

# ANALYSIS OF PNEUMATIC VALVE CONTROL SYSTEM

NOR SURIYANTI BINTI OSMAN  
B051110084

UNIVERSITI TEKNIKAL MALAYSIA MELAKA  
2015



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**ANALYSIS OF PNEUMATIC VALVE CONTROL SYSTEM**

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Robotics and Automation) (Hons).

by

**NOR SURIYANTI BINTI OSMAN**

**B051110084**

**920101-04-5518**

FACULTY OF MANUFACTURING ENGINEERING

2015

## DECLARATION

I hereby, declared this report entitled Analysis of Pneumatic Valve Control System is the results of my own research except as cited in references.

Signature : .....

Author's Name : .. NOR SURİYANTI BINTI OSMAN ..

Date : .....

## **APPROVAL**

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Robotic and Automation) (Hons.). The member of the supervisory is as follow:

.....  
(Project Supervisor)

**BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA**

TAJUK: **Analysis of Pneumatic Valve Control System**

SESI PENGAJIAN: **2014/2015 Semester 2**

Saya **Nor Suriyanti Binti Osman**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **\*\*Sila tandakan (✓)**

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh:

\_\_\_\_\_  
Alamat Tetap:

**Batu 10,**

**Bertam Hulu,**

**76450 Melaka**

\_\_\_\_\_  
Cop Rasmi:

Tarikh: \_\_\_\_\_

Tarikh: \_\_\_\_\_

\*\* Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

## ABSTRAK

Projek ini menerangkan kajian teori dan eksperimen terhadap pneumatik DCV yang digunakan dalam sistem pneumatik dan memberi tumpuan kepada sistem kawalan yang asas. Sistem kawalan pneumatik DCV ditakrifkan dengan sistem kawalan terbuka. Persamaan matematik dikembangkan dengan menggunakan asas undang-undang fizik dan prinsip-prinsip iaitu Kirchoff's current dan undang-undang Newton pada pneumatik DCV. Selain itu, persamaan yang diperolehi membantu dalam membina graf seperti step response dan nyquist, di mana analisis seperti masa tindak balas pergerakan, peratus lebihan pergerakan, nilai kestabilan dan kesalahan, kestabilan dan tindak balas kekerapan telah dijalankan. Teknik simulasi (MATLAB) komputer telah digunakan untuk menguji dan mendapatkan keputusan hasil teori sistem kawalan. Eksperimen terhadap sistem pneumatik dijalankan dan keputusan direkodkan. Dengan membuat perbandingan terhadap kedua-dua keputusan, kita dapat melihat keadaan pneumatik tersebut sama ada dalam keadaan baik atau tidak. Implikasi projek ini adalah untuk memberikan pemahaman terhadap sistem injap kawalan pneumatik yang bertujuan untuk meningkatkan prestasi injap pneumatik yang sedia ada.

## **ABSTRACT**

This project describes the theoretical and experimental study of a pneumatic valve utilized in the pneumatic system, focusing on its fundamental control system. The pneumatic valve control system is defined as an open loop control system. Mathematical equations are evolved by applying fundamental physical laws and principles namely Kirchhoff's current and Newton's law, on the pneumatic valve. Furthermore, the derived equations assist in developing curves like step response and nyquist where analysis such as rise and settling time, percent overshoot, steady value and error, stability and frequency response were carried out. MATLAB programming has be used in this project in order to test and get the theoretical result for the control system. Pneumatic system experiment are conducted and result are recorded. By comparing the theoretical and experimental result, we can see the behavior of the pneumatic valve either in a good condition or not. The implication of this project is for understanding the pneumatic valve control sistem in order to improve the performance of existing pneumatic valve.

## **DEDICATION**

This report is dedicated to my lovely father and mother, family and my supervisor for being an internal spirit and continual support to give big and deep effects to me when this project was held. Thank you.



## **ACKNOWLEDGEMENT**

First of all, I am grateful to The Almighty God for establishing me to complete this final year project.

I would like to express the deepest appreciation to all coordinators who give me the opportunity to do my final year project in Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia.

I place on record, my sincere gratitude to my principle supervisor, Dr. Ahmad Yusairi bin Bani Hashim, my project supervisor from Manufacturing Engineering (Robotic and Automation) Department for his constant encouragement. I am extremely grateful and indebted to him for his expertise, sincere and valuable guidance.

