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Analysis of Means Based on Exponentiated Inverted Weibull Distribution

B. Srinivasa Rao
Professor of Statistics, Department of Mathematics & Humanities, R.V.R & J.C College of Engineering, India,
boyapatisrinu@yahoo.com

B. Vara Prasad Rao
Professor of Computer Science & Engineering, Department of Computer Science & Engineering, R.V.R & J.C College of Engineering, India,
boyapativaraprasad@gmail.com

V. R. Bala Suseela
Assistant Professor of Statistics, Q.I.S. College of Engineering, India,
balasuseela.m@gmail.com

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Analysis of Means Based on Exponentiated Inverted Weibull Distribution

B. Srinivasa Rao
Department of Mathematics & Humanities, R.V.R & J.C College of Engineering, India

B. Vara Prasad Rao
Department of Computer Science & Engineering, R.V.R & J.C College of Engineering, India

V. R. Bala Suseela
Q.I.S. College of Engineering, India

The probability model of a quality characteristic is assumed to follow the exponentiated inverted weibull distribution. The technique of analysis of means for a skewed population is applied with respect to exponentiated inverted weibull distribution. The subgroup means are used to develop control charts to assess whether the population from which these subgroups are drawn is operating with admissible quality variations. The results are illustrated by examples on live data.

Keywords: ANOM, EIWD, Q-Q plot.

1. Introduction

The probability density function (pdf) of the exponentiated inverted Weibull distribution is

$$f(x) = \theta\beta x^{-(\beta+1)} (e^{-x^{-\beta}})^{\theta} ; \quad x > 0, \beta > 0, \theta > 0. \tag{1}$$

The cumulative distribution function (cdf) is

$$F(x) = (e^{-x^{-\beta}})^{\theta} , \qquad x > 0, \beta > 0, \theta > 0. \tag{2}$$

The exponentiated inverted Weibull distribution's hazard function is

$$h(x) = \frac{\theta\beta x-(\beta+1)\ (e^{-x^{-\beta}})^{\theta}}{1-\ (e^{-x^{-\beta}})^{\theta}} . \tag{3}$$

A skewed, unimodel distribution on the positive real line is the exponentiated inverted Weibull distribution. The median and k^{th} moment of EIWD are:

$$E\ (x^{k}) = \theta^{\frac{k}{\beta}}\ \Gamma\ (1 - \frac{1}{\beta}). \tag{4}$$

Flaih et al. (2012) [18] have examined the other distributional features in depth.

