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DEPARTEMENT BEDRYFS- EN SISTEEMINGENIEURSWESE
DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

FRONT PAGE FOR FINAL PROJECT DOCUMENT (BPJ 420) - 2017

Information with regards to the mini-dissertation

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Author [Last name, Initial(s) e.g. Botha, P.J.]	van Loggerenberg, N
Student number	14035911
Supervisor/s [Last name, Initial(s) e.g. Botha, P.J.]	Breytenbach, W.P.
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Abstract [Provide an abstract of the mini-dissertation. An abstract is a short summary of the contents covered in the item.]	Interim Report for BPJ420 including problem investigation, literature study, data analysis and solution.
Category [Enter the category in which the project was done. E.g. Operations Research, Simulation, Logistics…]	Statistical Process Control
Sensitive Parts [Indicate if there are sensitive parts that should not be published on UPSpace, e.g. Appendix A and H should not be published.]	None

Declaration

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EXECUTIVE SUMMARY

The aim of this document is to provide the reader with information regarding the quality problems the company Parsec (Pty) Ltd experiences in their manufacturing facility, and the solution to solving this problem. Research has been done in order to understand what companies in the same industry with similar problems have done to address the problem.

The document first provides the background of the company and its related industry. The problem investigation follows, with detailed information regarding the production process of producing electronic printed circuit boards. After this, a thorough literature study is presented, with technical aspects of printed circuit boards, as well as an investigation into the case studies regarding companies with similar problems. Relevant data was then captured and analysed, after which a demonstration of the solution to reducing defects on printed circuit boards, follows.

With the limited data captured and analysed in this project, it can be concluded that Parsec has to focus energy in investigating the reason for the significant amount of missing components, damaged components, and dry joints on their PCBs. Further, the solution will aid production managers in monitoring future defects on the PCBs. Once a defect to be reduced has been identified, it would be recommended for Parsec's technicians to use SPC as well to monitor and control the characteristics of that specific defect.

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ABBREVIATIONS

AOI:	Automatic Optic Inspector
CEF:	Consumer Electronics Factory
COQ:	Cost of Quality
CTQ:	Critical to Quality
DMAIC:	Define Measure Analyse Improve Control
DOE:	Design of Experiments
ESS:	Environmental Stress Screening
PCA:	Process Capability Analysis
PCBA:	Printed Circuit Board Assembly
PCB:	Printed Circuit Board
QC:	Quality Control
SMD:	Surface Mount Device
SMT:	Surface Mount Technology
SPC:	Statistical Process Control
THD:	Through Hole
TQC:	Total Quality Control
VBA:	Visual Basic for Applications

REDUCING THE AMOUNT OF DEFECTS AT THE QUALITY CONTROL STATION BY USING STATISTICAL PROCESS CONTROL

1 INTRODUCTION

Quality is a fundamental characteristic of any product or service and can be traced back as far as 3000 B.C. in Babylonia, where the Code of Hammurabi states: “The mason who builds a house which falls down and kills the inmate shall be put to death” (Seyd, 2009).

In today’s time, companies worldwide continuously strive to control and effectively improve the quality of their products and services, as this presents a business with a competitive edge, and allows economic growth within a business.

Controlling and improving quality is easier said than done however. More and more businesses head in the direction of producing products and services of low volume and high variety. This makes it hard to engineer standardized and customized processes that comply with the specified needs and requirements of products and services.

This project will attempt to investigate, analyse and suggest sustainable solutions regarding the quality control- and monitoring for products manufactured by the company Parsec (Pty) Ltd.

2 BACKGROUND

2.1 Company Background

The company Parsec is an Original Design Manufacturer that mainly specializes in the designing, manufacturing, integration and support of advanced technology systems. Parsec develops and produces customized electronic systems and products for clients in the information security, defence & aerospace mining & industrial, telecommunications and rail sectors.

Parsec’s manufacturing facility is equipped with advanced automated electronic manufacturing equipment operated by skilled technicians and operators. Highly experienced electronic engineers are responsible for the development of sub-systems and new products. Further, advanced customized testing and measurement equipment, and computer-aided software, support the development of these sub-systems and new products. Expertise areas of Parsec include hardware, software, CAD design as well as firmware (Parsec, 2015a).

Parsec’s facility is located in Route 21 Corporate Park in Irene, Gauteng.

2.2 Industry Background

Around the globe, many different business industry sectors compete against and with each other in order to produce top quality services and products for consumers. A few of these industry sectors in South Africa include communication and transportation, construction, agriculture, mining, manufacturing etc.

For this project, the industry focus will be in the manufacturing sector, specifically in the electronic engineering field. Electronic engineering entails the generation, transmission, and processing of data by means of computers, signal processing, transmission networks, and software, just to name a few (Parsec, 2015b).

Electronic engineering mainly integrates Printed Circuit Board (PCB) technology hardware, with accompanying software.

Figure 1 below is an example of one of the many PCBs that Parsec manufactures:

Figure 1: Printed Circuit Board (Parsec, 2015b)

2.3 Process Overview

The high variety of products, each with their own process path, makes the manufacturing process a multiplex process. Each product goes through the same stations, but in a different order, and some products, go through some stations more often than others do. Each station has its own amount of resources, and some stations are not shared amongst products.

Figure 2 below demonstrates the process path for Product 1. The different stations include:

A: Surface Mount Technology (SMT)
B: Automatic Optic Inspector (AOI) and X-ray
C: Wash and dry
D: Quality Control (QC)
E: Through-hole (THD)
F: Tacking
G: Depaneling
H: Test
I: Coating
J: Environmental stress screening
K: Final quality assurance

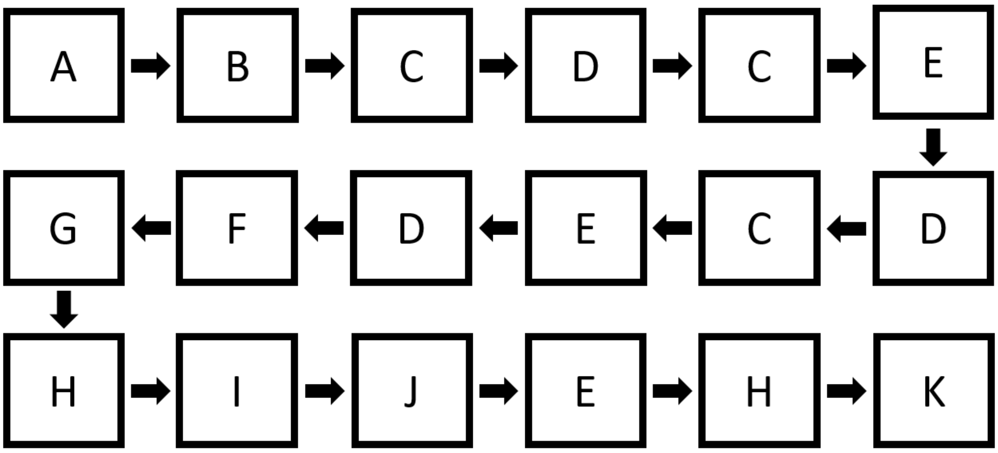


Figure 2: Process path for product 1

From left to right, top to bottom, Figure 3 shows examples of the rework, washing, inspection, quality control, surface mount device (SMD), and the through-hole processes.

Figure 3: Different manufacturing processes (Parsec, 2015b)

2.4 Problem statement

The quality control- and rework stations are constantly inspecting and reworking defective PCB's. These defects are reworked by technicians by means of soldering, resulting that the PCB has to be washed and dried again before proceeding in the process, as the flux in the soldering causes components on the board to rust should it be left in open air for too long. The substantial amount of defects thus influence the whole process and causes many wastes.

Due to the multiplex process, it has not yet been established what the root causes of the defects on the PCB's are. Since rework is not a value-adding activity in any production process, defects has to be reduced on a continuous basis.

Investigation regarding the different type of defects has to be done and the type and amount of defects has to be monitored and controlled, in order to aid in the solution of reducing the number of defects per PCB, and thereby reducing the workload of the quality control- and rework stations.

During the course of the project, three main problems became visible:

1. Inconsistent and irregular data capturing formats and platforms resulting in capturing inaccurate defects data, or no data at all.
2. No standardized records to analyse and use for a SPC system.
3. No means of monitoring and controlling the occurrence of defects on PCBs.

2.5 Project Aim

The objective of this project is to identify which type of defects appear on the PCBs in the first step of the production process, develop statistical process control charts to monitor these defects continuously, and then supply a tool to production managers to aid them in identifying out-of-control defects in order to determine the root causes thereof.

In doing so, the possibility of further defects occurring should be eliminated, and the workload of the quality control and rework station will thus be reduced.

3 Project Motivation

With the manufacturing of electronic printed circuit boards, large varieties of defects occur on the PCBs on a day-to-day basis. Apart from the fact that the quality of the company's PCBs plays a significant role in the competitive electronic manufacturing industry, the quality of PCBs also effects the production process negatively, if corrective actions are constantly necessary to repair defective products. It became visible that a very limited amount of defect data are mined on a daily basis, resulting in management to be unaware of the significant amount of defects occurring on PCBs.

The production process at Parsec's manufacturing facility definitely has room for improvement in many areas, and Parsec currently struggles to keep head above water with delivering the volumes of PCBs to their clients each month. This not only costs the company to turn away orders of potential clients, but Parsec also risk the possibility of losing current customers by not meeting monthly demands. Further, Parsec pays monthly penalties if not complying with promised deliveries.

Reworking defective PCBs takes up a lot of time in the production process, and are one of the many areas where the improvements there of can positively affect the production process. If the amount of defects are reduced, Parsec will be able to spare a lot of time spent on non-value adding activities, and rather utilize that time to increase their monthly throughput. With this project, Parsec wants to see whether statistical process control could be the solution to reducing the amount of defective PCBs

4 Project Approach and Deliverables

A thorough problem investigation and literature study are required to comprehend how statistical process control can aid the company in reducing the amount of defects found on PCBs. Historical data on defects will then be analysed, and control charts will be designed in order to monitor defects. Lastly, an easy-to-use tool will be designed for technicians and production managers for future controlling and monitoring of this problem. The detailed investigation and solution of this deliverable will be compiled in the final report for BPJ420.

Deliverables for BPJ420:

- Project Interim Report
- Final Project Report
- Project Poster
- Project Presentation

5 Problem Investigation

5.1 Production Process

Parsec manufactures a variety of products of which some are less and some are more complex than others are. Due to this, the production volumes off product types vary, and the length and order of the products' process paths is unique for each product. The activity conducted at each station however, is almost the same. The only difference would be that different types and amount of components are required to be soldered onto product number one, compared to product number two – but both requires components to be soldered onto them. In order to comprehend the process and related terms, a brief description of each station follows, should it be utilized in other sections of this document.

A: Surface Mount Technology

The first station in the production process is where a machine automatically solders electronic components onto the surface of a printed circuit board. This can be done manually by human technicians as well, but due to the miniaturization of components and the compact placement thereof, a programmed machine is much more efficient and precise.

B: Automatic Optic Inspector (AOI) and X-ray

After station A, the boards are inspected by an AOI machine operated by a technician. An AOI is a machine that visually inspects PCBs. The machine is programmed to inspect specific areas on the PCB, which differ for different product types. A camera scans the PCB to detect possible missing components, misaligned components etc. The machine inspects quality defects as well, such is solder fillet sizes. The X-ray machine are used to inspect solder balls underneath components, which cannot be seen by the AOI.

Depending on a client's requirements, this station performs one of three activities:

1. AOI or X-ray each PCB in a batch coming out of the SMT machine
2. AOI or X-ray only a few PCBs of a batch every now and then.
3. Inspects the IPC standards (Association Connecting Electronic Industries) of the solder joints.

C: Wash and dry

After each station where electronic components could possibly be soldered onto the PCB, or where reworks are necessary to correct the solder connections of components, the PCB has to be washed in order to get rid of the solder's flux residue. The flux could cause components to rust if it is left in the open air for too long. The PCB has to then be dried completely. The drying process can be done in an oven, or some of the washing machines is equipped with a drying compartment as well.

D: Quality Control (QC) and Reworks

According to some clients' production process specifications, the PCBs has to be inspected after each station where possible soldering on the board took place. This could be after station A (SMT), station D (reworked) or station E (through-hole components soldered onto the board). Inspection has to also take place after each washing process, as components can break off during it.

As this project focusses on the investigation of the different defects occurring on the PCBs as well as how to monitor, control and reduce the amount thereof, the operation of the QC station are below explained in more detail:

Two technicians usually operate this station. Either the one technician visually inspects a PCB under a microscope and then marks defects found with small yellow stickers while the other technician reworks these defects by means of soldering, or both technicians inspects and reworks a PCB at once. Only the PCBs on which there then have been soldered, needs to be washed and dried, and inspected again. The technicians however do not always keep track of which PCBs have been worked on, and which not, causing all of the PCBs to be washed again. This is an unnecessary repeat of a non-value adding activity.

Further, the stations preceding the QC station, will always either be the SMT station, or the THD station, as this is the only two stations where soldering is performed on the PCBs, except for possible reworks at the QC station itself. Many defects are detected on boards coming from the SMT process, meaning that either the AOI did not detect some defects, or the AOI did not detect repeating defects early enough to prevent further printing of defective PCBs at the SMT station. Statistical process control might come in handy at this point of the production process, in order to prevent the production of defective PCBs caused by the SMT machine.

E: Through-hole (THD) and Mechanical Integration

Certain components cannot be soldered onto the board by the SMT machine, as the components requires to be inserted into drilled holes in the PCB, and then soldered onto the opposite side of the PCB. This station also integrates finished PCBs that requires accompanying mechanical frames and housings. In Figure 4, it can be seen that the PCB (on the right) needs to be integrated with the frame on the left side.

