CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter describes the framework of the study and the Plan phase (of PDSA cycle) of the research. This chapter also explains the details and approaches used in problems identification, selection of methods or theories and data analysis tools.

3.2 PDSA CYCLE

The research framework of the study follows PDSA (Plan, Do, Study, Act) cycle, developed at 1994, and modified at 1996. The model is applied to define aims, objectives, methods in implementing new processes and evaluate improvement.

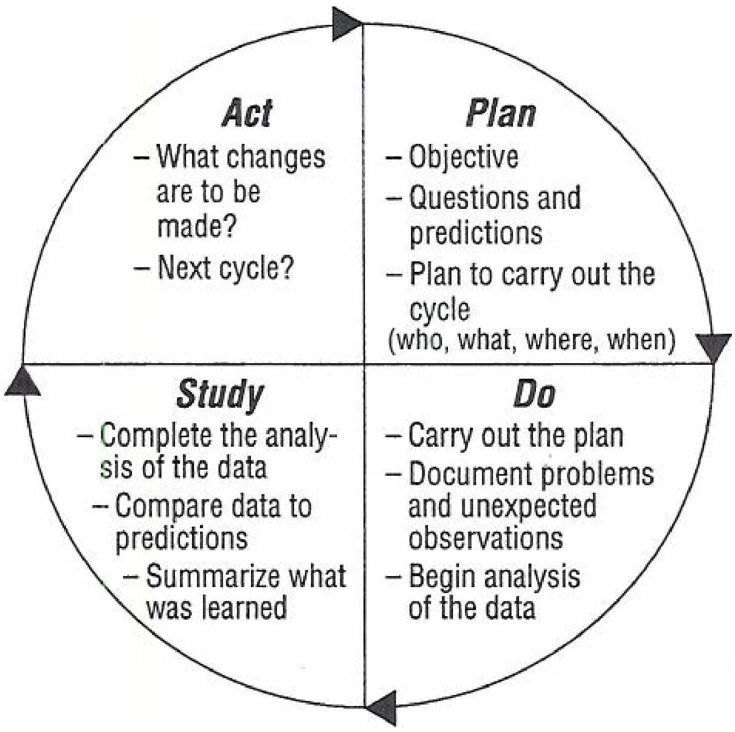
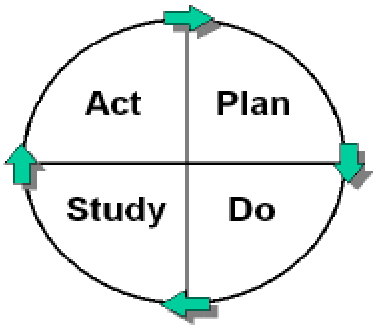


Figure 3.1 PDSA cycle and the tasks for each phase (Source: Langley *et al*, 1994)

The proposed PDSA cycle by Langey, Moen and etc. is a very general framework. Modification is done so that the PDSA cycle is suitable for this study. Figure 3.2 shows the modification done on the PDSA cycle.

- Company selection
- Project description and company profile
- Problems identification
- Define aims and objectives
- Formation of project team
- Selection of method and theory
- Impact assessment

- Results validation
- Changes (optional)
- Future plan



- Data presentation
- Analysis of data

- Data collection before implementation
- Implementation of FMS.
- Data collection after implementation

Figure 3.2 Modified PDSA cycle and the tasks of each phase

3.3 Plan Phase

The plan phase helps to reveal the current problems of the fertilizer plant. Then goals and objectives that mean to solve these problems are defined. The goals and objectives are stated in chapter 1. A team is formed to take care of these problems and execute FMS. The team members come from different departments. Finally, the impacts of these problems are explained. To be specific, tasks done in plan phase are:

- Company selection
- Project description and company profile
- Problems identification
- Define aims and objectives
- Formation of project team
- Selection of method and theory
- Impact assessment

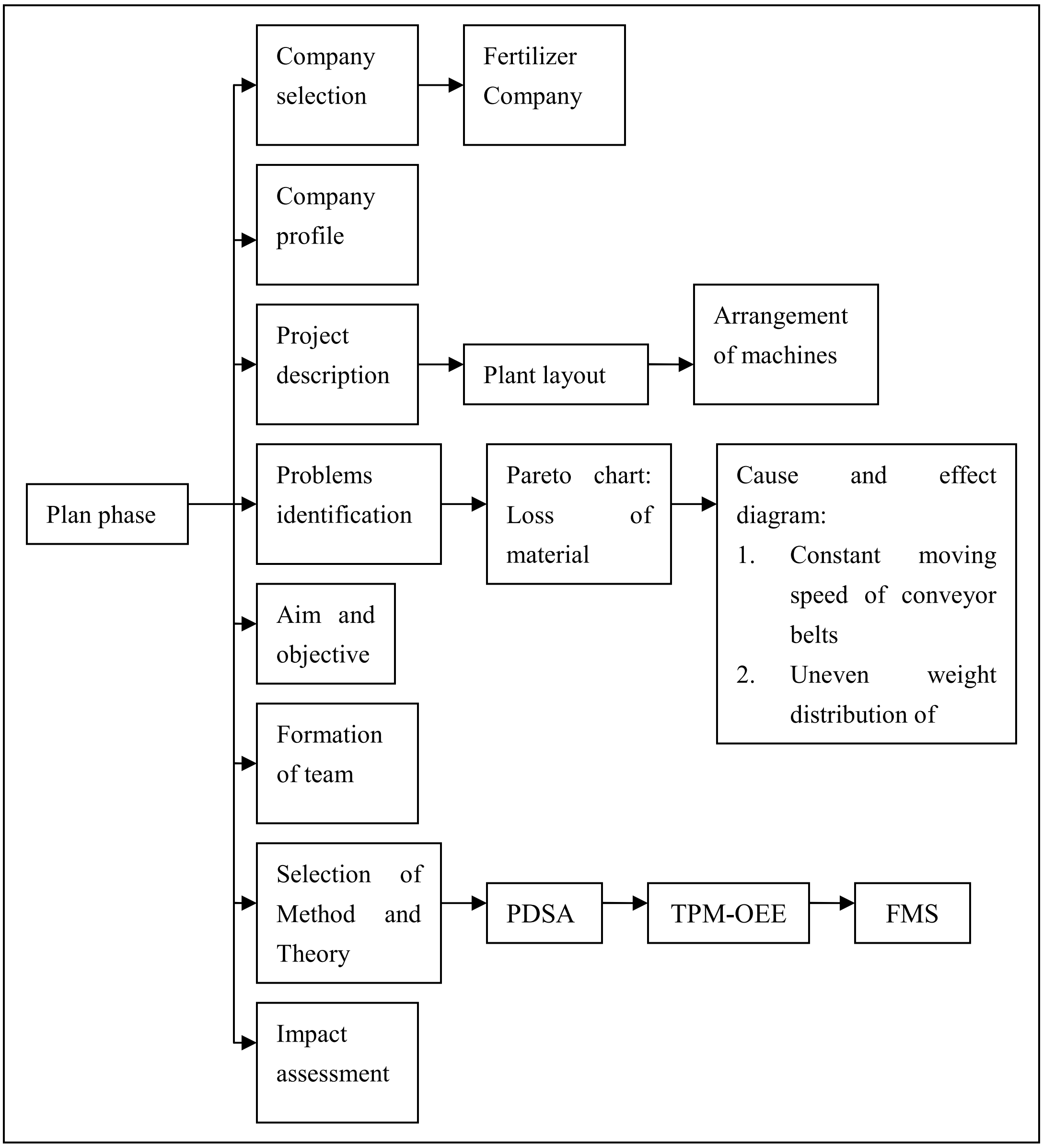


Figure 3.3 Tasks done in plan phase and their corresponding tools

3.3.1 Company Selection

Firstly, a company or plant that suits for the research is selected. The selected company or plant needs to be one that desire the need of manufacturing process improvement or elimination of the existing problems as only then, significant results would be seen in later period when these research are implemented into the manufacturing systems of the plant. Also, the management of the plant should have the willingness to accept new ideas and concepts, and later make changes and improvements in the plant. With that, data collection and studies can be conducted at the knowledge of the management and at the convenience and ease of the researcher.

