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An Interactive Visualization Web Application for Industrial-Focused Statistical Process Control Analysis

Dharshini Devi Subramaniam[1], Soon Chong Johnson Lim[2*]

[1]Human Resources Department,
Careglove Global Sdn. Bhd., Lot. 17479, Lorong Senawang 3/2 Off Jalan Senawang 3,
Senawang Industrial Estate, Seremban, Negeri Sembilan, 70450, MALAYSIA

[2]Faculty of Technical and Vocational Education,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author

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Abstract: Statistical process control (SPC) implementation plays a major role in quality assurance during the manufacturing process. Nevertheless, the adoption rate of SPC commercial software solutions is unsatisfactory in most Malaysian manufacturing companies due to high software subscription costs and difficulties in applying the software without proper know-how, guidance, and training. This study proposes the development of a purpose-built interactive data visualization web application for rapid SPC analysis in the manufacturing industry using open-sourced software packages. An agile software development model is applied as the software development methodology. In the requirement phase, an interview session was conducted to identify project requirements among stakeholders, i.e. industrial practitioners that are involved with SPC analysis. Based on the feedback and expectations from stakeholders, a design of a web application for SPC analysis that incorporates interactive parameter settings and automated reporting was proposed. The web application was developed using the R programming language and the Shiny package library, and deployed at ShinyApps.io, a web service provider. For evaluation, a usability testing procedure was designed and conducted with five industrial SPC practitioners to determine the usefulness of the web application. The outcome of the usability testing indicated positive results and feedback from evaluators. In conclusion, the developed web-app can assist users, particularly from the manufacturing industry sectors, to perform fast SPC data analytics, visualization, and reporting with ease.

Keywords: Statistical process control, data analytics, interactive visualization, web application

1. Introduction

Here introduce Nowadays, manufacturing companies are facing fierce market competition to offer quality products with a shorter time-to-market. Quality refers to the extent to which processes, products, services, and relationship are free from defects, constraints, and items that do not add value for the customer [1]. In this context, statistical process control (SPC) analysis is one of the common techniques that are widely used in manufacturing industries for such a purpose. The main focus of SPC implementation is to discover and diminish the variation that affects the reliability of the operation [1]. SPC can be applied to reduce waste in production by detecting and resolving the variance in the production cycle that may affect the product quality.

In modern manufacturing, SPC analysis is tightly linked with the manufacturing system. For instance, SPC control charts can be generated based on data from probes measuring dimensions using coordinate measurement machines

*Corresponding author: johnson@uthm.edu.my

(CMM) [2]. The results can be linked with a work order system where operators or a production supervisor can be alerted should there be any potential production issues. SPC is commonly applied through commercial software packages, apart from manual charting or spreadsheet applications [3]. Related commercial software systems such as *Infinity Qs*, *SPC XL 2000*, *IntraStage*, and *Analyse-it* are available on the market [4]. Besides, online SPC applications such as *QDM SPC cloudbase* and *WinSPC* are also available. However, a study by Ab Rahman et al. [4] showed that while large Malaysian manufacturing companies are able to afford commercial software packages, it is difficult for small and medium enterprises (SMEs) to follow such a practice due to several factors, e.g. knowledge and training requirements and cost of ownership. In fact, in the context of the Malaysian manufacturing sector, the adoption rate of SPC software packages is low, mainly due to the high cost of software licensing, maintenance, and customization features [5].

From the literature survey, there are a few studies that are related to purpose-built software solutions for SPC analysis. For instance, Zain et al. [6] conducted a study to design an online SPC application for conducting simple statistical analysis. The application design is mainly catered for Malaysian small and medium enterprises (SMEs), and is able to output an X-bar R chart, an X-bar S chart, and histogram. This study is an example of the early development of SPC in the context of local SMEs and has provided useful suggestions for further development. Laosiritaworn & Bunjongjit [7] have developed a SPC application using the Visual Basic programming language for the actuator production process. The developed application can be directly linked with a company's SQL database server system and is able to perform X-bar R chart and X-bar S chart analysis in a graphical manner. There are certain control parameters that are applied in the application, such as sample size and code number of the control chart. In addition, a study conducted by Škulj et al. [8] has proposed a SPC web service, eSPC, using an open-source programming language for plastic tube production. The eSPC web service is mainly focused on the output of control charts and functions according to the input data obtained from the data acquisition system, i.e., production quality related data. From the input data, the eSPC web service is able to generate a control chart in XML format. However, the application has limited functionality for SPC analysis, where users need to input the control limits and standard deviation values to create control charts.

