

A STUDY ON THE PERFORMANCE OF LOCAL EXHAUST  
VENTILATION SYSTEM USING MAHALANOBIS APPROACH

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SYSTEM USING MAHALANOBIS APPROACH

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## **SUPERVISOR'S DECLARATION**

We hereby declare that we have checked this project report and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering and Natural Resources.

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Date : 25 January 2012

## STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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*Special dedication to my supervisor, Ms. Aminatulmimi binti Ismail, thank you for  
being very patient guiding me in completing this thesis.*

*And,*

*To my beloved parents and friends, that encouraged and fully supports me  
throughout completing this thesis.*

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# **A STUDY ON THE PERFORMANCE OF LOCAL EXHAUST VENTILATION SYSTEM USING MAHALANOBIS APPROACH**

## **ABSTRACT**

The title of this experiment is a study on the performance of local exhaust ventilation system using Mahalanobis approach. The objectives of this study are to obtain normal pattern operation of local exhaust ventilation (LEV) system and to characterize the pattern to study the performance of the above system. An experiment was conducted in determining the average face velocity of the fume hood. This was done by taking several readings at equidistant points. The average face velocity was checked on reference guidelines of fume hood to see whether the fume hood is safe to use or otherwise. Then, with the same data obtained from the experiment, it was analysed using Mahalanobis Distance approach. Then, the result of both methods will be compared. After it had been analysed, 5 points of face velocity were obtained compared to the 16 initial points, thus proving Mahalanobis approach making it a better and faster way in determining the performance of the fume hood and the LEV system.



# **SATU KAJIAN MENGENAI PRESTASI PENGALIHUDARAAN EKZOSTEMPATAN MENGGUNAKAN PENDEKATAN MAHALANOBIS**

## **ABSTRAK**

Sistem ekzos setempat ventilasi seharusnya diperiksa secara berkala untuk memantau prestasinya. Dalam projek ini, satu kaedah statistik baru yang dipanggil Jarak Mahalanobis telah digunakan untuk tujuan ini. Tujuan projek ini adalah untuk mengenal pasti pola operasi normal bagi system pengudaraan ekzos setempat (LEV) dan mencari corak untuk mempelajari prestasi system di atas. Satu eksperimen telah dijalankan dalam menentukan purata halaju tukup wasap. Ini telah dilakukan dengan mengambil beberapa bacaan di setiap jarak yang sama. Purata halaju permukaan telah dibandingkan dengan panduan rujukan sedia ada untuk melihat sama ada tukup wasap selamat untuk digunakan atau sebaliknya. Kemudian, dengan data sama yang diperolehi daripada eksperimen, analisis dilakukan dengan menggunakan pendekatan MD. Sebagaimana kejayaan teknik MD dalam pengecaman pola, keputusan menunjukkan bahawa MD dengan skala ketaknormalannya mempunyai satu keupayaan yang bagus dalam mengiktiraf prestasi LEV. Keputusan yang diperolehi memuaskan jika dibandingkan dengan kaedah tradisional. Selepas dianalisis, 5 titik halaju muka diperolehi berbanding dengan 16 titik awal. Oleh itu, ini membuktikan pendekatan mahalanobis member satu cara yang lebih baik dan lebih cepat dalam menentukan prestasi tukup wasap dan sistem LEV.

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## LIST OF ABBREVIATIONS

LEV	Local Exhaust Ventilation
MD	Mahalanobis Distance
MTGS	Mahalanobis Taguchi Gram-Schmidt system
MTS	Mahalanobis Taguchi System
OA	Orthogonal Array
SN	Signal to noise

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background of Study**

Malaysia is creating and building a transformation to become a developed nation. By 2020, our prime minister's target is to transform Malaysia's economic growth to quadruple than they were in 1990. Making China as an example, Malaysia has built many factories to contribute towards the country's economic growth (New Straits Times, 2012). In the progress of this development, chemical engineering is one of the crucial industries in Malaysia as well as manufacturing and electronics.

However when this is in progression, we must not forget the concerns that must be faced. One of the most vital and important is the health aspects and safety arena that includes around invisible gases encasing everyone. With the increase of chemical substances used today in multiple productions, as well as dust particles, exhaust gases, and other forms of pollution, the users are exposed to harmful air within long period of time.

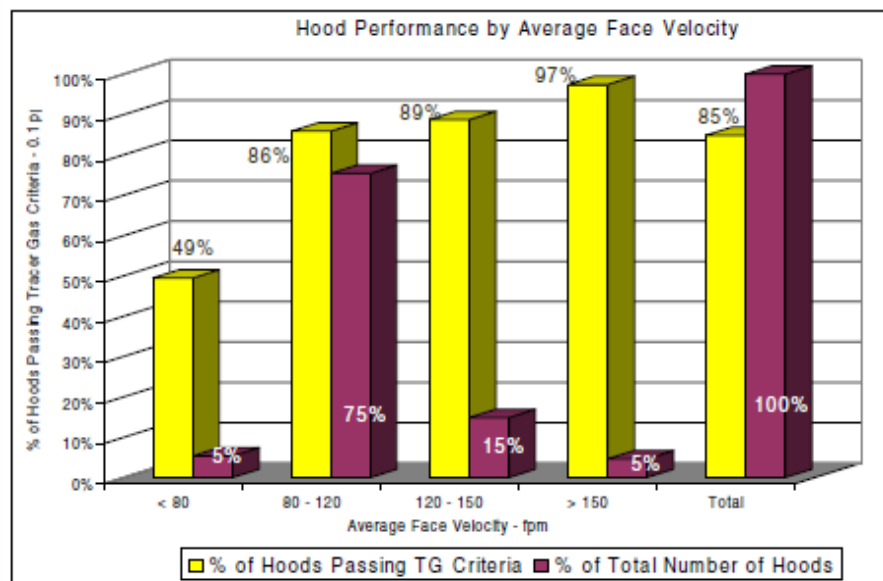


Because of such harmful matter, the operations in the factories must ensure that they have effective ventilation. Additionally, maintaining and improving air quality in your plant or work place should be a concern, as it involves the health of the users. When it comes to air contaminants, local exhaust ventilation(LEV) is absolutely required when you have dust, exhaust fumes, solvent vapours, lead fumes, and acid mist, all known as toxic or corrosive contaminants. If the plant is contaminants at a high level, it is a must that the output airs need to be filtered out before being released into the air, because failure to do so can cause other health problems to the public.

Poor performances of LEV will effect environment directly. The release of air contaminant will not only pollute the environment affect people as well. In order, to ensure that LEV system is able to function effectively, ventilation system should be checked periodically to monitor its performance and detect system malfunction.

Additionally, according to Occupational Safety and Health Act in 1994, LEV testing and examination is done to control the users exposure to hazardous substances and contaminants which has been one of the important requirements of the regulations made under Factories and Machinery Act 1967.LEV system must be checked within a space of not more than one month by the employer. It also has to be examined and tested by a registered Hygiene Technician at an interlude not more than a year.

Based on the Figure 1.1 below, it currently lists that face velocities recommended is below 60 feet per minute (Neuman, 2001). The study shows that there are still fume hoods that did not pass the criteria, which could be hazardous or even may cause fatality if it was used. That is why there is a growing need in ensuring easily of the hood performance which will reduce the health risks at the workplace.



**Figure 1.1** Graph of hood performance by Average Face velocity (Source: Neuman, 2001)

## 1.2 Problem Statement

As Malaysia is a rapidly developing country, modern industry with a complex of operation and processes uses increasing number of chemical substances. The workplace environment may be harmed with various substances such as dusts and chemicals that could be hazardous if inhaled due to their chemical properties. Many health problems

occur as resultants on the exposure to the chemical substances for a long time. Because of these factors, a well-function system is a mandatory in every factory to increase the safety level. Essentially, LEV system is installed in every building for heat control and removal of air contaminant from the area

LEV should be installed in factories or closed building whereas the generation of air pollutant is generally significant. A typical LEV system works by drawing contaminated air from a process through a partial enclosure of hood or closed to the source of emission or contamination.

Nowadays, LEV is installed in every factory but the effectiveness maintenance and proper design were often overlooked by the factory owner. As a result, the money spent is wasted and LEV became ineffective. Thus, each of the components of LEV must be inspected regularly. Periodic testing are required to ensure system performance is adequate.

In 2009, Chemical Fume Hood Book stated that when installed, fume hoods should be inspected in accordance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE 110 to ensure proper containment. Thus, it is very important in checking the performance of the LEV as it relates to the health and well-being of the users of LEV (Jafari, 2008).

Based on previous research, there are many ways to inspect performance of LEV such as tracer gas measurements, smoke release observations, air velocity

measurements, face velocity measurement and decay-rate testing under access hoods (Beamer et al., 2004).

But nowadays, one of the alternative ways of checking the performance of the LEV in this proposal is by using Mahalanobis approach. Mahalanobis Distance (MD) is a metric, which is a rule for determining the distance of two points, of a non-spherically symmetric distribution.

### **1.3 Research Objectives**

The objectives of this study are:

1.3.1 To obtain normal pattern operation of local exhaust ventilation (LEV) system.

1.3.2 To characterize the pattern to study the performance of the above system.

### **1.4 Scopes of Study**

The evaluation of the performance of LEV System experiment was conducted by measuring velocity of air flow at evenly distributed points in the plane of the hood face area of the hood opening. It will then be calculated to see whether the fume hood is efficient or otherwise. Random points of air flow rates from the same sets of data were calculated by MD and compared with the initial result.

## **1.5 Significance of Proposed Study**

The MD will give a lot of benefit to the engineering field and other fields involving the usage of LEV system, which is important as an inefficient LEV can be hazardous and harm the users. This approach can simplify and shorten the time in checking the performance of the LEV just by using random points of the fume hood air flow. With this approach, the health and well-being of the users of LEV can be ensured as the periodic fume hood function inspection can be done easily.

## **1.6 Expected Outcome**

The results from the experiment will give us the characterization pattern of the LEV. By analysing using MD the result will be similar with the conventional way in determining the efficiency of the fume hood, thus making the MD a better and faster way in determining the performance of the fume hood and the LEV system overall.

## **1.7 Concluding Remarks**

In this chapter, it had been discussed about the introduction of the research. Chapter 2 is reviewing about the theoretical of the research and the chapter 3 is reviewing the methodology of the research, and how the research and experiment was conducted. Chapter 4 is discussing about the results obtained. Chapter 6 is the summary of this project.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Ventilation system**

Ventilation is a process of providing fresh air to an enclosed space or area. The purpose of ventilation is to create a healthy working environment by removing air contaminants that may be harmful to the users and people surrounds. Ventilation system is an important aspect of health as a clean supply of air, especially in an enclosed area, is important for the working environment. Many parts of the industries have to involve in jobs or works that involves dusts, gases or fumes. The main purpose of a ventilation system is to expell the air contained from a confined space, and replaces them with clean and fresh air through the system.

In 2001, Goodfellow defined briefly about ventilation in their book, stating that ventilation uses a competent amount of air flow rate which is as low as it could, to reduce the impurities when it enters at the points that has been fixed. There

are two way in obtaining the low air flow, the first by removing the contaminants beforehand and the other is by supplying noncontaminated air from an inlet to avoid the impurities entering the area. In 2002, Energy Efficiency and Renewable Energy Clearinghouse concluded that ventilation can be divided into three main parts that are natural ventilation, whole house ventilation and spot ventilation.

### **2.1.1 Natural ventilation**

Natural ventilation is a process where outside air is dragged inside using a medium of open windows or doors. The principle of natural ventilation is the differences in the dispersion of air pressures around a building. Basically, air flows from spaces of high pressure to spaces of low pressure, with gravity and wind pressure affecting it. Natural ventilation patterns are depending on the location and control of doors and windows (Energy Efficiency and Renewable Energy Clearinghouse, 2002).

According to HKU Arch in 2001, natural ventilation can be divided into two categories namely controlled natural ventilation and infiltration. Controlled natural ventilation is a displacement of air that be done on purpose by using natural forces through specified openings such as windows and doors. Infiltration can be defined as the flow of air through non deliberate openings driven by wind, temperature-difference pressures and/or appliance that is forced by pressures through the building. What makes it differs from natural controlled ventilation is that infiltration is difficult to be controlled



and is not the most popular choice than other ventilation strategies but it is a main source of ventilation in buildings.

### **2.1.2 Spot ventilation**

Spot ventilation is one of the types of ventilation where the motion of air was controlled by using localized exhaust fans to rapidly discharge contaminants and moisture at the feed. Common household examples include range hoods over stoves in the kitchens and bathroom exhaust fans. Spot ventilation is commonly used in combination with natural ventilation in order to improve the effectiveness (Energy Efficiency and Renewable Energy Clearinghouse, 2002).

### **2.1.3 Whole-house ventilation**

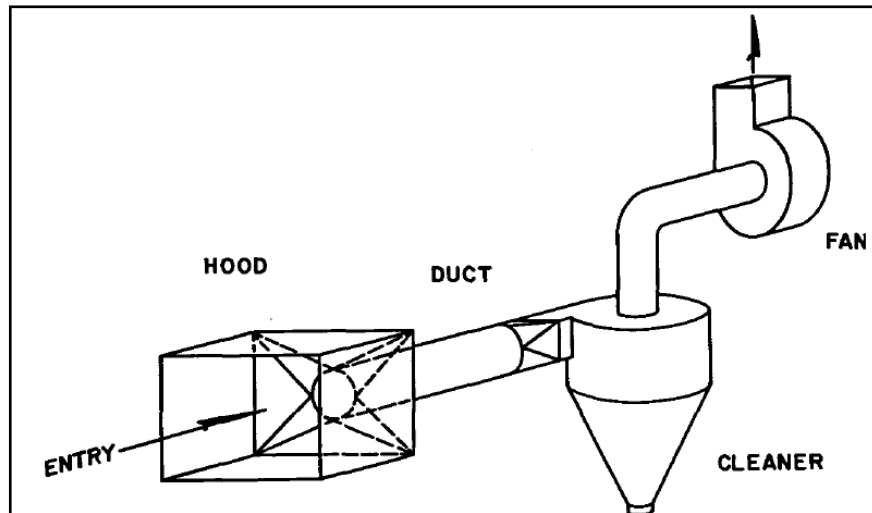
A whole-house ventilation system is where one or more fans and duct systems to supply and insert air to the desired position as to the house. By using this system, it controls the exchange of inlet and outlet air more efficiently. Whole-house ventilation consists of two parts, the first one where it may be exhaust-only. The other one is the supply-only, or other than these two, is the balanced system that is a combination of both exhaust and fresh air intake substances. Whole-house ventilation systems give controlled, uniform ventilation within the whole house.