In addition, I would like to take this opportunity to record my sincere thanks to all lectures from UTeM, Melaka, Malaysia especially in Manufacturing Engineering (Robotic and Automation) Department, my senior; Miss Sufiah Akmala binti Ramdan, and all technician in UTeM for their help and encouragement.

A thank to my parents for their unceasing encouragement and support and lastly, I also place on record, my sense of gratitude to one and all who, directly or indirectly, have lent their helping hand along my final year project session.

# TABLE OF CONTENTS

Abstrak	i
Abstract	ii
Dedication	iii
Acknowledgement	iv
Table of Content	v
List of Tables	x
List of Figures	xi
List Abbreviations, Symbols and Nomenclatures	xiii
<b>CHAPTER 1: INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Problem Statement	4
1.3 Objectives	4
1.4 Scope	4
1.5 Organization of Report	5
1.6 Gantt Chart	5
1.6.1 Project Schedule 1	5
1.6.2 Project Schedule 2	6
1.6.3 Project Schedule For Entire Project (Project 1 and 2)	6
1.7 Concluding Remarks	7
<b>CHAPTER 2: LITERATURE REVIEW</b>	<b>8</b>
2.1 Pneumatic System	8
2.1.1 Air Compressor	10
2.1.2 Electrical Motor	10
2.1.3 Air Receiver	10
2.1.4 Pressure Switch	10
2.1.5 Safety Valve	10
2.1.6 Auto Drain	10

2.1.7	Check Valve	11
2.1.8	Pressure Gauge	11
2.1.9	Air Dryer	11
2.1.10	Air Filter	11
2.1.11	Air Service Unit or F-R-L Unit	11
2.1.12	Directional Control Valve	12
2.1.13	Air cylinder	12
2.2	Pneumatic Valve	13
2.2.1	Control of Pressure	13
2.2.2	Control of Flow Rate	14
2.2.3	Control of Actuator Direction	15
2.3	Directional Control Valve	16
2.3.1	Internal Construction Approaches	16
2.3.1.1	Poppet/Piston Type	16
2.3.1.2	Spool Type	17
2.3.2	Flow Paths Approaches	18
2.3.2.1	Two-Way Directional Valve	18
2.3.2.2	Three-Way Directional Valve	18
2.3.2.3	Four-Way Directional Valve	19
2.3.2.4	Five-Way Directional Valve	19
2.3.3	Position Approaches	20
2.3.4	Actuation Approaches	20
2.3.5	Operation Approaches	20
2.3.5.1	Spring Offset	20
2.3.5.2	Normally Open and Normally Closed Valves	21
2.3.5.3	Detents	21
2.3.6	Additional Valve Types	21
2.3.6.1	On/Off Solenoid Valves	22
2.3.6.2	Proportional Valves	22
2.3.6.3	Servo Valves	22
2.4	Installation of Pneumatic System	22
2.5	Control System	24
2.5.1	Classification of Control System	24

2.5.1.1	Natural Control System	24
2.5.1.2	Manmade Control System	24
2.5.1.3	Combinational Control System	24
2.5.1.4	Time Varying and Time Invariant Systems	25
2.5.1.5	Linear and Nonlinear Systems	25
2.5.1.6	Continuous Time and Discrete Time Control Systems	25
2.5.1.7	Deterministic and Stochastic Control Systems	25
2.5.1.8	Lumped Parameter and Distributed Parameter Control Systems	25
2.5.1.9	Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO)	26
2.5.1.10	Open Loop and Closed Loop System	26
2.5.2	Basic Steps to Design a Control System	26
2.5.3	Mathematical Model of Control System	27
2.5.3.1	Magnetic Circuit	27
2.5.3.2	Mechanical Subsystem	29
2.5.3.3	Valve Flow Ability	31
2.6	MATLAB	32
2.7	Concluding Remarks	33
 <b>CHAPTER 3: METHODOLOGY</b>		<b>34</b>
3.1	Collecting Internet Article and Journal	34
3.2	Reading Books	34
3.3	Overall Report Methodology	34
3.4	Phase 1: Identification of the DCV Basics	35
3.4.1	Step 1: The Type of Pneumatic DCV Used	36
3.4.2	Step 2: The Working Principle of Pneumatic DCV	36
3.4.3	Step 3: The Pneumatic DCV Construction	36
3.4.4	Step 4: The Parameter for both Electromagnetic and Mechanical Subsystem	37
3.5	Phase 2: Modelling the Control System of the DCV	37
3.5.1	Step 1: The Block Diagrams of Pneumatic DCV	37
3.5.2	Step 2: The Free-Body Diagram (FBD) Used for this Project	37