Previous studies have shown many promising SPC-related software applications that cater to different industrial contexts. It can be noticed, however, that interactive visualization, customization features, and user interface features are less discussed and highlighted in previous studies. In addition, stand-alone computer-based applications are less practical as they can only be accessed on a specific machine. Given the popularity of mobile devices, web-based applications are the trend that enables ubiquitous and multi-user access. In the context of local SMEs, companies are searching for a cost-effective and affordable SPC application that possesses a friendly user interface (UI) design and good functionality [6]. This paper presents the design and development of a SPC web application in an attempt to address the aforementioned challenges. This study attempts to research the practical challenges and issues faced by practitioners from local SMEs and their needs pertaining to SPC. Based on the initial survey outcome, a web application that suits their needs is designed and developed based on open-source software. The purpose-built web application features an easy-to-use UI that enables interactive SPC data analytics, visualization, and reporting that can be suited for industrial needs. We shall detail the design and development of this application in the following sections.

2. Methodology

In this study, agile software development was adopted as the chosen software development model. Agile is one of the software development models that is an iterative and systematic process where requirements and solutions are defined through collaboration and self-organization [9]. The Agile model normally gives more importance to interaction and personal and working software compared to the complete documentation. There are six phases in agile software development: requirement, design, development, testing, deployment, and review. The following sub-sections will explain the details of each phase of the methodology. Fig. 1 shows the operational framework of this study.

2.1 Requirement Phase

The first stage of agile software development is requirement analysis, where its aim is to analyze the design requirements for developing the software product upon identification of user requirements and, subsequently, the setting of project scope, resources, and deadlines. For this project, the focus of the study concentrates on producing a web-application that is capable of producing an interactive visualisation of analyzed SPC results. Due to the time limitation, the scope of the SPC analysis is only limited to the X-bar mean control chart, which is a commonly-used SPC chart in the industry. Identification of research problems is carried out by using the document analysis method and case studies, i.e., the review of previous research articles that are related to user interface design, web application development, and SPC.

To better understand the actual needs of stakeholders, an interview session was conducted with two stakeholders (i.e., industrial practitioners) to identify the project requirements. Among the questions asked during the interview are related to software used by the user for SPC analysis, functionality and features of the software system, practical issues during SPC analysis, and the user's expectations regarding a potential SPC web-based application. This interview session shall identify the actual user requirements among the stakeholders.

