Applications in teaching Statistical Quality Control with different R interfaces

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***Abstract*— Continual improvement in the quality of products, processes, and services has been facilitated by applying statistical methods. The statistical process control technique (SPC) provides enhanced results, as it utilizes statistical methods throughout all the developmental stages of a project and/or production. One of these techniques is control charts, which are powerful tools for viewing and understanding different types of process variations. Therefore, it is essential for professionals linked to engineering and technological fields to be familiar with these techniques and software programs, in order to facilitate the development process for creating control charts. The majority of these software programs designed for easy utilization and friendly interface for SPC applications are sold at high prices and thereby make access impossible to this computational resource for freelance professionals, small businesses, and especially students. The GNU R interface is open source and provides free access as one of the alternatives. So, for this purpose, this paper presents the description and application of control charts in three different R interfaces, as its objective is to use them for the teaching and learning process. (*Abstract*)**

Keywords— Statistical Quality Control; R Commander; RStudio; RExcel (key words)

I. INTRODUCTION

Statistics is currently used in practically all scientific and technological domains. It has become more and more important due to the growing need for resource management in the most diverse fields. Nowadays, the field of Statistical applications ranges among all types of sciences and engineering. It also plays a role in the fields of finance, economics, and administration. Statistical concepts and methods are not only useful but indispensable in understanding diverse phenomena surrounding us. They provide the means for perceiving diverse situations when uncertainties and variations are present and make it possible to judge and make correct decisions based on concrete results.

In engineering, statistics has broad applications for controlling product and service processes. It is also used in planning new production strategies and forecasting sales.

Specifically in Engineering, statistics is focused on controlling processes and manufacturing, assessing the variation and quality in products, seeking to follow-up on process stability. In this way, one of the main statistical applications is applied to Statistical Process Control (SPC), which monitors variability through statistical control charts and the Six Sigma program, which employs standardized procedures for collecting data and statistical analysis, for the purpose of identifying, treatment, and doing away with sources of error, seeking to achieve improvements in quality and processes, aiming at cutting down on defects.

The teaching of statistics has been added to many undergraduate course curricula in Brazil, as it is included in practically all engineering courses. No other discipline has

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interacted as much in other disciplines as statistics has. The teaching of this science is currently required in almost all undergraduate courses in the most diverse fields, with extremely few exceptions [1].

The Brazilian Education Law on Bases and Guidelines (LDB 9394/96), which systematizes the Brazilian educational system (public or private) from elementary to undergraduate teaching, presents a curricular recommendation for including Statistical subjects in different educational levels around the country, making it extremely necessary to carry out research studies and projects to provide quality teaching in this field.

Besides this, new information and communication technologies are becoming increasingly evident evermore in the contemporary society, stimulating and making more feasible even more the running of *software programs* in teaching statistics. There is already a consensus among educators, that statistic disciplines must be followed-up by some type of technology to diminish the need for performing manual calculations and provide access to data sets in practical cases and real situations [2] [3] [4] [5] [6].

There is still no consensus on the appropriate statistical software program for this purpose [5]. So for this purpose, there is a possibility to run accessible and free-of-charge software programs, for example, R [7]. Then, what is the reason for running R? R is a language and interface for statistical computational processing. It is an open source project, based on the concept of freely accessible software and as it can be licensed free-of-charge, for students as well as universities. It runs on several versions of Windows, MacOS, GNU/Linux and Unix. There are a large number of additional packages, which are also free-of-charge. It is also used for many statistics and it is being constantly modified [5] due to its permanent updates.

The majority of *software programs* used for SPC with easy utilization and friendly interface are sold. The average annual expense for SPC software licenses is a little over $2,000 (US dollars) [8]. Therefore, the cost for purchasing and licensing generally becomes unfeasible for freelance professionals, small businesses, and students. Thus, a free-of-cost alternative is the R interface [7].

In spite of all the advantages cited, due to the fact that R is a programming language, some authors have mentioned that it is relatively difficult to learn, especially at the introductory level [5] [9] [10]. The purpose of this article is to describe some interfaces in R as support alternatives for teaching SPC.

Several studies have been carried out to help students in learning SPC by way of computational tools [11] [12] [13], including in the R interface [8] [14] [15] [16].

Reference [14] presents R as a tool for helping to learn monitoring and SPC, through the QCC package, via examples commented in the main control charts as: Shewhart, Cumulative Sum – CUSUM, and Exponentially Weighted Moving Average – EWMA in the R Console interface. The application of SPC, based on R, is demonstrated by [8] for the industrial context. Reference [15] presents a brief overview on packages for the purpose of SPC and for methods, also addressing other useful packages for engineering courses. These studies have made it possible to update and revitalize the disciplines in the fields of statistics and engineering.

