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Testing Challenges in Web-based Applications with respect to Interoperability and Integration

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ABSTRACT

Testing is one of the critical processes in software development life cycle. It plays key role in the success of software product by improving its quality. Web-based applications are emerging and evolving rapidly; their importance and complexity is also increasing. Heterogeneous and diverse nature of distributed components, applications; along with their multi-platform support and cooperativeness make these applications more complex and swiftly increasing in their size. Quality assurance of these applications is becoming more crucial and important; testing is one of the key processes to achieve and ensure the quality of these software or Web-based products. There are many testing challenges involved in Web-based applications. But most importantly interoperability and integration are the most critical testing challenges associated with Web-based applications. There are number of challenging factors involved in both integration and interoperability testing efforts. These integration and interoperability factors have almost 70 percent to 80 percent impact on overall quality of Web-based applications. In software industry different kind of testing approaches are used by practitioners to solve the issues associated with integration and interoperability, which are due to ever increasing complexities of Web-based applications. It is fact that both integration and interoperability are inter-related and it is very helpful to cover all the possible issues of interoperability testing that will reduce the integration testing effort. It will be more beneficial if a dedicated testing team is placed to perform the both integration and interoperability testing.

Keywords: Integration and interoperability testing, Web-based applications assurance, software testing

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INTRODUCTION

Computer applications are widely used in almost every business and its demand is increasing dramatically. Along with this widespread demand, the size of software applications and their complexity is also increasing. Now software applications have great affect on the operation and success of the business as well as have implications on human lives or stability of the society. The reliability (quality assurance) of these applications (software products) has become more important and critical.

Different processes and activities are involved in the release of a high quality software product. We can say that the software needs to be well conceived, well designed, well implemented and well tested. One of the most important activities (process) associated with any software development effort is testing. It plays key role in the field of software engineering, and is an important process used to support quality assurance. **Testing** is one of the most important phases of software development life cycle. The main objective of software testing is to indicate the difference between actual and expected behaviour of the software system. In other words, it ensures the reliability and quality of a software product. According to [1], software testing is the process of executing a programme with the intentions to find errors.

Testing of Web-based applications is different from conventional software testing, but the goal is same here, which for example: to remove errors before deploying the application on networks (internet or intranet). The **Web-based applications** typically work in a distributed, asynchronous fashion. These applications are very complex and their inter-dependency between different Web-components can cause more and more errors. These applications are created from different heterogeneous Web-components that interact with each other, and with users through novel ways. These applications are based on number of different components (Web components) written in different languages and frameworks like; Active Server Pages (ASP), PHP Pre-processor (PHP), Java Server Pages (JSP) and Asynchronous JavaScript and extensible Mark-up Language (AJAX) etc. The Web applications are accessed through the Web browser over internet or intranet.

Since Web-based applications are ubiquitous and distributed in nature, therefore it is not an easy task to test them. The uncovering of errors is very difficult in Web-based applications as compare to other traditional software applications. **Testing of Web-based application** is very difficult due to its nature like: heterogeneity, multi-platform support, autonomous, cooperative and distributed etc. Web-based applications are mostly complex software which are evolved and updated rapidly. Along with its complexity and often rapid change in requirements, normally these applications have shorter development time.

These factors can be a hurdle to testing efforts and make it more complex and challenging than other traditional software. In recent years, the Web applications have been integrated with mission critical systems by the different organizations due to which the quality and reliability of these applications is more and more crucial and therefore testing of these applications is very costly, time consuming and a big challenge. Web-based applications gather information and data from several heterogeneous sources. This raises the issue of integration as well.

The integration of different software components of Web-based applications is a taunting task. The usage of in-compatible technologies, differences in architecture of different components and applications can make it more difficult. Therefore, **integration testing** of Web applications is very crucial for the successful operations of these components among themselves. The integration testing of the components of Web-based applications involves a

lot of factors, which might be raised during packaging, integration and deployment of the application. So, its integration testing is one of the challenging tasks.

In Web applications the whole information with different structure and format is required to be integrated transparently and seamlessly [16]. This is a complex requirement which raises the issue of interoperability in the Web applications. **Interoperability** is one the most important and key issue in Web-applications. According to [2], interoperability of software system is the ability to share information among different computing components, operating systems, applications and networks.

Interoperability is much complex and difficult to handle in software as compare to hardware. According to [18], Interoperability testing involves multiple levels:

- The standards meet the business requirements they were intended to address (validation testing),
- The standards conformance of key implementations, what was implemented agrees with the specification (conformance testing), and
- That sets of business applications can successfully operate together (interoperability testing).

The Web applications are run on cross-platform environment therefore the running of different components of Web applications on different platform is an issue. To validate this requirement **Interoperability testing** is used. The running environment of Web applications is heterogeneous and autonomous therefore interoperability testing of these applications is not an easy task. It is one of the most important and challenging tasks to improve the quality of software applications.

We have performed the industrial survey to collect and obtain the views of practitioners regarding interoperability and integration testing challenges in Web-based applications. Through the data analysis, we conclude that the most of the issues of interoperability and integration are inter-related, and if, we cover all the possible issues of interoperability testing then it will reduce the effort not of the integration testing but on other issues as well (like security, performance, scalability, reliability).

Web-based applications are playing pivotal role in many business domains, for example finance, sales, retail, marketing, and management of particular products. In the applications of large enterprises and mission critical systems, the importance of software integration and interoperability cannot be neglected. Different integrated components are developed in different platforms, tools and by using different methodologies. Therefore, we suggest there should be a separate sub-testing team consisting of 2-3 testers (depends upon the size and type of enterprise or organization) with multiple skills (multi-lingual expertise, standards, methodologies and tools) to handle the issues of interoperability and integration.

CHAPTER 1: BACKGROUND

In this chapter, brief background is discussed of World Wide Web, and Web-based applications. Along with this, some important and significant differences between Web-based applications and traditional desktop applications are narrated. Brief introduction of Quality assurance of Web applications and its importance is presented.

1.1 Internet and World Wide Web

The internet is the network of networks of computers which operates world-wide using a common set of communications standards and protocols. We can say that World Wide Web (WWW) (or simply the Web) is a repository of information (documents, videos, sounds etc.) and is a network of different sites that can be searched and retrieved through the Hypertext Transfer Protocol (HTTP) [5]. At the beginning WWW was a set of simple protocols and formats, as time passed, it began to be used for various complex and sophisticated hypermedia and information retrieval concepts.

We are living in the age of information technology, which is also known as E-age; everyone wants to be connected with internet to get latest and updated information of his/her own interest. People in today's business world prefer to have their own Websites for enhancing the businesses with the help of latest upcoming technological developments, which can assist the entrepreneurs to scale up the business by directly contacting their retailers and customers. Most of the large and small organizations have now realized the enormous potential of internet to reach the markets.

Now, Web has become the one of crucial ways of information gathering and retrieving, and it is also a primary way of communication, a perfect place for expressing and discussing both private and professional interests. Along with this it is a huge market place and economic factor. It has become an important and vital platform for entertainment, news, research, e-commerce, medical and health activities, communication and collaboration [3]. Today, the customers, employees, and business partners expect the organizations to have the Web presence [1].

1.2 Web-based Applications

With the rapid growth of the Web and Internet, many new and complex applications (Web applications) are emerging [4], most of which are based on innovative ideas for nurturing through World Wide Web. In other words, we can say that technology has revolutionized the business solutions, which are gradually transferring towards Web-based applications. The WWW has given the developers a novel approach and challenge to implement complicated, interactive applications with sophisticated graphical user interfaces (GUIs), and large numbers of back-end software components that are integrated in new and interesting ways [5].

Mostly, small and medium size business organizations have simple Web applications based on simple Web pages to publicize their services and products. The bigger organizations and larger enterprises have full-fledged Web (e-commerce) applications to sell their wares, goods and services. These goods and services can be from cookies to cars, from consulting services companies to entire virtual companies that exist only on the Web (Internet) [1].

The rapid growth of internet and Web applications has changed the thinking of the practitioners and researchers, as a result of the openness and accessibility of the Internet, the

competition in the business-to-consumer arena has reached at its extreme. In other words we can say that the Internet has created a new market for the consumers. The consumers now have built great expectations to buy services or goods through the internet, but the Website (application) with lack of functionalities of one's organization can lead the consumer to find another Website for conducting the business. It means that the consumers require higher quality expectations from Web applications than other traditional software applications [1]. For example, when people buy desktop software products and install them to their local or home computers, and if they find that product of an average quality they will continue to use that product, because they have paid for that particular software application and they perceive that as useful. "Even a less than satisfactory programme can't be easily corrected", therefore if that application just satisfies the consumers' basic needs, they will retain that software application [1].

On the other hand, the consumer or customer will not use an average-quality Web-based application; he/she will prefer to use the other competitors' site. Due to this poor quality of Web application, the company will lose that customer/ consumer as well the company's corporate image will be mottled [1].

1.3 Difference between traditional applications and Web-based Applications

The Web-based applications are different from the conventional software in many ways. Generally, the distinction between Web applications and traditional software applications is made according to the unique characteristics which are technical and organisational [21].

1.3.1 Technical Differences:

The technical differences between Web-based applications and traditional software systems are obvious. The major of these are as follows: [21]

- The most obvious difference between Web applications and conventional software development is the use of specific technologies and the ways these technologies are interconnected. For instance, the technical structure of Web applications merges complex business architecture with complex information architecture and highly component-based technical architecture. The link of business architecture and technical design is much tighter than for conventional software systems and information architecture is more complex than traditional software applications.
- The architecture of Web applications is modularized. Web applications are based on numerous Commercial off-the-shelf (COTS) components which are integrated with each other (mostly backend middleware layers). Therefore strong integration skills are much more important and critical in most Web systems. It is fact that the architecture of Web-based applications is very similar to client server architecture but there exist an important difference. In client-server applications both client and have predefined characteristics and are static while Web-based applications dynamically generate the contents [58].
- The technologies of Web applications is evolving rapidly which increases the importance of creating flexible solutions that can be updated and transformed to latest and new technologies with minimum effort. Similarly the understanding of these new technologies is very crucial and restricted for developers which increase the project risks.

- Compatibility and interoperability issues are more problematic in Web-based applications than traditional applications. Web-based applications are often affected by some challenging factors that are the major sources for interoperability and compatibility issues. The servers are distributed in different components of operating systems like Windows, Solaris, UNIX/ Linux, Mac etc. Similarly on client site different browsers are involved which create more challenging to develop and test Web-based applications [58].
- Content of Web applications are very crucial and therefore effective information design and suitable content management is very important in these applications.
- For traditional software application, users make an investment, buy it and install it in his/her machine and learn to use it. On the other hand, in Web-based applications user can switch from one Website to another competitor's Website with minimum effort. Therefore much more efforts are required to keep users engage by providing much more evident satisfactions to them. Therefore much more emphasis is kept on the user interface and its associated functionalities.
- The implementation of Web applications in mission critical systems is increasing rapidly which are directly access by the external users, customers and partners. Any bug or problem with application is typically more visible externally which is much more problematic.
- Web-based applications need faster maintenance requirements than traditional applications and this cause by the rapidly evolvement of requirements of these applications [58].

1.3.2 Organizational Differences

With technical differences there are also numbers of important organizational characteristics which are different in Web applications. These important differences are as follows: [21]

- In Web-based applications, domain is often misunderstood due to rapid change and evolves of technology, business models, development skills and competing systems. This leads to uncertainty in the context of project and resolving strategies and requirements become more problematic. Mostly Web applications projects are vision-driven instead of needs-driven which leads to initial lack of clarity.
- Most often, in Web-based applications the business requirements of clients are changed swiftly therefore more effective design tools are required in these applications.
- Mostly Web-based projects have very short delivery schedule as compare to other traditional software projects and a very small team work on that.
- In Web-based applications there is an ongoing process of content updating and other interface changes and editorial changes.

Along with this, in Web applications there is lack of accepted testing processes; user satisfaction and the threat from one's competition; minimal management support; criticality of performance; evolving standards; understanding of additional disciplines required for Web applications; security considerations; legal, social and ethical issues; variety of backgrounds of developers; rapidly evolving implementation environment, encompassing

various hardware platforms. These differences show the additional complexities of Web applications and highlights potential characteristics that may impact on its usability. [7]

1.4 Quality assurance of Web applications

As the demand of Web applications is increasing rapidly, their complexities are also increasing dramatically, and reliability and quality assurance of these applications has become an important and critical issue. Since the Web applications are ubiquitous and heterogeneous in nature and different from conventional and traditional desktop applications therefore quality assurance of such applications is not an easy task. The quality of Web applications is a complex, multidimensional attribute [26], and great effort is required to ensure the quality of the Web-based applications.

One of the most important activities (process) associated with any software development effort is Testing. It plays key role in the field of software engineering and is an important process used to support the quality assurance. Testing is one of the most important phases of software development life cycle. It is almost impossible to remove all kinds of bugs and errors from any kind of software product because of its complex nature. It is always preferable to reduce the bugs and errors at minimum possible level, which is helpful for successful operational software applications. The main objective of software testing is to indicate the difference between the actual and expected behaviour of the software system. In other words it ensures the reliability and quality of a software product.

The main goal of testing Web-based applications is not different from the conventional and traditional software applications i.e. the uncovering of errors in Web applications before deploying. Due to the complexities, heterogeneity, distributed nature and interdependency of the different Web components, we can find plenty of bugs and errors in Web applications.

Testing phase of software development life cycle (SDLC) becomes more challenging when it comes to Web-based applications due to its distributed and complex nature. It is important to consider different development aspects (like, client/server architecture, interaction among different components of the application, graphical user interface, networking and Web-services issues) of the Web-based application before its testing. For successful operation of Web-based applications, it is important to make sure that all components and modules of the application are working according to its given requirements; it can be done through proper testing of the application.

Testing of Web-based application is considered very difficult due to its nature like, heterogeneity, multiplatform support, autonomous, cooperative and distributed etc. These kinds of applications are mostly complex software which are evolved and updated rapidly. This rapid evaluation and expansions of Web applications and their complex and heterogeneous natures provoke the need of suitable techniques, tools and methodologies to meet the desired quality objectives. Research is being carried out in this field and several technological and methodological proposals for developing Web applications are coming from both academia and industries [8]. Most of these proposals are well suited to obtain external and visible quality attributes like usability and accessibility. These proposals, methodologies and tools do not directly consider internal quality attributes of the Web applications, like maintainability, interoperability, and testability [8].

With these methodologies, models and proposals in the field of development of Web applications, the field of Verification and Validation (V&V), and quality assurance of Web-based applications is still immature and lack of a common method. Due to the very short time-to-market of the Web-based applications, the testing practice is more often neglected by testers and developers, and considered too time consuming and lacking a significant payoff

[9]. The improvement in the quality of Web-based applications requires many features and processes, including suitable models' extraction, restructuring, assessment of multilingual alignment, accessibility and testing [10]. Therefore, in short, we can say that there is high demand for testing methodologies and tools for quality assurance and testing of Web-based applications and systems.

1.5 Integration and Interoperability Issues of Web-based applications

The Web-based applications are based on number of different Web components written in different languages and frameworks. These different components communicate and interact with each other to share information and data, and present to the consumer or user. This raises the issue of integration of these different components. The integration is a big issue in the heterogeneous Web-based applications, because different components might be developed in different languages and platforms. These differences in programming languages and development tools can create the problems and difficulties in integration of those components. It is possible that after integration these components could not perform as they were expected. Therefore, integration testing plays key role to find out errors which occur before and after the integration of different components and services of the Web applications. Integration testing plays important role but it is not an easy task. Integration testing of the components of Web-based applications involves a lot of challenging factors, which might be raised during packaging, integration and deployment of the application. So, its integration testing is one of the challenging tasks.

Web-based applications have become the crucial components of our life and are involved in critical activities. Now the business integration is key endeavour of Enterprises. In current business run, the Enterprise's decision makers want to align their business with the current market. They are adopting the Service Oriented Architecture (SOA, also called Web services (a type of Web applications)), which is essential for their businesses. Now, most of the small medium enterprises (SMEs) are aligning their business processes in SOA. This provides a way to make business processes automated, open and interoperable. Now, most of biggest business organizations have automated their business process and they need to think about interoperability to cooperate with other business processes for achieving business goals. [11]

Maintaining interoperability among different automated business process and components and Web components is an important but challenging task in Web-based applications. According to [2], interoperability of software system is the ability to share information among different computing components, operating systems, applications and networks. For Business-to-Business (B2B) Web applications, efficient integration is required to achieve the interoperability. The different frameworks for B2B integration have many research issues which need to be addressed. For example, process-based integration of services, and dependable integration of services, etc [12].

The interoperability of Web based applications cannot be guaranteed due to many reasons; [13]

- The Web services standards and specification supported can be different
- Error handling mechanism can be different
- Difference in supported protocols etc.

CHAPTER 2: PROBLEMS DEFINITION AND GOALS

With the rapid growth of Web, Web applications are growing fastest among other software systems in use today. These applications have become the critical components of the global information infrastructure, and support a wide range of important activities. For example, business functions, scientific activities and medical activities [14]. Now, Web applications have great impact on the business, economies, health and scientific activities and any error and bug in these applications can do the serious damage on the businesses, economies and human lives. To improve and maintain the quality and reliability of these applications, verification and validation has great impact. Testing is a wide spread approach for software validation.

Web applications have special characteristics and characters like distribution, dynamic, hypermedia, multi-platform support and interaction, due to which traditional software testing approaches are not suitable. A lot of proposal and methodologies and automated tools are available to perform the testing of Web applications, each of which has its own pros and cons.

2.1 Purpose and Objective

Business-oriented Web-based applications are emerging swiftly, which results in new challenges. This thesis will modernize the testing, analysis and verification procedures for the distributed nature of Web-based applications. It will help to provide a new roadmap for testing specific domains of Web-based applications like: interoperability and integration.

The purpose of this thesis is to identify the role of testing in Web-based applications and their challenges. The focus of research discipline is software testing that address the areas of Web-based applications and this work will investigate the particular testing challenges in the domains of interoperability and integration. The expected outcome of this thesis will be a report on testing challenges of Web-based applications, which will elaborate specific domains of Web-based applications: interoperability and integration. To achieve the goal the following objectives are set:

- The understanding of the characteristics of Web applications
- The understanding of different types of Web applications and their roles
- The infrastructure and architecture of Web applications
- Importance of quality assurance of Web applications
- The role of software testing in the Web-based applications
- The key testing challenges involved in Web-based applications in academia and industry
- The understating of interoperability and integration
- The testing challenges to Web-based applications with respect to interoperability and integration both in academia and industry
- Analysis of collected data from industry regarding testing challenges with respect to interoperability and integration

In most organizations testing is neglected by the consideration as tedious process [17], but it has great importance to assure the quality of software product. It plays key role in the success of software products by improving their quality. It is always preferable to reduce the bugs and errors at minimum possible level, which is helpful for successful operational software applications and testing is the key process to achieve that.

Web applications are composite of different kind of complex interdependence distributed components and systems which include different operating systems, different applications, services and databases etc. These different components communicate with each other in different programming languages, interfaces and data structures and interoperate on a network with hardware, operating systems, different communication protocols, and Web browsers [15]. In Web applications the whole information with different structure and format is required to be integrated transparently and seamlessly [16]. This is a complex requirement which raises the issue of interoperability in the Web applications. These extra components further increase the complexities of Web applications. These growing complexities of Web-based applications have made the testing more challenging. The integration and interoperability testing of these components in Web applications is very challenging and time consuming task.

2.2 Research Questions (RQ(s))

The research questions will be investigated with a concise literature review including journals, articles, books and other research oriented resources, along with industry practitioners' views. This thesis will focus on the following research questions:

1. What are the Web-based applications and what are the testing challenges involved in Web-based applications?
2. How interoperability and integration affect the Web-based applications?
3. What are the testing challenges associated with interoperability and integration of Web-based applications?
4. How the existing testing approaches can be updated/ modified to meet the challenges in the areas of interoperability and integration?

2.3 Research Method/Approach

This is an academic thesis, which will follow the mixture of qualitative and quantitative research methodologies for the investigation of above mentioned research questions which include the thorough studies of articles and books, and industrial survey. First, we identify the problem to understand the domain of the said topic and its analysis. Then we perform the thorough studies of research articles, books and other relevant materials. Along with this, we perform industrial survey, and then analysis of result collected from the survey and then validation and future work. This flow of thesis work is also shown in the Figure 1.

2.3.1 Literature Review

The research has performed by thorough studies of relevant material including journals, articles, books and other available authentic resources to elaborate the challenges of testing Web-based software applications. The sources from which we collect data and information are well reputed and considered authentic resources, like; IEEE explorer, ACM digital library, Books, eBooks from ebrary, Science Direct, Engineering Village, InterScience,

Wiley, Google search engines (like Google Scholar), W3C (World Wide Web Consortium), and SpringerLink. We collect data from latest articles and books from 1990 and onward.