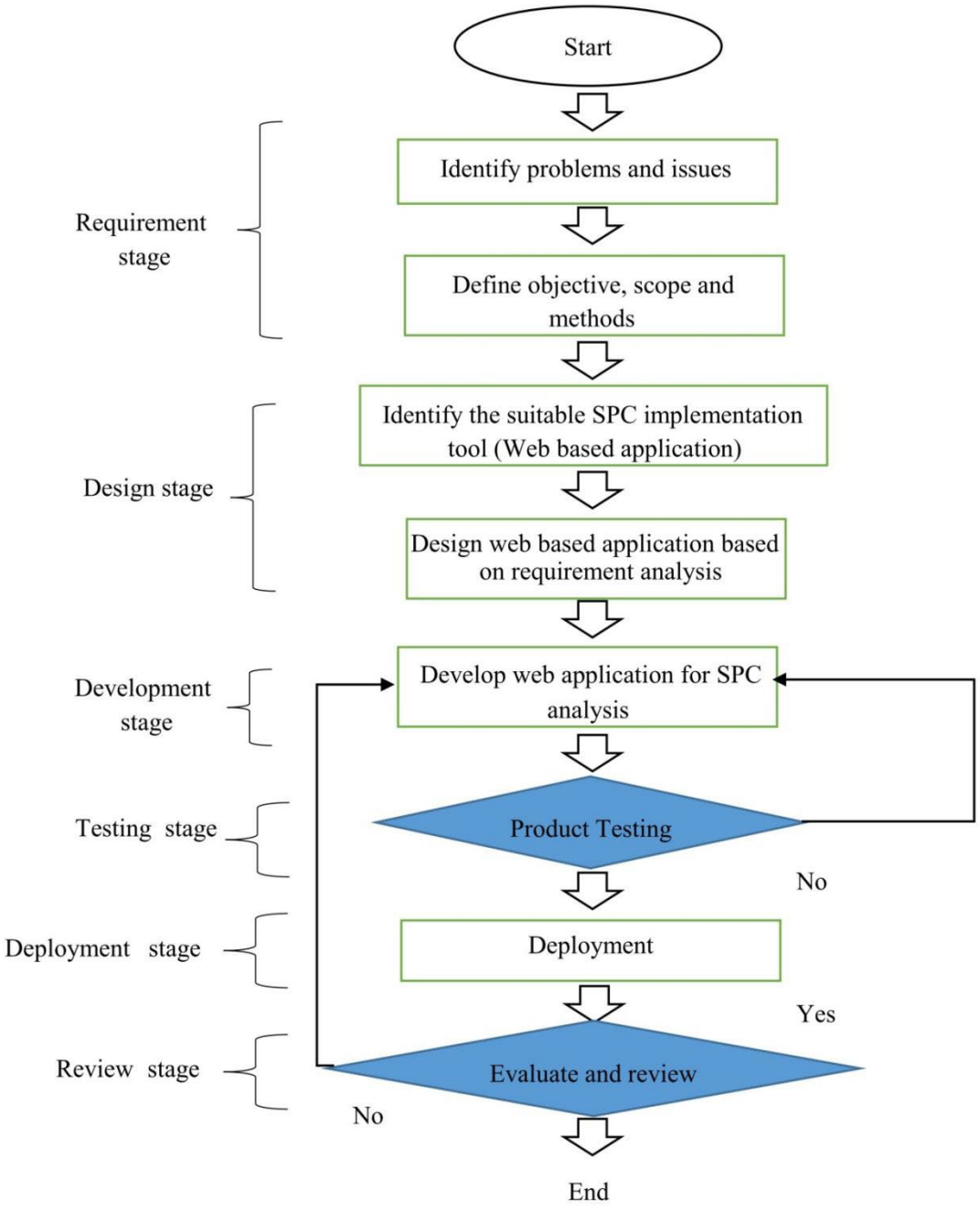

Fig. 1 - Operational framework

2.2 Design Phase

Designing is an important stage in the software development process. This phase explains the overall design of the user interface (UI) development. The aim of this stage is to translate the analysis of user requirements into software design. Based on the interview from the previous phase, a summary of stakeholder expectations for the SPC application is as follows:

- The application should be able to be accessed without requiring any installation.
- Capable of performing statistical analysis to detect out-of-control values in the manufacturing process.
- Able to show the visualization of the graph
- Must contain parameters such as sigma option, sample size, frequency, and column selection.
- Data files can be browsed through the currently used platform, such as a computer.

In order to develop a user interface web application, there are some factors that need to be considered, such as UI design suitability, layout design, and functionality of the web application. Consistency in UI elements, along with other considerations such as simplicity, prompt status feedback, and user in-control, are emphasized during the UI design. Besides the basic SPC analysis elements such as mean, standard deviation, upper control limit and lower control limit to detect the out of control in a production process, specific functionality such as X-bar chart visualisation using control parameters such as sigma slider, column selection, row selection, sample size, and subgroup frequency are incorporated. Visualization changes in SPC analysis results can be updated in accordance with different parameter controls. Besides, UI customization features such as color customization, as well as automated reporting features are also available. Fig. 2 indicates an example of the web application UI design.

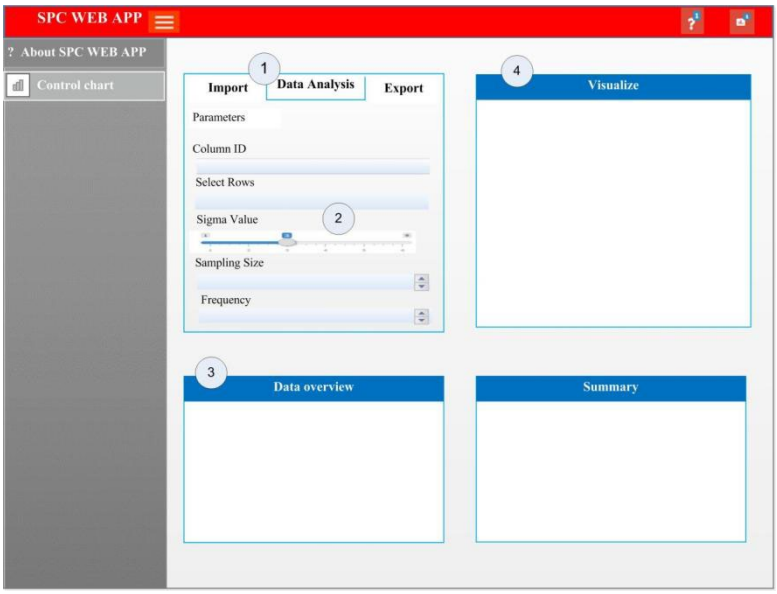

Fig. 2 - An example of a UI design for an SPC web application: (1) data analysis tab; (2) interactive parameter control; (3) imported raw data overview window; (4) results visualization window