There are four types of systems, which are exhaust ventilation systems where there is force inside air out of a home. The second one is supply ventilation systems, force outside air into the home. Next is the balanced ventilation system, where the force has the same amounts quantities of air into and out of the home. And lastly, energy recovery ventilation systems, where the process consists of heat transfer from incoming or outgoing air to minimize energy loss.

## **2.2 Local Exhaust Ventillation System**

LEV system is engineering control which to encase and induct the contaminant materials and also ensuring air flow at an appropriate rate. LEV system is widely used in many parts of the industry involving an enclosed space or area (Alden and Kane, 1985).

LEV usually consist of four major elements that are hoods, fan, ductwork and cleaning device. Hoods functioning to capture the air contaminant and fan functions as the air moving device. Ductwork is to transport the contaminant and lastly air cleaning device is a collection unit for contaminant. The element in LEV is shown in Figure 2.1.



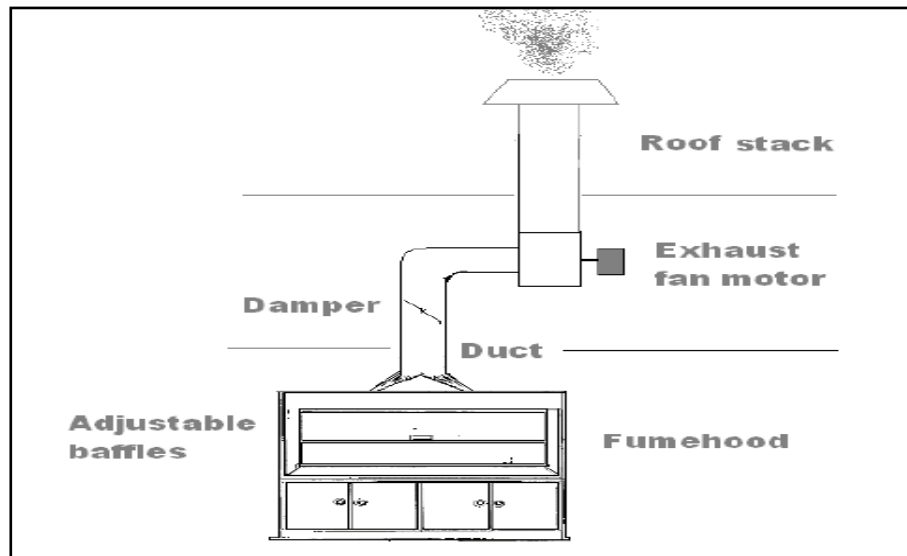
**Figure 2.1** Schematic diagram of LEV  
(Source: Mutchler,1973)

### 2.2.1 Fume Hood

There are many types of local exhaust ventilation system. However, in this study, fume hood will be used as the subject study of the LEV. The use of a laboratory fume hood is to decrease chemical exposure. The fume hood will enclose the perilous substances, the vapours, gases and dusts by removing it via an exhaust system, where usually at the roof of the building are where the captured air through the vent.

A fume hood structure as shown in Figure 2.2 is basically a cabinet, with an open side for access to the interior of the hood. A transparent, movable sash, allows the user to enlarge the fume hood opening. The hood is connected, via ductwork, to an exhaust fan, usually located on the roof of the building in which the hood is located. The exhaust fan draws air from the room in which the hood is in through the

hood opening and out through the ductwork. A fume hood is an integral part of the building air handling system.



**Figure 2.2** Diagram of a fume hood  
(Source: Northwestern University, 2009)

### 2.3 Advantages of LEV

There are several reasons that LEV are more commonly used as with least possible air volumes, they offer better contamination control, thus making it more economical as it will reduce the costs of air moving, cleaning and makeup air requirement. So it can be said that the most effective local exhaust hood uses the least exhaust volumetric flow rate that will give the most contaminant control. Consequently, having enough information and knowledge of the mechanism is vital for a well functional hood design (Cascetta et al., 1996).

ACGIH added in 2006, that there are five advantages of LEV, the first one is it is the only choice when handling toxic airborne chemicals. A LEV also has the ability to control various contaminants such as dusts and metal fumes. It also

removes the contaminants in the workplace to ensure the safety of the workers. The LEV also needs less amount of makeup air because of the exhausted air are in small quantities. The fifth advantage is that by using LEV, as there is less makeup air to heat or cool, it will reduce the energy costs.

## **2.4 Disadvantages of LEV**

ACGIH stated in 2006, there are four disadvantages of LEV. The disadvantages are LEV must be designed concede to industrial hygiene practice to control the contaminants. Moreover, LEV may have the necessity for a more excessive cost investment than general ventilation systems to pay for design, construction and installation materials. The design of LEV may be more complicated than other ventilation systems as well as it may need more formidable maintenance organization.

## **2.5 Conventional ways to study on performance of LEV**

Nowadays, there are many chemical substances that are harmful to the user as well as the environment. People are expose to the contaminated weather without noticing it. Therefore it is very crucial to study on the performance of the LEV. There are many conventional ways in evaluating the performance of LEV. Beamer et.al (2004),describe in their article on how NIOSH field evaluation led to the invention of recommended testing procedures for evaluations of LEV capture

efficiency for mail-handling machine, by methods of indicator for gas measurements, smoke discharge observations, and air velocity determination.

### 2.5.1 Air velocity measurement

In air velocity measurement, air velocity meter is used to take velocity measurements which the data were taken at a point where the discharge of a possible impurities at about 2 sec. The foreign matter was freeing at theoretically no velocity into air and 200 feet per minute (fpm) is the suggested capture velocity (Beamer et al., 2004). Range of capture velocities are shown in Table 2.1.

**Table 2.1** Range of capture velocities

Condition of Dispersion of contaminant	Example	Capture Velocity, fpm
Released with practically no velocity into quiet air.	Evaporation from tanks; degreasing, etc.	50-100
Released at low velocity into moderately still air.	Spray booths; intermittent container filling; low speed conveyer transfers; welding; plating; pickling	100-200
Active generation into zone of rapid motion	Spray painting in shallow booths; barrel filling; conveyer loading; crushers	200-500
Released at high initial velocity into zone at very rapid motion	Grinding; abrasive blasting; tumbling	500-2000

(Source: ACGIH, 2007)

### **2.5.2 Tracer Gas method**

For the tracer gas method, by dispensing tracer gas (TG) at a constant rate at the contaminant control and by evaluating the corresponding downstream TG concentration inside the exhaust duct, NIOSH measured control efficiency quantitatively. Firstly, the TG was released inside the duct to find the concentration  $C_{100}$  corresponding to 100% capture, and this will be done before and after the TG method conducted. Then when the TG was released at any given point, the capture efficiency at the release point will be calculated as  $C/C_{100}$  (Beamer et.al, 2004).

### **2.5.3 Smoke release observations**

A smoke generator that is functioning to generate smoke was released it into the input part of the machine at all locations. The objective is to examine the capture of smoke where impurities quite likely be formed. As a result, if the smoke was trapped rapidly and entirely by the exhaust system, it indicated standard control design and performance. Meanwhile, if the smoke was slow to be trapped by the exhaust inlet, the ventilation system design was ineffectively (Beamer et.al, 2004)

## **2.6 Mahalanobis Distance (MD)**

### **2.6.1 Definition of MD**

Mahalanobis Distance (MD) is a metric system, which is a rule for determining the distance of two points, of a non-spherically symmetric distribution. MD can be used in problems where variables are not independent. In 2010, Torra and Narukawa defined MD in their journal as a generalization of the Euclidean one, incorporate in its meaning, the covariance matrix where the association of the variables will also be considered when analysing the distance between two points, in  $R^n$  for  $n > 1$ .

The MD for the initial variable space is calculated by the inverse set data of the variance–covariance matrix of interest, involving the correspondent of data (Maesschalck et.al, 2000). In 2010, Kuma also defining MD as methodology differentiates multivariable data groups by a uni variate distance measure that is calculated from the multiple parameters measurement.

### **2.6.2 Concept of MD**

The concept of MD is that to supply a great method of calculating the similarity some set of conditions is to an ideal set of conditions. This tends to be very helpful in identifying which regions in a landscape are most similar to some “ideal” landscape. As an example, for the field of wildlife biology we might define an



“ideal” landscape as that which best fits the niche of some wildlife species. By inspection, we may find that a wildlife species typically occurs within a particular ascent range, or on slopes of a specific steepness. Using MD, the whole landscape can quantitatively characterize in terms of similarity to the ideal elevation or slope of that animal.

In addition, MD is based on both the mean and variance of the predictor variables, plus the covariance matrix of all the variables, and accordingly takes advantage of the covariance among variables. The region of constant MD around the mean forms an ellipse in 2D space or an ellipsoid or hyper ellipsoid when more variables are used.

## 2.7 Calculation using MD

The calculation of MD can be done with the less complex steps as below, but the calculation process may be employed as function applications (Hayashi, 2002)

$$y_{i,f} = \frac{y_{i,f} - \bar{y}_i}{\sigma_i} \quad (2.1)$$

Next, calculate a correlation matrix R

$$R = \begin{bmatrix} 1 & r_{12} & \dots & r_{1P} \\ r_{21} & 1 & \dots & r_{2P} \\ \dots & \dots & \dots & \dots \\ r_{P1} & r_{P2} & \dots & 1 \end{bmatrix} \quad (2.2)$$

$$r_{ij} = r_{ji} = \frac{1}{n} \sum_{f=1}^n y_{i.f} . y_{j.f} \quad (i, j = 1, 2, \dots, P) \quad (2.3)$$

Then, calculate the inverse matrix A from the matrix R. Matrix A is the reference space (Mahalanobis Space).

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1P} \\ a_{21} & a_{22} & \dots & a_{2P} \\ \dots & \dots & \dots & \dots \\ a_{P1} & a_{P2} & \dots & a_{PP} \end{bmatrix} \quad (2.4)$$

$$= \begin{bmatrix} 1 & r_{12} & \dots & r_{1P} \\ r_{21} & 1 & \dots & r_{2P} \\ \dots & \dots & \dots & \dots \\ r_{P1} & r_{P2} & \dots & 1 \end{bmatrix}^{-1} \quad (2.5)$$

Using the elements from the reference space, MD can be calculated as follows:

$$MD = \frac{1}{P} \sum_{i,j=1}^P a_{i,j} y_i y_j \quad (i, j = 1, 2, \dots, P) \quad (2.6)$$

Where  $y_i$  and  $y_j$  are the standardized data from 2.1.

## 2.8 Method of MD

MD can be calculated using two different methods: Mahalanobis Taguchi system (MTS) and Mahalanobis Taguchi Gram-Schmidt method (MTGS).

### 2.8.1 Calculation of MD by Mahalanobis Taguchi System (MTS)

MTS is a tool of diagnostic and forecasting in identifying the degree of abnormality of monitoring based on multivariate variables of “normal” group of observations. MTS involves 4 phases according to Huei et al. (2004).

Phase 1: Construct a measurement scale with MS as the reference

A set of “normal” variables observations must be obtained and standardized for us to create a measurement scale in order to calculate the MD. MD measures distances in multidimensional spaces. The equation for calculating the MD can be stated as:

$$MD_j = 1/k (Z_{ij}^T C^{-1} Z_{ij}) \quad (2.7)$$

Where  $MD_j$  is MD for the  $j$ th observation in a sample size of  $n$ ,  $j$  is 1 to  $n$ ,  $k$  is number of variables,  $Z_{ij}$  is normalized vector obtained by normalizing values of  $X_{ij}$  ( $i=1$  to  $k$ ),  $Z_{ij}$  is  $(X_{ij}-m_i)/s_i$ ,  $m_i$  is mean of the  $i$ th characteristic,  $X_{ij}$  is Values of the  $i$ th characteristic,  $s_i$  is standard deviation of the  $i$ th characteristic,  $C^{-1}$  is inverse of the correlation matrix.

Phase 2: Validate the measurement scale

For validating the measurement scale, observations outside the MS was chosen, usually “abnormal” observations. In the MTS, the decision maker chooses only the variables that are needed for developing an MTS measurement scale, so the variables must be chosen very carefully so it is appropriate. After the measurement

scale is fixed, the variables are assessed through the observations outside the MTS. We take the numbers of abnormal observations as  $t$ , and we use the average and standard deviation and correlation matrix of these “normal” observations to calculate the MD in the “abnormal” observations. Following the MTS theory, if it is a good scale, then the MD of “abnormal” observations will be larger than the MD of “normal” observations.

#### Phase 3: Screen important variables

The main function on the third phase is to discover the vital and important variables to go with the model analysis or diagnosis. OAs and SN ratios are very useful in the identification of crucial variables. For an OA, each run accommodate a level combination of factors or variables to investigate each variable’s outcome to the response.

#### Phase 4: Diagnose or predict future observations with important variables

Regardless that as technology enhances making it easier for us to collect numbers of data; it is still better having less number of data that need to be gathered. Thus, for this last phase, the MTS measurement scale was reconstructed and reassembled by taking the essential variables that we had obtained from previous steps, and then validate if the measurement scales obtained can properly foresee and analyse the future observations.

