Part VI

On-Line Quality Engineering

On-Line (Cases 88–92)

CASE 88

Application of On-Line Quality Engineering to the Automobile Manufacturing Process

Abstract: In this study we apply on-line quality engineering (On-QE) to a sampling inspection process for a transmission case after the machining process has been completed.

1. Conventional Approach to Quality in Automobile Manufacturing

In our conventional procedure, we inspected one sample every 50 to 350 parts, according to an interval predetermined by the nature of the characteristics being inspected. By prioritizing operational efficiency, we have made a judgment as to whether a work lies within or beyond a tolerance without process management based on process stability factors such as trends or process capability indexes, C_{pk}. In addition, once the measurement cycle is set up based on engineers' technical experience before a mass production phase, it has been modified very little except through design changes or when there are significant quality problems.

In other words, our conventional management is based on the mindset that "work within tolerances never causes a loss." A problem with this approach is that we have not really known whether working within a tolerance is close to the target, lies on the verge of the limits, or has an increasing/decreasing trend. When a product unit was confirmed to be out of tolerance, we had to measure all the completed products again to try to determine the point at which products beyond tolerance limits had begun to be machined.

If we adjust a target according to a trend, we can prevent a product beyond tolerance from occurring. On the other hand, if a process is stable, with no dispersion and deviation, the measurement cycle should be lengthened. Otherwise, it needs to be shortened. However, conventionally, we have quite often taken an excessive number of measurements, even if a process is stabilized, or an insufficient number of measurements even when unstable.

2. Obstacle in Application to an Automobile Production Line

To perform an On-QE analysis with current data, we collected actual data regarding 18 major characteristics in a process. Table 1 reveals the fact that obvious imbalance between control cost and quality loss leads to a large loss under current conditions, especially in that the quality loss accounts for the majority of the total loss. On the other hand, the optimal configuration improves the balance of loss, thereby reducing the proportion of quality loss to 50%. In addition, by adopting a calculated optimal measurement interval, adjustment interval, and adjustable limit, we could compress the total loss to 1/33 and gain a considerable improvement.

However, judging from our current facilities capability, we realized that the optimal adjustable limit calculated contains infeasible matters such as a 1-μm-level adjustment. Therefore, by determining an optimal adjustable limit, as long as it is practical under the current conditions, we had to recalculate an optimal adjustment interval and measurement interval. As shown in Figure 1, although we needed

Table 1
Evaluation of balance between control cost and quality loss[a]

	Current Condition		Optimal Condition	
	Monetary Value[b]	Proportion to Total Loss (Balance) (%)	Monetary Value[b]	Proportion to Total Loss (Balance) (%)
Control cost				
Measurement cost (1)	5	0.5	3	10.0
Adjustment cost (2)	1	0.1	12	40.0
Quality loss (3), (4), (5)	994	99.4	15	50.0
Total loss [sum of (1)–(5)]	1000	100.0	30	100.0

[a] (1) Measurement cost in process, (2) adjustment cost in process, (3) loss within adjustable limit, (4) loss beyond adjustable limit, (5) loss due to measurement error.
[b] The monetary value is estimated by assuming that the total loss = 100.

