Achieving Process Analysis in TFT-LCD Manufacturing Industry by Using Statistical Technique

Kun-Lin Hsieh*
Department of Information Management & Research Group in Systemic and Theoretical Sciences
National Taitung University
684, Sec. 1, Chung Hua Rd., Taitung, Taiwan 950, R.O.C.

Yen-Sheng Lu
Photondynamics Inc.
Taiwan Branch Tainan Office
Suite A5, 11F, 30, Jungjeng, South Rd., Yungkang city, Taiwan 710, R.O.C

Abstract: - Enhancing yield via detailed process analysis had become an important competitiveness determinant for thin film transistor-liquid crystal displays (TFT-LCD) factories. Until now, few studies were proposed to address the related issues for process analysis in TFT-LCD industry. Therefore, the process know-how, effect analysis or the improvement chances which are hidden behind process analysis will be frequently omitted. Hence, how to apply usedul techniques into analyzing the manufacturing processes will become an important issue to be addressed in TFT-LCD industry. In this study, we proposed a procedure based on statistical analysis technique to achieve the purpose. A real illustrative case owing to TFT-LCD manufacturer at Tainan Science Park in Taiwan will be applied to verifying the rationality and feasibility of our proposed procedure.

Key-Words: - process analysis, thin film transistor-liquid crystal displays (TFT-LCDs), statistical technique, stepwise regression

1 Introduction

The market for liquid crystal displays (LCDs) is known as a growing rapidly and impacting new fields. Personal digital assistants (PDAs), cellular phones, digital cameras, computers, notebooks, flat panel TVs and various computer game units will be the primary LCD products. Generally, during the past several years, the market for LCDs has grown at over 20% on average per annum. The demand gradually increased particularly in South Korea, Japan and Taiwan (Su et al., 2004). The price for LCD products is significantly reduced due to both the technology maturity and ample manufacturing capacity. The downward pricing trend further promotes LCD applications. The most widely used LCD for high information content display is the thin film transistor-liquid crystal displays (TFT-LCD). The TFT-LCD panel has a sandwich structure (Singer, 1994) consisting of two glass plates with liquid-crystal material in between. The bottom substrate is the TFT array. The top substrate is the color filter plate. Color filter glasses are usually purchased from outside vendors.

The manufacturing technology, capital investment and industrial infrastructure are key factors affecting LCD industry competition (Su et al., 2004). The ability to improve yield in the manufacturing process is an important competitiveness determinant for LCD factories due to the significant yield loss ranging from 5 to 25%. However, few studies were proposed to address the manufacturing process in detailed until now. And, it will limit or omit the possible chance of improving manufacturing process. In order to survival during the competitive environment, how to mine the useful information from the “know how” or “domain knowledge” of manufacturing process will be an important issue to all enterprises. An analysis procedure based on statistical technique to the TFT-LCD manufacturing industry was proposed in this study. In order to verify the rationality and feasibility of our approach, an illustrative example owing to TFT-LCD manufacturer at Tainan Science Park in Taiwan will be also chosen in this study.

2 Stepwise regression

Stepwise model-building techniques for regression designs with a single dependent variable had been described in numerous sources (e.g., see Darlington, 1990; Hocking, 1966, Lindeman, Merenda & Gold,

1980; Morrison, 1990; Neter, Wasserman & Kutner, 1985; Pedhazur, 1982; Stevens, 1986; Younger, 1985). The basic procedures of Stepwise model-building will involve: (1) identifying an initial model; (2) repeatedly altering the model at the previous step by adding or removing a independent variable (or process parameters) in accordance with the "stepping criteria"; (3) terminating the search when stepping is no longer possible given the stepping criteria, or when a specified maximum number of steps has been reached. The details on the use of stepwise model-building procedures will be given as follows:

(1) The initial model can be defined as Step 0. The initial model always includes the regression intercept (unless the No intercept option has been specified with respect to the real requirement). As for the backward stepwise and backward removal methods, the initial model also includes all effects specified to be included for the analysis. The initial model for these methods is therefore the whole model. For the forward stepwise and forward entry methods, the initial model only includes the regression intercept (unless the No intercept option has been specified.). The initial model may also include 1 or more effects specified to be forced into the model. If j is the number of effects specified to be forced into the model, the first j effects specified to be included are entered into the model at Step 0. Any such effects are not eligible to be removed from the model during subsequent Steps. Effects may also be specified to be forced into the model when the backward stepwise and backward removal methods are used. As in the forward stepwise and forward entry methods, any such effects are not eligible to be removed from the model during subsequent Steps.

(2) The forward entry method is a simple model-building procedure. At each Step after Step 0, the entry statistic is computed for each effect eligible for entry in the model. If no effect has a value on the entry statistic which exceeds the specified critical value for model entry, then stepping is terminated, otherwise the effect with the largest value on the entry statistic is entered into the model. Stepping is also terminated if the maximum number of steps is reached.

(3) The backward removal method is also a simple model-building procedure. At each Step after Step 0, the removal statistic is computed for each effect eligible to be removed from the model. If no effect has a value on the removal statistic which is less than the critical value for removal from the model, then stepping is terminated, otherwise the effect with the smallest value on the removal statistic is removed from the model. Stepping is also terminated if the maximum number of steps is reached.

(4) The forward stepwise method employs a combination of the procedures used in the forward entry and backward removal methods. At Step 1 the procedures for forward entry are performed. At any subsequent step where 2 or more effects have been selected for entry into the model, forward entry is performed if possible, and backward removal is performed if possible, until neither procedure can be performed and stepping is terminated. Stepping is also terminated if the maximum number of steps is reached.

(5) The backward stepwise method employs a combination of the procedures used in the forward entry and backward removal methods. At Step 1 the procedures for backward removal are performed. At any subsequent step where 2 or more effects have been selected for entry into the model, forward entry is performed if possible, and backward removal is performed if possible, until neither procedure can be performed and stepping is terminated. Stepping is also terminated if the maximum number of steps is reached.

(6) Either critical F values or critical p values can be specified to be used to control entry and removal of effects from the model. If p values are specified, the actual values used to control entry and removal of effects from the model are 1 minus the specified p values. The critical value for model entry must exceed the critical value for removal from the model. A maximum number of Steps can also be specified. If not previously terminated, stepping stops when the specified maximum number of Steps is reached.

3 Proposed Procedure

The propsoed procedure will be given as follows.

Step1. Verifying the distribution of defect count on a panel to obey a Uniform distribution or not.

Basically, a glass can be frequently divided into several panels according to the requirement of specification. Each panel will be performed via the same manufacturing processes. Hence, if there are any particular causes (e.g. the equipment operation conditions) to be happened, the defect (or abnormal position) will not have the same probability value, i.e. the distribution of defect is not a Uniform distribution.

Hence, we can make the necessary analysis to mine are there any critical areas on a panel? In order to make such analysis, we discussed with the senior engineers to initially divide a panel into a 6×6 matrix. That is, total thirty six areas are formed on a panel. Then, we can collect the defect count lying on those thirty-six areas from the historical data. According to probability philosophy, if the defect is randomly happened, the probability value of any area on a panel will obey a Uniform distribution. Restated, we can take necessary statistical test, e.g. a distribution fitness test (or $\chi 2$ test), to verify it. That is, we can make a hypothesis as follows:

H_0: the defect count on a panel will obey a Uniform Distribution.
H_a: the defect count on a panel can not obey a Uniform Distribution.)

The statistic will have the following formula:

$$\chi_0^2 = \sum_{i=1}^{n} \frac{(o_i - e_i)^2}{e_i} \quad (1)$$

Where, o_i will denote the actual defect count on i-th area; e_i will represent the ideal defect count obeying the Uniform distribution on i-th area. Then, we can take the χ_0^2 value to compare with the cutoff value $\chi^2_{\alpha, v=n-1}$. If the judgment is to reject H_0, we can obtain the conclusion as "the defect count on a panel will not significantly obey a Uniform distribution". That is, the sensitive position (or critical area) will exist.

