Reliability Improvement Opportunities Using QMP Statistical Rankings

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1. Introduction

A new method of reporting reliability results for circuit packs used in the telecommunications industry has been developed. The new method uses QMP metrics to improve the process of reporting circuit pack return rates. The use of QMP (Quality Measurement Plan) metrics was originally proposed by Hoadley, in 1981, in the Bell System Technical Journal[1] for the purpose of reporting quality assurance audit results to Bell System management. In this application, QMP has been expanded to include the reporting of circuit pack reliability rates. The method described is applicable to a wide range of quality and reliability assessment problems.

This new method of reporting reliability results is a significant improvement over the previous method because:

- it produces a confidence interval in addition to a point estimate,
- it uses Bayesian statistics to consider five months of historical data in addition to the current month's data, and
- it reports the results in an easily interpreted graphic format instead of a tabular format.

The method described in this paper has been successful in improving the information derived from circuit pack return data that was already collected by an existing system. The existing system included serial number identification of each circuit pack tracked through various return and repair processes. Using QMP metrics it is possible to report reliability results with more accuracy and a better communication of the return rate phenomenon.

2. Application Software

This application was developed on a personal computer running MS-DOS [2] and was subsequently ported to a UNIX®[3] mainframe corporate database environment. The difference between these two computing environments relates to the quantity and source of the data rather than the implementation.

The software tools used included: a C language program to compute the QMP metrics, ORACLE [4] relational database system software to process the large amounts of data, and Documenter's Workbench [5] software to produce the report graphics.

Details of the software implementation can be found in a published paper entitled "Reporting Reliability Results Using QMP Metrics and UNIX Software"[6].

3. The Reliability Reporting Problem

DSC Communications Corporation (DSC) is a leading designer, developer, and manufacturer of digital switching and transmission systems for the worldwide telecommunications marketplace. In its fifteen year history, DSC has shipped more than a million telecommunications circuit packs. It is the responsibility of the Quality and Reliability Assurance Organization to collect and report the reliability of more than eight hundred circuit pack codes.

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Recently, one of DSC's largest customers asked a number of questions about the reliability of circuit packs already in service. The principle question asked was: Which circuit pack codes are experiencing failure rates greater than predicted? The existing system was not capable of responding to the customer's questions. Thus in the fall of 1991, this new method of reporting circuit pack reliability rates was created.

First note that given a universe of circuit packs in service, it is possible to compute the number of predicted returns each month. The relevant reliability theory assumes (1) a constant failure rate (exponential distribution) for circuit packs in service, (2) properly manufactured circuit packs experience a higher failure rate only during the manufacturing **burn-in** process, and (3) circuit packs are removed from service, before the wear-out process begins.

Assuming a constant failure rate, the number of expected failures per month can be computed as follows:

$$\textit{Expected Failures} = \textit{failure rate} \times \textit{hours per month} \times \textit{units in service}$$

The failure rate for telecommunications circuit packs is commonly expressed in FITs[7] (Failures In Time) per one billion operation hours. The FIT rate for the example circuit pack is 9,627 predicted failures in one billion hours. There are an average of 730 operating hours per month. In our example circuit pack, shown in Figure 1, there are 770 units in service for the month of July. Thus the **Expected Failures** in our example is:

$$\textit{Expected Failures} = \frac{9627}{1{,}000{,}000{,}000} \times 730 \times 770 = 5.41$$

There is a difference between expected failures per month and predicted returns per month. It is estimated that about one-third of the circuit packs returned each month will not have a fault identified during the testing process. These circuit packs, when tested at the manufacturer, will be diagnosed as **No Fault Found** (NFF). In the process of restoring system service, sometimes more than one circuit pack may be replaced before the service is restored. Some of the replaced circuit packs are not defective, they were replaced as part of the trouble-shooting process that is focused on restoring service not identifying defective circuit packs. Once service is restored, typically all of the circuit packs removed from service are returned to the manufacturer as defective. To account for this predicted level of returns greater than the actual failures, the number of **Predicted Returns** is computed as follows:

