Quality control process improvement of flexible printed circuit board by FMEA

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Abstract. This research focuses on the quality control process improvement of Flexible Printed Circuit Board (FPCB), centred around model 7-Flex, by using Failure Mode and Effect Analysis (FMEA) method to decrease proportion of defective finished goods that are found at the final inspection process. Due to a number of defective units that were found at the final inspection process, high scrap may be escaped to customers. The problem comes from poor quality control process which is not efficient enough to filter defective products from in-process because there is no In-Process Quality Control (IPQC) or sampling inspection in the process. Therefore, the quality control process has to be improved by setting inspection gates and IPCQs at critical processes in order to filter the defective products. The critical processes are analysed by the FMEA method. IPQC is used for detecting defective products and reducing chances of defective finished goods escaped to the customers. Reducing proportion of defective finished goods also decreases scrap cost because finished goods incur higher scrap cost than work in-process. Moreover, defective products that are found during process can reflect the abnormal processes; therefore, engineers and operators should timely solve the problems. Improved quality control was implemented for 7-Flex production lines from July 2017 to September 2017. The result shows decreasing of the average proportion of defective finished goods and the average of Customer Manufacturers Lot Reject Rate (%LRR of CMs) equal to 4.5% and 4.1% respectively. Furthermore, cost saving of this quality control process equals to 100K Baht.

1. Introduction
FPCB is components in the smart phone, it is produced by electronics manufacturer. A study factory is one of the FPCB manufacturer, its production begins from receiving FPCBs in sheet form from suppliers then bringing them into punching and assembly processes. At the end of the assembly process, FPCBs will be cut from sheet form to single pieces for 100% checking functions at the In-Circuit Test (ICT) and Functional In-circuit Test (FCT), respectively. Then FPCBs will be 100% inspected appearances at the final inspection process and sampling inspection at the Out-going Quality Assurance (OQA) inspection process. Proportion of defective finished goods were found at the final inspection process have to be scraped because could not be reworked. It made high scrap cost. Often, finished goods do not achieve production capacity’s target per day. Production data for FPCBs, model 7-Flex from June 2016 to May 2017 shows the average proportion of defective finished goods, OQA
Lot Reject Rate (%LRR of OQA), and Customer Manufacturers Lot Reject Rate (%LRR of CMs) equal to 5.7%, 8.4% and 5.9%, respectively and the scrape cost is around 1,000K Baht.

2. Problems
Focusing on FPCB’s production, model 7-Flex makes researcher to realize that the root cause of high defective proportion at the final inspection process because of the poor quality control process in current. It is not efficient enough to filter defective products from in-process because there is no IPQC or sampling inspection for appearance inspection during the process. Currently, the appearance inspection process have only one position but two inspection gates. There are the final inspection to 100% inspect and OQA inspection to sampling by following AQL 0.4, level II. Both of them are located at the end of assembly process before auto packing process. These are the minimum for appearance inspection of customer requirement. The current manufacturing and inspection processes for FPCB, model 7-Flex are shown in ‘Fig. 1’. Although inspectors at the final inspection processes rejected and removed defective finished goods but they were also found at the OQA inspection process and escaped to customers. Top three of defective finished goods were found at the inspection process from June 2016 to May 2017 are namely wrinkle, scratch and dent on Anisotropic Conductive Film (ACF) areas, their defective proportion equal to 2.8%, 1.6% and 0.4%, respectively. Defective photos are shown in Table 1.

![Figure 1. Manufacturing and inspection processes.](image)

**Table 1.** Top three defective.

| Top three defective | 1st          | 2nd          | 3rd          |
|---------------------|--------------|--------------|--------------|
| Photos              | ![Photo](image) | ![Photo](image) | ![Photo](image) |
| Defective type      | Wrinkle on ACF | Scratch on ACF | Dent on ACF |
| Defective proportion| 2.80%         | 1.60%         | 0.40%        |
3. Analysis procedures