3.5.3	Step 3: Mathematical Models for Transfer Function of Electromagnetic and Mechanical Subsystem	38
3.6	Phase 3: Evaluation the DCV Control System	38
3.6.1	Step 1: MATLAB Evaluation Measurement	39
3.6.2	Step 2: MATLAB Input Program	39
	3.6.2.1 Transient Response Analysis	39
	3.6.2.2 Frequency Response Analysis	39
3.6.3	Step 3: Data Analysis	40
3.6.4	Step 4: Summary	40
3.7	Concluding Remarks	40
 <b>CHAPTER 4: RESULTS AND RECOMMENDATION</b>		 <b>41</b>
4.1	Identification the Basics of DCV	41
	4.1.1 Valve Description	41
	4.1.2 Working Principle	42
	4.1.3 DCV Construction	43
4.2	Modeling the Control System of the DCV	43
	4.2.1 Electromagnetic Subsystem	44
	4.2.2 Mechanical Subsystem	47
4.3	Evaluation the DCV Control System	49
	4.3.1 Electromagnetic Response	49
	4.3.2 Mechanical Response	50
	4.3.3 Experimental Results	53
	4.3.3.1 Air Flow Rate	56
	4.3.3.2 Pressure-Response Time	57
	4.3.3.3 Voltage-Current-Actuate Rate	58
4.4	Concluding Remarks	59
 <b>CHAPTER 5: CONCLUSION</b>		 <b>61</b>
5.1	Conclusions	61
5.2	Recommendations	62
 <b>REFERENCES</b>		 <b>63</b>

<b>APPENDICES</b>	<b>66</b>
A. Pneumatic Symbols	67
B. Common Command	73
Matrix Operators	
Relational and Logical Operators	
Special Characters	
C. Experiment 1- Identification the DCV Basics	76
Experiment 2 - Modelling the Control System of DCV	
Experiment 3 - Evaluation of DCV Control System	
Experiment 4 - Pneumatic Test Procedure	
D. MATLAB Program	84
Air Flow Rate Calculation	
E. 5/2 Way Double Solenoid Valve Drawing	94
F. Pneumatic Training Set Specification	97

## LIST OF TABLES

1.1	Developments on pneumatic valve	2
1.2	Pneumatic valve issues	3
1.3	Input and output signal parameter	3
2.1	Power and signal element components	23
4.1	Specification of Pneumatic Valve	42
4.2	List of Pneumatic Valve Part	43
4.3	Electromagnetic Subsystem Parameter of 5/2-Way Double Solenoid Valve	48
4.4	Mechanical Subsystem Parameter of 5/2-Way Double Solenoid Valve	48
4.5	Specification of Pneumatic Valve	54
4.6	Pneumatic Valve Performance	55
A.1	Graphical Symbols Of Cylinders	67
A.2	Symbol of Air Preparation Units, Pneumatic Valves	68
A.3	Actuation Variation with Symbols	70
A.4	Symbol of Lines and Functions	71
B.1	MATLAB Commands and Predefined Functions	74
B.2	MATLAB Matrix Operators with Predefined Operations	75
B.3	Relational and Logical Operators that Used in MATLAB	75
B.4	Special Characters that Used in MATLAB	76
C.4	Pneumatic Valve Performance	81

## LIST OF FIGURES

1.1	Project Schedule 1	5
1.2	Project Schedule 2	6
1.3	Project Schedule For Entire Project (Project 1 And 2)	6
2.1	Schematic of compressed air	9
2.2	Pneumatic components system	9
2.3	Pneumatic system	14
2.4	Needle valve with tapered nose	14
2.5	Double acting cylinder	15
2.6	Two directional control valve with extend condition	15
2.7	Two directional control valve with retract condition	16
2.8	Poppet type valve	17
2.9	Rotary spool type valve	17
2.10	Sliding spool type valve	18
2.11	Two-way directional valve	18
2.12	Three-way directional valve	19
2.13	Four-way directional valve	19
2.14	Five ported, 4-way directional valve	19
2.15	Position approaches	20
2.16	Spring offset symbol	21
2.17	Detent symbol	21
2.18	Schematic installation of the pneumatic system	23
2.19	Basic steps in designing of control system	27
2.20	Schematic diagram of the spool valve structure	29
3.1	Flow chart of overall report methodology	35
3.2	Main working principle of pneumatic	36
3.3	DCV Double solenoid, spool-sliding type valve will be described	36
3.4	Basic mathematical characteristic of pneumatic DCV	38



