Flow Algorithm to Enhance Operational Performance and Improve Maintenance Effectiveness

by

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LIST OF ABBREVIATIONS

A	Ampere / Current
ABM	Age Based Monitoring
ATM	Assembly and Test Manufacturing
CBM	Condition Based Maintenance
CECA	Cause and Effects Chain Analysis
COD	Contain Own Defects
C_{pk}	Capability
DCI	Death Correlation Index
DOA	Defect On-Arrival
EOL	End of Line
EUPH	Effective Unit Per Hour
FMEA	Failure Mode and Effects Analysis
FVI	Final Visual Inspection
HMLV	High Mix and Low Volume
HR	Highly Reflective
mFVI	Manual Final Visual Inspection
ML	Machine Learning
MNC	Multi-National Corporation
MPV	Main Parameter of Value
MTBA	Mean Time Between Assist
MTBF	Mean Time Between Failures
Nd:Yag	Neodymium:Yttrium-Aluminum Garnet
OBM	Output Based Monitoring
OC	Output Coupler
OCR	Optical Character Recognition
ODM	Original Design Manufacturers
OEM	Original Equipment Manufacturer
OES	Optical Emission Spectroscopy
OOC	Out of Control
PdM	Predictive Maintenance
PM	Preventive Maintenance
PMI	Post Mark Inspection Camera
ROI	Return of Investment
RPN	Risk Priority Number

RUL	Remaining Useful Life
SPC	Statistical Process Control
TPM	Total Productive Management
TRIZ	Theory of Inventive Problem Solving
TSP	Time series Prediction
UPH	Unit Per Hour
W	Watt
WIP	Work In Progress

Algoritma Aliran Bagi Meningkatkan Prestasi Operasi Pembuatan Dan Menigkatkan Keberkesanan Penyelengaraan

ABSTRAK

Keunggulan dalam bidang pembuatan bererti operasinya berfungsi dengan berkesan dan keluaran diperolehi dalam masa yang ditetapkan, dengan kualiti terbaik serta memenuhi kesemua spesifikasinya. Kemajuan sector pembuatan ke arah keunggulan memerlukan prestasi operasi yang lancar serta strategi penyelenggaraan yang berkesan. Kebolehan untuk menyelesai masalah amat penting bagi aspek operasi pembuatan tetapi tidak lengkap tanpa sistem penyelenggaraan yang mantap. Terdapat banyak kaedah untuk menyelesai masalah dalam sector ini tetapi yang melibatkan penambahbaikan sistem pengelenggaraan adalah terhad. Objektif kajian ini adalah untuk membangunkan satu algoritma aliran operasi yang akan membolehkan pengguna menyelesaikan masalah dalam bidang pembuatan serta membolehkan sistem penyelenggaraan menjadi lebih cekap. Algoritma baru ini berfungsi dengan menganalisa masalah sedia ada dan menumpukan masalah kepada lokasi terperinci di dalam mesin dengan membina modal analisis fungsi dan mengenalpasti parameter nilai utama masalah (MPV) tersebut. MPV kemudian dibandingkan dengan sistem peyelenggaraan sedia ada untuk menentukan prestasi operasinya sama ada berkesan ataupun tidak. Jika didapati prestasi operasi tidak lestari, maka suatu kaedah barudiperlukan untuk mengubah cara penyelenggaraan dijalankan dengan membolehkanMPV dipantau atau diukur. Prestasi MPV dipantau secara aktif dengan mengambilkira analisis kestabilan serta analisis kemampuan untuk mementukan masa terbaik untuk mengambil sebarang tindakan keatas peralatan berasaskan matrik penilaian risiko. Algoritma baru ini akan disahkan melalui operasi menanda laser dan prestasi peralatan laser (mesin). Prestasi diod laser dapat dicirikan dengan menganalisis status diod laser berbanding dengan diod yang berbeza jangka hayatnya dengan kuasa outputnya, serta pemantauan aktif kuasa laser dengan arus laser di permulaan setiap lot baru. Ini membolehkan amalan penyelenggaraan berubah daripada amalan reaktif kepada penyelenggaraan berdasarkan keadaan (CBM). Untuk prestasi proses, amalan penyelenggaraannya berjaya ditingkatkan dengan merealisasikan pengecaman watak optik (OCR) yang membolehkan pemantauan secara aktif semua produk yang ditandakan dan sekali gus menyinkirkan pergantungan kepada pemeriksaan visual manual. Ini dilakukan dengan membina suatu senarai aksara mesin laser yang digunakan untuk perbandingan dengan setiap produk yang ditandai. Sebarang penolakan yang dikesan, akan diasingkan dan disingkirkan daripada operasi tersebut. Peningkatan ini membolehkan kadar pengeluaran bertambah sebanyak 8% dan mengubah penyelenggaraan dari PM menjadi CBM. Kesimpulannya, algoritma aliran baru ini berjaya menyelesaikan masalah pembuatan dan memperbaiki amalan penyelenggaraan sebagai penyelesaian keseluruhan yang menyeluruh.