The fertilizer plant of research is selected because a few problems occurred in the plant are seriously affecting the productivity. Therefore, the management of the plant requested the researcher to upgrade their manufacturing processes and to ensure quality of the products.

3.3.2 Company profile

The selected fertilizer plant of research is an innovative company, with aims to have breakthrough improvements every year. The fertilizer plant of research is located at Lahad Datu (Sabah, east of Malaysia). The name of the plant could not be revealed to avoid infringements. The fertilizer plant started its business since January 2010, and the plant was invited by Sabah local government to join POIC. Many of its automated equipment and handling machine are supplied by a supplier company in Petaling Jaya, Selangor. The products of the fertilizer plant are general fertilizer and customized fertilizer. The plant adopts computer-based systems in shop floor to track the instantaneous weight of the raw material. The plant is using automated group technology layout. Details of shop floor and plant layout are discussed later in this chapter.

Table 3.1 Corporate information

Plant	Fertilizer plant
Built Up Area	17,000 meter square
Incorporation date	18th January 2010
Authorized capital	RM 2,500,000.00
Paid up capital	RM 1,500,000.00
Plant location	Lahad Datu, Sabah
Head office	Kuala Lumpur
Labour force	412
Products	Various combination of fertilizer, based on request of customer
Production capacity	236.72 tons daily
Serving field	Gardening, protected forest, government department
Working hours	8.30am to 5.30pm

Corporate Mission

- To be the technology leader of fertilizer industry through continuous research & development
- To offer engineering solutions and create value for strategic customers globally

Business Strategies

- Product diversification & expand customer base
- Process Technology Advancement
- Strategic Alliance in Technological Advancement

Products

The products of the fertilizer plant are general fertilizers and customized fertilizers. The content of general fertilizer is based on the secret recipe of the plant. There are 7 types of raw materials in the general fertilizer. The secret recipe refers to the relative ratio of all the materials. General fertilizer is used for general purpose and is mass produced daily. Purity of the material and pH value of the final products are important in the quality aspect.

Customized fertilizer will only be produced if and only if it is ordered by customer. The recipe is supplied by the customer. The maximum number of types of raw materials is 7; otherwise it exceeds the production capabilities. The fertilizer plant controls the pH value of the final product. The products have a pH range from 5.5 to 7.5, depending on the relative ratio of each material. The contents of both fertilizers would not be shown to avoid infringement.

Workforce

Except for the security guards, the workers have only single morning shift, which is 8.30am to 6.00pm. There are 387 technicians and operators in the plant, 71 percent are local workers and 29 percent are foreigners. There are total of 9 security guards, 5 for morning shift and 4 for night shift. In the plant, there are total of 17 staffs in the operations levels, which comprises of:

- 3 engineers from electrical department
- 4 engineers from mechanical department
- 2 engineers from quality control department

- 2 engineers from quality assurance department
- 1 logistic planer
- 1 supervisor of security department
- 4 supervisors of electrical, mechanical, quality control and quality assurance departments.

There are total of 8 staffs in the management levels, which comprises of:

- Chief Executive Officer (CEO)
- Chief Financial Officer (CFO)
- Chief Operating Officer (COO)
- General manager
- Production manager
- Quality control manager
- Quality assurance manager
- Human resource manager

Organization chart is shown in Figure 3.4.The fertilizer plant is a subsidiary company. It shares their staffs of management level with the parent company, which is located at Kuala Lumpur. Staffs of operations and management levels have web meeting weekly, on Monday.

3.3.3 Project Description

In this section, the plant layout, flow of material, components or machines of the GT cell and the arrangement of the machines are explained in details. The data of March is shown (where it is before the implementation of FMS).

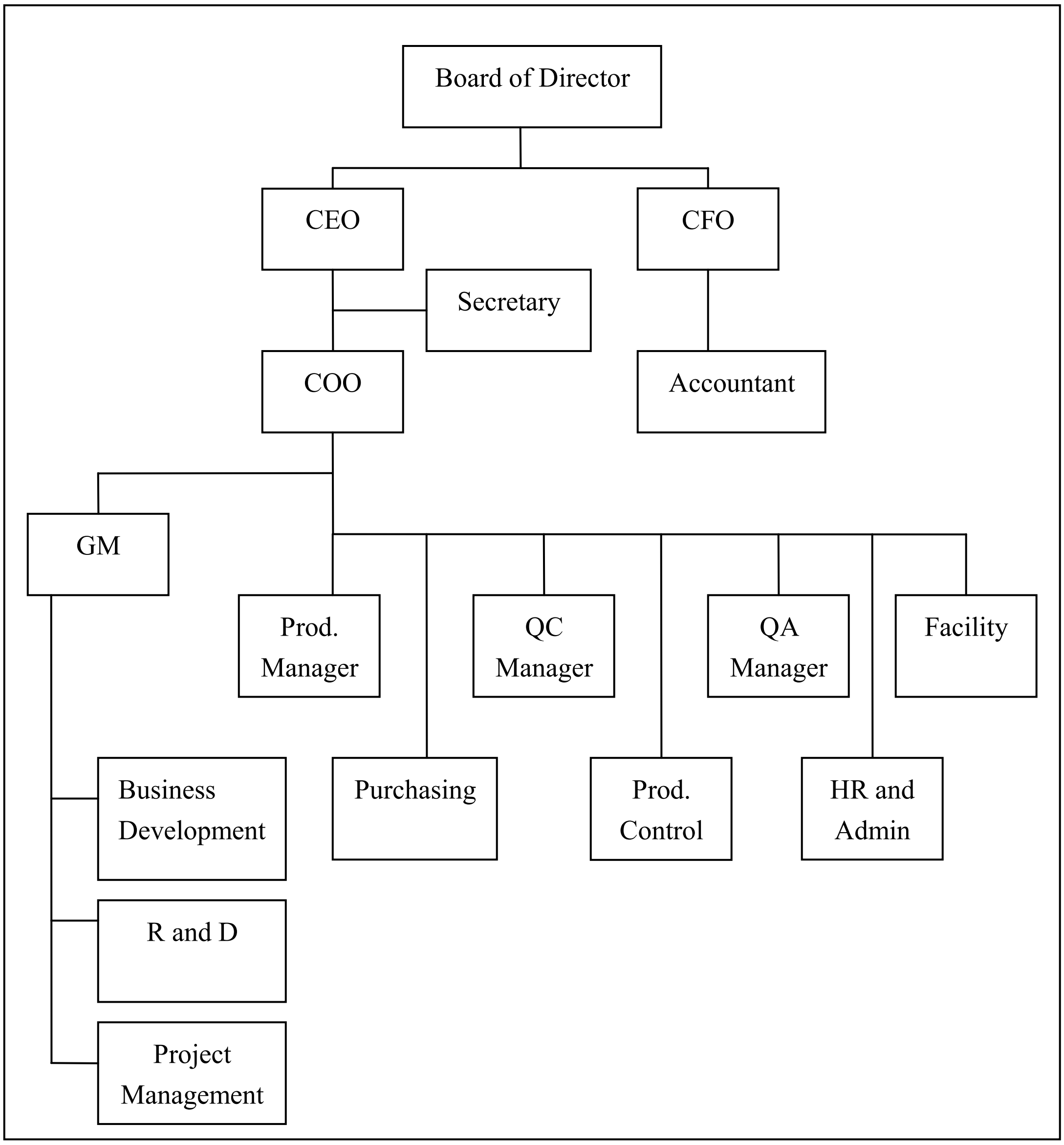


Figure 3.4 Organization chart

Plant Layout

In general, the built up area of the plant is 17,000 meter square and land area is 20000 meter square. There are total of 5 main area of the plant, which are raw material depot, fertilizer processing area, warehouse, quality control area and office.