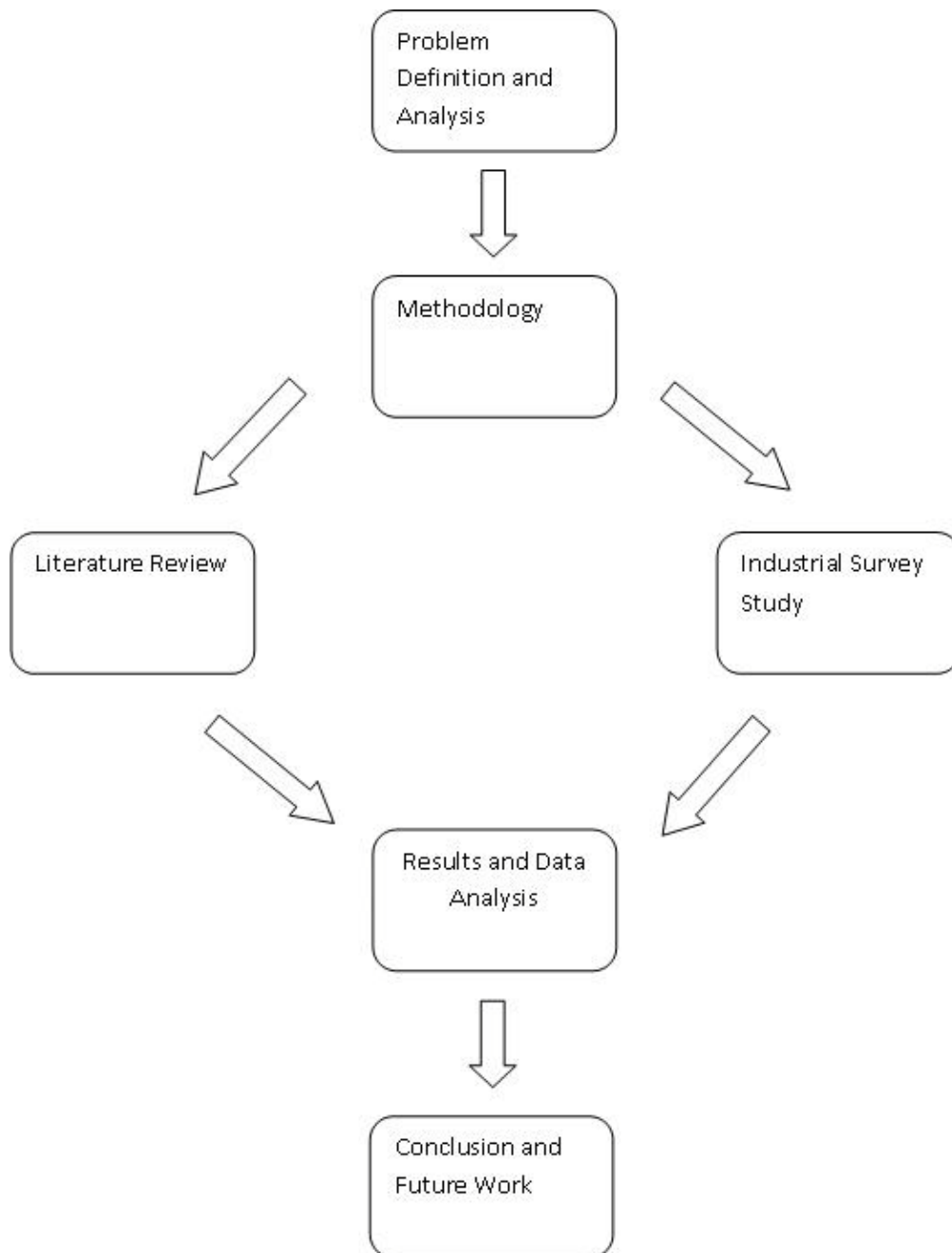


Figure 1 - Workflow of Thesis

Along with this we also collect data from different Websites, whitepapers and articles to collect latest information and data related to our thesis research. The focus of collection of data from different resources is to identify the Web-based applications, their challenges and their testing challenges especially with respect to interoperability and integration.

2.3.1 Survey Study Design

The survey questionnaire are prepared according to the research questions and sent to the different organizations developing Web-based applications. The purpose of this survey is to

collect the views of industry's practitioners with respect to interoperability and integration testing of Web-based applications. The idea is to analyse the practitioners' views and academia and to reduce the gap between them. The industrial survey is discussed in chapter 6 in detail.

The thesis research report is a state of the art testing challenges of Web-based applications with respect to interoperability and integration. Thesis report is written in accordance with quality of the research articles, books, journals and careful extraction of data from different qualitative information resource, and from the industrial survey.

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CHAPTER 3: WEB APPLICATIONS

In this chapter Web applications are defined. The characteristics and different categories of Web applications are discussed. The architecture of any software application has great importance. The overall infrastructure of Web applications is discussed in detail.

3.1 Web Applications

A Web application is an application that is invoked with a client (mostly by Web browser) over the Internet, Intranet or Extranet. According to [24], A Web-based application allows the information processing functions to be initiated remotely from a client (browser) and executed partly on a Web server, application server and/or database server. These applications are specifically designed to be executed in a Web-based environment.

When we visit on Web, we can find different kind of Websites. According to [23], in general, there are two types of Websites, the one type is based on the HTML (Hypertext Markup Language) also called static Websites and behave like simple printed newspapers or magazines. These Websites have published and printed materials for the end users. The examples of such kind of Websites are the different Websites of newspapers e.g. The New York times, BBC etc. The second type of Websites enables the end users to interact with the Website. In this type Web pages are generated dynamically in the response of end user's input or action. These Websites work as software and utilities, also called as Web applications. Web applications (also called Web software) run on servers and end users access these applications through Web browsers [23]. The examples of Web applications are supply chain management, online banking systems, online retail systems and different email services like Google, yahoo and hotmail. Web applications are more complicated as compare to simple static Websites and provide a new way to deploy software applications to the end users. According to [20], Web-based applications are based on mixture between print publishing and software development, between marketing and computing, between internal communications and external relations, and between art and technology.

According to [5], Web applications are interactive software which has complex Graphical User Interfaces (GUIs) and numbers of back-end software components are integrated. These applications have revolutionized the business arena and have provided new opportunities to businesses and to the end users.

Web applications utilize different novel technologies, tools, programming models, and programming languages to fulfil the high quality requirements. These applications also utilize servers, browsers, and usually internet to reach the end users. According to [19], the better way to define Web application is in terms of its components. The components that include in Web application are:

- **Web Server;** the computer that delivers Web pages
- **Application Server;** a server and a programme that handles all the operations of backend computing applications (like databases) and end users
- **Front-end Systems;** the user interface for end users
- **Back-end Systems;** different applications and databases used by the end user to access or update programme

- **Code, Business Logic, Static files;** programmes and parameters that instruct servers and systems on how to process information

3.2 Characteristics of Web-based Applications

Every software application has their specific characteristics, some of those are common and some are related to specific applications. These characteristics are very important to keep in mind before the development of any application. Like other software applications, Web-based applications have characteristics which act as important factors in these applications. According to [22], there are some general characteristics that apply to all Web applications but with different degrees of influence. The degrees of influence vary with different categories of applications. The following general characteristics and attributes are encountered in majority of Web-based applications:

3.2.1 Network intensive

Since Web applications are delivered to a diverse community of users, the nature of Web-based applications is network intensive. These applications reside on network (like Internet, Intranet or Extranet).

3.2.2 Content Driven

Mostly Web applications present textual, graphical data, audio and video to the end users by using hypermedia.

3.2.3 Continuous Evolution

Most Web applications evolve continuously. These applications updated on the regular interval, even some applications are updated on hourly schedule to provide latest information to the end users.

3.2.4 Short development schedule

Mostly Web-based applications have very tight development schedule. It means these applications have very short time for the development and developed under compressed time schedule. The time to market for a complete Website from planning to implementation and testing can be a matter of few days or weeks.

3.2.5 Security

To protect sensitive content and information provided by the user, and for successful data transmission strong security measures are implemented in the Web-based applications.

3.2.6 Aesthetic

One of the most important characteristics of Web applications is aesthetic appearance. Aesthetic appearance of those Web-based applications which designed for selling products and ideas is as important as technical design.

The above all are some simple but important characteristics of Web-based applications, but as the complexities of these applications are growing, some other characteristics such as distributed, heterogeneity, autonomous, dynamic, hypermedia, multiplatform support, ubiquitous are very important to understand. These characteristics are the important factors that are necessary to keep in mind before the designing, implementing, testing and deployment of the Web-based applications. These characteristics can assist the developers and software engineers to built successful applications.

3.3 Types/Categories of Web-based Applications

Along with characteristics of Web-based applications the understanding of different types and categories of these applications is also important for the developer to develop successful applications. The Web-based applications are of many types each of which has its own issues and importance. The following different categories of Web applications are mostly present on the Web: [22] [23]

- **Interactive:** These types of applications are usually provides the mutual interaction and communication way among the community of users like chat rooms, instant messaging etc.
- **Informational:** In these types of applications read-only information is provided to the end users through different and simple navigations and links.
- **Customizable:** Through these applications end users can customize the contents of the applications according to their needs and preferences. For instance, a user can customize email settings according to its needs and preferences.
- **Download/ Deliverable:** These kind of applications provide the facilities of downloading different applications, files etc. For example, if a user wants to upgrade or update Microsoft Windows, he/she can do it through the Web applications provided by the Microsoft.
- **Form-based Input:** Through these applications end users can submit their data, queries to the database of the organization and extract the required information.
- **Transactional:** Through these Web applications users make the request or place the order to obtain goods or services. For instance online shopping, online ticketing purchase.
- **Web Services:** Web services allow us to create the interoperable distributed applications. These are cross-platform technology and can be developed in multiple technologies and make the data available to different applications that run on different platforms. Familiar Web Services include Business to Consumer (B2C), Business to Business (B2B), search engines, stock tickers, FedEx tracking, and credit card services etc.
- **Web Portals:** These kinds of applications provide the facilities to the users to other contents of the Web or services which are not in the domain of the portal applications.

- **Data Warehouses:** These applications provide the facilities to the user to query their request in the collection of large databases to retrieve and extract particular information. Google is a good example of such kind of applications.

3.4 Design infrastructure of Web Applications

Three design elements; architecture, navigation and interface are the fundamental design elements to implement and deploy the Web-based applications [23]. These three elements provide the insight infrastructure of the Web applications.

3.4.1 Structure of Web Applications

According to [22], the architectural design of the Web applications is based on the structures and design patterns. The overall architectural structure of Web application is based on the goals, contents to be presented, the end users and the navigational criteria. According to [25], there are four different structures to design typical Web application. These different structures are:

Linear Structures: These structures are used when the sequence of interactions is common/predefined and predictable. The simple linear structure is shown in the figure - 2 (a). The figure - 2 (b) shows the linear structure with optional flow. When applications become more complex, diversion occurs to acquire complementary content as shown in figure – 2 (c).

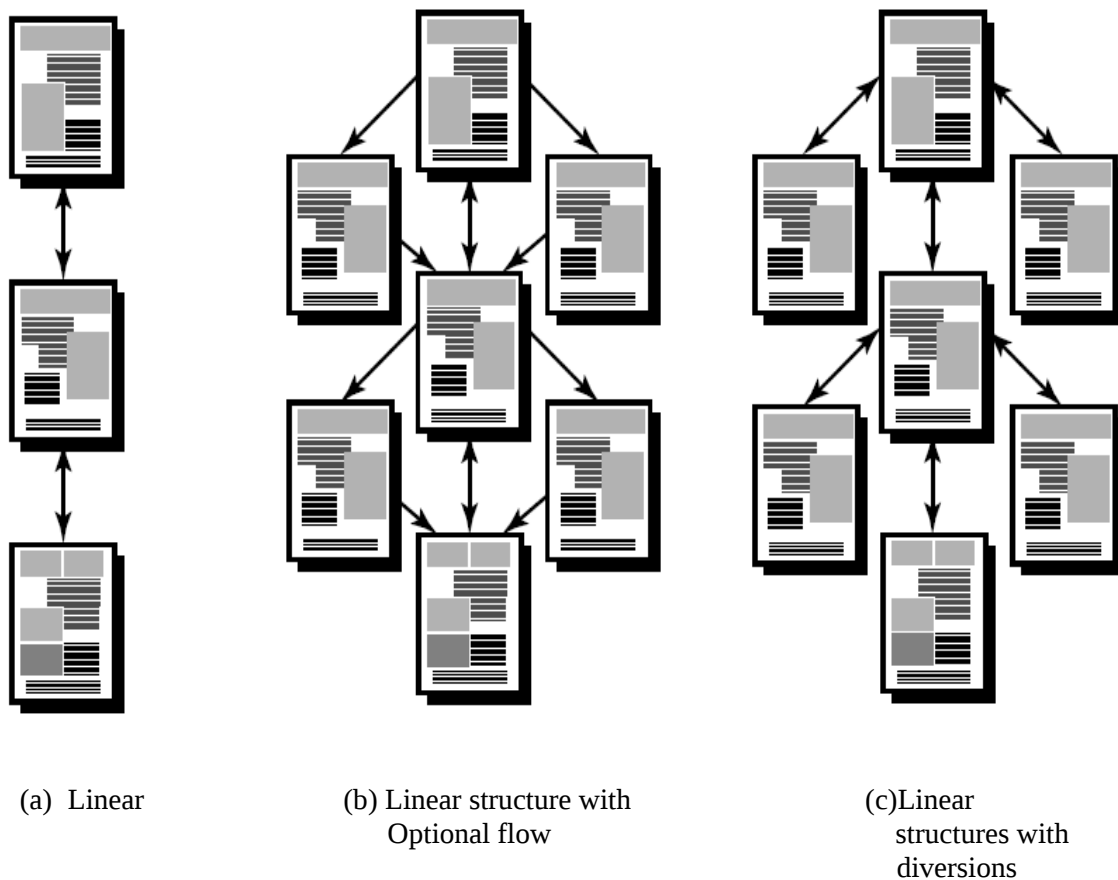


Figure 2 - Linear Structures of Web applications [22]

Grid Structures: When the contents of Web applications can be organized and categorized (vertically and horizontally) in two or more dimensions. These types of structures are useful in Web sites which contain highly regular contents [25]. The grid structure is shown in the figure - 3 [22].

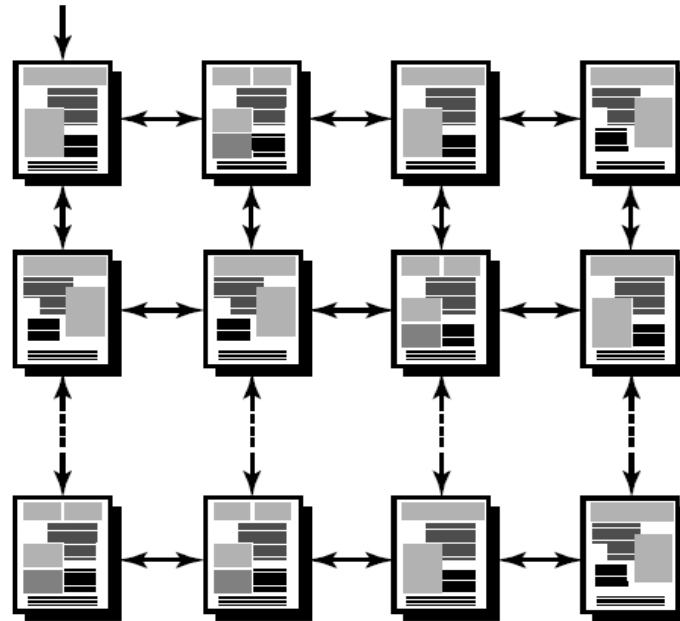


Figure 3 - Grid structures of Web-based applications

Hierarchical Structures: The hierarchical structure is most commonly used in Web applications. This structure facilitates horizontal flow control across vertical branches of the structure. This structure is shown in the figure - 4. Hierarchical structure allows rapid navigation and access to the different contents of the Web application.

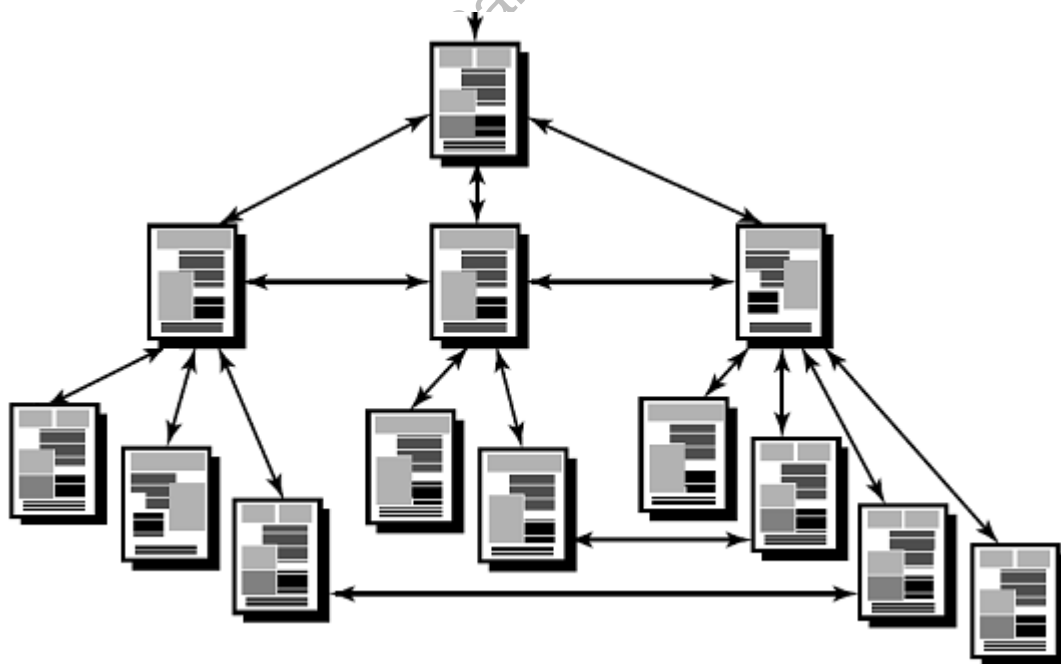


Figure 4 - Hierarchical structures of Web-based applications

Networked Structures: In such kind of applications the different Web pages (components) interact with each other (each component of the system has virtual link with every other component) by passing different controls. These kinds of structures provide flexible navigation but end user can be confused easily. The networked structure is shown in the figure - 5 [22].

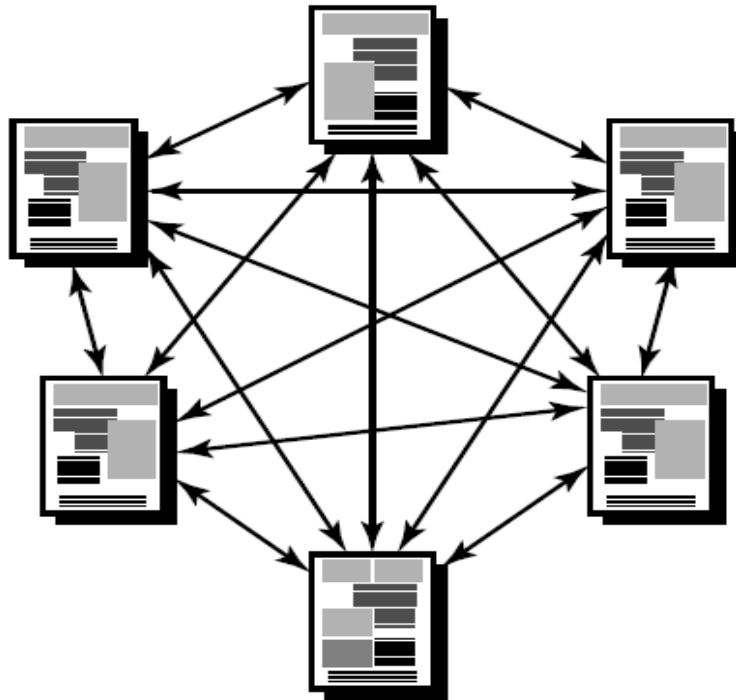


Figure 5 - Networked structures of Web-based applications

The design patterns of Web applications can be applied on the architectural level, component level and navigational level [22]. Architectural level and component level design patterns are used to obtain the data processing functionalities in the Web based applications and navigational or hypertext level are used to design the navigational features that provide the simplest and easy way to the end users to move through the different contents of Web applications.

3.4.1.1 Architecture of Web applications

These patterns also provide the architectural views of the Web applications. The architectures of the Web-based applications is rely on the technology popularized by the World Wide Web, the Hypertext Markup language (HTML), and its primary transport medium, Hypertext Transfer Protocol (HTTP).

At start of Web the architecture of Web applications were very simple. Figure - 6 [65] describes the simplicity of Web applications of that time. Client sends request through web browser to server and gets requested HTML documents from server in response. This system was only capable of navigation of mostly textual information in HTML form and it did not make use of server functionalities.

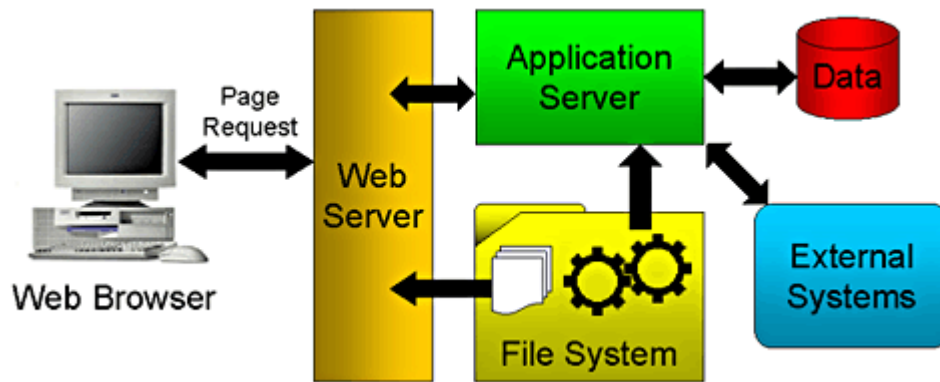


Figure 6 - A simple architecture of Web-based Application

According to [65], both HTML and HTTP define a typical architecture of the Web applications but a lot more components are involved in these applications. As technology grows, Web applications are also matured, complex and big in size. The architecture of complex application has divided in many components that linked together to make web application functional. Different scripting languages are used to develop these components and run on multiple computers. Figure 3.5 elaborate different components of web application and shows data flow in different modules of application. Some of these components are also belong to conventional client/server applications like file system, application server, data and external systems. Web server and Web browser are distributed and unique components to the web space. The client interacts with browser by clicking different links on it or by filling form fields to access Web server functionalities. Browser transmits the input of client through HTTP protocol to web server. Now it is the duty of Web server to entertain the request, if the request consists of static pages or media files then web server handle it directly otherwise it invokes the application server. In the second case application server executes the active pages and returns static HTML pages to Web server. Then web server returns these pages to browser. These pages may also contain client side script which is directly executed on web browser and shows results to client.

The typical architecture of Web application is based on three-tiers or n-tiers as shown in figure - 7 [57]. This architecture of Web applications includes presentation tier, business tier, data access tier and data tier.

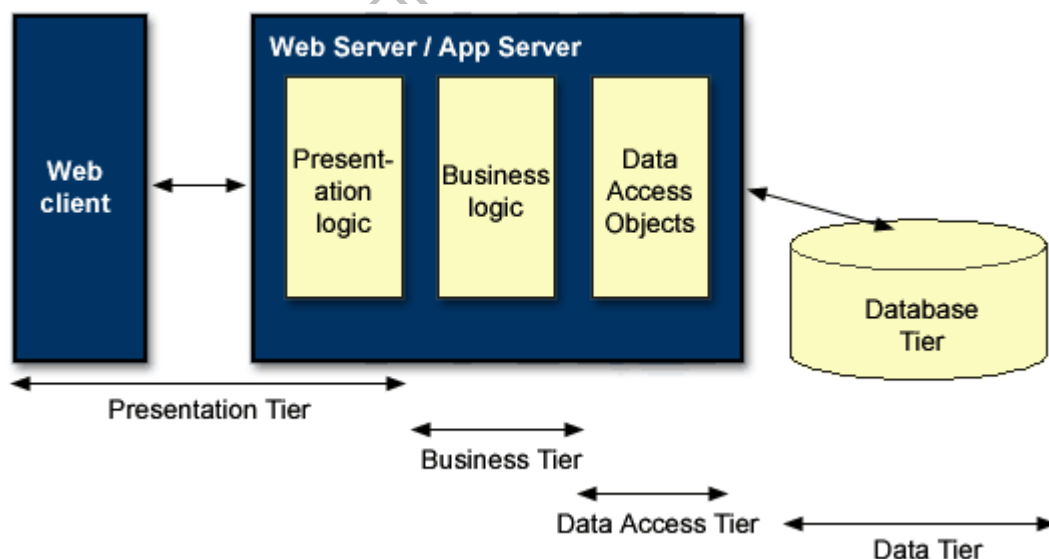


Figure 7 - Typical architecture of Web-based applications

3.4.2 Navigation

The navigation provides the pathways to the end users to access the different contents and services of the Web applications. The role and complexity of navigational links depend upon the size of Web applications. Large Web applications normally have different categories of end users who have different roles to perform. These users can be visitors, registered users or privileged users. Semantic navigation unit is created by the software designer for each goal associated with each type of user role. This semantic navigation unit is composed of different sub-structures that provide different navigational paths to each category of users to achieve certain goals and desired sub goals.