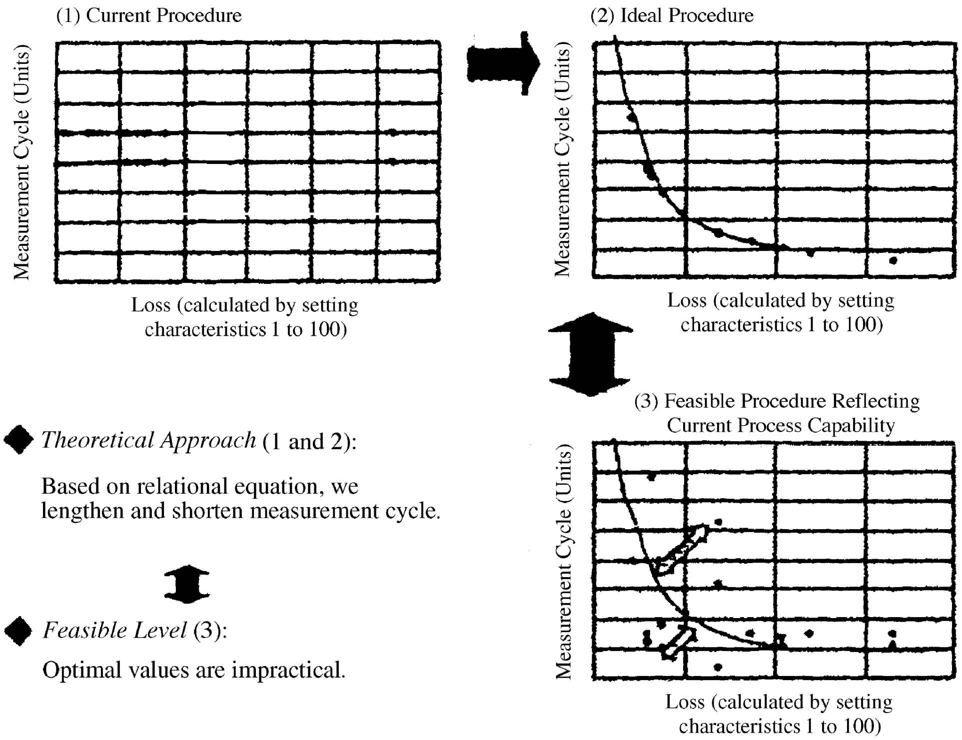

Figure 1
Limitation of application of analytical result to actual manufacturing line

to lengthen or shorten the fixed measurement interval (1) by following an ideal curve (2), the measurement cycle based on the current feasible adjustable limit follows (3).

As a next step, we analyzed the relationship between the process capability indexes C_p and C_{pk}, which were regarded as a basis in our conventional process control and loss. To convince management people, we had to find a connection between the On-QE method and our traditional management method. By doing this analysis, we confirmed that "a larger loss leads to smaller C_p and C_{pk}, and a smaller loss leads to larger C_p and C_{pk}" (Figure 2). In sum, our conventional approach to improving a process capability index is consistent with the new approach to reducing a loss.

To obtain the full understanding and cooperation of people in manufacturing lines for the use of On-QE, we improved processes with both the loss function and process capability indexes for the time being.

3. Design of System for Applying On-QE to an Automobile Production Line

Although we have successfully clarified the expected benefit earned thus far through the use of On-QE, the following three issues exist for its actual application to our manufacturing processes:

1. Since data analysis of the four-month-long results unveiled instability in the manufacturing processes, we were urged to build up a controlled condition (control limit: $\pm\Delta/3$), which is regarded as a precondition for applying the On-QE. More specifically, it was necessary to design a system for facilitating this corrective activity or a business system for effectively collection and analysis measurements with immediate feedback to operations.
2. Because we lack a system for managing and accumulating actual data, including time for a measurement or adjustment operation, we have not been able to understand actual data such as producer's loss, adjustment interval, time lag, or measurement/adjustment cost. Because of this, we need to build up a system to improve data accuracy by gathering and incorporating data efficiently into the calculation of loss.
3. Some of the theoretical optimal adjustable limits and the like are not feasible because of the technical capability of current machinery or tools. For instance, even if an optimal adjustable limit is calculated to be 1 μm, current machinery is only accurate to 5 μm. By identifying all these technical limitations, we need to prepare an operational rule reflecting the actual feasibility of our theoretical values.

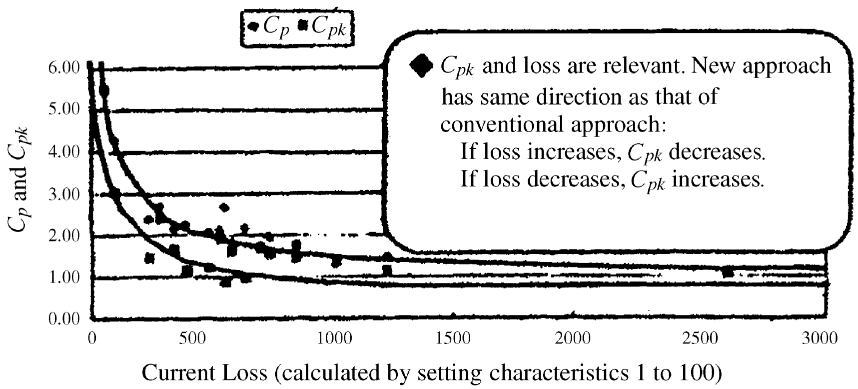

Figure 2
Relationship between quality loss and C_p and C_{pk} in the manufacturing process