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Flow Algorithm To Enhance Operational Performance And Improve Maintenance Effectiveness

ABSTRACT

Manufacturing excellence means the operation works effectively to deliver the output within the desired time, with the highest quality and meeting all specification. The journey towards manufacturing excellence requires smooth operational performance and a strong maintenance strategy to enable it. Problem solving becomes a critical enabler to achieving manufacturing excellence by resolving issues that arisefrom imperfect operations but problem solving is just half the effort, the other part is theeffectiveness of the maintenance practice. Many problem-solving methodologies use very good techniques and approaches to tackle manufacturing problems effectively but do not necessarily look at maintenance within the same effort. The objective of this study was to develop an operational process flow algorithm that would enable user to easily follow to get to a solution and also positively influence the maintenance practice so that both the problem and the maintenance practice are comprehensively improved. The algorithm works by analyzing the problem and narrowing down to a specific problem area of the operation through function modelling analysis and identifying the main parameter of value (MPV) of the problem. Next, the MPV is compared to the current maintenance practice to determine if its performance is sustainable. If notsustainable, then a new method to improve the maintenance is worked out by firstly making the MPV parameter quantifiable. Performance of the MPV is actively tracked by using stability and capability analysis to determine when best to intercept and make the change via a risk assessment matrix. The developed algorithm was then validated onthe laser marking operation with both the equipment and operational process performance being validated. The laser diode performance was successfully characterized by analyzing health of diode at different stages of life vs. its measured power output and active monitoring of the laser power and laser current offset performance at the start of each production batch. This allowed the maintenance practice to change from run-to-fail to condition based maintenance (CBM). For the process performance, its maintenance practice improved by successfully enabling optical character recognition (OCR) that allowed 100% active monitoring of all marked products and eliminated manual visual inspection. This was done by building an imaging baseline of characters that are used to compare with each marked product. Any rejects detected are segregated and weeded out within the operation itself. The improvement enabled the overall effective unit per hour (EUPH) to increase by 8% and changed the maintenance from a PM to a CBM. In conclusion, the new flow algorithm was successful in resolving manufacturing problems and improving maintenance practice as a comprehensive overall solution.

CHAPTER 1 : INTRODUCTION

1.1 Background

Manufacturing operations in a plant is made up of a variety of multifaceted processes that are categorized typically by many processing steps, variable process cycle time, dynamic relationship between various equipment and complex interrelations between tool performance and output quality. The semiconductor manufacturing industry is a perfect example of such processes, which usually involves multitude of processing steps, weeks of processing time, re-entrant process flows that manages re-work, and volatile relationships between tool performances and yield. Semiconductor producers are all facing a progressively competitive market environment due to an increase in competitive cost demands. In this thesis, the examples and focus processes are on the manufacture of semiconductor electronic components i.e. the microprocessor in an industrial plant. Improving and increasing microprocessor productivity has always been a priority as the more the company produces in a single timeframe, the more the revenue that flows in. Newly released products need to penetrate the target market in sufficient numbers, reasonably good quality and are competitively priced to retain the market segment share for the company or grow it. Inside an Assembly and Test Manufacturing (ATM) plant for a variety of Original Design Manufacturers (ODM) and Original Equipment Manufacturer (OEM), there are a large number of different types of tools or equipment that are used to complete the manufacturing process of a microchip product from silicon wafers initially to completed packaged products ready to use by the end user.

The equipment used ranges from old technology based tools right up to the new state of the art tools within a factory floor and equipment usage selection varies with the type of product that it is used to manufacture, for example, in Intel Technology's plant located in Penang, Malaysia, there are multiple different wavelength laser marking tool in the single factory and each tool's capability is different (based upon its wavelength source) and is used to mark on different surface of the product that it is intended for. Furthermore, high mix and low volume (HMLV) production stresses higher equipment utilisation and yield but lesser unscheduled downtime. Therefore, ATM factories worldwide have been analysing various methods and techniques to generally:

i. Reduce manufacturing cost
ii. Improve process yield so that more finished products can be shipped out;
iii. Attain low downtime in the manufacturing ecosystem so that all equipment in the factories are up and creating value rather than idling (scheduled/unscheduled downtime);
iv. Realize shorter cycle time for the overall manufacturing process.

