CHAPTER 6

Conclusions and Recommendations

6.1 Conclusions

Since the current process of monitoring tester performance is not effective enough to detect tester problems that unnecessary tester downtime is taken place, the new process has been developed to obtain the higher effectiveness in detecting tester problems.

Current process of monitoring tester performance is called TSPC which is used three parts known readings run across group of testers and plot the average of difference between reference and reading on control charts. When out of control is identified, actions taken on tester are necessary to find out the causes of out of control. TSPC requires standard parts used as TSPC parts generated from secondary standard generation process. TSPC is performed at least once a day called routine run and performed when there is a hardware or media change to verify tester performance.

Based on six sigma guidelines, the new process is developed through four phases of six sigma. In measurement phase, the problems of the current process are analysed, and the causes of problems are identified. Tools like fishbone diagram Pareto diagram, and Failure Modes and Effects Analysis (FMEA) are used to identified the causes of problems. From this phase, it can be concluded that the effectiveness of the current TSPC is only 30% that the major cause of ineffectiveness is from TSPC parts, generated from secondary standard generation process, which are sensitive causing in unnecessary SPC out of control from part degradation.

Hence, new process of tester monitoring has been developed by using manufacturing tested data from test operation, that tests production parts everyday. With a number of this data, it is expected to be useful in developing new process based on statistical analysis. In addition, manufacturing tested data is considered to be used because this data is already available without cost, and also easy to use. In analysis phase, the use of manufacturing tested data is analysed. Same wafer quad relation is used as the basis in developing the new process of monitoring tester performance. New process is applied for the product that has stability in same wafer quad performance which can be analysed by correlation procedure and hypothesis testing. Hence, the shifts in mean of same wafer quad can be used to identify the tester performance.

When same wafer quad relation is verified on the applied product, it is used as the basis of hypothesis testing that is the comparison based on same wafer quad. In improvement phase, each ET testing Vail are determined for the shift on same wafer quad performance by comparing interested tester to same tester at different time, different testers at same time, and different testers at different time. If the shift of same wafer quad causes significant difference to other testers, tester performance is investigated for the cause of that shift. If cause is not verified by tester, process could be one of the causes.

The new process is developed by creating the new system on the company's internal web. SPC charts are drawn to observe the process behaviour and tester performance. Statistical analysis of hypothesis testing is used to detect the shift of the interested tester from the same tester at same time frame, different testers at same time frame, or different testers at different time frame. Although hypothesis testing results are used as a tool to identify tester performance, other information have to be considered to obtain the accurate decision-making such as the mean and sigma of the tested readings based on same wafer quad, control limit width, the yield impacts, sample size, and so on.

In the final phase, control phase, work instruction is followed. Engineers have to observe this new system everyday to monitor tester performance. The follow-up is also done after the corrective actions are taken on the testers that are investigated. The new system is periodically reviewed. The weekly reports are submitted to the responsible group to make further analysis and improvement. Control plan should be followed.

After the new process is completely developed, it is implemented and currently used. There are a lot of benefits that could be obtained from the new process of monitoring tester performance. The company can save the cost high as $US 12,386 in a month. Tester downtime is reduced by 13% while the errors of classifying Type II errors are minimised. TSPC part usage is reduced by 53%. Furthermore, there are the other costs that can be saved after implementing the new process of monitoring tester performance such as cost of IAT arms, cost of secondary standard generation process, and cost of TTO. However, the current TSPC is still maintained for the hardware changes. The new process is replaced only for routine TSPC.

By applying six sigma to the improvement of the process of monitoring tester performance, the project is ultimate with the new process that improves the effectiveness from 30% up to 78% by using manufacturing tested data. As a result, it can be summarised that the new process of monitoring tester performance by using manufacturing tested data can provide more effectiveness than TSPC process.

Based on six sigma method, a lot of tools and techniques from six sigma breakthrough were applied to the implementation of this thesis. The uses of those can be summarised in Table 6.1.