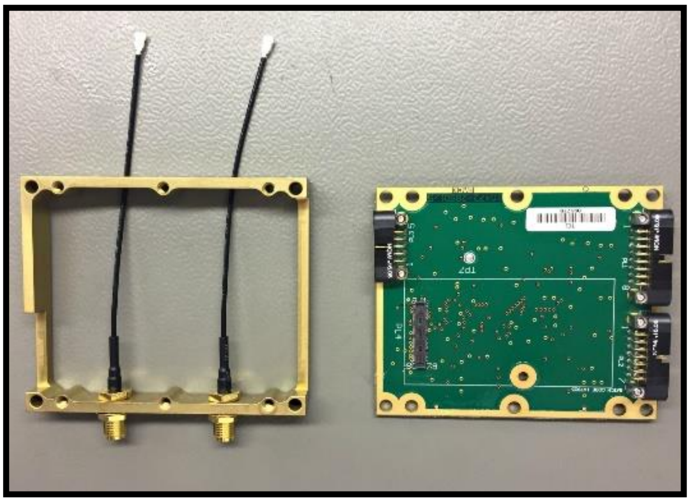


Figure 4: Mechanical integration of a PCB

F: Tacking

After all of the electronic components are soldered onto the PCB, certain fragile components, as well as components with wires needs to be tacked (Figure 5: fastening components with a blackish adhesive paste) in order to ensure that these components will be fixed and will stay in place.

Figure 5: Tacking demonstration

G: Depaneling

A PCB may either be on its own panel, or a few PCBs may be clustered together on one panel due to high volume production. When depaneling products, PCBs are separated from its frame and from the other PCBs on the same panel.

H: Test

At this station, pre- and post-testing takes place. Pre-testing is the first step in the inspection process where the PCBs are not inspected for visual defects, but rather testing whether the PCB electronically functions as it should. This is done by connecting the PCB to a computer, which performs all kinds of electronic tests. The only difference between pre- and post-testing is which occurs at station J in between.

I: Coating

In order to protect the PCB against moisture, dust, chemicals and extreme temperatures, it is coated with conformal coating. Uncoated PCBs may be damaged and lead to malfunctioning electronics. Some testing pads on the PCB however cannot be coated, and are therefor masked as shown in Figure 6:

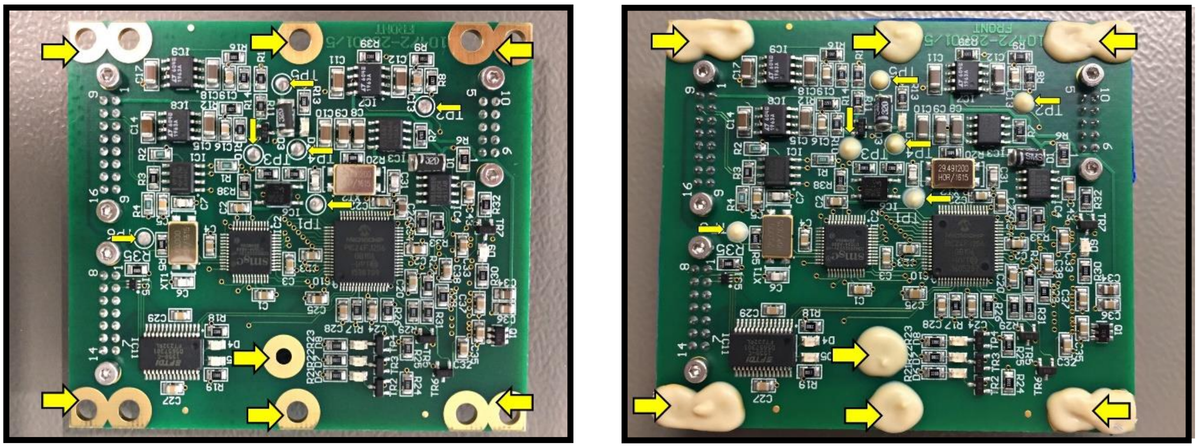


Figure 6: Unmasked and masked PCB

J: Environmental stress screening

During this process, PCBs are exposed to thermal cycling and vibration, and then post-tested, in order to determine if the PCB could resist all of the extreme conditions that it was exposed to.

K: Final quality assurance

At this final station of the production process, the PCBs are inspected for the last time before being packed and shipped. The inspection consists out of visual inspection and photos taken of the PCB, which are then combined into one file with the positive results received from the post-testing station.

Production Lines

Because of the high variety of products Parsec produces for their different clients, the manufacturing facility does not have established production lines for every type of product. The manufacturing facility operates in project teams – each team focussing on producing products for a specific a project. The only process stations not belonging to a sole project, is station A (SMT), station B (AOI and X-ray), station C (wash and dry), station J (Montgomery et al.) and station K (final quality assurance).

5.2 Technical Printed Circuit Board Basics

In the continuous developing electronics industry, trends towards miniaturization of components on printed circuit boards (PCB's) as well as denser packing of the components on the PCB's, has resulted in the break-through technique of Surface Mount Technology (SMT). Surface Mount Devices (SMD) drove manufacturing of PCB's to a completely new production level, and due to the reduced sizes of the circuits, and the compact density of the components on the PCB's, quality inspection has developed to be a critical and complex component in the production process (Goumas et al., 2010).

5.2.1 Printed Circuit Board Constitution

In order to completely comprehend the different types of defects occurring on the PCB's, a few technical basics regarding the layout of the PCB needs to be clarified. Figure 7Figure 7 below demonstrates the composition of the PCB by means of a cross section view:

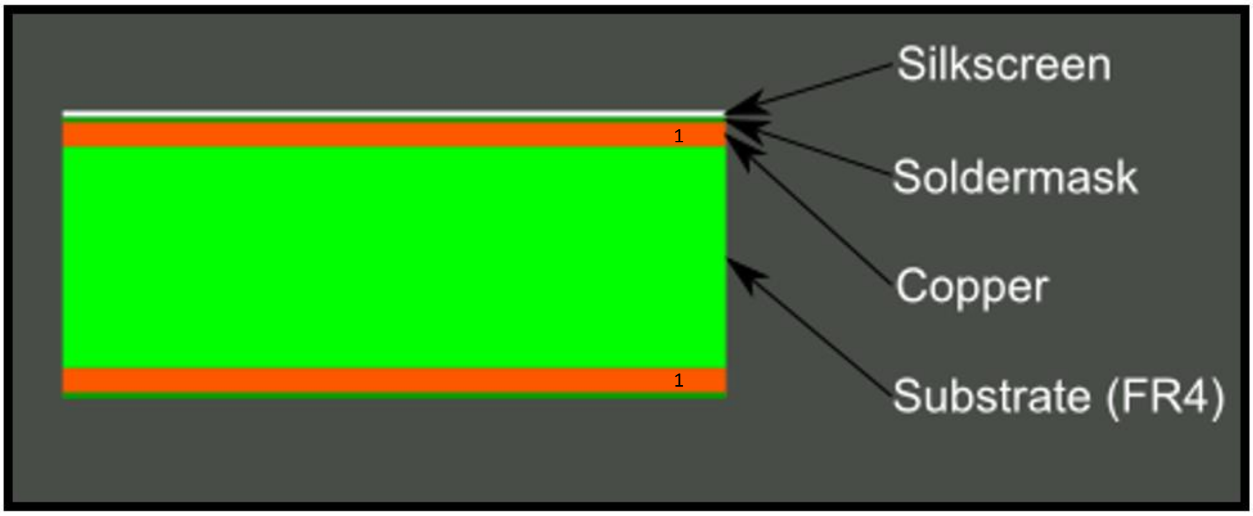


Figure 7: PCB composition (Sparkfun, n.d.)

The substrate is the base material of the PCB and is usually fiberglass. The layers on either side of the middle (labelled with number 1's) represents thin copper foil, and a single PCB can have as many as 16 layers of copper. The next layer is the soldermask. This layer is responsible for the green colour of a PCB. The soldermask layer is overlaid onto the layer of copper, in order to insulate certain areas of the copper. When components are soldered onto the PCB, the soldermask ensures that components are only soldered onto the portion of copper exposed on the surface of the board (copper pad). Lastly, the silkscreen layer on top of the soldermask layer adds symbols, letters and numbers to the PCB to aid humans in better understanding the board, as well as allow for easier assembly (Sparkfun, n.d.).

On the top view of a PCB, only the copper layer, the soldermask, and the silkscreen is visible. Figure 8 below represents a top view.

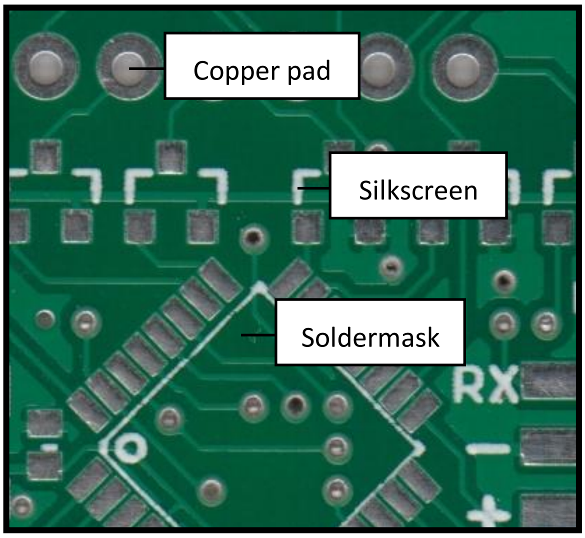


Figure 8: PCB surface (Sparkfun, n.d.)

Other important terms include:

Pad – the exposed portion of metal (copper) onto which a component is soldered.

Paste stencil – a thin metal stencil, which is temporarily placed over the board, to allow solder paste to be deposited onto specific areas.

Pick-and-place – the machine, which places components on a circuit board.

Reflow – the process of melting the solder in the paste, to create mechanical and electrical joints between the pads and the component.

Solder paste – small balls of solder are suspended in a gel, and are applied to the surface of a PCB with the help of a paste stencil (Sparkfun, n.d.).

5.2.2 Types of Printed Circuit Board Defects

During each step of this production process, several different types of defects can occur. During the first step of the SMT production process, insufficient or a surplus amount of solder paste can be the cause of defects forming during reflow. Missing components, rotated components (also known as components with incorrect polarities) and misaligned components are the most general defects occurring during the pick-and-place step of the SMT production process (Wu et al., 2009). Lastly, the reflow production step is where defective solder-joints are formed due to a surplus, lacking, or insufficient solder (Goumas et al., 2010).

Some of the most common types of defects include:

Dry solder joint (Figure 9)**:** This occurs when there is a lack of solder paste on the pad causing an open connection with the component pins.

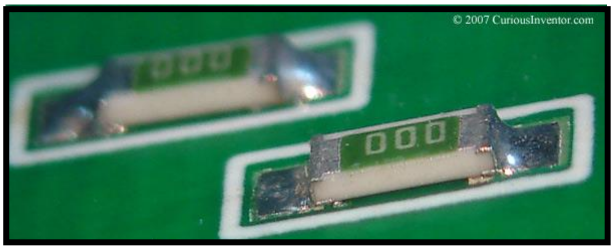


Figure 9: Dry solder joint (Inventor, n.d.)

Wrong Polarity: This defect occurs when components are soldered onto the PCB in the opposite of the right direction.

Solder bridge/shorts (Figure 10)**:** This occurs when there are a surplus of solder resulting in pads and component pins to connect where they shouldn't be.

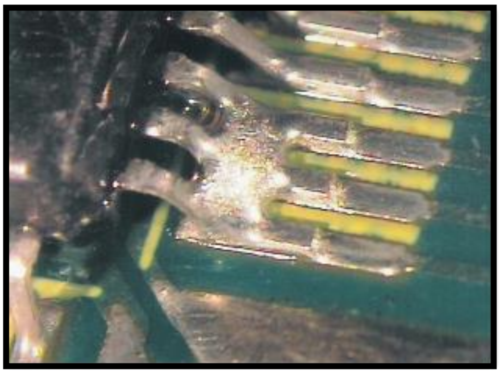


Figure 10: Solder bridge (Associates, n.d.)

Missing/missing components: This defect is not caused by SMT. Components may break off if the PCB is not handled carefully.

Tombstone (Figure 11)**:** A SMD component, which is partially or completely lifted from the PCB pad.

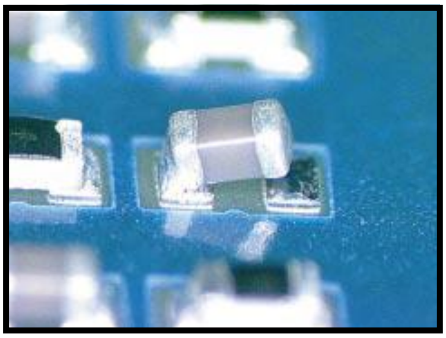


Figure 11: Tombstone (Janóczki, 2013)

Misaligned component/component shift (Figure 12)**:** A component can be misaligned to its target. This might happen during reflow due to the component's ability to float on the molten solder, or the pick-and place machine could have placed to component off target.

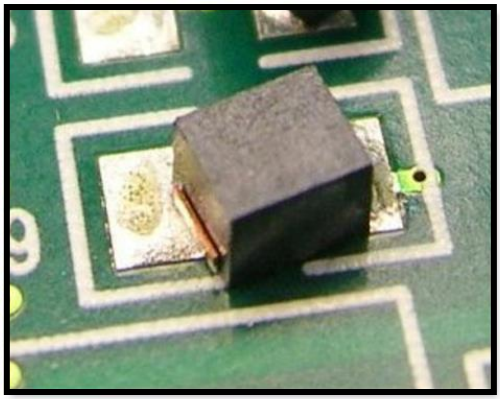


Figure 12: Misaligned component (Associates, n.d.)

5.3 Defects Rework Consequences

Each time rework is performed on a PCB, the stations which are added to the production path of the process are demonstrated in Figure 13, with the first dotted D-square being the rework performed:

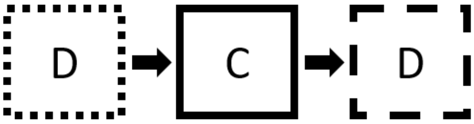


Figure 13: Added stations to production process

The amount of time lost in production each time a PCB needs to be washed (station C) and inspected again (second striped D-square), is significant. Parsec makes use of two washing machines. The one washing machine, washes and dries a PCB in 60 minutes, and only has a limited capacity. The other washing machine washes and dries the PCBs in 120 minutes and has a limited capacity as well. A significant amount of time would be eliminated from the production process, if less defects occur on the volumes of PCBs produced each month. This could be one of many ways for Parsec to increase their throughput, and deliver orders on time.