4.1	Double Solenoid, Spool-Sliding Type Valve	41
4.2	Working Principle of DCV	43
4.3	Block Diagram of Electromagnetic Subsystem with Voltage (V) as Input and Magnetic Force (F) as its Output	44
4.4	Block Diagram of Mechanical Subsystem with Magnetic Force, (F) as Input and Spool Movement, (X) as its Output	44
4.5	Free Body Diagram of Electromagnetic Subsystem	45
4.6	Free Body Diagram of Electrical System	45
4.7	Free Body Diagram of Magnetic System	45
4.8	Free Body Diagram of Mechanical Subsystem	47
4.9	Free Body Diagram of Mechanical Subsystem	47
4.10	Step Response of 5/2-Way Pneumatic Valve using Transfer Function in Electromagnetic Subsystem	50
4.11	Step Response of 5/2-Way Pneumatic Valve using Transfer Function in Mechanical Subsystem	52
4.12	Nyquist of 5/2 Way Pneumatic Valve using Transfer Function in Mechanical Subsystem	52
4.13	Air flow rate of 5/2 Way Double Solenoid Valve with Three Different Pressure: 29.01, 43.51 and 58.02 PSIA	57
4.14	Response Rate of 5/2 Way Double Solenoid Valve with Three Different Pressure: 29.01, 43.51 and 58.02 PSIA	58
4.15	Voltage-Current-Response Rate with the Different Voltage Used from 0 to 24V	59
	Appendix C Pneumatic System	82
	Appendix E 5/2-Way Double Solenoid Valve Construction	94

## **LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE**

DCV	-	Directional Control Valve
FYP	-	Final Year Project
FBD	-	Free Body Diagram
FRL	-	Filter, Regulator and Lubricator
Max	-	Maximum
MIMO	-	Multiple Input Multiple Output
SISO	-	Single Input Single Output
SCFM	-	Standard Cubic Feet Per Minute
PSIA	-	Pounds Per Square Inch Absolute

# **CHAPTER 1**

## **INTRODUCTION**

This chapter describes the introduction of the project of pneumatic valve control system. Begin with the introduction to current issues, followed by translation of the problem statement from the questions and identification of project objectives. Next, project scope and report organization will be discussed. Lastly, Gantt chart will be covered in this chapter.

### **1.1 Background**

Pneumatic is one of the power sources that is widely used in automated machine equipment in performing various automation projects. Most of the industries prefer to use pneumatic because it is simple, cheap, easy to handle and maintenance and possesses a high level of controllability. In addition, pneumatic medium; the air are widely available and compressible (Majumdar, 1996).

In pneumatic system, pneumatic valve is a vital mechanical component. The Romans first founded the valve concept. They used bronze plug as cock in their aqueducts (Borden, 1998). In general, valve consists of a body and a moving part which control air passages within the body. The moving part is essential in controlling system pressure, direction of flow and rate of flow in the system.

Pneumatic valves are available in several types. The valve type depends on the internal construction, number of the flow path in the valve, number of position or square in the valve body, actuation and operation type (Lansky, 1986).

The evolution of complex processes in industries and necessity to reduce production cost, a study approach is required to monitor the valve operating condition. Thus, it is important for engineers to analyze significant issues of the pneumatic valve to prevent the pneumatic valve from the damaged working condition. Several new methods have been implemented to maintain the pneumatic valve in good condition.