3.1. Analyze defective finished goods

Top three defects from June 2016 to June 2017 are namely wrinkle, scratch and dent on Anisotropic Conductive Film (ACF) areas, respectively. All of them is defects caused by the FPCBs movement. Every process that has FPCB movement activities also has chances to generate defects on products. Actually, defective proportion from June 2016 to May 2017 is around 5.7%. Pareto chart of defective proportion is shown in ‘Fig. 2’. If researcher applies Pareto’s rule, the proportion of wrinkle on ACF is more than 20% of all defective units so it is priority that have to be detected and removed from processes before loading FPCBs into assembly process because they do not have components. Scrap cost of PFCB without component is lower than FPCBs with components. So if the defective products are removed from processes before the assembly process, they will make cost saving. Moreover, the Pareto chart shows some defects were escaped form supplier such as abnormal plating, incomplete gold plating and air bubble. Due to these defects cannot be completely generated by 7-Flex’s production.

![Pareto chart of defective finished goods](image)

*Figure 2.* Pareto chart of defective finished goods.

3.2. Analyze processes

Process analysis is step for finding processes that can generate defects on products both functions and appearances. Researcher and production team considered together by using (FMEA method for analyzing to determine risks of failure modes of each process. Scoring for severity, occurrence, and detection of failure modes are shown in Table 2. The FMEA’s result of current 7-Flex’s punching and assembly processes are shown in Table 3 and Table 4, respectively. The first 20% of Risk Priority Number (RPN) following Pareto’s rule is namely punching 1st, punching 2nd, punching 3rd, punching 4th, blanking, and auto packing process, respectively.
### Table 2. Scoring of FMEA.

| Severity of effect on products (customer effect) | Rank | Occurrence of failure modes | Rank | Detection by design control | Rank |
|-----------------------------------------------|------|-----------------------------|------|-----------------------------|------|
| All finished goods have to be scrapped and production line have to be stopped. | 10   | Occurrence is more than 10% | 10   | Failure modes can not be detected | 10   |
| All finished goods have to be scrapped but production line have not to be stopped. | 9    | Occurrence is between 5% to 10% | 9    | Failure modes are difficult to detect | 0    |
| All finished goods are waved before shipment and rework. | 8    | Occurrence is between 1.50% to 4.99% | 8    | Failure modes can be detected by operators self-check | 8    |
| Finished goods >50% have to be scrapped but remaining units can be reworked. | 7    | Occurrence is between 0.30% to 1.49% | 7    | Failure modes can be detected by operators self-check during process | 7    |
| Finished goods ≤50% have to be scrapped but remaining units can be reworked. | 6    | Occurrence is between 0.10% to 2.99% | 6    | Failure modes can be detected by Go-No-Go fixtures | 5    |
| All finished goods can be reworked. | 5    | Occurrence is between 0.05% to 0.09% | 5    | Failure modes can be detected by auto machine | 5    |
| All finished goods have defects but can shipment in terms of Use As If (UAI). | 4    | Occurrence is between 0.01% to 0.04% | 4    | Failure modes can be detected by Go-No-Go fixtures during process | 4    |
| All finished goods have defects but can shipment because they are within loose specification. | 3    | Occurrence is between 0.001% to 0.0099% | 3    | Failure modes can be detected by auto machine during process | 4    |
| All finished goods have defects but can shipment because they are within normal specification. | 2    | Occurrence is less than 0.001% | 2    | Failure modes can be detected by auto machine and process is locked by interlock system | 2    |
| No defective finished goods. | 1    | Failure modes are protected | 1    | Failure modes can be detected by auto machine during process and process is locked by interlock system | 1    |

### Table 3. Result of FMEA of punching process.

| No. | Sub-process | Potential failure modes | Severity | Occurrence | Detection | RPN |
|-----|-------------|-------------------------|----------|------------|-----------|-----|
| 1   | FPC receiving | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 2   | Label attachment | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 3   | 2D panel matching | Bad mark programming error cause missing components | 6        | 6          | 5         | 180 |
| 4   | Punching 1 | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 5   | E-Check 1 | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 6   | E-Check 2 | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 7   | Punching 2 | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 8   | Ag shield sheet applied | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 9   | SUS Lamination | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 10  | SUS curing | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 11  | Punching 3 | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 12  | Punching 4 | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |

**Table 3. Result of FMEA of punching process.**
Table 4. Result of FMEA of assembly process.

| No. | Sub-process | Potential failure modes | Severity | Occurrence | Detection | RPN |
|-----|-------------|-------------------------|----------|------------|-----------|-----|
| 13  | FPC receiving | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
|     |              | Air bubble, Delamination | 5        | 4          | 7         | 140 |
|     |              | Pad peel off, Ink peel off | 9        | 2          | 7         | 126 |
| 14  | FPC setting  | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 15  | 3D panel matching | Bad mark, programming error cause missing components | 9        | 5          | 5         | 225 |
| 16  | Solder printing | Solder defects (Height, Volume, Shape) | 5        | 3          | 3         | 75  |
|     |              | Painting misalignment | 9        | 3          | 3         | 135 |
| 17  | Solder Printing Inspection (SPI) | SPI Programming error cause reject | 1        | 5          | 5         | 40  |
| 18  | SMT on connector side | Component misalignment | 9        | 3          | 3         | 216 |
|     |              | Wrong component | 9        | 3          | 8         | 236 |
| 19  | AOI Pre-flow | AOI Programming error cause reject | 1        | 2          | 8         | 16  |
| 20  | Reflow       | Solder defects (Cosmetic cause from heat) | 1        | 2          | 8         | 16  |
|     |              | Over heat | 9        | 2          | 8         | 144 |
| 21  | AOI Post-reflow | AOI Programming error cause reject | 1        | 2          | 8         | 16  |
| 22  | FPC setting  | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 23  | Solder printing | Solder defects (Height, Volume, Shape) | 5        | 3          | 3         | 75  |
|     |              | Painting misalignment | 9        | 3          | 5         | 135 |
| 24  | Solder Printing Inspection (SPI) | SPI Programming error cause reject | 1        | 5          | 3         | 40  |
| 25  | SMT on IC side | Component misalignment | 9        | 3          | 3         | 216 |
|     |              | Wrong component | 9        | 3          | 8         | 236 |
|     |              | Penality reverse | 9        | 2          | 8         | 144 |
| 26  | AOI Pre-flow | AOI Programming error cause reject | 1        | 2          | 8         | 16  |
| 27  | Reflow       | Solder defects (Cosmetic cause from heat) | 1        | 2          | 8         | 16  |
|     |              | Over heat | 9        | 2          | 8         | 144 |
| 28  | AOI Post-reflow | AOI Programming error cause reject | 1        | 2          | 8         | 16  |
| 29  | 3D IC matching | Bad mark, programming error cause missing data | 1        | 3          | 3         | 25  |
| 30  | Filler dispensing | Epoxy defects over flow | 6        | 6          | 6         | 216 |
|     |              | Contamination on IC surface | 6        | 6          | 7         | 225 |
| 31  | Oven curing  | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
|     |              | Un-curing epoxy glue | 5        | 2          | 7         | 70  |
|     |              | Epoxy crack | 4        | 2          | 8         | 64  |
| 32  | 3D X-Ray     | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
| 33  | Blanking     | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
|     |              | Dent from blanking die | 9        | 7          | 8         | 384 |
|     |              | IC crack | 9        | 6          | 8         | 232 |
|     |              | Blanking misalignment | 7        | 5          | 7         | 245 |
| 34  | In-Circuit Test (ICT) | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
|     |              | Dent from fixture or pin in machine | 9        | 4          | 8         | 288 |
| 35  | Functional Circuit Test (FCT) | Handling defects (Dent, Scratch, Wrinkle) | 6        | 8          | 8         | 384 |
|     |              | Dent from fixture or pin in machine | 9        | 4          | 8         | 288 |
| 36  | Final inspection | Lacque defects | 1        | 3          | 9         | 27  |
| 37  | OQA inspection | Lacque defects | 1        | 2          | 8         | 18  |
| 38  | Auto packing  | Handling defects (Dent, Scratch, Wrinkle) | 1        | 2          | 10        | 30  |