5.4 Defect Data Collection

The only data Parsec currently possesses regarding the defects on PCBs is the manual reports done by the QC technicians, reports created by the AOI machine, and manual entries into the main information system Parsec currently makes use of, called Jira.

5.4.1 Manual Reports

This type of defect recording is not mandatory for any technicians reworking defective PCBs, but are solely done by certain technicians because of personal preference in order to keep record for themselves of the reworks they did on specific boards each day, to populate this data only at the end of the day on the Jira system. This result in these reports not always being a real representation of the work done by a certain technician on that day, since the workload to copy these data into the Jira system at the end of the day is time consuming, and thus some technicians on busy days simply directly populate defects on the Jira system.

Since not all quality control technicians records the defects data this way, these records are insufficient to use for statistical analyses. Figure 14 below serves as an example of these manual rework lists:

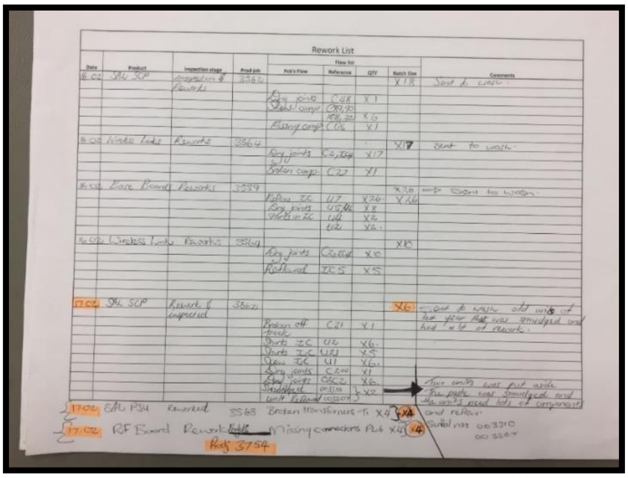


Figure 14: Rework List

5.4.2 Automatic Optic Inspector Reports

As mentioned earlier, the AOI and X-ray machines can either test each PCB in a batch, or it can test only a few sample PCBs per batch, depending on a client's requirements. Most of the time, only very small samples are tested. Unfortunately this results that these reports can also not be utilised for accurate statistical interpretations.

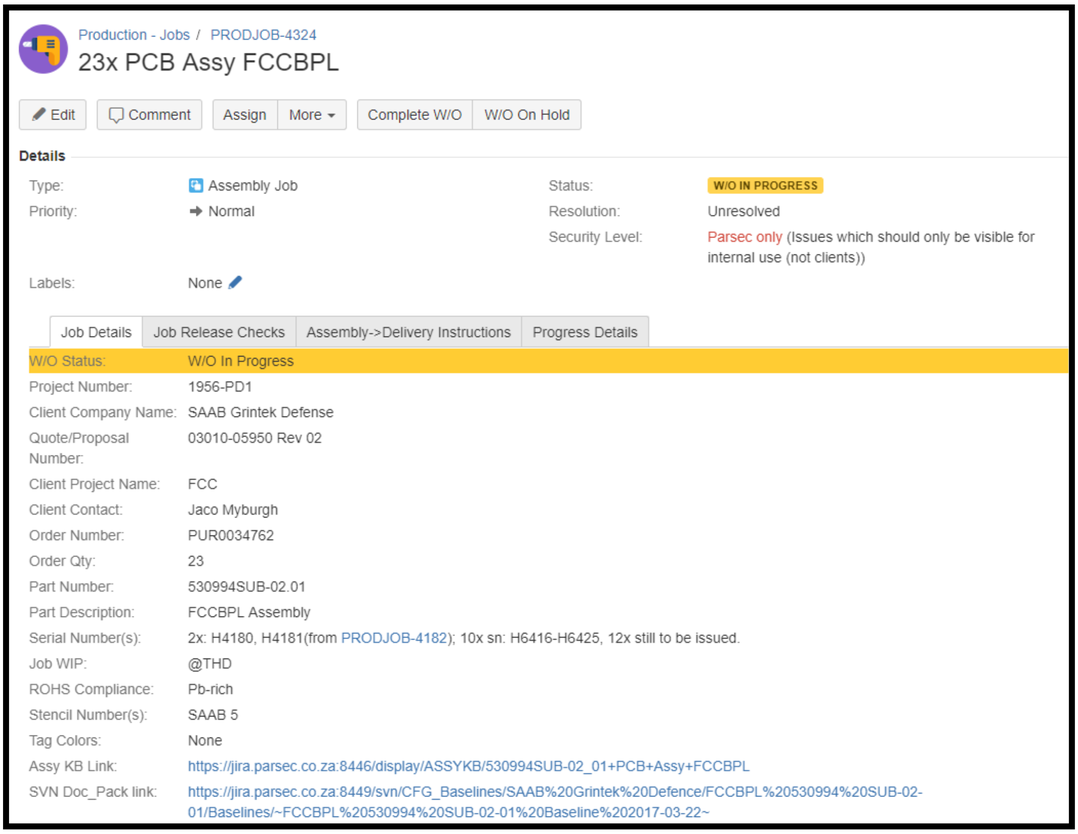
5.4.3 Jira System Reports

The third possible source to obtain data regarding defects on PCBs is from the Jira System made by all stakeholders of a production job. This is the main platform Parsec makes use of to track any information regarding production progress of individual PCBs, possible stockouts of components, test results of the PCBs etc.

It is mandatory for all employees involved in a certain production job, from technicians to production- and project managers, to update any work done and any relevant concerns or information on the production job issue.

Although this is a source where any type of information regarding a production job is available, this type of data collection is not attractive, as it is time consuming to manually type in any inputs on a production job issue. Further, there is no standardised data input practise. Each stakeholder uses his own word choice and inputs, making it impossible to statistically analyse information without first analysing each individual entry on the issue, and then transferring relevant information to Excel.

Figure 15 and Figure 16 below demonstrates what a production job issue in Jira consists of:

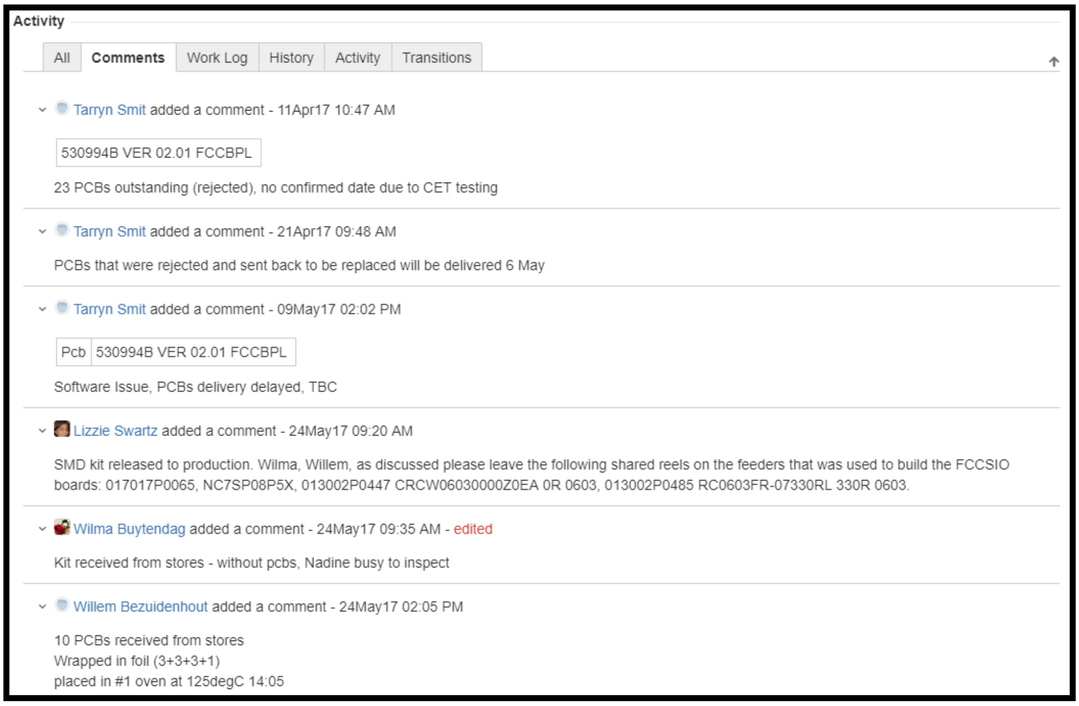


23x PCB Assy FCCBPL

Type: Assembly Job
Priority: Normal
Status: W/O IN PROGRESS
Resolution: Unresolved
Security Level: Parsec only (Issues which should only be visible for internal use (not clients))
Labels: None

W/O Status: W/O In Progress
Project Number: 1956-PD1
Client Company Name: SAAB Grintek Defense
Quote/Proposal Number: 03010-05950 Rev 02
Client Project Name: FCC
Client Contact: Jaco Myburgh
Order Number: PUR0034762
Order Qty: 23
Part Number: 530994SUB-02.01
Part Description: FCCBPL Assembly
Serial Number(s): 2x: H4180, H4181(from PRODJOB-4182); 10x sn: H6416-H6425, 12x still to be issued.
Job WIP: @THD
ROHS Compliance: Pb-rich
Stencil Number(s): SAAB 5
Tag Colors: None
Assy KB Link: https://jira.parsec.co.za:8446/display/ASSYKB/530994SUB-02_01+PCB+Assy+FCCBPL
SVN Doc_Pack link: https://jira.parsec.co.za:8449/svn/CFG_Baselines/SAAB%20Grintek%20Defence/FCCBPL%20530994%20SUB-02-01/Baselines/~FCCBPL%20530994%20SUB-02-01%20Baseline%202017-03-22~

Figure 15: Production Job 4324 Details (Parsec, 2017)



Tarryn Smit added a comment - 11Apr17 10:47 AM

530994B VER 02.01 FCCBPL

23 PCBs outstanding (rejected), no confirmed date due to CET testing

Tarryn Smit added a comment - 21Apr17 09:48 AM

PCBs that were rejected and sent back to be replaced will be delivered 6 May

Tarryn Smit added a comment - 09May17 02:02 PM

Pcb	530994B VER 02.01 FCCBPL

Software Issue, PCBs delivery delayed, TBC

Lizzie Swartz added a comment - 24May17 09:20 AM

SMD kit released to production. Wilma, Willem, as discussed please leave the following shared reels on the feeders that was used to build the FCCSIO boards: 017017P0065, NC7SP08P5X, 013002P0447 CRCW06030000Z0EA 0R 0603, 013002P0485 RC0603FR-07330RL 330R 0603.

Wilma Buytendag added a comment - 24May17 09:35 AM - edited

Kit received from stores - without pcbs, Nadine busy to inspect

Willem Bezuidenhout added a comment - 24May17 02:05 PM

10 PCBs received from stores
Wrapped in foil (3+3+3+1)
placed in #1 oven at 125degC 14:05

Figure 16: Stakeholder entries in the comment section (Parsec, 2017)

By not having a consistent and proper data collection system in place, Parsec currently cannot make proper statistical interpretations of the amounts and type of defects detected and reworked on a day-to-day basis. This is a problem, as this type of data would also be crucial in order to implement a proper functioning statistical process control system, and to convince management of the value of the money and time going into the inspection and reworks of PCBs.

6 Literature Review

6.1 Case Studies

6.1.1 Case study 1 (Chan and Law, 1995)

Philips Electronics N.V., is a registered technology company in the Netherlands, headquartered in Amsterdam. The company operates business in the aerospace, military, lightening, medical equipment, consumer electronics, domestic appliances as well as communication systems. This case study is based on a process-orientated quality improvement project, in the Consumer Electronics Factory (CEF) in Hong Kong, owned by Philips Electronics N.V.

With any quality improvement project in the manufacturing organization, man, machine and material needs to cooperate in the production of products, and should therefor be considered equally. Management, the production process and the material are interrelated and together contributes to the quality of products.

CEF includes the manufacturing of portable audio products such as radio cassette recorders, compacts disc players and clocks. The factory consists out of two main departments: chassis assembly and encasing. Chassis assembly focusses on the production of printed circuit board assemblies (PCBA) whilst encasing includes the set of assembly, testing and packing. Quality problems in encasing are simply identified and solved during the assembly and inspection process. In the chassis assembly department, quality problems which are mainly soldering defects, are not so easy to identify.

In the year 1991, the company started to implement a process control system for the manufacturing of PCBAs by making use of a total quality control (TQC) approach, with the objective to eliminate causes of soldering defects and thereby improving the quality of their products. The aspects of this implementation project are discussed in this case study. In CEF, PCBAs are manufactured using surface mount technology, the same method Parsec uses to manufacture their PCBs.

a) Total Quality Control in the Consumer Electronics Factory

In order for the TQC project to succeed, the company appointed a TQC project leader (TPL) which had to report to the engineering- and general manager. The TQC project consisted out of two teams: the process control team and the design control team. Figure 17 below demonstrates the team members out of which each team consisted:

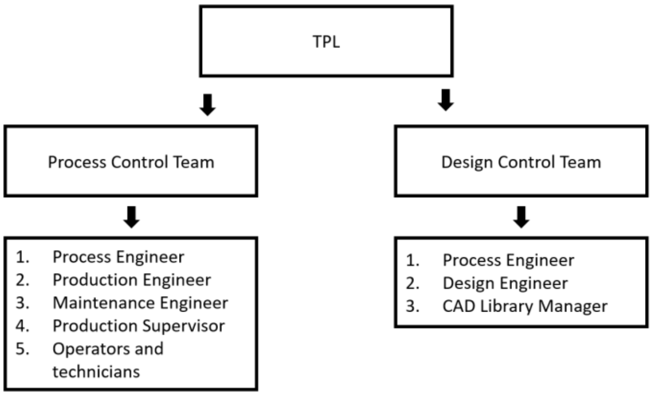


Figure 17: TQC Project Team (Chan and Law, 1995)

The design control team's duty was to optimize and design the control system in the company. In order to achieve good quality, the design of the PCBA and the design of the assembly process should be optimal. Certain rules were adopted in the circuit design of the PCBA. An example of this was ensuring larger solder pads and larger gaps between components in order to prevent the bridging defect. Technical constraints restricted the design team to conform 100 percent to the design rules, but the design quality of the PCBS could be determined by a 'predicted design defect rate'. This could be calculated by taking the defect rates of similar circuit designs into consideration. The quality performance and design defect rate targets of the PCBA layout design was evaluated regularly in meetings.