Step2.Screening out the sensitive position (or critical area) by using stepwise regression.

Next, we can take the yield to be the output variable and the thirty-six defect counts to be input variables, and the stepwise regression technique will be performed again (The detailed procedure can be referred to Section 2). Finally, the potential critical area on a panel can be mined via stepwise regression technique. The mined information about critical area can provide the useful information about manufacturing control and the practitioners can pay more attentions to the significant processes or manufacturing layer. Besides, the know-how about the manufacturing process can also be kept via yield model construction.

Step3. Construct the yield model based on linear system and screen out the possible information about the future improvement.

According to the result obtained from Step 2, we can construct the linear yield model. Herein, yield will be viewed as the response variable (or the output variable of a system) to our proposed modeling approach, and the defect (i.e. abnormal position) count of the critical area can be taken as the input variables to our proposed procedure. That is, the relationship between yield and defect count on critical area can be represented as:

$$\text{Yield}=f(\text{defect count}_{\text{area }(1)},\ldots,\text{defect count}_{\text{area }(36)}) \quad (2)$$

Where the defect $\text{count}_{\text{area }(i)}$ will denote the defect count on (i)-th critical area with the sequence of layer will be denoted as area (1) → area (2) →⋯→ area (n). After the linear yield model being constructed, we can obtain the useful information about the improvement from the coefficients of the independent variables (i.e. the defect count on the critical area). For instance, if the coefficient is a negative value, it will represent the larger defect count to obtain a higher yield. Obviously, it can not obey the general recognition. Restated, it maybe denote another causes to be happened.

4 Illustrative example

A TFT-LCD manufacturer's data at Tainan Science Park in Taiwan will be taken as an example to demonstrate our proposed procedure. Basically, TFT-LCD manufacturing processes can be mainly divided into three parts (in Figure 1).

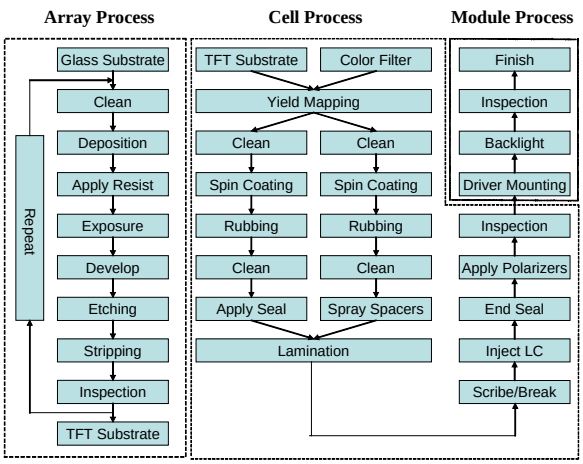

Figure 1. TFT-LCD manufacturing processes.

Then, we will take the procedure mentioned in Section3 to perform the analysis. The detailed procedure will be given as follows:

Step1. Verifying the distribution of defect count on a panel to obey a Uniform distribution or not.

A hypothesis will be assumed as follows:

H_0: the defect count on a panel will obey a Uniform Distribution.
H_a: the defect count on a panel can not obey a Uniform Distribution.)

In order to make the analysis, the thirty-six areas on a panel can be graphically depict in Figure 2. An example of defect count on a panel will be given as Table 1(a). Then, we will process the statistical test. The ideal defect count obeying a Uniform distribution will be listed in Table 1(b), where the ideal defect count based on a Uniform distribution can be computed as (total defect count)/(total area count)=35.13889. Next, the computation procedure of statistics according to Equ. (4) will be given as Table 1(c).

6	31	32	33	34	35	36
5	25	26	27	28	29	30
4	19	20	21	22	23	24
3	13	14	15	16	17	18
2	7	8	9	10	11	12
1	1	2	3	4	5	6
	1	2	3	4	5	6

Figure 2. The designed area on a panel.