This study has been structured as follows: section 2 introduces a brief theoretical reference and some quality statistical control techniques; section 3, there is discussion on the R Commander, RExcel and RStudio interfaces; section 4 describes SPC applications using all the interfaces. Conclusions and final considerations are expressed in section 5.

II. STATISTICAL QUALITY CONTROL

Quality plays a fundamental role in the scope of industries and businesses, as this has been a core theme in business strategies in order to become more and more competitive. Quality has also become a cutting-edge factor in consumers' choices of products and services. Consequently, Statistical Process Control (SPC) has been amply used in order to achieve improved quality in products, processes, and services.

SPC employs statistical methods throughout all stages which are considered critical or extremely important in the development of a project and/or production. Nowadays, all factories employ at least some simple SPC tools for improving industrial processes [17]. Reference [17] stresses the main idea of SPC, which is, improved processes with less variation to provide improved levels of quality in production. And considering improvements in processes, this not only means improved quality, but also lower costs. Control charts are highlighted among the SPC tools, as they constitute powerful instruments for viewing and understanding different types of variation in a process. Using them makes it possible to detect when a process leaves a controlled or foreseeable condition and starts to act in an unpredictable manner, influenced by what are called "special causes".

The most popular control charts are the Shewhart type, due to their simplicity as a decision rule. They are charts adapted to detect large modifications in a specific quality characteristic. However, they are not effective for small and persistent modifications. Then, cumulative sum (CUSUM) control chart and Exponentially Weighted Moving Average (EWMA) are alternatives or complements for this purpose.

A. CUSUM and EWMA Control Charts

Control charts with memory are also denominated as advanced control charts, such as the Cumulative Sum (CUSUM) control chart and Exponentially Weighted Moving Average (EWMA) control chart, which are enhanced Shewhart type charts, developed for specific situations as to simultaneously minimize the occurrence of false alarms and non-datum alarms [17].

The CUSUM control chart introduced by [18] is an alternative to the Shewhart control chart for detecting small changes in the characteristic distribution of quality, in order

to maintain strict process control and provide an estimation of a new process level or average. This type of chart with memory directly incorporates all the data sequence plotting for accumulated sums of sampling value deviations of a target value.

The EWMA control chart introduced by [19] studied the case of normally distributed observations, which is a good alternative to the Shewhart type control chart, for detecting small changes at the order of 1.5 standard deviations, or less, in the quality characteristic distribution and supply estimation on a new process level or average.

There is a great deal of discussion on the benefits and disadvantages of CUSUM and EWMA charts in [17]. These two charts serve the same purposes, as they are characterized by their enhanced efficiency to detect small changes in processes instead of the Shewhart type. The CUSUM and EWMA charts employ the entire series of data to calculate the control limits and points on the chart differently

These charts were selected due to their increased application in other fields of engineering, as well as the industrial productive process, for example: service assessment and environmental monitoring. Therefore, they are recommended for future professionals who will be mainly linked to the field of engineering and technology, which are served and employ by these tools.

III. Overview of R (software)

This section proposes to give an overview of R software in the following *interfaces*: R Commander, RExcel and RStudio, including instructions on its *download* and installation, as well as a brief description on the main characteristics of each *interface*.

A. R Commander

The R Commander interface is also open source and acquired free-of-charge. It is available from the Rcmdr package, which runs in a menu graphic interface [20]. The graphic interface as shown in (Fig. 1) does not require the user to remember command names and arguments and thereby decreases the chances of typing mistakes. These characteristics are especially attractive when beginners start running it or when this type of software is run infrequently [20], besides being a useful instrument as a teaching tool [10].

R Commander is not available in the default R installation, it is necessary to download and install a package specific for each of the following operating systems: Windows, Mac and Linux. This process can be performed directly from the R program by accessing the Package/Install Package menu. The download and installation will automatically take place. To access the R Commander option, the Rcmdr must be loaded, by typing library(Rcmdr) or require(Rcmdr) on the Console *prompt* screen (the main R system screen). Fig. 1 displays the main R Commander screen.