Fig. 3 illustrates the UI interaction design for a web application in unified modelling language (UML) notation. UML is a graphical way of visualizing software system interaction. In this study, UML diagrams are used to indicate the components, structure, and interactions of the web application. The interaction design is aimed at allowing easy user navigation. In accordance with Figure 3, the interaction design of the interactive web application is detailed as follows:

1. A user logs into the web application with a username and password in the user interface layer.
2. The server layer verified the username and password to enable user access to the web application.
3. The user chooses the sampling type and when a raw data file (either .csv or .xlsx file) is uploaded successfully, the relevant data will be sent to the server layer for processing.
4. The server layer will process the data file and send the responses of the data overview and parameters to the user interface layer.
5. The data analysis subsystem window in the UI will enable customization through parameter tuning. A data overview from the input will also be displayed.
6. When the user customizes the displayed parameters, the request to execute the changes will be sent to the server layer.
7. The server layer will execute the changes in the control chart and interpret the statistical analysis results when the parameters are customized and send the display result to subsystem visualization and summary in the user interface.
8. When the X-bar chart is able to be visualized, the user can perform color changing and send download requests to the server layer.

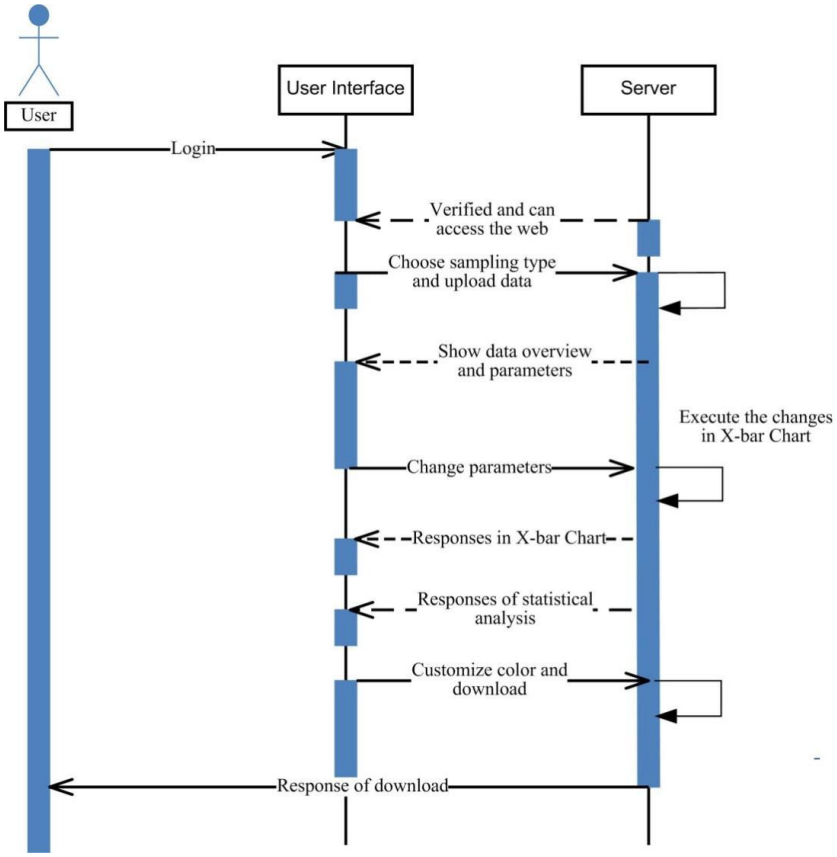

Fig. 3 - Interaction design in UML for user interface (UI)

2.3 Development Phase

The development phase illustrates how the Web-App is being developed. In this phase, practical features such as user login, buttons, and navigation design are being materialized. Fig. 4 shows the overall software system architecture that consists of a two-layered web-based implementation: the client interface layer and the web server layer. The client interface layer consists of a web-based interface that is known as the front-end of the interactive web-based application. This layer contains a web-based interface that helps the user easily carry out functions such as logging in, selecting parameters for the control chart, and notifications such as instruction videos and feedback forms. The design of this web application UI contains self-explanatory icons, familiar headlines, and simple text to achieve the user interface principles such as user friendliness and intuitive design. The server layer serves as the back-end of a web app that handles multiple functions such as performing statistical analysis, plotting and visualization, reporting, and output tasks, which enables the user to interactively perform SPC using this web application. The server layer contains five modules, namely: import, data analysis, visualization, export, and summary.