3.4.3 Interface

The interface of a Web application is its first impression and it provide the communication way between user and Web application. It provides great flexibility to the end user to perform their specific tasks. The user interface of Web application has the great importance and poor interface design of Web application result into the loss of customers and consumers.

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CHAPTER 4: QUALITY ASSURANCE AND TESTING OF WEB-BASED APPLICATIONS

4.1 Quality Assurance of Web-based applications

The success of software engineering depends upon the delivery of high quality software. Quality is one of the key factors in the market growth and success of a product. In recent years, quality of software product and quality in service has become principles for many corporations and organizations to distinguish themselves from competitors and to cover larger market place. Quality is an ambiguous word; means there are lot of definitions available for quality. According to IEEE, quality is the degree to which software meets customer or user needs or expectations. The simplest definition of quality is in the mean of customer satisfaction. Robert Glass [28] summarize the customer satisfaction in mathematical equation as

$$\text{Customer satisfaction} = \text{compliant product} + \text{good quality} + \text{delivery within schedule and budget}$$

He also argues that quality is an important factor in the development of a product, but if the customer is not satisfied then nothing else really matters.

Quality assurance includes all the process-related activities to achieve the quality. It is involved from the start of a project. In other words we can say that it is an umbrella activity which is applied on each step in the software development process. It controls the insight and oversight quality of the software. According to [23][27], Software quality assurance include the following important elements and methods.

- Quality management approach
- Effective software engineering methods and tools
- Formal technical reviews applicable to whole software process
- Effective testing strategies and techniques
- Procedures to control documentations and changes in it
- Procedures to assure compliance to standards
- Mechanisms for measurement and reporting

In 1990's mostly Websites were typically static and composed only of Web pages stored in some file systems that were connected together through hyperlinks. The main aim of Websites was simply to provide information across the Web in a simple plain and intuitive way. Therefore at that time, quality assurance was a relatively unchallenging and simple task [26]. Now Web has become the essential part to many software applications in various parts of the businesses and organizations. The dependency of people on Web applications is increasing continuously due to which the Web systems have become more and more complex. These applications are increasingly integrated in business strategies of small and large organizations. Therefore quality, reliability, accessibility, usability, adaptability and functionality have become very crucial and important factors for the Web applications. The process of Web engineering is used to develop the high quality Web applications [23]. It defines the specific techniques, methodologies and models to develop Web-based applications. The main aim of engineering of Web-based applications is to attain and produce high quality software products. Quality assurance of Web-based applications is very

crucial and vital to achieve the high quality. The quality assurance of Web applications is the responsibility of Web developers and Software quality assurance group.

To ensure the quality of Web applications the development team should follow the above mentioned methods of software quality assurance [23]. That is, Web developers should follow the quality management approach, effective software methods and tools, formal reviews, effective testing strategies and techniques, follow the standards and usage of appropriate mechanisms for measurement and reporting.

4.1.1 Quality attributes of Web-based applications

Different persons (end-users of Web applications) have different views and opinions about the good Web Application. These opinions and views depend upon the end user and vary widely, because some individuals like flashy graphics and some want simple text. Some users want detailed information and some only like short and abbreviated presentations. It is fact that the user perception of likeness of Web application might be more important than any technical discussion of Web applications quality. This raises the question about the perception of quality of Web application and about the different attributes that must be exhibited to achieve goodness in the eyes of the end-users and also exhibit the technical characteristics of quality that enable the Web engineers to enhance, adapt, correct and support the Web application over the long term. [23]

Almost all general quality characteristics can be applied to Web applications but the most important and relevant quality attributes are prepared by [29], who developed a quality requirement tree that identifies a set of attributes that lead to develop high quality Web applications. The figure 8 shows this quality requirement tree for high quality Web applications.

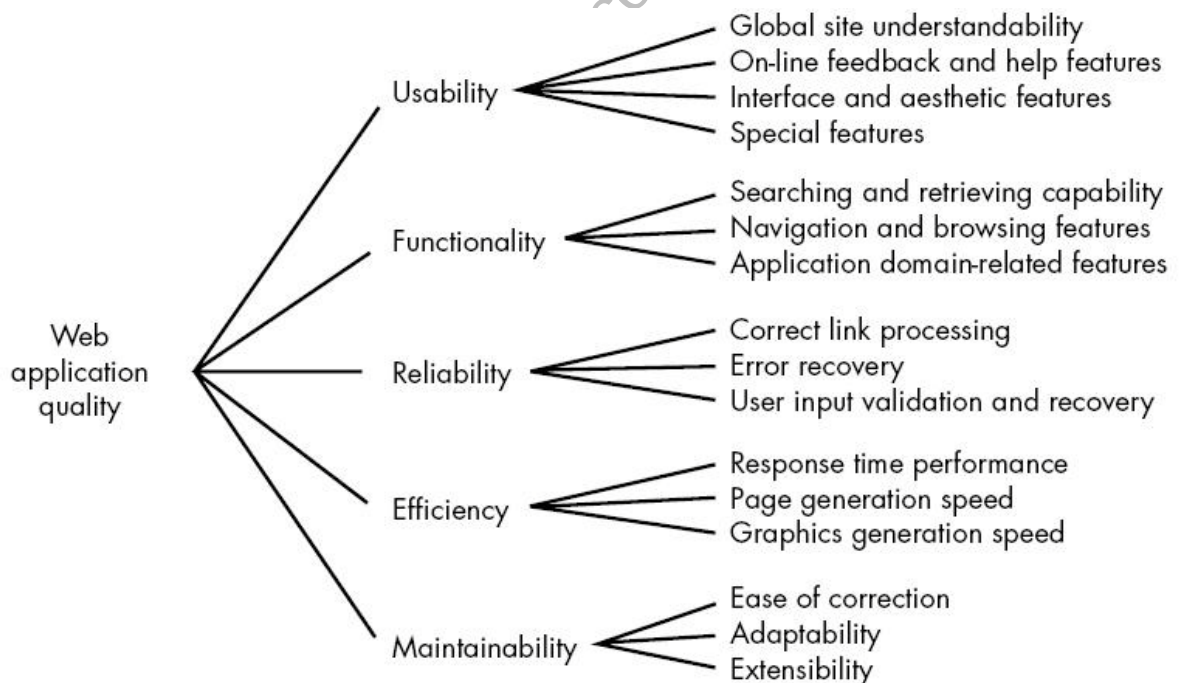


Figure 8 - Quality Requirement Tree [23]

4.1.2 Quality assurance enabling technologies

In order to build reliable and high quality Web applications the Web engineer should be familiar with the quality assurance enabling technologies. These enabling technologies are component based development, internet standards and security [23]. The brief description of these enabling technologies is as under:

4.1.2.1 Component based Development

The explosive growth of Web-based applications has evolved the component technologies. The available famous infrastructure standards for web development are CORBA (Common Object Request Broker Architecture), COM/DCOM (Component Object Model/ Distributed Component Object Model) and JavaBeans. These different standards are helpful to deploy and integrate third party components and to develop custom components to communicate with each other and with other system services.

4.1.2.2 Internet Standards

Internet standards are specifications which are stable and well-understood, has multiple, independent, and interoperable implementations with operational experience and recognizably useful in some or all elements of the Internet [30]. In early 1990's HTML (Hyper Text Markup Language) was the dominant standard to develop Web applications but now the Web applications have become more complex, their size is growing, therefore new standards have emerged. XML (Extensible Markup Language) and XHTML (Extensible Hypertext Markup Language) are new standards that have been adopted to develop next generation Web applications. These standards allow developers to define their own custom tags to describe the content of Web pages in Web applications. By following these standards the quality of Web applications is increased in the mean of robustness, interoperability, integration, functionality, reliability and accessibility.

4.1.2.3 Security

When our application deployed and launched on the network or Internet, there are great risks of unauthorised used. There are great threats of vulnerabilities. The hackers try to unauthorised access in the intent of some profit or for some other aims. Sometimes internal personnel can be involved in unauthorised access of particular application for their specific benefits and aims or malicious intents. Therefore security measures are very important to build high quality Web applications. A lot of security measures are being applied to minimize the threats of vulnerabilities and malicious use of the particular applications like firewall, encryption, and other security policies.

4.2 Testing of Web-based applications

Along with other quality assurance activities, one of important and critical element or component of quality assurance is testing. Testing has great importance to develop high quality software products and its importance and implications cannot be overemphasized. Testing represents the final review of specification of the system, design of the system and implementation of the system. According to [1], Testing is the process to execute and inspect the program with the intent of finding errors.

Web applications have become the crucial components of our lives. The importance of these applications cannot be overemphasized. These are crucial vehicles for information exchange, commerce, and a host of social and educational activities. The rapid evolve, complex and ubiquitous nature of Web based applications are the major hurdles to achieve the high

quality. Mostly ad hoc methods are used to achieve the quality of Web based applications. These methods and techniques are important to understand and improve the quality but due to the growing complex nature of Web-based applications more systematic methods and tools are required.

Different formal technical reviews and other important activities of quality assurance are helpful to uncover the errors but are insufficient. Testing is considered as tedious procedure in the Web applications development and mostly it is neglected by the Web engineers due to the short development schedule of these applications. But it is fact that today most organizations rely on Web applications more than ever to provide manage information with strategic and operational importance, and services to customers and end-users. This increased the awareness of the importance and of testing Web applications as a critical and crucial activity. The testing is the key process and activity of the quality assurance and in the development of Web-based applications. The process of systematic and well planned testing has the greater possibility to uncover the errors and to ensure the high quality of Web-based applications.

Testing is the most applicable method to verify the performance and functional requirements of the applications. It is one of the most important processes (phase) in the software development life cycle because it ensures the quality, stability, adoptability, sustainability and acceptability of Web-based applications. In other words we can say that it include all verification and validation activities of the Web applications.

4.2.2 Testing Challenges to Web-based applications

The main aim of testing Web-based applications is not different from the testing of conventional software applications. That is to find out the errors and bugs in the applications before deployment on Internet, or Intranet. Due to the enormous involvement of different interdependence Web components, the complex nature of applications, heterogeneity and distributed nature, we can find plenty of bugs and errors in Web applications. We can find more errors but how? It's a very big challenge in Web-based applications because the importance of rooting out errors in Web applications cannot be understood.

Due to the large number of different elements and a lot of interdependent components of Web-based application the Web engineer faces many challenges during the designing and testing of these applications. Many assumptions about the environment, platform and other resources are required. Web-based applications are error prone and have many failure points that must be considered before designing and deploying the testing approach. Following are the few major challenges regarding testing of Web-based applications: [1]

The enormous and varied users: The Website provide the user interface of the Web application to the end user and these end-users possess different skill sets on the Website by employing a variety of different browsers by using different operating systems and devices. The user can access the Web application using a wide range of connection speeds.

Business Environment: The business environment play major role in the testing of web based applications in case of e-commerce Web application a lot of issues like tax calculation, shipping costs determination, completing and executing financial transactions, tracking of customer profiles.

Locales: The user of Web-based application can be of any nationality and country therefore the internationalization issues such as language translations, time zone considerations, and currency conversions are the big challenges

Testing Environments: To test the Web applications is very expensive and time consuming because we need a duplicate of the production environment. That is Web servers, application servers, and database servers that are identical to production equipment are required to ensure the quality and test the Web applications. For best testing results, the duplicate of network infrastructure is also required. In case of financial transactions application testing we need all the duplicate resources (software and hardware) to ensure the high quality of the application.

Security: Security is one of the biggest challenges in the Web-based applications, because the Web application is open to world after deployment on the Internet or Intranet. Therefore protection from unauthorised access is very crucial; otherwise hackers can attack to the application and can rip off the customers' personal information and credit card information.

Integration testing challenge: Enormous different Web components are involved in the Web based applications. These Web components are developed by different vendors and are integrated to the applications according to the business need. The integration of these components can result in the malfunctioning; therefore integration testing of these components has great importance and is one of the biggest challenges for the Web engineers. The issues of integration and integration testing are discussed in detail in next chapter.

Compatibility issues: It is one of the significant challenges to test the Web application that is the browser compatibility, because a number of different browsers are being used in the market today and each has its own behaviour. There are standards existing for browser operation but most vendors try to enhance their browsers to operate in a non-standard way. The integration of different Web components also raises the issue of compatibility because there are different components of different vendors are used and that might not compatible with each other.

Interoperability issues: When the Web based applications are developed through integration approach of different technologies then the issues of interoperability like seamlessness, scalability, reliability, performance and security are apparent. So interoperability testing is very crucial to ensure these attributes and high quality. But interoperability testing is itself a big challenge. The issues of interoperability and interoperability testing are discussed in next chapter.

There are a lot of more challenges associated with Web based applications, for instance, performance, usability, scalability, conformance, reliability and system testing, and detail of which is beyond the scope of this thesis work. Most testing challenges depend upon the nature of the Web applications. More complex the Web application, more effort will be required to test the Web application.

CHAPTER 5: INTEGRATION AND INTEROPERABILITY TESTING

The enormous growth of Web-based systems and applications has revolutionized the software development. These applications have effects on almost all types of enterprises, businesses or organizations (governmental, educational, industrial, scientific etc.). Each of these organizations and businesses, develop different systems with multiple technologies. These systems interact among themselves within their related organizations as well as with users. Currently, different enterprises and businesses are integrating their systems to provide better services to their customers. These new trends and evolution has made these systems (Web-based applications) more sophisticated and complex than ever.

The terms integration, interoperability and interface frequently occur when we discuss different approaches through which two or more different systems, components, organizations or businesses can work together. We are discussing integration (along with integration testing) and interoperability (along with interoperability testing) in details.

5.1 What is Integration?

Integration is the process of combining and joining data, information, software components, subsystems and business process into large scale single system (Web-based application) [44]. The system should be single Web application, enterprise application or B2B application. According to [46], the process of integration begins with start of development phase when only two lines of code is written and it is considered that this process completes when the full system has been built, installed and tested. The need of integration of software components, subsystem and business process is increased due to requirement of developing large scale Web-based applications and reusability of existing subsystem to reduce the cost.

5.2 System Integration

As the technology changes, organizations have more concerned to adopt new technologies to become more competitive. Now organizations are carried out more efforts on system integration to revolve around new technologies and minimize the cost and failures [44]. Integrated solutions not only demands less effort and cost but also provides global environment of association between the workers. The integration of technologies with new business processes also facilitates employees, organizations and their competitors to share data and information regardless of their locations [45].

There exist numerous different definitions of system integration in literature and industry but no one is uniform and complete. Different researchers and vendors have different point of views in defining the system integration. But large number of researchers and vendors define system integration as “What to integrate and how to integrate” [45]. System integration is the process of joining the subsystems physically or functionally to make them one functional system [44]. The subsystems may be different software components or modules and small/large scale applications. System integration is also providing the way to integrate new technologies into existing system and to join new and existing subsystems by gluing their interfaces together.

According to [45], the term system integration was restrained to technical aspects of hardware and interconnectivity of computing components. Mechanically integration had

implication of making different pieces of equipment work together. Integration had started to include in software, data and communication with the increase involvement of industry and information. These days system integration has fully evolved in business process, information/ knowledge sharing and management, organizational structures and interactions.

5.3 Levels of Integration

According to [61][62][63], integration can be classified in terms of levels at which it implements. There are different approaches used by organizations to perform integration, but most commonly categorized levels of integration, are namely as platform, presentation, data, application and process level integration.

5.3.1 Presentation Integration

At this level data and information from different IT resources are combined and displayed in a single view. This provides facility to employees and customers within the organization to access data from one source. Web-based solutions are example of these systems which provide information about customers accessed from different subsystems such as stock, bank and other business departments.

5.3.2 Data Integration

Data integration provides access to data from different databases in such manners that all the databases are synchronized. According to [61], data integration consist of database gateways and data warehouses which provide access to databases by using structured query language and tools of extracting data. If databases have one or several same records, updating the record in one database should also automatically update other databases due to synchronization of databases. By integrating different database systems together we can manage, transfer and update data in a secure and fast way. Integrated solutions of database systems manage, transfer and update the data in a secure and fast way.

5.3.3 Platform Integration

Platform integration is used to make connection between hardware, operating systems and applications. According to [61], technologies like messaging, Remote Procedure Calls, Object Request Brokers (ORB) and publish and subscribe mechanisms can be used to apply platform integration. Implementation of platform integration by using messaging technology and Remote Procedure Calls can only provide asynchronous and synchronous connection between hardware, operating system and applications. Object Request Brokers that combine message and Remote Procedure Calls provide both type of connectivity (synchronous and asynchronous).

5.3.4 Application Integration

Applications integration provides the way by which one application can make use of the features or functionalities of other applications, which are integrated together as big Web applications or other large scale systems. Application level integration is implemented by using set of different technologies such as event and application interface integration, etc. Event integration can be implemented through message brokers; the technology used in platform integration, that provides different operation on data like translation, transformation and rule based routing [61]. Application interface integration is performed through application adapters; that provides the usage of Enterprise Resource Plan (ERP) packages

such SAP and PeopleSoft [62]. Application integration reduces the cost and time duration of projects by reusing functionalities of other applications.

5.3.5 Process Integration

Process integration basically refers to the association of processes/ business processes such as B2B, and facilitates organizations to interact with their business partners with highest level of abstraction [62]. This level of integration is performed with help of middleware products and this integration provides ease to business managers to define, update and examine business processes by using graphical modeling interface and declarative languages. Business manager can also make changes in existing integrated solution to regenerate it by changing business model through same graphical interface and declarative language [61].

5.4 Methods of Integration

Integration improves the efficiency of organizations through increased automation and according to [61], there are three basic methods to perform integration based on tools and technologies described above in levels of integrations.

Method used to perform integration between different subsystems and functionalities of business process, is referred as vertical integration.

Method used to perform integrations between different system controls and managerial subsystems, is referred as star integration.

Method used to perform integration between the systems of different organizations is referred as inter organization or horizontal integration.

5.4.1 Vertical Integration

Vertical integration is the process of aggregating different subsystems according to functionalities of subsystems involved in the integration [64]. This method provides cheapest integrated solutions by creating functional entities, but reusability of subsystem to generate new functionalities is not possible through this method. To generate new or improved functionality, there is only one possibility that new or other functional entities are used to perform integration. It provides quick and cheap way to perform integration by providing information of only necessary vendors.

5.4.2 Star Integration

It is the method of integration by which each subsystem makes directly connection with all the remaining subsystems involved in the integration process [64]. It is also called spaghetti integration due to its nature of linking every subsystem with others, so over all shape of this network looks also like spaghetti. The cost of this method depends upon the subsystem, what types of interfaces are they used during the integration process. The cost will be rise if vendor-specific interfaces are being used to perform integration instead of ownership-specific interfaces. The ultimate benefit of this method is the possibility to generate new functionalities by reusing the functionalities of existing subsystem.

5.4.3 Horizontal Integration

In this type of integration, different components and subsystems of Web-based applications are connected with specialized subsystem communication path (bus) to interact with each other [64]. This method is also known as enterprise service bus and provides cheap way of integration to combine different software components or subsystems. Addition of specialized subsystem bus reduces the number of connection between the integrated subsystems; each subsystem requires only one connection interface with bus to communicate with other subsystems and the bus has ability to translate one interface to another interface. This reduces the cost and complexity of the connection interfaces involved in the integration of subsystems. This method integrates the components in such flexible way that one subsystem can be replaced with other subsystem having the same functionality and this activity requires only the change in interface of subsystem with bus.

5.5 States of Integration:

According to [45], there are four states of system integration; each one of them has its own definition, behaviors, mechanism and criticality. Every state has been applied to particular circumstances/situations of an organization. It is important for an organization to think about states of system integration while considering what is integration and how it will be applied.

1. Interconnectivity
2. Interoperability
3. Semantic consistency
4. Convergent integration

First three states depend upon the technology and its status. The fourth state is the most important and complicated than others. It represents the convergence of technology, human performance and information.

5.5.1 Interconnectivity

It is basically the root state of integration and it establishes the base for other states. Interconnectivity makes it possible that different equipment and technologies work together, and performs tasks such as data sharing, file transferring, connection establishment between different components or subsystems and defining paths to share information without affecting functionality and application structure [45][38][47].

5.5.2 Interoperability

Interoperability is the ability of different components, systems, applications, and services to function with each other in such a way that every component, system, application or service can utilize the capabilities of each other [45]. This level of integration provides the facility to update and functional other subsystems and interfaces with other databases. We discuss the interoperability in section 5.9 in detail.

5.5.3 Semantic consistency

One of the most important and crucial phases in the development of enterprise and Web-based applications is to implement database management systems because it requires the most part of effort and investment provided during the whole process of development [45].

According to [38], semantic consistency integration cannot be attained from simple implemented database management system but it also requires that data should be efficiently modernized and well defined to user. This level of integration provides validation of data and conditions, facility to access data and diminishing the chances of human errors in the interpretation of data by standardizing data formats and definitions.