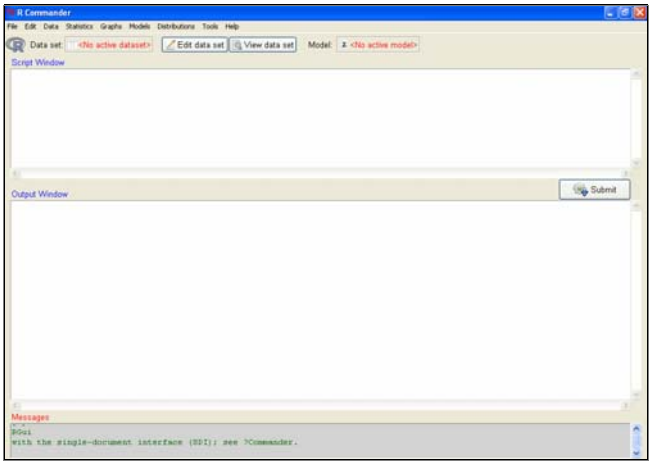

Fig. 1. The main R Commander GUI system screen.

In the upper part of the screen on Fig. 1 are the following menus: File, Edit, Statistics, and so on. Below the menus there is a toolbar and buttons for selecting, editing, and viewing active data sets. Below the toolbar, three windows are displayed: the script, output, and message windows. It is important to emphasize that R lets students work with scripts, thereby making outputs reproducible. The purpose of this "memory" is to see how the analysis was conducted. And, the commands generated by R Commander results from actions displayed on the script window. These commands can be edited and rerun; they can also be saved and loaded afterwards. After pressing the Submit button, the line or selection where the curser is placed will be loaded [20].

The output is printed and displayed on the Output window; however error messages, alerts, and other information are displayed respectively in red, green, and blue on the message window. Charts are displayed in a separate window, named the Graphics Device, outside the main R Commander window [10] [20].

The Rcmdr functionalities have already been enlarged beyond its original purpose, although it still enables direct access to a small fraction of the R default distribution analyses, without mentioning the nearly 4000 packages which have been implemented in R. Thus, besides improving the utility of R as a teaching tool, a plug-in package enables the addition of developer packages to be added to the Rcmdr interface. Based on additional plug-ins, package functions are added to the toolbar [20]. Currently, there are around thirty plug-ins implemented in Rcmdr.

The process for installing the packages and *plugins* which are used by Rcmdr is the same as the one run by R Console. Two plug-ins return to the control charts: the SPC RcmdrPlugin.qual package [21] and the RcmdrPlugin.qcc package [22], both are based on the qcc package [23]. In this document, we will only focus on the first. To load this, access the Rcmdr Tools/Load plug-in(s), on the main R. Commander screen (Fig. 1). Then select the RcmdrPlugin.qual package.

At the time the package is loaded, the R. Commander main screen will display a new menu "Quality Control" on the toolbar, as Fig. 2 shows.

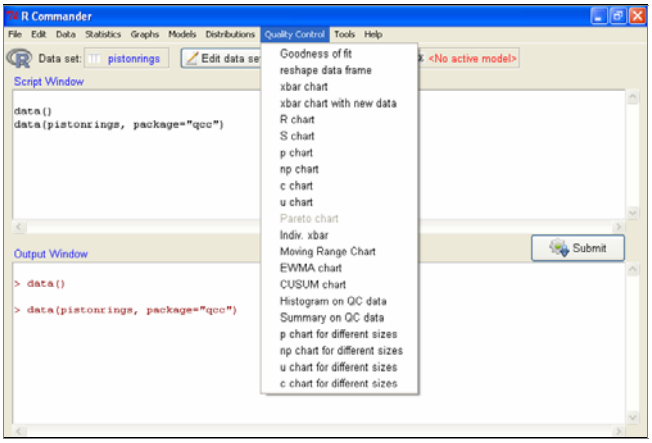

Fig. 2. The R Commander main screen with the active SPC plugin menu.

R Commander makes it possible to use available data sets in R, create a data set, merge existing data sets, and import data from an Excel, Access, or dBase text file. It also allows the user to import a data set from the Internet and other statistical software programs as SPSS, Minitab and Stata. These functionalities are available on the Data menu, on the R. Commander main screen (Fig. 1). In Fig. 3, the loading of data from an Excel spreadsheet is displayed.

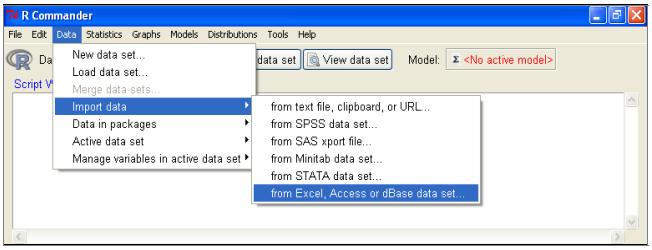

Fig. 3. The import data menu for importing data from a file.