3.3. Improve current quality control processes

The defective finished goods analysis makes researcher to know that defective proportion of raw materials were escaped to 7-Flex’s production and found at the final inspection process up to 0.3% from 5.7%. But in fact, production accepts defective proportion from raw material only 0.25%. So researcher designs inspection gate to sampling raw material before bringing production, this gate is called In-coming Quality Assurance (IQA) inspection process. MIL-STD-105E is applied for this gate because inspection's results are attribute data. Single sampling plan is used because it is the easiest for inspectors to use. This gate is designed to follow AQL 0.25, general inspection level II because this inspection is not destruct products and products’ price is not too expensive. Furthermore, the FMEA’s result shows the maximum and minimum score of RPN equal to 504 and 16, respectively. Inspection gates should be added after the critical processes for fastest detecting and filtering defective products during process. Practically, from punching 1st to punching 4th process is continuous process and FPCBs are operated in sheet form. So researcher adds the inspection gate next to punching 4th process to 100% inspect and individual bad mark the defective products, this gate is called punching inspection process. Surface Mount Technology (SMT) process at assembly process will not mount
component on bad marked products. Another inspection gate is added next to punching inspection to assure product’s quality by sampling because the punching inspection process and its inspectors are new. Single sampling plan is still used for this gate by following AQL 0.4, level II because target of defective proportion in-process is not over 0.5%. This gate is called punching Out-going Quality Assurance (OQA) inspection process. After finished the punching process, FPCBs will be brought into assembly process. FPCBs are still operated in sheet form by fixtures and removed from the fixture after finished 3D X-Ray process. From FPC receiving to 3D X-Ray process at the assembly process is continuous processes and uses the same fixture. The FMEA’s result shows RPN of epoxy overflow defect of under-fill dispensing process equals to 324. It is too high because if epoxy is stained on IC’s surface and cured at oven curing process (next to the under-fill dispensing process), FPCB have to be scraped. But if epoxy on IC’s surface is cleaned before curing, FPCB can accept. The defective proportion of epoxy overflow equals to 0.2% from 5.7%. Although it is not too much but cannot rework after curing so operators have to 100% inspect for the defect and clean if they find the defect. For this reason, another inspection gate is added next to the under-fill dispensing process to specially check epoxy on IC’s surface. Next critical process is blanking process because it have press, cutting, and many movements. After finished the blanking process, FPCB in sheet form becomes single piece and is tested functions at ICF and FCT processes. After that it is inspected appearance at the final inspection process. Even if the blanking process is critical to generate defects, they are detected at the final inspection process. Next to OQA inspection process is auto packing process and not critical. The new inspection processes for 7-Flex’s production is shown in ‘Fig. 3’. Totally, researcher add more four inspection gates. This is the improved quality control process.

3.4. Implement improved quality control processes

The improved quality control process have implemented for FPCB production, focus on model 7-Flex since July 2017 until. Moreover, the improved quality control process is used for production in terms of quality control plan (QCP) document to check processes before starting operations by operators. It identifies process sequences and their parameters that have to be checked include checking method. The parameters are separated by two characteristics, there are process and product. The checking method consists of equipment, sample size, and for checking and specification for referring. Furthermore, the QCP also identifies reaction plan to inform problems if operators find abnormal parameters after checked.

![Figure 3. New inspection processes.](image-url)
4. Results
After improved the quality control process and have implemented for FPCB production, model 7-Flex from July 2017 until now. Production data of inspection processes from June 2016 to September 2017 is shown in Table 5. It consists of the %LRR of IQA, the defective proportion at punching inspection process, the %LRR of OQA at punching inspection process, the rework rate at under-fill process, the defective proportion at final inspection process, the %LRR of OQA at final inspection process, and the %LRR of CMs. The inspection data of the old inspection processes have trend to decrease after implemented the improved quality control process while the inspection data of the new inspection processes can detect defective products. The average of defective proportion at final inspection process, the average of %LRR of OQA at final inspection process, and the average of %LRR of CMs in last three month equal to 1.1%, 1.0%, and 1.7%, respectively, they decrease from the average data of June 2016 to May 2016 equal to 5, 8, and 3.4 times, respectively. Trends of data of the six inspection processes and data of the customers’ inspection process from September 2016 to 2017 are shown in “Fig. 4’. And important, cost saving after the study factory implemented the improved quality control process from July 2017 equals to 100K Baht because the scraps in finished goods level or FPCBs with components at final process are decreased and the scraps cost of FPCBs in sheet form at punching process are less than the scraps cost of FPCBs in finished goods level at assembly process. The scrap cost of finished goods with components is around 300 Baht per unit but the scrap cost of sheet form without components is around 10 Baht per unit.

