RELIABILITY REPORTS - PRODUCT, CUSTOMER, & PROCESS

John A. Conte, P.E.
Manager, Quality and Reliability Metrics
DSC Communications Corporation
Plano, TX 75075

SUMMARY

This paper describes a method of graphically reporting reliability results and statistically comparing actual returns against predicted returns. The system described, aggregates circuit pack return data by more than 1200 hundred product types, three process models (new, repaired and steady state), and more than thirty customer groupings.

KEY WORDS

Failure Rates, Reliability, Reports, Statistical Measure, Telecommunications

INTRODUCTION

An elaborate method of reporting reliability results for circuit packs used in the telecommunications industry has been developed. The method uses QMP (Quality Measurement Plan) metrics to improve the process of reporting circuit pack return rates. The use of QMP metrics was originally proposed in the Bell System Technical Journal for the purpose of reporting quality assurance audit results to Bell System management (Hoadley 1981). 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 significant 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,
- it standardizes results for circuit packs of various complexities relative to an index of 1.0 times predicted,
- it reports the results in an easily interpreted graphic format, and
- it provides for data aggregation by product type, customer groupings and process models.

The method described in this paper improved the information derived from circuit pack return data that was collected in an existing system. The existing system included serial number identification of each circuit pack tracked through the return and repair process. Using QMP metrics it was possible to report reliability results in such a way as to communicate a better understanding of the statistical significance of the month to month actual returns compared to predicted returns. This method provided an information source that was used to successfully identify and improve design, manufacturing, and repair processes. The overall result was a substantial increase in measured reliability and increased customer satisfaction.

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 it's fifteen year history, DSC has shipped more than two million telecommunications circuit packs. It is the responsibility of the Quality and Reliability Assurance Organization to collect and report the reliability of more than twelve hundred circuit pack types.

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About three years ago, one of DSC's largest customers asked a relatively simple question about the reliability of circuit packs in service: "Which circuit pack types are experiencing return rates greater than predicted?" The method of reporting the reliability of DSC's circuit packs is the subject of this paper. The development of this system over the past three years, to include customer and process models has greatly enhanced the value of this system.

First understand, 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:

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

The failure rate for telecommunications circuit packs is commonly expressed in Failures In Time (FITS) per one billion hours of operation (Bellcore NWT-000332, 1985). The FITS rate for each circuit pack type is derived in a prediction process that accounts for each component that is a part of the complete assembly. The FIT rate for the example circuit pack type is 9,627 predicted failures in one billion hours. There is an average of 730 operating hours per month (30.4 days times 24 hours per day). In our example circuit pack, shown later in Figure 1, there are 770 units in service for the month of July. Thus the **Expected Failures** in our example is:

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

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 repair process. These circuit packs, when tested by 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, in fact, defective. They were replaced as part of the trouble-shooting process that is focused on restoring service and 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. DSC currently tolerates a No Fault Found Rate of 33% as acceptable. To account for this predicted level of returns greater than the actual failures, the number of Predicted Returns is computed as follows:

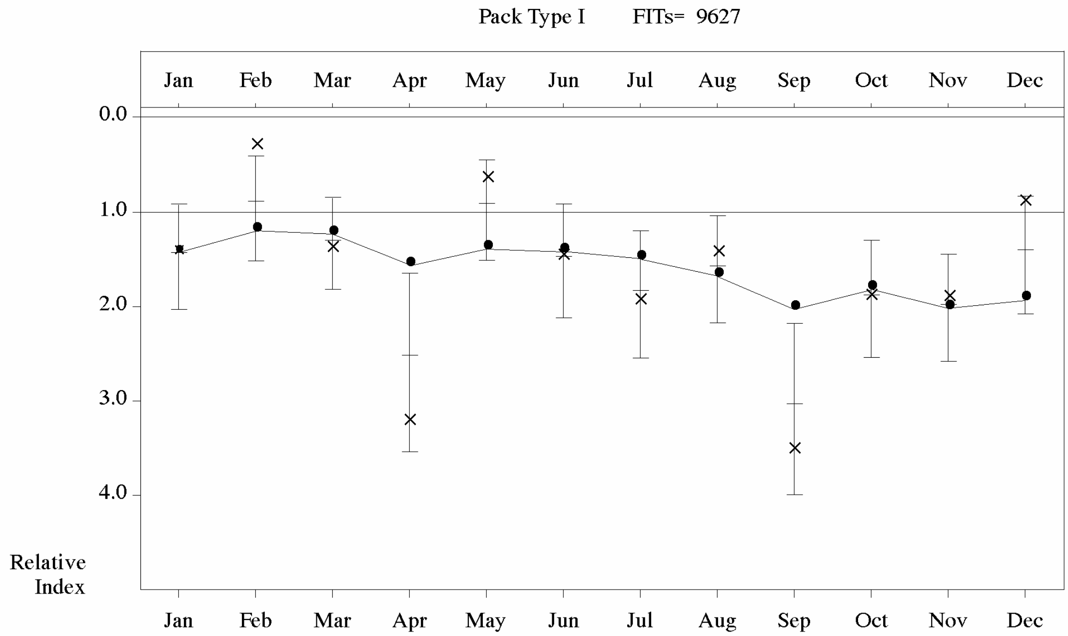
$$\textit{Predicted Returns} = (\,1 / 1 - \textit{NFF Rate}\,) \times \textit{Expected Failures} = 5.41 / 0.67 = 8.12$$

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.

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 (Hoadley 1981), (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 relative to the estimated true quality, and (5) when combined with a detailed graphical presentation, QMP conveys an excellent understanding of the return rate phenomenon.

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.



	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

Interpretations that could be made from the July computation include:

1. The **Current Index** for July 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 an "× ".

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.

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 always falls 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 boundaries of the 90% confidence interval of the Best Measure. For the July computation these values range between 1.20 and 2.55 times 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.

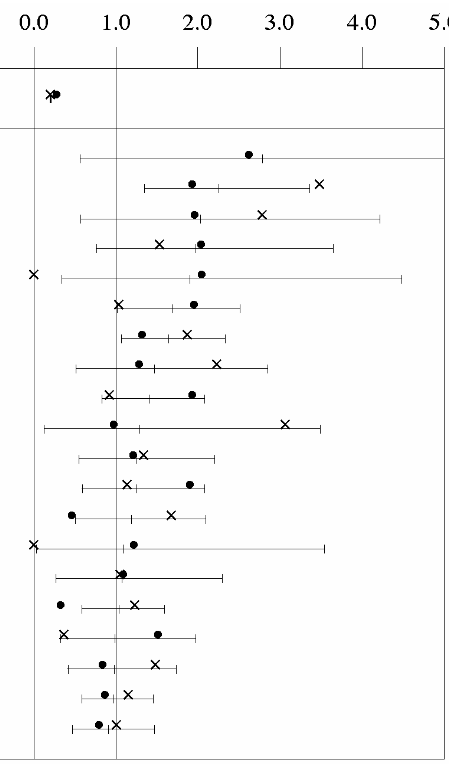
This Bayesian based statistic is thus capable of describing both the mean and variability of these computed monthly return rates.

STATISTICAL RANKING OF PRODUCT TYPES

It is now possible to produce more than twelve hundred QMP trend charts, one for each circuit pack type. However, the question still remains: "Which of these circuit pack types has the greatest improvement opportunity?"

By transforming the reliability objective, predicted returns for a given FIT prediction to a relative index of 1.0, circuit packs with different FIT rates can be compared. By creating an I-bar graphic that includes historical data inferences it is now possible to compare multiple circuit pack types within a single "ranking chart" with many of the qualities of a control chart. The ranking chart is able to show (1) the reliability return rates of various packs relative to a predicted index, (2) indicate statistical significance or lack of it, and (3) enable pattern interpretation and detection of changes.

