**CHAPTER 2**

**RESEARCH METHODOLOGY**

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# **Keywords:** Automation Tools, Analysing Tools, Cloud Computing, Heuristic Search, A\*, Fuzzy Logic

# **2.1 Questionnaires**

1. Work and Responsibilities in Organization in Software Development, Software Testing, Quality Engineering and Software Integration and Deployment
2. Describe the methods of development and Testing used in organization
3. Describe the methodologies and status of manual testing
4. Problems associated with manual testing
5. Problems used with manual testing tools
6. Repositories used for Test Cases
7. Uses of Cloud storage in Development and Testing Environment
8. Methodologies of using Dynamic Storage in Software Environment
9. Opinion of using automated testing as a solution coming with manual testing.
10. Factors needed to be considered before implementation of automation.
11. What should be the process of implementing automation?
12. As per the current situation is there any automated process carrying out doing software build, Testing and Delivery?
13. Opinion and suggestions implementing Adaptive Automation with Storage
14. Challenges of implementing adaptive automation?
15. Algorithms used for adaptive software testing tools development in dynamic environment with large cloud storage.
16. Overcoming the challenges of implementing adaptive automation using tools and techniques
17. Level of satisfaction after implementing adaptive automation in System development, System Testing, Thereafter Integration and Delivery.

# **2.2 Automation Tools for Software Systems Testing**

As per the response and data collected from questionnaires, following tools are listed for study and practical implementation to check the behaviour of adaptive automation. Following tools are chosen for deep study and concluding the Research.

### 2.2.1 Selenium WebDriver

Selenium is an open source library with bindings in multiple languages (Java, C#, Python, etc.) that allows an engineer to write code that is then translated into human-like interactions with various browsers and mobile devices.   At its core Selenium spins up a lightweight server on a machine that sends commands in the JSON format to a browser or device.  These JSON commands typically include information such as the action to be performed (click, enter text, submit form, etc.) as well as information about how to identify the element for the action to be performed on.

These pieces of identifying information are based on the Document Object Model (DOM) or a web page or app and, for all intents and purposes, can be thought of as the HTML of a page.

### 2.2.2 Selenium

It is test automation framework for Web applications. Selenium is an automation framework of choice for Web automation engineers, particularly for those who possess advanced programming and scripting skills. Selenium become a core framework for other open-source automation tools such as Katalon Studio, Watir, Protractor, and Robot Framework. Selenium supports multiple operating systems (Windows, Mac, and Linux) and multiple browsers (Chrome, Firefox, IE, and Headless browsers). And it can be programmed with scripts can be written in various programming languages such as Java, Groovy, Python, C#, PHP, Ruby, and Perl. Engineers have flexibility with Selenium, can write complex and advanced test scripts to meet various levels of complexity, it requires advanced programming skills and effort to build automation frameworks and libraries for specific testing needs.

It is the most popular automation testing tool for web applications. Selenium can be run in multiple browsers and operating systems**.** It is compatible with other automation testing frameworks.

With selenium, a browser centred automation test scripts can be created which are scalable across different environments. Scripts can be created using Selenium that is of great help for prompt reproduction of bugs, regression testing, and exploratory testing.

### 2.2.3 Robot framework

Robot Framework implements the keyword-driven approach for acceptance testing & acceptance test-driven development (ATDD). Test capability can be extended by implementing additional test libraries using Python and Java. Selenium WebDriver is an external library in Robot Framework. Test engineers can leverage Robot Framework as an automation framework for web testing as well as for Android and iOS test automation. Robot Framework can be easy to learn for engineers who are familiar with keyword-driven testing.

### 2.2.4 JBehave

JBehave is an open source BDD (Behaviour Driven Development) library that allows users to write their test cases in plain English and have them automatically translated into chunks of Java code to be executed.

JBehave allows someone like a product owner or scrum master to write test cases, hand them off to automation engineers and have those engineers write the automation scripts.

JBehave also creates easily digestible and human readable reports after execution, including information such as what test cases were run, how many test cases passed/failed and provides screenshots for any failed test cases.

Everything in JBehave is customizable and flexible, giving each team the power to define their own test runs and even create custom reports.

### 2.2.5 RestAssured

RestAssured is an open source framework that allows for easy and flexible testing of API based applications.

### 2.2.6 Docker

Docker is an open source tool that allows users to "containerize" applications and environments.