Table 5. Inspection data of 7-Flex production.

| Year | Month | %LRR of IQA (%) | Defective proportion at punching inspection (%) | %LRR of OQA at punching inspection (%) | Rework rate at underfill inspection (%) | Defective proportion at final inspection (%) | %LRR of OQA at final inspection (%) | %LRR of CMs (%) |
|------|-------|-----------------|-----------------------------------------------|---------------------------------------|------------------------------------------|------------------------------------------|-----------------------------------|----------------|
| 2016 | June  | N/A             | N/A                                           | N/A                                   | N/A                                      | N/A                                      | N/A                               | N/A             |
|      | July  | N/A             | N/A                                           | N/A                                   | 7.64                                    | 15.33                                    | N/A                               | N/A             |
|      | August| N/A             | N/A                                           | N/A                                   | 6.35                                    | 5.68                                     | N/A                               | N/A             |
|      | September | N/A             | N/A                                           | N/A                                   | 5.79                                    | 5.36                                     | 0.52                              | 1.13            |
|      | October| N/A             | N/A                                           | N/A                                   | 4.51                                    | 6.39                                     | 6.04                              | 8.45            |
|      | November | N/A            | N/A                                           | N/A                                   | 4.32                                    | 6.43                                     | 7.25                              | 9.45            |
|      | December | N/A           | N/A                                           | N/A                                   | 4.01                                    | 5.64                                     | 6.82                              | 7.25            |
|      | January | N/A            | N/A                                           | N/A                                   | 5.87                                    | 5.32                                     | 6.49                              | 8.45            |
|      | February | N/A          | N/A                                           | N/A                                   | 4.77                                    | 4.9                                      | 4.81                              | 5.81            |
|      | March  | N/A             | N/A                                           | N/A                                   | 5.79                                    | 4.82                                     | 4.42                              | 5.81            |
|      | April  | N/A             | N/A                                           | N/A                                   | 4.66                                    | 4.08                                     | 4.19                              | 5.81            |
|      | May    | N/A             | N/A                                           | N/A                                   | 5.12                                    | 4.15                                     | 4.08                              | 5.81            |
|      | June   | N/A             | N/A                                           | N/A                                   | 5.19                                    | 4.74                                     | 3.94                              | 0.52            |
|      | July   | 4.59            | 4.92                                           | 3.00                                  | 0.49                                    | 6.02                                     | 0.91                              | 1.50            |
|      | August | 5.32            | 5.01                                           | 2.92                                  | 0.60                                    | 1.12                                     | 1.01                              | 1.59            |
| 2017 | September | 4.59         | 4.92                                           | 3.00                                  | 0.49                                    | 6.02                                     | 0.91                              | 1.50            |

Figure 4. Trends of data of the inspection processes of 7-Flex production.
5. Conclusions
FMEA method is used for analysing processes to estimate their failure modes’ risk then add appearance inspection gates next to the critical manufacturing processes both 100% inspection and sampling. In-process inspection gates are added for checking and reworking product immediately. Totally, four new inspection gates are added, the improved quality control process have total six appearance inspection gates. Inspection’s results after implement the new improved quality control from July 2017 are decreased as expected. The defective proportion, %LRR, and scraps at the final inspection process are decrease because some defective products were detected and removed since the punching process and were reworked next to under-fill process. Moreover, decreasing of scraps in finished goods level make cost saving almost 100K Baht

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