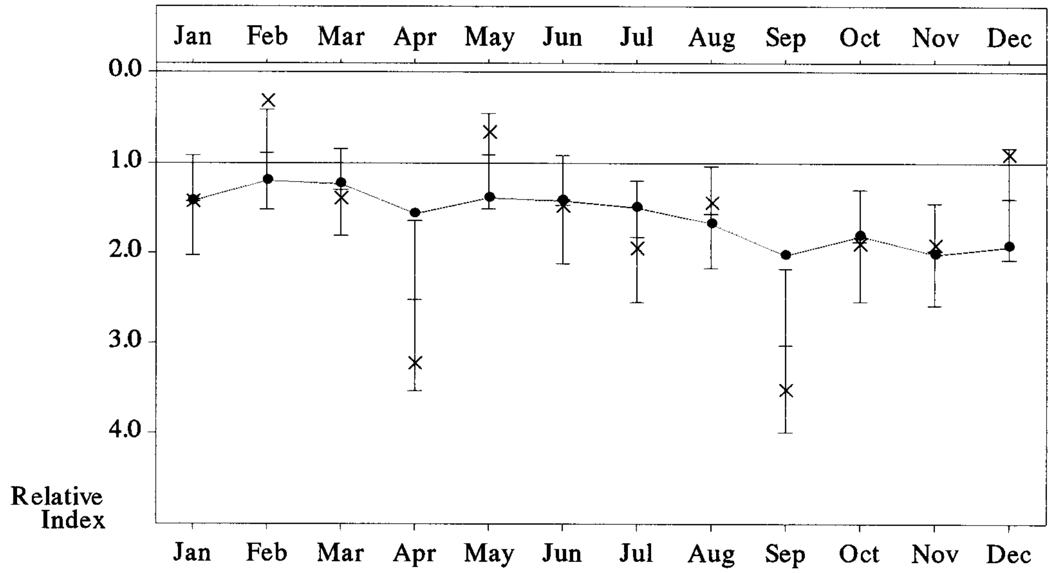
$$\textit{Predicted Returns} = 1.5 \times \textit{Expected Failures} = 1.5 \times 5.41 = 8.12$$

Now that the number of predicted returns has been computed, a comparison to the actual number of returns can be made and the statistical significance can be assessed.

4. The Quality Measurement Plan

The QMP metric was chosen as a reliability assessment metric because (1) it is a powerful estimate of true population quality, (2) it uses five months of historical data in addition to the current month's data, (3) it is known within the telecommunications industry, (4) it provides a confidence interval about the estimated true quality, and (5) when combined with a detailed graphical presentation, QMP conveys an excellent understanding of the return rate phenomenon.

Pack Code I FITs= 9627 MTBF= 103,875 hrs



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Packs Universe	593	596	674	674	704	764	770	778	831	842	835	822
Packs Returned	9	2	10	23	5	12	16	12	31	17	17	8
Pred Returns	6.25	6.28	7.11	7.11	7.42	8.05	8.12	8.20	8.76	8.88	8.80	8.67
Current Index	1.44	.32	1.41	3.24	.67	1.49	1.97	1.46	3.54	1.92	1.93	.92
Best Measure	1.43	.89	1.30	2.52	.91	1.47	1.83	1.57	3.03	1.88	1.98	1.40
Process Average	1.43	1.20	1.24	1.57	1.39	1.42	1.50	1.68	2.03	1.82	2.02	1.93
5th Percentile	.92	.41	.85	1.65	.45	.92	1.20	1.04	2.18	1.30	1.45	.83
95th Percentile	2.03	1.52	1.82	3.54	1.51	2.12	2.55	2.17	3.99	2.54	2.58	2.08

Figure 1. QMP trend chart using representative rather than actual data

In the example QMP trend chart given in Figure 1, a horizontal box has been drawn around the twelve variables that will be used for the July QMP computation. More specifically, those twelve variables are the **Packs Returned** in the months of February through July and the **Predicted Returns** for the months of February through July. The QMP computation function will return for July the five values in the vertical box - the **Current Index**, **Best Measure**, **Process Average**, **5th Percentile** and **95th Percentile**. These five values are portrayed on the QMP chart with an I-bar.