B. *RExcel*

As seen here, the R software is an excellent tool and provides a broad range of applications, but its flexibility also complicates usability for new users. On the other hand, Microsoft Excel spreadsheets are extremely easy to use, as they are widespread throughout industry. Thus, to [9], merging these two tools has its benefits; and it is possible to run the RExcel application to ease this situation. RExcel is a supplement for Microsoft Excel and enables access to the R package within Excel. This supplement is already integrated in the Rcmdr interface. However, it runs only in Windows.

The easiest way to install the *RExcel* application in R, and the additional necessary packages is by downloading the RAndFriendsSetup version package [24], available at http://rcom.univie.ac.at and clicking the Download link. Then after concluding the RExcel installation, the user can click the icon on the desktop or access it directly in Excel in the Supplements/*RExcel*/Connect R option. Fig. 4 displays the Microsoft Office Excel 2007 version spreadsheet with the R menu on the Supplements tab.

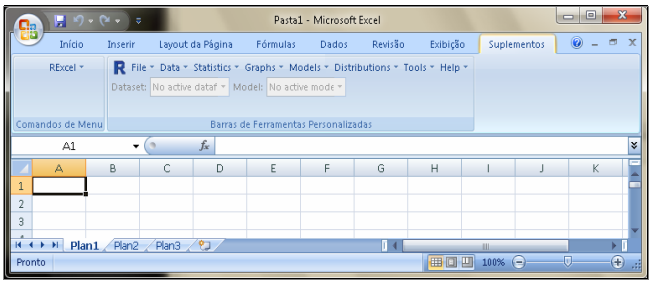

Fig. 4. See the RExcel Menu in Excel 2007.

It is also possible to view all the standard menus from *RExcel* in Fig. 4 (File, Data, Statistics, Graphs, Models, Distributions, Tools, and Help) and the active data set, in the Data set field. When the user clicks the *RExcel* icon on the desktop, it opens R, o *RExcel,* and Rcmdr simultaneously.

The RcmdrPlugin.qual package will be used for control charts as in the previous section, loaded in *RExcel* in Tools/Load Rcmdr plug-in(s). After loading the package a new menu named "Quality Control" is displayed in RExcel, as shown in Fig. 5.

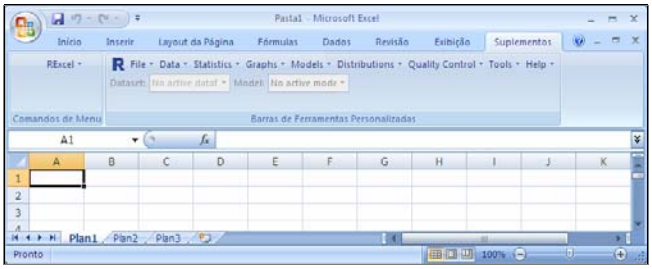

Fig. 5. The Quality Control Menu in RExcel, which enables.

Just like the R Commander, *RExcel* allows the user to work with diverse types of data. These functionalities are available on the Data menu, on the *RExcel* main screen.

C. *RStudio*

The RStudio IDE is a powerful and productive interface for R, as it is also a free open source application for various operating systems, such as Windows, Mac, and Linux [25]. As stated in [26] students can feel more comfortable using RStudio than the other R interfaces, which makes it become a good option for teaching in the classroom.

RStudio requires version 2.11.0 or higher to be previously installed. This installation of R is available at http://cran.r-project.org/ and *RStudio* at http://rstudio.org. Regarding the download and installation of the additional packages, the procedure is the same as was performed in the R software, however in *RStudio* it is found in the Tools/Install Packages option or directly on the Packages tab on the lower right screen in *RStudio.*

The main screen in *RStudio* is different from R, as it is displayed in 4 distinct panels. In the upper left hand corner of (Fig. 6) the Source window is displayed.

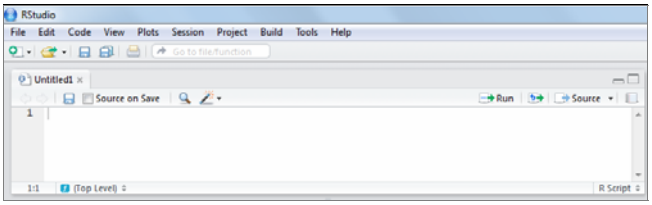

Fig. 6. The RStudio Source Screen

The scripts (previously typed programming codes and saved in an .R file extension), text files, Sweave documents, R documentation, TeX and HTML documents, among others are displayed on this screen.