The effort is basically to increase machine uptime, reduce defects and stoppages in process and have a maintenance program that keeps the equipment and process running smoothly with zero to minimal interruptions from the day to day task and achieving best in class output quality. Maintenance is the backbone that holds the overall operations together as with multiple types of equipment from the front end to the back end processes as shown in Figure 1.1 of microprocessor manufacturing, if the maintenance is not sufficient, then very quickly the impact would be seen per high mean time between assist (MTBA), higher frequency of equipment failing and that leads to higher production stoppages. Maintaining the equipment alone is not good enough if the effectiveness of the maintenance activity is insufficient.

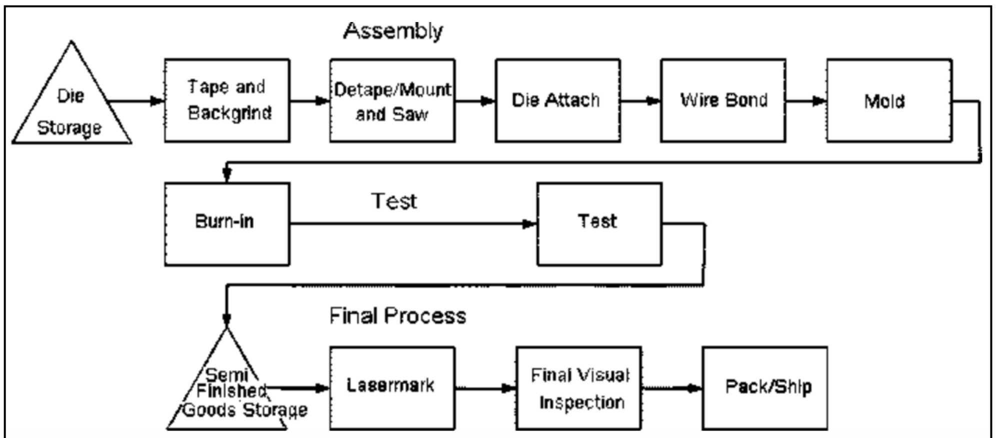

Figure 1.1: Assembly test manufacturing production flow (Zhang, 2007)

Across the manufacturing industry, there are many types of maintenance used and the maintenance processes have evolved over time to cater to the needs of the equipment and operation. The part that makes the maintenance effort worthwhile is how well the failure modes from the equipment is addressed so that the equipment does not fail for those failure modes during its operation under production mode. The better the maintenance, the less the tool is a problem during production. There are several types of maintenance used across the manufacturing industry and to name some of the standard ones that are widely used are:

i. Reactive Maintenance (Repair after failure happens)

ii. Run to fail (push to part to the max then discard)

iii. Proactive Maintenance (fix before it fails)

a. Preventive maintenance (time-based maintenance and is the most common)

b. Predictive Maintenance (parts condition monitoring and failure prediction)

c. Condition based monitoring (performance-based maintenance)

iv. Reliability Centred Maintenance (RCM)

From a recent survey conducted by ATS (Advanced Technology Services Inc) 2019 from 200 manufacturing facilities:

i. 76% PM

ii. 60% Run to fail.

iii. 52% Computerized maintenance management system (CMMS)

iv. 41% PdM using analytical tools

v. 22% Reliability Centred maintenance (RCM) or Conditional Based Maintenance (CBM) using operational data analysis

vi. 4% Others

1.2 Choosing the Right Maintenance Methodology

When deciding on maintenance strategies, there are many aspects that determine which would work best given the system level information like knowing value of equipment parts if broken, would determine how much is lost when a tool breaks down for a specific part, complexity of fixing parts as that would require a maintenance personnel with expertise and specific time duration to get the tool back up versus other non-direct impact values for example, lead time for deliveries of parts all play a role in determining the best approach for maintenance for a given tool.

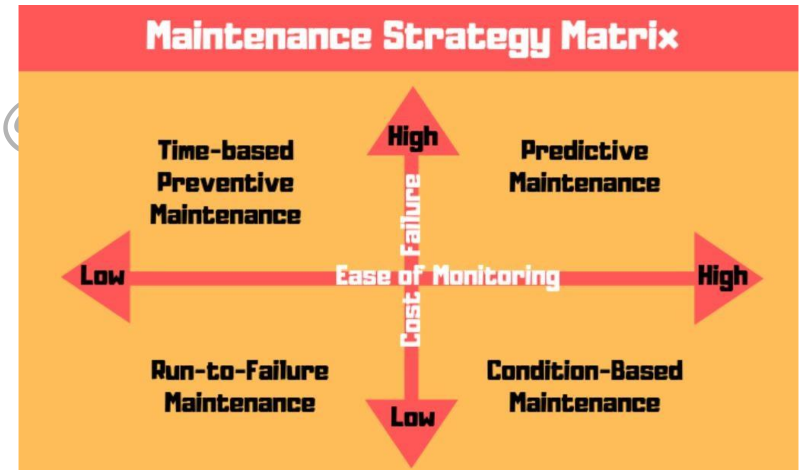

Figure 1.2: Maintenance strategy matrix (Chan, 2020)