5.5.4 Convergent integration

This state of integration is the most important and complicated than the other states. It corresponds to the integration of technologies with new or existing business process, information systems and human performance [47]. There are seven prerequisite factors of convergent integration to perform integration of new organizational designs and practices; [47][45]

- Integration of different technologies
- Integration of applications and software
- Data and data repository integration
- Communication network integration
- The design and integration of new business processes with new technical capabilities
- The embedding of knowledge in new business processes and enabling technologies
- The integration of human performance with new process

5.6 Integration Testing:

In the modern time, integration of existing and new software components is playing key role in development of large and complicated Web based systems but it is very difficult to ensure that software components are integrated properly [48]. The purpose of integration testing is to make sure that modules and their interfaces in an application interact with each other in a correct and secure way. Integration testing is also known as module level testing but it should not be mixed with concept of system testing. Basically integration testing is based on functional requirements specification and design which are used as an input in integration testing process. Theoretically many integration testing techniques are available but some of them only give the proper guidelines to make correct test cases such as bottom-up, top-down, black box, sandwich, incremental and big-bang. Integration testing covers following types of concerning areas during integrating different modules:

- Calls of different software components, while interacting to each other
- Data and information sharing between the modules in proper manners
- Compatibility, which ensures one module that does not effect on the performance and functionality of the other modules.
- Nonfunctional issues

According to [49], it is important that integration testing should be conducted in development environment or separate testing environment instead of live environment. Most of the times, integration testing is done by the development team supervised by development team leader and a person from quality assurance group. In such circumstances the responsibility of development team leader is to ensure that integration testing must be progressed with suitable choice of test techniques. The development team leader then provides results of testing to the test team leader.

5.7 System Integration Testing

The purpose of system integration testing is to make sure that interoperability between different applications/systems is successfully performed [48]. It is also important that applications under test do not produce any affect on the functionality of other systems. In such situations when application under test has limited or no existence of interoperability with other systems then there is possibility to perform system integration testing and system testing simultaneously [48]. During the system integration testing high level of interoperability requirements of systems will be tested without considering internal structure of the application under test. It is suggested that system integration testing should perform in the live environment and exploit live date; otherwise ensuring the correct results of system integration tests is very critical [48].

There are many techniques to perform system integration testing such as top-down, bottom-up, fault based and error guessing techniques, black box and white box testing techniques etc. According to [59], to perform system integration testing requirement specification, design document and test cases are used as basic inputs. The emphasis of system integration testing is to test high level interoperability and performance of systems so that it is conducted by the highly skilled testing team under the supervision of testing team leader. It is the responsibility of testing team leader to take care of that the correct techniques have been followed during testing process. System integration testing ends with completion of full functional system and ensures that tested and verified system will be produced.

5.8 Integration Testing Challenges

The size of Web applications are growing due to involvement of new emerging process like business processes and highly secure requirements from customers. The existing integrated solutions are the cheapest and fast way to develop such kind of large Web-based applications. But testing of such application is complex task due to its large size, integration of multilingual components and use of different operating systems. The most important and commonly known challenges during integration testing are: [66]

- Inconsistent Infrastructure and Environment
- Inconsistent Interaction Models
- Distributed Nature of Systems
- Performance and Reliability issues due to Heterogeneity
- Interoperability

There are different approaches and techniques of integration testing are available in the industry and academia to tackle these testing issues.

5.8.1 Inconsistent Infrastructure and Environment:

Web-based applications consist upon number of different heterogeneous components and run on diverse environment. It means, heterogeneity is one of the key features of Web-based applications. According to [66], heterogeneity may introduce the incompatibilities between different programming languages, databases, different operating systems and external operational environments involved in development and deployment of Web-based applications. Complex integrated solutions consist upon different software components which are developed by using different programming languages and technologies. The assurance of compatibility and interoperability between these components is one of major concern during the testing process. Databases are the most important components of Web-based applications for the management and flow of data. Different types and versions of

databases are available in the market such as MySQL, SQL Server and Postgre etc, so there is always chance of incompatibility issues among the different databases and software components that access these databases. The assurance of compatibility between different software, operating systems and operational environments are also very critical tasks.

5.8.2 Inconsistent Interaction Models:

Web-based applications are based on number of different Web components which are developed by different group of teams by using different methods and approaches. According to [66], in complex Web-based applications, control protocols and data models play key role in the reliable communication and interaction among different integrated subsystems. Control protocols are responsible of defining rules that how integrated components interact to each other. Data models define the contents and format of communication between them. Since Web-based applications can be based on number of different components and most of the time different groups of developers are involved in development process. They may have different views and assumptions about the development of those components and their interaction (i.e. control protocols and data models) with each other. Except these constraints; different components of Web-based applications may expose multiple interfaces that can vary these constraints and also change the type of the relationship between the components.

5.8.3 Distributed Nature of Systems:

Web-based applications are mostly developed under distributed environments, so the issues related to distributed systems such as race condition and dead lock can be inherited [66]. Distributed nature of systems can have great impact on working of Web-based applications and these issues can be solved during integration testing. Existence of more than one versions of same software component generates multi version issues in system.

5.8.4 Performance and Reliability issues due to Heterogeneity:

Testing of Web based application and assurance of key quality feature are challenging task for testing team and to achieve guarantee of these features required most of the testing effort. Performance and reliability are the key quality features that can affect the overall working and presentation of Web application. The assurance of this quality feature also produce good impact on customers and users of Web application. Heterogeneity allows integration of different subsystems or components that are developed in different programming languages, under different platforms and environments that can be achieved through standardization [66]. The process of standardization produces the extra overhead during communication of components and this overhead causes the degradation of performance and reliability of whole application.

5.8.5 Interoperability

Interoperability is the ability of two or more systems, applications or components to exchange information and to use the information that has been exchanged [31]. Interoperability itself is a critical testing challenge which has further challenging factors and characteristics. The detail of interoperability is described in section 5.10.

5.9 Integration Testing Approaches

The understanding of the theory of challenging factors of integration testing, their causes and their importance is very crucial before making the integration testing strategy. The integration testing strategies should be applied from the requirement phase and be continued until release. The major integration testing approaches available in academia and used in industry are;

- End to end integration testing
- Increment/Decrement approaches
- Open source testing
- Model based testing
- Coupling-based testing
- V model
- System testing
- Big bang testing

5.10 Interoperability

When different enterprises are integrated, the systems and technologies of each enterprise are required to be integrated transparently and seamlessly to share whole information with different structures and formats. The sharing of information transparently and seamlessly is very complex requirement which raises the issues of compatibility and interoperability. Interoperability is a broad concept and a lot of definitions exist both in academia and industries. The few definitions of interoperability are;

According to IEEE [31], interoperability is the ability of two or more systems, applications or components to exchange information and to use the information that has been exchanged.

According to [32], interoperability is the ability of systems, components, units or forces to provide services to and accept services from other systems, components, units or forces, and to use the services so exchanged to enable them to operate effectively together.

According to IDABC (Interoperable Delivery of European eGovernment Services to public Administrations, Business and Citizens), European Interoperability Framework [33], interoperability is the ability of information and communication technology (ICT) systems and the business processes they support, to exchange data and to enable sharing of information and knowledge.

According to [36], interoperability is the ability of two or more different systems or components to exchange and use shared information and also the ability of systems to provide and receive services from other systems and to use the services so interchanged to enable them to operate effectively together.

In the field of eHealth applications [34], *“Interoperability means the ability to communicate and exchange data accurately, effectively, securely, and consistently with different information technology systems, software applications, and networks in various settings, and exchange data such that clinical or operational purpose and meaning of the data are preserved and unaltered”*.

Interoperability is a multi-faceted and multi-level concept. To obtain true interoperability, we need to understand its whole theory. Numerous frameworks are present in the academia to categorize the types or levels of interoperability. These levels should be addressed sequentially or linearly from lower level to upper level to achieve true and successful

interoperability. But, there are few exceptions where the linearity is loose and certain characteristics of upper level interoperability type may become available without fully addressing all the lower level of interoperability types. For instance, organizational interoperability level introduced by [33] shows loose linearity with regards to proposed lower semantic and technology interoperability levels. [37]

There exist numerous models which present the different levels and types to achieve successful interoperability. In following, we discuss few of these models briefly. One of the interoperability model used in USA [38] is LISI (Levels of Information Systems Interoperability) which classify the five different levels of interoperability. These levels are;

Level 4

Universal Systems

Enterprise level shared systems

Level 3

Integrated Systems

(Shared applications and data)

Level 2

Distributed Systems

(Different heterogeneous products can exchange)

Level 1

Connected Systems

(Different homogeneous products can exchange)

Level 0

Isolated systems

(No physical or electronic connection exist)

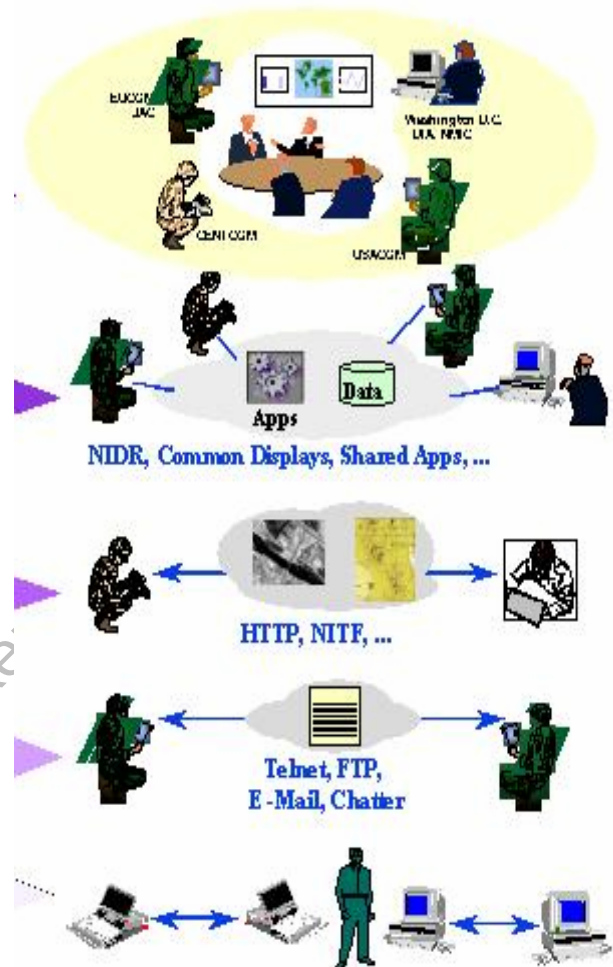


Figure 9- Levels of LISI model

There are four attributes defined in LISI which affected by the above mentioned five levels. These attributes are; Procedures, Applications, Infrastructures and data.

Another model of interoperability is NMI (NATO C3 TA Model of interoperability) [39], which also define the five levels or layers of the interoperability;

Level 0: *No Data Exchange:*

There is no physical connection exists between systems

Level 1: *Unstructured Data Exchange*

In this level connection exists between systems and unstructured data i.e documents are exchanged.

Level 2: *Structured Data Exchange*

The structured data is exchanged, network management

Level 3: *Seamless Sharing of Data*

The system are managed and based on common exchange model, automated data sharing , security,

Level 4: *Seamless Sharing of Information*

Universal interpretation of information through cooperative data processing

A lot of other models are available in the literature [40] [41] [42] [43], which define the different levels of interoperability in different perspectives. One of the other popular models [37] defines the following three main categories or types of interoperability. These categories are channels interoperability, information interoperability and process interoperability.

5.11 Types of Interoperability

One of the other popular models [37] defines the following three main categories or types of interoperability. These categories are channels interoperability, information interoperability and process interoperability.

5.11.1 Channels level Interoperability

It is also known as connection interoperability and it is defined as the ability of information system to exchange data and information in terms of signals [37]. It is the basic type of interoperability and provides the mechanism to establish connections (both physical and logical) between two or more systems. The information is exchanged between the systems through reliable communication channels or mediums. There are certain standards, protocols and specifications are used to ensure interoperability to transfer information on multiple networks. The OSI reference model (TCP/IP) is the example of this. This type is also known as technical level interoperability.

5.11.2 Information Interoperability

Information interoperability is the ability of two or more different systems, applications, components and services that communicate, share and exchange data, information and knowledge effectively and accurately, as well as to integrate with other systems, applications, components and services in order to deliver new electronic products and services [55].

According to [37], at information level interoperability can be divided into further three types; Morphological interoperability, Syntactical interoperability and Semantic interoperability.

5.11.2.1 Morphological Interoperability

Morphological (also called structural) interoperability is the ability of systems to exchange information or data based on commonly accepted data formats [37]. In other words, we can

say that this type of interoperability ensures that exchanged data is in same structures and formats.

5.11.2.2 Syntactical Interoperability

Syntactical interoperability is the ability of systems, components, applications to present and interpret the exchanged data in the same way on both ends. It is an application level interoperability which allows several different software components, services to co-operate with each other regardless their interfaces, implementation languages and execution platforms [52]. There are number of standards and solution are proposed and available which are used to tackle the syntactical interoperability issues and problems. For instance, XML, Web Services are used to resolve many application level interoperability problems and issues [52].

5.11.2.3 Semantic Interoperability

The achievement of successful semantic interoperability is very important and it plays key role to provide quality information services in Web-based applications. According to [54], semantic interoperability is the ability of different information systems, components, applications and services to exchange information on the basis of shared, pre-established and negotiated meanings of terms and expressions. In other words, we can say that it is knowledge level interoperability that links semantic conflicts from difference in meanings, perspectives and assumptions between different organizations and businesses and provide a semantically compatible information environment based on the agreed concepts [52].

Semantic interoperability is one of the challenging tasks in heterogeneous Web-based applications. Numbers of different semantic issues are involved in such systems that need to be resolved for quality information exchange between the systems. One of the main semantic issues is the difference in meaning between different systems (organizations, businesses, countries). For example, the information stored in one system in one organization or country can have different meanings as compare to information stored in the system of another organization or country. For example the grading systems in education system differ from country to country. Mostly, the semantic issues occur at data and metadata levels. In short, to ensure the semantic interoperability, there should be agreed rules and defined standards that represent the same meanings at different systems.

5.11.3 Process Interoperability

It is a top level interoperability which required when different businesses are collaborated and there systems and technologies need to be exchange information seamlessly and in affective way. According to [53], it is a business level interoperability that provides the facility to collaborative business partners the ability to achieve common objective and create mutual benefits through purposeful exchange of information. Process interoperability mainly relates the different methods of integration of different systems, applications, components and services to actual work environment and settings.

Process interoperability is emergent concept which requires a lot of knowledge of different businesses and their processes, which is beyond the scope of this research. Process interoperability is difficult to achieve. It can only be accomplished if the other interoperability levels (like structural, semantic) have been achieved. The Service Oriented

Architecture (SOA) and Web services can be used to achieve the process interoperability [11].

5.12 Interoperability Testing

Interoperability is one the most challenging tasks to tackle, because in current times, the Web-based systems are very complex and a lot of different heterogeneous components; like different applications, different operating systems, different components, databases and multiple protocols are involved. These different applications, components and systems communicate with each other in different environments, different programming languages, different data structures and interfaces. The assurance of interoperability of these heterogeneous systems is the most fundamental problem and challenge that needs to be solved other than security, usability, scalability, reliability and functionality etc. Interoperability and its consequences have become the key issues to be handling for the development of information system infrastructure [35].

Interoperability testing is used to ensure the seamless exchange of information between different components, applications, systems, databases and services which is very necessary to improve the quality of Web-based applications. It concern that how two components, applications, systems, services can interoperate with each other. According to [56], interoperability testing is assessment of a component, application, system or service to verify that it performs as expected while interoperating with other component, application, system, database or service.

Due to the complex nature of Web-based applications and involvement of many heterogeneous, distributed components many challenging factors are involved in the interoperability testing process. The major challenging factors are [59][60];

- Diverse information, data retrieval and operating systems
- Technical level issues (multiple protocols etc)
- Heterogeneity issues
- Semantic issues
- Organizational level issues
- Issues of different Implementation standards
- Seamlessness
- Performance
- Security
- Reliability
- Scalability

In some sense all of these issues are inter-related with each other and all should be solve to ensure the successful interoperability between different components, applications, operating systems, services involved in Web-based applications.

When we do the interoperability testing of Web-based applications, all these challenging factors and issues should be well defined and keep in mind of the testing team. The understanding of theory and causes of these issues, their impacts, their influence and their pros and cons should be well understood before applying the testing strategy. The interoperability testing strategies should be applied from the requirement phase and be continued until release. All the components should be according to the specification and standards. In other words we can say that interoperability testing involved two main things i.e. conformance testing and interoperability testing [56]. There are many different approaches are present in the academia to solve the challenging factors of interoperability. The major testing approaches are;

- Functional testing
- End-to-End integration testing
- Operational testing
- Path-based testing
- Fault-based testing
- Model-based testing

There are also other different approaches which are presented in the literature and academia and also beneficial for the interoperability testing.

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CHAPTER 6: THE SURVEY STUDY DESIGN

Industrial survey and interviews are used as data collection instruments to obtain required information [50]. The survey plays a key role to obtain and collect the data and information from the industry. In other words, it provides us great information about the current practices, methodologies, models and approaches used by the practitioners.

Currently, many different techniques are used for the data collection. These techniques are called survey. According to [51], the main purpose of conducting survey is to produce statistics and results, and these statistics and results are collected and obtained by asking questions to people (sample of relevant people).

According to [50], survey and interview are ways for the data collection which provide us option to conduct face-to-face, one-on-one, in person interview, conduct interview or survey through telephone, and through email and Web. We conduct the survey face-to-face, through telephones and through emails to collect required information regarding testing challenges in Web-based applications with respect to interoperability and integration.

6.1 Design of the Survey Questionnaire

The design of any survey or interview questionnaire plays an important role to collect and obtain required information. The design of our Survey Questionnaire study classify in the following different levels and parts;

6.1.1 Structure of Survey Questionnaire

Surveys and interviews are good way to collect the required information. but mostly these interviews and surveys are time consuming and problematic to collect and extract the exact required information [68], because it is possibility to get wrong, inappropriate or insufficient information instead of required information. A good structure of an interview and survey questionnaire is very important to collect the relevant required information. The questionnaire should be structured and designed in a systematic way and flow (logical flow) of the questions should be relevant, precise in order, simple and easy to fill. This can help the interviewee and respondent of the survey to provide better and precise information that we want to ask. The design and structure of our survey's questionnaire is also follow these flow and easy to understand by the respondent.

This survey questionnaire has the close ended questions which provide the respondent the multiple choices to answer the specific question which provide great help to the respondent. Along with this we have some open ended questions which encourage the respondent to express his thoughts, views and experiences. This further helps that what is going on in industry and what they want to do.

6.1.2 Target Audience

Our thesis is based on qualitative research which includes the thorough studies of literature and survey to obtain information and collect data from industry to observe and analyse the testing challenges in Web-based applications with respect to interoperability integration and how these challenges can be resolved. For this purpose we choose the personnel of 10 different organizations which are developing Web-based applications including;

- Project managers who are involved in the management of Web-based applications
- Senior Test Engineers involved in Web-based applications
- Seniors Developers who are involved in development of Web-based applications

6.1.3 Survey Questionnaire

We design and create our survey questionnaires through detailed literature review regarding testing challenges in Web-based applications especially with respect to interoperability and integration. We both group members discussed with each other in detail before making the survey questionnaires. We also discussed in detail with our supervisor regarding the survey questionnaires. After careful extraction of data we prepared the mixture of open-ended and close-ended questionnaires under the supervision of supervisor. The interview questionnaire is described in the Appendix A.

After completion of survey questionnaire, we started to contact with target companies and personnel. We target the organizations developing Web-based applications in Sweden, Denmark, and Pakistan and few other countries where we had the contacts. We contacted with the personnel of these organizations through emails, and phone and took the time for face-to-face meeting, on telephone meeting and in some cases through emails.

We soon started to get responses from the contact personnel and feedback from them. We started to extract and analyse the results carefully.

6.1.4 Relationship with Research Questions

We created the survey questionnaires carefully according to our research questions. We prepared each question in such a way that it provides us the exact information and data that we want and that help us in our research. Now we are briefly discussing our research questions and their relationship with survey questionnaires.

RQ1: What are the Web-based applications and what are the testing challenges involved in Web-based applications?

To investigate the answer of this research question, we perform a detailed literature studies to understand the Web-based applications, their purpose, their scope and their types. Along with this we also study that what are the testing challenges involved in such applications. To cover the testing challenges, we create the survey question to identify the critical testing challenges in Web-based applications that are being faced in the industry with their criticality level. We include the following mixture of close ended question along with open ended other option to know other testing challenges in the practitioners' views.

What are the most critical testing challenges in Web based systems? Please rank these with their criticality level. (1= Lowest and 5= Highest).

For further detail please see the Q2 in Appendix A.

RQ2: How interoperability and integration affect the Web-based applications?

We thoroughly study the literature and articles to understand what are interoperability and integration, why they are important in Web-based applications, what are their types and how these two have great affect on the quality of Web-based applications. To know the practitioners' views, we create the following survey close-ended question. We provide the respondent options in percentage to select one according to his experience and observation.

How much integration and interoperability have effects on quality of Web systems?
For more detail please see Q3. in Appendix A.

RQ3: What are the testing challenges associated with interoperability and integration of Web-based applications?

We explore and study thoroughly resources, articles, books and journals to identify the factors, issues and challenges in Web-based applications with respect to interoperability and integration. To know the practitioners' views we create following two questions both for testing challenges associated with integration and interoperability in Web-based applications.

What are the most critical issues of integration testing in Web-based systems? Please rank these issues with their criticality level. (1 = Lowest & 5 = Highest)

What are the most critical issues of interoperability testing in Web-based systems? Please rank these issues with their criticality level. (1 = Lowest & 5 = Highest).

For more detail please see the survey question no. 4 and 10. in Appendix A.

RQ4: How the existing testing approaches can be updated/ modified to meet the challenges in the areas of interoperability and integration?

This research question is the conclusion of our research, and to investigate this question through industry we include the Survey question number 18, 19 and 20. (Please see the Appendix A). To support our arguments and current testing approaches presented in academia with respect to interoperability and integration we also include additional questions which are very closely related to our research. To read these questions please see the Appendix A.

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CHAPTER 7: RESULTS OF SURVEY QUESTIONNAIRE

The results of survey questionnaire play key role to observe and know the views of practitioners and professionals about a specific problem(s). In this chapter, we present the survey results obtained from different personnel (professionals, practitioners) of different software organizations in different countries.

7.1 Brief Description of Companies

In this section we present brief introduction of different software organization where we conducted the survey. We conducted the survey in ten different software development and research organizations of different countries such as Pakistan, Sweden, Denmark and Belgium. These organizations are much matured in the field of IT and Web application development. We are presenting here a short description of the companies. We are using companies name as 'Company A', 'Company B' and so on instead of their original names due to privacy of those companies.

7.1.1 Company A

Company A is a software development company and matured especially in development of Web-based application. It provides broadcasting solution based on multi platforms such as Web-based, mobile and TV, for the propagation of sound and moving images. Company A also provides the services to the content provider and web publisher so that they can communicate with their audience by using moving image and streaming media technologies. They are now developing and updating their new and existing media system to provide facility to large scale organizations and media companies.