Using a simple Docker image and 1-2 commands a user can instantly deploy an environment on their local machine with a set of predefined conditions such as installed browsers with specific versions, specific applications installed or preconfigured network settings.

### 2.2.7 TestNG

TestNG is a lightweight testing framework in between JUnit and JBehave/Cucumber.  TestNG is ideal for teams that don't want to deal with the overhead of configuring BDD frameworks or are writing tests (such as API level) that do not lend themselves to BDD concepts such as stories or features.

### 2.2.8 Cucumber

Cucumber is another commonly used BDD library.  It is very similar to JBehave but will be more familiar to those coming from a non-Java coding background.

It is designed over the concept of BDD (Behaviour-driven development). It performs the automated acceptance testing by running the stories that best describe the behaviour of the application. It gets a single up-to-date living document that is having both specification and test documentation.

Cucumber is scripted in Ruby. It also supports Java and.NET. It also has cross-platform OS support.

### 2.2.9 Apache JMeter

It is Java desktop application designed for load testing. It mainly focuses on web applications. This tool can be used for unit testing and limited functional testing.

Its architecture is centred on plugins with the help of which JMeter provides a lot of out of box features. It supports many types of applications, servers and protocols like Web, SOAP, FTP, TCP, LDAP, SOAP, MOM, Mail Protocols, shell scripts, Java objects, and database. It also includes Test IDE, dynamic reporting, command line mode, portability, multithreading, caching of test results and highly extensible core. It supports many types of applications, servers and protocols like Web, SOAP, FTP, TCP, LDAP, SOAP, MOM, Mail Protocols, shell scripts, Java objects, and database.

### 2.2.10 Appium

This Test automation framework is intended for mobile applications, and automation of native, hybrid and mobile web applications built for iOS and Android. This tooluses vendor-provided automation frameworks and is based on client/server architecture. Appium is easy to install and use.

### 2.2.11 Robotium

It is an open-source test automation framework primarily meant for Android UI testing? It supports both native and hybrid applications. Using Robotium, time-saving, readable and easy to use automated grey box UI tests intended for android apps can be written. System testing, functional testing, and user acceptance testing over Android-based apps with the help of Robotium can be performed.

### 2.2.12 UFT

**Unified** Functional Testing (UFT) is a commercial testing tool for functional testing. It provides a feature set for API, web services, and GUI testing of desktop, web, and mobile applications across platforms. This tool has advanced image-based object recognition feature, reusable test components, and automated documentation. UFT uses Visual Basic Scripting for testing processes and object control. UFT can be integrated with Mercury Business Process Testing and Mercury Quality Center. This supports CI with Jenkins. It was previously known as QuickTest Professional (QTP).

It brings developers & engineers coming together under one umbrella and provides high-quality automation testing solutions. It makes functional testing less complex and cost-friendly. Its features include **Cross browser & multi-platform compatibility,**Optimized distributed testing, multiple testing solutions, image-based object recognition and canvas, visual test flows.

### 2.2.13 IBM Rational Functional Tester

IBM RFT is a data-driven testing platform. It supports applications such as .Net, Java, SAP, Flex, and Ajax. RFT uses VB, .Net and Java as programming languages. RFT has a feature called as Storyboard testing in which users’ actions on AUT are recorded and visualized in a storyboard format through application screenshots. It can be integrated with IBM Jazz application lifecycle management systems such as IBM Rational Team Concert and Rational Quality Manager.

This tool is intended for**automated functional testing & regression testing**. It allows to perform data-driven and GUI testing. The automated testing is based upon script assure technology which highly improves the efficiency of testing and provides easy script maintenance. This tool does automate performance testing over web and server-based apps. It has RCA capabilities to remove performance bottleneck. It provides real-time reporting and test data customizations. It also offers load and scalability testing.

### 2.2.14 TestComplete

Environment Supported are web, mobile, and desktop testing. Programming/scripting languages support: JavaScript, VBScript, Python, and C++Script. Testing performed: keyword-driven and data-driven testing with Test Complete offers easy-to-use record and playback feature. Like UTF, TestComplete’s GUI object recognition capability can automatically change with UI objects which helps reduce the effort to maintain test scripts when the AUT is changed. It can be integrated with Jenkins in a CI process. This tool works for desktop, mobile and web applications. With Tet Complete, Functional UI tests can be built and run via robust record & replay capabilities or by scripting in your favorite languages, including Python, JavaScript, VBScript with support for applications, such as .Net, and native and hybrid iOS and Android apps, along with regression, parallel, and cross-browser testing capabilities.