Therefore, choosing the type of maintenance to use is entirely up to the operations/Process Engineer to determine which would be best as each maintenance type has its benefits and features but depending on the application area it may vary. The maintenance strategy matrix is a good guide to work with as shown in Figure 1.2. Once a maintenance method has been chosen and utilised, the effectiveness of the maintenance is measured by how good or how well the equipment runs before an unscheduled downtime occurs. For instance, an equipment using a time-based maintenance would need to be up and running for a month if a monthly preventive maintenance (PM) was carried out on the equipment. This means the machine is not allowed to have any unscheduled downtime during that whole month (before the next monthly PM) to be considered a successful PM. Any failures or stoppages (a result of failure from PM based items) that causes disruption to the operation would deem the PM ineffective. From an operation perspective, mean-time between assist (MTBA) or production output or even cycle time are typical gauges used to measure effectiveness of an operation and is a guide to determine if an equipment is healthy or not.

1.3 Maintenance Effectiveness

Effectiveness of a maintenance activity is critical to ensure the "what" being done is done has a positive outcome on the results and there are ways to quantify and measure those parameters via operations matrixes as mentioned in the subtopic earlier. However, maintenance alone is not enough to ascertain manufacturing excellence as clearly stated by Adams (2019) that equipment care strategy together with operations strategy must blend well to get the right maintenance strategy. What this means is that there needs to be a somewhat a conversation between the equipment operations as well as the production team that are aligned on the overall operation's needs. Manufacturing excellence needs to have the smarts to optimize the operation by either (1), incorporating real time monitoring and actioning it OR (2), incorporate problem solving techniques and actively looking to resolve issues even before it becomes a problem.

Different types of maintenance methods can be adopted for example, predictive maintenance (PdM) that has the ability through statistical and mathematical formulation to predict the outcome of a failure and that can be used to inform the maintenance team to action it before it fails. Other methods are reliability centred maintenance (RCM) or even condition-based maintenance (CBM) that allows for active monitoring of key operations attributes and then taking action when there is a deviation from identified baselines. Gao, Feng and Tan (2016) stresses that by incorporating problem solving attributes, the maintenance steps starts to incorporate KAIZEN features whereby it looks for imperfections in the operation (comparing to goals like MTBA, MTTR, Cycle Time, Output, etc.) and finds ways to improve the system working towards reaching the ideal state. Therefore, either enhancing the maintenance strategy from a reactive or run-to-fail to a more proactive method or alternatively incorporate problem solving to a maintenance strategy would both yield a more effective maintenance outcome with better results.

1.4 PdM in the Manufacturing Industry

Many success stories of predictive maintenance in the manufacturing or semiconductor industry has been in the planning aspect of an operation as an example from Lin (2019) uses a time series prediction algorithm to predict a target devise's remaining useful like (RUL) which is claimed to be better than the conventional methods of using exponential models. Jordon (2019) in his research on using machine learning and Lean in improving medicine production, procurement and dispatching and how to keep the machinery from going down via machine learning. Kabir (2015) discusses the use of predictive maintenance in offshore wind turbines in combining effort with condition based monitoring and predictive health monitoring (PHM). The need for PdM to be used in this case is clear as the turbines are in remote locations and complex to work on and take a long time to fix things if something goes wrong with operations. However, as good as it is there are also limitations with implementing PdM as it involves high cost for the initial stage of setting the system up with unique sensing capability. Time is needed to establish a baseline as with determining RUL, a time trend of data is required to be made available and the clarity of that data is critical to ensure the RUL prediction would be as accurate as possible. In the manufacturing world, time is money and depending on need or budgetary concerns, ideal state of maintenance will not always be the goal the management would go with usually but rather one that can yield almost the same results with the shortest time and least impact and lowest cost involve to reap a higher ROI in the quickest manner.

1.5 Laser Marking Operation in the Assembly Test Factory

This research focuses on the manufacturing operation of the laser marking operation in the ATM factory as the process is a very critical operation that engraves via laser on the surface of the product the various details like production batch number, product specs, date of manufacture as well as a unique ID that identifies the end product to the customer and at the same time can be used to track operational steps.