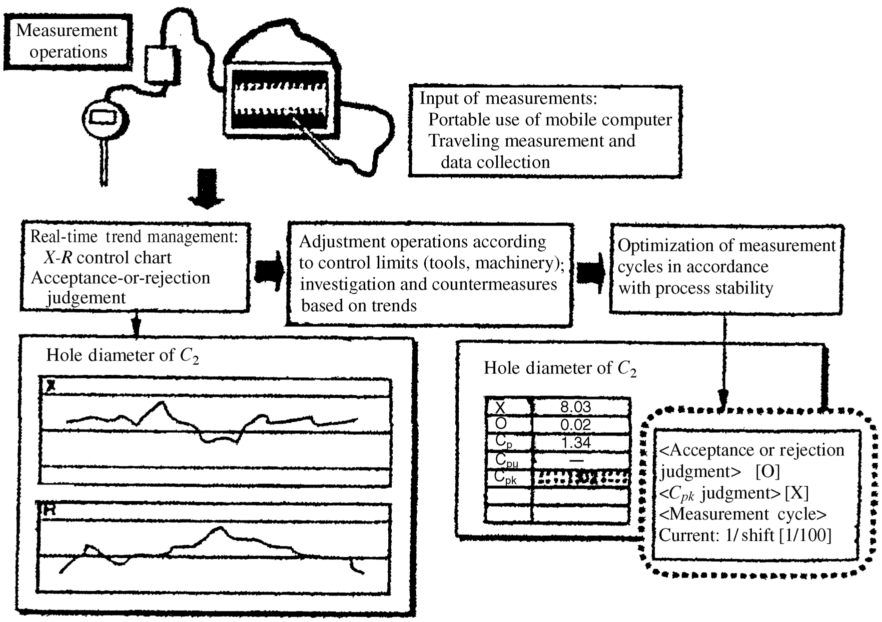

Figure 3
Work flow based on real-time quality data trend management and analysis system

For the foregoing issues, we took the following technical measures. First, although we have conventionally stored measurements on paper, they have not been fully used for analytical tools such as a control chart. Therefore, using the following three-step process, we built up a business system for efficient gathering and analysis of measurement data and feedback to actual operations. Then, in accordance with each level of process stability, we applied On-QE to each characteristic.

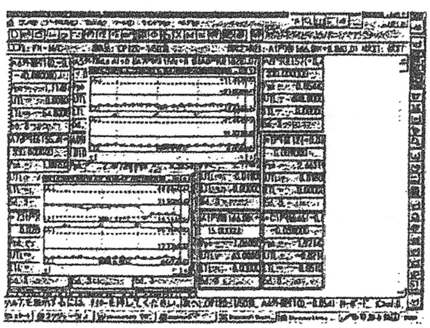

Figure 4
QTS: real-time display of control charts

- *Step 1.* We developed and introduced a real-time quality data trend management and analysis system (QTS), shown in Figures 3 to 5. More specifically, immediately after collecting sampling test data in real time, we create or renew an $\overline{X}$–R control chart and at the same time make a judgment on control limits or sound the alarm for an irregular trend. Each operator does his or her own operations by looking at the trends.
- *Step 2.* Based on the trend management above, we realize a controlled condition through a quick investigation and countermeasures in manufacturing lines (control limit: $\pm\Delta/3$).
- *Step 3.* In accordance with the process stability level, we optimize measurement/adjustment intervals and feed them back to actual operations.

In addition, for reliable feedback of plant-administrative and production engineering issues that are clearly defined through our new activity im-

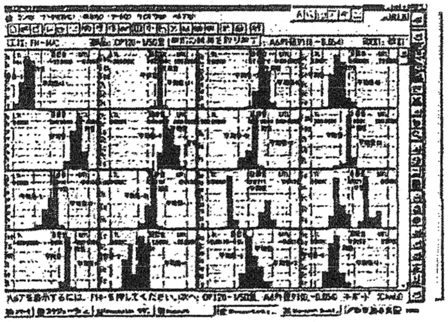

Figure 5
QTS: display of histograms for all characteristics

plemented in an efficient and intensive manner, we organize a promotion group and determine each role together with plant administrative and production engineering departments.

