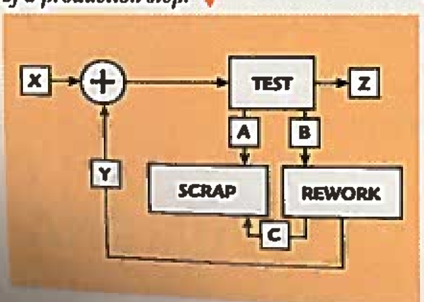
Cost Analysis of Rework and Test

A common dilemma encountered in high volume manufacturing of medium-complexity parts or assemblies is how to estimate whether it is more cost-effective to rework parts that fail a particular test criterion at some point in the process or simply scrap them immediately. At the extremes of manufacturing where the volume is high and the cost of the part is rather low or the part is not reworkable, or where the throughput is low and assemblies are complex and expensive, the choices are more obvious. A gray area exists where it is possible to fix or repair the defective part and the cost of scrapping is not insignificant. Here, a careful trade-off analysis must be conducted to weigh the ultimate economic benefits of reworking or scrapping. This situation is often encountered in RF assemblies where it is usually possible to recover some performance by either tuning or part replacement and failures are not always catastrophic. Before deciding upon an approach, several questions must be answered: What are the criteria for conducting such a trade-off analysis? What are the key parameters and how can this process be quantified? This article explains an approach that borrows from control theory for a simple method of analysis for practical applications.

Fig. 1 A simple flow diagram of a production step.



DEFINITIONS AND ASSUMPTIONS

A simple flow diagram of a production step (or sequence of steps) followed by a test step is shown in ***Figure 1***. The material input rate (or output rate from a previous step) is X, the output rate of the rework process is Y and the output of the total process through this particular step is Z.

A certain amount of scrap is generated through the test and rework functions where particular types of failures or faults are deemed to be irreparable and rework itself may uncover or introduce new defects. It is assumed that the scrapped material has no economical value. Note that the same setup is used for the test of both new and reworked parts. A number of simplifying assumptions were made that may not strictly hold in practice depending on the actual details of a process. An example is the assumption that rework does not affect the test failure rate. It is quite possible that reworked parts are scrapped or reworked again at rates different from new parts. This situation can be accommodated easily by using a slightly more complex flow diagram.

The throughput and yield of such a process first must be calculated to be able to proceed with a cost trade-off analysis. Intermediate quantities are defined, including the test scrap rate, as

$$A = (X + Y)q$$

where

q = first-pass scrap rate constant

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The rework rate is determined using

$$B = (X + Y)r$$

where

r = first-pass rework rate constant

The throughput (normalized to X) is then calculated easily as

$$Z = \frac{\left[(r+1) - q\right]}{(1 - r + rm)}$$

where

m = rework-to-scrap-rate constant

In addition, the manufacturing cost per unit (before test) C_{tmc}, test cost per unit T, average cost of rework for one unit R, rework cost factor $rw = R/(C_{tmc} + T)$ (typically, $rw < 1$) and test cost factor $t = C_{tmc}/(C_{tmc} + T)$ (typically, $t < 1$) are defined.

It is important to have a handle on these quantities, which usually can be obtained from historical data. It is difficult to generate these values up front for a new process. The quantities are normalized to total manufacturing cost (TMC) up to the test point for clarity and ease of calculation. The fixed cost of testing, which would indirectly include (through overhead) the cost of equipment and space, obviously must be considered. Note that (r + s) is always less than unity for a real process.

COST OF REWORK

The cost of a unit easily can be calculated by inspection if no rework was attempted, that is,

$$C = \frac{(C_{tmc} + T)}{(1 - q - r)}$$

Also, the unit cost with rework may be calculated from the flow diagram to be

$$C_{rw} = \left\{\frac{(C_{tmc} + T)}{Z}\right\} + B \bullet R$$

Note that B and Z are normalized quantities. For rework to be economically feasible, C_{rw} should be less than C. This equation is expressed as

$$C_{rw} - C = (C_{tmc} + T)\left\{\frac{1}{Z} - \frac{1}{1 - q - r}\right\} + B \bullet R < 0$$

This condition may be simplified as

$$D_{tc}(q,r,m,rw) = \left(\frac{1}{Z} - \frac{1}{1 - q - r}\right) + B \bullet rw < 0$$

where

$$B = \frac{1}{(1 - r + rm)} \bullet r$$

Only when this condition is satisfied does it make economical sense to make facilities available for reworking units that have failed the test. In practice, it is desirable that this quantity be less than zero by some insignificant amount to justify the impact of allocating rework resources beyond the margin of error associated with various estimates and approximations involved in this calculation.