1.5.1 Characteristics of the Laser Operation

Laser marking operation is a simple operation with excellent throughput time and relatively fast operation. The output rate is around a few thousand units/hour as the equipment feeder lines up unit in JEDEC tray with a fixed outer dimension (these trays are the medium of transport throughout the manufacturing line for the units) but the number of units on one tray is dependent on the product form factor and can range from 3 units (for large form factor products) to 110 units (small form factor products) and the speed to mark a tray full of units is on average approx. 30 seconds. Therefore, due to the speed of the marking operation, the ratio of equipment to product output is high contributing to lesser equipment needed to support the factory needs.

Current maintenance practise is combination of preventive maintenance and Run-to fail maintenance for some specific part i.e. the laser diode, quality switch and the two special coated mirrors. What makes all these parts maintained via run-to-fail is because they are optoelectronic making them last longer than standard mechanical parts and they are critical to laser generation. Typical lifespan average of these parts is about a year to a year and half. The performance of these parts is such that when there is a problem, the part is considered bad, there are no gradual symptoms but a good state and a bad state. However, being optoelectronic, the condition of the parts are not readily or easily known.

1.6 Problem Statement

Effectiveness of maintenance practise is a concern as the laser equipment is primarily made up of two main sections, firstly the laser section that generates the laser that is used to engrave the units. The quality of the marking is determined by the quality of the laser generated. The second section is the mechanical part (handler) that feeds the machine with the unmarked product and moves out the marked products. If any of the two sections have an issue, then the performance of the operation would take a hit. There would be some significant amount of losses especially to the output as the output volume would be lesser than the target/day.

Depending on the breakdown per excursion defects pareto (Figure 1.3), blur marking, illegible marking and marking out of position make up about 2/3 of the defects out from the operation as they all are related to activities that are checked and worked upon during the PM whereby blur mark is the quality of the laser that is not satisfactory whereas illegible mark relates to a failure combination between mark quality and mechanical fault and finally, units out of position is with regards to the problem with the mechanical movement of the unit. Unfortunately, most of the time, failure is attributed back to the quality and efficiency of the PM that is not satisfactory as the breakdown happens while the tool is still under the warranty of the PM, leading to low mean-time between failure (MTBF) and low tool utilisation. Also, due to complexity of the equipment, PdM is not possible for the laser as the main laser parts are optoelectronic and there are no predefine standard measurements matrix that can be used or measured as to feed into a PdM method for the operation thus leaving the maintenance to a PM for most of the mechanical parts and run-to-fail for the optoelectronic parts that are namely the laser diode, quality switch, Beam expander, highly reflective mirror and output coupler mirror.

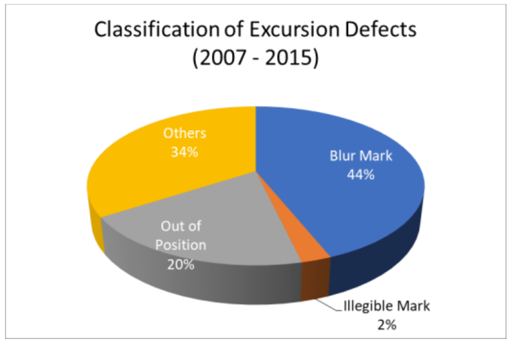

Figure 1.3: Defects pareto of the laser marking process

Secondly, the operating cost to maintain laser equipment is relatively high as according to frequency of PM and the changes recommended by the equipment provider, multiple key optical parts require changes at different intervals throughout the lifespan of the equipment. For example, the laser diode (single most expensive consumable part) requires changes every year and may seem ok at first but the biggest concern is that the quality of the laser is very much dependant on the laser diode and factors like laser beam alignment is critical in ensuring laser output is good. Beam alignment unfortunately is a very manual process and requires a technician with specialised skillset to perform the task. Even with a slight deviation of +/- 0.50mm is good enough to have no laser.

The concern here is that the actual condition of part is not known and the parts change take place nevertheless and there have been cases where the parts fail before it is meant to be changed (downtime related to PM activity) and also times when the tool performs well and the parts do not seem to show any signs of degradation and is changed out as well due to the requirements of the PM. Therefore, the cost to sustain equipment will remain high if there is no change in the operation or capability to know the true actual condition of the critical parts.

Finally, factory escapees i.e. defective units that were not caught within the factory for laser marking quality being reported at the customer's site. This is one of the biggest concerns to the business when a walking wounded unit that is a reject is not caught within the factory but reaches the customer's side and they catch the defect due to failure at their end. The consequences for something like this is very rarely not stop at one unit that is a random defect but typically would have a few hundred units depending on the type of defect. Cosmetic defects are the lesser evil and can be weeded out quickly from the customer site as it is a visual type defect.