## 2.8.2 Calculation of MD by the Mahalanobis Taguchi Gram–Schmidt System (MTGS)

According to Srinivasaraghavan et al. in 2006, the MD in MTGS is calculated differently from MTS. The equation for calculating MD by MTGS is given as follows:

$$MD_j = 1/k (u_{1j}^2/s_1^2 + u_{2j}^2/s_2^2 + \dots + u_{kj}^2/s_k^2) \quad (2.8)$$

Where  $u_{ij}$  is Gram Schmidt vector coefficients,  $s_k$  is Standard deviations of the Gram Schmidt vectors  $U_k$ ,  $i$  is 1 to  $k$  ( $k$ =number of variables),  $j = 1$  to  $n$  ( $n$ =sample size)

The two steps to calculate the MD from the raw data are listed below in MTGS:

1. Defining the reference datum: The MD for the normal subgroup is called the reference datum which is calculated. The reference datum defines a reference with which the abnormal subgroup can be compared.
2. Validation of the Datum: In the second step, the reference datum developed in the previous stage is used to calculate the MD for an abnormal group. This basically constitutes validating the datum.

## 2.9 Advantages using MD

Basically, there are many advantages of MD instead of other conventional distance. For example, the Euclidean distance, does not display how well the unknown data set fits with the reference data set. MD is valuable over the Euclidean distance because it takes into account the distribution of the points (correlation). Then, MD is dimensionless and takes into account not only the average value but also the variance and the covariance of the variables measured. It is also accounts for ranges of acceptability (variance) between variables (Srinivasaraghavan et al., 2006).

The first advantage is that it automatically taken for the ratio and scales of the coordinate axes. It also regulates for counterpart between the variance features. Another advantage is that it can produce curved as well as linear decision boundaries.

The MD is also beneficial as it is not as sensitive to large differences in the order of magnitude of features such as the dimensions compared to Euclidean Distance (ED). However by using MD, it will be liable to scale the results so that one or more large OOM features does not dominate the MD due to the behaviour of the covariance matrix calculation.

## 2.10 Application of MD

According to Taguchi in 2005, MD can be used in designing air bags for a car. We want to prevent the possible errors such as an air bag that did not actuate at the moment of a crash and an air bag activated when there was no crash. Acceleration at several locations in a car is obtained from time to time at an interim of a few thousandth of a second. The data will be collected in multiple driving conditions such as on a quick acceleration or stop, driving at smooth and rough road situations and so forth. Other sources of information, such as driving speed will be combined with data obtained, to construct a Mahalanobis space.

The computer in the air bag system is continually calculating a MD. The system will send a signal to actuate the air bag before a crash when the distance becomes greater than a predicted beginning. In some cases, such as when there is a child sitting there or an adult is sitting on the seat and bending over, we do not want to activate the air bag. For such cases, MTS studies are being executed within automotive companies.

Asada (2001) used the MTS to predict the production of wafers. Yield of wafers is resolved by the variability of electrical characteristics and dust, where the research that was done focused on one wafer product that had a high yield. MD was calculated on multiple wafers to differentiate the relationship between distance and yield. The signal-to-noise ratios were used to show the adequacy of estimating and the effect of the parameters. This research was done to show the suitability of the MD to forecast the ineffective components.

## **CHAPTER 3**

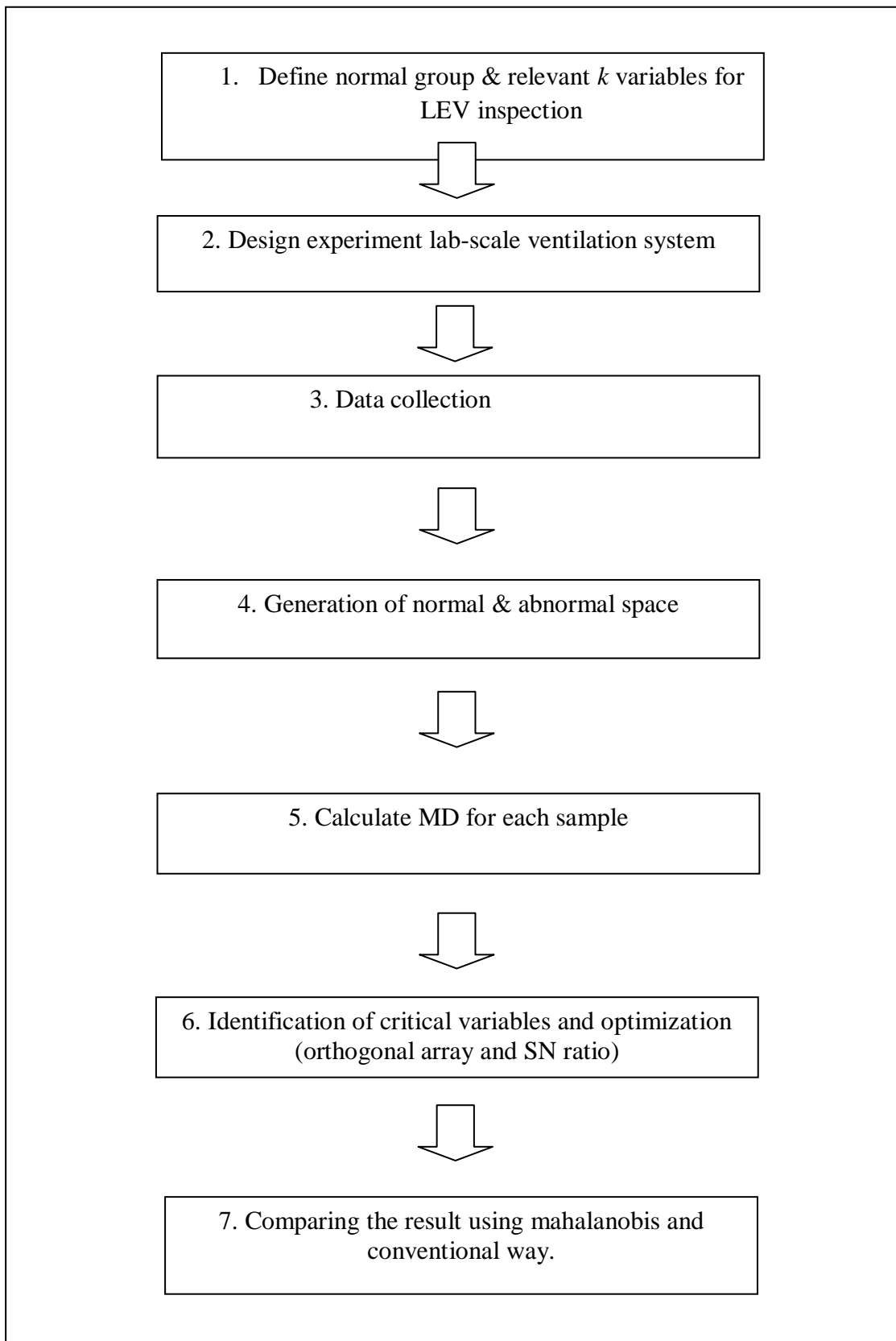
### **METHODOLOGY**

#### **3.1 Research Design**

This research was conducted firstly by conducting an experiment in determining the average face velocity of the fume hood. This will be done by taking several readings at equidistant points. This experiment was conducted where the points of the face velocity at the sash of the hood will be taken by using an anemometer at the position the same as when an actual person is using the hood in a normal working condition, and not by stepping beside the hood to give a more accurate result.

The average face velocity then was checked on reference guidelines of fume hood to see whether the fume hood is safe to use or otherwise. This methodology was based on a study by Connell (2010). Later, with the same data obtained from the experiment, it was analysed by using MD approach. It will be then compared the result of both methods that has been mentioned above. The flowchart of the process is shown in Figure 3.1





**Figure 3.1** Flowchart of overall process

## 3.2 Instruments and Equipments

### 3.2.1 Laboratory Fume Hood

The laboratory fume hood will be an example of a LEV, and will be used in order to obtain the face velocity in checking the performance of the LEV.

### 3.2.2 Anemometer

The anemometer will be used in determining the face velocity of the fume hood.



**Figure 3.2** Anemometer in laboratory

### 3.2.3 Manometer

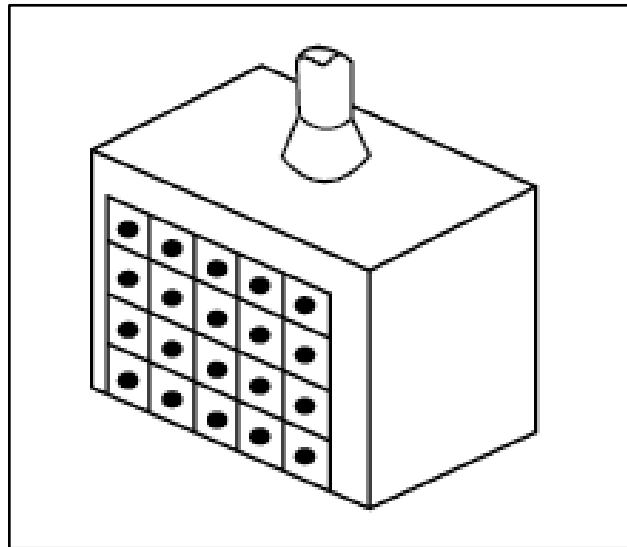
The manometer will be used in determining the static and velocity pressure of the ducts of the LEV.



**Figure 3.3** Manometer pitot tube

### 3.3 Data Collection

The research is going to be conducted on a fume hood at University Malaysia Pahang. In this research, the hood will provide an opening where 16 velocity points will be taken. This is based on Guidelines on Occupational Safety and Health, where opening of the hood is divided into at least 16 equal areas, and measurement is taken at the centre of equal area. Precaution steps will be considered when taking these points as we want to get the most accurate result, where the points will be taken similar with normal working conditions.



**Figure 3.4** Sample Point on LEV  
(Occupational Safety and Health Ministry of Human Resources Malaysia, 2008)

An anemometer is used to evaluate air velocity upstream of the hood. These measurements were made along the centerline, the center of each plate extending outwards away from the hood in a straight line. The centerline measurements were taken at the midpoint of the hood at nine positions upstream of each plate up through

34.9 cm from the face (1.25 D). There were more points to assess closer to the hood, as it is the region of highest velocity decline, giving us estimation of where the most change occurs and by what magnitude. Three replicate measures of centerline velocity were made for each plate at each of the chosen airflow rates, repositioning the anemometer between each replicate.

Thus, we would not take the points while stepping of the hood, because none of the users of the fume hood will operate on such manner. The face velocity will be taken on a normal working condition which the person using the LEV is standing at the centre of the hood. This is because the air flow will have deviation when compared to when there is a person directly in front of the hood, and when there is not. This will directly affect the reading of the velocity points that will be taken, thus making it very crucial taking the velocity points in the correct position.

Measuring of hood face velocity was carried out by dividing the hood face into different sectors. By using an anemometer, face velocity at each sector was measured. The average of all the measurements was then taken as face velocity of the hood. To reduce the measurement error caused by air turbulent, measuring of static pressure should be made about 2 – 6 duct diameters downstream in a straight section of the duct. In pitot traverse calculation to obtain the traverse points, ten VP measurements were made on each of two traverses across the duct. Measurements were made on the centre of concentric circles or equal area.

### **3.4 Data analysis**

#### **3.4.1 Testing of LEV System**

Every ventilation system should be tested the effectiveness. The most important measurement in testing of the system is volumetric flow in cubic meters per second ( $\text{m}^3/\text{s}$ ) and pressure (static pressure, velocity pressure, and total pressure).

The testing of LEV consists of:

- i) Inspection of LEV
- ii) Determination of capture or face velocity
- iii) Determination of hood static pressure
- iv) Determination of duct static pressure along the ducting system
- v) Determination of hood velocity pressure and transport velocity
- vi) Determination of air cleaner's efficiency
- vii) Determination of fan's capacity and efficiency

Out of these steps, only 3 data is taken which are hood static pressures, hood velocity pressure and face velocity. Static pressure (SP) is a force that compresses or expands the air. It is used to overcome the fractional resistance of ductwork and other resistance such as filter, elbows and so on.

SP it always acts perpendicular to the duct wall and creates outward pressure before the fan and inward pressure after the fan. Velocity pressure (VP) is the

pressure required to accelerate the air from rest to a particular velocity. It exists only when air is in motion and always acts in the direction of air flow. Total pressure is the algebraic sum of SP and VP.

When air enters a suction opening, the air stream gradually contracts a short distance downstream and as a result, a portion of the SP is converted into VP. The smallest plane diameter occurred is known as the vena contract. After this point, the air stream gradually expands to fill the duct and consequently, a portion of the VP is converted into SP. Both of those conversions are always accompanied by losses which reduce the air flow.

The amount of air flow reduction can be defined by a factor known as the coefficient of entry,  $C_e$  related to the  $C_e$  is term "hood and entry loss" or  $h_e$ . It is defined as the factor representing the loss in pressure caused by air flowing into the duct.

### **3.4.2 Calculation of Volumetric Flow rate**

Volumetric air flow rate ( $Q$ ) also an important parameter especially to create a sufficient capture velocity in front of the hood. The capture velocity that is created in front of the hood entry must be sufficient to capture the contaminant and draw it into the hood and away from the workers breathing zone. Volumetric flow rate can be determined from the equation:

$$Q=VA \quad (3.1)$$

Where V is average linear velocity, A is Cross sectional area of duct or hood at the measurement location

### 3.4.3 MD calculation

Mahalanobis Taguchi System (MTS) is a method in creating a systematic method using the MD created by Taguchi. The function of the MTS is to develop and optimize a diagnostic system with a measurement scale of abnormality.

In MTS, the signal-to-noise (SN) ratio is used to assess the effectiveness of a system. As the MTS is not only used in diagnosis but also for predicting the system, MTS can be used to develop and optimize a system of multivariable diagnosis, pattern recognition, and prediction of occurrence of particular events.

Taguchi et al., 2005 states in his book that to design and optimize the MTS, we must follow the following steps;

#### Task 1: Generation of normal space

Step 1: Define the normal group.

Step 2: Define k variables ( $1 < k < 1000$ ).

Step 3: Gather data from the normal group on k variables with sample size n,  $n \gg k$ .

Step 4: Calculate the MD for each sample from the normal group.

4a. Compute the mean and standard deviation for each variable and normalize

the data.

$$z = \frac{x - \bar{x}}{\sigma_x} \quad (3.2)$$

4b. Compute the correlation matrix.