By making the most of periodic data related to measurements or tool changes, which are gathered by the QTS, we calculate a measurement/adjustment interval and time lag. By multiplying them by cost indexes, we convert them into a measurement/adjustment cost such that a loss can be computed later (parameters in the On-QE: C, D, u, and l). As for application procedures and the applicability of theoretical optimal values, we create business rules reflecting operational constraints or efficiency in the promotion meetings.

4. Achievements and Future Considerations

Based on analysis of the actual data for the 18 major characteristics, we defined four different levels representing process stability (from good to bad, each figure in parentheses indicates the number of characteristics for each level):

- *Level 3* (7). Trend management with a control limit of $\pm\Delta/3$ can be implemented because of process stability.
- *Level 2* (1). Plant administration needs to be improved because of significant deviation (intentionally biased adjustment of tools when changed).
- *Level 1* (5). A process needs to be improved because of the large variability.
- *Level 0* (5). A process needs to be investigated, analyzed, and corrected immediately because of process instability and various trends (e.g.,

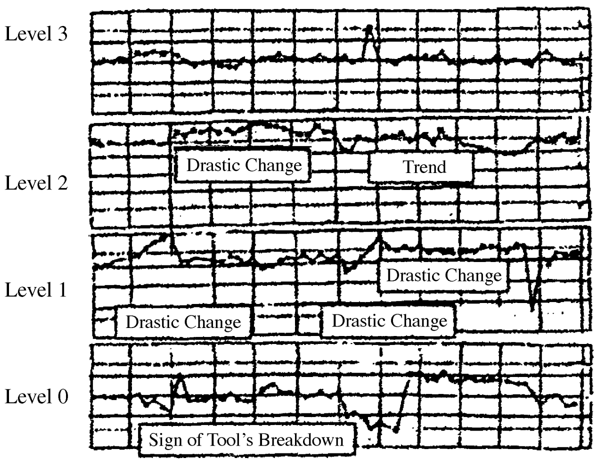

Figure 6
Example of X control chart for each process stability

insufficient adjustment of tools when changed or neglect of adjustment of tools when a part beyond control limits is found).

(See Figure 6.) Accordingly, we prepared a flowchart of process improvement and began to implement a systematic activity (Figure 7).

Through this activity, we obtained the following benefits:

1. The loss by process management in the current manufacturing lines was clarified, and drastic improvement in process stability was obtained (Figure 8). Consequently, we reduced problems dramatically in the process, thereby diminishing quality problems (Figure 9). In addition, by prolonging the measurement cycle (from 1/50 in our conventional process to 1/100 or 1/350), we achieved a 55% reduction in labor hours (Figure 10).
2. As a basis for a systematic activity, we established a business work flow that can improve quality continuously.
3. By clarifying the gap between the optimal measurement/adjustment cycle calculated and limitations in its use in the current processes and technical issues obtained through tracking of countermeasures and results, we