The Process Control Team's duty was to set up a system to control and improve the production process. The team made use of familiar tools including SPC (statistical quality control), FMEA (failure mode and effect analysis), QFD (quality function deployment), experimental design (Taguchi methods) and fishbone (cause-and-effect) diagrams. The objective for this team was to monitor and detect deviation and then make corrections where necessary. Philips confirmed four control loops around the production process with the aim to achieve equipment control, shop floor control, process improvement and innovation in the production process. The relationship between these four control loops are demonstrated in Figure 18 (A = manufacturing recipe; B = interactive setting; C = measurement):

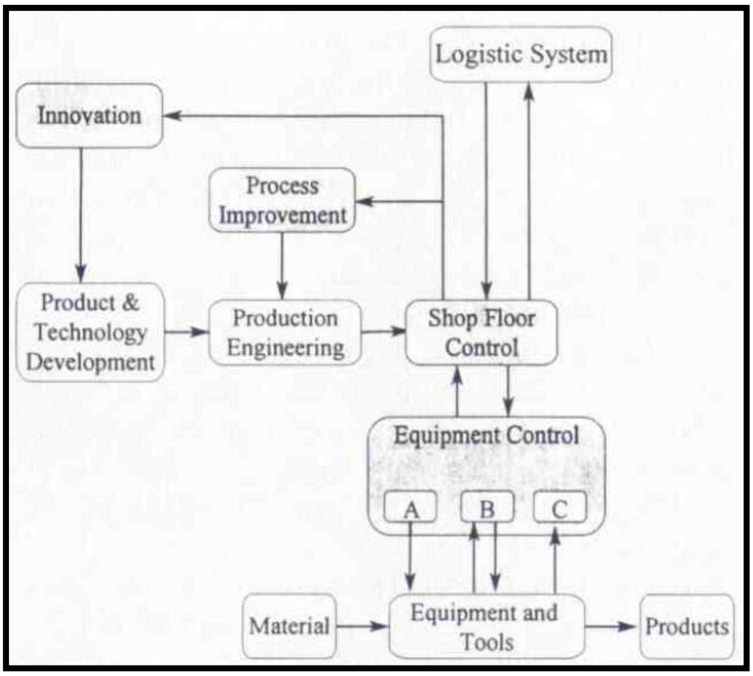


Figure 18: Control loops in the production system (Chan and Law, 1995)

A brief explanation of the four loops:

Equipment control: This loop consisted of a two-way data exchange mechanism between the shop-floor controller and the system that creates the manufacturing instructions (Figure 18). A manufacturing recipe is released, after which information regarding the process steps and the needed equipment set-up is downloaded, and settings regarding the equipment is generated. This is the data flow from the shop floor to the equipment. The instructions to be performed by the equipment entails a number of process parameters with an initial value, as well as orders to execute certain measurements, of which the results are sent back to the shop floor controller. Depending on the results obtained, the shop floor control system will generate and adjust equipment settings as necessary.

Shop floor control: Order flow, quality, equipment utilization and material flow are important factors to consider in shop floor control. Since CEF produces a large variety of products, production inefficiency is a challenge and will be dealt with later in this case study.

Process improvement: Process improvement was improved by improving measurement set-up, higher precision instruments and better metrology concepts.

Innovation: Environmental constraints and competition drove the company to achieve higher quality at lower costs. The project team implemented new methods to control the measurement of certain parameters, formulated new SPC charts for auto-insertion processes etc.

b) Technical Aspects for Quality Improvement

Different PCBAs require different production conditions. Settings on the pick-and-place machine for example depend on a PCBAs width, whilst the solder jet pressure depends on the component density. Modifying parameter setting for each PCBA however is not a practical solution, as set-up time causes a lot of machine downtime.

CEF started to do research for a project, which would allow machines to automatically adjust parameters once the type of PCBA product is identified. Based on the findings of this research, management decided that automatic parameter adjustment would not be practical for CEF, and decided to rather adopt an appropriate set of parameter settings for all PCBAs.

Other technical decisions made by CEF included:

PCB material quality: The company implemented a sampling inspection plan, with detailed checklists for visual inspection of PCB material and components purchased from vendors. The long-term strategy of this inspection plan was to track and identify different types of defects and to maintain good relationships with vendors, to reduce future defective material and components incidents.

Choice of flux: Flux with low residue improves the quality of products. CEF conducted tests on different fluxes obtained from two local suppliers, and found that halogen-free flux has lower levels of residue and stickiness. CEF replaced their existing flux, with the halogen-free flux.

Mechanization – material identification system: Correct cartridges of material needs to be loaded onto the SMT machine, in order to avoid the occurrence of wrongly placed miniature components on dense PCBAs. A team conducted a project to mechanize material identification to eliminate wrong component insertion due to human error. The implemented system consisted out of an identification unit, a data acquisition unit, an inspection unit and an alarm unit.

An audit was performed two years after the TQC in CEF was employed. Result of the audit showed that overall defect rates for solder joints decreased by 65 percent. Other tangible and intangible benefits were obtained as well.

Relevance to Final Year Project

Although this case study does not provide detailed methods and information regarding how the project team made use of statistical process control, it is assuring to gain evidence that statistical process control has been used in the electronic manufacturing industry before, and that combined with other techniques, whether technical or not, the overall defect rates for solder joints decreased. This case study also showed that defects on PCBs are a common issue, and the technical decisions made by Philips Electronics will be suggested to Parsec. A control loop which Parsec has to strongly consider, is improving their metrology process. This case study confirms that SPC and accurate data is necessary to solve parts of Parsec's quality problems.

6.1.2 Case study 2 (Tong et al., 2004)

This case study focusses on a company who used six-sigma quality improvement of PCBs by using the define-measure-analyse-improve-control (DMAIC) approach. First, the company identified and defined the problem, after which they conducted a process capability analysis (PCA). Statistical process control (SPC) were then used to analyse and measure the company's current printing performance. After this, the company designed a few experiments (DOE) in order to enhance the six sigma level of the screening process. Control strategies were then recommended.

The company (name unknown) is an electronic company based in southern China at an industrial park. The company produces PCBs by making use of the surface mount technology (SMT) technique. The company describes the main manufacturing processes as solder screening, component placement, and solder reflow.

According to the company, the solder screening process is regarded as the most important process in the manufacturing of PCBs. The screening process entails the process where solder paste is transferred onto the solder pad of a PCB. If this process is not control, solder defects such as bridging, shorts circuits, misalignments and open circuits occur.

The Five phases of the Six-Sigma approach

The DMAIC approach of this case study will now be explained:

1 Define phase

In this case study, the focus is on the improvement of the sigma level of the PCB screening process. More specifically, the amount of solder paste (height) which is transferred onto the PCB is the critical factor that needs to be controlled. The company therefor identified the solder paste height to be the critical-to-quality (CTQ) characteristics which needs to be controlled.

2 Measure phase

The team responsible for improving the quality requested the operators to measure the solder paste height on a specific product. These measurements were taken on five different points on the PCBs. Figure 19 shows the circuit design of the PCB. Two points were taken at the U1 component, two points at the U2 components and the last point at the J1 component.

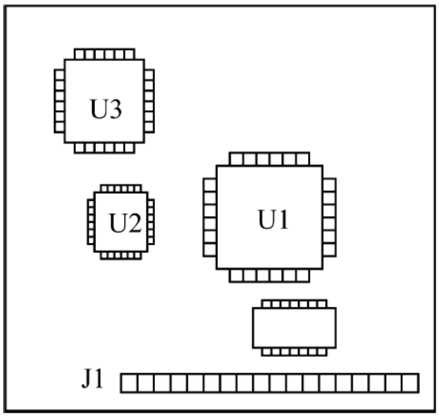


Figure 19: PCB Circuit design (Tong et al., 2004)

These measurements were taken on five PCBs every four hours, and recorded on a SPC data sheet. Figure 20 illustrates the Xbar-R control chart plotted from the SPC data sheet:

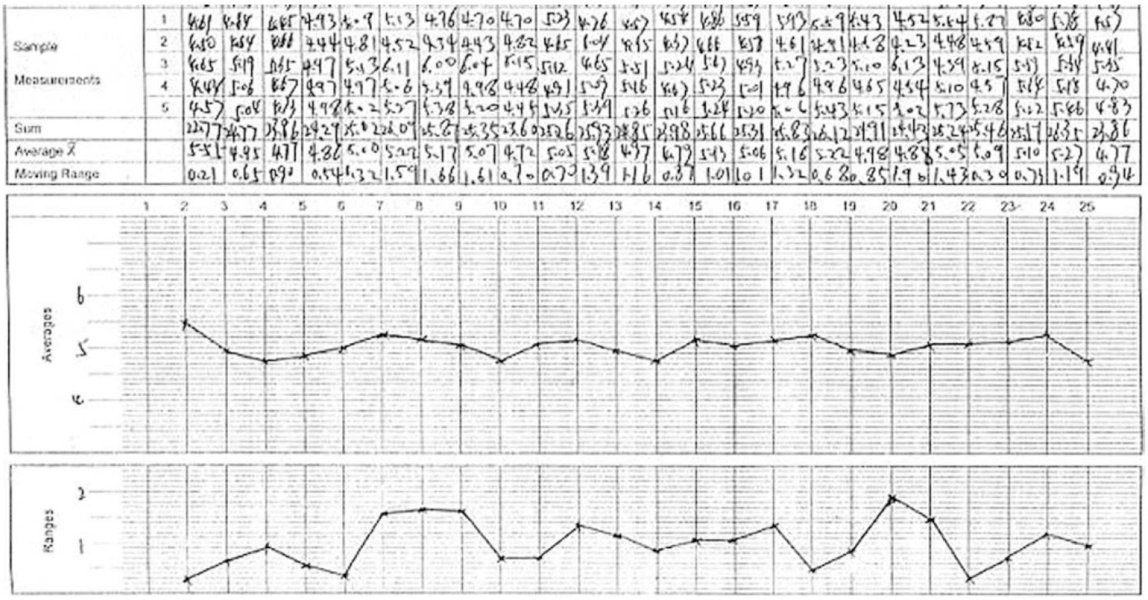


Figure 20: SPC data sheet and Xbar-R control chart (Tong et al., 2004)

It should be noted, that the Statistical Process Control in Figure 20 executed by the authors suggests stratification, since the data points are hugging the centre line. This implies that this SPC process contains errors.

3 Analyse phase

The company conducted a process capability analysis in order to determine the printing performance of the screening machine. The results demonstrated that the screening machine was not adequate. Reasons for this, was because the value of the capability index *Cp* was calculated as only 1.021, which is less than the four-sigma level of 1.33. Furthermore, the *Cpk* capability index had a value of 0.387, which showed that the process was not on target. In Figure 21 the capability plot, a high variance in the height of the solder paste as well as a mean shift in the height distribution can be seen.

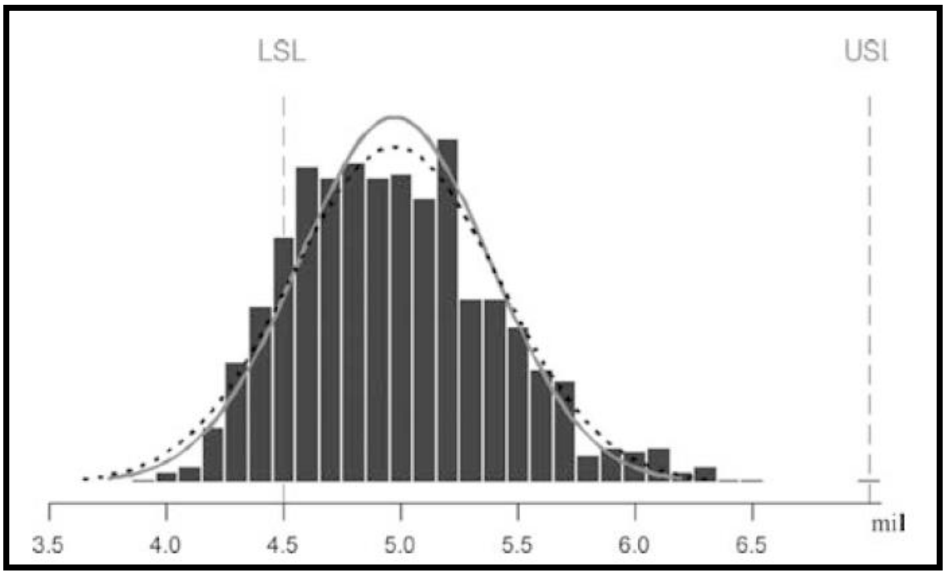


Figure 21: Capability plot (Tong et al., 2004)

4 Improve phase

In order to improve the performance of the screening machine, a DEO was used to determine the optimal settings of the CTQ input factors in the screening process. Firstly, initial experiments were conducted with already known significant factors in order to detect other significant factors. Further experiments were then conducted on the new determined significant factors in order to obtain standards settings for these factors. These newly determined optimal settings would improve the performance of the screening process. The DOE are explained in the DEO section.

5 Control phase

Control strategies recommended for the company such as monitoring control charts over time as well as other control strategies are explained after the DEO section.

Improvement using DOE

The first experiments were done on factors that, according to several studies conducted by the authors, have affects on the printing performance of the screening machines. These factors are the age of the stencil, the solder paste volume, the blade type and the side of the stencil used.

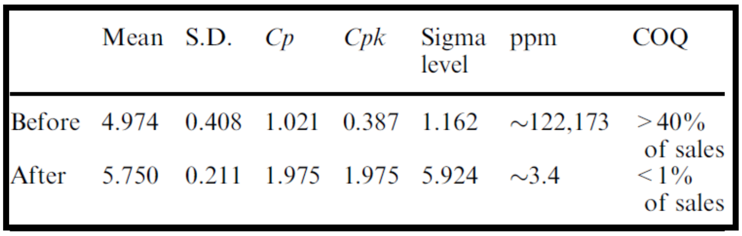
Further experiments were then conducted on the solder paste viscosity, the speed of the squeegee and the blade type of the squeegee.