4c. Compute the inverse matrix of the correlation matrix.

4d. Compute MD for each sample from the normal group.

$$MD = \frac{1}{k} Z A^{-1} Z^t \quad (3.3)$$

Where  $K$  is total number of variables,  $I$  is number of variables ( $i = 1, 2, \dots, k$ ),  $j$  is number of samples ( $j = 1, 2, \dots, n$ ),  $Z$  is standardized vector of normalized characteristics of  $x_{ij}$ ,  $T$  is transpose of the vector,  $A^{-1}$  = inverse of the correlation matrix.

#### Task 2: Confirmation of discrimination power

Step 5: Gather data on  $k$  variables for samples from outside the normal group; sample size =  $r$ .

Step 6: Calculate the MD for each sample from outside the normal group.

Step 7: Evaluate the discrimination power.

#### Task 3: Identification of critical variables and optimization

Step 8: Optimize the MTS. Evaluate critical variables. Optimize the number of variables. Define the optimum system.



## **CHAPTER 4**

### **RESULT AND DISCUSSION**

#### **4.1 Overview of Result**

In this chapter, results are presented, discussed, analyzed, and summarized. The result of volumetric flow rates, pressures and MD calculation can be achieved from inspection and testing of ventilation system. Total of 11 experiments are run to obtain static pressure (SP), velocity pressures (VP), traverse points, and face velocities. Then, results obtained are compared to ACGIH standard. If the results comply with the standard, the MD is calculated for each sample. MD is calculated to come up with establish pattern recognition for prediction of LEV performance.

In the MD calculation, MD can be used to discriminate between normal and abnormal objects. Once MD is calculated, the number of attributes is reduced using the tools of orthogonal array (OA) and signal-to-noise ratio (SN) by evaluating the contribution of each attribute. Each row of the OA determines a subset of the original system by the including and excluding that attribute of system.

## **4.2 Traverse Point**

Because the air flow in the cross-section of a duct is not uniform, it is necessary to obtain an average by measuring VP at points in a number of equal areas in the cross-section. In order to obtain a representative average velocity in a duct, it is necessary to locate each traverse point accurately. Basically, the number of traverse points increase with increasing duct size.

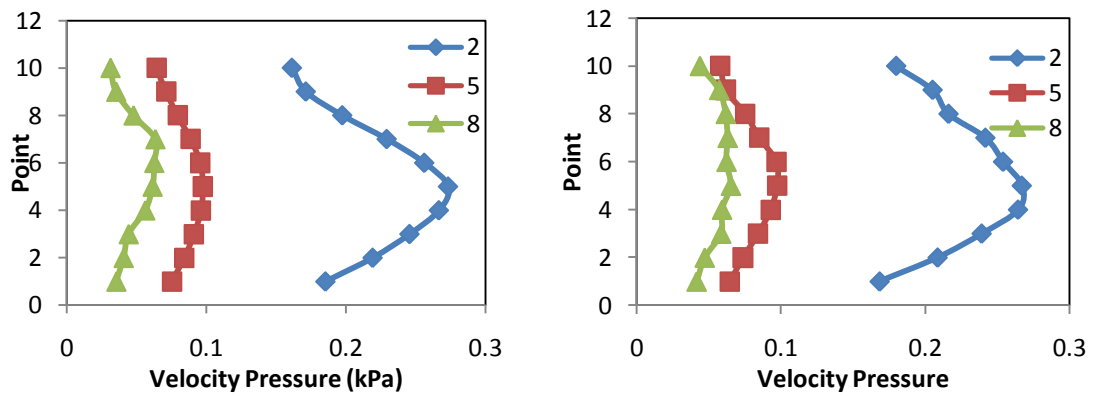
For circular 6 inches and smaller, 6 points per axis while for circular larger than 6 inches, 10 points per axis. The distributions of traverse points for circular ducts, as indicated are based on log-linear Pitot traverse method. The traverse points generated were analyzed to visualize the performance of each hood.

### **4.2.1 Normal data**

Figure 4.1, 4.2 and 4.3 show the traverse points for normal data test 1, 2 and 3 respectively.

#### Test 1

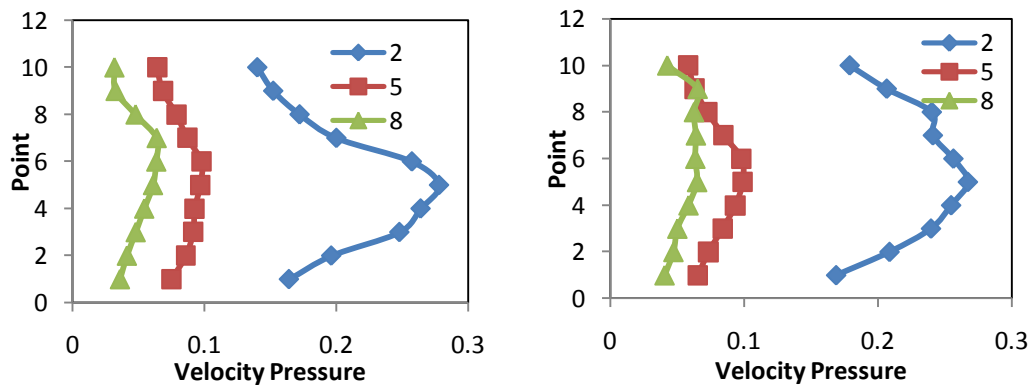
Figure 4.1 shows some air flow patterns that could develop after a disturbance and the resulting difficulties in obtaining good reliable measures are evident.



**Figure 4.1** Traverse point in (a) vertical and (b) horizontal axis

As compared to figure 9-11 in ACGIH Book in 1998, traverse points in figure 4.1 is a good VP distribution which passes the requirement. It is also satisfactory for flow into fan inlets but may be unsatisfactory for flow into inlet boxes as it may produce swirl in boxes. Out of 3 points, Duct number 2 have the largest velocity pressure with a peak measurement of 0.27 kPa.

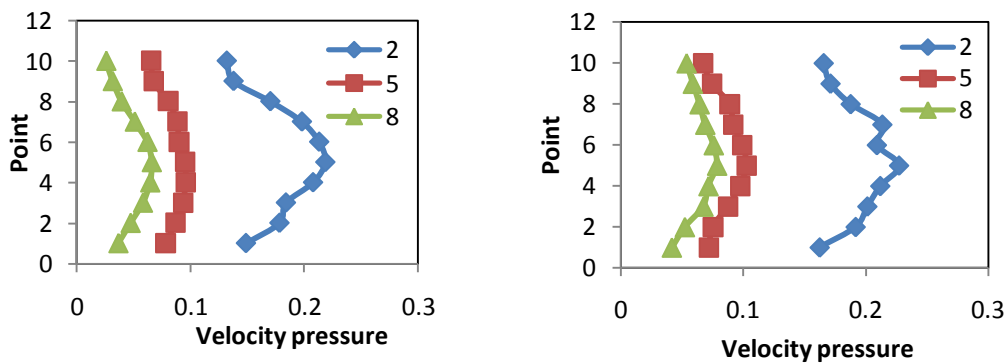
## Test 2



**Figure 4.2** Traverse point in (a) vertical and (b) horizontal axis

Figure 4.2 shows some air flow patterns that are similar to the previous test that could develop after a disturbance and the resulting difficulties in obtain ingood reliable measures are evident. As compared to figure in ACGIH Book in 1998, the figure shows that it is good VP distribution. For Test 2, the highest velocity pressure was also 0.27 kPa.

### Test 3



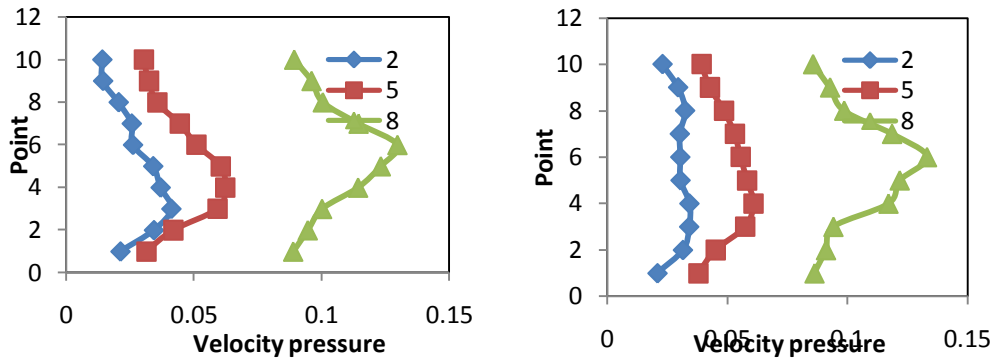
**Figure 4.3** Traverse point in (a) vertical and (b) horizontal axis

Figure 4.3 shows some air flow patterns that are good VP distribution. It could develop after a disturbance and the resulting difficulties in obtaining good reliable measures are evident. The peak velocity pressure for test 3 is 0.22 kPa and both horizontal and vertical gives acceptable readings.

### **4.2.2 Abnormal Data**

Figure 4.4, 4.5 and 4.6 show the traverse points for abnormal data test 1, 2 and 3 respectively.

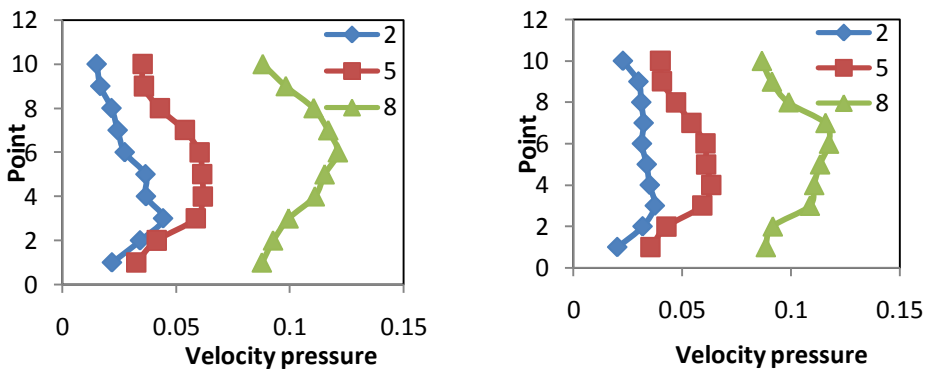
Test 1



**Figure 4.4** Traverse point in (a) vertical and (b) horizontal axis

As compared to figure in ACGIH Book in 1998, the figure shows that it is good VP distribution. It is also satisfactory for flow into fan inlets. From figure 4.4, for the abnormal data, duct number 8 have the largest velocity pressure, with a maximum reading at 0.13 kPa.

Test 2

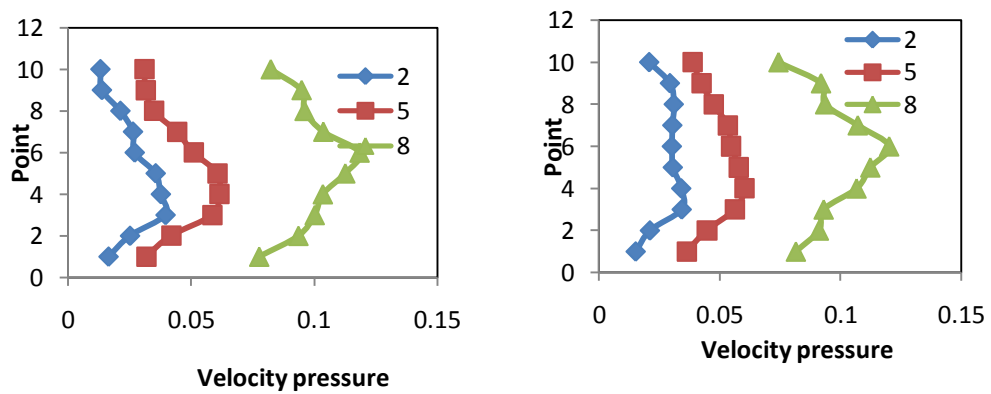


**Figure 4.5** Traverse point in (a) vertical and (b) horizontal axis

Figure 4.5 shows some air flow patterns that could develop after a disturbance and the resulting difficulties in obtaining good reliable measures are

evident, where the pattern were similar to the test before. As compared to figure in ACGIH Book in 1998, the figure also shows that it is good VP distribution. For test 2, the velocity pressure consist maximal value of 0.12 kPa.

Test 3



**Figure 4.6** Traverse point in (a) vertical and (b) horizontal axis

Figure 4.6 shows some air flow patterns that were similar to the previous tests, which could develop after a disturbance and the resulting difficulties in obtaining good reliable measures are evident. As compared to figure in ACGIH Book in 1998, the figure shows that it is good VP distribution. It has a peak velocity pressure of 0.12 kPa.

### **4.3 MD Data**

#### **4.3.1 Normal Group**

The MD can be used to minimize the number of variables required to forecast the performance of a system. The objective of the MD analysis for LEV is to explain the relationship between performances of LEV and face velocity as described by experiments. The purpose is to provide an understanding of the relationship between LEV performance and face velocity. This relationship will offer an opportunity to efficiently improve the performance. The first step in performing MD is analyzed a normal group as the Mahalanobis space. Basically, it is very rare to have a normal data of MD value greater than 5.0.

The LEV performances consisted of 11 test sets and 16 variables on each test. A comparison to ACGIH using the measured data satisfaction rating for the 11 data sets was made to select the normal group. Then, 8 samples were selected for the normal group. The samples were selected as the largest grouping of samples. 3 samples that fell outside of the normal group are selected as the abnormal group. The data for the normal is provided in table 4.1 below and MD was then calculated. Table 4.2, 4.3 and 4.4 are normalized data, correlation matrix and inverse matrix respectively for each sample from the normal group.

