbf{P(X = x) = \binom{n}{x} p^x q^{n-x}, X = 1, 2, 3, \ldots n} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

$$\mathbf{(p + q)^n = \sum_{x=0}^{n} \binom{n}{x} p^x q^{n-x}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

532 questionnaires approved that system is comfortable.

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268 questionnaires disapproved system comfortable.

Fig. 3 represents the cumulative frequency for questionnaire,

Table **7** and Fig. 4 represents the discreet probability distribution test for Linux comfortability.

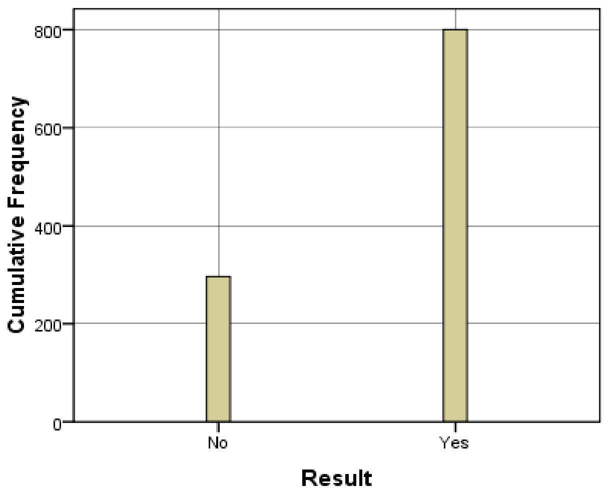

Fig. 3 Cumulative Frequency for questionnaire results

TABLE 7 BINOMIAL TEST

Result	N	Observed Prop.	Test Prop.
Yes	504	.63	.50
No	296	.37	
Total	800	1.00	

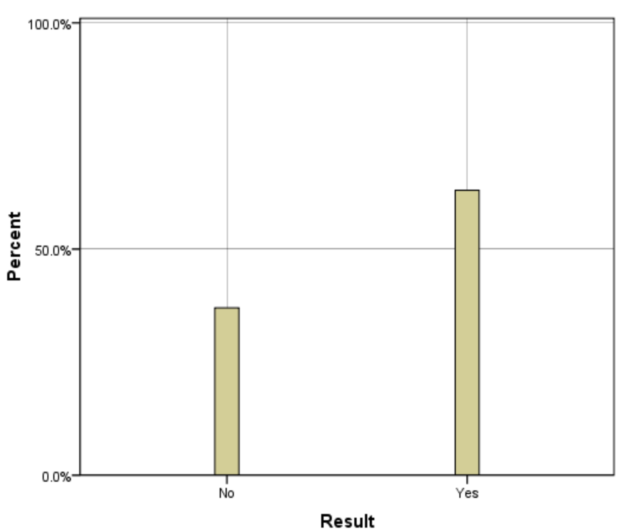

Fig. 4 Discrete binomial probability distribution for questionnaire result

$$\mathbf{P(X = x) = \binom{800}{x} (0.63)^{x} (0.37)^{800-x}, X = 1, 2, 3, \dots n}$$

TABLE 8 CUMULATIVE PROBABILITY

x={1,2,3,….n}	$\binom{800}{x} (0.63)^{x} (0.37)^{800-x}$	P(X)
1	$\binom{800}{100} (0.63)^{100} (0.37)^{700}$	$2.9\ e^{-2170}$
2	$\binom{800}{200} (0.63)^{200} (0.37)^{600}$	$4.75\ e^{-106}$
3	$\binom{800}{300} (0.63)^{300} (0.37)^{500}$	$1.65\ e^{-48}$
4	$\binom{800}{400} (0.63)^{400} (0.37)^{400}$	$6.58\ e^{146}$

Table **8** represents some of cumulative probability using discrete binomial distribution.

Expected mean of discrete random variable is

$$\mu_x = \sum_{x \in X(s)} X f_x(X) =$$

$$X_1 f_x(X_1) + X_2 f_2(X_2) + \cdots +$$

$$X_n f_n(X_n) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (8)$$

$$\mu_x = (504 \times 0.63) + (296 \times 0.37) = 427$$

Variance of discrete random variable is

$$V(X) = \sigma_{X^2} = \sum_{i=1}^{n} (X_i - \mu_x)^2 \dots\dots\dots\dots\dots\dots\dots\dots (9)$$

$$\sigma_{X^2} = (504 - 427)^2 + (296 - 427)^2 = 23090$$

Finally, standard deviation for discrete random variable is

$$SD = \sigma = \sqrt{\sigma_{X^2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (10)$$

$$SD = \sqrt{23090} = 151.95 \cong 152$$

Also we can compute standard deviation for all estimated distribution and compare results. The best discrete distribution has a smallest standard deviation, whereas smallest standard deviation is more representative for population.

5 CONCLUSION

In researches based on sampling, we should determine the population size and population characteristics. That is to achieve results with high accuracy. Operating system has ultra large number of users. Sampling is complicated process. We should take into account the sample characteristics, sample size, method used for gathering samples and to be sure that the samples will cover all population characteristics and groups.

That is which confident on previous results is not quite exposed. These researches were built based on small samples not considering the population size. Also these samples did not cover all population characteristics and groups.

This research represents a methodology for measuring software usability. This methodology based on sampling, population size, population characteristics and all the rules required to achieve as accurate as possible results. Also this methodology uses discrete probability distributions to define random variables, expected mean, expected variance and expected standard deviation for population. This random variable covers population's characteristics. We also used Chi Square test to check if the sample is distributed under normal distribution.

This methodology was applied to test the usability for open-source operating system "Linux (3.9.2)". We selected one random variable that measures Linux comfortability "C". The expected result for this variable is "Yes or No". By applying the last methodology on a sample of 800 uses by 11 questionnaires, the results showed that Linux was comfortable for 63% of the sample. The expected mean value for the population was 427 and the standard deviation was 152.

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