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



* QAT Action Required - returns > 1, BM > 1.50, & 5th percentile > 1.00

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

In the example ranking chart given in Figure 2, twenty circuit pack types 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 types 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. It was predicted for this product line that 3,940 packs would be returned based on standard prediction methods.

2. Of the 376 pack types only 16 had Best Measures for December greater than 1.00 (Pack Types A - P). This represents 4.2% of the circuit pack types in this product line.

3. The composite Best Measure for the product line is 0.20. This is very 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.

Interpretations for Pack Type A results include:

1. It has the worst Best Measure of all 376 pack types 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, a 13% probability exists for getting one unit returned when the expected value is 0.16. But the QMP metric is looking at a six 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 type is being returned at a rate greater than predicted. Since the QMP confidence interval encompasses the "standard value of 1.0" and it has such a large confidence interval this pack type is not a strong candidate for improvement opportunity.

The circuit pack type of greatest concern here, i.e., the pack type that has the greatest **improvement opportunity** is Pack Type B.

Interpretations for Pack Type B results 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, is 3.48 (8/2.30).

3. From the Process Average it can be assessed that the current month return ratio (Current Index) is worse than the six month average of 1.93 times predicted. This could suggest a decline in performance or it could be just statistical variation.

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

Two more circuit pack types will get attention because they also have Best Measures greater than most of the 376 pack types and because they have confidence intervals that are entirely to the right of the predicted standard of 1.0. They are Pack Type F and Pack Type G. An asterisk is used to the right of each I-bar to identify improvement opportunities using the criteria of actual returns in the month greater than 1, the Best Measure of return rate greater than 1.50 times predicted, and the 5th percentile greater than 1.00.

AGGREGATION BY CUSTOMER GROUPING

Our customers have been interested in this new method of reporting reliability results from the beginning of this project. But their interest, in general, has only been for their individual universe of product. Beginning in 1993, we began aggregating our data by major customer groups. The monthly ranking chart for a product line and a customer grouping became the standard of reporting reliability of circuit packs to our customers. Each ranking report listed up to forty circuit pack types returned in the month. This usually included all pack types returned by the customer in the month. Typically, this ranking included circuit pack types with return rate Best Measures ranging from 0.10 to one or two times predicted. Few reliability differences between customer groupings were ever found as a result of this aggregation of data by customer groupings. Most circuit pack types with notably high return rates for a customer grouping were notably high for the entire universe. For an example of a rare but significant customer difference for a specific part type, refer to Figure 3.

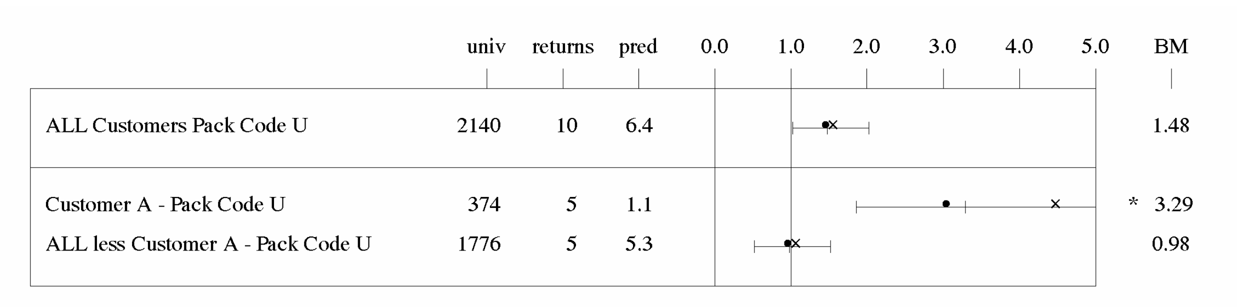


Figure 3. An example of a statistical significance between customer groups.

This type of data reporting helped us focus our corrective action plans at the few pack types with customer differences. We learned two basic lessons from this effort.

- The extraordinary inspection and workmanship efforts performed in the factory for one particular customer resulted in no significant increase in reliability of the product they purchased.

- Most significant differences in the reliability experienced between customers could be traced to a software load particular to one customer and not the other.