**Table 4.1** Data for Normal Group

<b>SAMPLE</b>	<b>P1</b>	<b>P2</b>	<b>P3</b>	<b>P4</b>	<b>P5</b>	<b>P6</b>	<b>P7</b>	<b>P8</b>	<b>P9</b>	<b>P10</b>	<b>P11</b>	<b>P12</b>	<b>P13</b>	<b>P14</b>	<b>P15</b>	<b>P16</b>
<b>1</b>	504	465	508	420	490	431	379	419	463	422	341	398	385	433	303	385
<b>2</b>	496	473	501	422	499	437	368	410	471	426	329	404	382	431	321	368
<b>3</b>	460	497	481	454	451	438	430	421	434	401	381	381	352	423	318	381
<b>4</b>	447	471	411	387	422	435	372	386	396	404	338	398	356	402	351	385
<b>5</b>	501	478	499	418	491	428	362	422	465	414	338	392	375	422	318	371
<b>6</b>	442	492	521	450	406	457	446	421	370	454	291	412	337	437	318	364
<b>7</b>	427	501	477	442	427	466	451	408	364	448	314	416	356	421	326	375
<b>8</b>	436	498	479	438	443	461	448	417	371	451	323	409	332	420	314	363
<b>SUM</b>	3713	3875	3877	3431	3629	3553	3256	3304	3334	3420	2655	3210	2875	3389	2569	2992
<b>AVRG</b>	464	484	485	429	454	444	407	413	417	428	332	401	359	424	321	374
<b>STDVTN</b>	31	14	34	22	36	15	40	12	47	21	26	12	20	11	14	9



**Table 4.2** Normalized Data for normal Group

<b>SAMPLE</b>	<b>P1</b>	<b>P2</b>	<b>P3</b>	<b>P4</b>	<b>P5</b>	<b>P6</b>	<b>P7</b>	<b>P8</b>	<b>P9</b>	<b>P10</b>	<b>P11</b>	<b>P12</b>	<b>P13</b>	<b>P14</b>	<b>P15</b>	<b>P16</b>
<b>1</b>	1.27	-1.37	0.70	-0.41	1.02	-0.89	-0.70	0.49	0.99	-0.26	0.35	-0.28	1.30	0.87	-1.31	1.23
<b>2</b>	1.01	-0.80	0.49	-0.32	1.27	-0.48	-0.97	-0.25	1.16	-0.07	-0.11	0.24	1.14	0.68	-0.01	-0.67
<b>3</b>	-0.13	0.87	-0.10	1.16	-0.07	-0.39	0.58	0.68	0.38	-1.24	1.91	-1.78	-0.37	-0.03	-0.25	0.78
<b>4</b>	-0.54	-0.94	-2.20	-1.92	-0.89	-0.62	-0.87	-2.23	-0.45	-1.11	0.24	-0.28	-0.17	-2.01	2.17	1.23
<b>5</b>	1.17	-0.45	0.43	-0.50	1.05	-1.09	-1.12	0.74	1.03	-0.64	0.24	-0.80	0.79	-0.15	-0.22	-0.34
<b>6</b>	-0.70	0.54	1.08	0.96	-1.34	0.87	0.97	0.66	-1.00	1.25	-1.58	0.94	-1.13	1.24	-0.22	-1.12
<b>7</b>	-1.18	1.18	-0.23	0.60	-0.75	1.48	1.10	-0.42	-1.13	0.97	-0.69	1.28	-0.17	-0.25	0.36	0.11
<b>8</b>	-0.89	0.97	-0.17	0.42	-0.30	1.14	1.02	0.33	-0.98	1.11	-0.34	0.68	-1.38	-0.34	-0.51	-1.23

**Table 4.3** Correlation Matrix

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>	<i>Column 9</i>	<i>Column 10</i>	<i>Column 11</i>	<i>Column 12</i>	<i>Column 13</i>	<i>Column 14</i>	<i>Column 15</i>	<i>Column 16</i>
<i>Column 1</i>	1	-0.76	0.39	-0.33	0.91	-0.84	-0.81	0.30	0.97	-0.49	0.35	-0.49	0.87	0.35	-0.41	0.21
<i>Column 2</i>	-0.76	1	0.09	0.78	-0.57	0.81	0.91	0.30	-0.69	0.51	-0.15	0.28	-0.77	0.04	-0.08	-0.45
<i>Column 3</i>	0.39	0.09	1	0.61	0.36	0.07	0.15	0.87	0.28	0.43	-0.27	0.14	0.18	0.96	-0.86	-0.49
<i>Column 4</i>	-0.33	0.78	0.61	1	-0.23	0.57	0.79	0.73	-0.29	0.48	-0.08	0.12	-0.45	0.60	-0.57	-0.44
<i>Column 5</i>	0.91	-0.57	0.36	-0.23	1	-0.67	-0.69	0.32	0.92	-0.38	0.41	-0.41	0.83	0.29	-0.47	0.10
<i>Column 6</i>	-0.84	0.81	0.07	0.57	-0.67	1	0.90	0.05	-0.87	0.85	-0.60	0.77	-0.73	0.09	-0.01	-0.53
<i>Column 7</i>	-0.81	0.91	0.15	0.79	-0.69	0.90	1	0.28	-0.80	0.66	-0.31	0.44	-0.81	0.18	-0.17	-0.38
<i>Column 8</i>	0.30	0.30	0.87	0.73	0.32	0.05	0.28	1	0.24	0.26	0.04	-0.15	-0.01	0.77	-0.90	-0.41
<i>Column 9</i>	0.97	-0.69	0.28	-0.29	0.92	-0.87	-0.80	0.24	1	-0.63	0.54	-0.63	0.86	0.25	-0.33	0.29
<i>Column 10</i>	-0.49	0.51	0.43	0.48	-0.38	0.85	0.66	0.26	-0.63	1	-0.84	0.89	-0.48	0.43	-0.30	-0.72
<i>Column 11</i>	0.35	-0.15	-0.27	-0.08	0.41	-0.60	-0.31	0.04	0.54	-0.84	1	-0.91	0.31	-0.29	-0.03	0.62
<i>Column 12</i>	-0.49	0.28	0.14	0.12	-0.41	0.77	0.44	-0.15	-0.63	0.89	-0.91	1	-0.32	0.18	0.04	-0.53
<i>Column 13</i>	0.87	-0.77	0.18	-0.45	0.83	-0.73	-0.81	-0.01	0.86	-0.48	0.31	-0.32	1	0.18	-0.18	0.43
<i>Column 14</i>	0.35	0.04	0.96	0.60	0.29	0.09	0.18	0.77	0.25	0.43	-0.29	0.18	0.18	1	-0.81	-0.41
<i>Column 15</i>	-0.41	-0.08	-0.86	-0.57	-0.47	-0.01	-0.17	-0.90	-0.33	-0.30	-0.03	0.04	-0.18	-0.81	1	0.27
<i>Column 16</i>	0.21	-0.45	-0.49	-0.44	0.10	-0.53	-0.38	-0.41	0.29	-0.72	0.62	-0.53	0.43	-0.41	0.27	1

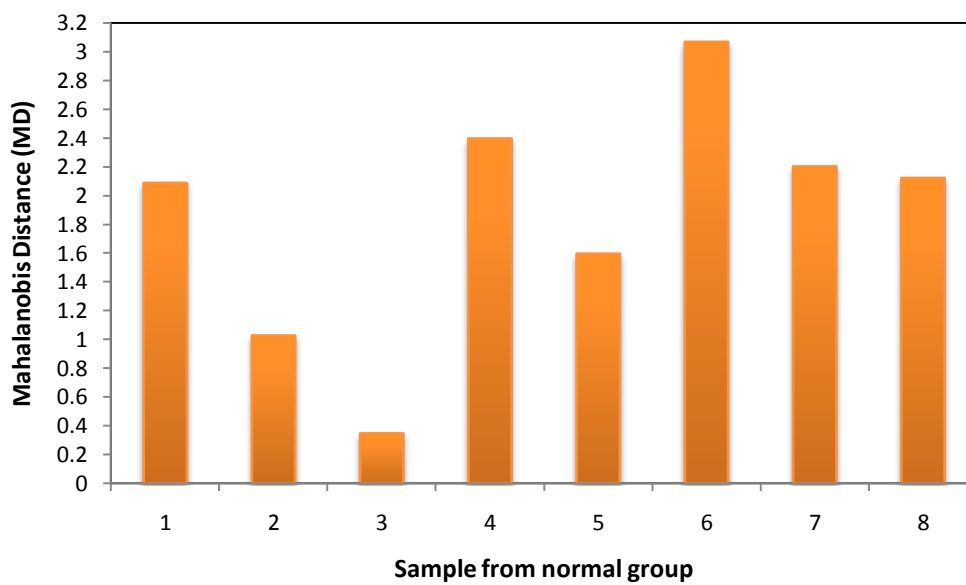
**Table 4.4** Inverse Matrix

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>	<i>Column 9</i>	<i>Column 10</i>	<i>Column 11</i>	<i>Column 12</i>	<i>Column 13</i>	<i>Column 14</i>	<i>Column 15</i>	<i>Column n 16</i>
<i>Column 1</i>	0.42	-0.34	0.08	-0.19	0.38	-0.40	-0.37	0.06	0.42	-0.29	0.22	-0.27	0.38	0.07	-0.11	0.17
<i>Column 2</i>	-0.34	0.35	0.04	0.27	-0.30	0.37	0.38	0.07	-0.35	0.30	-0.20	0.23	-0.35	0.04	-0.01	-0.22
<i>Column 3</i>	0.08	0.04	0.24	0.15	0.08	0.04	0.05	0.22	0.05	0.12	-0.07	0.05	0.02	0.22	-0.21	-0.14
<i>Column 4</i>	-0.19	0.27	0.15	0.27	-0.16	0.27	0.29	0.17	-0.20	0.25	-0.15	0.16	-0.23	0.15	-0.13	-0.21
<i>Column 5</i>	0.38	-0.30	0.08	-0.16	0.35	-0.36	-0.33	0.07	0.38	-0.25	0.20	-0.24	0.34	0.07	-0.11	0.15
<i>Column 6</i>	-0.40	0.37	0.04	0.27	-0.36	0.45	0.42	0.04	-0.42	0.38	-0.29	0.33	-0.39	0.04	0.01	-0.26
<i>Column 7</i>	-0.37	0.38	0.05	0.29	-0.33	0.42	0.41	0.07	-0.39	0.35	-0.24	0.27	-0.38	0.06	-0.02	-0.24
<i>Column 8</i>	0.06	0.07	0.22	0.17	0.07	0.04	0.07	0.22	0.04	0.10	-0.03	0.01	-0.01	0.20	-0.21	-0.12
<i>Column 9</i>	0.42	-0.35	0.05	-0.20	0.38	-0.42	-0.39	0.04	0.43	-0.33	0.26	-0.30	0.39	0.04	-0.09	0.20
<i>Column 10</i>	-0.29	0.30	0.12	0.25	-0.25	0.38	0.35	0.10	-0.33	0.38	-0.30	0.32	-0.30	0.13	-0.07	-0.28
<i>Column 11</i>	0.22	-0.20	-0.07	-0.15	0.20	-0.29	-0.24	-0.03	0.26	-0.30	0.27	-0.28	0.22	-0.08	0.02	0.22
<i>Column 12</i>	-0.27	0.23	0.05	0.16	-0.24	0.33	0.27	0.01	-0.30	0.32	-0.28	0.30	-0.25	0.05	0.01	-0.22
<i>Column 13</i>	0.38	-0.35	0.02	-0.23	0.34	-0.39	-0.38	-0.01	0.39	-0.30	0.22	-0.25	0.37	0.01	-0.05	0.20
<i>Column 14</i>	0.07	0.04	0.22	0.15	0.07	0.04	0.06	0.20	0.04	0.13	-0.08	0.05	0.01	0.21	-0.20	-0.14
<i>Column 15</i>	-0.11	-0.01	-0.21	-0.13	-0.11	0.01	-0.02	-0.21	-0.09	-0.07	0.02	0.01	-0.05	-0.20	0.21	0.10
<i>Column 16</i>	0.17	-0.22	-0.14	-0.21	0.15	-0.26	-0.24	-0.12	0.20	-0.28	0.22	-0.22	0.20	-0.14	0.10	0.24

Table 4.5 shows the resulting MD value for each sample from the normal group. The distributions of MD for samples from the normal group were plotted in Figure 4.7.

**Table 4.5** MDs for the Normal Group

SAMPLE	MD
1	2.0880
2	1.0269
3	0.3462
4	2.3967
5	1.5956
6	3.0687
7	2.2022
8	2.1221



**Figure 4.7** Mahalanobis Distance for Normal Group

### **4.3.2 Abnormal Group**

Data on 16 variables for samples was gathered from outside the normal group. 3 samples were collected as the abnormal group. An MD for an abnormal sample should become much larger than the normal data and usually is more than 5.0. The data for the abnormal is provided in table 4.6 below. The MD was then calculated using the data for the abnormal group. Table 4.7, 4.8 and 4.9 are normalized data, correlation matrix and inverse matrix respectively for each sample from the abnormal group.