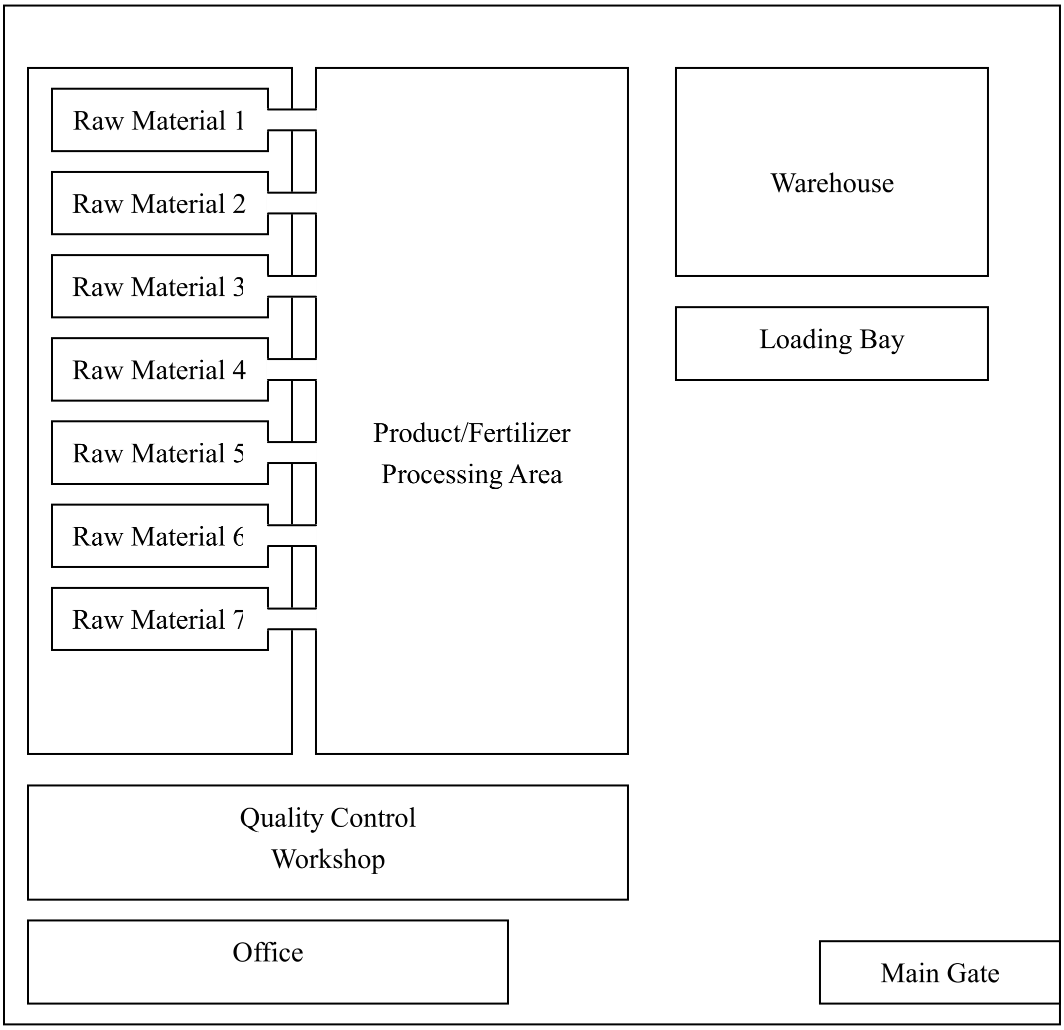


Figure 3.5 Plant layout and the main areas of the plant

The production of fertilizer starts with orders of customer. Once the company received an enquiry from customers, staffs from team feasibility study discuss about the enquiry received. Items concerned and planning are capability of producing on schedule, amount to order for raw material and cost in transportation. Decision makers include managers, senior engineers and technician from different departments. After it is decided to accept the enquiry or orders, decision makers quote for the products. Mostly, the reasons of rejecting the orders are due to incapability of producing high volume of product, high manufacturing cost and lack of the raw material.

Raw Material Depot

The production starts with transporting of raw material. POIC is an important port to Sabah. The specialty about this port is that many factories are built very near to port or seashore, so that raw materials that are transported by ships can be passed to the factories in a very short distance. After the raw materials reached the port, the raw materials (which are packed in sacks) are loaded on a truck and transported to the raw material depot. Then cranes load the raw materials into material tanks with rotating blades. Weighing machines are attached beside the tanks (Figure 3.6). There are total of 7 types of raw materials in the combination of the fertilizer, so workers have to load 7 times (of different materials) into 7 different tanks.

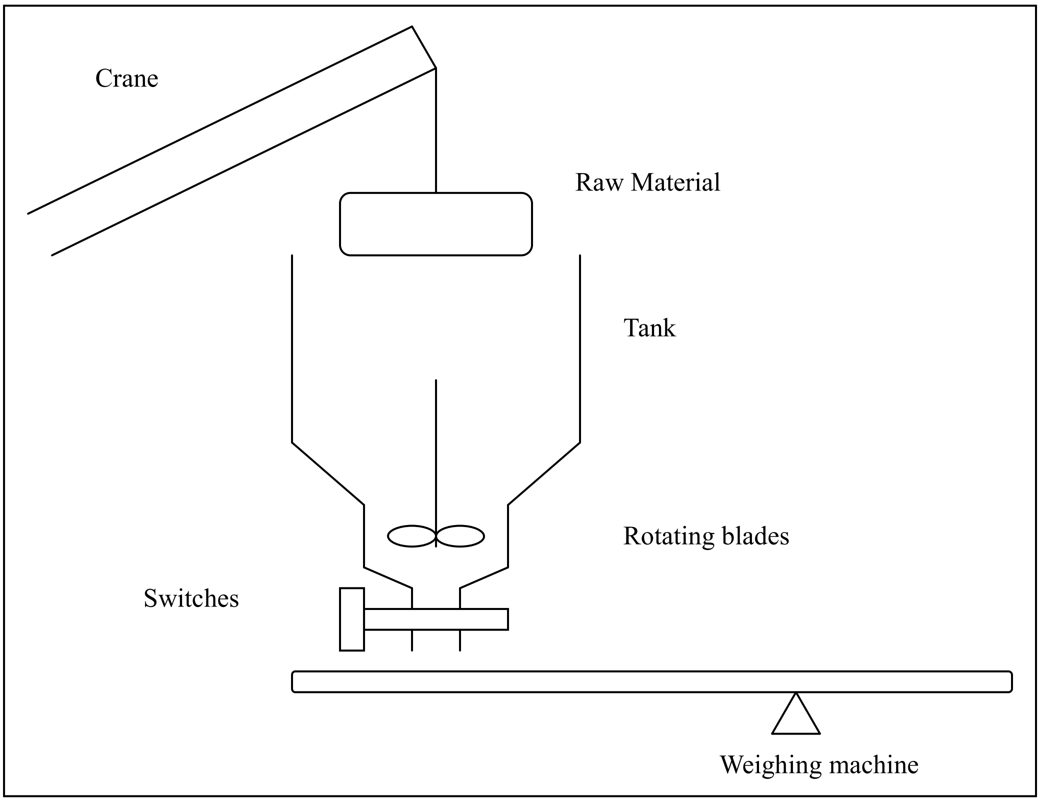


Figure 3.6 Raw material depot (material tank) and its arrangement of machines

Fertilizer Processing Area

In fertilizer processing area, the setup of the layout is automated GT layout, which is an automated machine cell, consisting of a group of processing workstations, interconnected by automated material handling machines. The processing machines, weighing machines and material handling machines are provided by a supplier company in Petaling Jaya. The GT cell and its configuration is shown in Figure 3.7, 3.8 and 3.9.