Main effect- and interaction plots were then used to understand the influence each one of the above-mentioned factors has on the performance of the screening machine. Analytical results implied that the solder paste viscosity, the speed of the squeegee, the blade type, and the side of the stencil a major influence on the height of the solder paste has.

Control Strategy Recommendations

Recommendations were made for some of the critical-to-quality factors influencing the height of the solder paste. Optimal setting recommendations were lower paste viscosity (<150 mPa.s), low speed of squeegee (0.4 inch/sec), front blade type, and the right side of the stencil. Table 1 shows a comparison of the printing performance of the screening machines before and after the optimal settings were used. The results show that nearly a six-sigma level performance can be achieved, and that only one percent of sales would be due to quality costs (COQ).

Table 1: Printing performance comparison



	Mean	S.D.	*Cp*	*Cpk*	Sigma level	ppm	COQ
Before	4.974	0.408	1.021	0.387	1.162	~122,173	>40% of sales
After	5.750	0.211	1.975	1.975	5.924	~3.4	<1% of sales

This case study provides more detail of how statistical process control has been used in order to improve the quality of the PCBs and reduce the solder joint defects. For this project, it will have to be determined whether a similar type of statistical process control system, would be the first ever SPC system introduced to Parsec in order to reduce defects, or whether a less technical SPC system will be sufficient at first. By implementing such a technical SPC system, many interdisciplinary decisions will have to be made, in order to achieve optimal success and reliance on the system.

6.2 IE Techniques

6.2.1 Statistical Process Control

Statistical Process Control (SPC) is a technique used in the industrial engineering industry, for monitoring and controlling a variety of different processes. In today's competitive manufacturing industry, it is crucial for manufacturers to be able to produce products and services of high quality. Apart from the fact that good quality provides organizations with a competitive edge, it also financially benefits a company largely if products are manufactured right the first time, and corrective actions thus are not necessary.

SPC entails the controlling of processes in order to detect variation, investigate the causes of this variation, and then eliminate the assignable causes. Two of the main tools applied in SPC is control charts and process capability analyses (PCA). The control charts concept was first introduced by Walter A. Shewart in a Bell Laboratories technical memorandum (Montgomery, 2007). Control charts are used to observe if a process is in control, where quality characteristics of this process are monitored. Depending on the type of data obtained by measuring these different quality characteristics, different types of control charts are used. If the data obtained is variable data, variable control charts are used. If the data is discrete, attribute control charts are used (Avakh Darestani and Nasiri, 2016).

6.2.2 SPC in Solution Development

The data captured for this project is classified as discreet type of data since two classes can be identified: either a PCB has defects, or it does not. Further, the data captured are classified as countable data. The reason for this, is that even though two classes can be identified, only one class can be counted. Only the number of defects that occurred on a PCB can be counted, but the number of defects that did not occur on a PCB, is impossible to know.

In the development of the solution for this project, SPC will be used in an informatics system to aid production managers in monitoring and controlling defects on PCBs, and also aid them to identify which actions are necessary to take in order to reduce the amount of defects.

The solution will consist out of three elements:

1. User-friendly data capturing system, in order to consistently capture accurate defect data.
2. The defect data records
3. Informatics tool consisting out of statistical process control charts and other statistical analyses.

The informatics tool will automatically and continuously update control charts with each new entry into the defect data records. c – control charts will be used with the statistical process control application to the data set, with c being the amount of defects per opportunity.

7 Data Analysis

7.1 Data Description

Only a limited amount of data sufficient for accurate statistical process control was available to capture from the Jira information system. The dotted square in Table 2 below demonstrates what these data was:

Table 2: PCB Products

Product Class	Class 3		Class 2	
Industry	Military		Mining	Industrial
Current Projects	P3	Altarrig		

Only the technician doing quality control and reworks for the P3 project , documented data regarding the type and amount of defects, of some production jobs she worked on. This is due to the preference of the technician – specifying the day's work in detail, instead of just documenting the amount of PCBs she worked on that day. It was never before required of technicians to document the type and amount of defects on specific PCBs, and therefore resulting in the limited amount of data available.

Further, the technician started to document this type of data only during the past few months, resulting in only 21 production jobs with data fit for use. The Production Management Director of Parsec estimates that Parsec processes more or less 500 Class 3 production jobs per annum. The data captured for this project is thus a very small representative of the defects occurring on PCBs, but are sufficient to demonstrate to management the advantages a SPC system can bring to the company. A proper user-friendly PCB defects data capturing system will thus be incorporated in the solution. Without proper data, a SPC system can not function properly. Table 3 below serves as an illustration of the data captured:

Table 3: Data Illustration

Production Job	Job Size	Product Description	Serial Number	Defect	Component	Date
3740	8	06019-12045/1	H0244	Misalignment	IC1	2017-05-13
3740	8	06019-12045/1	H0244	Misalignment	IC2	2017-05-13
3746	22	06019-21560/9	G9135	Dry Joint	C95	2017-07-06
3746	22	06019-21560/9	G9149	Wrong Polarity	P123	2017-07-06
3793	17	52005-04230/1	H2631	Dry Joint	T1	2016-11-29
3793	17	52005-04230/1	H2632	Dry Joint	T5	2016-11-29
3187	10	30030-01141-03	H0148	Wrong Polarity	U1	2017-01-20
3287	10	30030-01141-03	H1696	Missing Component	U45	2017-01-20
4001	56	GSLCT-11400	H1701	Missing Component	U5	2017-03-24
4001	56	GSLCT-11400	H3307	Wrong Polarity	U26	2017-03-24
4124	76	941-06116-5001	H3307	Missing Component	C22A	2017-07-24
4124	76	941-06116-5001	H3341	Missing Component	C22B	2017-07-24

7.2 Control Charts

Due to the limited amount of data, the assumption was made that the different types of PCBs in the data set has the same level of complexity. If this was not assumed, different control charts would have to been designed, and not enough samples would have been available for valid statistical representations. In deliverable for the company, this can however not be assumed, and distinction would have to be made between different complexity classes of different products.

7.2.1 Defects per Job

This control chart was designed in order to analyse defect occurrences between different production jobs. It should be noted, that the sample sizes for the different production jobs is not constant. A u-control chart will thus be used, with $\bar{u}$ being the ratio of the total number of observed defects to the total number of inspected PCBs.

Table 4: Defects per Production Job

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
n	8	22	17	10	56	5	76	5	3	6	40	4	15	6	2	4	130	10	11	6	8
c	10	72	22	23	36	36	85	12	14	17	5	28	17	35	22	46	11	65	33	18	14
u	1.25	3.27	1.29	2.3	0.64	7.2	1.12	2.4	4.67	2.83	0.13	7	1.13	5.83	11	11.5	0.08	6.5	3	3	1.75

$$\bar{u} = \frac{\sum u}{21} = \frac{77.9}{21} = 3.7$$

The width of the control limits are computed by using the different sample sizes for each production job. The width will thus vary inversely with n_i , the number of PCBs in a production job. Figure 22 below demonstrates the control chart constructed:

$$UCL = \bar{u} + 3\sqrt{\bar{u}/n_i}$$

$$UWL = \bar{u} + 2\sqrt{\bar{u}/n_i}$$

$$LWL = \bar{u} - 2\sqrt{\bar{u}/n_i}$$

$$LCL = \bar{u} - 3\sqrt{\bar{u}/n_i}$$

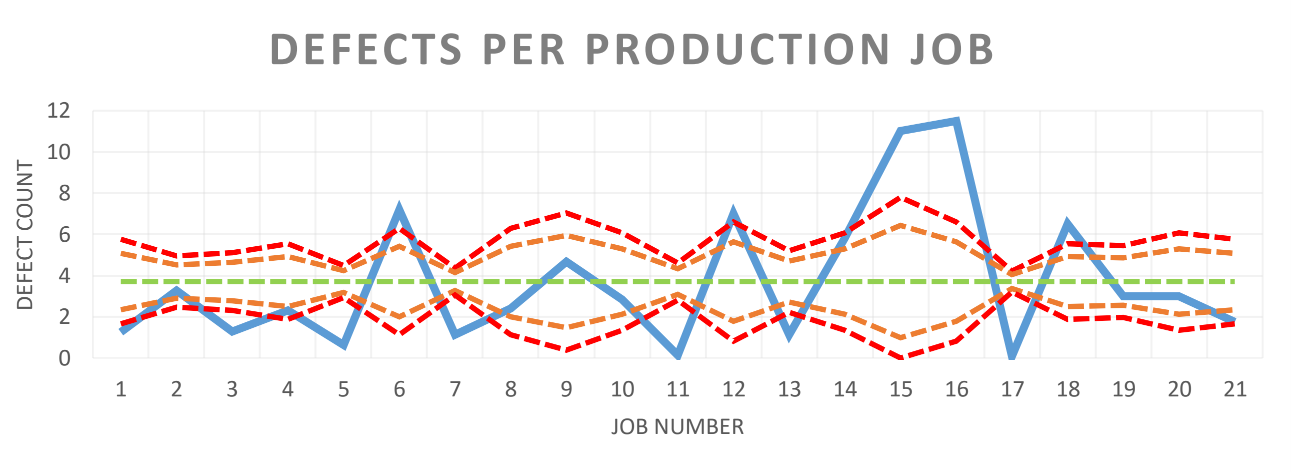


Figure 22: Defects per Production Job Control Chart

In the control chart above, it can be seen that production job number 6, 12, 15, 16 and 18 contains a significant amount of defects more than the prescribed control limits. This provides strong motivation for management to investigate the possible causes.

7.2.2 Defects per 3 PCBs

With this control chart, the amount of defects per sample size of three PCBs was constructed.

Table 5: Defects per 3 PCBs

Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
n	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
c	9	7	16	13	6	26	7	5	5	3	3	6	3	4	4	3	4	3	6	4	9
Sample	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**
n	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
c	28	10	4	8	5	22	23	3	12	8	3	5	4	19	19	9	4	3	3	3	3
Sample	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**
n	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
c	3	3	3	5	4	12	10	6	6	9	7	12	12	49	8	3	3	3	3	3	3
Sample	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**
n	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
c	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	12	7	7	7	7	11

$$\bar{c} = \frac{\sum c}{84} = \frac{621}{84} = 7.31$$

$$\bar{c} \geq 5$$

$\therefore$ Control limits statistically valid

$$UCL = \bar{c} + 3\sqrt{\bar{c}}$$

$$UCL = 15.4$$

$$UWL = \bar{c} + 2\sqrt{\bar{c}}$$

$$UWL = 12.7$$

$$LWL = \bar{c} - 2\sqrt{\bar{c}}$$

$$LWL = 1.9$$

$$LCL = \bar{c} - 3\sqrt{\bar{c}}$$

$$LCL = 0$$

In Figure 23 below the resulting c-control chart are constructed:

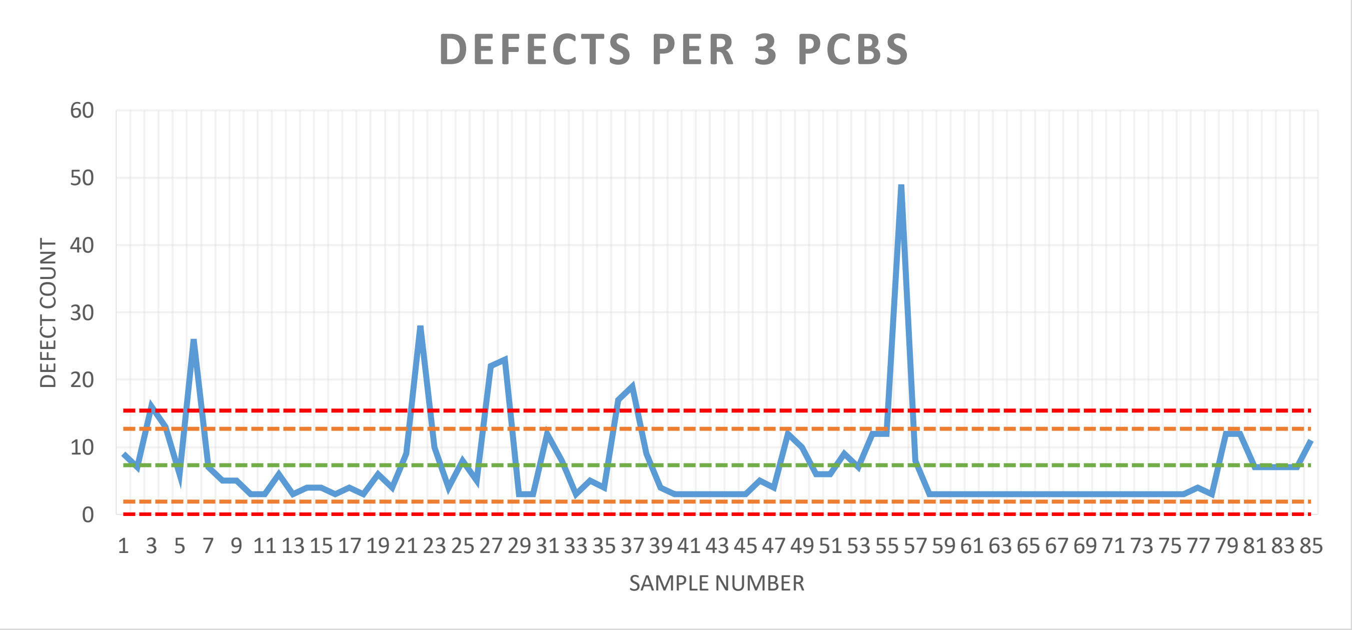


Figure 23: Defects per 3 PCBs Control Chart

Sample number 3, 6, 22, 27, 28, 35, 36 and 56 appears to be above the upper control limit. Investigation has to be done with regards to the reason for the many defects occurring in these single PCBs. As mentioned earlier, due to the limited amount of data available, it was assumed that all PCBs in this data set has the same level of complexity. It is a fact though, that a PCB consisting out of more components and solder joints, would be prone to more defects. This complexity factor thus have to be considered when constructing control charts. PCBs with the same level of complexity has to be compared with one another.

Process Performance and Capability Study

By applying run rules to the control chart above in Figure 23, the best points are selected in order to determine the capability of the production process.