### 2.2.15 HP Quality Center

HP Quality Centre software standardizes testing. It is an integrated IT quality management software application. Automated testing is one of its key features which constantly allows to test earlier and quicker. Sharing with reusability allows HP QC to have bug-free and reliable applications.

# 2.3 Approach and Steps of Study/Analysing Right Tool

1. Market Research: I have done Search for tool available whether Free Open Source, Community versions or Paid one fit in the requirements. To study open source automated tools and based design algorithm and methodologies and simulation of code base libraries of adaptive nature intelligent enough to understand their execution environment.
2. Experts View: Get feedback from the users and experts or from Forum of experts to get experiences on the features of tools. To take input from the users for their feedback to make the algorithm in a way so that it simulates itself as per the nature of protocol and requirements
3. Personal Experience: As per my personal work experience working with tools I have done research shortlisted best tools that best suits requirements and affordability of adaptive tools.
4. I Prepared comparison chart and done SWOT Analysis to select the best tool works on the principle of Run Time Dynamic Adaptive Automation. Studied the level of satisfaction/experience of users before using automated (adaptive design and test pattern algorithm) Build and Test of software applications. Then Study the level of satisfaction of users after using automated (adaptive) software applications.
5. As per the comparison and study of tools and methodologies find problems in application of Adaptive Software in Technical Organizations and designed an engineering algorithm in terms of model and methods for assembling software systems that can dynamically adapt to context and can ‘account for them-selves’ specific to run time dynamic environment.
6. Then done minimizing tools for the requirements fits exactly we have to get through above mentioned guidelines.

# **2.4 Study on Cloud Computing Terms (Types and Definition, services)**

There are few concepts those need to be addressed if cloud computing been used for Dynamic Run Time Adaptive Automation and Data Access/Storage.

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(National Institute of Standards and Technology) which is summarized as follows: Cloud computing model is for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be provisioned/released with minimal effort or service provider interaction.  The full definition and explanation can be found in [this](http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf) public NIST document. Additionally, NIST has published a final version of cloud computing technology roadmap. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | **Different types of clouds and distinction between them.‎** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | | | | | | | | | | | | | | | | | | |  | | | | | | | | | | | | | | | | | | | | | | |  | | | | | | | | | | | | | | | | | | | | | | | There are four kinds of cloud deployment models: private clouds, community clouds, public clouds, and hybrid clouds.  A private cloud infrastructure is provisioned for exclusive use of organizations. It’s owned, managed, and operated by organizations, by third parties, or combination of them. It may exist on or off organizations premises.  A community cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It can be owned, managed, and controlled by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises. A public cloud infrastructure is open to use by the public. A public cloud may be owned, managed, and operated by a business, academic organization, or government organization (or some combination of the three). The infrastructure for this type of cloud exists on the premises of the cloud provider.  A hybrid cloud is a combination of two or more separate cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology which enables data and application portability (e.g., cloud bursting for load balancing between clouds). | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | **Definition of “SaaS” or “PaaS”. And a "Service" with respect to cloud.** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  | |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | ​A service is something that provides “value” to the organization’s lines of business. There are mainly three basic service models: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Another service model (that is not officially defined by the National Institute of Standard and Technology) is Database as a Service (DaaS). | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | **Different types of service models**. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | Software as a Service, or SaaS, is the delivery of applications that are developed and hosted by the SaaS vendor. The end user accesses the applications over the Internet.  Unlike traditional packaged applications the SaaS vendor owns the software and runs it on computers in its data centre. The customer does not own the software but can rents it, usually for a scheduled time fee.   Platform as a Service, or PaaS, is a model in which the user creates an application or service using tools and/or libraries from a provider. The provider provides the networks, servers, storage, operating systems, and other services that are required to host the consumer’s application or service.  Although less established and not as widely available as compared to SaaS and IaaS offerings, ready-to-use application platforms offer great promise for organizations that aren’t compelled to own and manage the underlying infrastructure. A well-known platform that uses the PaaS model is Google App Engine.   Infrastructure as a Service, or IaaS, is the virtualized processing, storage, and networking services along with automation and management capabilities in this area offer the most flexible level of services in the cloud computing model.  A well-known platform that uses the IaaS model is Amazon Elastic Compute Cloud.  Database as a Service, or DaaS, is a cousin of SaaS. It is a physical data management strategy for managing an on-site private cloud made up of several different database architectures.  These architectures can provide varying degrees of database service to an application based on business requirement’s related to availability, scalability and performance.  The main objective of the DaaS strategy is to provide a high-quality database service while maximizing ROI on database software/hardware and supporting agile development efforts through faster service delivery. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# **2.5 Patterns/Algorithms for Adaptive System Design, Development and Test**