An important fact should be noted concerning throughput vs. cost: In ef-

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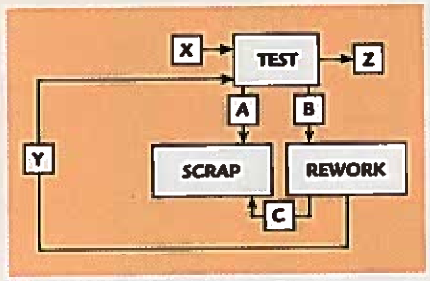


▲ *Fig. 2 The effect of rework.*

fect, rework boosts the yield of the process, which, in turn, lowers the cost per unit. In a situation where the assembly process is also a limiting factor, another important benefit is the increase in throughput. Some of the scrap is recycled into good units and added to the output flow. In fact, irrespective of the unit cost, rework always improves the throughput for a given limited capacity.

An example is shown in ***Figure 2***. It is made slightly more realistic by including the rework impact on the process itself where A = Xq1 + Yq2 and B = Xr1 + Yr2. ***Table 1*** lists a selection of typical coefficients for these equations. Cost and throughput improvements with rework are calculated and listed in ***Table 2***. The throughput in this case can be calculated as

$$Z(q1,q2,r1,r2,m) = (1-m-q1) - (m+q2)(1-m)\frac{r1}{\left[1-(1-m)r2\right]}$$

Effective throughput and cost of the reworked units for each scenario are also indicated in addition to total rework and scrap rates, which are normalized quantities. Note that for reasonable typical estimates of rework and scrap rates, cost savings are almost always possible. The throughput or yield always improves as mentioned previously. Also note that only for very high first-pass yields (for example, above 90 percent) and for very high cost of rework does rework become uneconomical.

A plot of the throughput and D_{tc} (m = 0.5, r = 0.2 and rw = 0.8) is shown in ***Figure 3*** as a function of the first-pass scrap rate q. Note that D_{tc} changes sign for q > 0.23 at which point the yield is slightly over 65 percent. At this scrap rate or higher, rework may be considered for this process since it would reduce the effective unit cost.

TABLE I

TYPICAL COEFFICIENTS

First-pass fail rate	(q1)	0.15	0.30	0.30	0.30	0.08	0.30
Rework fail rate	(q2)	0.25	0.25	0.25	0.25	0.25	0.10
Rework rate	(r1)	0.10	0.10	0.20	0.20	0.20	0.25
Rework rework rate	(r2)	0.075	0.075	0.075	0.075	0.075	0.050
Rework scrap rate	(m)	0.1	0.1	0.1	0.1	0.1	0.2
Rework cost factor	(r)	0.25	0.25	0.25	0.10	0.90	0.25

TABLE II

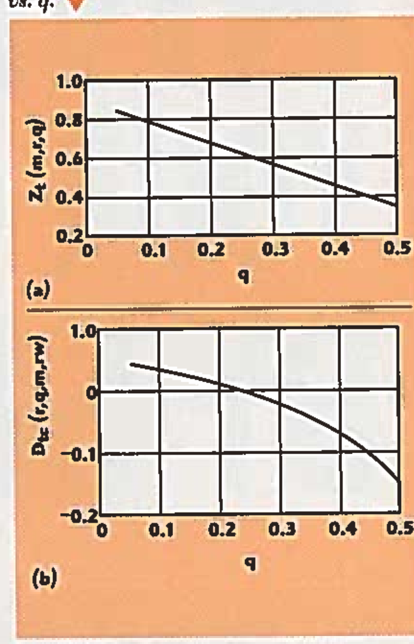
COST AND THROUGHPUT IMPROVEMENTS WITH REWORK

Throughput	0.81	0.66	0.61	0.61	0.83	0.59
Improvement (%)	7	9	22	22	16	31
Scrap	0.16	0.31	0.32	0.32	0.10	0.35
Rework	0.11	0.11	0.21	0.21	0.21	0.26
Cost	1.27	1.55	1.69	1.65	1.39	1.77
Improvement (%)	5	7	16	17	0	20

TEST AND WEED OR NOT?