**Table 4.6** Data for Abnormal Group

<b>SAMPLE</b>	<b>P1</b>	<b>P2</b>	<b>P3</b>	<b>P4</b>	<b>P5</b>	<b>P6</b>	<b>P7</b>	<b>P8</b>	<b>P9</b>	<b>P10</b>	<b>P11</b>	<b>P12</b>	<b>P13</b>	<b>P14</b>	<b>P15</b>	<b>P16</b>
<b>1</b>	164	167	168	164	154	153	152	153	155	155	148	146	103	162	138	153
<b>2</b>	160	161	163	150	148	158	141	143	150	157	146	132	127	154	130	143
<b>3</b>	161	162	161	162	152	152	150	154	152	151	149	147	101	157	136	152
<b>SUM</b>	485	490	492	476	454	463	443	450	457	463	443	425	331	473	404	448
<b>AVG</b>	161.67	163.33	164.00	158.67	151.33	154.33	147.67	150.00	152.33	154.33	147.67	141.67	110.33	157.67	134.67	149.33
<b>STDVTN</b>	2.08	3.21	3.61	7.57	3.06	3.21	5.86	6.08	2.52	3.06	1.53	8.39	14.47	4.04	4.16	5.51

**Table 4.7** Normalized Data for abnormal group

<b>SAMPLE</b>	<b>P1</b>	<b>P2</b>	<b>P3</b>	<b>P4</b>	<b>P5</b>	<b>P6</b>	<b>P7</b>	<b>P8</b>	<b>P9</b>	<b>P10</b>	<b>P11</b>	<b>P12</b>	<b>P13</b>	<b>P14</b>	<b>P15</b>	<b>P16</b>
<b>1</b>	1.12	1.14	1.11	0.70	0.87	-0.41	0.74	0.49	1.06	0.22	0.22	0.52	-0.51	1.07	0.80	0.67
<b>2</b>	-0.80	-0.73	-0.28	-1.14	-1.09	1.14	-1.14	-1.15	-0.93	0.87	-1.09	-1.15	1.15	-0.91	-1.12	-1.15
<b>3</b>	-0.32	-0.41	-0.83	0.44	0.22	-0.73	0.40	0.66	-0.13	-1.09	0.87	0.64	-0.65	-0.16	0.32	0.48

**Table 4.8** Correlation Matrix

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>	<i>Column 9</i>	<i>Column 10</i>	<i>Column 11</i>	<i>Column 12</i>	<i>Column 13</i>	<i>Column 14</i>	<i>Column 15</i>	<i>Column 16</i>
<i>Column 1</i>	1	0.996	0.866	0.782	0.891	-0.573	0.81	0.63	0.99	-0.05	0.42	0.65	-0.64	0.99	0.85	0.76
<i>Column 2</i>	0.996	1	0.906	0.726	0.849	-0.500	0.75	0.56	0.97	0.03	0.34	0.58	-0.57	0.98	0.80	0.70
<i>Column 3</i>	0.866	0.906	1	0.366	0.545	-0.086	0.402	0.160	0.771	0.454	-0.091	0.182	-0.173	0.789	0.466	0.327
<i>Column 4</i>	0.782	0.726	0.366	1	0.980	-0.959	0.999	0.977	0.875	-0.663	0.893	0.982	-0.980	0.861	0.994	0.999
<i>Column 5</i>	0.891	0.849	0.545	0.980	1	-0.882	0.987	0.915	0.954	-0.500	0.786	0.924	-0.920	0.945	0.996	0.971
<i>Column 6</i>	-0.573	-0.500	-0.086	-0.959	-0.882	1	-0.947	-0.997	-0.700	0.849	-0.984	-0.995	0.996	-0.680	-0.922	-0.970
<i>Column 7</i>	0.806	0.752	0.402	0.999	0.987	-0.947	1	0.968	0.893	-0.633	0.875	0.973	-0.971	0.880	0.997	0.997
<i>Column 8</i>	0.632	0.563	0.160	0.977	0.915	-0.997	0.968	1	0.751	-0.807	0.969	1.000	-1.000	0.732	0.948	0.985
<i>Column 9</i>	0.986	0.968	0.771	0.875	0.954	-0.700	0.893	0.751	1	-0.217	0.564	0.766	-0.760	1.000	0.923	0.854
<i>Column 10</i>	-0.052	0.034	0.454	-0.663	-0.500	0.849	-0.633	-0.807	-0.217	1	-0.929	-0.794	0.799	-0.189	-0.577	-0.693
<i>Column 11</i>	0.419	0.339	-0.091	0.893	0.786	-0.984	0.875	0.969	0.564	-0.929	1	0.963	-0.965	0.540	0.839	0.911
<i>Column 12</i>	0.649	0.581	0.182	0.982	0.924	-0.995	0.973	1.000	0.766	-0.794	0.963	1	-0.99995	0.747	0.955	0.989
<i>Column 13</i>	-0.642	-0.573	-0.173	-0.980	-0.920	0.996	-0.971	-1.000	-0.760	0.799	-0.965	-0.99995	1	-0.741	-0.952	-0.987
<i>Column 14</i>	0.991	0.975	0.789	0.861	0.945	-0.680	0.880	0.732	1.000	-0.189	0.540	0.747	-0.741	1	0.911	0.839
<i>Column 15</i>	0.846	0.797	0.466	0.994	0.996	-0.922	0.997	0.948	0.923	-0.577	0.839	0.955	-0.952	0.911	1	0.989
<i>Column 16</i>	0.756	0.697	0.327	0.999	0.971	-0.970	0.997	0.985	0.854	-0.693	0.911	0.989	-0.987	0.839	0.989	1



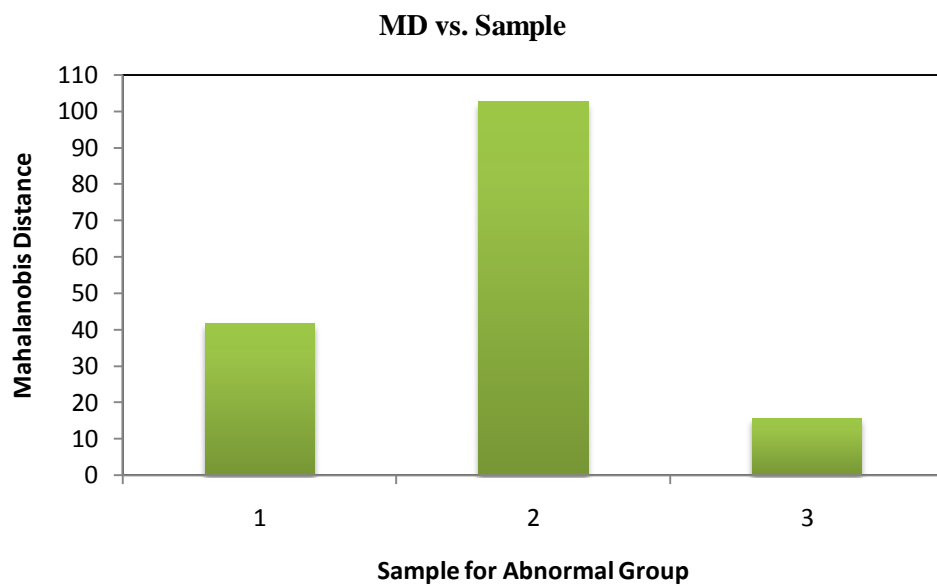
**Table 4.9** Inverse Matrix for abnormal group

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>	<i>Column 9</i>	<i>Column 10</i>	<i>Column 11</i>	<i>Column 12</i>	<i>Column 13</i>	<i>Column 14</i>	<i>Column 15</i>	<i>Column 16</i>
<i>Column 1</i>	0.27	0.25	0.14	0.33	0.33	-0.31	0.33	0.32	0.30	-0.20	0.29	0.32	-0.32	0.29	0.33	0.33
<i>Column 2</i>	0.25	0.24	0.14	0.30	0.30	-0.27	0.30	0.28	0.27	-0.17	0.25	0.28	-0.28	0.27	0.30	0.29
<i>Column 3</i>	0.14	0.14	0.13	0.10	0.11	-0.06	0.10	0.07	0.13	0.01	0.04	0.08	-0.08	0.13	0.11	0.09
<i>Column 4</i>	0.33	0.30	0.10	0.49	0.46	-0.50	0.49	0.50	0.39	-0.39	0.48	0.50	-0.50	0.38	0.48	0.50
<i>Column 5</i>	0.33	0.30	0.11	0.46	0.44	-0.46	0.46	0.47	0.38	-0.35	0.44	0.47	-0.47	0.37	0.46	0.47
<i>Column 6</i>	-0.31	-0.27	-0.06	-0.50	-0.46	0.51	-0.49	-0.51	-0.37	0.42	-0.50	-0.51	0.51	-0.36	-0.48	-0.50
<i>Column 7</i>	0.33	0.30	0.10	0.49	0.46	-0.49	0.49	0.50	0.39	-0.39	0.47	0.50	-0.50	0.38	0.48	0.49
<i>Column 8</i>	0.32	0.28	0.07	0.50	0.47	-0.51	0.50	0.51	0.38	-0.42	0.50	0.51	-0.51	0.37	0.48	0.50
<i>Column 9</i>	0.30	0.27	0.13	0.39	0.38	-0.37	0.39	0.38	0.33	-0.26	0.35	0.38	-0.38	0.33	0.38	0.39
<i>Column 10</i>	-0.20	-0.17	0.01	-0.39	-0.35	0.42	-0.39	-0.42	-0.26	0.39	-0.43	-0.42	0.42	-0.25	-0.37	-0.40
<i>Column 11</i>	0.29	0.25	0.04	0.48	0.44	-0.50	0.47	0.50	0.35	-0.43	0.49	0.50	-0.50	0.34	0.46	0.49
<i>Column 12</i>	0.32	0.28	0.08	0.50	0.47	-0.51	0.50	0.51	0.38	-0.42	0.50	0.51	-0.51	0.37	0.48	0.51
<i>Column 13</i>	-0.32	-0.28	-0.08	-0.50	-0.47	0.51	-0.50	-0.51	-0.38	0.42	-0.50	-0.51	0.51	-0.37	-0.48	-0.51
<i>Column 14</i>	0.29	0.27	0.13	0.38	0.37	-0.36	0.38	0.37	0.33	-0.25	0.34	0.37	-0.37	0.32	0.38	0.38
<i>Column 15</i>	0.33	0.30	0.11	0.48	0.46	-0.48	0.48	0.48	0.38	-0.37	0.46	0.48	-0.48	0.38	0.47	0.48
<i>Column 16</i>	0.33	0.29	0.09	0.50	0.47	-0.50	0.49	0.50	0.39	-0.40	0.49	0.51	-0.51	0.38	0.48	0.50

Table 4.11 shows the resulting MD value for each sample from the abnormal group. The distributions of MD for samples from the abnormal group were plotted in Figure 4.8.

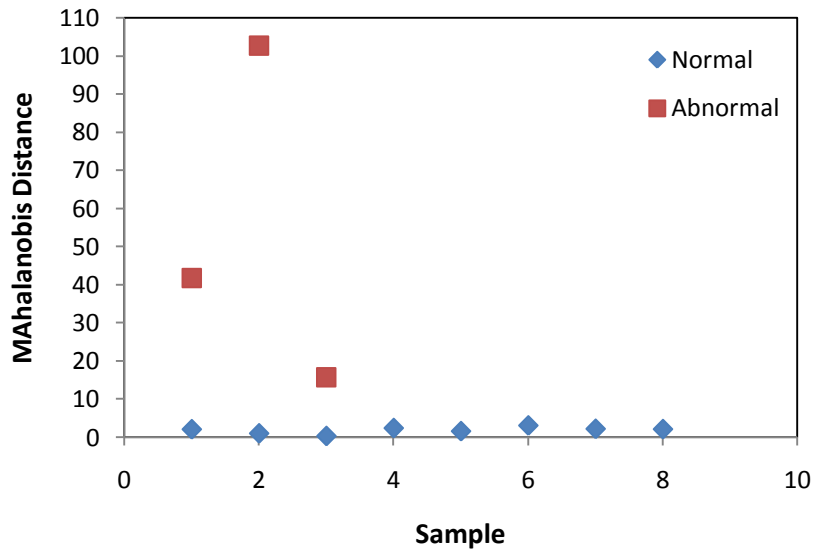
**Table 4.10** MDs for the Abnormal Group

SAMPLE	MD
1	41.6085
2	102.5828
3	15.6583



**Figure 4.8** Mahalanobis Distance for Abnormal Group

From the MD of normal group and abnormal group, the discrimination power is evaluated. From figure 4.9, the discrimination power is very good. In some studies it may be sufficient to have an MTS that can discriminate x percent of bad samples. After confirming a good discrimination, the data is optimized.



**Figure 4.9** Discrimination Power

For optimization of MTS, orthogonal arrays (OA) and signal to noise array (SN) are convenient to distinguish which attributes are important. Each factor is accredited to a column in the OA where every row represents the experiment combination of a run. A two level OA is used to express inclusive and exclusive. In a two level OA, 1 illustrates the level that corresponds to presence of a variable and 2 indicate the level that corresponds to the absence of the variable. The respective attribute will be used or ignored with respect to the OA and the *SN* ratio is calculated.

The proper orthogonal array can be selected by knowing the number of variables and the number of levels. The appropriate array can be found by looking at

the column and row corresponding to the number of parameters and number of levels. These arrays were created using an algorithm Taguchi developed, and allows for each variable and setting to be tested equally

There are various different types of SN ratio. However, MTS uses the larger the better which is also known as dynamic SN ratio. SN ratio is characterized as the measure of accuracy of prediction of the scale. It displays the severity of the abnormalities and the dissimilarity of the average SN values of every attribute when it is included and excluded. The way to judge is as follows:

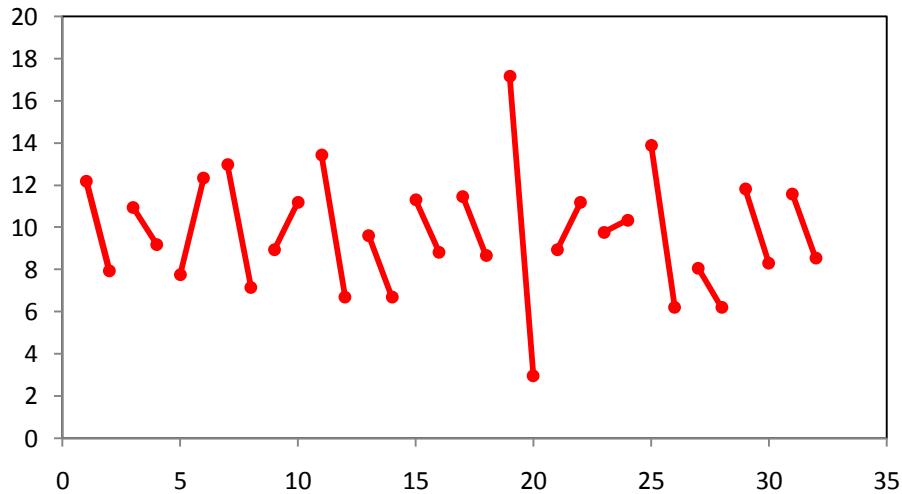
- 1) If SN value for a variable in level 2 is more than in 1 i.e. the variable is not used, then the discriminative power increases.
- 2) If SN value for a variable in level 1 is more than in 2 i.e. the variable is used, then the discriminative power increases.
- 3) If SN value for a variable in level 1 is equal to what in 1, it has no effect on the discriminative power.