7.1.2 Company B

Company B is a Danish organization that provides the facilities of online maps for geographic information to the public and private sector. The company develops the solutions which covers geo data on Web about lands and water of the Denmark. The company has eight departments that handle and present geographical information to worldwide customers by covering the main fields of geographical work such as Reference Network, Topographic Data, Nautical Charts and Cadastre.

7.1.3 Company C

Company C is research group in Belgium which is doing research in the area of open, distributed object support to platforms, develop advanced applications and working with close industrial cooperation. This group now is working on different problems and issues faced by industry in area of computer networks, middleware technologies, distributed systems, embedded systems, multi-agent systems, security and internet middleware. The company is also member of IBBT (Interdisciplinary Institute for Broadband Technology) a research institute that has mission to bring companies and different organizations together to do research on eHealth, mobility, Enabling technologies and eGovernment.

7.1.4 Company D

Company D is Swedish software Development Company which not only develops Web-based application but also provides consultancy services to other small and large scale organizations. The company is consisting of small team of developers which are very highly experienced in the development and testing of Web-based applications.

7.1.5 Company E

This company is founded in 1993 and developing Geographical Information System (GIS) solutions based on products of ESRI (Environmental Systems Research Institute) GIS software. Company is also providing the services of Network Engineers and ArcFm and Designer. It is the largest company in Denmark which provides GIS solution and training of on the GIS technologies. They have the largest GIS support department where they provide advice and consultancy to their customers on the geographical issues. They have large team of skilled developers and service provider specialists in the field of geo data which provide the GIS solutions and training to small and large scale companies.

7.1.6 Company F

The company F is the leading service provider in software development and telecommunication. It has more than 10 years experience in software development. The company is developing number of major security and communication software. The company has more than 100 qualified and skilled employees in software development, finance and manufacturing and it is also providing the consultancy services to their customers in the different areas of telecommunication.

7.1.7 Company G

Company G is the experienced company in the development of telecommunication software and provides consultancy services to the other large and small companies in Pakistan. The company has large team of professional developers and testers to provide telecommunication solutions and services. The company introduced wide range of mobile content management and platform for user generated contents for social networks. The company is also providing the extensible tools and services for the content producers for creation of different mobile contents such as mobile multimedia storefronts, widgets and text messaging.

7.1.8 Company H

Company H is specialist in development of Web-based applications and offers different technical and managerial consultancy to its customers. The company is also providing IT consultancy services to the small and large organizations. It has experienced and multilingual skilled developers and testers to develop mature Web solutions.

7.1.9 Company I

Company I is the leading IT and service provider in field of software development and based in different countries. The company is working in the latest technologies to develop user friendly and modified mobile solutions for public and private sectors. The company is also providing maintenance, mobile GIS, healthcare security and tracking services to small and large companies and individuals. It has highly skilled and technical experts in both

development and testing teams in the field of communication, security, GIS, Global Positioning System (GPS), Bluetooth and tracking technologies.

7.1.10 Company J

The company J is a leading software development company which provides solutions to its customers in different countries. The company is basically providing the solutions and services for different business processes. It is serving 1900 customers all over the world and having the automated business processes more than any other BPM (Business Process Management) vender. The company's developed solutions are covering different sectors such as banking and finance, healthcare and pharmaceuticals, manufacturing, energy and utilities, government, education and insurance. The company has also many products like BPM suit, Process Designer and Process Template to solve the issues in different business processes. The development and consultancy team of the company consists of many skilled and experienced experts which are not only developing the solutions but also providing the services such as training, professional consultancies and global support to their customers.

7.2 Survey Results

In following subsections we are presenting the results of survey questionnaire which are obtained from the industry

7.2.1 Critical Testing Challenges in Web-based Applications

Testing is the one of the major and curial phases in the development process of Web-based applications to measure the qualitative and quantitative aspects of the application. Many critical challenges occurred during the testing process of Web-based applications. Table 1 presents some of the most critical issues arise in industry while testing Web-based applications. This table illustrates that companies and their results are placed in columns and testing challenges faced by them are written in the rows of table.

Table 1- Web-based application's Testing Challenges

TESTING CHALLENGES	List of Companies											
	Criticality Rank (1-5) (1=lowest, 5=highest)											
	A	B	C	D	E	F	G	H	I	J	Avg	%age
Integration	5	2	4	4	5	5	3	4	2	5	3.9	78
Interoperability	3	1	4	5	5	4	4	4	3	4	3.7	74
Security	5	5	3	5	4	3	3	5	5	3	4.1	82
Performance	5	5	5	4	2	5	3	4	5	3	4.1	82
Usability	3	3	4	4	2	4	2	3	4	2	3.1	62
Conformance	3	1	3	5	2	3	2	4	3	-	2.6	52
Reliability	2	2	3	5	3	4	3	4	4	3	3.3	66
Scalability	3	2	2	4	3	2	2	4	4	3	2.9	58
System	3	3	4	4	4	3	3	4	3	5	3.6	72

Table also shows the criticality ranks (1-5) of every mentioned issue, taken through industrial survey that we have conducted during this research work. Average and percentage rank values of each issue are shown in last two columns of the table. These two columns elaborate that which critical testing challenge needs more concern during Web-based application testing.

7.2.2 Affects of Integration and Interoperability on quality of Web-based Application:

The quality assurance of Web-based applications is always tough task because there are so many factors which can affect the quality of these applications. Integration and interoperability are two most critical issues among other challenging factors. The integration and interoperability have direct impact on the quality of Web-based applications. Table 2 shows the survey results about the affects of integration and interoperability on overall quality of Web-based applications.

Table 2- Affects of Integration and interoperability on Quality of Web-based applications

Affect of Integration and Interoperability on quality of Web-based Applications		
Affect in Percentage	No. of Companies	Result in Percentage
90 %	3	30.00%
80 %	5	50.00%
50 %	2	20.00%

This table illustrates values in percentage, how much affect integration and interoperability create on quality of Web-based application in 1st column and in 2nd column there are values about how many companies selected respective percentage values. The third column shows the results in percentage how many companies checked particular option.

7.2.3 Integration Testing Challenges in Web-based Applications

The existing integrated solutions (legacy systems) play key role in development of large scale Web-based applications because they require less effort and cost to get necessary functionalities. Integrated solutions provide a way to combine the existing subsystem with new technologies and systems. The integration testing is more important than any other type of testing due to the involvement of complex subsystems in the process of integration, which based on multilingual technologies and different platforms. During this testing process so many issues are occurred that increase the complexity of the integration testing. Table 3 shows some of known integration testing challenges available in academia and also faced by industry.

The rows of table are representing the challenges associated with integration testing and columns illustrate the companies which are involved in the conducted survey. Last two columns define the overall rank average and percentage of respective challenge. Results of the survey (criticality ranks) are shown in the table that describes what type and criticality level of integration testing issues; a particular company is facing. The overall calculated rank average and percentage of particular issue is written in same row under **Average** and **Percentage** columns. This shows which issue is most critical and concerning in the industrial point of view.

Table 3- Integration Testing Challenges of Web-based applications

INTEGRATION TESTING CHALLENGES	List of Companies Companies											
	Criticality Rank (1-5) (1=lowest, 5=highest)											
	A	B	C	D	E	F	G	H	I	J	Avg	%age
Inconsistent Infrastructure and Environment	5	3	2	5	5	3	4	4	4	2	3.7	74
Inconsistent Interaction Models	3	3	3	5	4	4	3	4	3	4	3.6	72
Distributed Nature of Systems	2	4	3	4	3	4	4	4	3	3	3.4	68
Performance and Reliability issues due to Heterogeneity	2	4	4	5	3	5	2	4	3	3	3.6	72
Interoperability	4	3	1	5	5	3	-	4	4	4	3.3	66

7.2.4 Web-based Application's Size/Type can vary the criticality of Integration Testing Challenges

These days Web has involved in every field of life and so the size of Web-based applications is variable. The criticality of integration testing challenges varies due to the difference in size and type of Web-based applications. Table 4 presents the survey results about variation in criticality of integration testing issues with size/ type. The entries in 1st column shows option "Yes" for variation and "No" for no variation. The values of 2nd column are the number of companies which have given the response for respective options (yes/ no). Last column shows the results in percentage how many companies agreed or disagreed with the given statement in survey.

Table 4- Affects of challenging factors of integration on size/ type of applications

RESULT SUMMARY		
Options	No. of Companies	Percent %
Yes	9	90.00%
No	1	10.00%

7.2.5 Integration Testing Approaches

There are so many approaches are available in academia and industry to perform integration testing. Table 5 shows most commonly used approaches and no of companies are using which particular approach. Columns of table present testing approaches, no of companies are using particular approach and percentage value which approach is most commonly used in the industry. Every row illustrates specific integration testing approach and how many companies are using this approach, in the form of (numbers and percentages) value. Approaches having “*” with them in table are those which are not included in the survey options but the companies involved in the survey are also using these approaches.

Table 5- Integration Testing Approaches of Web-based applications

RESULT SUMMARY		
Integration Testing Approaches	No. of Companies	Percent %
End-to-End Integration Testing	7	70.00%
Increment/Decrement Approaches	4	40.00%
Model Based Testing	4	40.00%
Coupling Based Testing	3	30.00%
Open Source Testing	2	20.00%
* Bing Bang	1	50.00%
* V Model	1	50.00%
* System Testing	1	100.00%

7.2.6 Critical Issues of Interoperability Testing in Web-based Application

Interoperability testing is one of the major parts in the testing process of Web-based applications. This type of testing is also very important to guarantee interconnected components and subsystems are working properly. Table 6 shows some common interoperability testing challenges. The table represents interoperability testing challenges, list of companies, average and percentage in columns. Each row of the table presents the particular interoperability testing issue, criticality ranks given by the companies and overall rank average and percentage of that particular issue.

Table 6- Interoperability Testing Challenges of Web-based applications

INTEROPERABILITY TESTING CHALLENGES	List of Companies											
	Criticality Rank (1-5) (1=lowest, 5=highest)											
	A	B	C	D	E	F	G	H	I	J	Avg	%age
Diverse Information Operating and data Retrieval System	3	4	5	5	4	2	3	4	3	4	3.7	74
Technical Level Issues (Multiple Protocols etc)	5	2	2	4	4	3	3	4	4	3	3.4	68
Data Heterogeneity or Multiple Data Formats	5	2	2	4	5	2	3	3	4	3	3.3	66
Semantic Issues	3	2	3	4	3	4	3	3	3	4	3.1	62
Organizational Level Issues	3	2	2	4	2	2	2	4	3	3	2.8	56
Difference in Implementation Standards	3	4	3	5	5	4	3	3	4	4	3.8	76

7.2.7 Web-based Application's Size/Type affects on criticality of Interoperability Challenges

As we mentioned above in the integration part that size and type of Web-based applications affect the criticality of testing issues. Interoperability testing challenges also vary in size and criticality due to differences in size and type of Web-based applications. Table 7 presents the survey results about variation in criticality of interoperability testing issues with size/ type. The entries in 1st column shows option "Yes" for variation and "No" for no variation. The values in 2nd column are describing the number of companies which selected particular option (Yes/ No). Last column shows the results in percentage how many companies agreed and disagreed with the given statement in survey.

Table 7- Affects of challenging factors of interoperability on size/ type of applications

RESULT SUMMARY		
Options	No. of Companies	Percent %
Yes	7	77.78%
No	2	22.22%

7.2.8 Interoperability Testing Approaches

There are so many approaches are available in academia and industry to perform interoperability testing. Table 8 shows the commonly used approaches and number of companies that are using particular testing approach to tackle the interoperability testing issues. First column of table presents the testing approaches; second column shows number of companies which are using particular approaches and third column shows the percentage value of the approach which is most commonly used in the industry. Every row of the table illustrates specific integration testing approach and how many companies are using this approach, in the form of (numbers and percentages) value.

Table 8- Interoperability Testing Approaches of Web-based applications

RESULT SUMMARY		
Interoperability Testing Approaches	No. of Companies	Percent%
Functional Testing	9	90.00%
Fault based Testing	5	50.00%
End-to-End Interoperability Testing	4	40.00%
Operational Testing	3	30.00%
Model based testing	2	20.00%
Path based Testing	1	10.00%

7.2.9 Effectiveness of Approaches:

This section describes the effectiveness of above mentioned integration and interoperability testing approaches to provide solution the challenging factors of integration and interoperability. Table 9 shows the survey results, most of the companies disagree that these approaches can completely solve integration and interoperability testing issues. Columns of the table 9 consist of required option (Yes/ No), number of companies and result in percentage respectively. Rows of the tables are presenting option values “Yes” and “No”, number of companies those selected particular option and percentage value of the results how many companies are agreed and disagreed.

Table 9- Effectiveness of Integration and Interoperability testing Approaches of Web-based applications

RESULT SUMMARY		
Options	No. of Companies	Percent %
Yes	3	33.33%
No	6	66.66%

Most of the companies expressed that mentioned approaches are not giving the full solution for integration and interoperability testing issues then another concern is that what percentage of coverage, these given approaches are providing to solve these issues. Table 10 presents the short summery of the results, how much given approaches cover integration and interoperability testing issues.

Table 10- Percentage Coverage

RESULT SUMMARY		
Options	No. of Companies	Percent %
90 %	2	33.33%
80 %	2	33.33%
50 %	1	16.67%
20%	1	16.67%

This table describes survey results in such a way that percentage option values in question are written in the 1st column and companies in number is placed in 2nd column with respect to their selected option value. 3rd column of the table includes the percentage results of options according to what amount of companies selected that specific option.

7.2.10 Relationship between Integration and Interoperability

Integration and interoperability testing are inter-related with each other and we observed that if the interoperability testing is performed in such a way that it covers most of interoperability issues then the required effort and time to perform integration testing will be reduced. Industry results are collected from survey regarding the relationship between integration and interoperability are described in table 11. This table shows that survey options “Yes” and “No” are given in 1st column. The numbers of companies are presented in 2nd column and last column shows the percentage value of particular option, how many companies selected that specific option.

Table 11- Relationship between Integration and Interoperability

RESULT SUMMARY		
Options	No. of Companies	Percent %
Yes	7	70.00%
No	3	30.00%

Table 11 describes the results that most of the companies are agreed with, if we cover all the interoperability testing issues then it minimizes the effort on integration testing. The survey also includes the query how much this effort will be reduced. Table 12 illustrates the results in such manners that options of question are written in first column and the number of companies is given in 2nd column with respect to selected options. The result of each option in percentage (how many companies selected that option) is shown in the last column of the table.

Table 12- Reduction of effort on integration testing

RESULT SUMMARY		
Options	No. of Companies	Percent %
50%	2	28.57%
75%	4	57.14%
100%	1	14.29%

7.2.11 Separate team to handle both integration and interoperability testing issues

Integration and interoperability testing are the most difficult and critical in the testing process of Web-based applications due to use of inconsistent environment, multilingual technologies and multi platforms. By considering these aspects of integration and interoperability testing issues we suggest that there is need of separate sub testing team consisting of 2 or 3 testing experts, having knowledge and experience of multilingual technologies, at least known models and different platforms. We have queried in the survey about separate sub testing team for the practical implementation of this suggestion and most of the companies are agreed with this suggestion. Table 13 shows the results summary produced from survey results.

Table 13- Separate Testing team

RESULT SUMMARY		
Agreed	No. of Companies	Percent %
Yes	7	70.00%
No	1	10.00%

Table 13 illustrates responses of industry; no of companies and percentage results in the columns. Rows of the table are presenting the results how many companies are agreed or disagreed with our suggestion in the format of percentage values and number values.

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CHAPTER 8: ANALYSIS

The analysis of collected data through the survey results is very important and difficult task. We have collected a lot of data during the survey, which has a direct or indirect relationship with our research area. We have analyzed the collected data from the survey and extract the most relevant data to our research questions.

8.1 Research Questions and Data Analysis

The relationship between the results of the survey questionnaire and research questions is very important and provides great help to pursue the analysis of particular direction of a particular domain. The results obtained from the survey questionnaire regarding testing challenges in Web-based applications are presented in chapter 7. Furthermore, this chapter presents the analysis of results of survey questionnaire according to the flow of research questions.

8.1.1 RQ1 and analysis

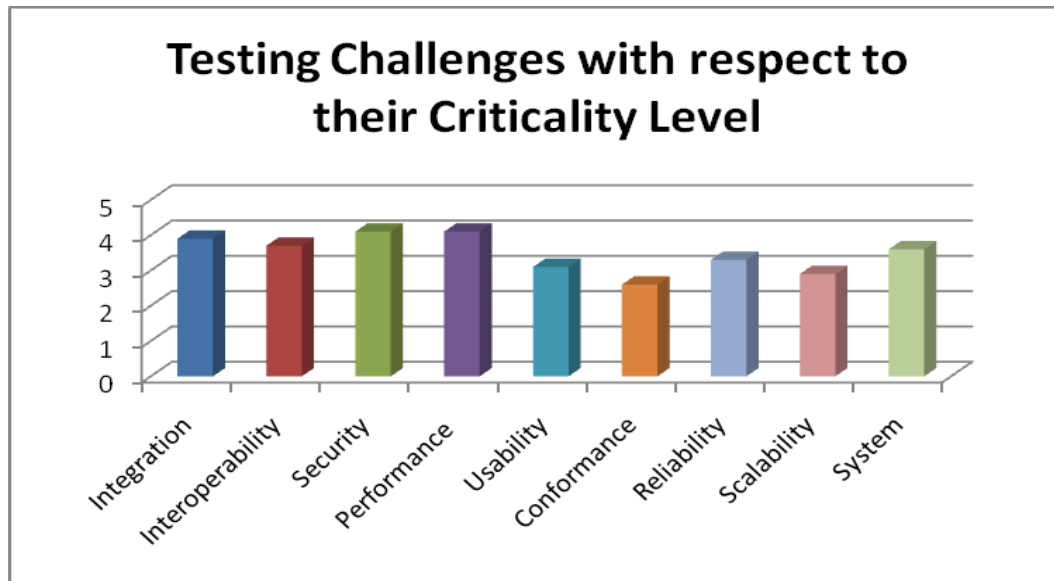
What are the Web-based applications and what are the testing challenges involved in Web-based applications?

This research question is related to the Web-based applications and testing challenges associated with these applications both in academia and industry. The answer (through literature review) of this question is presented in chapter 3 and 4 where in chapter 3, we gave the brief introduction of Web-based applications along with their characteristics, types, architecture and infrastructure. In chapter 4, we discussed testing challenges involved in Web-based applications in literature.

We have collected the results regarding testing challenges in Web-based applications faced by the industry according to their importance and criticality level. We have selected the nine different testing challenges of Web-based applications through literature review (integration, interoperability, security, performance, usability, conformance, reliability, scalability, and system). The results obtained from the industry are presented in Table 1. These testing challenges with their criticality level are also shown in graph 1.

The graph 1 is a 3D graph and x-axis shows the testing challenges and z-axis shows the criticality levels (from 1 to 5 (1 = lowest & 5 = highest)). The graph shows that testing challenges in Web-based applications with average highest criticality ranking (that is 4.1) are Security and Performance. The second and third most critical testing challenges are integration and interoperability respectively (that is 3.9 and 3.7). The other critical challenge with average criticality level is System testing (that is average criticality level 3.6)

It is also observed that for some organizations (company D & E) the most critical testing challenge is interoperability, and for some organizations these interoperability is least critical as compare to others (company B). For company A, E, F and J, the most critical testing challenges are integration testing. Similarly for company A, B, and I the most critical challenges are security and performance. For some companies the most critical challenges are security, conformance and reliability (company D). The results of each company of testing challenges in Web-based applications with their criticality level are shown in graphs in Appendix B.



Graph 1 - Testing challenges in Web-based applications with their average criticality level

8.1.1.1 Discussion

The results show that software testing process has great importance in the development of quality oriented Web-based applications. Almost all the testing challenges of Web-based applications which are presented in the literatures are being faced by the industry as well. A lot of effort is required to perform the testing of Web-based applications. All of these testing challenges should be resolved to develop quality oriented Web-based applications.

The results also show that the along with other most important critical testing challenges like security and performance in Web-based applications, integration and interoperability are two other important issues and significant testing challenges in Web-based applications. Mostly, it is seen from literature that the development of Web-based applications is carried out on ad hoc basis; means there is no systematic approach is used to develop the Web-based applications. Although, a lot of proposed approaches, methodologies and models are available in the literature, but mostly these approaches are not followed by the project managers and software development organizations due to the short development time and rapid changes in requirement. In result most of these applications fail due to lack of such approaches and methodologies.

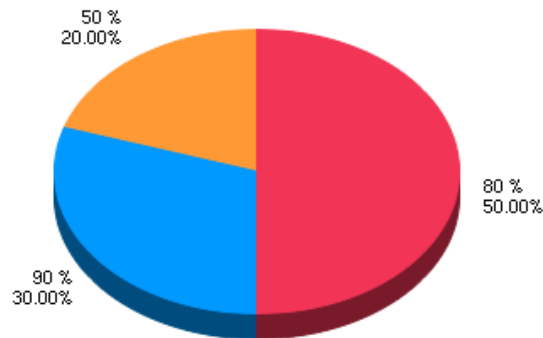
The involvement of Web-based applications is increasing smoothly with every business, and organizations, therefore understanding of testing challenges and test strategies are very crucial to improve the quality and reduce the failure factors of Web-based applications.

8.1.2 RQ2 and analysis

RQ2: How interoperability and integration affect the Web-based applications?

Both integration and interoperability has great affect on the Web-based applications in term of quality. Therefore quality assurance of both these factors is very important and crucial for the success of Web-based applications. We elaborate the answer of this research question in section 1.6 and in Chapter 5 through the literature reviews.

To confirm the importance and affect of integration and interoperability on the quality of Web-based applications in industry we have included this question in our survey questionnaire. We provided different values in percentage to know the importance of integration and interoperability on the quality of Web-based applications. The percentage values are very good to judge the importance and effectiveness of a specific problem or concept. Almost all the practitioners of ten companies answered this question. The results are shown in the table 2.