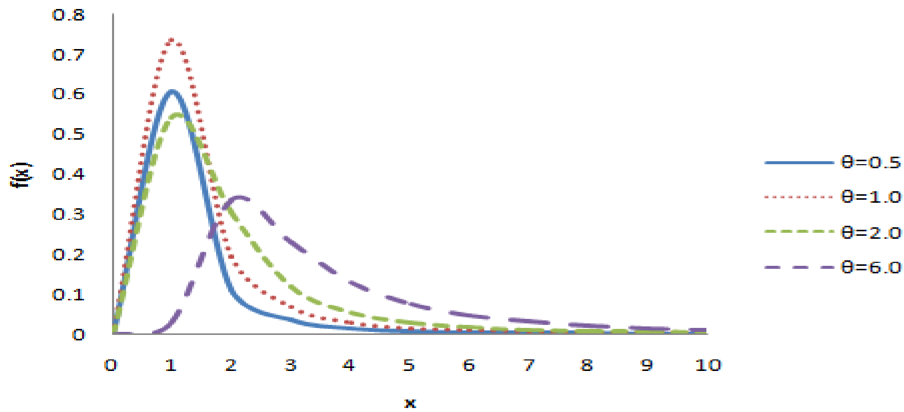

Figure 1. Pdfs of the EIWD for various θ and β=2

Many practitioners use the Shewhart control chart as a statistical quality control tool. If the remedy is known, the process is adjusted when these charts show the presence of an assignable cause. Otherwise, the presence of assignable cause is interpreted as an indication of heterogeneity in the subgroup statistic for which the control chart is generated. For example, if the statistic is sample mean, the process mean will be heterogeneous, reflecting departures from the target mean. Such an analysis is commonly carried out with the use of means to separate a collection of a given number of subgroup means into categories such that means within a category are homogeneous and those between categories are heterogeneous and the method is known as analysis of means(ANOM) given by Ott (1967)[33]. The concept of a control chart for means is regarded differently when applying the ANOM technique: grouping of plotted means to fall inside the control limits or some outside the control limits. All of the means must fall inside the control limits in order for all of them to be homogeneous. If we use $(1 - \alpha)$ as the confidence coefficient, the probability of all subgroup means falling under the control limits should be $(1 - \alpha)$. Assuming that subgroups are independent, the above probability statement becomes the n^{th} power of the probability that a subgroup mean will fall within the limits. Specifically, the confidence interval for $\bar{x}$ to lie between two specified limits in the sampling distribution $\bar{x}$ should be equal to $(1 - \alpha)^{1/n}$. Through EIWD, the same approach is applied throughout the rest of this chapter. We have only studied the control chart components of ANOM in this study because it aims to explore ANOM using control limits of extreme value statistics. We have not explored any recently created ANOM tables or approaches. However, a detailed literature about ANOM is available in Rao(2005) [11] and some related works in this direction are Ramig(1983) [10],Bakir(1994) [1], Bernard and Wludyka(2001) [2], Montgomery(2001) [6], Nelson and Dudewicz(2002) [8], Rao and Prankumar(2002) [12], Farnum(2004) [3], Guirguis and Tobias(2004) [5], Rao and Kantam(2012) [14], Rao *et al* (2012) [13], Rao *et al* (2012) [16], Rao and Sricha- rani(2018) [15] and references there in. The rest of the paper is organized as follows. ANOM applied to EIWD using extreme value control charts of EIWD is given in Sec tion 2 followed by numerical examples. Illustration of the application of the values in ANOM tables are given in Section 3. Summary and conclusions are given in Section4.

2. Analysis of means (ANOM) - EIWD

Assume $\bar{x}_1$, $\bar{x}_2$, . . . $\bar{x}_k$ are the arithmetic means of k subgroups of size 'n' each chosen from an EIWD model where the data variate follows EIWD. If these subgroup means are used to construct control charts, it will be possible to determine whether the population from which these subgroups are generated is performing with acceptable quality variations. We may utilise our control chart constants or the popular Shewart constants found in any SQC textbook, depending on the underlying population model. If all of the subgroup means fall inside the control limits, we say the process is under control. Otherwise, we would argue the process is uncontrollable. We can get the following probability assumptions if α is the level of significance of the above decisions.

$$P\,(LCL < \bar{x}_i\,,\ \forall_i = 1, 2 \ldots k < UCL) = 1 - \alpha \qquad (5)$$

The concept of independent subgroups (3.2.1) is applied.

$$P\,(LCL < \bar{x}_i < UCL) = (1 - \alpha)^{1/k} \qquad (6)$$

We can determine two constants, L* and U*, for each subgroup mean using equi-tailed probability.

$$P\,(\bar{x}_i < L^*) = P\,(\bar{x}_I > U^*) = \frac{1-(1-\alpha)^{\frac{1}{k}}}{2} \qquad (7)$$

L* and U* satisfy U* = -L* in the case of a normal population. We must calculate L* and U* separately from the sample distribution of $\bar{x}_i$ for skewed populations like EIWD. As a result, these are dependent on the number of subgroups 'k' and the size of the subgroups 'n'. L* and U* for α = 0.01, 0.05, and 0.10 are obtained using the equation (7) for given 'n' and 'k'. Tables 1, 2 and 3 include this information. A control chart for averages with an 'In Control' conclusion shows that, while subgroup means differ, they are all homogeneous in some way. In an analysis of variance technique, this is the null hypothesis. As a result, the constants in Tables 1, 2 and 3 can be applied instead of the analysis of variance method. For a normal population one can use the tables of Ott (1967) [33]. Our tables can be utilised for an EIWD. As a result, we've included several instances below in which the EIWD model's goodness of fit was evaluated using the Q-Q plot technique (the strength of linearity between observed and theoretical quantities of a model) and the homogeneity of means was examined in each case.