Table 1 (a). The actual defect count on a panel.

6	21	56	24	30	6	56
5	49	29	16	20	15	115
4	30	62	43	97	8	35
3	69	37	31	6	6	60
2	31	30	21	2	17	23
1	43	38	39	39	27	34
	1	2	3	4	5	6

Table 1(b). The ideal defect count on a panel.

6	35.13889	35.13889	35.13889	35.13889	35.13889	35.13889
5	35.13889	35.13889	35.13889	35.13889	35.13889	35.13889
4	35.13889	35.13889	35.13889	35.13889	35.13889	35.13889
3	35.13889	35.13889	35.13889	35.13889	35.13889	35.13889
2	35.13889	35.13889	35.13889	35.13889	35.13889	35.13889
1	35.13889	35.13889	35.13889	35.13889	35.13889	35.13889
	1	2	3	4	5	6

Finally, we can get the statistic $\chi_0^2 = 583.9771$ by using Excel 2003. It significantly exceeds the cutoff value (43.77~55.76) and the judgment is made to reject H0. That is, the distribution of defect count on a panel does not obey a Uniform distribution. Hence, we can make the detailed analysis to find out the critical area on a panel.

Table 1(c). The computation of statistics.

6	5.689087	12.38474	3.530984	0.751537	24.16339	12.38474
5	5.467743	1.072486	10.42426	6.522288	11.54205	181.5025
4	0.751537	20.53336	1.758652	108.9049	20.96023	0.000549
3	32.6298	0.098573	0.487505	24.16339	24.16339	17.58948
2	0.487505	0.751537	5.689087	31.25272	9.363395	4.193434
1	1.758652	0.23296	0.424264	0.424264	1.885134	0.036913
	1	2	3	4	5	6

Step2.Screening out the sensitive position (or critical area) by using stepwise regression.

Next, we can take the yield to be the output variable and the thirty-six defect counts to be input variables, and the stepwise regression technique will be performed. For simplifying the operation, we will employ SPSS 13.0 to perform the necessary analysis. Figure 3 will graphically depict the stepwise procedure and Figure 4 will list the result of SPSS, the final chosen model includes about eight critical area with the sequence (area 21→ area 2→ area 27→ area 30→ area 36→ area 26→ area 4→area 6). About 81% variation can be explained by such model and the result will be acceptable case to the real requirement. That is, it will provide more useful information to the real practice.

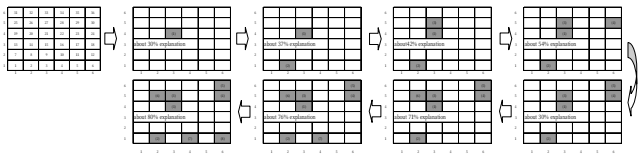

Figure 3. The stepwise procedure for the critical area on a panel.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.550[a]	.303	.297	15.40937
2	.615[b]	.378	.367	14.61714
3	.660[c]	.435	.420	13.99066
4	.746[d]	.557	.541	12.44897
5	.829[e]	.688	.674	10.48833
6	.855[f]	.731	.717	9.78323
7	.881[g]	.776	.762	8.95648
8	.903[h]	.816	.803	8.16161
9	.920[i]	.846	.833	7.50484
10	.952[j]	.907	.898	5.86266
11	.965[k]	.931	.924	5.06889
12	.974[l]	.949	.943	4.37271
13	.982[m]	.965	.960	3.66329

Figure 4. The stepwise result after performing SPSS13.

Step3. Construct the yield model based on linear system and screen out the possible information about the future improvement.

According to the result obtained from Step 2, we can construct the linear yield model as follows and the comparison diagram for the actual yield and the predicted yield will be denoted in Figure 5. Besides, the correlation r equals to 0.903 and it will represent a higher correlation. It will show that the effectiveness of the fitted model.