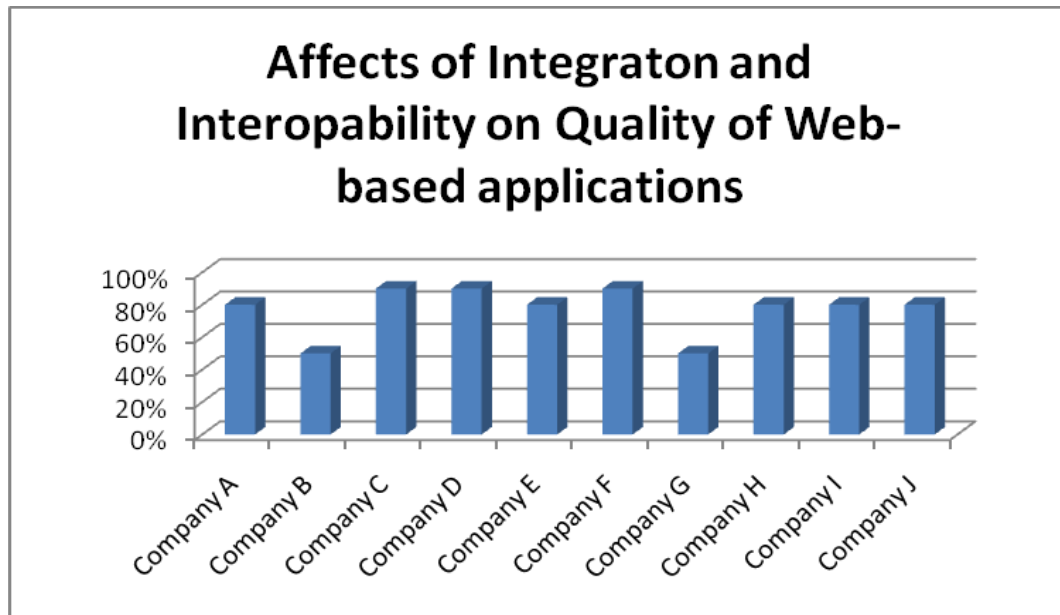
Graph 2 - Affects of interoperability and integration on quality of Web-based applications

Three (Companies C, D and F) out of ten respondents are agreed that both integration and interoperability issues have 90 percent affects on the quality of Web-based applications. Five (Companies A, E, H, I and J) out of remaining seven are agreed that interoperability and integrations have 80 percent affects on the quality of Web-based applications. The remaining two (Companies B and G) are agreed that both of these have 50 percent affects on the overall quality of Web-based applications.

The percentage of all 10 respondents is presented in graph 2. There are two percentage values with each portion of the graph. Each of the upper value shows the quality affects percentage and the lower value shows the number of respondents. The blue colour shows the 90 percent affects of interoperability and integration on the quality of Web-based applications while red colour shows the 80 percent and orange colour shows the 50 percent affects. The responses of each company are also shown in the graph 3.

8.1.1.2 Discussion

The results show that both integration and interoperability are not the important factors and challenges in Web-based applications but have direct impact on the quality of these applications. Both of these have 77 percent affects on the overall quality of Web-based applications. Therefore, a lot of efforts are required to cover all the possible issues of both of these (interoperability and integration) to improve the quality of Web-based applications.



Graph 3 - Company wise affects of integration and interoperability on quality of Web-based applications

8.1.3 RQ3 and analysis

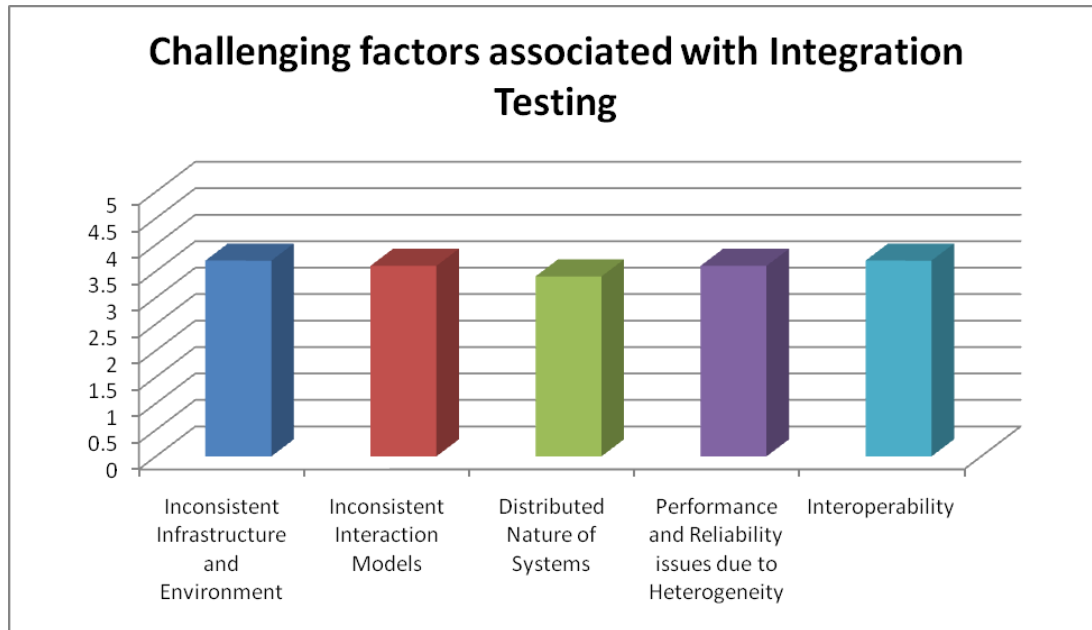
RQ3: What are the testing challenges associated with interoperability and integration of Web-based applications?

The testing challenges associated with interoperability and integration are discussed in chapter 5 through literature survey and review. The understanding of these associated issues is very important to develop affective testing strategies. To know the practitioner's view in the industry about the testing challenges associated with interoperability and integration, we divide our questions in two parts i.e. testing challenges associated with integration and testing challenges associated with interoperability. The average results of the companies with respect to integration are shown in table 3 and with respect to interoperability are in table 6.

8.1.3.1 Challenging factors of Web-based applications associated with Integration Testing

The results show that most challenging factors associated with integration testing are inconsistent infrastructure and environment, and interoperability (average 3.7 out of 5). The other two critical challenging factors associated with integration testing are inconsistent interaction models and performance and reliability issues due to heterogeneity (with average criticality level 3.6). The average results of the companies are also shown in the graph 4. The z-axis of the graph shows the criticality level and x-axis shows the challenging factors associated with integration testing process.

Company A, D and E think that most critical challenging factor in integration testing is inconsistent infrastructure and environment from any than other. Interoperability factor associated with integration testing is also most challenging task for the company D and E. The factor of performance and reliability issues due to heterogeneity is the most challenging task to tackle during the process of integration testing for the company D & F.

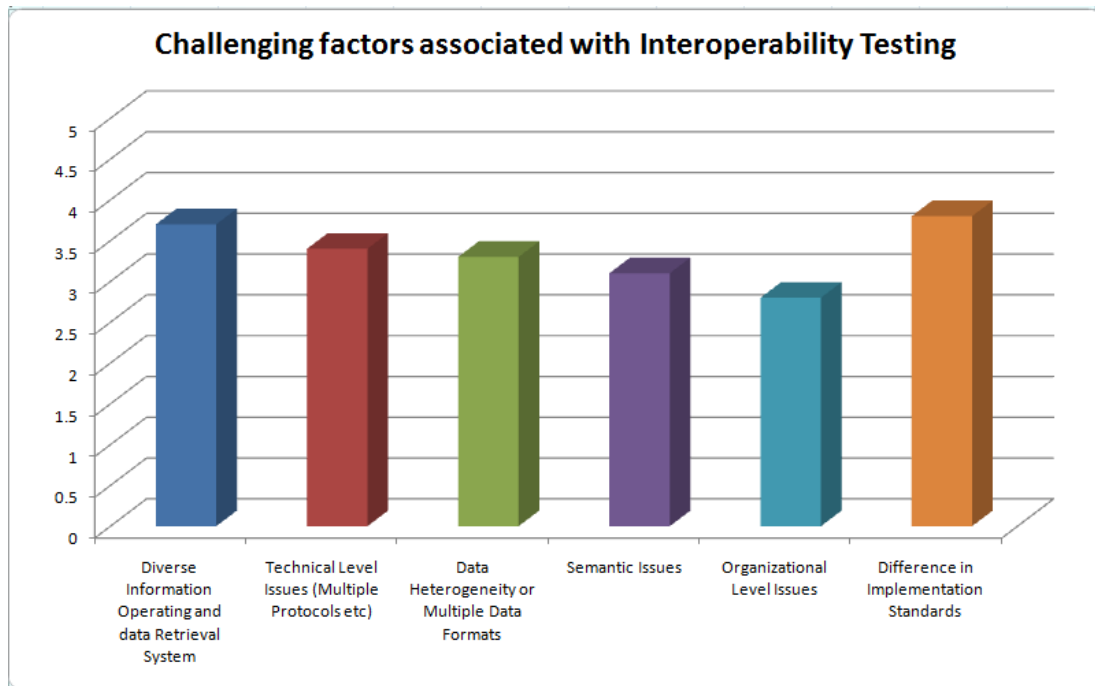


Graph 4 - Challenging factors of Web-based applications associated with integration testing.

We provided the short list of these challenging factors associated with integration testing to the companies and some companies also identify some additional challenging factors. For instance, company G identified three other factors; complexity, robustness and dependability with criticality level 3, 2 and 3 respectively. The company H identified another challenging factor technology with criticality level 4. The company J also identified the two factors which are also identified by the company G that is complexity level of integration: cyclic dependency between modules with criticality level 4.

8.1.3.2 Critical factors of Web-based applications associated with interoperability Testing

The results show that most critical challenging factor associated with interoperability testing of Web-based applications in industry is the difference in implementation standards (with average criticality level 3.8). The other most important challenging factor is diverse information retrieval and operating systems (with average criticality level 3.7). The other factors like technical level issues, data heterogeneity, semantic issues and organizational level issues are also critical (average criticality level 3.4, 3.3, 3.1 and 2.8 respectively). The average results of challenging factors associated with interoperability testing with their criticality level are shown in the graph 5. The z-axis shows the criticality level and x-axis shows the challenging factors associated with interoperability testing process.



Graph 5 - Challenging factors of Web-based applications associated with interoperability testing

Diverse information, data retrieval and operating systems is the most critical challenging factor associated with interoperability testing for company C and company D but it is least critical for company F. For company A and company E, the most critical challenge is data heterogeneity of multiple data formats and for companies B, C and F, this factor is least critical. The difference in implementation standards is the most critical challenge for the companies D and E as well. Organizational level issues are less critical for half of the companies.

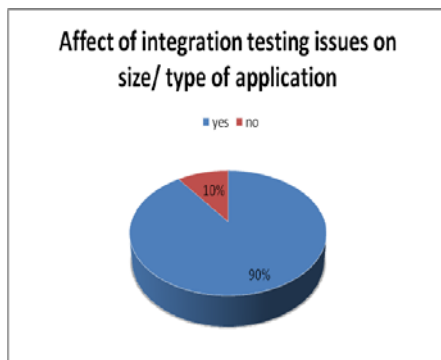
There is also another critical factor associated with interoperability testing with criticality level 2 is identified by the company J which is tools limitation and implementation difficulty or some time it is not possible.

8.1.3.3 Discussion

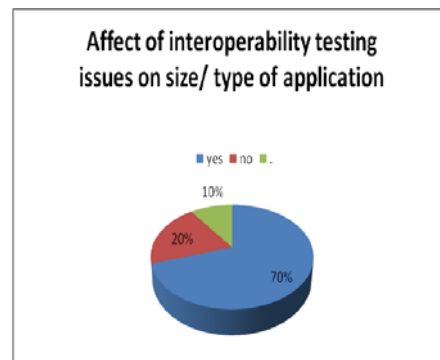
The companies' feedback and practitioners' views show that interoperability and integration testing issues are very crucial for the companies during the development of Web-based applications. All the challenging factors are critical and require great effort to tackle. It is important to understand the theory of these issues, their impacts on the application, their importance and their criticality level. This understanding can help us to create and apply better test plans and test strategies.

We have observed that all these factors (both of integration and interoperability) heavily depend upon the size/type of applications. It means that these factors can vary with the size/type of applications. For instance, organizational issues of interoperability have no impact on small organizations (which are not part or involved in/ of business integration etc). From survey we have observed that 90 percent of respondents are agreed that these factors vary with size/ type of applications. Only 10 percent (company E) respondents think that these factors do not change with the size and type of applications. One another respondent (company A) thinks that the critical factors of integration can change with size or type of application but interoperability factors do not change with the size and type of applications.

The affects of integration and interoperability testing issues on size/ type of application are also shown in graph 6 and 7. The blue colour shows “Yes” of the companies and red colour shows “No” of the respondents, the green colour in graph 7 shows no reply from the respondent.



Graph 6 - Affects of challenging factors of integration testing on size/ type of applications



Graph 7 - Affects of challenging factors of interoperability testing on size/ type of applications

8.1.4 RQ4 and analysis

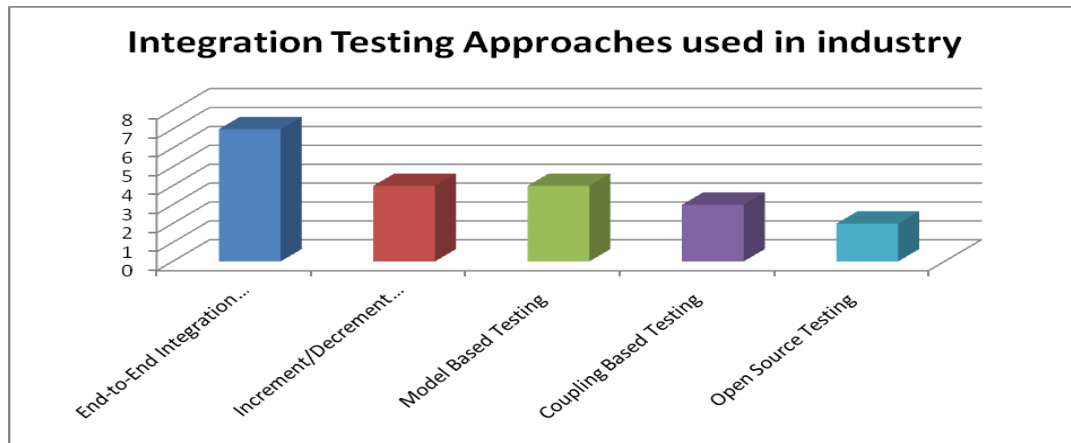
How the existing testing approaches can be updated/ modified to meet the challenges in the areas of interoperability and integration?

A lot of integration and interoperability testing methodologies, tools, models, approaches and proposals are available in academia. We have mentioned few of these testing approaches and methodologies in chapter 5 through the literature survey. All of these testing approaches have their own pros and cons. We selected few major integration and interoperability testing approaches to know the practitioners' views that which approaches they used to tackle integration and interoperability issues.

8.1.4.1 Testing approaches used in industry to tackle integration issues

The results of different approaches for integration testing used in industry are shown in table 5. The results shows that most used testing approach to tackle integration issues is end-to-end integration testing. Seven (companies A, B, F, G, H, I and J) out of ten companies are using end-to-end integration testing approaches along with others testing methodologies. Four (Companies C, D, F and J) companies are using increment/ decrement approach to handle integration testing issues. The other most used approach is Model-based testing which is used by the companies D, F, G and I to handle integration testing issues. The results are also shown in graph 8. The x-axis shows the different testing approaches used in industry and z-axis shows number of companies which are using these approaches to handle integration issues.

We also observe that few companies identify some additional testing approaches to handle integration issues. One of testing approach is V-model which is used by the company F. Another two integration testing approaches identify by the company J which are system testing and Big Bang testing. These testing approaches are available in literature but we did no include in the survey questionnaire because Big Bang testing approach comes under the category of increment/ decrement testing approaches.

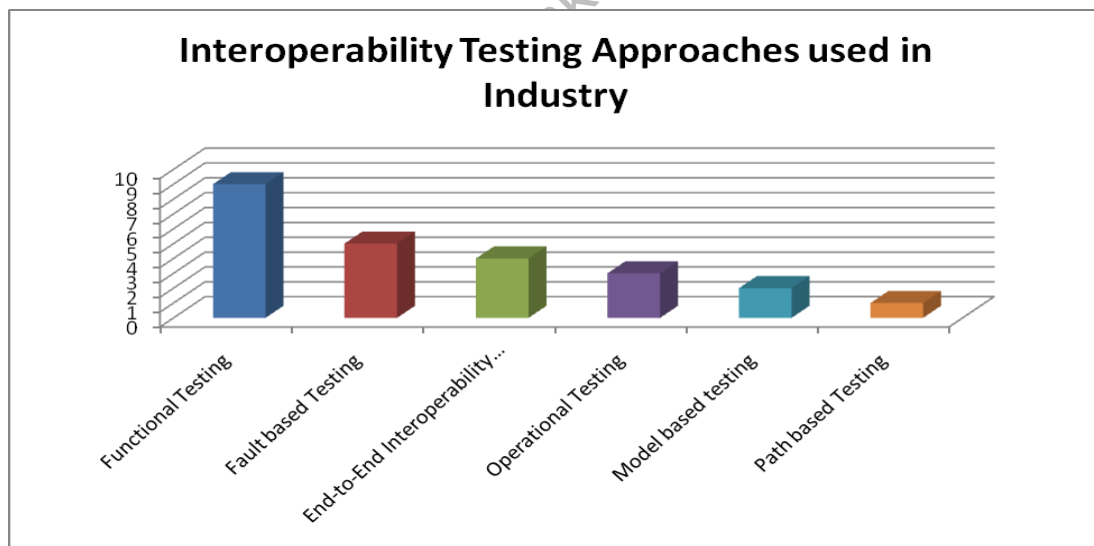


Graph 8 - Integration testing approaches used in 10 companies

Automated testing also plays key role in the testing process. It automates the testing process to speed up the testing process as well as provide the expected results through databases etc. Most of these companies are performing manual testing to tackle the issues of integration. Few companies are also using automated tools to perform the integration testing. Company B is using Eclipse and XML Test suit as automated tools to handle the integration testing. Company E is using Selenium automated testing tool. Remaining all other companies are using manual testing.

8.1.4.2 Testing approaches used in industry to tackle interoperability issues

The results of different testing approaches used to tackle the interoperability challenging factors are shown in table 8. The most used testing approach is functional testing to handle interoperability issues.



Graph 9 - Interoperability testing approaches used in 10 companies

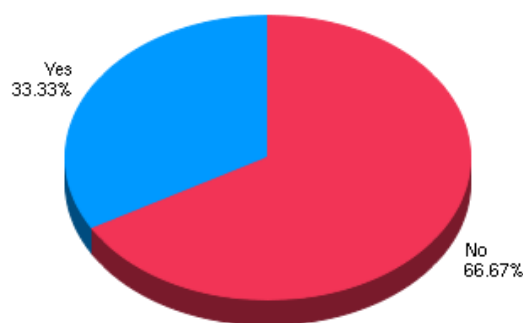
Almost 90 percent companies (companies B, C, D, E, F, G, H, I, and J) are using this approach. 50 percent companies (companies A, C, D, F and G) are using fault-based testing techniques. Companies A, H and J are also using the End-to-End interoperability testing technique. Operational testing technique is also using by the companies A, D and J. Model-based testing technique to handle interoperability challenges is used by only two companies (D and G). One company (company I) is using the Path-based interoperability testing techniques. The results of testing approaches used in industry are shown in graph 9. The x-axis of the graph shows the testing approaches used in industry and z-axis shows the number of companies that are using these approaches.

We observe that most companies do not used the automated testing tool to perform the interoperability testing. They all perform it manually except one company E. The company E is using Selenium Server automated tool to perform the interoperability testing. We also noted that company E is using this tool for both interoperability and integration testing.

8.1.4.3 Are the existing approaches enough to solve Integration and Interoperability Testing issues?

It is important to know the practitioners' view before providing any suggestion of new strategy or proposal or for any modernization in the existing methodologies, approaches and techniques. The practitioners and professionals know better that what is required in industry to fulfill the requirements of the customer and consumer. Therefore, for this purpose, we ask from the practitioners that whether they satisfied with the existing testing approaches, whether the existing testing approaches are enough to solve all the possible issues of both integration and interoperability or not.

We observe that there exist mix opinions in the industry. In some practitioners' opinion the existing techniques are enough and some think that the existing approaches are not enough to solve both integration and interoperability testing issues. The results of practitioners' suggestion and thoughts are shown in table 9.



Graph 10 - Results of effectiveness of existing integration and interoperability testing approaches

According to the results, 60 percent practitioners think that the existing approaches are not enough to solve integration and interoperability issues. There should be more testing strategies and methodologies are required to handle these issues in affective manner.

Although, it is fact that the given approaches and methodologies are solving the testing issues associated with integration and interoperability of Web-based applications but as the market of these applications is growing, businesses want to be more competent and enterprises are merging to attain mutual benefits, the complexities and criticality is also increasing. The existing approaches then may not affective as they are. Therefore new technological, theoretical and practical solutions are important.

The practitioners think that existing testing approaches solve almost 60 percent to 70 percent issues of both integration and interoperability. According to companies A and C, the existing approaches solve almost 90 percent issues associated with integration and interoperability testing. The companies D and F think that 80 percent issues are solved. Almost 50 percent issues are solved in the opinion of company H and 20 percent issues solved in the judgments of company B.

Almost 30 percent companies think that the existing approaches are enough to solve integration and interoperability issues and there is no need for any new methodology or approach. These companies are company E, company I and company J. One company (company G) did not provide the answer of this question. The results are also shown in the graph 10. The red colour shows the opinion of practitioners that think existing approaches are not enough and we need more suitable solutions for the challenging factors of integration and interoperability testing. The blue colour shows the views of companies that think existing techniques are enough.

8.1.4.4 Relationship between integration and interoperability

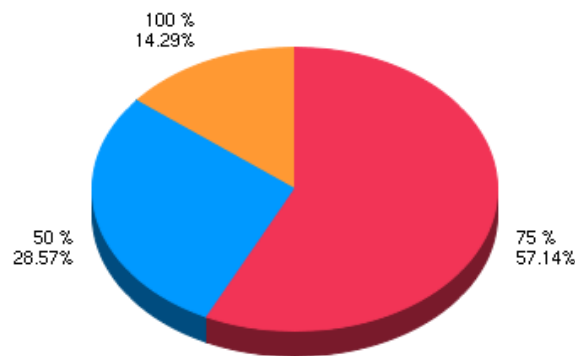
Through our literature survey and in-depth study regarding interoperability and integration, we conclude that a relationship exist between interoperability and integration. The nature of Web-based applications is heterogeneous, distributed and multiple different components, applications and operating systems are involved. Most of these characteristics are involved both in integration and interoperability. For instance, heterogeneity, distributed nature, difference in standards, dependability factors are involved in both integration and interoperability. To know the practitioners' opinions and views about this relationship we ask them a question that whether these are inter-related or not. In response, we received the mix opinions and views from the professionals and practitioners. Seventy percents practitioners are agreed that these two issues are inter-related with each other and thirty percents think that these issues are independent and have no relationship with each other.