2.3.1 Import Module

This module is used to upload data in .csv (comma separated values file) and .xlsx (Microsoft Excel Spreadsheet file) format. This module can only accept .csv or .xlsx files that contain a header title. If the column section contains dates, it should be in '*2020-05-01*' format because, according to ISO8601 [10], this web application only covers the date and time on the x-axis, and date or time representation cannot include words with no specified numerical meaning in the standards.

2.3.2 Data Analysis Module

This module reads the uploaded file and shows the data overview and parameters for customization. The uploaded data set can be seen through the data overview box, and a user can customize the columns, rows, sigma, sampling size, and frequency options according to their needs. The column, row, sampling size, and frequency selection parameters are in numerical form, and the sigma value can be changed using a value slider with a value ranging from 1 to 6. These parameter values can be altered with visualization changes to the X-bar control chart reflected through the visualization box.

2.3.3 Export Module

This module enables a user to customize the color of the background, line, and point of the graph by using a special feature in the interactive web application. This module also allows users to download the visualized chart using the download feature. The plotted chart can be downloaded in.*pdf*,.*doc*, and.*html* formats.

2.3.4 Visualization Module

This module will display the plotted control chart graphically and visually according to the chosen parameter values. In addition, this module also performs visualization updates according to the interactively updated parameter values.

2.3.5 Summary Module

This module will display the statistical data analysis of the control chart, such as mean, standard deviation, upper control limit (UCL), and lower control limit (LCL). This module can automatically calculate the UCL and LCL values and identify the outlier points that are outside of the control limits of both UCL and LCL. This module also enables the automatic generation of reporting summaries and the export of such a report.

The entire Web-App is developed by using the R programming language as the base scripting language, with plugins from several library packages such as *Shiny* and *ggplot2*. A software integrated development environment (IDE), *Rstudio*, is used as the primary programming tool. Technically, the development of the web application involved the programming of two main scripts: (1) a user interface (UI) script that enables user interaction with the application, such as buttons, dropdown lists, navigation components, etc., and (2) a server script that functions as a computational module for analysis, visualization, and reporting feature of the application.

Corresponding to the aforementioned software system architecture and modules, Fig. 5 illustrates the interaction design during SPC analysis in UML notation. The interaction design of SPC analysis is explained as follows:

1. A user selects the appropriate sampling type in the import section. The selected sampling type will send a request to the import section.
2. The user can browse raw data files from the desktop environment. Then, the user clicks the visualize action button. When the user completes the upload task and clicks the visualize button, the related information will be sent to the data analysis section for further processing.
3. The data analysis section will display the parameters such as data ID, data column, row and sigma related to the X-bar chart. The uploaded file will be processed with a data overview displayed.
4. When a user performs parameter changes, the results will be visualized graphically to reflect the changes, with the corresponding statistical analysis results displayed in the summary subsystem.
5. A user can change the color of the plot, line, and background in the export section and the updated X-bar chart will be visualized.
6. The export section is able to perform tasks such as color changing and results downloading to return the downloaded result to the user.