However, the more unrecognisable defect is laser causing defects that are subsurface. These defects cannot be caught by visual inspection and can only be detected once the product is used. The downside to this kind of defect happening is the impact is most certainly in the hundreds to thousands of units as the root cause mostly is due to the laser diode itself. The root cause for this is the ineffectiveness of the outgoing inspection for visual defects and the limitation at the laser area for unknown condition of the laser diode together with other critical optoelectrical parts, therefore, unable to effectively detect these kinds of defects and stop them at the operation itself.

1.7 Objective

The research is accomplished by complying the following specific objectives:

i. To develop a process flow algorithm that will guide the user to enable operational process improvement and at the same time be able to improve the maintenance practise effectiveness.

ii. To validate the flow algorithm on the laser marking operation’s equipment related problem as well as the laser marking process concerns.

1.8 Scope and Limitation

i. In terms of the laser equipment parts, will only focus on the laser diode as it is the single most expensive consumable part of the laser system as well as a critical element in generating any laser.

ii. Beam alignment and other optoelectronic parts and effects are excluded in this research.

iii. The design and operation of the laser selected is the diode pumped 100W, 1064nm wavelength infrared laser.

iv. Detailed analysis of the water cooling as well as the air-cooling capabilities of the laser system is excluded in this research as they are both considered secondary problems and will assume that these parts are good and have no direct bearing on our results. These parts will be set to ensure sufficient cooling to the system and the main focus of the research will be on the diode which is a major part of the laser tool's operation and performance.

1.9 Significance of Study

This thesis provides engineers/technicians or maintenance personnel a systematic approach to be able to identify key main parameter of value of the equipment and then find ways to quantify and improve equipment performance in a manufacturing line using a flow algorithm that suggests steps to take to make the engineering system quantifiable and measurable and would lead back to enhance the maintenance effectiveness.

The laser diode (optical part) can have its performance and lifespan monitored and quantified making it measurable and in turn predictable to a certain extent. This therefore makes the equipment part fit into the scope of condition-based performance monitoring and ultimately save cost as the equipment part will only be changed when the performance drops below the desired threshold (prior to diode failure) and this will improve the uptime of the overall engineering system in the production line.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

In a complex manufacturing ecosystem, like a semiconductor manufacturing plant, is typically made up of hundreds of manufacturing processes and steps and various function-based tools. The capital expenditure for equipment and tools usually range in the millions and in any typical manufacturing facility, there are many similar equipment due to scalability factor. Any small equipment or tooling mishap results in a sizeable reduction of productivity and eventually impacts revenue as there is no output. According to Montgomery (2000), the complexity of the manufacturing process is so demanding that if only one equipment is down or underperforming, would impact the entire operations causing idleness and being unproductive. Hence, maintenance is always essential to sustain equipment at perfect operating conditions. In general, maintenance practices can be divided into three categories based on the core principles employed, i.e., reactive maintenance (run-to-fail), Time based maintenance, and condition-based maintenance (CBM), as shown in Table 2.1.

Table 2.1 Category of maintenance strategies

Maintenance Practice	Main Principle
Run-to-Fail	When failure occurs, then repair
Time Based Maintenance (PM)	Parts changed by time limit
Condition-Based Maintenance (CBM)	Maintenance based on sensing of machine condition and reacting

‘Run-to-fail’ principle or reactive maintenance is where maintenance is only carried out after the equipment has had a failure occur. This method is easy to implement but may cause long equipment downtime and certainly impacts production output and high inventory costs for spare parts as nobody is prepared for a downtime until it actually happens. Time-based maintenance generally covers maintaining equipment in a periodic time interval, which are determined from either historical inferred reliability information or from manufacturer recommendations. Since time-based maintenance is typically used to schedulemaintenance to avoid the equipment from major failure, it is commonly referred to as Preventive Maintenance (PM). However, this method does not compute the real-timecondition of the equipment or parts, this leads to the equipment or tool being either “over- maintained” (disposing of parts that are still in good operating condition) or “under-maintained” (results in frequent unexpected major failures) if the timeline is not defined accurately. CBM alternatively is built upon accurate detection and interpreting of trend and indicators of equipment operation, and is better positioned to handle equipment deterioration, and at the same time allows better maintenance decisions based on both current and past behaviours.

2.2 Proactive Maintenance Usage in the Semiconductor Manufacturing Industry

In today’s semiconductor manufacturing area, majority of maintenance work is still done using either time-based or output-based or even wafer-based scheduling strategies is seen in many companies. This approach makes sense in the scheduling planning as it is better to have numerous scheduled downtimes compared to one un-scheduled downtime.