Table 1. EIWD constants for analysis of Means (1-α) = 0.99

n	2		3		4		5		6		7		8		9		10	
K=1	0.758	8.7071	0.7898	7.7384	0.8112	6.3133	0.80272	6.2277	0.8404	6.3852	0.8547	5.4749	0.8628	5.4506	0.8762	5.4096	0.8815	4.9718
2	0.7515	12.1252	0.7772	10.4534	0.7936	8.047	0.8146	8.1949	0.8026	8.0197	0.8428	6.5779	0.847	6.6057	0.8652	7.0007	0.8683	5.8563
3	0.747	13.7673	0.7719	12.8322	0.7876	9.5541	0.8008	9.4769	0.8015	9.0739	0.8367	7.2749	0.8409	7.6173	0.8589	7.7852	0.8615	7.0708
4	0.7444	15.3688	0.7703	14.6718	0.7847	11.7961	0.8004	10.587	0.8009	10.0064	0.8274	7.5231	0.8382	8.1438	0.8551	8.525	0.8594	7.7041
5	0.7435	16.0388	0.7686	15.0332	0.784	12.1866	0.7994	11.6186	0.8008	10.6796	0.8019	7.895	0.8343	8.3396	0.8519	8.9115	0.8552	7.762
6	0.7423	16.7814	0.7664	15.7381	0.7835	13.6194	0.7983	12.4435	0.7978	11.6238	0.8014	8.2747	0.8332	8.5494	0.848	9.8047	0.5529	8.0099
7	0.7423	17.0339	0.7649	16.3523	0.7834	14.2467	0.7981	13.6032	0.7972	11.8114	0.8012	8.6193	0.8327	8.6157	0.8474	10.0953	0.852	10.7706
8	0.741	17.802	0.7615	18.1839	0.7794	14.2643	0.7977	13.7637	0.7892	12.7831	0.8011	9.0149	0.832	8.7076	0.8422	10.2345	0.8508	11.8338
9	0.7381	18.2054	0.7612	20.3299	0.7791	14.283	0.7974	15.1283	0.7882	13.4542	0.8007	9.2995	0.82299	8.9213	0.8417	10.4616	0.8487	15.1821
10	0.7381	18.2054	0.7612	20.3299	0.7791	14.283	0.7974	15.1283	0.7882	13.4542	0.8005	9.2995	0.8299	8.9213	0.8417	10.4616	0.8487	15.1821
15	0.7379	18.9099	0.7571	21.964	0.7739	15.8422	0.7955	17.6079	0.7717	17.6998	0.8001	10.7151	0.819	9.988	0.8376	11.6139	0.8459	15.244
20	0.7215	19.4074	0.7515	23.3729	0.7688	16.0428	0.7935	20.8849	0.7126	18.0746	0.7983	13.7151	0.8179	9.9895	0.8315	12.1173	0.8322	15.2724
25	0.7215	19.4074	0.7515	23.3729	0.7688	16.0428	0.7935	20.8849	0.7126	18.0746	0.7983	13.7151	0.8179	9.9895	0.8315	12.1173	0.8322	15.2724
30	0.7129	20.9358	0.7511	24.3175	0.531	21.2428	0.7931	20.8979	0.706	24.7401	0.7966	15.4405	0.8178	11.5769	0.8315	13.1644	0.831	15.5478
35	0.7129	20.9358	0.7511	24.3175	0.7531	21.2428	0.7931	20.8979	0.706	24.7401	0.7966	15.4405	0.8178	11.5769	0.8315	13.1644	0.831	15.5478
40	0.7129	20.9356	0.7511	24.3175	0.7531	21.2428	0.7931	20.8979	0.706	24.7401	0.7966	15.4405	0.8178	11.5769	0.8315	13.1644	0.831	15.5478
45	0.7129	20.9358	0.7511	24.3175	0.7531	21.2428	0.7931	20.8979	0.706	24.7401	0.7966	15.4405	0.8178	11.5769	0.8315	13.1644	0.831	15.5478
50	0.7129	20.9358	0.7511	24.3175	0.7531	21.2428	0.7931	20.8979	0.706	24.7401	0.7966	15.4405	0.8178	11.5769	0.8315	13.1644	0.831	15.5478