Graph 11 - Results of relationship between integration and interoperability

The results regarding this are shown in table 11. According to the results and views, companies B, E, F, G, H, I and J are agreed that both integration and interoperability are inter-related with each other. On the other hand companies A, C and D are disagreed. The results of practitioners and companies' opinion and thoughts are also shown in graph 11.

One other important conclusion from our literature survey is that if, we cover all the possible challenging factors of interoperability then the testing effort of integration testing will be minimized. We also received mix responses from the practitioners regarding this. The results of these individuals are shown in table 12. The companies which are agreed that both integration and interoperability are inter-related think that if, we are succeeded to cover and tackle all possible issues of interoperability testing then the effort on integration on interoperability testing will definitely be minimized. Their opinions are varied about the minimization of effort. Four out of seven (companies E, H, I and J) say that 75 percent effort will be reduced on integration testing issues. Two (companies B and G) think that if we cover all the possible issues of interoperability testing then 50% effort will be reduced. One of the practitioners (company F) says that 100 percent effort will be reduced. The results of these seven companies are also shown in graph 12.



Graph 12 - Results of reduction of effort on integration testing

8.1.4.5 How can we improve the integration and interoperability testing?

The results and analysis show that both integration and interoperability have great affect on the quality of Web-based applications. Along with importance, these two have such requirements and characteristics (challenging factors) which are very crucial to understand and also to test them. In our opinion a dedicated effort is required to cover all the possible issues and challenging factors of integration and interoperability testing especially in more complex and large-scale Web-based applications. As it is obvious from analysis, we need new testing strategies and methodologies to solve the challenging issues of both integration and interoperability testing. Along with this, we suggest, there should be a separate sub-testing team based on 2-3 personnel (depends upon the size and type of enterprise or organization) with multiple skills (multi-lingual expertise, standards, methodologies and tools) to handle the issues of interoperability and integration.

Practitioners and professionals opinions and views were very important about this suggestion, therefore we asked the question from them that whether it is suitable, possible or beneficial or not. We got very good responses regarding this. More than 60% practitioners are agreed that it is a good idea and there should be a separate and dedicated testing team to handle the testing issues of both integration and interoperability. One practitioner says that it depends upon the size of organization and application type. According to him, small organization cannot afford this separate testing team. It is also interesting to see that only one practitioner thinks that there should be no separate or dedicated team to handle the issues of

both integration and interoperability. Two practitioners did not provide their suggestions and opinions about this.

8.1.4.6 Discussion

From the above results and analysis, it is obvious that there are a lot of testing approaches and strategies are used in industry to handle and tackle the challenging factors of both integration and interoperability testing. Although, end-to-end integration testing and other approaches are affective to tackle the challenging issues of integration testing, and functional testing approach along with others are affectively used to solve and handle the challenging factors of interoperability testing but still these approaches are not mature enough to cover all the rapid emerging challenging issues of Web-based applications. The XML, Service Oriented Architecture (SOA) are good solutions to solve most of the problem of integration and interoperability but they still have the limitations. For instance, the standards are available for the Web applications development but mostly these standards are not followed by the different organizations, for example, if a company developing a browser, there are standards available to develop this application but the manufacturers try to add some new features that other browser do not have for better competence. This can create the problems (compatibility issues) for other applications that need to be run on that browser. Similarly a lot of other examples are available.

We need to follow up the standards proposed by the World Wide Web Consortium (WWWC) to develop quality oriented applications but how to follows these standards. According to us, the WWWC should provide the training and advertise the implementation standards as well as there should be positive way to ensure that. Secondly, there should be a generic testing strategy and architecture or infrastructure should be proposed to affectively handle and tackle the challenging factors of integration and interoperability testing. From the analysis and results, we also observe that a relationship is exist between integration and interoperability and if we cover all the possible challenging factors of interoperability testing then it will reduce the effort on integration testing. From thorough literature survey, we also observe that interoperability testing covers other important issues like; performance, security, scalability and reliability. It means, if, we successfully cover all the issues of interoperability testing, it will not reduce the testing effort on integration testing but on performance, security, scalability and reliability as well. Through results and analysis we also observe that there should be a separate sub-testing team to handle the both integration and interoperability testing efforts.

8.2 Validity

Validation of research work and its results is very important and essential entity in both qualitative and quantitative research area. This thesis work includes both the qualitative and quantitative research. The results of quantitative part are assessed by the criteria provided by Trochem [67]. The criteria include four different categories to assess the validity for qualitative research. These four categories are discusses in following.

8.2.1 Creditability

According to [67], creditability criteria involves that the results of research are credible or believable by the perspective of participants. We plan a multi phased research strategies to achieve the creditability of the thesis. In first phase, literature review is performed to find the testing challenges in Web-based applications especially with respect to interoperability and integration and then survey questionnaire is designed according to research questions to find out the testing challenges of Web-based applications (with respect to interoperability and integration) faced in industry. Ten different companies are selected which are developing

Web-based applications to conduct the survey through email, phone and face to face. The target companies and audience for survey questionnaire is discussed in chapter 6. Through this validation process, we are confident to achieve the creditability of the thesis.

8.2.2 Transferability

Transferability is the ability to generalize the research results to other contexts and settings [67]. In this thesis report, the survey results are very helpful to identify the testing challenges in Web-based applications with respect to interoperability and integration and different testing approaches used to tackle these challenges in software industry. The thesis research can be very supportive to software organizations which are developing large scale Web-based applications to improve their testing process by applying a separate sub testing team. In this thesis, the context is described in detail. With the help of these settings, the findings of the thesis are generalized and helpful for the software industry.

There can be possible threat to the different subjects involved in the survey process. All have at least two years of experience in integration and interoperability testing but their experience in particular domain may have effect on the research results. One another possible threat can be the difference in educational background and culture. The size and type of project or organization may have effect on our finding of separate sub testing team, which is suitable for large scale applications and for large enterprises.

8.2.3 Dependability

Dependability emphasize on the changes that occur in the context of research over the time [67]. The survey questionnaire was sent to different subjects (companies) along with the overview of thesis and with description of questions. We tried to select same level of organizations but it is fact that some companies are large organizations and some are medium. One possible threat can be the difference in level and size of the organizations or projects.

8.2.4 Confirmability

Confirmability of the research ensures that the results can be confirmed by the other researchers [67]. In this thesis, the survey results of each respondent are properly documented to ensure the confirmability. The survey questionnaire is designed according to the research questions which are discussed in chapter 6. Since we conduct survey through emails, phones and face to face therefore one possible threat can be the difference in these ways. Although, we try to ensure that the authors have the same meanings and things that we want to ask.

CONCLUSION

The main focus of our research is testing challenges in Web-based applications with respect to interoperability and integration. The research is based on the detailed study of literature and industry survey of ten (10) companies. The studies and survey results show that most critical testing challenges to Web-based applications are integration and interoperability along with performance and security. These challenging issues of testing require a lot of efforts to be resolved. Both Integration and interoperability have great impact on the overall quality of Web-based applications. The results of industrial survey show that almost 70 to 80 percent quality of Web-based applications is based on integration and interoperability.

Both integration and interoperability have their own specific critical issues and challenging factors which make testing process more difficult.

According to the survey results, most critical challenging factors of integration testing are inconsistent infrastructure and environment, and performance and reliability issues due to heterogeneity. The most critical challenges associated with interoperability testing efforts are differences in implementation standards, and diverse information, data retrieval and operating systems. The results also show that most widely used testing approaches to solve challenging issues of integration are end-to-end integration testing and increment/decrement testing approaches. The most widely used testing techniques to cover the issues of interoperability are functional testing and fault-based testing. Most of the companies do both integration and interoperability testing manually and not using automated testing tools except of the two companies.

The results and their analysis show that the existing techniques are not enough to solve the challenging factors of integration and interoperability testing. We need generic methodologies, architectures, infrastructures and testing approaches to cover all the possible issues and problems that may occur during integration and interoperability testing. In this way the process of testing will be very simple and easy to conduct.

It is also observed that both integration and interoperability are related to each other and if, we successfully cover all the possible issues and challenging factors of interoperability testing then it will not only reduce the testing effort of integration testing but also other testing issues like, performance, security, scalability and reliability as well.

Finally, we conclude that since Web-based applications are playing pivotal role in many business domains, for example finance, sales, retail, marketing, and management of particular products. Secondly, the importance of software integration and interoperability also cannot be neglected in large enterprises and mission critical systems. Different integrated components are developed in multiple platforms using different methodologies and tools.

Therefore, we suggest that there should be a separate sub-testing team consisting of 2-3 testers (depends upon the size and type of enterprise or organization) having multiple skills (multi-lingual expertise, standards, methodologies and tools) to handle the issues of interoperability and integration.

FUTURE WORK

This thesis research focuses specifically on testing challenges of Web-based application with respect to interoperability and integration; further research in this domain can be more beneficial for both academia and industry. Both integration and interoperability have very broad scope and a lot of research is required to mature the testing approaches, methodologies, architecture and infrastructure for them. The following are the major areas of integration and interoperability testing of Web-based applications where research can be done;

During our research work we observed that there exist a relationship between challenging factors of integration and interoperability. It is beneficial for the academia and industry if further research is done to find out the true relationship between integration and interoperability. This will be very helpful to reduce the testing efforts on the both integration and interoperability.

We observed through industrial surveys that most of the companies are doing integration and interoperability testing manually. Though automated testing tools are very beneficial and helpful to speed-up the testing process but they are not using or taking aid from the automated tools to perform both integration and interoperability testing. Therefore a study should be conduct to understand why companies are not using (unwilling to use) automated tools to perform both integration and interoperability testing.

Since Web-based applications have become crucial components of our lives. These are now involved in each domain (business, government, education etc.). We have suggested a separate testing team for both integration and interoperability testing. We recommend this team should be implemented in large enterprises. We also suggest that further research should be done to get broader feedback through case studies of more companies and through practitioners.

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REFERENCES

- [1] Myers, Glenford J. *Art of Software Testing*. Hoboken, NJ, USA: John Wiley & Sons, Incorporated, 2004
- [2] Peng Liang, Keqing He, Bing Li, Jin Liu, "The Interoperability between Different e-Business Specifications"
- [3] Weinreich, H., Obendorf, H., Herder, E., and Mayer, M. 2008. "Not quite the average: An empirical study of Web use ". *ACM Trans. Web* 2, 1 (Feb. 2008), 1-31
- [4] Lei Xu, Baowen Xu, "A Framework for Web Application Testing", CW'04, IEEE, 2004
- [5] Jeff Offutt, Ye Wu, Xiaochen Du and Hong Huang, "Bypass Testing of Web Applications", Proceedings of the 15th International Symposium on Software Reliability Engineering (ISSRE'04) 1071-9458/04, IEEE
- [6] Arora, Geetanjali. Building Web Services with XML, Independence, KY, USA: Premier Press, Incorporated, 2002. p 32
- [7] Vince Bruno, Andrey Tam, James Thom, "Characteristics of Web applications that affect usability: A Review", Proceedings of OZCHI, Canberra, 2005.
- [8] Giuseppe Antonio Di Lucca, Anna Rita Fasolino, Francesco Faralli, Ugo De Carlini, "Testing Web Applications", ICSM'02, 2002, IEEE.
- [9] E. Hiean;Rc-Mee;"Going Faster: Testing The Web Application", IEEE Software, Mar. 2002, pp. 60- 65
- [10] Filippo Ricca and Paolo Tonella, "Analysis and Testing of Web Applications", IEEE, 2001
- [11] Juwel Rana, Mihaela Ion, "Challenges of Interoperability issues for enterprise software and application", internal report, V 0.1, Osco Team, Italy, 2007.
- [12] B. Medjahed, B. Benatallah, A. Bouguettaya, A. H. H. Ngu, and A. K. Elmagarmid, "Business-to-Business Interactions: Issues and Enabling Technologies". The VLDB Journal, Vol. 12, No. 1, May 2003, pp. 59-85.
- [13] Sujatha Kuppuraju, Aravind Kumar, Geetha Presenna Kumari, "Case study to verify the interoperability of a service oriented architecture stack", Services Computing (SCC07), IEEE
- [14] S. Elbaum, S. Karre, G. Rothermel, "Improving Web applications testing with user session data", IEEE, 2003
- [15] Christof Bornhovd, "Semantic Metadata for the Integration of Web-Based Data for Electronic Commerce", Proceedings of the International Workshop on Advance Issues of E-Commerce and Web-Based Information Systems (WECWIS1999), IEEE Computer Society, New York, 1999, pp. 137-145.
- [16] Peng Liang, Keqing He, Bing Li, Jin Liu, "The Interoperability between Different e-Business Specifications", ITCC, 05, IEEE

- [17] Arturo Sanchez, Brandon Vega, Alexander Gonzalez, Gregory Jackson: “*Automatic support for testing Web-based enterprise applications*”, ACM Southeast Regional Conference 2006: 325-330
- [18] J. Sanjay, R. Frank, C. Andreas, K. Deogratias, “*Distributed simulation for interoperability testing along the supply chain*”, Winter Simulation Conference, IEEE, 2007
- [19] ITRG. “*Building and Deploying Secure Web Applications*”. London, Canada: ITRG, 2002. p3.
- [20] Powell, T.A., *Web Site Engineering: Beyond Web Page Design*, Prentice Hall, 1998.
- [21] D. Lowe, B. Henderson-Sellers, “*Characteristics of Web Development Process*”, International Conference Advances in Infrastructure for Electronic Business, Science, and Education on the Internet. SSRR 2001
- [22] Deshpande, Y., Murugesan, S., Ginige, A., Hansen, S., Schwabe, D., Gaedke, M., et al. (2002). Web Engineering. *Journal of Web Engineering*, 1(1), 003-017.
- [23] Goger S. Pressman, *Software Engineering A Practioner’s Approach*, McGraw-Hill, 2001
- [24] Finkelstein, A. C. W., Savigni, A., Kappel, G., Retschitzegger, W., Kimmerstorfer, E., Schwinger, W., et al. (2002). Ubiquitous Web Application Development - A Framework for Understanding. *6th World Multiconference on Systemics, Cybernetics and Informatics*, Orlando, Florida, US.
- [25] Powell, T.A., *Web Site Engineering*, Prentice-Hall, 1998
- [26] Ricca, F. “*Analysis, testing and Re-structuring of Web applications*” Proceedings of the 20th IEEE International Conference on Software Maintenance (ICSM’04), 2004
- [27] Nasib S. Gill, “*Factors affecting Effective Software Quality Management Revisited*”, ACM SIGSOFT Software engineering Notes, Vol. 30, March, 2005.
- [28] Glass, R. L. 1998. “*Defining Quality Intuitively*”, *IEEE Softw.* 15, 3 (May. 1998), 103-104,107
- [29] Olsina, L., Lafuente, G., and Rossi, G. 2001. “*Specifying Quality Characteristics and Attributes for Websites*”, In *Web Engineering, Software Engineering and Web Application Development* S. Murugesan and Y. Deshpande, Eds. Lecture Notes In Computer Science, vol. 2016. Springer-Verlag, London, 266-278.
- [30] Lyman Chapin, *The Internet Standards Process*, Internet Activities Board, Network Working Gorup, RFC:1310, March, 1992
- [31] IEEE (1990), IEEE (Institute of Electrical and Electronics Engineers): Standard Computer Dictionary- A Compilation of IEEE Standard Computer Glossaries
- [32] Federal Standard 1037C, Department of Defense Dictionary of Military and Associated Terms in support of MIL-STD-188.
- [33] IDABC: European Interoperability Framework. Luxembourg, European Communities, 2004

- [34] G. Patricia, A. Noam et al, "Coming to terms: Scoping Interoperability for Health Care", Health Level Seven, EHR Interoperability Work Group, Feb 7, 2007
- [35] Levels of Information Systems Interoperability, C4ISR Architectures Working Group, 30 March 1998, available at: US DoD, OSD (C3I), CIO, Director for Architecture and Interoperability Website: <http://www.c3i.osd.mil/org/cio/i3/>
- [36] www (2001) library.csun.edu/mwoodley/dublincoreglossary.html
- [37] Vassolios Peristeras, Konstantinos Tarabanis , "The Connection, Communication, Consolidation, Collaboration Interoperability Framework (C4IF) For Information Systems Interoperability", IBIS – Issue 1, 2006
- [38] C4ISR Architectures Working Group: Levels of Information Systems Interoperability (LISI), 1998
- [39] NATO Allied Data Publication 34 (ADatP-34): NATO C3 Technical Architecture (NC3TA), Version 4.0, 2003.
- [40] Tolk A. and J. A. Mugira: The Levels of Conceptual Interoperability Model. Simulation Interoperability Workshop, Orlando, Florida, 2003.
- [41] U.S Air Force and Don Brutzman and Tolk A.: Report on JSB Composability and Web Services Interoperability via Extensible Modeling & Simulation Framework (XMSF), Model Driven Architecture (MDA), Component Repositories, and Web-based Visualization
- [42] Seligman, L. and A. Rosenthal: "A Framework for Information Interoperability." The Edge Mitre's Advanced Technology Newsletter 8(1): 3-4, 2004.
- [43] Clark, T. and R. Jones: Organisational Interoperability Maturity Model for C2, 1999.
- [44] C.V. Ramamoorthy, C. Chandra, H.G. Kim, Y.C. Shim, V. Vij, " System integration problems and approaches", 0-8186-26976192 Q 1992 IEEE
- [45] Judith M. Myerson, *Enterprise System Integration*, Second Edition, 2001
- [46] Paul Gerrard, Neil Thompson, *Risk based E business testing*, 2002
- [47] Ralf Klischewski, "Information Integration or Process Integration? How to Achieve Interoperability in Administration", R. Traunmüller (Ed.): EGOV 2004, LNCS 3183, pp. 57–65, 2004
- [48] John Watkins, *Testing IT An Off-the-Shelf Software Testing Process*, 2004
- [49] Hong Zhu, Xudong He, "A Study of Integration Testing and Software Regression at the Integration Level", 0-7695-1372-7/01 2001 IEEE
- [50] John W. Creswell, "Research Design Qualitative, Quantitative and mixed Methods Approaches 2nd Edition", SAGE Publications Inc, USA, 2003
- [51] Floyd J. Fowler, " Survey Research Methods: Fundamental Principles of Clinical Reasoning & Research", SAGE Publications, 2002

- [52] Park J., Ram S., "Information Systems Interoperability: What Lies Beneath?", ACM Transactions on Information Systems, Vol. 22, No. 4, October 2004, Pages 595-632
- [53] Burkhart, Thomas; Werth, Dirk; Loos, Peter, "Realizing process interoperability using E-Mail communication", Applications of Digital Information and Web Technologies, 2008. ICADIWT 2008. First International Conference on the 4-6 Aug. 2008 Page(s):579 - 583
- [54] Kim H. Veltman, "Syntactic and Semantic Interoperability: New Approaches to Knowledge and the Semantic Web", The New Review of Information Networking, vol. 7, 2001
- [55] J. A. Martinez Usero, P. Beltrán Orenes, J. A. Martínez Comeche and R. San Segundo Manuel, "Information interoperability evaluation model for public websites", <http://eprints.ucm.es/5925/>, last visited dated 8-12-2008, 10:12 AM
- [56] James D. Kindrick, John A. Sauter, and Robert S. Matthews, "Improving conformance and interoperability testing", StandardView Vol. 4, No. 1, March/1996
- [57] Get an overview of the JavaServer Faces technology, <http://www.builder.au.com.au/strategy/architecture/soa/Get-an-overview-of-the-JavaServer-Faces-technology/0,339028264,320279591,00.htm>, last visited dated 20-12-2008, 11:10 AM.
- [58] Ye Wu and Jeff Offutt, "Modeling and Testing Web-based applications", GMU ISE Technical ISE-TR-02-08, November, 2002
- [59] Sheela Mahajan, Jian Chen, "CORBA On WWW: Evaluative Framework for interoperability issues" Proceedings Technology of Object-Oriented Languages, 1998.
- [60] William E. Moen et al, "An Extensible Approach to Interoperability Testing: The Use of Special Diagnostic Records in the Context of Z39.50 and Online Library Catalogs", Proceedings of the American Society for Information Science and Technology, volume 42 issue 1, 2006.
- [61] Wangler, B. and S.J. Paheerathan, "Horizontal and Vertical Integration of Organizational IT Systems", in Information Systems Engineering: State of the Art and Research Themes, Springer, 2000.
- [62] Wing Lam, Venky Shankararaman, *Enterprise Architecture and Integration Methods, Implementation and Technologies*, 2007
- [63] Jeffrey T. Pollock, *The Big Issue: Interoperability vs. Integration*, EAI Journal, 2001
- [64] Beth Gold-Bernstein and William Ruh. *Enterprise Integration: The Essential Guide to Integration Solutions*. Addison-Wesley, 2005.
- [65] Grady Booch, *The Architecture of Web Applications*, http://www.ibm.com/developerworks/ibm/library/it-booch_web/
- [66] Jerry Zeyu Gao et al, *Testing and Quality Assurance for Component-Based Software*, 2003
- [67] William M.K. Trochim, "Qualitative Validity", Research Methods Knowledge Base,

2006, (<http://www.socialresearchmethods.net/kb/qualval.php>), Jan 17, 2009, 17:10

[68] Tira Cohene and Steve Easterbrook, "Contextual Risk Analysis for Interview Design", Proceedings of the 2005 13th IEEE International Conference on Requirements Engineering

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APPENDIX A

Survey Questionnaire

Your brief introduction: *

Name:

Company:

Designation:

Country:

Email:

Experience of integration and interoperability testing (I&IT) (In years):

2. What are the most critical testing challenges in Web-based systems? Please rank these with their criticality level. (1= Lowest & 5= Highest)

	1	2	3	4	5
Integration Testing	☐	☐	☐	☐	☐
Interoperability Testing	☐	☐	☐	☐	☐
Security Testing	☐	☐	☐	☐	☐
Performance Testing	☐	☐	☐	☐	☐
Usability Testing	☐	☐	☐	☐	☐
Conformance Testing	☐	☐	☐	☐	☐
Reliability Testing	☐	☐	☐	☐	☐
Scalability Testing	☐	☐	☐	☐	☐

	1	2	3	4	5
System Testing	☐	☐	☐	☐	☐

3. How much integration and interoperability can affect on quality of Web systems?

☐ 20 % ☐ 50 % ☐ 80 % ☐ 90 % ☐ 100 %

4. What are the most critical issues of integration testing in Web-based systems? Please rank these issues with their criticality level. (1 = Lowest & 5 = Highest)

	1	2	3	4	5
Inconsistent Infrastructure and Environment	☐	☐	☐	☐	☐
Inconsistent Interaction Models	☐	☐	☐	☐	☐
Distributed Nature of Systems	☐	☐	☐	☐	☐
Performance and Reliability issues due to Heterogeneity	☐	☐	☐	☐	☐
Interoperability	☐	☐	☐	☐	☐

5. Other critical issues related to integration testing of Web-based systems, which are not listed above. (Please specify below with their criticality levels from 1 to 5)

	Critical Issues	Criticality level
1		
2		
3		

6. Do the above mentioned critical factors vary with respect to size / type of Web-based systems?

☐ Yes

☐ No

7. Which approaches are you using to tackle integration testing issues?

- ☐ Model based testing
- ☐ Open Source Testing
- ☐ End-to-End Integration Testing
- ☐ Increment/Decrement Approaches
- ☐ Agent Based Testing
- ☐ Coupling Based Testing

8. Other approaches (if any) to tackle Integration Testing issues which are not mentioned in above question.1 2 3 **9. Which automated tools are you using to perform integration testing?**1 2 3 4 5 **10. What are the most critical issues of interoperability testing in Web-based systems? Please rank these issues with their criticality level. (1 = Lowest & 5 = Highest)**

	1	2	3	4	5
Diverse Information, operating and data retrieval Systems	☐	☐	☐	☐	☐
Technical Level Issues (Multiple	☐	☐	☐	☐	☐

	1	2	3	4	5
protocols etc)					
Data Heterogeneity or Multiple data formats	☐	☐	☐	☐	☐
Semantic Issues	☐	☐	☐	☐	☐
Organizational Level Issues	☐	☐	☐	☐	☐
Difference in Implementation Standards	☐	☐	☐	☐	☐

11. Other critical issues related to interoperability testing of Web-based systems, which are not mentioned above. (Please specify below with their criticality levels from 1 to 5)

	Critical Issues	Criticality level
1		
2		
3		

12. Do the above mentioned critical factors vary with respect to size / type of Web based systems?

☐ Yes

☐ No

13. Which approaches are you using to tackle interoperability testing issues?

☐ Model based testing

☐ Operational Testing

☐ End-to-End Interoperability Testing

☐ Path based Testing

☐ Functional Testing

☐ Fault based Testing

14. Other approaches (if any) to tackle Interoperability Testing issues which are not listed above.

1

2

3

15. Which automated tools are you using to perform interoperability testing?

1

2

3

4

5

16. Are the given approaches enough to solve I&IT issues?

☐ Yes

☐ No

17. If your answer is "No" in Question 16 then what percentage of coverage, these given approaches are providing you to resolve I&IT issues.