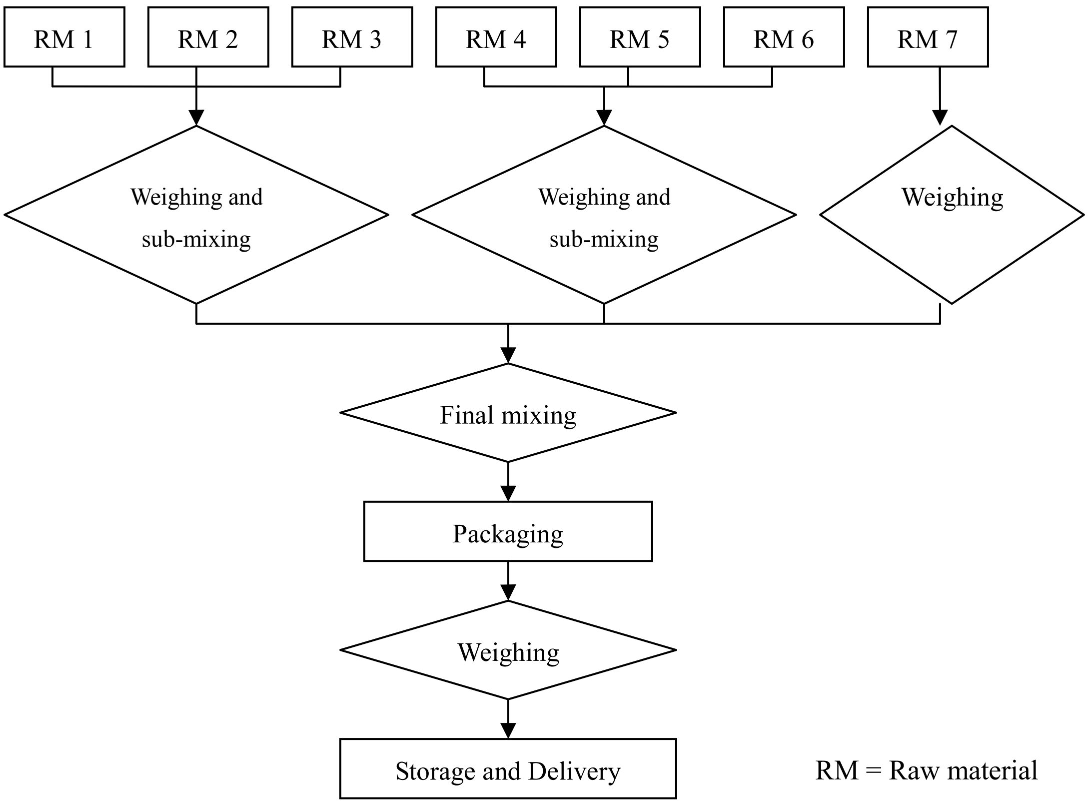


Figure 3.7 Flow of material in fertilizer processing area

The steps involved in the GT cell are:

1. Before any process is carried out, all the machines are needed to warm up to 82^{o}C.

2. Raw materials are poured into the material tanks and are sent to the fertilizer processing area. There are 7 types of raw materials, so there are 7 material tanks,

weighing machines and handling machines.

3. Raw material 1, 2 and 3 are totalized in a mixture and weighed. The totalize weighing machines are in belt scale. This is done same to raw material 4, 5 and 6.