Table 6.1: Statistical tools and techniques based on six sigma method

Tools and Techniques	Purposes	Comments		
		Used	Not	Why
Measurement Phase				
Process Map	To show graphical representation of the flow of a process	✓		
Roll Throughput Yield	To show defect rate per step and determine opportunities for improvement		✓	Not applicable
Cause and Effect Diagram	To identify, explore, and graphical display all the possible causes related to a problem	✓		
Cause and Effect Matrix	To link and prioritise all potential causes to customer requirements		✓	Use FMEA
Failure Modes and Effect Analysis (FMEA)	To examine and evaluate the potential failure modes and causes and rate the severity of their effects	✓		
Pareto Diagram	To focus effort on the problems that offer the greatest potential for improvement	✓		
Control Charts	To monitor, control, and improve process performance over time by studying variation and its sources	✓		

Boxplots	To show a graphical summary of values and help to identify extreme values	✓		
Normal Probability Plots	To test whether a given data set can be described as normal distribution	✓		
Minitab	To perform simple and complex data analyses, do data exploration, etc.	✓		
Central Limit Theorem (CLT)	To use in making inferential statistical decisions or make inferences about a population characteristics based upon sample data	✓		
Process Capability	To determine capability of the process to meet customer's expectations		✓	Not applicable
Gage R&R	To quantify the ability of inspectors or gages to accurately repeat their inspection decisions	✓		
Analysis Phase				
Confident Interval	To estimate the true population lies with a certain degree of confidence	✓		
Contingency Table	To test for statistic independence of two random variables		✓	Not applicable
Hypothesis for Variables - Mean (T-test)	To determine difference in means for two variable data	✓		
Hypothesis for Attributes	To determine difference in percent defects between different populations		✓	For attribute data
Hypothesis for Variables - Standard deviation (F-test, Homogeneity of Variance)	To determine difference in spread	✓		
Analysis of Variance (ANOVA)	To study mean difference for sample statistic by variance study	✓		
Regression	To develop an estimating equation	✓		
Correlation	To measure a linear association between two variables and determine the strength of relationship between the response and the predictor	✓		
Improvement Phase				
Design of Experiment (DOE)	To objectively evaluate the effect of one or more variables on an output while negating the effects of extraneous variables		✓	Use other alternative

Control Phase				
Statistical Process Control (SPC) and Control Charts	To provide a graphical representation of process performance and parametric stability, and to study variation and use statistical signals to monitor and improve performance	✓		
Control Plan	To operate the process consistently on target with minimum variation	✓		

6.2 Recommendations for Improvement

Improving the current process of monitoring tester performance can be done in various ways. Using manufacturing tested data is one alternatives which provide higher effectiveness in detecting tester problems. With limitations and assumptions, the proposed method might have some weaknesses. However, those weaknesses could be continuously improved when this new process is being used in the actual environment.

Some comments are recommended for further improvement after the new process is implemented instead of using routine TSPC. For example, the control limits of X-bar chart and S-chart which are re-calculated everyday based on 20 points of tested data each day could be more accurate if the out of control points are excluded after the corrective actions are taken or causes are identified. Thus, the control limits would be tighter so that they can detect the problems better. Moreover, S-chart should be considered before X-bar chart will be plotted. Out-of-control conditions of S-chart should be concerned and taken an action. As a result, the X-bar chart plotting would be more accurate. Although this project avoids this problem by not including the maximum and minimum data in calculating the control limits, it is just done for easiness in software operation that in fact it can not be ensured that maximum and minimum are the outliers.

On SPC, engineers should focus not only out of control points, but they should also notice the trend of the graph. There are seven conditions of the trends illustrating the abnormal conditions engineers have to be concerned. The trends of the graph sometimes tell about the causes of problems. The limitations of this new process is that it can detect only the long-term impacts that last more than 1 day or the major tester's problems causing a shift in mean of tested data. Trends of SPC can alleviate this limitation. Noticing the trends informs about the tester behaviours and process behaviours. However, it can not be concluded at a time what is the cause of problems. Then, other information has to be investigated for further root causes.

It is necessary for this new process that product applied has to have stable performance on same wafer quad. Thus, correlation procedure and hypothesis testing to confirm same wafer quad relation should be periodically reviewed otherwise the decision-making might be wrong. Since this is important, the software should be automatically making this analysis to confirm same wafer quad performance and product stability.