Table 2. EIWD constants for Analysis of Means (1-α) = 0.95

n	2		3		4		5		6		7		8		9		10	
K=1	0.7941	4.0607	0.8263	3.921	0.8527	3.7232	0.8656	3.5441	0.8781	3.5663	0.8902	3.2467	0.899	3.2957	0.9112	3.1422	0.9152	3.0465
2	0.775	5.4802	0.8072	5.1646	0.8323	4.689	0.8476	4.4461	0.8594	4.5305	0.8738	4.1083	0.8815	4.112	0.892	3.9531	0.8978	3.7166
3	0.7674	6.329	0.8008	6.1087	0.8226	5.3041	0.8388	5.0572	0.8529	5.2558	0.8677	4.678	0.8756	4.6904	0.8837	4.5594	0.8906	4.3053
4	0.7632	7.3312	0.7947	6.8763	0.8178	5.8916	0.8329	5.6529	0.8458	6.0606	0.8606	5.0266	0.867	5.1182	0.8798	4.9701	0.8862	4.6426
5	0.7586	8.5868	0.7909	7.6462	0.8115	6.2971	0.8297	6.2063	0.8418	6.362	0.8564	5.4593	0.8635	5.4436	0.8763	5.2858	0.8829	4.9564
6	0.7558	9.3438	0.7871	8.3216	0.8076	6.7624	0.8248	6.9417	0.8364	6.7428	0.8514	5.7172	0.859	5.721	0.8745	6.0099	0.8807	5.2709
7	0.7545	10.2224	0.7832	8.8086	0.8046	7.4056	0.8225	7.2909	0.8333	7.2214	0.8474	5.8261	0.855	5.9438	0.8718	6.2709	0.8769	5.5379
8	0.7537	10.7829	0.7804	9.2031	0.8016	7.5626	0.8188	7.5891	0.8314	7.5664	0.8451	6.0968	0.8527	6.2275	0.8698	6.5247	0.8075	5.7217
9	0.7529	11.8022	0.7796	9.4659	0.7082	7.7623	0.8153	7.8844	0.8297	7.6355	0.8442	6.3142	0.8493	6.4051	0.8663	6.7763	0.8726	5.7512
10	0.7515	12.1252	0.7772	10.4534	0.7936	8.047	0.8146	8.1949	0.8264	8.0197	0.8428	6.5779	0.847	6.6057	0.8652	7.0007	0.8683	5.8563
15	0.7477	13.5328	0.7742	12.3753	0.7882	8.959	0.8102	9.4166	0.8165	8.7222	0.8372	7.1838	0.8418	7.3313	0.8599	7.7311	0.8638	6.9381
20	0.7444	15.3688	0.7703	14.6718	0.7847	11.7961	0.8014	10.587	0.8095	10.0064	0.8274	7.5231	0.8382	8.1438	0.8551	8.525	0.8594	7.7041
25	0.7435	16.0388	0.7686	15.0332	0.784	12.1866	0.8994	11.6186	0.8009	10.6796	0.819	7.895	0.8343	8.3396	0.8519	8.9115	0.8552	7.762
30	0.7423	16.7814	0.7664	15.7381	0.7835	13.6194	0.7983	12.4435	0.7978	11.6238	0.8143	8.2747	0.8332	8.5494	0.848	9.8047	0.8529	8.0099
35	0.7423	17.0339	0.7649	16.3532	0.7834	14.2467	0.7981	13.6032	0.9972	11.8114	0.8128	8.6193	0.8327	8.6157	0.8474	10.0953	0.852	10.7706
40	0.741	17.802	0.7615	18.1839	0.7794	14.2653	0.7077	13.7637	0.7892	12.7831	0.8127	9.0419	0.832	8.7076	0.8422	10.2345	0.8508	11.8338
45	0.7381	18.2054	0.7612	20.3299	0.7791	14.283	0.7074	15.1283	0.7882	13.4542	0.8074	9.2995	0.8299	8.9213	0.8417	10.4616	0.8487	15.1821
50	0.7381	18.2054	0.7612	20.3299	0.7791	14.283	0.7074	15.1283	0.7882	13.4542	0.8074	9.2995	0.8299	8.9213	0.8417	10.4616	0.8487	15.1821