Another common dilemma encountered when manufacturing assemblies is determining when and how often to test them. These questions are irrelevant for a single-step process since the final test is the only possible test point. On the other hand, a typical assembly involves multiple processing steps, as shown in ***Figure 4***. Each process step adds value to the assembly in terms of labor and material, but also introduces defects. The end of each step is a potential test point where the defective parts can be weeded for rework or scrap. This procedure eliminates defective assemblies from the process and prevents waste of resources on units that are doomed for failure at the final test. On the other hand, testing requires resources. Obviously, a trade-off exists, but how else can it be determined when it makes economical sense to test and weed?

Fig. 3 The (a) effective throughput and (b) total cost of the reworked units vs. q. ▼



▼ *Fig. 4 Multiple process steps for a typical assembly.*

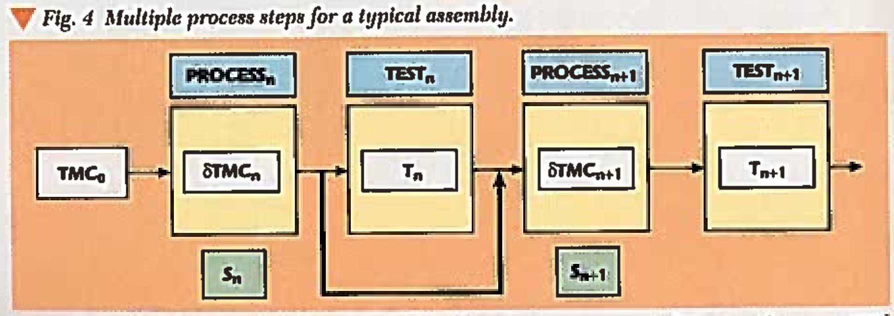


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TABLE III

PROCESS EXAMPLES

TMC before process$_n$	1	1	1	1
Yield from process$_n$ (= 1 – S_n)	0.20	0.30	0.55	0.95
Test$_n$ cost	0.05	0.15	0.15	0.10
TMC added at process$_{n+1}$	0.3	0.1	0.1	0.1
Test$_{n+1}$ cost	0.15	0.15	0.10	0.10
Test and weed for < 0	–0.370	–0.055	0.005	–0.005

A possible test point exists between steps n and n + 1. Several simplifying assumptions can be made to estimate the feasibility of eliminating this test step. Given process$_n$ and process$_{n+1}$, associated yields S_n and S_{n+1}, incremental increase of manufacturing cost δTMC_n and δTMC_{n+1}, and test cost of T_n for test step n, the cost of eliminating the test point n altogether can be estimated. For this process to be feasible the following inequality must hold:

$$T_n < \delta TMC_{n+1} + S_n T_{n+1}$$

A trade-off analysis is conducted with respect to the accumulated cost through the final test. Note that this result is independent of the yield of the second process step but dependent on the final test cost.

A key assumption here is that the test efficiency is 100 percent, that is, all defects are caught at every test step. Also note that the yield at each step is (1 – S_n). This trade-off analysis was carried out for a single test step although it can be easily extended to multiple steps to optimize the complete process, which obviously would become more complex than what is described in this article.

Note that for a typical high yield process, that is, for small S_n, the trade-off is dominated by relative magnitudes of T_n and δTMC_n. Various examples are listed in ***Table 3*** to demonstrate how the various quantities affect each other. As expected, the process benefits from intermediate testing for very low yields. Surprisingly, even at a high yield value and low incremental TMC added, it is possible to obtain a cost benefit from intermediate testing.

CONCLUSION

A simple method to analyze the cost trade-offs associated with reworking or scrapping failed assemblies has been presented. The analysis helps to determine where interim tests are cost-effective and how complex these tests should be. The analysis is particularly useful for medium-complexity parts in high volume production where the repair and rework is possible and the cost of scrapping the defective part is not insignificant. ■

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