The current process performance yields a $\bar{c}$ value of 7.31 implying that there occurs 7.32 defects on every three printed circuit boards. By utilizing only desired points selected by applying run rules, a new $\bar{c}$ value are computed:

$$\bar{c}_0 = \frac{\sum c}{74} = \frac{326}{69} = 4.7$$

The production process are thus capable to reach only 4.7 defects for every three printed circuit boards manufactured. Parsec should strive to reduce this amount of defects on a continuous basis.

7.3 Further Analysis

7.3.1 Pareto Analysis

Figure 24 below illustrates a pareto anaylsis of the data set. This statistical analysis demonstrates that by reducing the amount of missing components, damaged components and dry joint defects, will produce a significant overall effect. By only addressing 20% of the causes of the defects, an 80% difference in the amount of occurrences will be addressed.

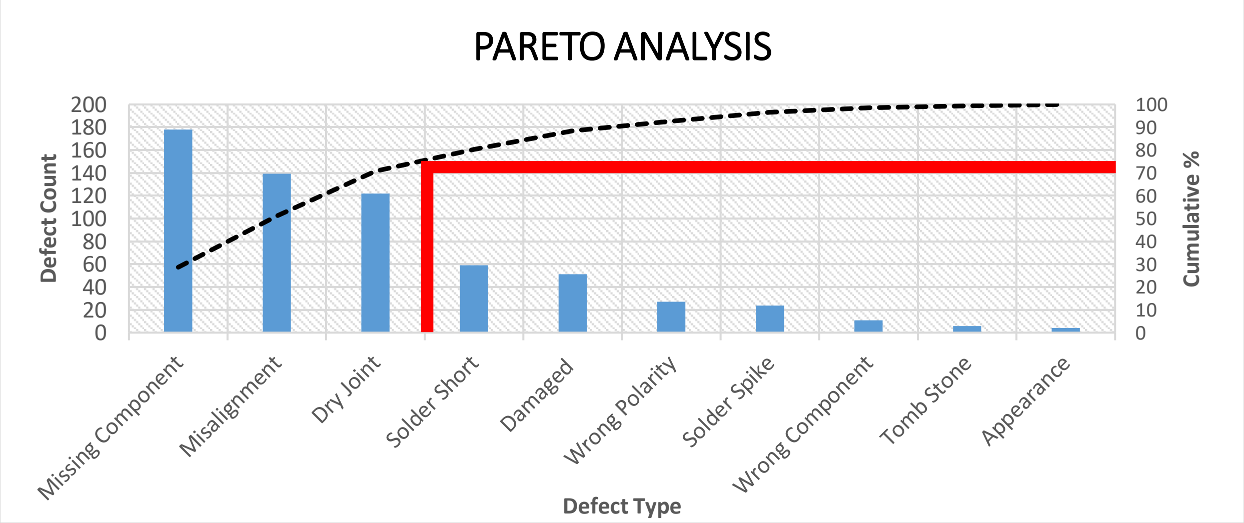


Figure 24: Pareto Analysis

7.3.2 Cause and Effect Diagram

A further way to analyse the defects of the PCBs is by utilizing a cause-and-effect diagram. In doing so, the various sources of the defects in the PCBs are illustrated, and the interrelationships amongst them can be useful to trace down the root cause of specific defects. This enables production managers and manufacturing engineers to focus their attention on specific quality problems and the solutions thereof.

In order to develop a meaningful and accurate cause-and-effect diagram, a lot of technical understanding and knowledge are required. In Figure 25, a cause-and-effect diagram for PCB soldering defects are illustrated. According to the pareto analysis in the previous section, the three main defects occurring on the PCBs at Parsec are soldering defects as well. This diagram focusses on the main sources of defects:

equipment, materials, and operators. The manufacturing engineers and production managers can utilize the diagram in Figure 25 as a starting point to work from when developing a cause-and-effect diagram customized for Parsec's needs:

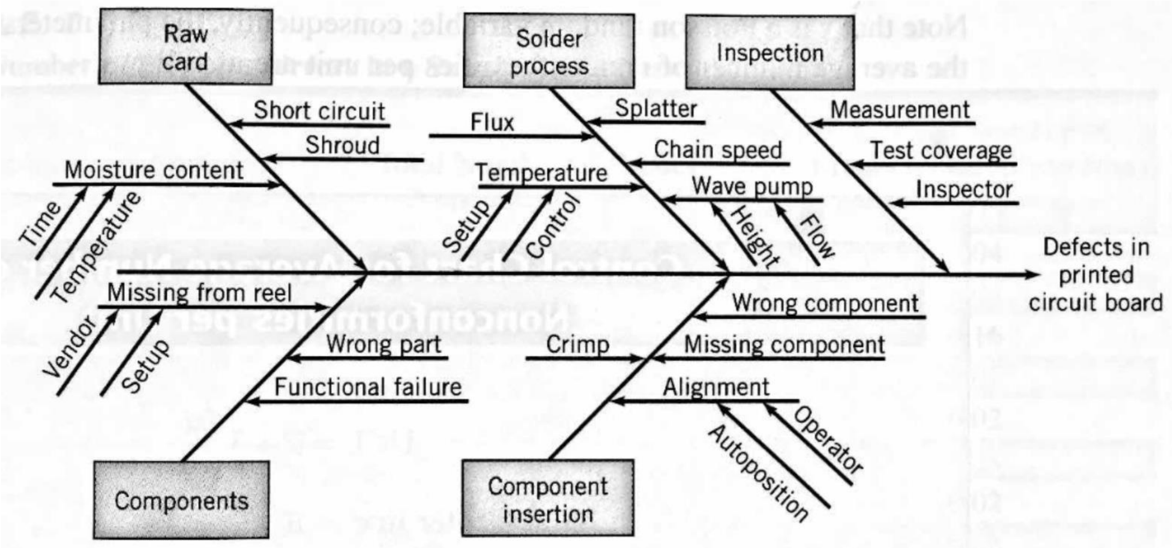


Figure 25: Cause-and-effect diagram (Montgomery, 2013)

8 Solution

As mentioned before, the solution consists out of three elements:

Table 6: Solution Summary

Element	Problem	Solution Description
Data Capturing System	Inconsistent and irregular formats and platforms resulting in capturing inaccurate data, or no data at all.	User-friendly data capturing system, in order to consistently capture accurate defect data.
Defect Records	No standardized records to analyse and use for a SPC system.	Standardized inputs to use consistent records for a SPC system.
SPC System	No means of monitoring and controlling the occurrence of defects on PCBs.	Informatics tool consisting out of statistical process control charts and other statistical analyses to monitor and control defects.

These elements work together in Excel in order to provide management with an accurate decision making tool. In the sections below, each element are discussed in more detail.

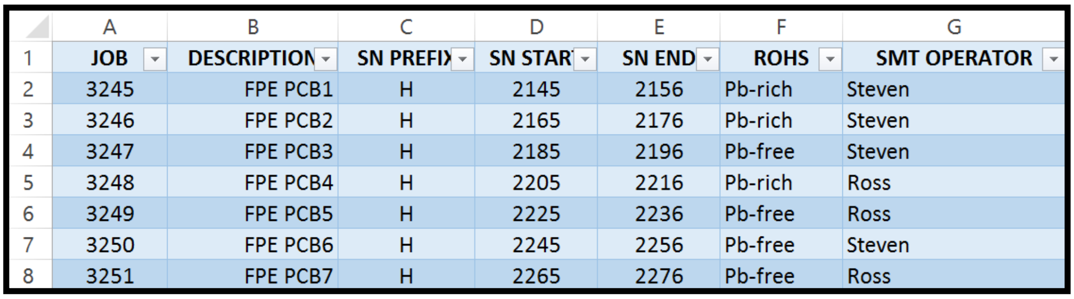
8.1 Data Capturing System

The defect data captured in Parsec's Jira system is not an effective and sustainable means of capturing accurate data to use for SPC. With the analysis of the limited amount of data that was available for this project, data had to first manually be transferred from the production job feed in Jira to a spreadsheet in Excel.

With the help of Visual Basic for Applications (VBA), a new data capturing system was designed, in order to solve the first problem. The flow of events are described below.

<u>Production Job Table</u>

Firstly, the production manager has to capture and continuously update the table in the Production Jobs sheet. This table consists of the information columns in Figure 26. The description is a description of the type of product, and then the range of serial numbers (SN) out of which the production job consist are populated as well. The ROHS compliance states whether soldering flux with or without lead were used:



	A	B	C	D	E	F	G
1	JOB	DESCRIPTION	SN PREFIX	SN START	SN END	ROHS	SMT OPERATOR
2	3245	FPE PCB1	H	2145	2156	Pb-rich	Steven
3	3246	FPE PCB2	H	2165	2176	Pb-rich	Steven
4	3247	FPE PCB3	H	2185	2196	Pb-free	Steven
5	3248	FPE PCB4	H	2205	2216	Pb-rich	Ross
6	3249	FPE PCB5	H	2225	2236	Pb-free	Ross
7	3250	FPE PCB6	H	2245	2256	Pb-free	Steven
8	3251	FPE PCB7	H	2265	2276	Pb-free	Ross

Figure 26: Production Job Table

<u>Technician Data Input</u>

After the production manager has populated the production job details, quality control technicians can start to populate defects with the custom designed form for the production job. In Figure 27, the details of this form are shown:

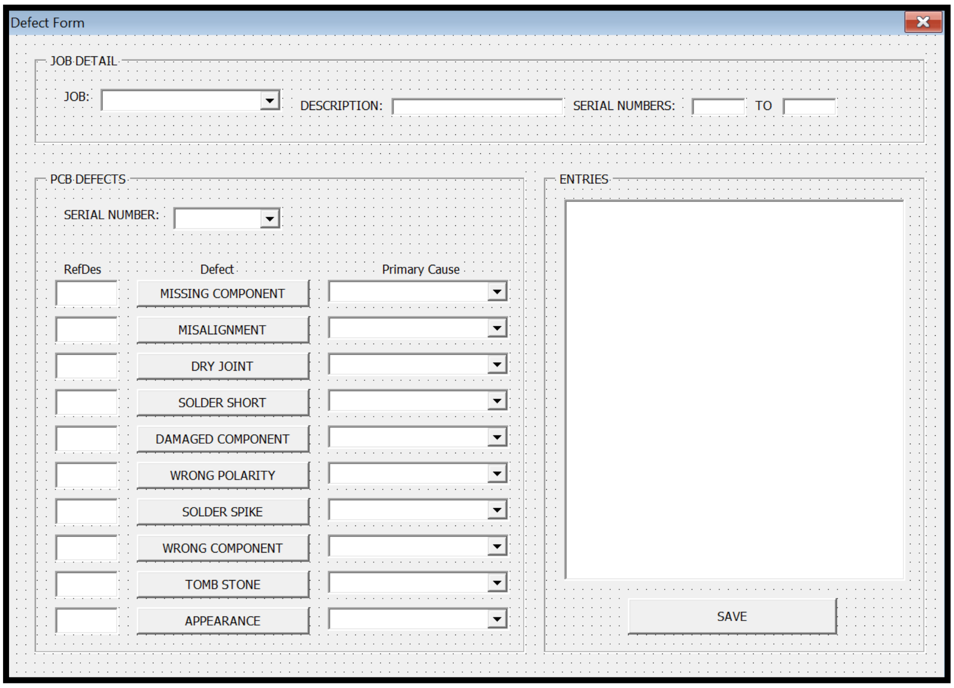
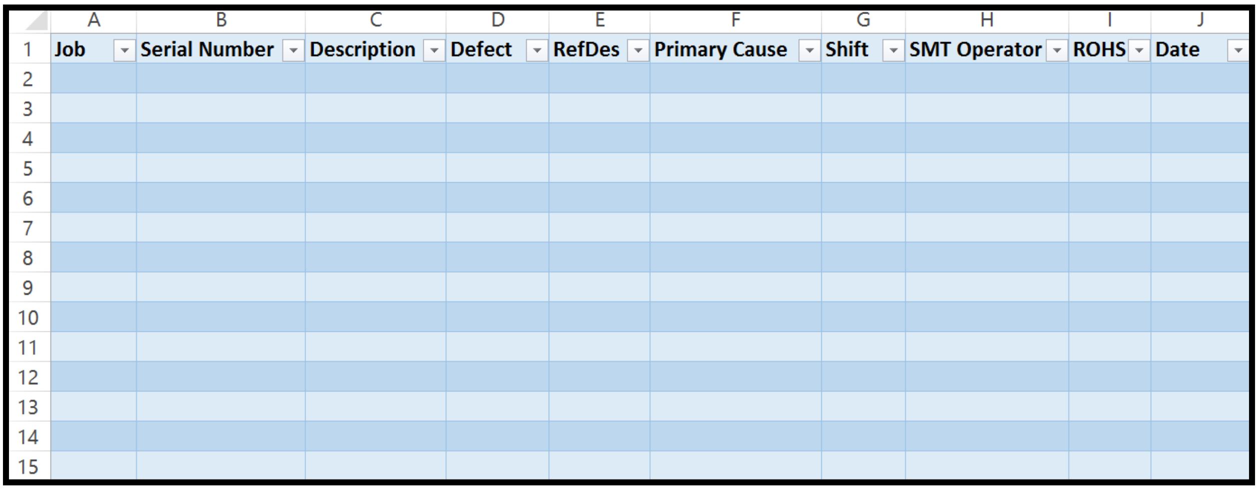


Figure 27: Defect Form

The quality control technicians first has to select which production job they are working on. This combo box is connected with the production job table the production manager populated, thus giving only populated production jobs as options to pick from for the user. Once a production job is selected, the description box and serial numbers are automatically populated into their respective text boxes.

After this, technicians can commence to populate each defect, by selecting the serial number in the serial number combo box. A description of the component on which the specific defect occurred are then typed in by the technician in the corresponding reference designator (RefDes) column. The entry is finished off by clicking on the specific defect button, as well as the primary cause of the defect. With the clicking of this button, a string of data regarding the job number, serial number, component, primary cause, date and defect type are transferred to the entry list box on the right side of the form. This process is then repeated for each different defect on each different PCB.