4. Then 3 mixtures are mixed into a final tank. The final mixture is totalized, packed with bagging machine and weighed.

5. Finally, the products are sent to warehouse for storage, or transported to port for shipping.

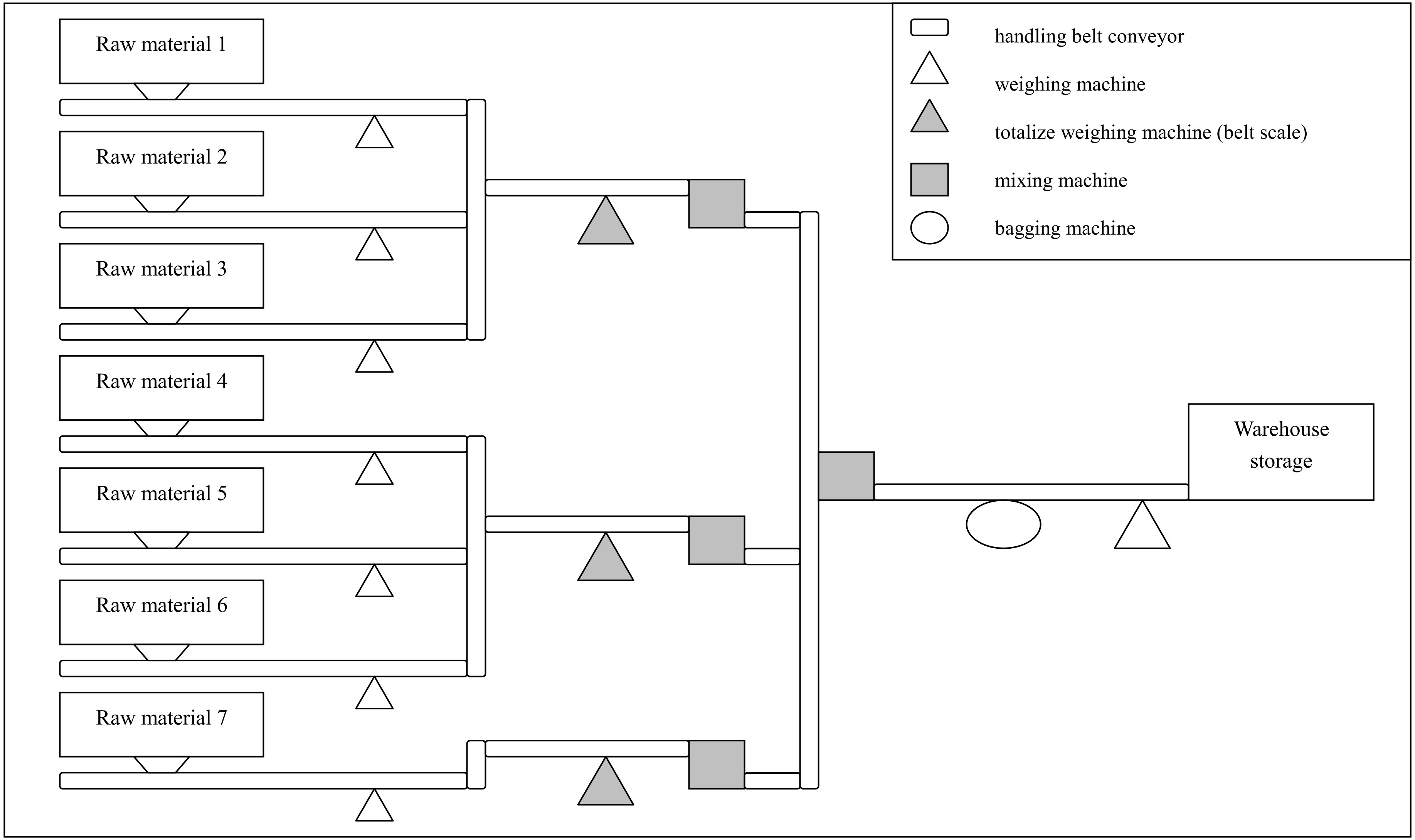


Figure 3.8 Schematic diagrams for the GT layout

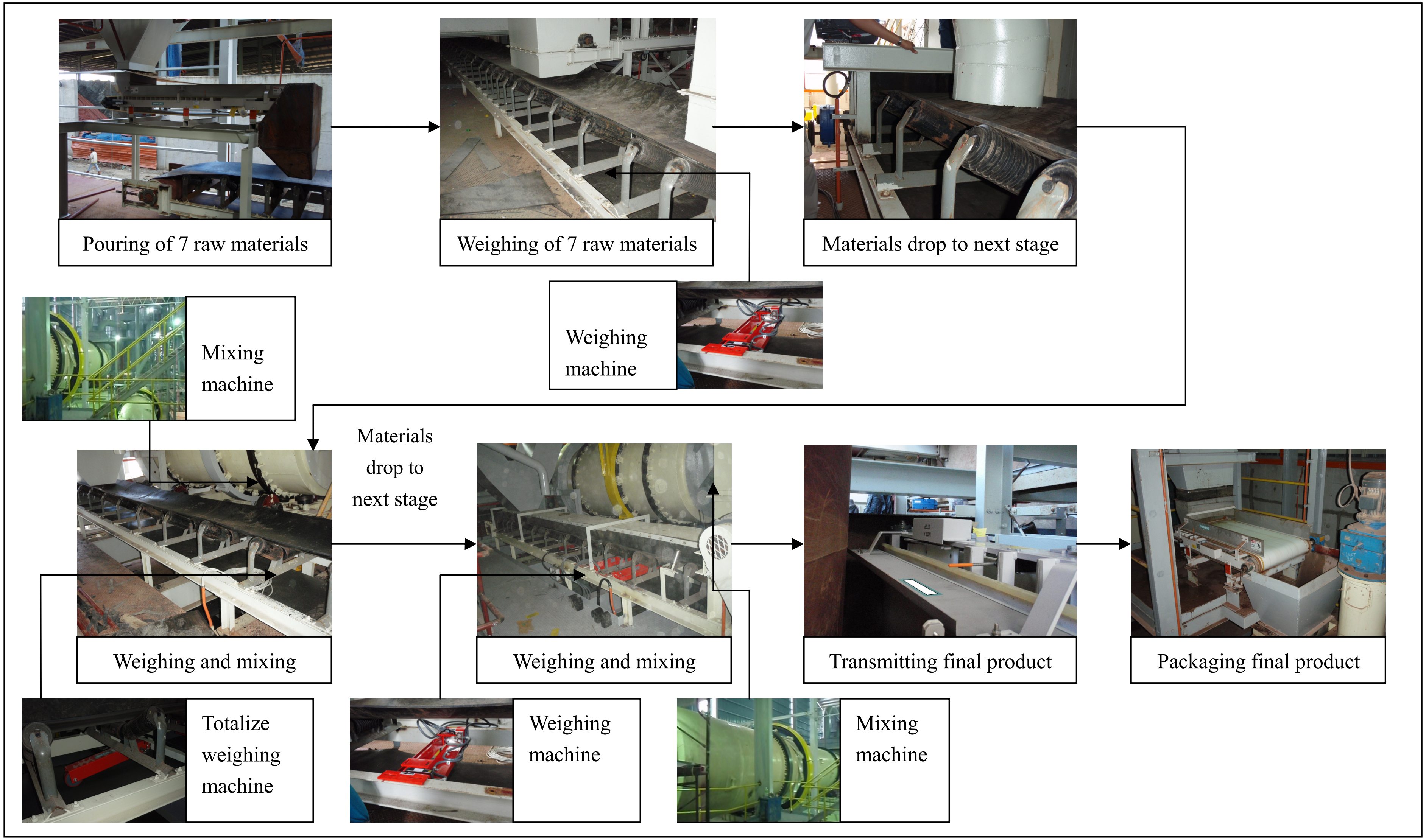


Figure 3.9 Processes of the machines in the GT cell and the flow of material

Functions of the Machines

1. Material handling machines (Conveyors)

   To transmit the WIP material between machines in the cell. The conveyors (or conveyor belts) are running at constant speed of 2km/h before implementation of FMS.

Figure 3.10 Conveyor belts of the GT cell

2. Weighing machines

   To weigh the WIP material or final product in unit ton.

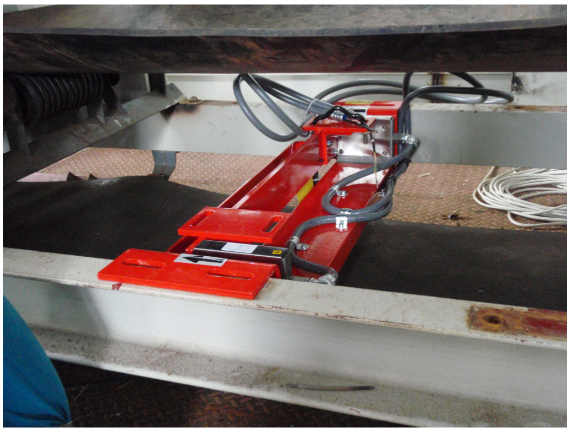


Figure 3.11 Weighing machine located below conveyor belt

3. Totalize weighing machines

To weigh the WIP material in unit kgm/s.

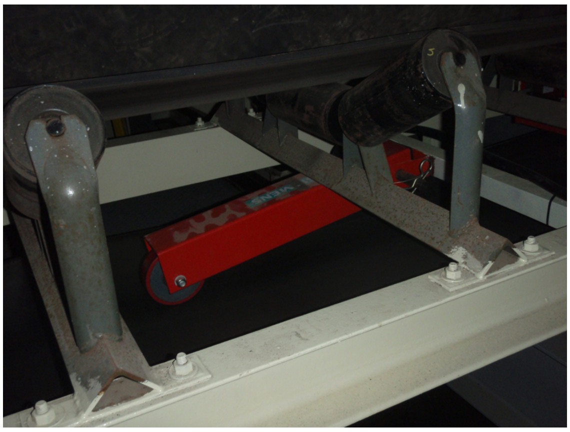


Figure 3.12 Totalize weighing machine located below conveyor

4. Mixing machines

To blend and mix the mixture of the WIP material

Figure 3.13 Mixing machine of the GT cell

5. Packaging machines

To pack the final product into a sack.

Figure 3.14 Packaging machine of the GT cell

6. Raw material depot / Material tanks

   Store raw material and control the rate of output.

Figure 3.15 Raw material depot of the GT cell

Arrangement of Machines

To make it simple, the machines cell is categorized into 3 stages:

- ♦ The first stage consists of the raw material depots, conveyors and weighing machines which are located at the highest level of the shop floor.
- ♦ The second stage consists of the mixing machines, conveyors and totalize weighing machines which are located at the middle level of the shop floor.
- ♦ The third stage consists of the final mixing machine, conveyor, weighing machine

and bagging machine which are located at the lowest level of the shop floor.

For the beginning of the first stage, the powder material is loaded in the material tanks. Then, the powder material is transferred by conveyors and fall to next stage by gravitational force when reaching the end of the conveyor belts. The powder material continues to be transferred by another conveyor of the consecutive stage (second stage), which are located at a lower level of the shop floor. The mixture of powder is totalized, blended and mixed at the end of second stage. The process continues until the materials are packed in the bagging machine (third stage).

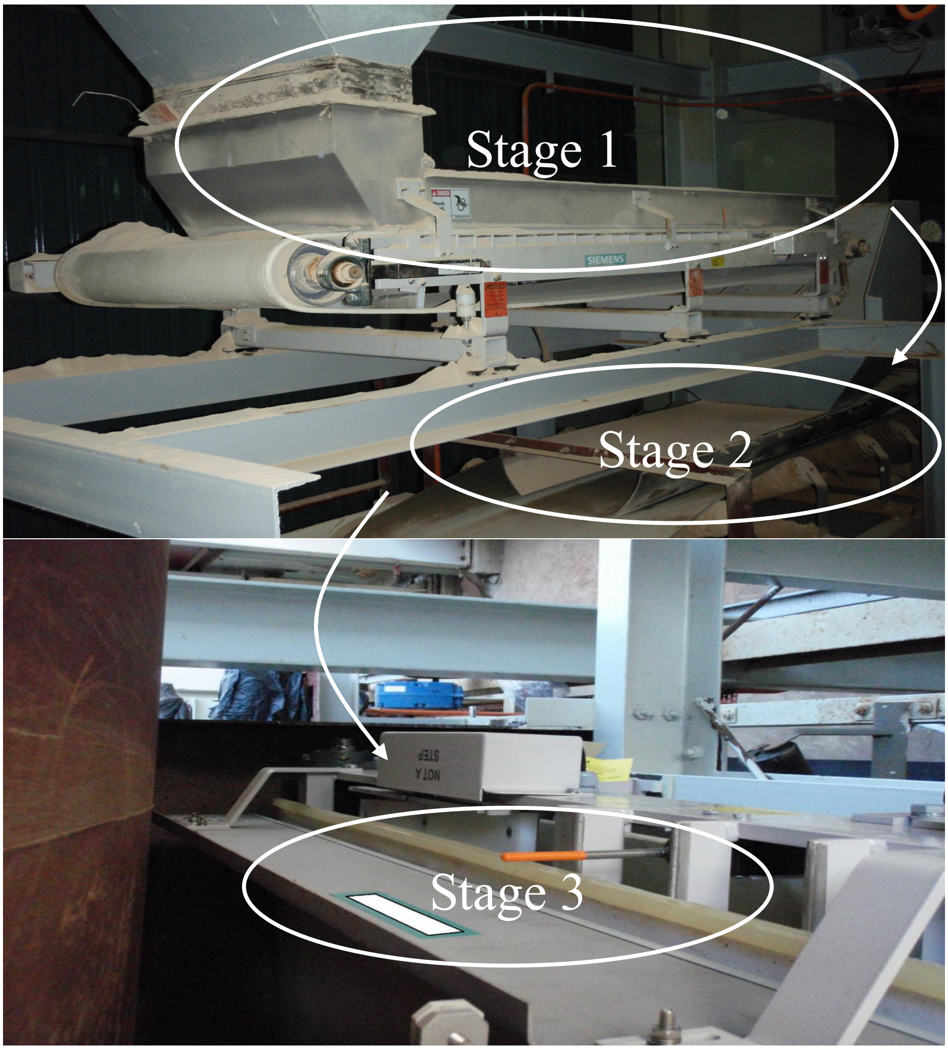


Figure 3.16 Three stages involved in the GT cell

3.3.4 Problem Identification

This study addresses the problems faced by the fertilizer plant. The research identifies the key problems of the fertilizer plant from feedbacks and interviews from the consultants, equipment suppliers, engineers, operators and management staffs of the fertilizer plant. Problems identified during the study are huge loss of raw material, low productivity, hazardous and dirty working environment, machines breakdown, low OEE of machines ,deterioration of quality of the products and high inventory level. The current state of the plant and performance of processes are explained and discussed in chapter 4.