☐ 20 % ☐ 50 % ☐ 80 % ☐ 90 % ☐ 100 %

18. Do you think that integration and interoperability testing are inter-related and if we cover all interoperability testing issues then it will reduce the effort on integration testing?

☐ Yes

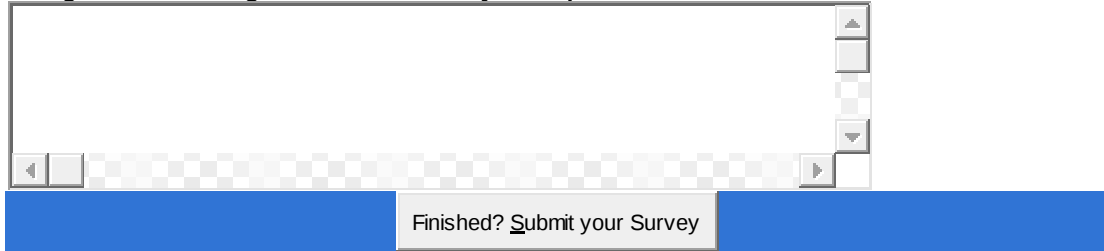
☐ No

19. If your answer is "Yes" in Question 18 then according to your experience how much effort will be reduced?

☐ 25 % ☐ 50 % ☐ 75 % ☐ 90 % ☐ 100 %

20.

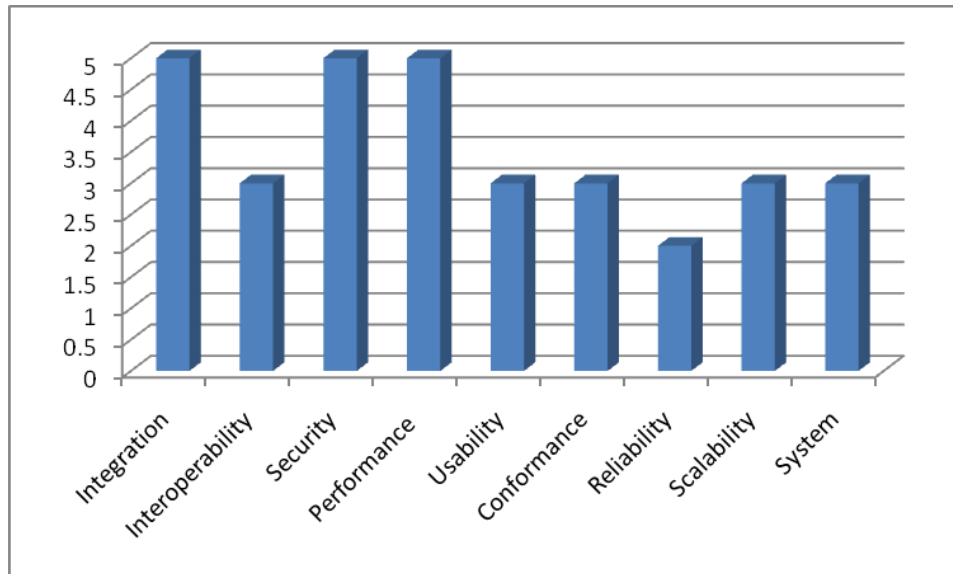
Since interoperability and integration are critical aspects in Web-based systems and we suggest a separate sub testing team to handle both interoperability and integration testing issues. What is your opinion?



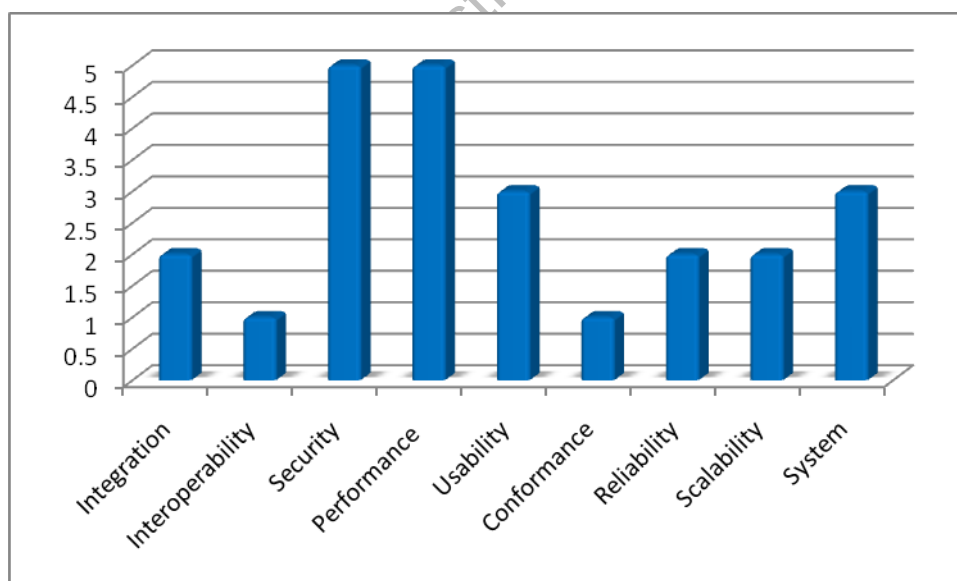
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APPENDIX B

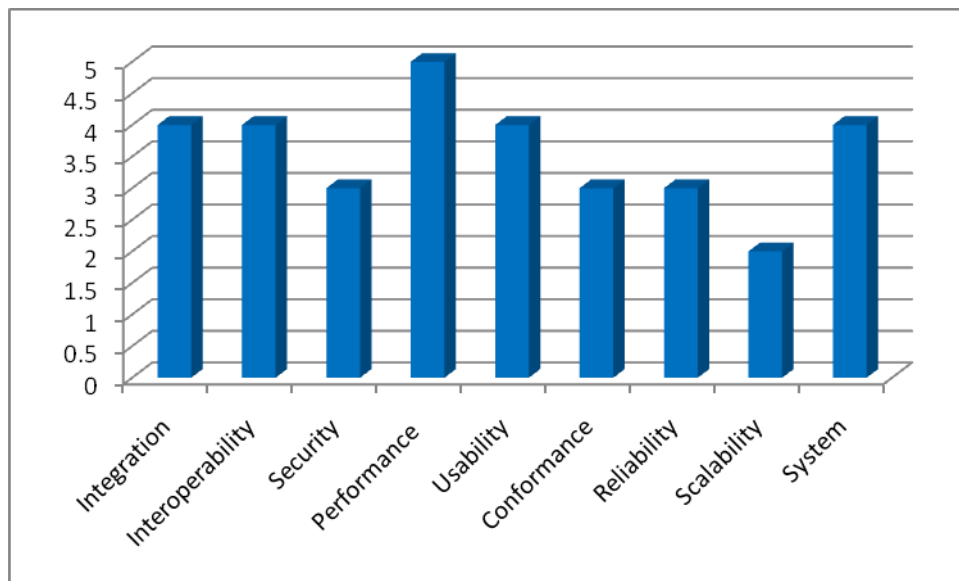
Testing Challenges graphs with their criticality Level of 10 companies



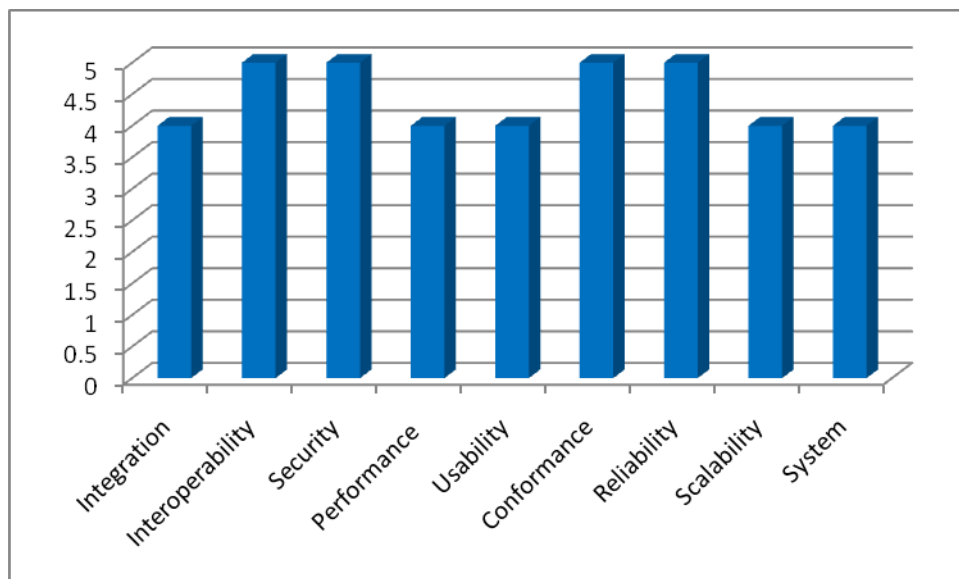
Graph (a) – Testing challenges of Web-based applications with their criticality level of Company A



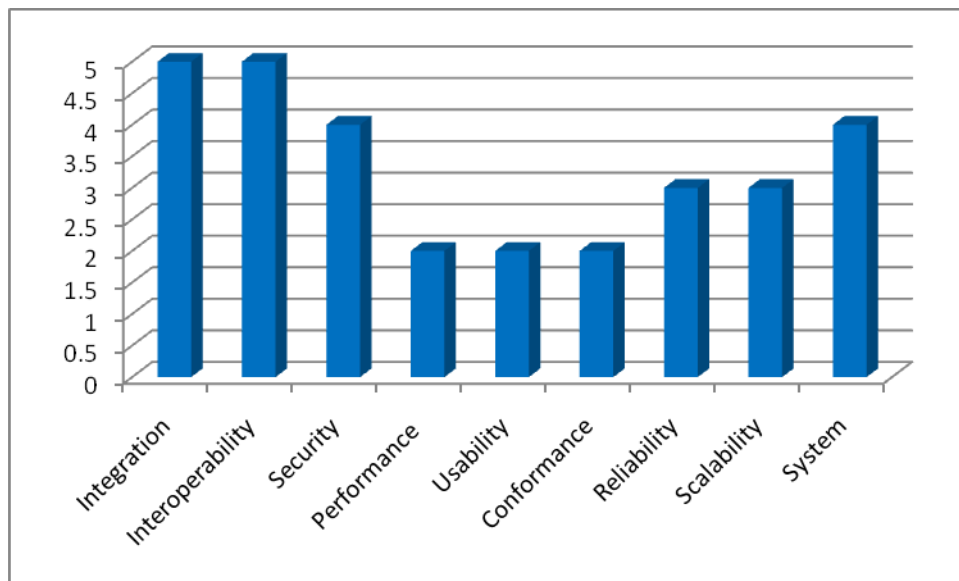
Graph (b) – Testing challenges of Web-based applications with their criticality level of Company B



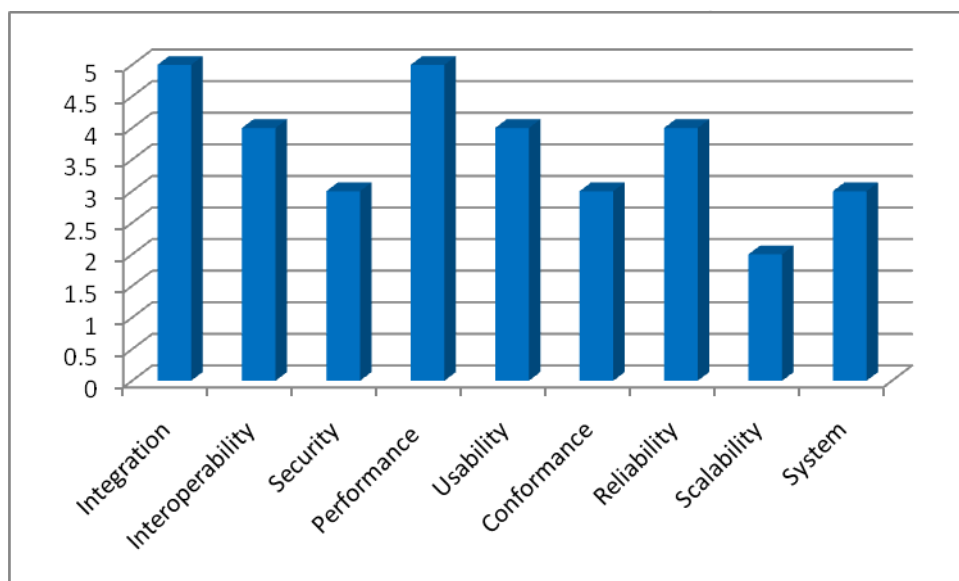
Graph (c) – Testing challenges of Web-based applications with their criticality level of Company C



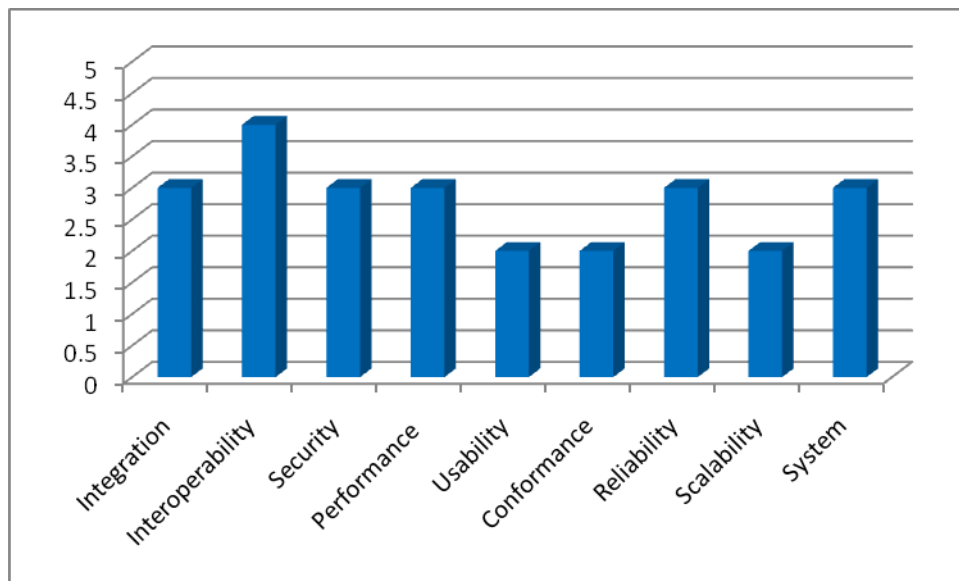
Graph (d) – Testing challenges of Web-based applications with their criticality level of Company D



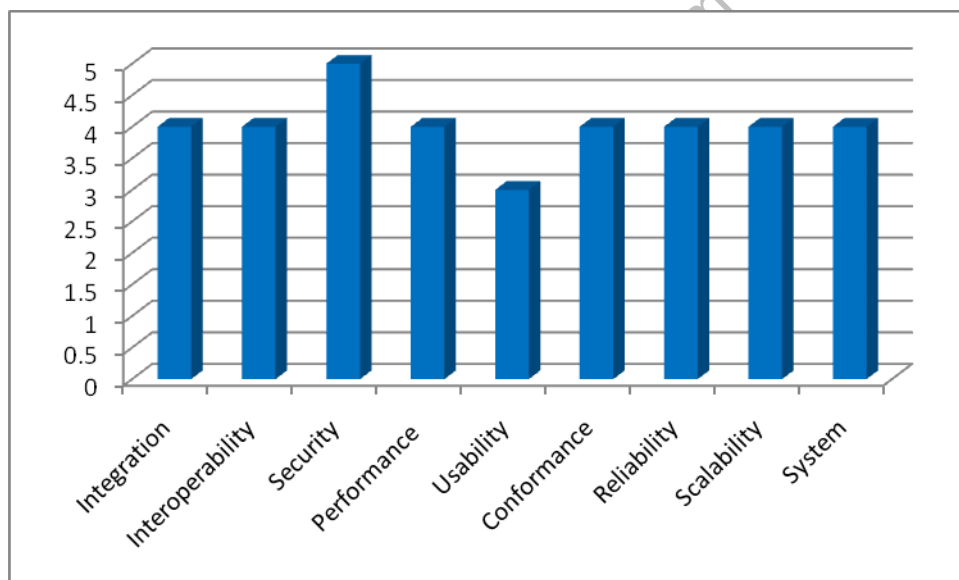
Graph (e) – Testing challenges of Web-based applications with their criticality level of Company E



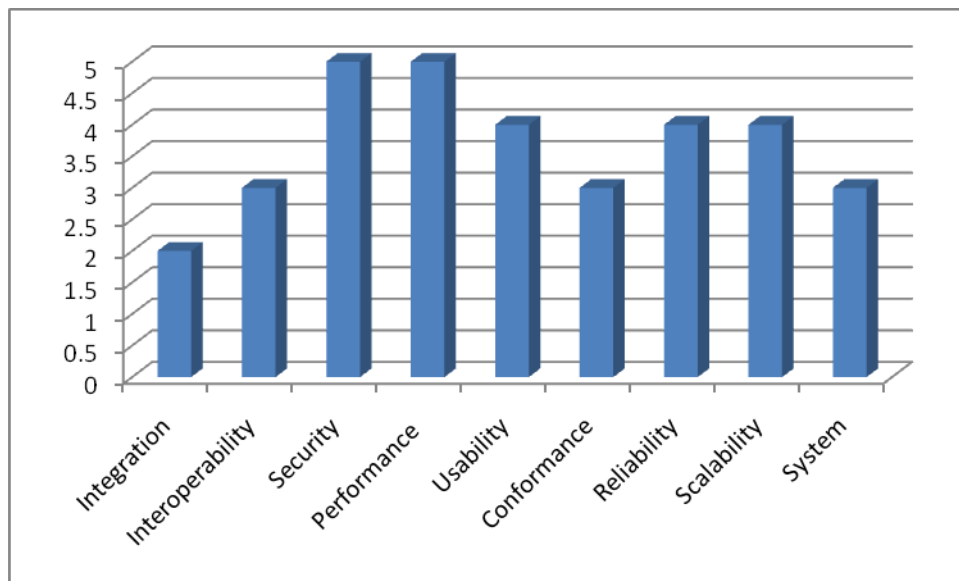
Graph (f) – Testing challenges of Web-based applications with their criticality level of Company F



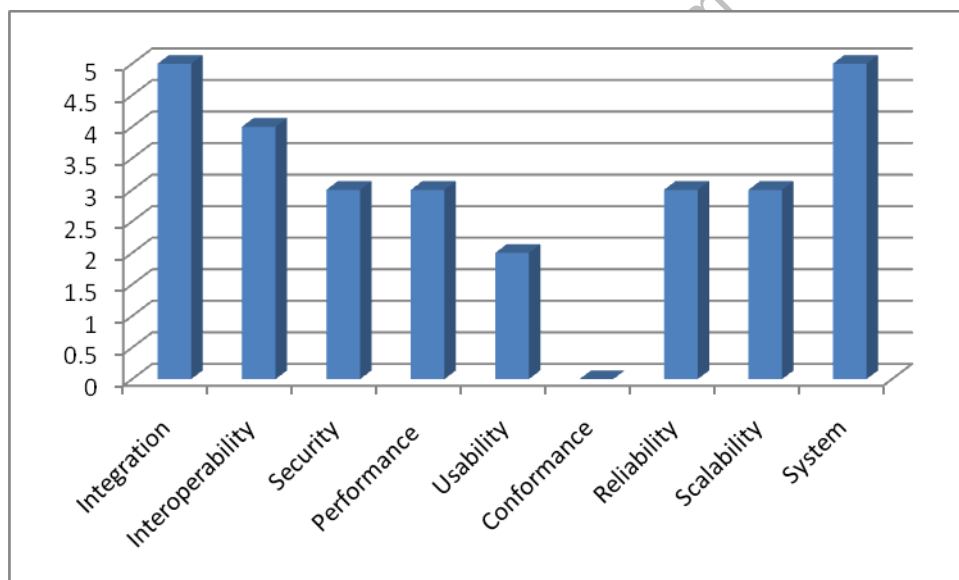
Graph (g) – Testing challenges of Web-based applications with their criticality level of Company G



Graph (h) – Testing challenges of Web-based applications with their criticality level of Company H



Graph (i) – Testing challenges of Web-based applications with their criticality level of Company I



Graph (j) – Testing challenges of Web-based applications with their criticality level of Company J