**Table 4.11**L12 Orthogonal Array and SNRatio (Two level orthogonal arrays)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16
L1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
L2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
L3	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1
L4	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
L5	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	1
L6	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	2
L7	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1
L8	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	2
L9	1	2	2	1	1	2	2	1	1	2	2	2	1	1	2	1
L10	1	2	2	1	1	2	2	1	1	2	2	2	1	1	2	2
L11	1	2	2	1	1	2	2	2	2	1	1	2	2	2	1	1
L12	1	2	2	1	1	2	2	2	2	1	1	2	2	2	1	2
L13	1	2	2	2	2	1	1	1	1	2	2	2	2	2	1	1
L14	1	2	2	2	2	1	1	1	1	2	2	2	2	2	1	2
L15	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	1
L16	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	2
L17	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
L18	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	2
L19	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	1
L20	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	2
L21	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	1
L22	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	2
L23	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	1
L24	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	2
L25	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1
L26	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2
L27	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	1
L28	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	2
L29	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	1
L30	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	2
L31	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	1
L32	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	2

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16
L1	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use
L2	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	Use	
L3	Use	Use	Use	Use	Use	Use	Use									Use
L4	Use	Use	Use	Use	Use	Use	Use									
L5	Use	Use	Use					Use	Use	Use	Use					Use
L6	Use	Use	Use					Use	Use	Use	Use					
L7	Use	Use	Use									Use	Use	Use	Use	Use
L8	Use	Use	Use									Use	Use	Use	Use	
L9	Use			Use	Use			Use	Use			Use	Use			Use
L10	Use			Use	Use			Use	Use			Use	Use			
L11	Use			Use	Use					Use	Use			Use	Use	Use
L12	Use			Use	Use					Use	Use			Use	Use	
L13	Use					Use	Use	Use	Use					Use	Use	Use
L14	Use					Use	Use	Use	Use					Use	Use	
L15	Use					Use	Use			Use	Use	Use	Use			Use
L16	Use					Use	Use			Use	Use	Use	Use			
L17		Use		Use		Use		Use		Use		Use		Use		Use
L18		Use		Use		Use		Use		Use		Use		Use		
L19		Use		Use		Use			Use		Use		Use		Use	Use
L20		Use		Use		Use			Use		Use		Use		Use	
L21		Use			Use		Use	Use		Use			Use		Use	Use
L22		Use			Use		Use	Use		Use			Use		Use	
L23		Use			Use		Use		Use		Use	Use		Use		Use
L24		Use			Use		Use		Use		Use	Use		Use		
L25			Use	Use			Use	Use			Use	Use			Use	Use
L26			Use	Use			Use	Use			Use	Use			Use	
L27			Use	Use			Use		Use	Use			Use	Use		Use
L28			Use	Use			Use		Use	Use			Use	Use		
L29			Use		Use	Use		Use			Use		Use	Use		Use
L30			Use		Use	Use		Use			Use		Use	Use		
L31			Use		Use	Use			Use	Use		Use			Use	Use
L32			Use		Use	Use			Use	Use		Use			Use	

#### 4.4 Response Graph of S/N Ratio



**Figure 4.10** Response Graph of S/N Ratio for MTS Optimization

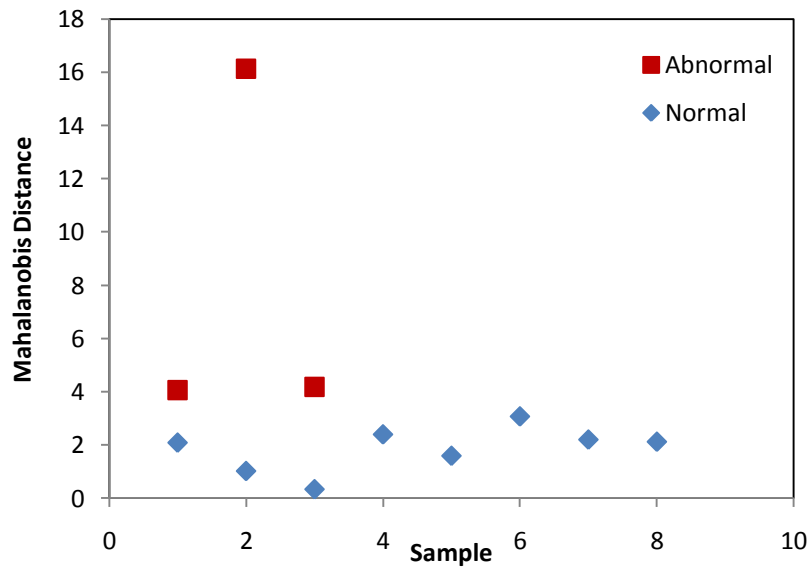
For the respective experiment, the signal-to-noise (S/N) ratio is calculated in the Orthogonal Array. S/N ratios are used in measuring the outcome of a factor which includes or excludes in the calculation of the MTS. The S/N ratio is an expression of the propagation of variation. The S/N ratio, acquired from the test MDs, is used as the response for each combination of orthogonal array.

Based on the signal-to-noise ratios calculated using the runs in the orthogonal array, calculations of tables regarding to the obtained S/N ratios are organized to determine the beneficial variables and recognize the candidate variables for elimination. For the calculation of the MTS, it is usually suggested to use the larger-the-better S/N ratio type, where the systems have better impact of the corresponding variable with the larger number of S/N ratio in the positive direction.

The favourable set of variables is determined by using signal-to-noise and ratio and orthogonal arrays. From Figure 4.10, the effective set of variables from

level 1 that have better S/N ratio compared to level 2 is  $X_1$ ,  $X_4$ ,  $X_6$ ,  $X_{10}$  and  $X_{13}$ . From this it can be concluded that discrimination has improve and it only requires these 5 points as the variables which contributes significantly to discrimination while the other points other than that will be discarded as they does not or are harming the discrimination.

#### 4.6 Confirmation of Result



**Figure 4.11** Discrimination power for result confirmation

In order to test the effectiveness of the MTS model obtained, the discrimination power by using the optimum design is plotted. From Figure 4.11, it shows that by using only  $X_1$ ,  $X_4$ ,  $X_6$ ,  $X_{10}$  and  $X_{13}$ , a better value for MD can be obtained. The number of useful variables was reduced from sixteen variables to five variables. By eliminating insignificant variables, we can reduce the time taken in measuring the efficiency and performance of the LEV, which comply with the initial objective of this research.



## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

The evaluation of performance of LEV is an essential tool in industrial area. In this paper, an improvement for checking the performance of LEV has been presented using the MD. The objectives of this thesis to obtain normal pattern operation of local exhaust ventilation (LEV) system and to characterize the pattern to study the performance of the above system are achieved. Despite the success of MD technique in pattern recognition, the results show that MD with its abnormality scale has a great capability in recognizing pattern of LEV. The results are satisfactory in comparison with traditional method. In fact computation using MD is a time-consuming operation because of matrix inversion, and because of the computation of the covariance matrix itself. Due to the linearization, the most important computational load is the computation of the covariance matrix. However, there is still a chance to continue the improvement of MD. It is recommended to obtain more raw data, in increasing the accuracy of the result and pattern of the MD. Further study can be conducted where the optimization points obtained can be checked on the LEV which can be applied to suitable industries.

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APPENDIX A: MTS CALCULATION FOR EACH LEVEL OF THE  
ORTHOGONAL ARRAY

**LEVEL 3**

**Abnormal Data**

SAMPLE	P1	P2	P3	P4	P5	P6	P7	P16
1	164	167	168	164	154	153	152	153
2	160	161	163	150	148	158	141	143
3	161	162	161	162	152	152	150	152

**Normalized Data**

SAMPLE	P1	P2	P3	P4	P5	P6	P7	P16
1	1.12	1.14	1.11	0.70	0.87	-0.41	0.74	0.67
2	-0.80	-0.73	-0.28	-1.14	-1.09	1.14	-1.14	-1.15
3	-0.32	-0.41	-0.83	0.44	0.22	-0.73	0.40	0.48

**Correlation Matrix**

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>
Column 1	1	1.00	0.87	0.78	0.89	-0.57	0.81	0.76
Column 2	1.00	1.00	0.91	0.73	0.85	-0.50	0.75	0.70
Column 3	0.87	0.91	1.00	0.37	0.54	-0.09	0.40	0.33
Column 4	0.78	0.73	0.37	1.00	0.98	-0.96	1.00	1.00
Column 5	0.89	0.85	0.54	0.98	1.00	-0.88	0.99	0.97
Column 6	-0.57	-0.50	-0.09	-0.96	-0.88	1.00	-0.95	-0.97
Column 7	0.81	0.75	0.40	1.00	0.99	-0.95	1.00	1.00
Column 8	0.76	0.70	0.33	1.00	0.97	-0.97	1.00	1.00

**Inverse Matrix**

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>
<b>Column 1</b>	0.24	0.22	0.13	0.28	0.28	-0.26	0.28	0.27
<b>Column 2</b>	0.22	0.21	0.13	0.25	0.25	-0.23	0.25	0.25
<b>Column 3</b>	0.13	0.13	0.12	0.10	0.11	-0.07	0.10	0.09
<b>Column 4</b>	0.28	0.25	0.10	0.39	0.38	-0.39	0.39	0.40
<b>Column 5</b>	0.28	0.25	0.11	0.38	0.36	-0.37	0.37	0.38
<b>Column 6</b>	-0.26	-0.23	-0.07	-0.39	-0.37	0.40	-0.39	-0.40
<b>Column 7</b>	0.28	0.25	0.10	0.39	0.37	-0.39	0.39	0.39
<b>Column 8</b>	0.27	0.25	0.09	0.40	0.38	-0.40	0.39	0.40

$ZA^{-1}$

<b>1.59</b>	<b>1.48</b>	<b>0.75</b>	<b>2.02</b>	<b>1.99</b>	<b>-1.94</b>	<b>2.02</b>	<b>2.02</b>
<b>-1.93</b>	-1.76	-0.76	-2.64	-2.54	2.60	-2.63	-2.65
<b>0.34</b>	0.28	0.01	0.62	0.56	-0.66	0.61	0.63

$ZA^{-1}Z^t$

<b>11.10</b>	<b>-13.87</b>	<b>2.77</b>
<b>-13.87</b>	17.83	-3.95
<b>2.77</b>	-3.95	1.19

**MD**

<b>11.10</b>	<b>17.83</b>	<b>1.19</b>
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#### LEVEL 4

##### Abnormal Data

SAMPLE	P1	P2	P3	P4	P5	P6	P7
1	164	167	168	164	154	153	152
2	160	161	163	150	148	158	141
3	161	162	161	162	152	152	150

##### Normalized Data

SAMPLE	P1	P2	P3	P4	P5	P6	P7
1	1.12	1.14	1.11	0.70	0.87	-0.41	0.74
2	-0.80	-0.73	-0.28	-1.14	-1.09	1.14	-1.14
3	-0.32	-0.41	-0.83	0.44	0.22	-0.73	0.40

##### Correlation Matrix

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Column 1	1	1.00	0.87	0.78	0.89	-0.57	0.81
Column 2	1.00	1.00	0.91	0.73	0.85	-0.50	0.75
Column 3	0.87	0.91	1.00	0.37	0.54	-0.09	0.40
Column 4	0.78	0.73	0.37	1.00	0.98	-0.96	1.00
Column 5	0.89	0.85	0.54	0.98	1.00	-0.88	0.99
Column 6	-0.57	-0.50	-0.09	-0.96	-0.88	1.00	-0.95
Column 7	0.81	0.75	0.40	1.00	0.99	-0.95	1

**Inverse Matrix**

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Column 1	0.27	0.25	0.15	0.31	0.31	-0.29	0.31
Column 2	0.25	0.24	0.15	0.28	0.29	-0.26	0.29
Column 3	0.15	0.15	0.13	0.12	0.14	-0.09	0.13
Column 4	0.31	0.28	0.12	0.43	0.41	-0.42	0.42
Column 5	0.31	0.29	0.14	0.41	0.40	-0.40	0.41
Column 6	-0.29	-0.26	-0.09	-0.42	-0.40	0.42	-0.42
Column 7	0.31	0.29	0.13	0.42	0.41	-0.42	0.42

**ZA<sup>-1</sup>**

<b>1.60</b>	<b>1.50</b>	<b>0.82</b>	<b>1.96</b>	<b>1.94</b>	<b>-1.84</b>	<b>1.96</b>
<b>-1.82</b>	-1.68	-0.81	-2.39	-2.32	2.31	-2.38
<b>0.22</b>	0.19	-0.01	0.43	0.38	-0.46	0.42

**ZA<sup>-1</sup>Z<sup>t</sup>**

<b>9.69</b>	<b>-11.28</b>	<b>1.59</b>
<b>-11.28</b>	13.51	-2.23
<b>1.59</b>	-2.23	0.64

**MD**

<b>9.69</b>	<b>13.51</b>	<b>0.64</b>
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**LEVEL 5**

**Abnormal Data**

SAMPLE	P1	P2	P3	P8	P9	P10	P11	P16
1	164	167	168	153	155	155	148	153
2	160	161	163	143	150	157	146	143
3	161	162	161	154	152	151	149	152

**Normalized Data**

SAMPLE	P1	P2	P3	P8	P9	P10	P11	P16
1	1.12	1.14	1.11	0.49	1.06	0.22	0.22	0.67
2	-0.80	-0.73	-0.28	-1.15	-0.93	0.87	-1.09	-1.15
3	-0.32	-0.41	-0.83	0.66	-0.13	-1.09	0.87	0.48