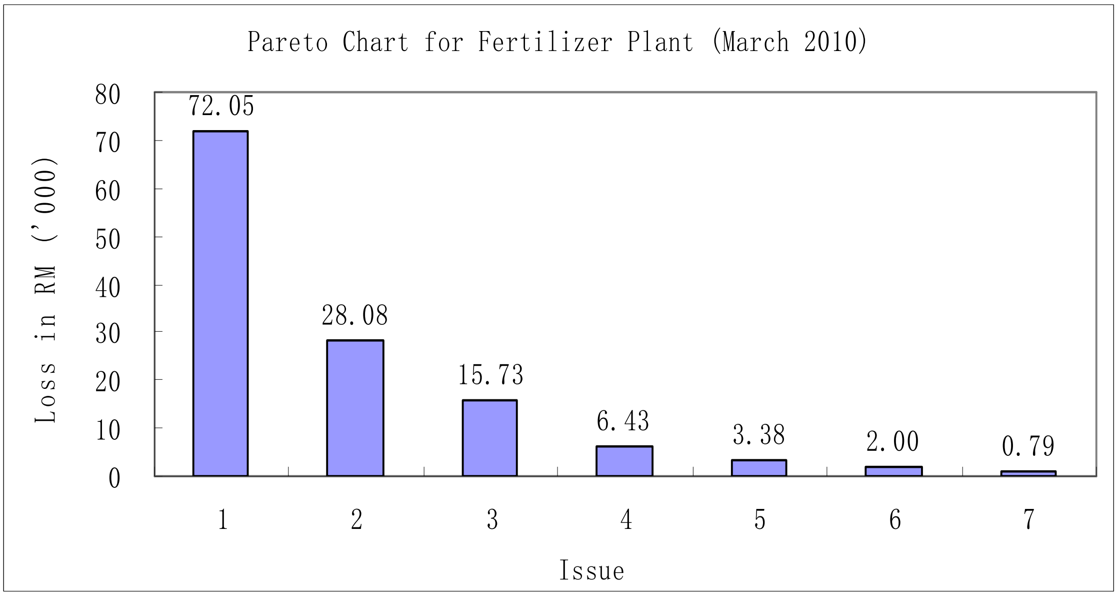
Pareto Chart

In order to find the root cause among the stated problems, a Pareto chart is used. A Pareto chart is a powerful quality improvement tool in problem identification and progress measurement. The Pareto chart (March) for the fertilizer plant is shown in Figure 3.17. From the figure, the root cause is loss of material. According to Pareto Principle (or 80/20 rule), 20 percent of the defects causing 80 percent of the problems or consume 80 percent of time and resources (Juran, 1940). Resolving this issue is prioritized. Explanation for loss of material is shown in details later of this section.

Cause and Effect Diagram

A cause and effect diagram is a powerful tool to breakdown the main potential causes of a known problem. The diagram reflects the relationships between identified effects and causes clearly. The diagram helps to uncover the root causes. A team is formed to brainstorm possible and potential causes that cause the loss of material. The cause and effect diagram is shown in Figure 3.18.

After performing several experiments, the project team found out that the main reasons of causing the dispersion and loss of material are due to the constant moving speed of the conveyor belts and uneven weight distribution on the conveyor belts. The details of the experiment are not discussed here to avoid infringement.



Issue	
1	loss of material
2	replacement of component
3	rework
4	human error
5	repair
6	extra cleaner
7	other

Figure 3.17 Pareto chart (loss of money value versus issues) in March

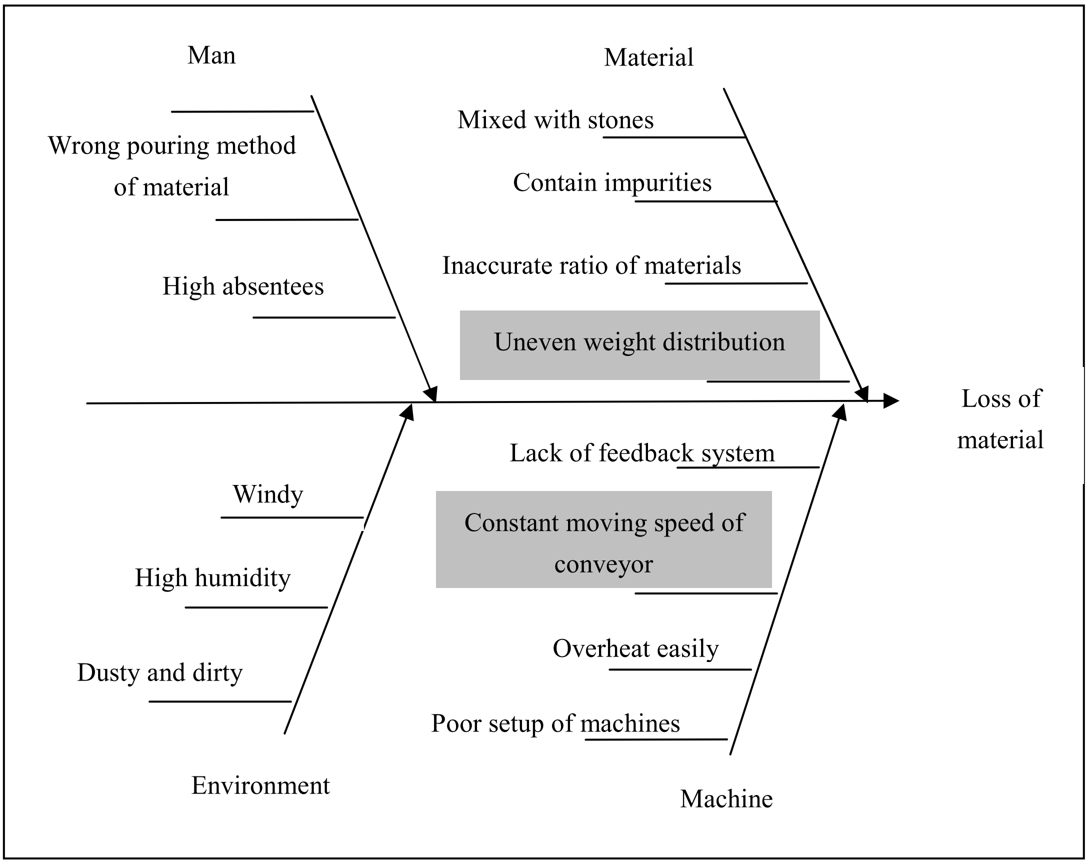


Figure 3.18 Cause and effect diagram for loss of material and its causes

Loss of Material

For each time of pouring and transferring the powder raw material through the depots and conveyors, there are averages of 2.6 percent loss of material. The framework of data collection and how loss of material is calculated is shown in the next chapter. The powder material is dispersed in the air.

There are total of 7 material tanks, so there are 7 tank **x** 2.6% = 18.2% loss for the **first** stage, left with 81.8 percent of the material. For the **second** stage, raw materials 1, 2 and 3 are mixed, raw materials 4, 5 and 6 are mixed and raw material 7 is weighed without mixing with any other raw materials. Therefore, the loss of material for the second process are 81.8% **x** 6 tank **x** 0.026 loss = 12.76% loss, and the material are left with 81.8% – 12.76% = 69.04%. Lastly, the **third** stage, the final mixing process consists of mixing 2 sub-mixtures and raw material 7; and 69.04% **x** 0.026 loss = 1.80% of material is lost, and the final mixtures are left with 69.04% – 1.80% = 67.24%.