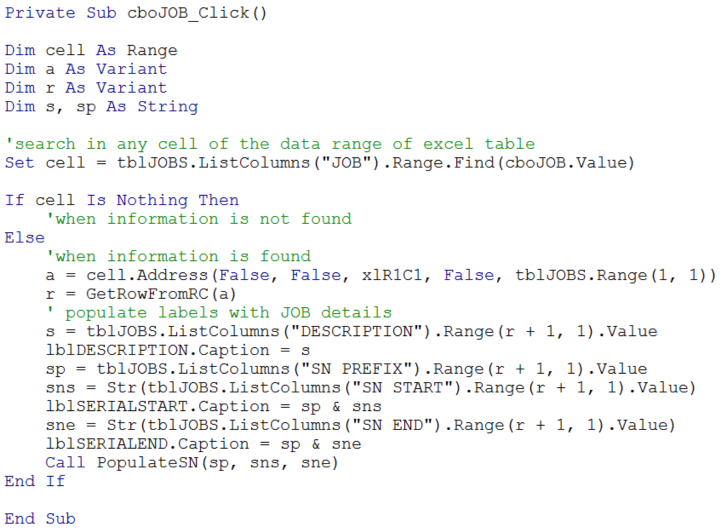
Once technicians are finished with a production job, they have to click on the 'SAVE' button, after which the list box will be cleared, and the entries inside of the list box will be transferred to the second element of the solution – the defect records table shown in Figure 28 below:



	A	B	C	D	E	F	G	H	I	J
1	Job	Serial Number	Description	Defect	RefDes	Primary Cause	Shift	SMT Operator	ROHS	Date
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

Figure 28: Defect Records Table

Figure 29 illustrates a snippet of the programming in VBA constructed in order to make the process described above, possible:

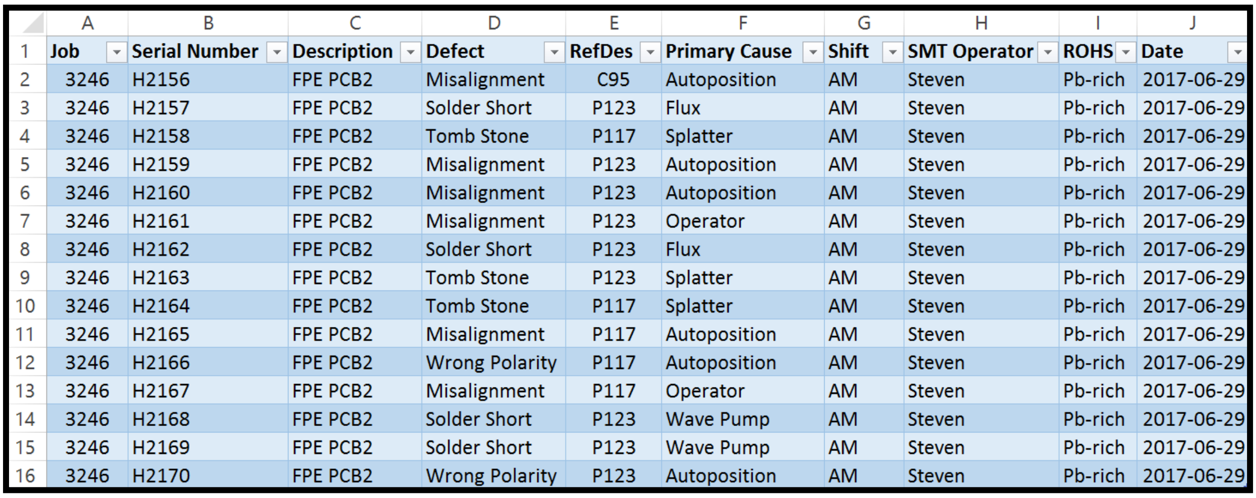


```
Private Sub cboJOB_Click()

Dim cell As Range
Dim a As Variant
Dim r As Variant
Dim s, sp As String

'search in any cell of the data range of excel table
Set cell = tblJOBS.ListColumns("JOB").Range.Find(cboJOB.Value)

If cell Is Nothing Then
    'when information is not found
Else
    'when information is found
    a = cell.Address(False, False, xlR1C1, False, tblJOBS.Range(1, 1))
    r = GetRowFromRC(a)
    ' populate labels with JOB details
    s = tblJOBS.ListColumns("DESCRIPTION").Range(r + 1, 1).Value
    lblDESCRIPTION.Caption = s
    sp = tblJOBS.ListColumns("SN PREFIX").Range(r + 1, 1).Value
    sns = Str(tblJOBS.ListColumns("SN START").Range(r + 1, 1).Value)
    lblSERIALSTART.Caption = sp & sns
    sne = Str(tblJOBS.ListColumns("SN END").Range(r + 1, 1).Value)
    lblSERIALEND.Caption = sp & sne
    Call PopulateSN(sp, sns, sne)
End If

End Sub
```

Figure 29: Visual Basic Application Programing

8.2 Defect Records

Each time a technician clicks on the ‘SAVE’ button on the user form, the entries are transferred to the defects record table. This is illustrated in Figure 30 below:



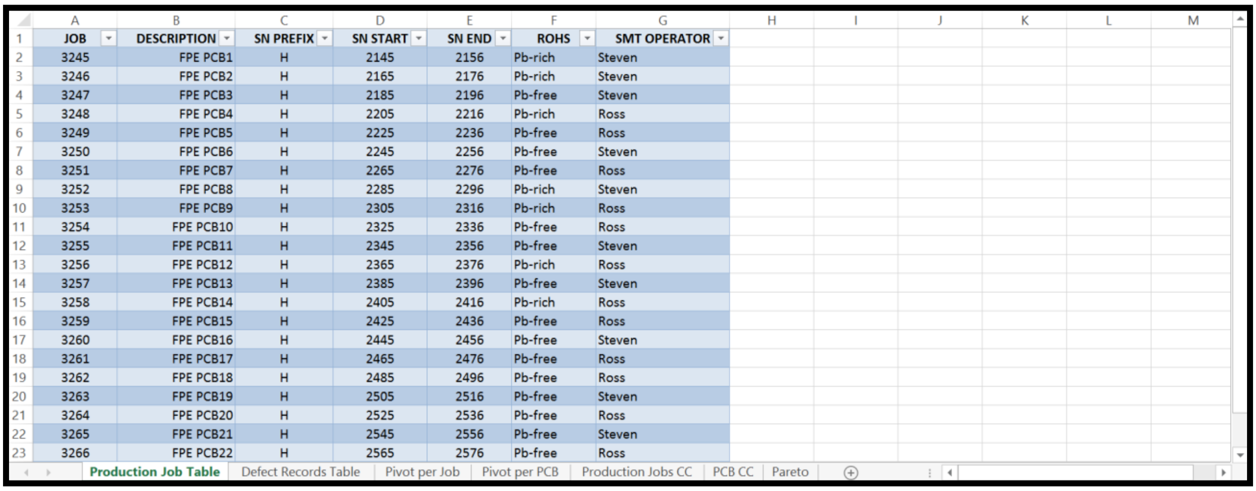
Job	Serial Number	Description	Defect	RefDes	Primary Cause	Shift	SMT Operator	ROHS	Date
3246	H2156	FPE PCB2	Misalignment	C95	Autoposition	AM	Steven	Pb-rich	2017-06-29
3246	H2157	FPE PCB2	Solder Short	P123	Flux	AM	Steven	Pb-rich	2017-06-29
3246	H2158	FPE PCB2	Tomb Stone	P117	Splatter	AM	Steven	Pb-rich	2017-06-29
3246	H2159	FPE PCB2	Misalignment	P123	Autoposition	AM	Steven	Pb-rich	2017-06-29
3246	H2160	FPE PCB2	Misalignment	P123	Autoposition	AM	Steven	Pb-rich	2017-06-29
3246	H2161	FPE PCB2	Misalignment	P123	Operator	AM	Steven	Pb-rich	2017-06-29
3246	H2162	FPE PCB2	Solder Short	P123	Flux	AM	Steven	Pb-rich	2017-06-29
3246	H2163	FPE PCB2	Tomb Stone	P123	Splatter	AM	Steven	Pb-rich	2017-06-29
3246	H2164	FPE PCB2	Tomb Stone	P117	Splatter	AM	Steven	Pb-rich	2017-06-29
3246	H2165	FPE PCB2	Misalignment	P117	Autoposition	AM	Steven	Pb-rich	2017-06-29
3246	H2166	FPE PCB2	Wrong Polarity	P117	Autoposition	AM	Steven	Pb-rich	2017-06-29
3246	H2167	FPE PCB2	Misalignment	P117	Operator	AM	Steven	Pb-rich	2017-06-29
3246	H2168	FPE PCB2	Solder Short	P123	Wave Pump	AM	Steven	Pb-rich	2017-06-29
3246	H2169	FPE PCB2	Solder Short	P123	Wave Pump	AM	Steven	Pb-rich	2017-06-29
3246	H2170	FPE PCB2	Wrong Polarity	P123	Autoposition	AM	Steven	Pb-rich	2017-06-29

Figure 30: Defect Records Table

8.3 Statistical Process Control System

The last element of the solution is the spreadsheet in Excel that consists of statistical process control charts as well as other statistical interpretations, constructed by using the data in the defect records table.

Figure 31 illustrates the complete Excel file with all its elements displayed in the tabs at the bottom of the figure:



JOB	DESCRIPTION	SN PREFIX	SN START	SN END	ROHS	SMT OPERATOR
3245	FPE PCB1	H	2145	2156	Pb-rich	Steven
3246	FPE PCB2	H	2165	2176	Pb-rich	Steven
3247	FPE PCB3	H	2185	2196	Pb-free	Steven
3248	FPE PCB4	H	2205	2216	Pb-rich	Ross
3249	FPE PCB5	H	2225	2236	Pb-free	Ross
3250	FPE PCB6	H	2245	2256	Pb-free	Steven
3251	FPE PCB7	H	2265	2276	Pb-free	Ross
3252	FPE PCB8	H	2285	2296	Pb-rich	Steven
3253	FPE PCB9	H	2305	2316	Pb-rich	Ross
3254	FPE PCB10	H	2325	2336	Pb-free	Ross
3255	FPE PCB11	H	2345	2356	Pb-free	Steven
3256	FPE PCB12	H	2365	2376	Pb-rich	Ross
3257	FPE PCB13	H	2385	2396	Pb-free	Steven
3258	FPE PCB14	H	2405	2416	Pb-rich	Ross
3259	FPE PCB15	H	2425	2436	Pb-free	Ross
3260	FPE PCB16	H	2445	2456	Pb-free	Steven
3261	FPE PCB17	H	2465	2476	Pb-free	Ross
3262	FPE PCB18	H	2485	2496	Pb-free	Ross
3263	FPE PCB19	H	2505	2516	Pb-free	Steven
3264	FPE PCB20	H	2525	2536	Pb-free	Ross
3265	FPE PCB21	H	2545	2556	Pb-free	Steven
3266	FPE PCB22	H	2565	2576	Pb-free	Ross

Figure 31: Complete Excel File

The first two tabs, ‘Production Job Table’ and ‘Defect Records Table’ are explained in the previous two sections. A ‘Pivot per Job’ tab and a ‘Pivot per PCB’ tab follows in order to summarize the figures needed to compute the control charts in the following two tabs.

8.3.1 SPC Control Chart for Production Jobs

This control chart plots the amount of defects for each different production job. The sample size for each production job differ, and the control limits are therefor adjusted for each production job. A u-control chart are used for this scenario. Figure 32 illustrates an example of this tab:

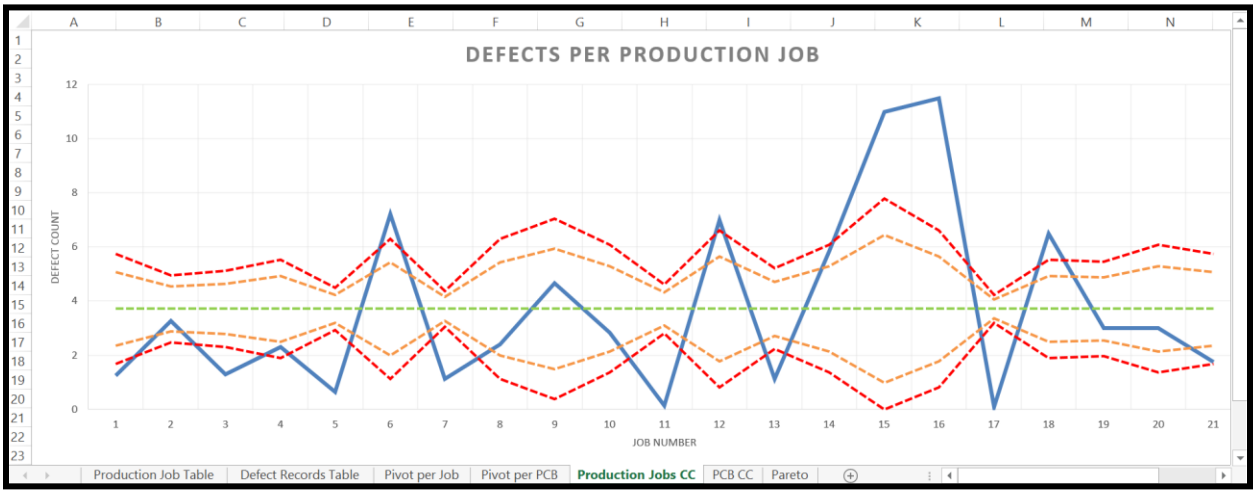


Figure 32: Production Jobs Control Chart

Data from the table in the ‘Pivot per Job’ tab are used to construct this control chart. The following formulas are used:

$$\bar{u} = \frac{\sum u}{No.\ of\ Jobs}$$

$$UCL = \ \bar{u} + 3\sqrt{\bar{u}/n_i}$$

$$UWL = \ \bar{u} + 2\sqrt{\bar{u}/n_i}$$

$$LWL = \ \bar{u} - 2\sqrt{\bar{u}/n_i}$$

$$LCL = \ \bar{u} - 3\sqrt{\bar{u}/n_i}$$

8.3.2 SPC Control Chart for Class 1, 2 and 3 Complexity

This control chart plots the defects of individual PCB samples. As mentioned before, the level of complexity of the PCBs differ, and therefor control charts are constructed for each different class of complexity. Three different complexity classes are used to distinguish between PCB complexities, each illustrated with its own control chart. Class 1 equals the low complexity PCBs, Class 2 the medium complexity PCBs and Class 3 the high complexity PCBs.