According to Duan, Deng, & Gong (2018), PM scheduling for a complex mechanical system with different failure modes requires optimal PM scheduling and is derived based on the following: when to perform the intermediate and major maintenance and which failure mode should be maintained at an intermediate maintenance time. Limitation is that this method may not be applicable to non-mechanical parts i.e. optoelectrical components performance and the method also is for after the fact failures to better enable scheduling of maintenance. Wang (2019) talks about preventive maintenance methods for leased manufacturing machinery and its economic benefit. Improvements are made by actively adjusting the best time interval to maintain the equipment from completed lease so that the end user has a good experience during the lease tenure. Limitation is that the method doesn't prevent failures but accepts equipment parts failure will happen over time and that it will be detected when being serviced before the next lease making it beneficial on the long run as a business. Lange (2015) discusses the scheduling of different types of preventive maintenance works at the semiconductor manufacturing facility and Regev (2016) proposes 2 models of segmented PM durations to run in a Fab manufacturing environment. Morrison (2014) also shows that mean cycle time optimization in semiconductor tool sets being conducted via PM planning with different PM cycles. Therefore, the use of PM is very vast from planning to equipment performance identification across the semiconductor maintenance and has yielded a lot of benefits to the operation but it is still a stand-alone application and not usually linked to the main problems.

A survey of maintenance practices in the semiconductor industry was conducted and revealed a necessity for PdM in the semiconductor manufacturing by Djurdjanovic and Liu (2006). Shenkiryk (2014) explains about the biggest challenges faced when building and implementing a condition assessment program and his process covered an implementation for large-diameter pipelines. Survey results and case studies identify different obstacles both industrial and academic sectors must overcome in wanting to implement PdM and is applicable to any organization that is currently operating using preventive maintenance as its main practice in maintaining equipment and machinery.

These challenges are summarized and include the following:

i. Identifying suitable and dependable sensors
ii. Improving monitoring methods for process or critical parameters
iii. Develop predictive methods for better equipment performance forecasting.
iv. Identify the best timeslot for maintenance to happen

The above challenges require deeper understanding of PdM and current practices in the semiconductor industry as better understanding of each process is required to successfully implement PdM as the requirements for each operation or equipment is different and will require different resources and approaches. Furthermore, in this research, a specific tool type in the manufacturing line was selected (laser marking equipment) and at present has no clear and effective way to predict the lifespan or quantify the output quality, therefore, a method that is able to change that and make it measurable would be very good in order to change the maintenance practice. PdM technologies, whether on-line or in-line inspection, are key in this change as they provide supervision and control over assets condition (Arnaiz, Konde & Alarcón, 2013). By being able to measure the performance or parameter of the equipment then knowing the condition of the tool in possible, then it is able to identify when would be a good time to introduce change to the system knowing how the tool would potentially react. High value and long-life products require continuous maintenance at the right time throughout their life cycle to achieve required performance with optimum through-life cost (Roy, Stark, Tracht, Takata, & Mori, 2017). This is extremely accurate when speaking about lasers as it is high cost and has a long-life span (>1 year) before any degradation starts to be seen so, it would be critical to be able to measure the performance and then when it starts to move deeper into the first year, sign of change / degradation can be addressed.

To be successful in maintenance, not necessarily the maintenance methodology adopted guarantees success as having one type of maintenance may be good for some aspects and for some it may be not sufficient. Therefore, how the information from maintenance is used to define the performance of the operation is crucial. There must be sufficient amount of data output that can be measured as that would then be able to identify and classify the performance of the part firstly. Once that is established then linking that to the main operation would be the best outcome in order to have an accountable maintenance system that would be able to positively influence the performance of the operation during production mode.

2.3 Usage of PdM as an Improved State of Maintenance

PdM is a very attractive maintenance method and one of the strong points of why it is used is that it is able to predict remaining useful life (RUL) of an operation and help with the cost for maintenance as excessive maintenance adopted in time based preventive maintenance can be minimized. Jiang and Kuo (2017) in their work show how predicting the RUL for aero propulsion engines have yielded better performance compared to othermethods and similarly knowing RUL has yielded 25% increase in tool usage (Lin, Chang, Liu, & Chen, 2019). In these works, the exponential model was used to be able to predict theRUL. However, due to the algorithm limitations and under unique scenarios, for example, when target device is about to die, whether the target device's aging feature suddenly rises or becomes smooth, the exponential model may not be able to keep up with the real-time prediction or worse still may even falsely predict long RUL due to the change that is against the aging process.