Table 3. EIWD contants for Analysis of Means (1-α) = 0.90

n	2		3		4		5		6		7		8		9		10	
K=1	0.8207	3.1439	0.8507	3.0643	0.8747	2.8686	0.8884	2.8081	0.9009	2.8144	0.9106	2.6946	0.9203	2.683	0.9333	2.6097	0.9393	2.5452
2	0.7948	4.0405	0.8273	3.8662	0.8535	3.7037	0.8669	3.5245	0.8797	3.5473	0.8916	3.231	0.8996	3.2644	0.9122	3.1322	0.9166	3.0297
3	0.7829	4.7446	0.8159	4.4776	0.8423	4.2086	0.8564	4.0456	0.8677	4.0249	0.8808	3.7055	0.8899	3.7427	0.8987	3.5165	0.9067	3.4153
4	0.7751	5.3889	0.8081	5.1046	0.8334	4.6523	0.848	4.4284	0.8597	4.5185	0.8744	4.0891	0.8816	4.0871	0.8924	3.9403	0.8983	3.6651
5	0.7722	5.9092	0.8036	5.5382	0.8276	5.0065	0.8431	4.719	0.8555	4.7805	0.8711	4.3742	0.8792	4.3679	0.8879	4.272	0.8937	3.8818
6	0.7679	6.2867	0.8012	6.0135	0.823	5.2593	0.8397	5.0092	0.8531	5.1531	0.8689	4.6361	0.8768	4.6151	0.8846	4.5122	0.8911	4.2533
7	0.7651	6.6925	0.7975	6.3767	0.8206	5.6092	0.8359	5.365	0.8483	5.5318	0.864	4.8422	0.8722	4.9221	0.8823	4.7102	0.8886	4.4534
8	0.7634	7.1949	0.7952	6.8338	0.8179	5.8424	0.8335	5.632	0.8462	6.0161	0.8609	4.9768	0.8672	5.0451	0.8813	4.8553	0.8864	4.6221
9	0.7608	7.7843	0.7931	7.247	0.8152	6.0656	0.8321	5.8266	0.8447	6.1772	0.8595	5.1775	0.8655	5.2238	0.8784	5.0726	0.8858	4.7795
10	0.759	8.5822	0.7911	7.6262	0.8115	6.2321	0.8299	6.184	0.8419	6.3334	0.8566	5.428	0.8636	5.3649	0.8765	5.2816	0.8829	4.9301
15	0.7545	10.3936	0.7826	8.8886	0.8042	7.4629	0.8197	7.4193	0.8329	7.2451	0.846	5.8798	0.8546	6.1307	0.8709	6.3524	0.8762	5.5874
20	0.7517	12.1146	0.7781	10.0787	0.7936	7.9694	0.8148	8.1128	0.8275	8.0021	0.8441	6.4113	0.8484	6.5167	0.8655	6.9735	0.8697	5.8004
25	0.7498	12.3703	0.7749	11.5798	0.7898	8.6683	0.8117	8.8083	0.8214	8.4752	0.8406	6.8994	0.8451	6.7271	0.8629	7.0841	0.8657	6.304
30	0.7477	13.5328	0.7742	12.3753	0.7882	8.959	0.8102	9.4166	0.8165	8.7222	0.8372	7.1838	0.8418	7.3313	0.8599	7.7311	0.8638	6.9381
35	0.7464	14.1094	0.7714	13.2931	0.7855	9.6102	0.8061	9.8299	0.8141	9.2662	0.8366	7.2977	0.8403	7.9112	0.8588	8.048	0.8614	7.3499
40	0.7454	15.0833	0.7708	14.4488	0.7851	11.4772	0.8032	10.4716	0.8096	9.3923	0.8282	7.5008	0.8385	8.0897	8.572	8.0866	0.8598	7.5338
45	0.744	15.3698	0.7687	14.7708	0.7843	11.82	0.7995	10.735	0.8068	10.656	0.8206	7.5989	0.836	8.2019	0.8543	8.8393	0.8555	7.7421
50	0.7435	16.0388	0.7686	15.0332	0.784	12.1866	0.7994	11.6186	0.8009	10.6796	0.819	7.895	0.8343	8.3396	0.8519	8.9115	0.8552	7.762