### Correlation Matrix

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Column 1	1	0.996	0.866	0.632	0.986	-0.052	0.419	0.756
Column 2	0.996	1	0.906	0.563	0.968	0.034	0.339	0.697
Column 3	0.87	0.91	1	0.160	0.771	0.454	-0.091	0.327
Column 4	0.63	0.56	0.160	1	0.751	-0.807	0.969	0.985
Column 5	0.99	0.97	0.771	0.751	1	-0.217	0.564	0.854
Column 6	-0.05	0.03	0.454	-0.807	-0.217	1	-0.929	-0.693
Column 7	0.42	0.34	-0.091	0.969	0.564	-0.929	1	0.911
Column 8	0.76	0.70	0.327	0.985	0.854	-0.693	0.911	1

### Inverse Matrix

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Column 1	0.12	0.11	0.08	0.11	0.12	-0.06	0.10	0.12
Column 2	0.11	0.11	0.09	0.09	0.11	-0.03	0.06	0.10
Column 3	0.08	0.09	0.14	-0.06	0.05	0.14	-0.10	-0.04
Column 4	0.11	0.09	-0.06	0.33	0.17	-0.33	0.34	0.30
Column 5	0.12	0.11	0.05	0.17	0.14	-0.12	0.16	0.17
Column 6	-0.06	-0.03	0.14	-0.33	-0.12	0.38	-0.37	-0.29
Column 7	0.10	0.06	-0.10	0.34	0.16	-0.37	0.37	0.31
Column 8	0.12	0.10	-0.04	0.30	0.17	-0.29	0.31	0.28

### $ZA^{-1}$

<b>0.62</b>	<b>0.59</b>	<b>0.34</b>	<b>0.70</b>	<b>0.68</b>	<b>-0.42</b>	<b>0.62</b>	<b>0.73</b>
<b>-0.74</b>	-0.61	0.14	-1.68	-0.99	1.60	-1.73	-1.58
<b>0.12</b>	0.02	-0.48	0.98	0.31	-1.17	1.11	0.86

### $ZA^{-1}Z^t$

<b>3.34</b>	<b>-4.33</b>	<b>0.99</b>
<b>-4.33</b>	8.94	-4.61
<b>0.99</b>	-4.61	3.62

### MD

<b>3.338</b>	<b>8.944</b>	<b>3.624</b>
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## LEVEL 6

### Abnormal Data

SAMPLE	P1	P2	P3	P8	P9	P10	P11
1	164	167	168	153	155	155	148
2	160	161	163	143	150	157	146
3	161	162	161	154	152	151	149

### Normalized Data

SAMPLE	P1	P3	P5	P7	P9	P11	P13
1	1.12	1.14	1.11	0.49	1.06	0.22	0.22
2	-0.80	-0.73	-0.28	-1.15	-0.93	0.87	-1.09
3	-0.32	-0.41	-0.83	0.66	-0.13	-1.09	0.87

### Correlation Matrix

	<i>Column</i> 1	<i>Column</i> 2	<i>Column</i> 3	<i>Column</i> 4	<i>Column</i> 5	<i>Column</i> 6	<i>Column</i> 7
Column 1	1	0.996	0.87	0.63	0.99	-0.05	0.42
Column 2	0.996	1	0.91	0.56	0.97	0.03	0.34
Column 3	0.87	0.91	1	0.16	0.77	0.45	-0.09
Column 4	0.63	0.56	0.16	1	0.75	-0.81	0.97
Column 5	0.99	0.97	0.77	0.75	1	-0.22	0.56
Column 6	-0.05	0.03	0.45	-0.81	-0.22	1	-0.93
Column 7	0.42	0.34	-0.09	0.97	0.56	-0.93	1

### Inverse Matrix

	<i>Column</i> 1	<i>Column</i> 2	<i>Column</i> 3	<i>Column</i> 4	<i>Column</i> 5	<i>Column</i> 6	<i>Column</i> 7
Column 1	0.13	0.13	0.09	0.13	0.14	-0.06	0.11
Column 2	0.13	0.13	0.10	0.10	0.13	-0.03	0.07
Column 3	0.09	0.10	0.15	-0.06	0.06	0.14	-0.09
Column 4	0.13	0.10	-0.06	0.34	0.18	-0.34	0.36
Column 5	0.14	0.13	0.06	0.18	0.16	-0.13	0.17
Column 6	-0.06	-0.03	0.14	-0.34	-0.13	0.39	-0.38
Column 7	0.11	0.07	-0.09	0.36	0.17	-0.38	0.38



$ZA^{-1}$

<b>0.62</b>	<b>0.60</b>	<b>0.43</b>	<b>0.55</b>	<b>0.64</b>	<b>-0.24</b>	<b>0.45</b>
<b>-0.67</b>	-0.56	0.05	-1.40	-0.87	1.29	-1.42
<b>0.06</b>	-0.04	-0.48	0.85	0.23	-1.05	0.97

$ZA^{-1}Z^t$

<b>2.84</b>	<b>-2.98</b>	<b>0.14</b>
<b>-2.98</b>	6.03	-3.05
<b>0.14</b>	-3.05	2.91

**MD**

<b>2.84</b>	<b>6.03</b>	<b>2.91</b>
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### LEVEL 7

#### Abnormal Data

SAMPLE	P1	P2	P3	P12	P13	P14	P15	P16
<b>1</b>	164	167	168	146	103	162	138	153
<b>2</b>	160	161	163	132	127	154	130	143
<b>3</b>	161	162	161	147	101	157	136	152

#### Normalized Data

SAMPLE	P1	P3	P5	P7	P9	P11	P13	P15
1	1.12	1.14	1.11	0.52	-0.51	1.07	0.80	0.67
2	-0.80	-0.73	-0.28	-1.15	1.15	-0.91	-1.12	-1.15
3	-0.32	-0.41	-0.83	0.64	-0.65	-0.16	0.32	0.48

#### Correlation Matrix

	<i>Column 1</i>	<i>Column 2</i>	<i>Column 3</i>	<i>Column 4</i>	<i>Column 5</i>	<i>Column 6</i>	<i>Column 7</i>	<i>Column 8</i>
Column 1	1	0.99627	0.87	0.65	-0.64	0.99	0.85	0.76
Column 2	0.99627	1	0.91	0.58	-0.57	0.98	0.80	0.70
Column 3	0.87	0.91	1	0.18	-0.17	0.79	0.47	0.33
Column 4	0.65	0.58	0.18	1	-0.99995	0.75	0.95	0.99
Column 5	-0.64	-0.57	-0.17	-0.99995	1	-0.74	-0.95	-0.99
Column 6	0.99	0.98	0.79	0.75	-0.74	1	0.91	0.84
Column 7	0.85	0.80	0.47	0.95	-0.95	0.91	1	0.99
Column 8	0.76	0.70	0.33	0.99	-0.99	0.84	0.99	1

### Inverse Matrix

	<i>Column</i> <i>1</i>	<i>Column</i> <i>2</i>	<i>Column</i> <i>3</i>	<i>Column</i> <i>4</i>	<i>Column</i> <i>5</i>	<i>Column</i> <i>6</i>	<i>Column</i> <i>7</i>	<i>Column</i> <i>8</i>
Column 1	0.26	0.25	0.16	0.27	-0.27	0.28	0.29	0.29
Column 2	0.25	0.24	0.16	0.25	-0.24	0.26	0.27	0.26
Column 3	0.16	0.16	0.15	0.09	-0.09	0.16	0.13	0.11
Column 4	0.27	0.25	0.09	0.39	-0.39	0.31	0.38	0.39
Column 5	-0.27	-0.24	-0.09	-0.39	0.39	-0.31	-0.38	-0.39
Column 6	0.28	0.26	0.16	0.31	-0.31	0.30	0.33	0.32
Column 7	0.29	0.27	0.13	0.38	-0.38	0.33	0.38	0.39
Column 8	0.29	0.26	0.11	0.39	-0.39	0.32	0.39	0.39

### $ZA^{-1}$

<b>1.77</b>	<b>1.67</b>	<b>0.98</b>	<b>1.98</b>	<b>-1.98</b>	<b>1.90</b>	<b>2.08</b>	<b>2.06</b>
<b>-1.98</b>	-1.83	-0.92	-2.48	2.48	-2.17	-2.51	-2.52
<b>0.21</b>	0.17	-0.06	0.50	-0.50	0.27	0.43	0.47

### $ZA^{-1}Z^t$

<b>12.07</b>	<b>-13.89</b>	<b>1.81</b>
<b>-13.89</b>	16.57	-2.68
<b>1.81</b>	-2.68	0.87

### MD

<b>12.07</b>	<b>16.57</b>	<b>0.87</b>
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## APPENDICES B: RESPONSE DATA

**Table B.1:** SN Ratio data

	<b>1</b>	<b>2</b>	<b>3</b>	<b>SN ratio</b>
<b>1</b>	41.60852	102.5828	15.65835	28.00317
<b>2</b>	37.64562	90.13884	13.46528	26.74758
<b>3</b>	11.10461	17.8251	1.185934	6.184204
<b>4</b>	9.692935	13.51277	0.641924	0.892138
<b>5</b>	3.337854	8.944285	3.623503	12.2568
<b>6</b>	2.844643	6.027461	2.91094	10.47178
<b>7</b>	12.0732	16.56584	0.867529	3.50269
<b>8</b>	10.76176	12.44342	0.460801	-1.97241
<b>9</b>	12.13432	27.18224	3.063141	14.17472
<b>10</b>	10.43793	22.24614	2.279523	11.68244
<b>11</b>	5.254343	15.4602	3.022376	13.01386
<b>12</b>	4.226578	12.08031	2.380264	10.98119
<b>13</b>	12.87523	23.792	1.749132	9.525253
<b>14</b>	11.29735	19.2122	1.121568	5.710501
<b>15</b>	10.18479	51.21736	15.99127	23.33103
<b>16</b>	6.965984	38.64433	13.1036	20.44127
<b>17</b>	9.731301	33.90442	7.677876	20.23904
<b>18</b>	7.406736	26.0395	6.084178	18.07641
<b>19</b>	16.41041	42.44815	6.25255	20.02214
<b>20</b>	13.26297	33.1341	4.66473	17.5653
<b>21</b>	12.2798	37.27172	6.945027	20.28663
<b>22</b>	9.707135	29.1463	5.408313	18.14572
<b>23</b>	0.263567	0.278579	0.212451	-12.1692
<b>24</b>	0.303053	0.200244	0.185558	-13.3492
<b>25</b>	0.470789	3.240624	1.37299	-2.33629
<b>26</b>	0.327985	2.666057	1.283204	-5.24782
<b>27</b>	11.30806	26.14567	3.673508	15.56025
<b>28</b>	9.101918	19.00994	2.362676	11.8937
<b>29</b>	0.470789	2.666057	3.673508	-1.97425
<b>30</b>	0.327985	26.14567	2.362676	-4.99528
<b>31</b>	11.30806	19.00994	3.673508	15.49285
<b>32</b>	9.101918	2.666057	2.362676	9.561143

**Table B.2:** Data of T1 and T2 of the SN ratio

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	SN ratio	
I1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	28.00317
I2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	26.74758
I3	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1	6.184204
I4	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	0.892138
I5	1	1	1	2	2	2	2	2	1	1	1	1	2	2	2	2	1	12.2568
I6	1	1	1	2	2	2	2	2	1	1	1	1	2	2	2	2	2	10.47178
I7	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	3.50269
I8	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	2	-1.97241
I9	1	2	2	1	1	2	2	2	1	1	2	2	1	1	2	2	1	14.17472
I10	1	2	2	1	1	2	2	2	1	1	2	2	1	1	2	2	2	11.68244
I11	1	2	2	1	1	2	2	2	2	2	1	1	2	2	1	1	1	13.01386
I12	1	2	2	1	1	2	2	2	2	2	1	1	2	2	1	1	2	10.98119
I13	1	2	2	2	2	2	1	1	1	1	2	2	2	2	1	1	1	9.525253
I14	1	2	2	2	2	2	1	1	1	1	2	2	2	2	1	1	2	5.710501
I15	1	2	2	2	2	2	1	1	2	2	1	1	1	1	2	2	1	23.33103
I16	1	2	2	2	2	2	1	1	2	2	1	1	1	1	2	2	2	20.44127
I17	2	1	2	1	2	2	1	2	1	2	1	2	1	2	1	2	1	20.23904
I18	2	1	2	1	2	2	1	2	1	2	1	2	1	2	1	2	2	18.07641
I19	2	1	2	1	2	2	1	2	2	1	2	1	2	1	2	1	1	20.02214
I20	2	1	2	1	2	2	1	2	2	1	2	1	2	1	2	1	2	17.5653
I21	2	1	2	2	1	2	2	1	1	2	1	2	2	1	2	1	1	20.28663
I22	2	1	2	2	1	2	2	1	1	2	1	2	2	1	2	1	2	18.14572
I23	2	1	2	2	1	2	2	1	2	1	2	1	1	2	1	2	1	-12.1692
I24	2	1	2	2	1	2	2	1	2	1	2	1	1	2	1	2	2	-13.3492
I25	2	2	1	1	2	2	2	1	1	2	2	1	1	2	2	1	1	-2.33629
I26	2	2	1	1	2	2	2	1	1	2	2	1	1	2	2	1	2	-5.24782
I27	2	2	1	1	2	2	2	1	2	1	1	2	2	1	1	2	1	15.56025
I28	2	2	1	1	2	2	2	1	2	1	1	2	2	1	1	2	2	11.8937
I29	2	2	1	2	1	1	1	2	1	2	2	1	2	1	1	2	1	-1.97425
I30	2	2	1	2	1	1	1	2	1	2	2	1	2	1	1	2	2	-4.99528
I31	2	2	1	2	1	1	1	2	2	1	1	2	1	2	2	1	1	15.49285
I32	2	2	1	2	1	1	1	2	2	1	1	2	1	2	2	1	2	9.561143
T1	12.18414	10.93142	7.752517	12.96575	8.917352	13.42641	9.601178	11.2979	11.44682	17.1564	8.922625	9.761084	13.90092	8.049576	11.8126	11.56955		
T2	7.923191	9.175911	12.35481	7.141578	11.18998	6.680924	6.680924	8.809429	8.660509	2.950929	11.18471	10.34625	6.20641	6.20641	8.294735	8.537777		