As per the data collected from questionnaires with regards to adaptive algorithms, A study is done and resulted with a simulated adaptive algorithm based on Search Algorithms, Informed Heuristic Search strategies and Fuzzy Logic. These approaches mentioned in algorithms can be used to develop adaptive software and tools for analysing and doing run time decision based on adaptive simulation and learning from environment and feedback mechanism.

**2.5.1 Informed (Heuristic) Search Strategies**

To solve big problems with number of possible states, problem-specific knowledge function must be added to increase the performance of search strategy algorithms.

**2.5.1.1 Heuristic Evaluation Functions**

Calculates the total cost of optimal path between two states of nodes/set. For example, A heuristic function for sliding-tiles games is processed by calculating number of moves that every tile makes from its goal state and then summing up all.

**2.5.1.2 Pure Heuristic Search**

It counts heuristic values for every node then expands them in the order. In this process two lists are created, a closed list for the expanded nodes and an open list for the defined but unexpanded nodes.

Then In each iteration, a node having minimum heuristic value is expanded, and all its child nodes are created/placed in the closed list. Then, the heuristic function is applied to the child nodes to place them in the open list according to their heuristic value. And in the End the shorter paths are saved, and the longer ones are disposed.

**2.5.1.3 A \* (Best First) Search**

It is form of Best First search because it avoids expanding paths that are already expensive but expands most promising/optimized paths first.

The function for A\* Search is defined as follows

f(n) = g(n) + h(n), where

* g(n) the cost (so far) to traverse the node
* h(n) expected cost to get from the node to the result
* f(n) estimated total cost of path through n to result. priority queue is used to implement same by increasing f(n).

**2.5.1.4 Greedy Best First Search**

It expands/executes the nodes that is estimated to be closest to goal. It expands nodes based on f(n) = h(n). It is implemented using priority queue and only estimated cost to get from the node to the goal is calculated.

**Disadvantage** − It can get stuck in loops. It is not optimal.

**2.5.2 Fuzzy Logic**

Fuzzy Logic Systems (FLS) gives acceptable but definite output even if incomplete, ambiguous, distorted, or inaccurate (fuzzy) input is given.

**2.5.2.1 What is Fuzzy Logic?**

Fuzzy Logic (FL) is a way of reasoning that resembles human understanding. The approach of FL concludes the way of decision making in humans that involves all interim possibilities between digital values YES and NO.

The conventional logic block takes precise input and produces a definite output as TRUE or FALSE, which is equivalent to human’s YES or NO.

The inventor of fuzzy logic, Lotfi Zadeh, observed that, the human decision making is different from computers which includes a range of possibilities between YES and NO, such as −

|  |
| --- |
| CERTAINLY YES |
| POSSIBLY YES |
| CANNOT SAY |
| POSSIBLY NO |
| CERTAINLY NO |

Hence the fuzzy logic works on the different levels of possibilities of input data to get the definite output.

**2.5.2.2 Implementation**

* It’s suitable for systems with various sizes and capabilities from small microprocessors to large, networked, workstation-based control systems also include networked storage cloud.
* It can be implemented in hardware, software, or in embedded systems.

**2.5.2.3 Need of Fuzzy Logic?**

It is useful for many commercial and practical purposes.

* It can control machines and consumer products.
* It may not produce accurate reasoning, but acceptable reasoning to get the work done.
* Fuzzy logic helps to deal with the uncertainty in engineering design and execution by working on the set of acceptable defined data.