$$Complexity = \frac{(Number\ of\ components)\ \times (Number\ of\ Solder\ Joints)}{Area\ of\ PCB}$$

Figure 33 illustrates an example of this tab:

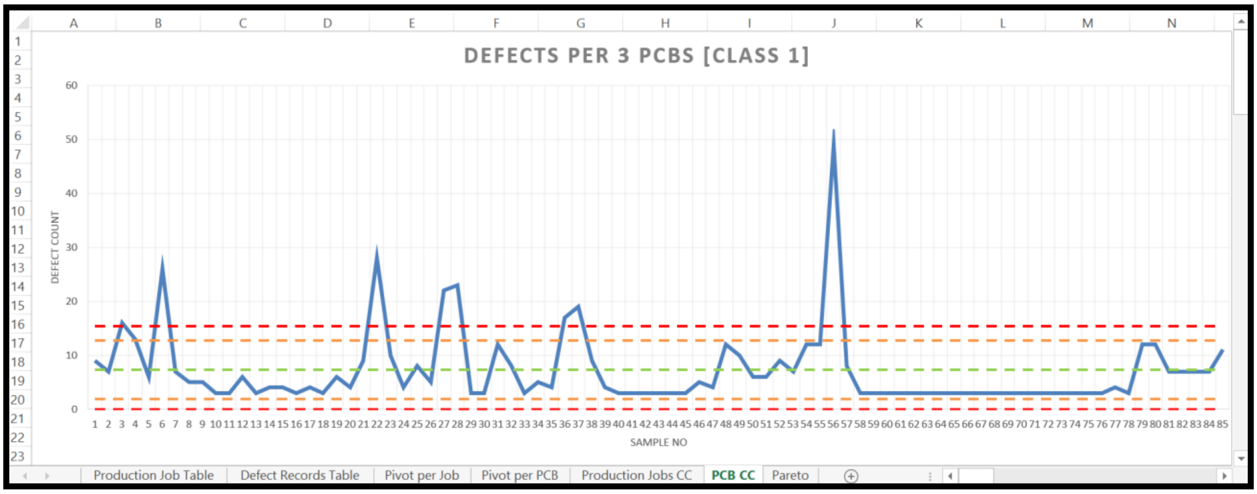


Figure 33: PCB Control Chart

Data from the table in the 'Pivot per PCB' tab are used to construct this control chart. The following formulas are used:

$$\bar{c} = \frac{\sum c}{No. of\ Samples}$$

$$UCL = \bar{c} + 3\sqrt{\bar{c}}$$

$$UWL = \bar{c} + 2\sqrt{\bar{c}}$$

$$LWL = \bar{c} - 2\sqrt{\bar{c}}$$

$$LCL = \bar{c} - 3\sqrt{\bar{c}}$$

8.3.3 Pareto Analysis

The spreadsheet includes a Pareto chart as well. This enables management to identify which 20% of defect causes will solve 80% of the defect problems, should that 20% be addressed. Figure 34 illustrates an example of this tab:

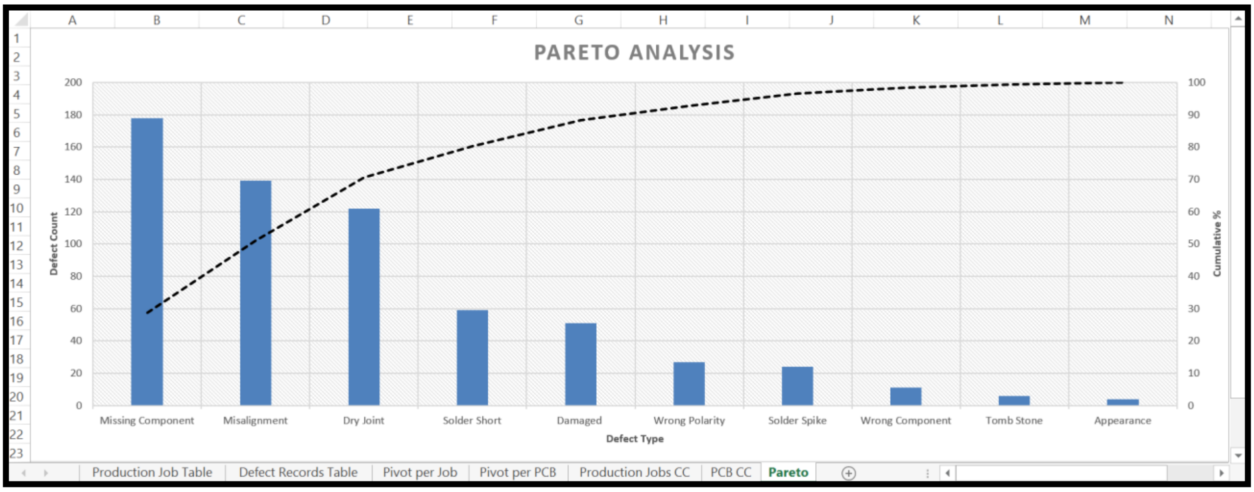


Figure 34: Pareto Analysis Tab

8.3.4 System Automation Specifications

The current Excel file was constructed manually. It is recommended however for Parsec to program the file in VBA in order to ensure that the control charts update continuously as new defect records are captured in the Defect Records Table sheet. The following specifications should be taken into consideration when programming in VBA:

1. For the PCB control charts, an amount of PCBs should be grouped into samples which still ensures statistical valid control limits. The condition on which control limits are statistically valid, is that the average amount of defects per sample should be equal or greater than five.
2. For the PCB control charts, PCBs should be classified into their respective complexity classes and control charts for the three complexity classes should then be constructed accordingly.
3. Control limits for the Production Job control charts should be customized for each different production job as the sample sizes differ.
4. A further recommendation would be for the spreadsheet to apply run rules on the control charts automatically, and provide warnings to the user should out-of-control-points be detected.

8.3.5 Identifying Root Causes

In order to reduce the occurrences of specific defects, the root cause of the defects should be identified. For Parsec, this has to be done by constructing a customized Cause-and-Effect diagram as mentioned before. The root causes of defects are extremely technical, and the solution thereof will therefor only be developed by production managers and electronic manufacturing engineers.

8.4 Alternative Solutions

Alternative solutions to reduce the amount of defects at the quality control stations, would still involve the use of Statistical Process Control. There are however, numerous ways SPC can be applied to address quality problems. Table 7 below demonstrates other types of control charts, and why these control charts were not chosen to solve the problem:

Table 7: Alternative Options

Control Chart Type	Description	Reason for Not Utilizing
$\overline{X}$ and $\overline{\boldsymbol{R}}$	These control charts is used for variable data. The variates in the data are distribution dependant. In the second case study in section 6 of this report, it is illustrated how these type of control charts can be used to address specific measurements influencing the quality of PCBs such as solder paste height.	Parsec has to first identify which defect types contributes the most to the quality problems. These control charts can be used only once it has been determined on which defects type should be focused, and what the characteristics are to be measured in order to address the specific defect problem.
$\overline{X}$ and $\overline{\boldsymbol{S}}$		
$\overline{X}$ and $\overline{\boldsymbol{MR}}$		
EWMA or CUSUM		

np or p	These control charts are used for attribute data. This is the case where 2 classes can be identified and counted. For example, the amount of defective PCBs versus the amount of non-defective PCBs.	This chart only specifies how many PCBs of the ones checked are defective. In Parsec's case, this is not very specific as to what exactly should be addressed in order to reduce defective PCBs.

8.5 Implementation of Solution

Since this will be the first SPC system to be implemented at Parsec, the current system is very basic, and can be evolved into a much more advanced system in the future. The idea of this system is to get production managers and technicians used to this new tool of solving quality problems. Once they are familiarized with the functions and advantages the system brings, other control charts and quality characteristics can be addressed.

9 Solution Validation

Careful attention to detail was given during the construction of the solution in Excel. Different errands and scenarios was tested in order to eliminate possible errors. Errors can occur by the means of the user not inserting the correct inputs into the system, and also by the means of technical incorrect practise.

9.1 Validating Actions

The following activities were or will be executed in order to test the solution so that all possible errors can be eliminated:

Table 8: Validating Activities

	Present Validation	Future Validation
Activities	The defect data used for analysis purposes in this project, were populated as dummies into the Excel spreadsheet, after which the results of the control charts was evaluated and compared to the control charts constructed manually before. This procedure resulted in identical control charts, as well as an identical pareto chart.	The Excel spreadsheet will be given to the quality technicians to utilize for a period to serve as a test run. Any difficulties experienced by them, will then be addressed. Further, the Industrial Engineer at Parsec will carefully analyse the control charts, to continuously test statistical validity and the accuracy of control limits.

9.2 Other Validating Feedback

During the executive committee meeting in August, the production manager director of Parsec presented the data analysed in this report. It was the first time that it was possible for Parsec to present information and analysis with regards to specific defects in their manufacturing facility.

These data raised many questions regarding the significant amount of certain defect types occurring. The reaction to this data validates that there is indeed a need for a proper defect data and also an accompanying statistical process control system.

10 Conclusion

After a substantial amount of research and investigation into Parsec's production process, it is assuring to have come aware that, even though the manufacturing facility has a lot of areas for improvement, and that these reasons might be factors in the quality problems experienced by the company, other similar companies (mentioned in the case studies) in developed countries experiences the same quality problems.

Research also confirmed that statistical process control are used by these companies in order to solve quality problems. Each company and manufacturing facility operates in a unique manner, and due to this, statistical process control are utilized in manufacturing facilities in the same industry by measuring characteristics unique to the specific problem the company experiences.

With the limited data captured and analysed in this project, it can be concluded that Parsec has to focus their energy in investigating the root causes for the significant amount of missing components, damaged components, and dry joints on their PCBs. Further, the solution will aid production managers and manufacturing engineers in monitoring future defects on the PCBs.

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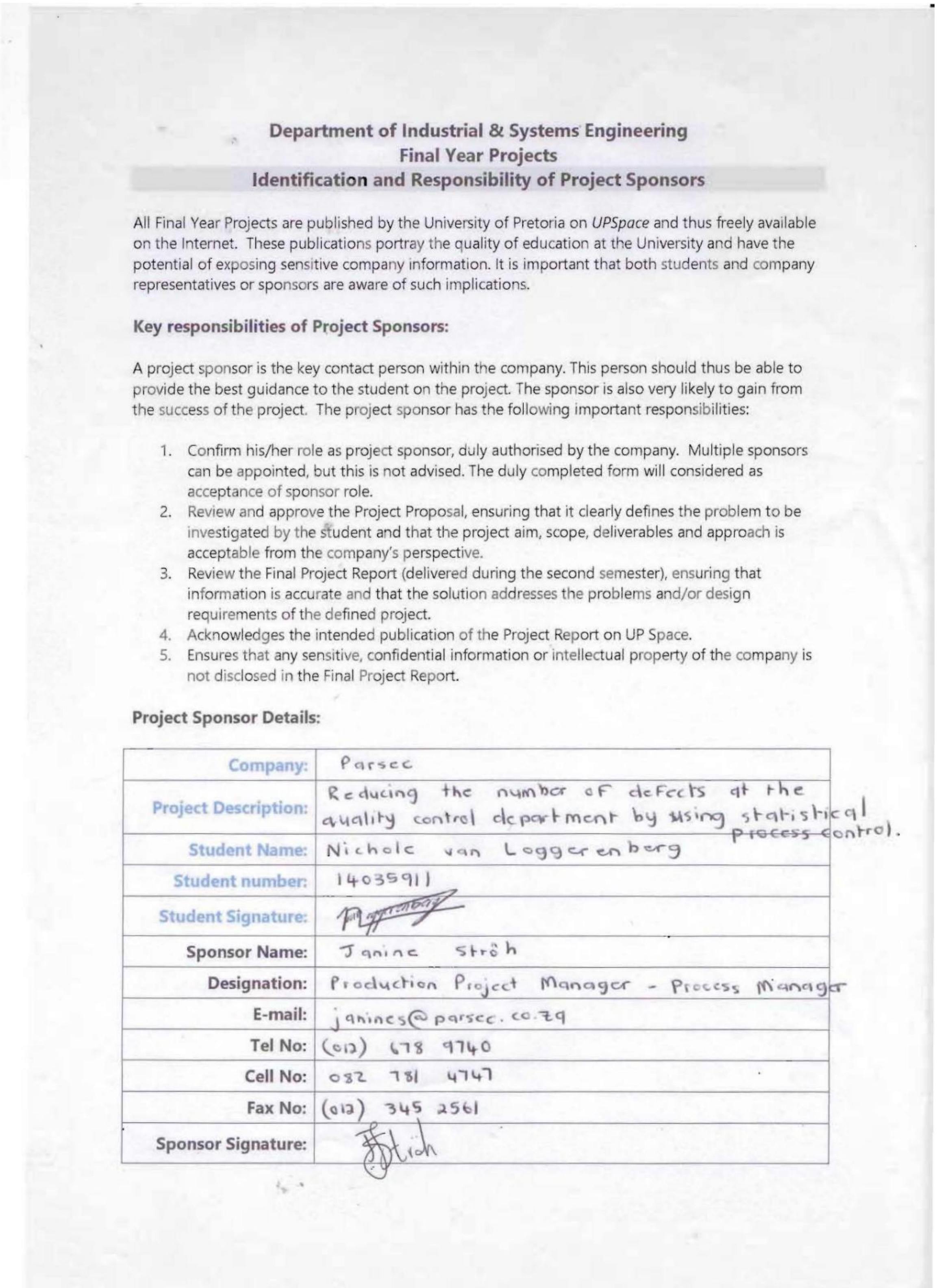
Appendix A

Project Sponsorship Form



Department of Industrial & Systems Engineering
Final Year Projects
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A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	Parsec
Project Description:	Reducing the number of defects at the quality control department by using statistical ~~process~~ control.
Student Name:	Nichole van Loggerenberg
Student number:	14035911
Student Signature:	
Sponsor Name:	Janine Ströh
Designation:	Production Project Manager - Process Manager
E-mail:	janines@parsec.co.za
Tel No:	(012) 678 9740
Cell No:	082 781 4747
Fax No:	(012) 345 2561
Sponsor Signature:	