Interpretations that could be made from the July computation include:

1. The **Current Index** of the July data is 1.97 times predicted. The **Current Index** is the ratio of the **Packs Returned** in July to the **Predicted Returns** in July (16 / 8.12 = 1.97). This is a point estimate based on the actual returns and predicted returns for a single month of data. The **Current Index** is plotted on the I-bar as a "x".

2. The **Process Average** for July is computed using July's current index and five months of previous current indexes. This value is the six month rolling average of ratios of **Actual Returns** to **Predicted Returns**. The **Process Average** is plotted on the I-bar as a "•" and collectively they are connected by a trend line.

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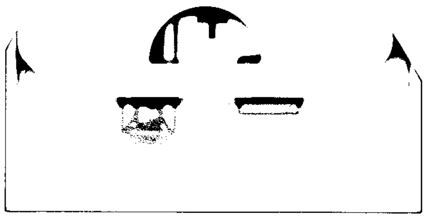

3. The **Best Measure** of the return rate for this circuit pack is 1.83 times worse than the predicted rate. This is Hoadley's **best** estimate of the **true** but unknown return rate ratio estimated on six months of data. This value is always between the **Current Index** and the **Process Average**. It is closer to the **Process Average** when the process displays stability and closer to the **Current Index** when the process exhibits instability. The **Best Measure** is plotted on the I-bar as a "-".

4. The **5th** and **95th** percentiles represent the bounds of the 90% confidence interval. For the July computation these values range between 1.20 and 2.55 times worse than the predicted rate. The QMP statistician would say that he is 90% confident that the **true** return rate is between 1.20 and 2.55 times that predicted. It would also be understood that this interval has a density function such that a higher probability exists that the true return rate is closer to the **Best Measure** than either the **5th** or **95th** percentile values.

5. Since the entire 90% confidence interval for July is below the 1.0 relative index line, the QMP statistician is at least 95% confident that the **true** return rate is worse than predicted. Looking at the entire year in retrospect, the QMP statistician drew the same conclusion for the months of April, July, August, September, October, and November.

The purpose for the original development of QMP was to "reduce statistical errors relative to a prior method of analysis".[1] The purpose of this application of QMP to the reporting of circuit pack return rates is the same. The Quality Measurement Plan is completely described in a 1981 issue of the Bell System Technical Journal[1] and in Bellcore Technical Reference TR-TSY-000438[8].

5. Statistical Ranking by Product Line Groupings

The QMP chart is a control chart. In this example, it is used for reliability assessment. It is now possible to produce some eight hundred control charts, one for each circuit pack code and the question still remains which of these circuit pack codes has the greatest improvement opportunity.

The purpose of a control chart is to (1) show the amount and nature of variation by time, (2) indicate statistical control or lack of it, and (3) enable pattern interpretation and detection of changes[9]. By transforming the reliability objective, predicted returns for a given FIT prediction to an index of 1.0, circuit packs with different FIT rates could be compared. By creating an I-bar graphic that includes historical data inferences it is now possible to compare multiple circuit pack codes within a single "ranking chart" with many of the qualities of a control chart.