AGGREGATION BY PROCESS

After about two years of working with these models, it was hypothesized that a significant difference might exist in the reliability of new circuit packs, versus repaired circuit packs, and extended service circuit packs. This hypothesis proved to be the most significant in the development of this reporting system.

The existing model for the ALL customer group was divided into the NEW, REPaired, and Steady STATE models. The NEW model represented newly manufactured product in the field less than one year. The REPaired model represented repaired product in the field less than one year. The Steady STATE model represented both new product and repaired product in the field more than a year. The most startling observation was that the initial composite computation of the Best Measure of the return rate for REPaired circuit packs was twenty times the composite Best Measure of the return rate for NEW circuit packs. Simply stated, a repaired circuit pack was twenty times more likely to fail in the field than a newly manufactured circuit pack.

For each process model, QMP ranking charts were generated each month and Quality Action Teams were focused on the circuit pack types that had the highest return rates. Most of this Quality Action Team activity was focused on circuit pack types identified in the REPaired process model. Because both the NEW and REPaired models reflected rather recent events, it was timely to focus on the return and repair process (REPaired) and the process of new manufacture of circuit packs (NEW). The very few circuit pack types that had higher than predicted return rates in the extended service aggregation (Steady STATE) had already been identified as circuit pack types requiring upgrade or replacement.

Fifteen months after the introduction of the NEW, REPaired, and Steady STATE models, the composite Best Measure return rate for REPaired circuit packs was 1.00 and only one circuit pack type failed to meet the predicted return rate with any statistical significance. Improvements also occurred in the NEW and Steady STATE results. Figure 4 provides the most recent comparison of the COMPosite, NEW, REPaired and Steady STATE process models.

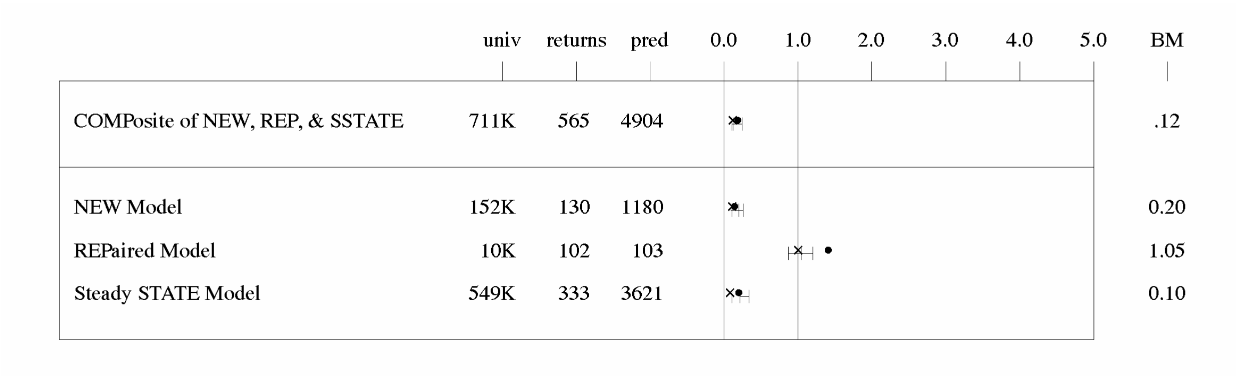


Figure 4. COMPosite model aggregated by process models NEW, REPaired, and Steady STATE

RESULTS

QMP reliability reporting is used to drive corrective action and improvement in the design, manufacturing, and repair processes at DSC. The high concentration of effort on the highest return rate packs has resulted in a substantial improvement during 1992, 1993, and 1994. In addition to these internal uses, QMP statistical rankings have been used to satisfy data reporting requirements for various customer reports.

CONCLUSION

This new method of reporting reliability data is an accurate, descriptive, and useful reporting mechanism. Used to initiate process improvements, this reliability reporting system has been instrumental in improving reliability for both new and repaired circuit packs. It demonstrates a successful and valuable use of 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 process improvement resources.

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