3. Illustration

Example 1: Consider the following data from 25 observations on metal product manufacturing that point to variances in iron content of raw materials supplied by five different vendors. Each of the five suppliers had five ingots chosen at random. The iron determinations on each ingot are listed in percent by weight in the table below.

Supplier				
1	2	3	4	5
3.46	3.59	3.51	3.38	3.29
3.48	3.46	3.64	3.40	3.46
3.56	3.42	3.46	3.37	3.37
3.39	3.49	3.52	3.46	3.32
3.40	3.50	3.49	3.39	3.38

Example 2: Three battery bands are being investigated. The three brands' lifespan lives (in weeks) are thought to differ. The following are the findings of testing five batteries from each brand. At a 5% level of significance, see if the lifespan of these two brands of batteries differ.

Weeks of Life	Brand1	100	96	92	96	92
	Brand2	76	80	75	84	82
	Brand3	108	100	96	98	100

Example 3: Four catalysts are being studied to see if they can influence the concentration of one component in a three-component liquid mixture. The concentrations below were obtained. At a 5% level of significance, see if the four catalysts have the same effect on the concentration.

Catalyst	1	58.2	57.2	58.4	55.8
	2	56.3	54.5	57	55.3
	3	50.1	54.2	55.4	54.9
	4	52.9	49.9	50	51.7

The following table summarises the goodness of fit of data in all three situations as demonstrated by the Q-Q plot (correlation coefficient), which reveals that EIWD is a better model, displaying a significant linear relationship between sample and population quantiles.

	Example 1	Example 2	Example 3
EIWD	**0.9167**	**0.8296**	**0.8223**
Normal	0.2067	0.4149	0.4447

We estimated the decision limits for the Normal and EIWD populations using these observations in the data as a single sample and presented them in Tables 4 and 5, respectively.