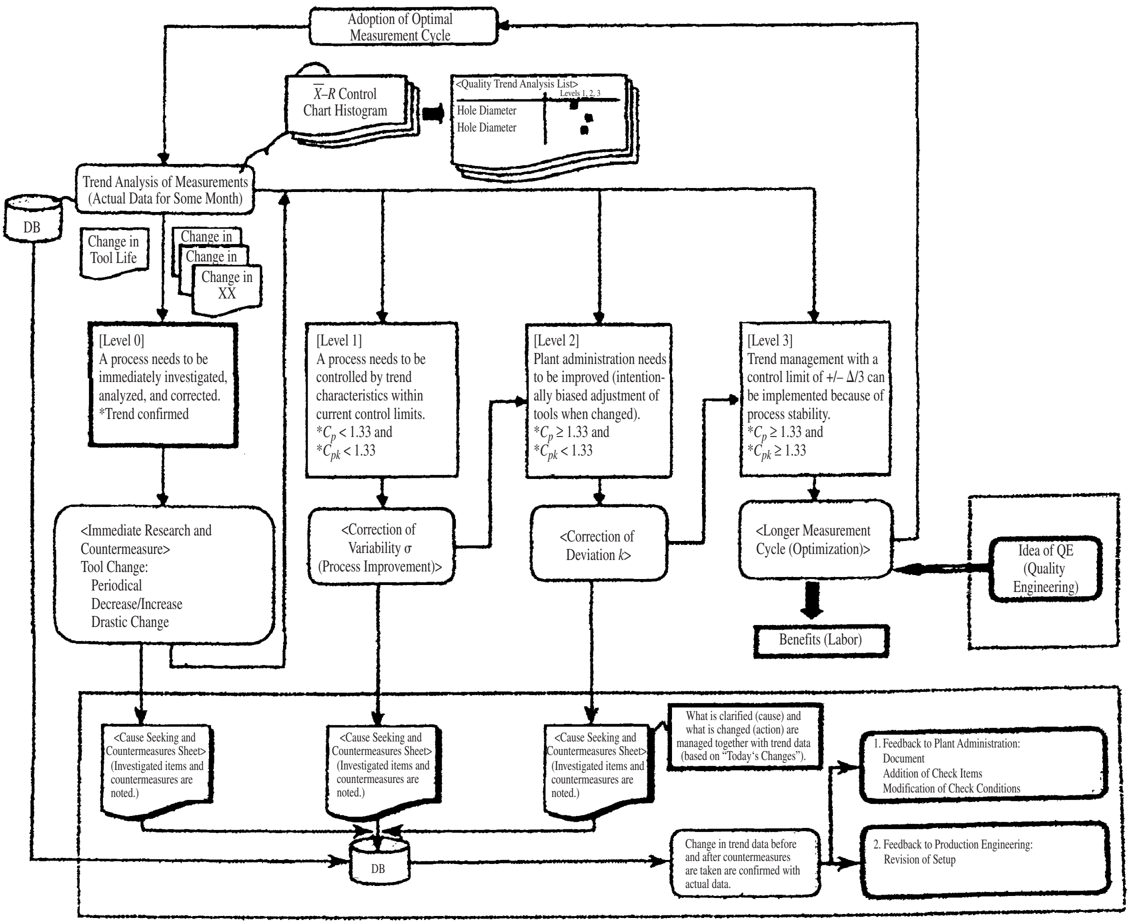

Figure 7
Flowchart of plant administration/process improvement based on process stability focused on trend values

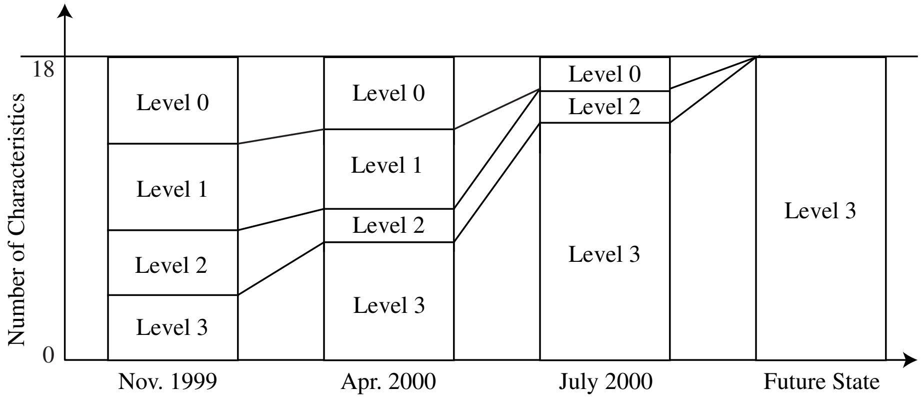

Figure 8
Transition of process stability for characteristics in 1/50 sampling test

established standards in measurement design in the mass production preparation phase.

The introduction to a new idea of the On-QE focus on a loss greatly affects conventional quality management, such as process management based on C_p and C_{pk}, or efficiency-oriented measurement design and operations that rest on a sampling test method in production engineering departments and plants. Particularly, in order to obtain an optimal value identified through calculation with the loss function, more resources, such as technology, labor hours, or management are needed for measurement or adjustment operations. Therefore, two key factors are that new technologies are developed from the two perspectives of accuracy and efficiency in measurement and that manufacturing management can essentially understand the loss function.