Yield = -0.974*defect $count_{area\ 21}$ + 0.27*defect $count_{area\ 2}$ + 0.621*defect $count_{area\ 27}$ - 0.968* defect $count_{area\ 30}$ + 1.225* defect $count_{area\ 36}$ -0.589* defect $count_{area\ 26}$ + 0.261* defect $count_{area\ 4}$ + 0.21* defect $count_{area\ 6}$

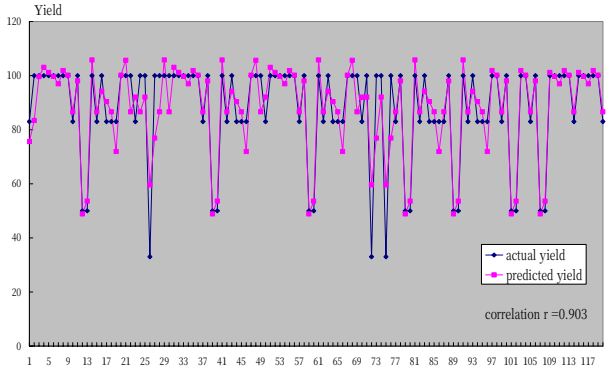

Figure 6. The comparison diagram for the actual and the predicted yield value.

From the constructed linear yield model, we can find out that several areas which do not include area 21, area 30 and area 26 will have a positive value. It will denote that the larger defect count will lead to a higher yield. After discussing with the senior engineers, we can make an assumption that the defect on those areas will represent the clustering effect from the real engineering experience or knowledge. That is, the necessary clustering analysis will be the subsequent job to make the process improvement in th future.

4 Conclusion

After applying a real example to demonstrate the proposed procedure based on statistical technique, we find out that the process analysis will make the practitioners to understand their domain knowledge or manufacturing core. The advantage of the proposed procedure can be summarized as:

(1) We analyzed the potentially sensitive position or critical area with respect to the abnormal position (or defect) on LCD-TFT panel and a complete data mining procedure is also proposed in this study. It will be viewed as a rational and feasible reference for the future analysis.

(2) The yield model can be constructed based on the critical area on a panel. From the real manufacturing consideration, the constructed yield can provide more useful information for improvement.

(3)The engineers can make more detailed analysis via using the proposed approach. The yield model can be viewed as an adjustable structure and the input variables will have the chance to adjust according to their manufacturing process.

Acknowledge

The authors would like to thanks the financial support from the National Science Council at Taiwan, R.O.C. with contract No. NSC 94-2416-H-143-001.

References:

[1] Darlington, R. B. *Regression and linear models*. New York: McGraw-Hill, 1990.

[2] Hocking, R. R. *Methods and Applications of Linear Models. Regression and the Analysis of Variance*. New York: Wiley, 1996.

[3] Lindeman, R. H., Merenda, P. F., & Gold, R. *Introduction to bivariate and multivariate analysis*. New York: Scott, Foresman, & Co, 1980.

[4] Morrison, D. F. *Multivariate statistical methods*. (3rd Ed.). New York: McGraw-Hill, 1990.

[5] Neter, J., Wasserman, W., & Kutner, M. H. *Applied linear statistical models: Regression, analysis of variance, and experimental designs*. Homewood, IL: Irwin, 1985.

[6] Pedhazur, E. J. *Multiple regression in behavioral research* (2nd ed.). New York: Holt, Rinehart, & Winston, 1982.

[7] Singer, P. Flat panel displays: an interesting test case for the U.S., *Semiconductor International*, 17(7), 1994, pp. 78-88.

[8] Stevens, J. *Applied multivariate statistics for the social sciences*. Hillsdale, NJ: Erlbaum, 1986.

[9] Su, C. T., Yang, T. and Wang, P. S., An optimal yield mapping approach for liquid crystal displays, *Journal of Quality*, Vol.11, No.4, 2004, pp.283-293.

[10] Younger, M. S. *A first course in linear regression* (2nd ed.). Boston: Duxbury Press, 1985.