**Table 1.1:** Developments on pneumatic valve

No.	New Development	References
1.	Unconstrained vibrational pneumatic valve	(Uehara & Hirai, 2005)
2.	Flow control valve using a vibration motor	(Akagi et al., 2008)
3.	Pneumatic valve with biomorph type PZT actuator	(Yun et al., 2006)
4.	Pneumatic actuator control system using PZT impact force	(Liu & Jiang, 2007)
5.	New flow control valve is driven by PZT vibrator	(Hirooka et al., 2009)
6.	Design and control of direct drive servo-valve operated by the piezostack actuator	(Jeon, Nguyen, & Choi, 2013)
7.	Design of a High-Speed Electromagnetic Control Valve Using the Numerical Analysis	(Han, 2014)

Uehara and Hirai invented an unconstrained vibrational pneumatic valve that has an orifice 2.0 mm in diameter and a metal poppet 6.0 mm in diameter (Uehara, & Hirai, 2005), Akagi invented a flow control valve utilising a vibration motor (Akagi, Dohta, Katayama, & Engineering, 2008), Yun invented a pneumatic valve along with biomorph type PZT actuator (Yun, Lee, Kim, & So, 2006), Liu et al. invented a pneumatic actuator control system using PZT impact force (Liu & Jiang, 2007) and Hirooka, Suzumori and Kanda developed a new flow control valve driven by PZT vibrator (Hirooka, Suzumori, & Kanda, 2009). Furthermore, Jeon, Nguyen and Choi designed and controlled direct servo-valve by piezostack actuator (Jeon, Nguyen, & Choi, 2013) and Han designed a high speed electromagnetic control valve using numerical analysis (Han, 2014). Refer Table 1.1.

**Table 1.2:** Pneumatic valve issues

No.	Issues	References
1.	Size, weight, safety	(Akagi et al., 2008) and (Hirooka et al., 2009)
2.	Flow capacity, dirty air, vibration, leaking, controllability	(Hirooka et al., 2010)
3.	Performance	(Yun et al., 2006), (Liu & Jiang, 2007) and (Akagi et al., 2008)

However, there is problem on size, weight, safety (Akagi et al., 2008) and (Hirooka et al., 2009), flow capacity, dirty air, vibration, leaking, controllability (Hirooka, Suzumori, & Kanda, 2010) and performance in pneumatic valve system (Yun et al., 2006), (Liu & Jiang, 2007) and (Akagi et al., 2008) as stated in Table 1.2.

Analyzing pneumatic valve control system has attracted considerable work to enhance its responsiveness based on the design of pneumatic valve and input signal parameter in this project. The pneumatic valve control system will be studied by utilizing basic information and control system of pneumatic valve and evaluation using both MATLAB and experiment.

**Table 1.3:** Input and output signal parameter

No.	Input Signal Parameter	Output Signal Parameter
1.	Electrical Supply, I	Magnetic Force, F
2.	Magnetic Force, F	Spool Movement, X
3.	Supply Pressure, P	Response Rate, t

Continuation to this, analyzed data will be used further in controlling and monitoring the operation of the pneumatic valve to prevent the pneumatic valve from the damage operating condition. Table 1.3 above indicates the important parameters for input and output (performance) signal for this project.

## **1.2 Problem Statement**

Directional control valve (DCV) has been widely used in industry in various applications. The increasing of the complex process and the necessity to scale down production cost has increased the demand on the good quality valve. Hence, it is important for engineers or designers to develop new methods of managing pneumatic valve issues. Size, weight, current capacity, dirty air, vibration, leaking, controllability and performance are the most frequently recorded issue on the pneumatic valve. This project intends to analyze the pneumatic valve control system to get an advance understanding in several typical valve issues that may cut system setup time and attain more precise motion.

## **1.3 Objectives**

The objectives of this project are to:

- a) Identify the DCV,
- b) Model the control system of the DCV, and
- c) Evaluate the DCV control system.

## **1.4 Scope**

This project is about analyzing the pneumatic DCV control system. It analyzes the stability issues by using a basic mathematical model of pneumatic DCV, control system, suitable MATLAB program and input parameter. This project will focus on the 5/2 way double solenoid-spool-sliding type valve and three primary operations; actuation valve, internal (spool movement) and emission gaseous operation. The basic mathematical model of the magnetic circuit, mechanical subsystem, and the air flow path will be encompassed in this project. Transient and frequency response, air flow rate, cylinder response rate, and power supply response will be used as evaluation measurement.

## 1.5 Organization of Report

The beginning chapter of this report describes the introduction of the pneumatic valve control system. It is followed by the description of the literature review. Next, this report proceeds with the explanation of the methodology used. Subsequently, the next chapter elaborates the results and discussion. In the end, the last chapter discusses the conclusions and recommendations of this report.