Reliability Rankings for December, 1992
Ordered by Best Measure (Worst 20)

Pack Code	univ	rtnd	pred	CI	BM	PA
376 Composite	600327	788	3940	.20	.20	.27
Pack Code A	20	1	0.16	6.44	2.78	2.62
Pack Code B	567	8	2.30	3.48	2.26	1.93
Pack Code C	328	1	0.36	2.78	2.03	1.95
Pack Code D	596	1	0.65	1.53	1.97	2.03
Pack Code E	141	0	0.21	.00	1.90	2.04
Pack Code F	1255	4	3.84	1.04	1.69	1.94
Pack Code G	710	14	7.48	1.87	1.64	1.31
Pack Code H	406	2	0.90	2.23	1.47	1.28
Pack Code I	822	8	8.67	0.92	1.40	1.93
Pack Code J	79	1	0.33	3.07	1.29	.97
Pack Code K	262	4	2.99	1.34	1.25	1.20
Pack Code L	2397	6	5.31	1.13	1.24	1.89
Pack Code M	783	7	4.17	1.68	1.18	.46
Pack Code N	179	0	0.20	.00	1.09	1.21
Pack Code O	587	1	0.95	1.05	1.07	1.08
Pack Code P	1428	12	9.75	1.23	1.04	.32
Pack Code Q	1224	1	2.78	.36	.99	1.50
Pack Code R	219	3	2.03	1.48	.98	.83
Pack Code S	1356	8	6.96	1.15	.97	.86
Pack Code T	1082	6	5.99	1.00	.91	.79

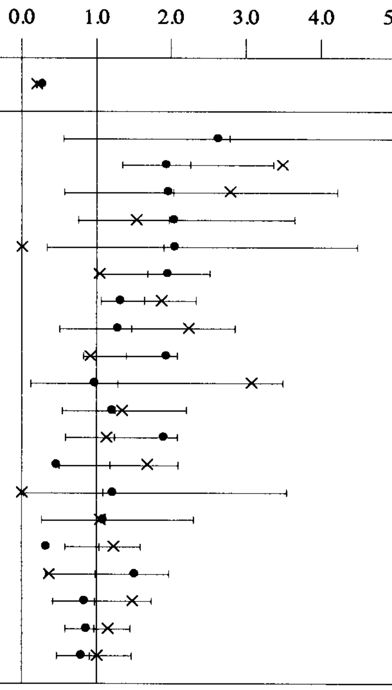

Figure 2. Reliability Ranking chart using representative rather than actual data

In the example ranking chart given in Figure 2, twenty circuit pack codes are ranked by Best Measure (worst to best). These are typical reliability ranking results for a representative product line at DSC.

First note, that the first line in the ranking is for a composite of the product line. Interpretation for this composite include:

1. A total of 376 circuit pack codes are contained in the product line. The total universe of circuit packs in that product line is 600,327 units. A total of 788 circuit packs were returned in December, 1992. It was predicted for this product line that 3,940 packs would be returned using standard prediction methods.
2. Of the 376 pack codes only 16 had Best Measures for December greater than 1.00. This represents 4.2% of the circuit pack codes in this product line. This compares favorably with our 1992 year end objective of no more than 5.0% of the pack codes having Best Measures greater than 1.0.
3. The composite Best Measure for the product line is 0.20. This is extremely good. It means that for this product line DSC is receiving about one-fifth the number of returns predicted. In other words, these circuit packs are performing, from a reliability viewpoint, five times better than predicted.

Interpretation for Pack Code A include:

1. It has the worst Best Measure of all 376 pack codes with a Best Measure of 2.78.
2. The total universe of packs is 20 and only one was returned in the month.
3. The predicted number of returns for December is 0.16. Only one unit was returned yielding a Current index of 6.44 (1.00 / 0.16). Since the number of units returned will be an integer value (0, 1, 2 ...), it is not unlikely to receive one return. Note that using a Poisson distribution, that a 13% probability exists for getting one unit returned when the expected value is 0.16. But the QMP metric is looking at a 6 month window of data. In that six month window two units have been returned when 0.96 units (6 times 0.16) would have been predicted. Again for the Poisson statistician, a 27% probability exists for getting two units returned when 0.96 are predicted.
4. What is obvious to the QMP statistician is that there is insufficient data to assess that the circuit pack code is being returned at a rate greater than predicted. Since the QMP confidence interval encompasses the "standard value of 1.0" and it is such a large confidence interval this pack code is not a strong candidate for improvement opportunity.