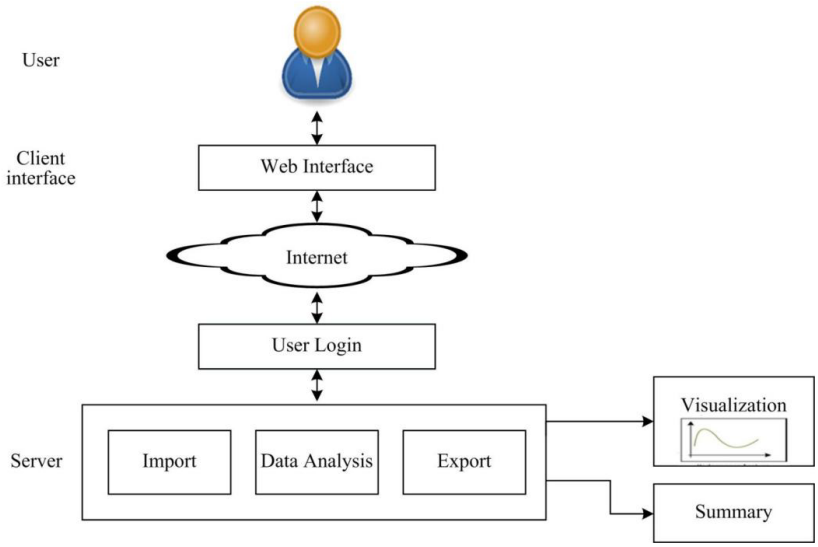

Fig. 4 - Web-based software system architecture

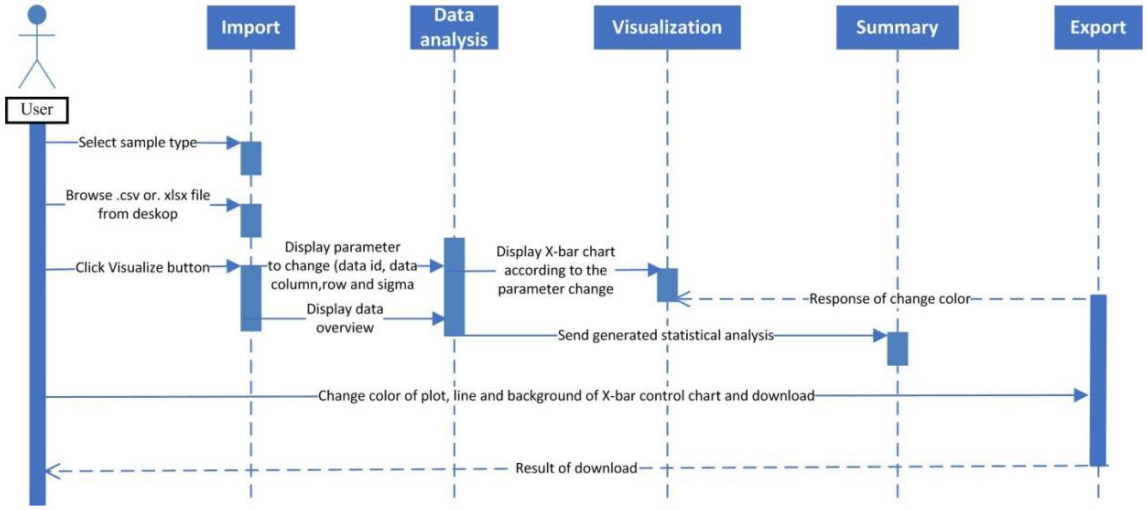

Fig. 5 - Interaction design in UML for SPC analysis

2.4 Testing and Deployment Phase

After the software development, the testing phase is entered where the web application undergoes the debugging and validation process to ensure error-free operation. Software testing is the process of determining whether or not a developed web application meets the expected specifications and is free of software bugs. In this study, software testing was performed using an automated testing tool, *Shinytest*, that is embedded within the *Shiny* package in R. *Shinytest* provides three categories of testing: unit tests, server function tests, and snapshot-based tests. This study uses snapshot-based tests to identify the errors and bugs in the interactive web application that was developed. Technically, *Shinytest* will record both the developed UI script and the server script by interacting with the developed web application and taking a snapshot of the application state. Later, the test script will be executed again in order to compare the result with the real one. If the result is identical, and there are no bugs or errors, the web application will proceed to the deployment phase. Otherwise, the web application will return to the development phase for maintenance. Upon successful validation and debugging, the web application will be deployed online as a web application on the RStudio server *ShinyApps.io*. This is a freely available server hosting for applications developed with the *Shiny* package. The deployment is aimed at enabling actual field implementation, evaluation, and review of the web application by a targeted user.

2.5 Evaluation and Review Phase

The evaluation and review phase will interpret the outcome and feedback given by users. In this study, usability testing was conducted through a guided questionnaire to simulate the actual usage scenario and its associated feedback from respondents. A guided questionnaire is developed through simulated situations and instructions for a user to complete a task. Respondents are required to access the web application based on the situation and instructions given in the questionnaire and answer the question based on the result they obtain when completing the task. The main purpose of this questionnaire is to identify whether a user is able to use the developed web application easily and to change or to customize the parameters for visualizing X-bar chart successfully according to the task given. The guided questionnaire contains four sections. Section A contains items that are related to the respondent's background, such as their occupation, experience with SPC, and proficiency with computing skills. Section B contains items to evaluate the user interface design of the developed web application. Section C contains items to evaluate the usability of the web application. Respondents need to complete a guided task and answer the questions based on the situational feedback. Section D is an open-ended question for respondents to provide their comments and suggestions.

3. Results and Discussions

Upon the completion of the testing phase, the web application is deployed at a hosting site for R Shiny projects called *ShinyApps.io* [1]. After this, the evaluation and review phase commences with the involvement of five industrial practitioners who have experience using SPC in their profession as respondents. Each respondent is provided with the deployed web application link and a set of questionnaires (online format) to collect their feedback. This section will focus mainly on the results of the review and evaluation process.