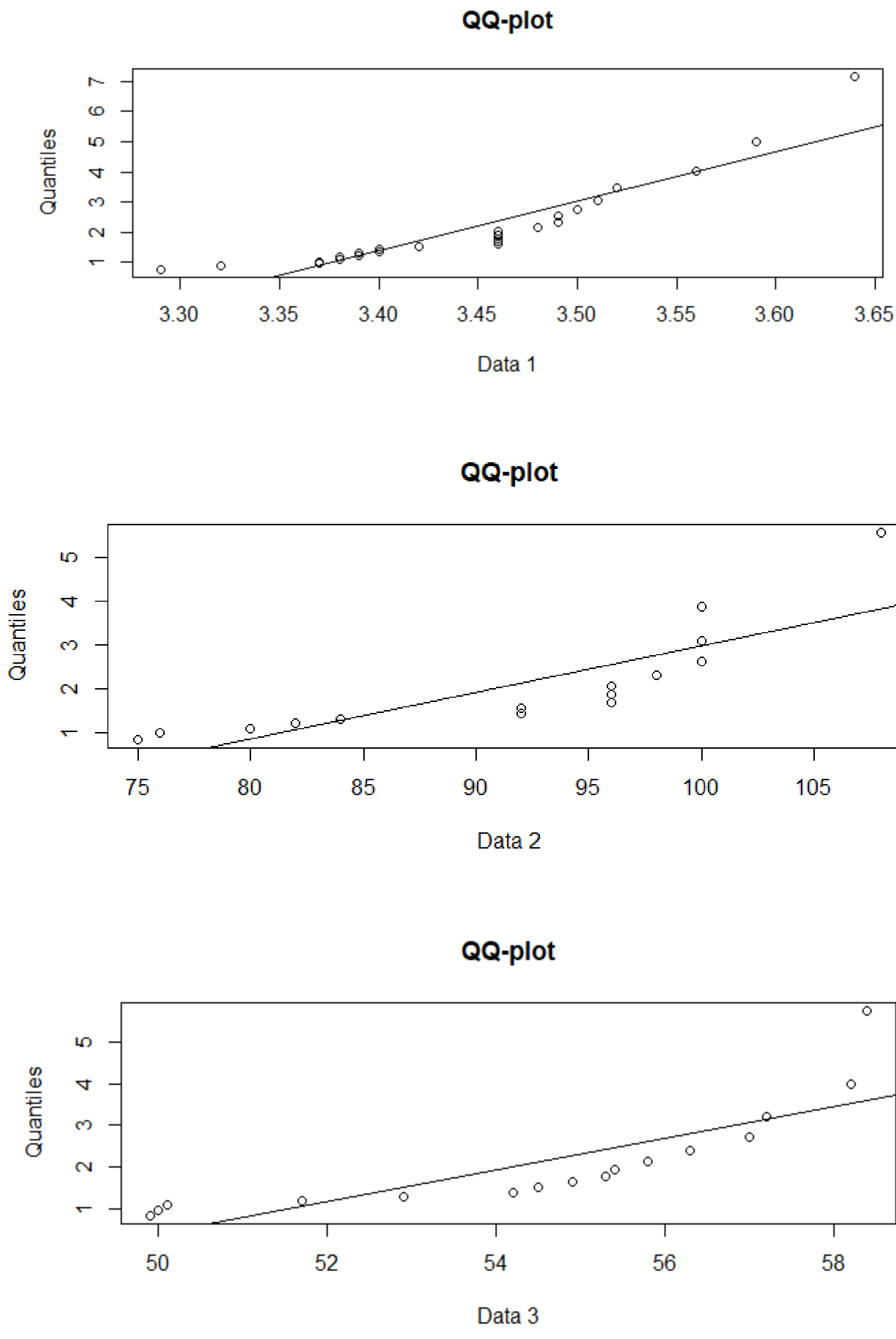

Figure 2. QQ-plots for the data in the illustrated examples

Table 4. Normal Distribution

	[LDL, UDL]	No. of Counts			
		In	P = in/k	Out	Out/k
Example 1 n=5, k=5, α = 0.01	[3.517,3.879]	**3**	0.6	2	0.4
Example 2 n=5, k=3, α = 0.05	[87.82,95.52]	**2**	0.7	1	0.3
Example 3 n=4, k=4, α = 0.10	[26.14,82.84]	**2**	0.5	2	0.5

Table 5. EIWD

	[LDL, UDL]	No. of Counts			
		In	P = in/k	Out	Out/k
Example 1 n=5, k=5, α = 0.01	[2.7560, 40.0562]	**5**	1	0	0
Example 2 n=5, k=3, α = 0.05	[76.8900, 463.5768]	**3**	1	0	0
Example 3 n=4, k=4, α = 0.10	[45.3994, 253.4340]	**4**	1	0	0

4. Summary & Conclusions

The number of homogeneous means for each data set is 3, 2, and 2, respectively, according to the normal distribution. The number of individuals that are not homogeneous is 2, 1, and 2. When the ANOM tables of our model (EIWD) are applied for the identical data sets, the number of homogeneous means is 5, 3, and 4, respectively, with no deviation of any mean from homogeneity. Thus, using the normal model resulted in homogeneity for some means and variance for others, indicating that those means may be rejected. This decision is valid if the data fits the Normal distribution effectively. As a comparison, the Q-Q plot has already proved that EIWD is a superior model than Normal, as evidenced by the Q-Q plot correlation coefficient of each data set with Normal as well as EIWD separately. As a result, we assumed that the decision process of the Normal distribution would be related with increased uncertainty. As a result, utilising EIWD (Table 5) to achieve homogeneity is a better option than using the Normal, ANOM technique to achieve heterogeneity.

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