The circuit pack code of greatest concern here, i.e., the pack code that has the greatest **improvement opportunity** is Pack Code B. Interpretation Pack Code B include:

1. Visually it is obvious that the entire confidence interval is worse than the predicted standard of 1.0. Therefore, the QMP statistician is at least 95% confident that the predicted reliability performance is not being met.
2. The Best Measure is 2.26 times predicted. The Current Index, the returned units divided by the predicted, was 3.48 (8/ 2.30).
3. From the Process Average it can be assessed that current month return ratio is worse than the six month average of 1.93 times predicted. Could this suggest a decline in performance or just statistical variation?

This circuit pack code will get much attention in the next month as DSC focuses its reliability assurance resources on the question of why this circuit pack code is performing so poorly.

Two more circuit pack codes will also get much attention because they also have Best Measures greater than most of the 376 pack codes and because they have confidence intervals that are entirely to the right of the predicted standard of 1.0. They are Pack Code F and Pack Code G.

In our last observation, it might also be noted that Pack Code I, from Figure 1, ranked ninth with a Best Measure of 1.40. With so little of the confidence interval better than standard, this pack code is also a serious candidate for improvement opportunity.

6. Applications of Results

The results of the QMP reliability reporting process are used to drive corrective action in the design and manufacturing processes at DSC. The high concentration of effort on the highest return rate packs has resulted in a 47% improvement during 1992. Best Measures of the return rates are also used as input to system reliability models. In addition to its internal use, QMP statistical rankings have been used to meet data reporting requirements for various customer report cards and sales proposals.

7. Conclusion

The result of this new method of reporting reliability data is a more accurate, descriptive, and useful reporting mechanism. It demonstrates a friendly use of sophisticated statistics. Using QMP metrics it is possible to report reliability results with more accuracy and a better communication of the return rate phenomenon to both management and customers. The identification of reliability improvement opportunities using QMP statistical rankings is essential to the effective allocation of resources. This improvement opportunity includes the feedback of QMP statistical rankings to all interested in improving reliability including design and manufacturing personnel.

8. Acknowledgements

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REFERENCES

1. Hoadley, Bruce. The Quality Measurement Plan (QMP), *Bell System Technical Journal,* Volume 60, No. 2, February 1981, pp. 215-273.

2. MS-DOS is a trademark of Microsoft Corporation.

3. UNIX is a registered trademark of AT&T.

4. ORACLE is a registered trademark of Oracle Corporation.

5. Documenter's Workbench is a trademark of AT&T.

6. Conte, John A., *Reporting Reliability Results Using QMP Metrics and UNIX Software*, 16th Annual Rocky Mountain Quality Conference, Sponsored by the Northern Colorado, Denver, and Pikes Peak Sections of the American Society for Quality Control, June 8th and 9th, 1992.

7. Bell Communications Research, *Reliability Prediction Procedure for Electronic Equipment,* Technical Reference NWT-000332, Bellcore, Red Bank, NJ.

8. Bell Communications Research, *The Quality Measurement Plan (QMP)*, Technical Report TSY-000438, Bellcore, Red Bank, NJ.

9. Wadsworth, Harrison M., Stephens, Kenneth S., and Godfrey, A. Blanton, *Modern Methods for Quality Control and Improvement,* John Wiley & Sons, 1986.

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John A. Conte is employed by DSC Communications Corporation as Manager of Quality Metrics where he is responsible for reporting quality and reliability results to management and customers. His accomplishments, in his three years at DSC, include the introduction of QMP trend analysis techniques, the establishment of consistent reporting procedures, and the establishment of a multi-user computing environment for reporting quality and reliability results.

In 1989, John Conte retired from AT&T after twenty-one years service where he was responsible for the support the Quality Assurance Information Systems. John has a B.S. and M.S. in Industrial Engineering from the University of Missouri at Columbia, is both an ASQC Certified Quality Engineer and ASQC Certified Reliability Engineer and is registered as a Professional Engineer in Missouri and Texas.

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