The questionnaires contain four sections. Section A contains six items to analyze the respondent profile: occupation, level of education, experience with SPC, application of statistical knowledge in career or work, software used to perform

[1] https://devidharshini.shinyapps.io/SPC_WEB_APPLICATION/

SPC analysis, and computing skills. From the result, all the respondents are from two manufacturing companies that consist of a quality control operator, a quality control chemist, a quality supervisor, a production supervisor, and a production technician. In terms of educational level, three of them have graduated with a bachelor's degree, and the rest are diploma holders. Experience wise, two of the respondents have SPC analysis experience of between three and five years, while the other three respondents have experience with SPC for more than five years. This shows that all the respondents are knowledgeable about the subject. Table 1 summarizes the respondents' feedback on items related to the application of statistical knowledge in their career or work. From the table, it is noted that they have primarily applied statistical knowledge to detect defects during production.

Table 1 - A summary of respondents' feedback on the application of statistical knowledge in their career

Questionnaire Item	Feedback	Respondent's Occupation
In which aspect of career or work you apply statistical knowledge?	"*To inspect the quality defect*"	Quality control operator
	"*Data Analysis*"	Quality control chemist
	"*To identify the defect and out of control data in production site*"	Production technician
	"*Inspect quality defect*"	Quality supervisor
	"*Detect actual and target value in production line*"	Production supervisor

In terms of software used for SPC analysis, it was found that four out of five respondents used Microsoft Excel for statistical analysis, with the exception of one respondent using Minitab 14, a statistical software. In short, most of the respondents are proficient at using spreadsheet applications such as Microsoft Excel for SPC analysis purposes. The last item is related to the respondents' computing skills. Fig. 6 provides a good summary of the computing skills survey. From the results, it was found that all respondents were proficient in word processing and four of them were proficient in spreadsheets. In addition, three respondents are proficient in operating systems and databases, with only one respondent each in multimedia and programming skills.

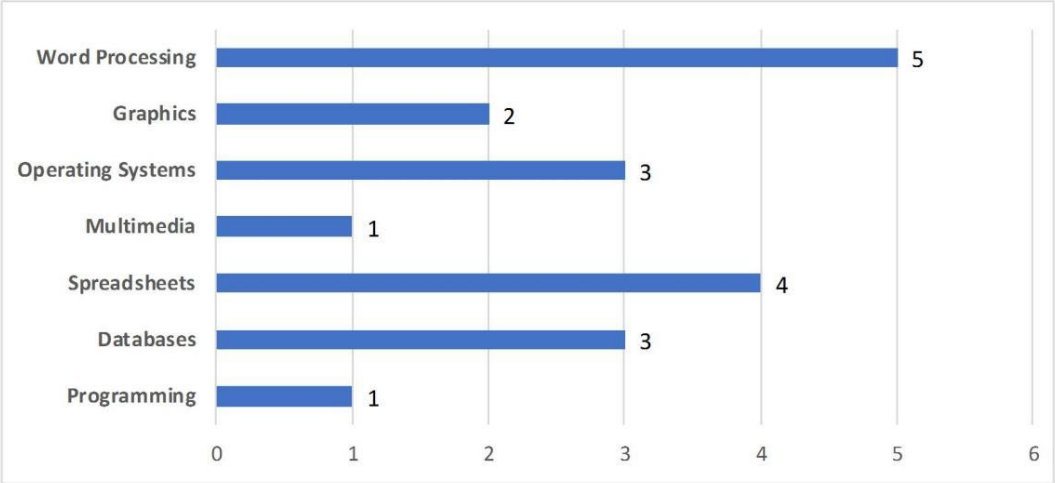

Fig. 6 - A summary of the respondents' computing skills

Section B of this questionnaire is related to the UI design of the interactive web application. Aspects studied in this section are each respondent's thoughts about the application when logging in, elements that are attractive to the respondent, and the arrangement of features and information in the developed web application. The first item of Section B is agreed upon by all five respondents, where the developed web application is related to control chart analysis. The next item that is analyzed in this section is the elements that are attractive in the web application. The results are summarized in Fig. 7. The findings showed that all five of them found the UI to be attractive, followed by the navigation menu (4 respondents). In contrast, only one respondent found the written content (tutorial) attractive. The results indicated that the web application was liked by most of the respondents. The last item in this section is the arrangement of features and information within the web application, where all respondents agreed that the web application is understandable, simple, and easy to access.