Another comment is on the using of inferential statistical analysis or hypothesis testing. With the proposed method, 2-sample T-test is used because the factor that is being concerned is only time for comparing own tester to SD or tester for comparing own tester to DS and DD. The factor of different wafer quads is not concerned that it is supposed that wafer variation is none. In fact, there is much variation between different wafer quads so this factor becomes impact. As a result, mean square error has changed affecting to the results of mean differences between different testers or time frames. Two-way ANOVA is considered because two factors become concerned that are time or tester and wafer. To illustrate that wafer affects to the hypothesis testing or in the other words there are the significant differences between different wafer quads, the example of two-way ANOVA is given to compare the mean of own tester and different tester at same time frame by considering wafer is another factor other than tester.

One-way Analysis of Variance on LFA

Source	DF	SS	MS	F	P
Tester	1	53666	53666	15.84	0.000
Error	36	121950	3388		
Total	37	175616			

Two-way Analysis of Variance on LFA

Source	DF	SS	MS	F	P
Wafer	18	95142	5286	3.55	0.005
Tester	1	53666	53666	36.03	0.000
Error	18	26808	1489		
Total	37	175616			

One-way Analysis of Variance on OVW

Source	DF	SS	MS	F	P
Tester	1	2.57	2.57	1.74	0.191
Error	70	103.00	1.47		
Total	71	105.57			

Two-way Analysis of Variance on OVW

Source	DF	SS	MS	F	P
Wafer	35	98.334	2.810	21.07	0.000
Tester	1	2.565	2.565	19.24	0.000
Error	35	4.666	0.133		
Total	71	105.566			

This analysis is done on tester ECT436Z on LFA of Vail on January 28th, 2000 and ECT738Z on OVW of Vail on March 1st, 2000 that raw data is shown in Appendix Q and Appendix R, respectively. For LFA, it can be seen that not only there are the significant difference on means between different testers, but there also be the significant difference on means between different wafer quads. It means both tester and wafer quad factors are the sources of variation. For OVW, one-way ANOVA indicates no significant difference between two population means when tester used as a factor, but two-way ANOVA indicates there are significant difference on means based on different testers and significant difference on means based on different wafer quads. It can be seen that different testers result in no significant significance in means on one-way ANOVA, but result in significant difference in means on two-way ANOVA because errors from wafer variation is taken into account. Results of hypothesis testing is different dependent on which way is used so appropriate method should be selected. As a result, the analysis by using 2-sample T-test or one-way ANOVA that considers only tester as a factor might have errors from different wafer quad variation. Then, hypothesis testing implemented, of own tester to SD, DS, and DD, should consider the difference in wafer quad variation that two-way ANOVA is more appropriate. However, because of software limitations, 2-way ANOVA can not be implemented at this time. The best way now is only a single factor is considered.

In addition to wafer quad variation, the interaction of different wafer quads on different testers or time frames is also considered. Interaction has affected to the results of hypothesis testing. Two-way ANOVA with replication can account for this. Since this method has to deal with a lot of data that each wafer on each tester has to have data more than one, in this thesis it is assumed that no interaction between wafer quads and testers or time frames.

Normality test has to be tested on sample data before doing hypothesis testing. Especially, F-test which is sensitive to normality of the data. However, this study assumes that data is all normally distributed. Likewise, on hypothesis testing the data or qualified wafer quads should be examined for the outliers that the ones which could be identified for the cause of errors should be eliminated before making a comparison. Due to software limitations, the proposed system has not afforded for this yet. All wafer quads that their counts meet minimum requirements are included in the hypothesis analysis including outliers. Then, some abnormal wafers might impact to the decisions, but they do not usually affect much because the comparison is based on same wafer quads matching. It means that although a wafer quad give too high or too low reading on the focused tester, the reading on other testers that test same wafer quad would get the same direction. However, the outliers should be eliminated before making a statistical analysis.

As the new process of monitoring tester performance is proposed, it can be seen that the procedure to use this new system is so complicate. There are no certain procedures or instructions to point out which cases the causes are from tester issues. This system just provides the information concerned in making a decision which tester should be taken actions to find out root causes. The priority of choosing testers to take actions depends on engineer's decisions. Using this system requires the skills and experiences of users. Anyway, when this system is used for a period of time, there might be the certain instructions which help the users use it more easily and effectively.