**2.5.2.4 Fuzzy Logic Systems Architecture**

It has four main parts as shown −

* **Fuzzification Module** − It converts the inputs, which are defined numbers, into fuzzy sets and splits the input signal x into five steps may be defined as

|  |  |
| --- | --- |
| **LP** | x is Large Positive construct |
| **MP** | x is Medium Positive construct |
| **S** | x is Small construct |
| **MN** | x is Medium Negative construct |
| **LN** | x is Large Negative construct |

* **Knowledge Base** − It creates IF-THEN rules provided by system designers.
* **Inference Engine** − It defines and simulates the human understanding process by making fuzzy inference on the inputs and IF-THEN rules, combining.
* **Defuzzification Module** – It processes the fuzzy set obtained by the inference engine and transformed into an exact value.

The **membership functions work on** fuzzy sets of variables and Input.

**2.5.2.5 Membership Function**

Membership functions quantify linguistic term and presents a fuzzy set diagrammatically. A **membership function** for a fuzzy *set A* on the universe of X is defined as μA:X → [0,1].

Each element of fuzzy set is mapped to a data between 0 and 1. This is called **degree of membership**. Membership Function quantifies the degree of membership of the element in *X* to the fuzzy set *A*.

* x axis represents the universe of discourse.
* y axis shows the degrees of membership in the interval.

multiple membership functions can be defined applicable to fuzzify a numerical value. Hence simple membership functions are used because use of complex functions does not add more precision in the output.

All membership functions are shown as below in graph diagram.



The triangular membership function shapes are more frequent among various other membership function shapes.

**2.5.2.6 Algorithm**

* Define linguistic variables and terms.
* Construct membership functions for them.
* Construct knowledge base of rules.
* Convert scattered data into fuzzy data sets with functions. (fuzzification)
* Evaluate rules in the rule base. (Inference Engine)
* Combine results from each rule. (Inference Engine)
* Convert output data into non-fuzzy values. (defuzzification)

**2.5.2.7 Logic Development**

**Step 1: Define linguistic variables and terms**

Linguistic variables are input/output variables may be in the form of known words or sentences to form simple constructs. For example, room temperature, may be categorized as, cold, warm, hot, etc.

Temperature (t) = {very-cold, cold, warm, very-warm, hot}

Every component of this defined set is a linguistic term which can cover some part of overall temperature values.

**Step 2: Construct membership functions for them**

The membership functions of temperature are represented as below.



**Step3: Construct knowledge base rules**

To construct knowledge-based rules a matrix of room temperature values versus target temperature values is created that an air conditioning system is expected to have.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **RoomTemp. /Target** | **Very\_Cold** | **Cold** | **Warm** | **Hot** | **Very\_Hot** |
| Very\_Cold | No\_Change | Heat | Heat | Heat | Heat |
| Cold | Cool | No\_Change | Heat | Heat | Heat |
| Warm | Cool | Cool | No\_Change | Heat | Heat |
| Hot | Cool | Cool | Cool | No\_Change | Heat |
| Very\_Hot | Cool | Cool | Cool | Cool | No\_Change |

Build a set of procedure or regulations into the knowledge defined construct in the form of conditional IF-THEN-ELSE structures.

|  |  |  |
| --- | --- | --- |
| **Sr. No.** | **Condition** | **Action** |
| 1 | IF temp= (Cold OR Too\_Cold) AND target=Warm THEN | Heat |
| 2 | IF temp= (Hot OR Too\_Hot) AND target=Warm THEN | Cool |
| 3 | IF (temp=Warm) AND (target=Warm) THEN | No\_Change |

**Step 4: Obtain fuzzy value**

Fuzzy set operations perform evaluation of rules. The operations used for OR/AND are Maximum and Minimum. Combining all results of outcome to get a result. This result is a fuzzy value.

**Step 5: Perform defuzzification**

Then Defuzzification is performed according to membership function with output variable.



**2.5.2.8 Advantages of FLSs**

* Within fuzzy reasoning Mathematical concepts are simple to understand.
* FLS can be modified by altering rules due to flexibility of fuzzy logic.
* Fuzzy logic Systems can also consider imprecise, distorted, noisy input information.
* FLSs are easy to construct and understand.
* Fuzzy logic is a solution to complex problems in all fields of life, specifically run time dynamic systems as it works on the concepts of human reasoning and decision making.

**2.5.2.9 Disadvantages of FLSs**

* Lacking systematic approach to fuzzy system designing.
* are understandable only when defined in easy terminologies.
* Suitable for the systems which do not need high accuracy as output.