## 1.6 Gantt Chart

This project consists of two phases that are Final Project (FYP) 1 and FYP 2. The time allocated for completion of each stage of the project is one semester that equivalent to 14 weeks (Figure 1.1 and 1.2). Meanwhile, the time allocated for the entire project is equivalent to two semesters of 28 weeks, excluding semester break (Figure 1.3).

### 1.6.1 Project Schedule 1

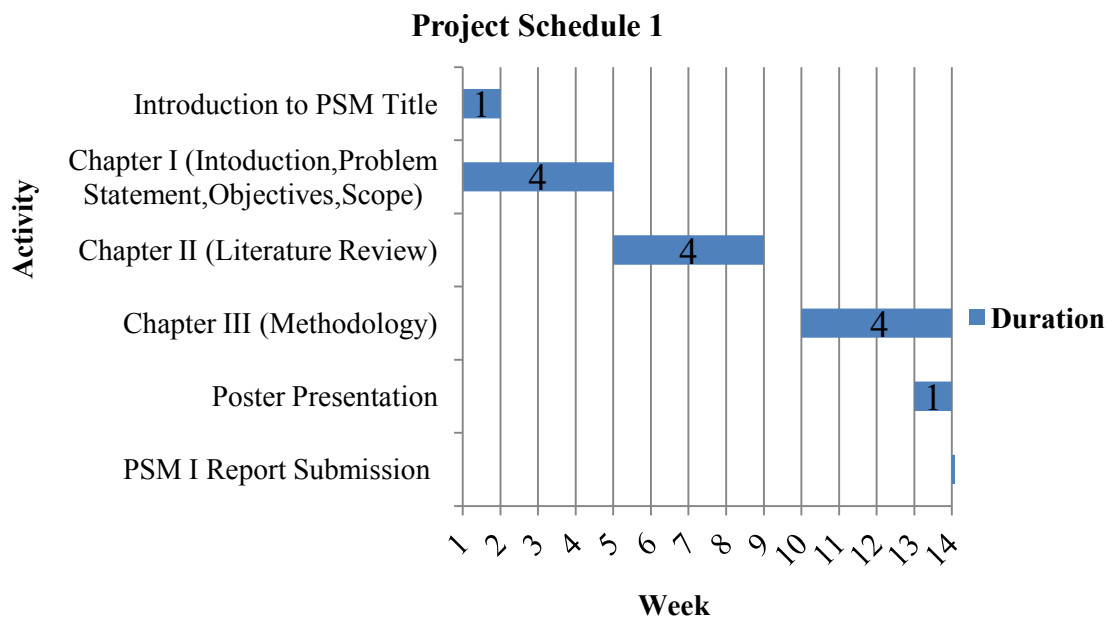


Figure 1.1: Project Schedule 1

### 1.6.2 Project Schedule 2

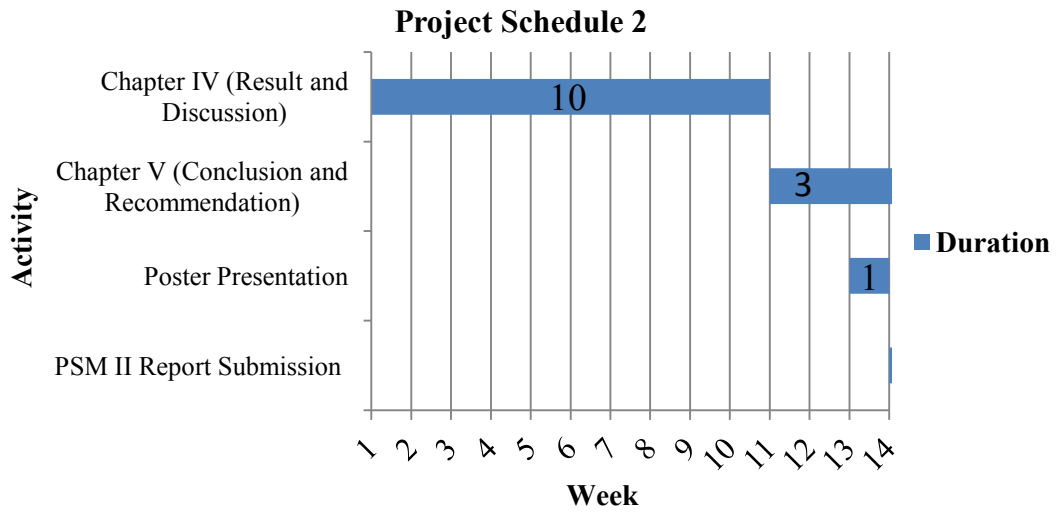


Figure 1.2: Project Schedule 2

### 1.6.3 Project Schedule for Entire Project (Project 1 and 2)

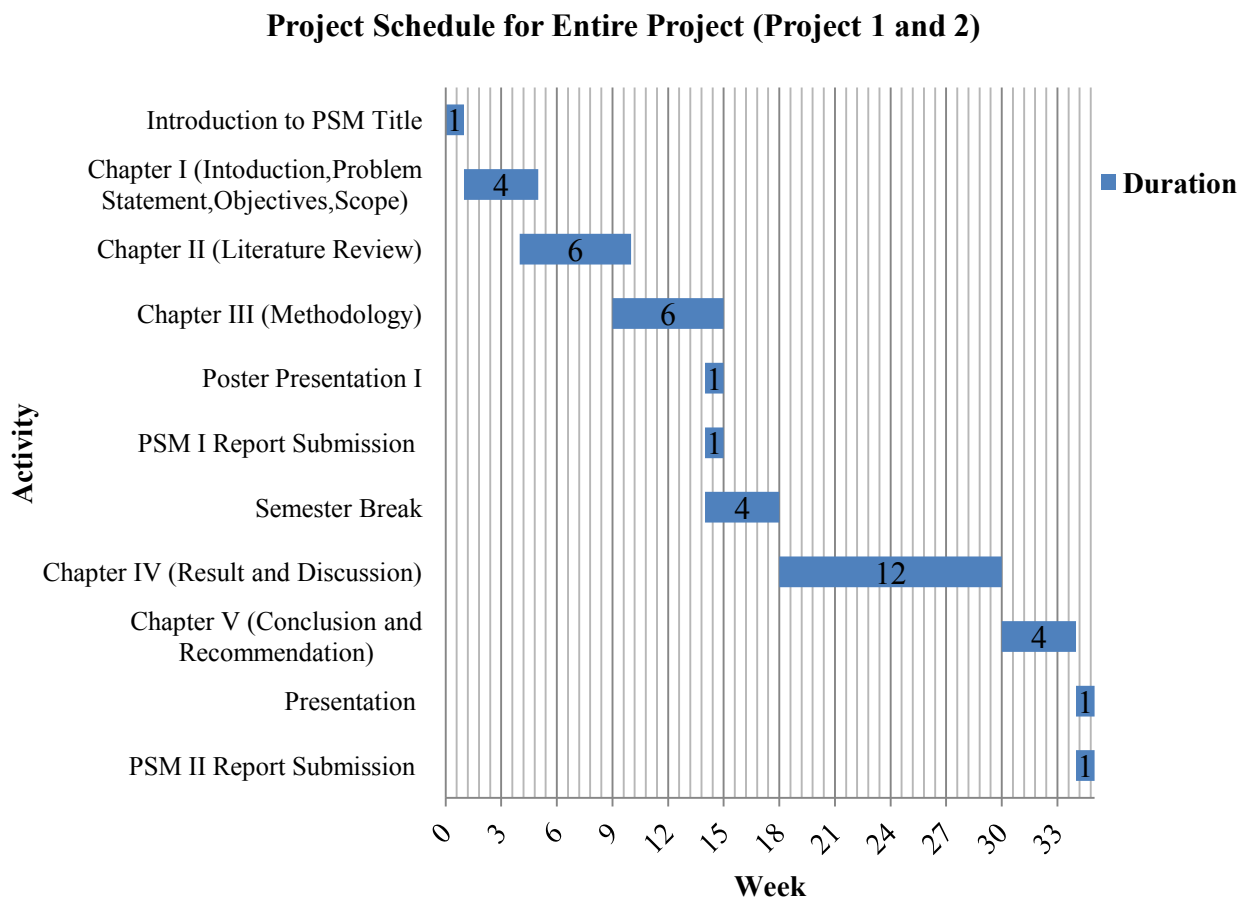


Figure 1.3: Project Schedule For Entire Project (Project 1 and 2)