As the system informs about the tester performance, the focused tester has to be investigated to further find out for the root causes of tester problems. Those root causes might be from media, calibration process, degradation of hardware, etc. The initial investigation can be implemented immediately by looking at factoring report, downtime report, preventive maintenance report, and so forth before following the tester troubleshooting guide in Appendix F. Therefore, additional feature that is the attachments of those reports should be directly linked to this new system so that the users can save time and be convenient in investigating the root causes.

6.3 Recommendations for Further Study

Since the proposed process of monitoring tester performance has still many drawbacks, it should be continuously improved to optimise its effectiveness. One of its drawbacks is that the new process requires one-day tested data to analyse the tester performance. As a result, it may be too late that those testers would be used in testing the parts from production until the engineers is notified for taking actions to those testers. Unfortunately, parts that have already tested would not be re-test if they are passed. This problem gives the wrong testing results that the good parts might be rejected and the bad parts might be shipped to customers. The latter case is more severe because customers may be unsatisfied causing company's image lose. Additionally, there are no any following processes that would be checked or inspected for the mistakes and misclassifying those parts in electrical performance. The company cannot know how many defect items are shipped to customers. Therefore, the proposed process of monitoring tester performance should be improved to be more real-time so that the testers can be immediately detected when they go wrong. Furthermore, the company should provide the inspection for electrical testing. Then, the defect rate after testing on ET can be detected. This would also be useful for the further improvement.

The sample size of number of qualified wafer quads that the counts of each wafer quads have to meet minimum requirements should be realised. Although the degree of freedom in making hypothesis testing can support this at certain level, the results would be obtained higher confidence if the sample sizes of qualified wafer quads are met. As the sample sizes of number of qualified wafer quads are concerned, the hypothesis testing has not enough confidence because there are few wafer quads matching when making comparison based on same wafer quad, especially between own tester and SD. As a result, comparing to SD is not focused although monitoring tester performance by comparing to the same tester is seem better because of SPC principles. Therefore, when the conclusion is drawn on tester performance, sample size of qualified wafer quads should be considered. However, further project should be looking for the method that uses few amounts of sample size or the method that provides a large enough sample size for statistical confidence.

On this project, it focuses on continuous parameter such as LFA and OVW. These two parameters are just the demonstrated cases so this system can also be applied to other continuous parameters which follow normal distribution. In spite of continuous parameter, discrete parameter is another type that is concerned on testing on ET. The examples of discrete parameter are Off-Track Capability_Error Floor (OTC_EFL), Pulse-width at 50% height (PW_50), and so on. The continuing project might be implemented to support those parameters that the methodology might be similar to or might be differed from continuous data.

As well as Vail, this project can also be applied to other products that are volume-built and stable over time such as Bigbear, Durango, etc. However, the system should be improved to support for the products that are small volume-built or the products that are not stable as well.

Although the new process is replaced for TSPC that is run on routine, the current TSPC is still performed when there are the hardware changes. It is performed to confirm the tester performance whether it is still operating effectively. Due to the problems of TSPC defined earlier in the problem statement section, it has a problem with part degradation when they are handled and used for several times resulting in changing in reference reading. Since this cause is still affected to TSPC on hardware changes, it should be realised to find out other methods avoiding this problem. The procedure in running TSPC might be changed, or TSPC parts might be used in the limited period depended on historical records of part degradation.

In addition to using manufacturing tested data to monitor tester performance, there may be other methods that can overcome the drawbacks of this process. The statistical analysis and six sigma breakthrough can be used to help making the decision. It would be better if the root causes of problems can be solved directly. Unlike the current process that uses the result to tell about the causes, it would be preferred if the problems can be solved at the sources. Calibration process and preventive maintenance procedure might be improved.

The improvement of the process of monitoring tester performance has now proposed. However, with the scope and limitations they cause this application use in the limited area. When time and effort are available, the project can be continued to overcome the given limitations and assumptions resulting in widely using in the widespread application.