Ideally with assume of no loss of any material, the planned productivity of the plant is 44 tons of fertilizer per hour, with 44 tons x 8 working hours = 352 tons daily. However, with the total loss of 32.76 percent of material, the plant produces 29.59 tons per hour, or 236.72 tons daily. This is a very serious problem as the plant does not fully utilize the raw material.

Figure 3.19 Loss of material occurs at raw material depot (stage 1)

Uneven Weight Distribution of Materials

In the **first** stage, the weight of the powder material is not distributed evenly on the conveyor belts. This creates hill of material, and results in increasing the area of dispersion of the powder. Therefore, the loss of material is amplified. The reasons

Figure 3.20 Loss of material occurs at stage 2

for this uneven path of materials are:

1. The way of workers pouring raw materials into the tank. The raw materials are concentrated at certain point when the materials are poured into the tank.

2. There are pills or stones in the raw materials. These alien materials affect the effectiveness of rotating blades inside the tank. This means that the quality for the raw materials of suppliers is bad.

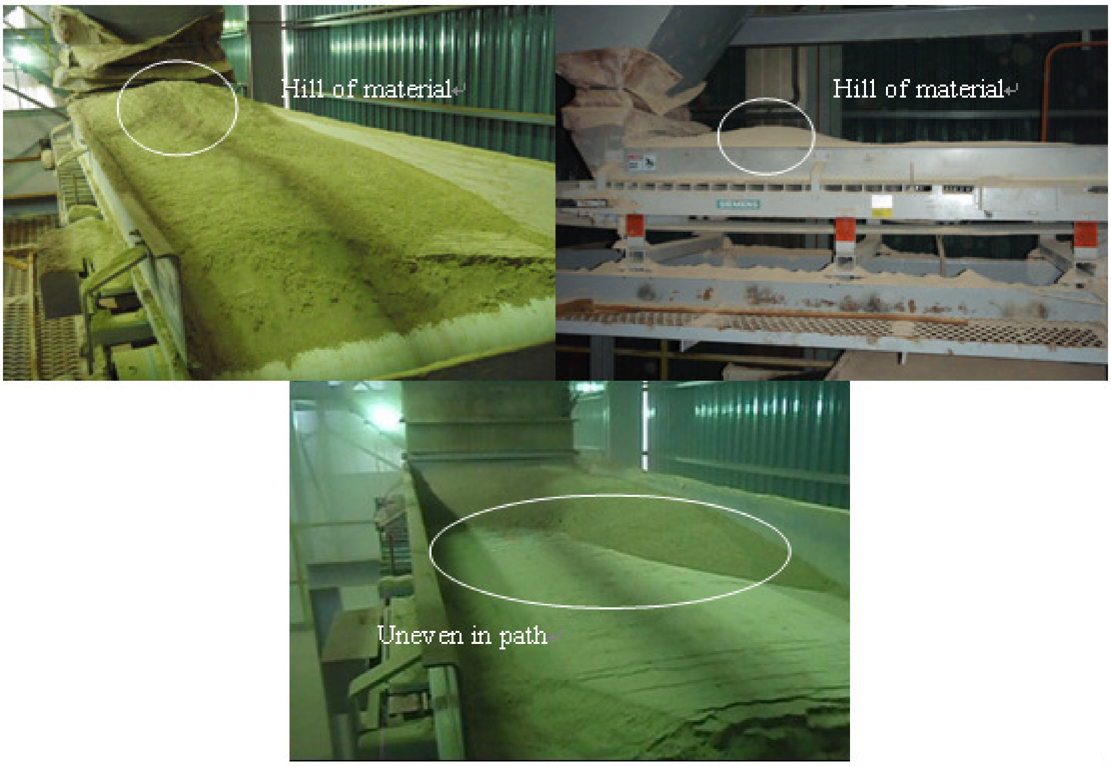


Figure 3.21 Uneven weight distribution and hill of material

Figure 3.22 Pills and stones mixed in the raw materials create uneven weight distribution

Constant Moving Speed of Conveyor Belt

After considering the production rate, the constant moving speed of the conveyor belts is set at 2 km/h (0.56 m/s). The foundation of the optimized speed is based on Taguchi's method (robust design) and is not discussed in this paper. This setup of speed is perfect if the materials are distributed constantly over the conveyor belts. However, the occurrence of uneven weight distribution of materials on the conveyor belts cause loss of material, and indirectly induces other problem such as dusty environment, formation of soil, deterioration of speed sensor etc.

3.3.5 Define Aim and Objective

The objectives of the study or plan are stated in chapter 1.

3.3.6 Formation of Project Team

A team which consists of 6 executives was built to look into the issue and to execute the engineering tools. The team members came from different departments. Team members are listed as below:

Table 3.2 Team members of the project

Former department and responsibility	Job title for present project
General manager	Project manager
Production manager	Production manager
Senior engineer from mechanical department	Maintenance manager
Senior engineer from electrical department	Production engineer
Quality assurance manager	Quality assurance manager
Quality control manager	Quality control manager

3.3.7 Selection of Method and Theory

A search of suitable company for this study is done and a fertilizer plant is selected for this study. The framework of this study is PDSA cycle. As informed by the management of the plant, they wish to eliminate the waste of raw material, and hence Flexible Manufacturing System (FMS) and Total Productive Maintenance (TPM) are used as tools of improvements. The way of implementing of FMS is explained in the next chapter. In order to calculate overall equipment effectiveness (OEE), Total Productive Maintenance (TPM) is the best method in doing so. Other terms such as Mean Time Between Failure (MTBF) are used.

Table 3.3 Engineering technique or AM system used in the project

Engineering technique/ AM system	Function
PDSA cycle	To create the framework of study
TPM - OEE	To calculate the machine utilization
FMS	To improve the current GT cell
Other quality assurance -Pareto chart -Cause and effect diagram -Line and column chart	 -To identify root cause and its impact -To breakdown the main potential causes of a known problem / root cause -To observe the trend of data

Factor Considered in the Study

The factors taken account into consideration during the data collection process are:

- Weight: In order to calculate the loss of material on the material handling machines (conveyor belts), the initial raw material weight and the final processed material weight is compared.
- Amount of time: The total amount of time for this research is 9 months. During these 9 months, data of before and after implementation are collected, observed, analyzed and compared.
- OEE: The OEE of the key machines for 9 months are calculated. OEE represents machine utilization and earning capacity of a plant.
- Actual monthly output: The monthly outputs for 9 months are recorded. Monthly output represents productivity of a plant.
- Percentage of loss of material per hour: The averages for the percentage of loss of material per hour are recorded. Loss of material is the main concern of this study.
- MTBF: MTBF is the time between 2 failures. MTBF is directly proportional to OEE of the machine.
- Reworked material per month: Rework on material increases WIP material, which in turn increases inventory as well. To reduce inventory, rework on material must be kept as low as possible.
- Confidential proprietary information: There are certain data in the plant that are deemed as confidential proprietary information in which this study is not able to cover and hence, data was not shown to avoid infringements.
- Focused data: The data collected was based on a series of machines which form a

manufacturing GT cell. All data collected was to improve processes after implementation of theories and methodologies suggested by this research.

3.3.8 Impact Assessment

In this section, sub-problems or issues caused by the loss of material are explained. The problems stated below are considered as wastes to the plant; and can be quantified into losses, which are shown in next chapter.

Environmental Problem

The dispersion of material not only causes the loss in material, but it is also causing environmental problem to the fertilizer plant. As shown in Figure 3.23, the dispersed powder is causing dusty environment near the processing machines. In additions, the fertilizer plant is lack of ventilation. The dust level of the factory is 285.3 mg/m^3/day, which exceeds the acceptable dust level of 166.8 mg/m^3/day. Moreover, the plant does not provide face mask to the workers. This definitely causes health and ergonomic problems to the workers, which decreases their job satisfaction, performance and productivity. Dusty environment causes sickness on eyes, nose, lungs and skin. Presently, workers face problems of blur vision, difficulty in respiration, smelly odor and itchy on skin. The dust of the raw material is chemical that hazardous to human health, for example sulfur causes itchy on skin, and the worse case can be skin cancer.

Formation of Soil

The fertilizer plant was built on seashore. The humidity of air is very high. The dispersed powder mixes with moisture and form chemical soil. The formation of soil can happen anywhere in the plant, and stick on any surface of the machines and plant. The plant is running at single shift. During working hours, cleaners have to mop the floor every 2 hours to avoid slippery. However, the soil accumulates at night, causing a very dirty environment starting on every morning shift.