Therefore, when introducing a new manufacturing line, we need to design processes that enable us to implement precision measurement or adjustment operations while utilizing On-QE in the future. On the other hand, to obtain management's understanding, it is quite important to accumulate examples that make all participants feel involved: for example, the cost of tools or wasted materials or savings from reduced labor hours. In short, by

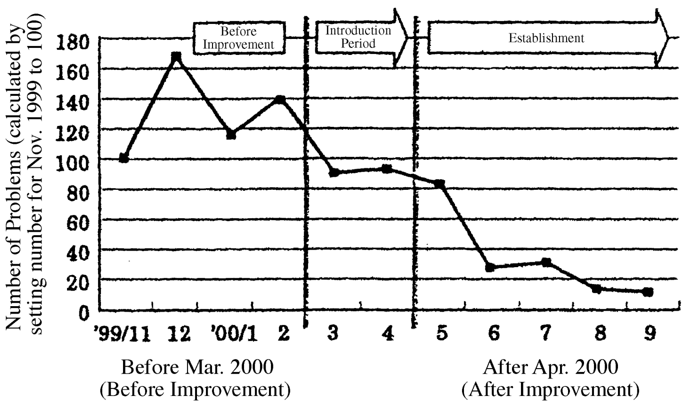

Figure 9
Transition of quality problems

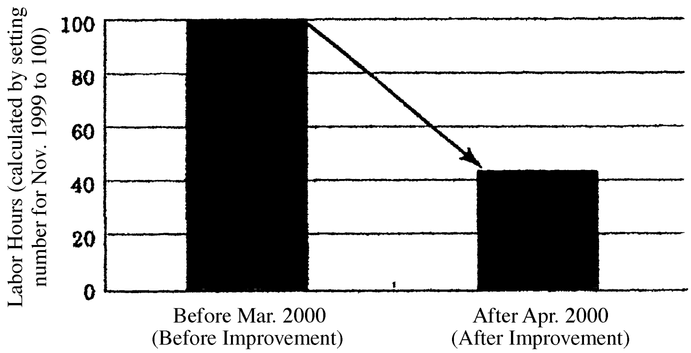

Figure 10
Labor reduction for sampling test (On-QE-applied seven characteristics)

verifying On-QE's contribution to these indexes used in plant management, we need to convince all people of the significance of the new activity.

5. Effective Application of On-QE

When applying a new idea or methodology to a production line, we must understand a new activity's significance by explaining the differences from and connection with a conventional procedure. In this case, to foster examples that can make all participants feel comfortable with the benefits is a key to success. In our study we achieved a longer measurement cycle that is closely related to actual operations. Through our application of On-QE to the current lines, we realized one of the most practical uses of On-QE.

The loss function is regarded as an effective index that should be used proactively not only for process improvement in mass production but also for process planning conducted by production engineering departments. In conclusion, we propose the following approaches:

1. Make the best of the loss function as a process evaluation index in mass production. As we have done in this study, use the loss function to analyze and optimize current processes and measuring instruments.
2. As an index to determine specifications for optimal processes and measuring instruments in mass production lines, utilize the loss function. If data obtained in technical trials are used, we can set up optimal methods of taking measurements, making adjustments, or calibrating measuring instruments according to a tolerance and loss for each characteristic: that is, proactively make the most of the loss function not only to improve current lines but also to design new lines. More specifically, fix specifications of machinery and measuring instruments that can be adjusted in accordance with On-QE after mass production begins or to design measurement processes.

6. Approach to Machining Systems for Developing Production Technologies

On-QE has proven its merits when used in association with off-line quality engineering. In this case it can be utilized as a mass production evaluation index for a machining system that is developed by off-line quality engineering.

An off-line quality engineering–applied system should be assessed on the basis of On-QE. In other words, if off-line quality engineering achieves robust design of the system, it can stabilize mass production processes. Therefore, On-QE analysis during mass production can become a yardstick for evaluating production engineering. On the other hand, if new technical issues are identified, as long as a business cycle feeds them back to production engineering development or process or machinery design, we can steadfastly enhance our technological level.

Reference

Yoshito Ida and Norihisa Adachi, 2001. Progress of on-line quality engineering. *Standardization and Quality Control*, Vol. 54, No. 5, pp. 24–31.

This case study is contributed by Yoshito Ida and Norihisa Adachi.