Lin (2019) prefers to use an alternative method to predict via the time seriesprediction algorithm (TSP). This algorithm looks at the pre-alarmed state to alert themaintenance team on the upcoming maintenance and also the death correlation index (DCI)to know if the engineering system in in the dead state. The downside to this is the ability of the RUL prediction or the TSP Algorithm is that the application may not able applicable for optoelectronic parts. Zhang, Hutchinson, Lieven and Nunez-Yanez (2020) also state in their research that the drawback of the standard method of finding the RUL and suggest long-short term memory (SLTM) neural network as an alternative to predicting RUL with a narrower error band.

Shaikh and Prabhu (2003) notes that the ‘strictly predictive’ approach uses artificial intelligence (AI) and/or other predictive methods to assess the RUL of the current equipment, which allows scheduling of maintenance to take place just prior to failure or is required. Susto and Beghi (2016) have noted that PdM is an important approach to tackle maintenance issues and it is gaining an increasing attention in advanced manufacturing to minimize scrap materials, downtime, and associated costs. PdM approaches are generally based on either statistical methods or machine learning (ML) methods that require the availability of historical process and maintenance data. Given the exponential growth in data logging in modern equipment, time-series datasets are increasingly available in PdM applications

However this is only half the solution of the problem as the maintenance only looks at ways to fix the equipment for it to perform effectively during production run and the other part is finding a solution to the problem itself is a task. Across the manufacturing industry, there are many different types of problem-solving methods that are used to solve problems and how do we know what to choose when?

2.4 Problem Solving Algorithms

When solving a problem, choosing the right approach is often the key to arriving at the best solution. In psychology, one of these problem-solving approaches is known as an algorithm. An algorithm is a problem-solving formula that provides step-by-step instructions to achieve a desired outcome (Cherry, 2020). An algorithm is a defined set of detailed step-by-step procedures that provides a consistent approach to a particular problem and yields the same results every time it is performed. Random problem solving involves at its core a problem statement or concern, brainstorming of what the possible solution would be and finally implementing a solution and checking if the problem has been resolved. This does not require any specific skillset but just prior knowledge or experience in the similar field of application. However, if the same problem is sent to 5 different people to resolve most likely the outcome would be 5 different methods that have different levels of solving the problem. The higher probability of success is for the one that defines the problem the best and would eventually have a solution that yields more success, perhaps but may not be the case. Therefore, in the manufacturing industry, consistency is required as downtime is critical to the operation and having multiple downtime just to fix the same problem is not acceptable. Hence, the need for an algorithm type problem solving methodology would be preferred over free-flowing random solutions.

There are so many problem solving algorithms used across the industry and some widely acceptable and used algorithms are for example the Define, Measure, Analyse, Implement, Control (DMAIC) from Six Sigma, Seven steps of problem solving, Plan-Do-Check-Act (PDCA) from Lean manufacturing, Total Quality Management (TQM), Just In Time (JIT), Failure Mode Effect Analysis (FMEA) and TRIZ just to name a few are all problem solving algorithms that approach problem solving is a very systematic way. What makes these methods stand out is that they are very effective in yielding positive results to the outcome.

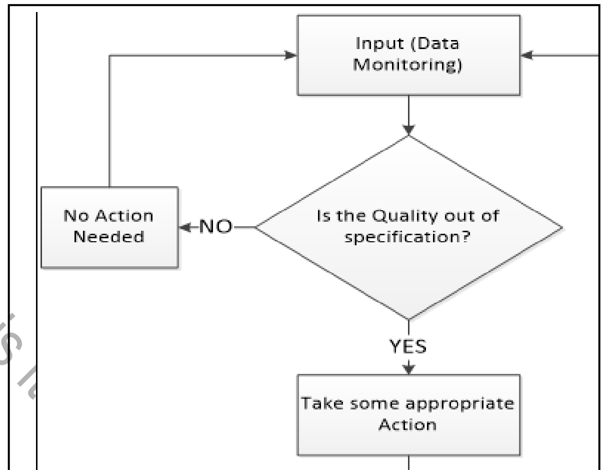

Figure 2.1: General improvement flow

Mobley (1996) defined this algorithm (Figure 2.1) as part of his analysis and study on the manufacturing industry and how it could be used to resolve problems that arose. This general approach was also the base for many other problem-solving methods from Lean and one of the most powerful derivation of the problem-solving model was the Six-Step Problem-Solving Process (Identify, Analyze, Develop Solution, Implement Solution, Evaluate Results & Standardize Solution) by McMahon (2012) as well as the fundamentals of Six Sigma's DMAIC (Define, Measure, Analyze, Inspect & Control) which are both widely used in the industry. The downside to the Mobley model was that it had the general steps to manage a problem in the manufacturing world but it was too simple and straight forward and most importantly it was very subjective to the fact it only narrows down the problem but it is entirely up to the person /engineer that is going to resolve it on how to do it and outcome