Figure 3.23 Dusty environments around various machines

Increase in Weight of the Conveyor

The accumulation of soil on the conveyor increases the total weight of the conveyors. For the weighing machines, errors and deviations occur while weighing the WIP materials and the final mixture of materials. Technicians have to regulate the weighing machines so that the extra weight of the soil is nullified.

Figure 3.24 Formation of soil at various machines

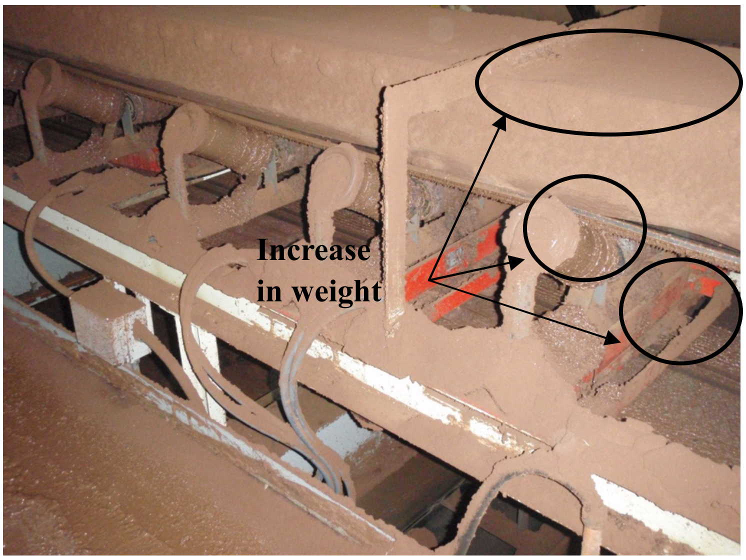


Figure 3.25 Increase in weight on the conveyor

Deterioration of Speed Sensor

For the totalize weighing machines, the calculation of weight involves rotational speed of speed sensors' rollers. The accumulation of the soil on the speed sensors' rollers increases the diameter of the rollers, so their rotational speed is affected. This is causing error in weighing the WIP material.

Moreover, the accumulation of soil decreases the gap between rollers and conveyor belts. High pressure is exerted between the speed sensors' rollers and the conveyor belts. Therefore, the fatigue life of the rollers is reduced drastically.

The rollers of the speed sensor are exposed to coarse surface while running. The high friction causes wear to the surface of the rollers. This is causing error in the calculation of weighing the WIP materials. Also, the speed sensors are easily overheated and need to cool down for 12 minutes after running of 5 hours.

The accumulation of soil on the conveyor belts causes minor stoppage to the machines. The soil is stuck between the gap of the conveyor belts and the rollers. The repairs take 6 minutes to clear the soil.

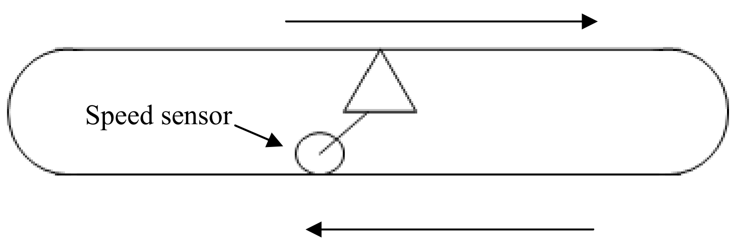


Figure 3.26 Schematic diagram of speed sensor and how it is arranged

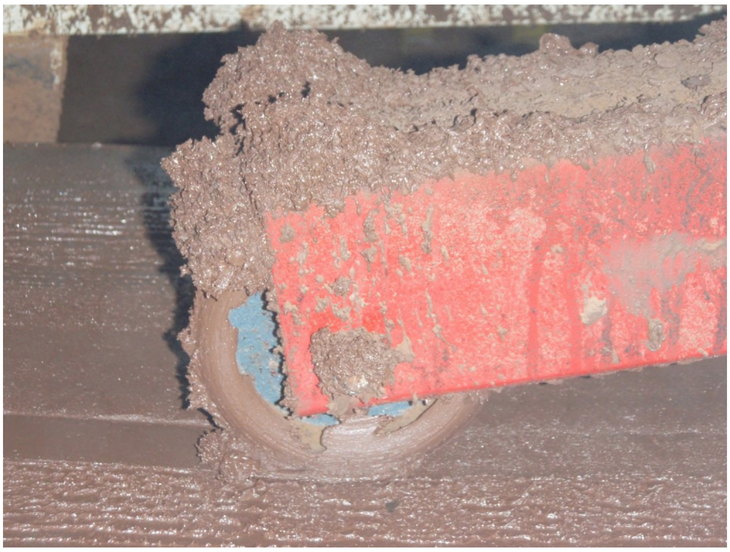


Figure 3.27 Formation of soil on the roller of speed sensor

Deterioration of Quality

The soil has a chance to mix with the raw materials, WIP materials and the final products. This is affecting the quality of the products. The relative ratio of each materials is affected, results of change in pH value of the final products.

The plant is built near seashore, so the air contains high percentage salt. While the soil is forming, salt in the air mixes into the soil. The soil (which contains certain percentage of salt) is added to the WIP materials and final product, and this is seriously deteriorating the quality of the products. This is because salt causes undesirable effect on plants and vegetables.

High Inventory Level

As stated above, the soil degrade the quality of the products. The products have to be reworked, and results in increase of quantity of WIP material or inventory level. WIP material consumes resources and storage space of the plant. Holding cost of a plant is directly proportional to inventory level, so the holding cost could be increased as well.

Holding cost (for the plant of research)

= monthly holding cost per tons X total weight of reworked material in 1 month

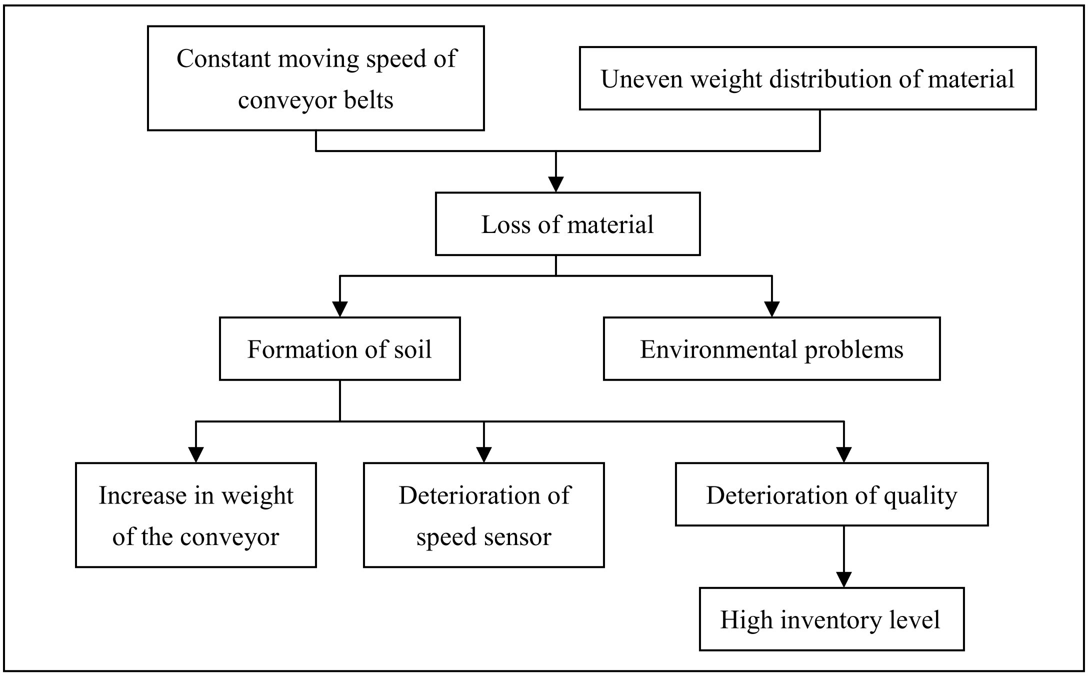


Figure 3.28 Relationships of cause root and the sub-problems