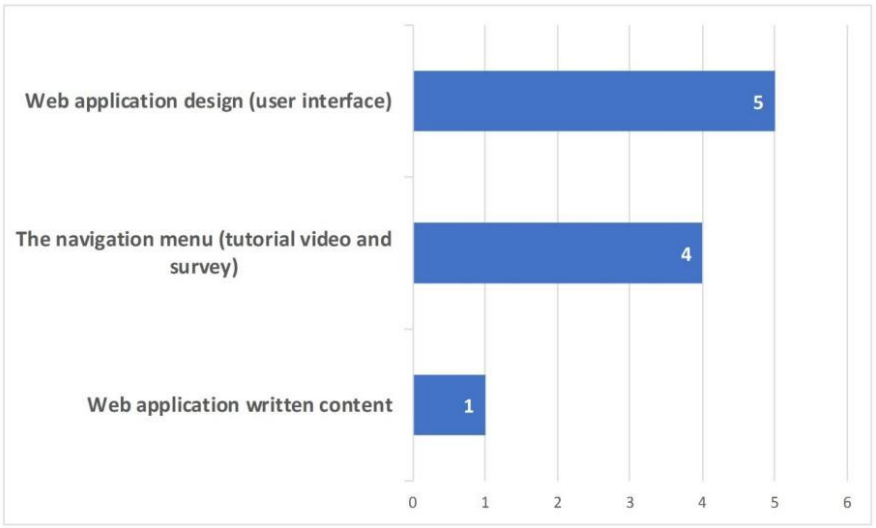

Fig. 7 - Features that are attractive to respondents

Section C of this questionnaire is related to the usability of the web application. Table 2 summarizes the guided items and their corresponding responses to usability. From the table, it is clear that all respondents were able to follow the guided questionnaire items without any issues, except for items 5 and 6, which achieved an 80% response. For these two items, the corresponding respondent replied that the task is a little confusing and difficult to complete. In Section D, respondents were asked to give their comments and suggestions to improve the developed web application's design and usability. Table 3 shows a summary of comments and suggestions made by respondents. From the outcome, it was found that most of them agreed that the developed web application could produce an X-bar chart and perform statistical analysis successfully. Nevertheless, they felt that improvements had to be made to the functionality of the web application to cater to additional features of SPC analysis in terms of data size, data format, and automated reporting. In general, respondents gave good comments about the UI design of the web application.

Table 2 - A summary of respondents' responses to the guided items of Section C

No.	Item Description	Percentage of "Yes" Response
1	Did you able to upload the .csv file successfully?	100%
2	Did you able to change the data column successfully?	100%
3	Did you able to input row parameter as 13 successfully?	100%
4	Did you able to visualize the plotted X-bar chart graphically ?	100%
5	Did you able to observe the changes in visualization of the plotted X-bar chart when data column and row parameter are changed?	80%
6	Did you able to change the sigma value to 4 and observe the changes in UCL and LCL value on summary box?	80%
7	Did you able to change the color of plot, line and background of the X-bar chart successfully?	100%
8	Did you able to complete the download X-bar chart in pdf successfully?	100%

Table 3 - A list of respondents' comments and suggestions

No.	Feedback	Respondent's Occupation
1	*"By the way the SPC Web Application is good but need some improvement where the system should be able to adapt/read more format of statistical process control. So far good."*	Quality control operator
2	*"Well so far the application works well. It is just some improvement still needed as this system still have limitations in terms of feature and it would be superb if it can read bigger size/ various type of data. Still well done as this system works well for simple statistical control."*	Quality control chemist
3	*"This application can produce X-bar chart and generate statistical analysis successfully. Can update the feature of the application such as add note that enable the user to present the chart and produce corrective action report."*	Production technician
4	*"Easily can understand the explanation given by the developer. This application is useful and friendly to use."*	Quality supervisor
5	*"The app is good in term of analysis X-bar chart and identify the thresholds out of control. But it will be better if make improvement in term of interpretation of X-bar chart and make a suggestion to the process."*	Production supervisor

4. Conclusions

This study has successfully designed and developed an interactive data analysis and visualization web application for SPC analysis with all the intended features. Overall, the development and deployment of the web application has been successful, and the evaluation and review of the web application using a guided questionnaire has received positive feedback from five industrial practitioners. In conclusion, the developed web application can assist users, particularly from the industrial sectors, to perform SPC analysis, visualization and reporting with ease. For future work, emphasis shall be placed on how to further improve the functionality and features of the web application, which includes data importing, additional types of analysis, visualization capability, and customized reporting output. All of this will help this web application to better serve its purpose as an industrial-focused SPC analysis tool.

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