The upper right screen (Fig. 7) shows the first tab which is used for managing different workspaces. And the second tab displays the history of all the scripts, functions, and run actions.

Fig. 7. The RStudio workspace management screen

The same default window is enabled in R as seen on the lower left, located on the Console screen as seen in (Fig. 8).

Fig. 8. Console RStudio

And finally, in the lower right window (Fig. 9), 4 other tabs are clustered in the window: the first one is a file manager (File tab), the generated charts are displayed by *RStudio* on the second one (Plots tab). The installed packages are displayed on the third one (Packages tab). And finally, the fourth one is for Help (Help tab) in R/RStudio.

Fig. 9. RStudio Window for managing charts, packages, and help.

It is possible to automatically comment or not when editing the script on the Source window (without any need for typing) a specific part of the code by using the Edit/Comment/Uncomment Lines options and keeping the cursor on the desired line for running or selecting a set of desired lines. On this screen, it is also possible to indent commands automatically, a common practice in the organization of scripts in computer science.

Scripts can be run by clicking the Run button, it is no longer necessary to right-click the mouse on the script line, as was standard practice in R. It is also possible to run several command lines by selecting the desired lines and executing by clicking the Run button or by pressing the Ctrl+Enter keys.

The *RStudio* Console includes a variety of resources to facilitate your work in R, in such a way as to make your work more productive and simple. One of the resources, we would like to mention on the Console screen in *RStudio* is the automatic conclusion of the code by pressing the Tab key. This automatic text insertion resource also works for function arguments.

The Workspace tab (Fig. 7) on the upper right screen of *RStudio* is displayed in the workspace where the data are displayed as a data set (vectors, matrixes, etc.) accessible in the workspace and variables, which can be modified by double-clicking them. It is also possible to load a data set and load a new workspace on this tab and then easily alternating between them.

The same thing occurs in the default Console in R, the RStudio Console in (Fig. 8) allows the user to run previously used commands by pressing the Up (↑) and Down (↓) keys. There is also a list of recently used commands displayed by pressing the Ctrl+Up (↑) or Crtl+Down (↓) keys.

The Plots tab is on the lower right screen in *RStudio* (Fig. 9) the plotted charts are displayed here and it is possible to save these in a PDF format and also the figures in a variety of image formats.

IV. Applications for Statistical Quality Control

The purpose of this section is to introduce SPC applications in previously introduced R interfaces. The RcmdrPlugins.qual packages will be used for these applications in R Commander and RExcel, and in RStudio the package and qcc will be used.

A. Applications using R Commander

Access the Data/Data set menu in the packages/Read data attached package to access a given data set in the R program. The screen is displayed for selecting the available package and data set for the selected package. It is even possible to define a different name for the data set by accessing the "Define data set name" field. It also lets the user retrieve more detailed information on the data set by clicking the "Selected data set Help" button. In this application, the *pistonrings* data set package was selected.

This data set as presented in [27] shows the internal diameter (in mm) of piston rings of a specified automobile. The data set is made up of 40 samples, each one equal to the size as: n = 5. The organization of the samples is sub-grouped and it is performed on the Quality Control menu/reshape data frame, whereas, it is necessary to select the variable of the data set, input the number of samples in the sub-group and a name for the changed data set.

The organization of the data set into sub-groups is based on the construction of control charts. The commands are presented in the next-to-the-last line in Fig. 7 which result from the operation run from the Quality Control menu/ /xbar chart. However, this package is not enabled for performing this in the direct mode, the diagnostic phase I (retrieving a representative data sample of the control limits) and phase II (process monitoring based on the specified control limits

from the previous phase), which are classical procedures of correct planning and construction of control chart [28].

This situation can be corrected by changing the last command line displayed on the script window, which is a result from running the last command line on the *Scrip* Window (Fig. 10) and it is displayed on the control chart in Fig. 11.

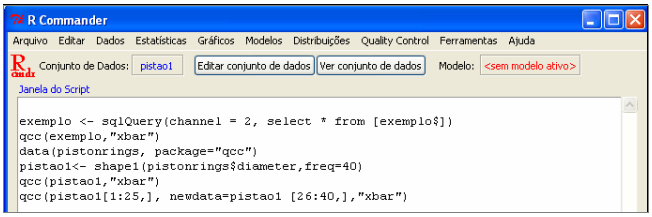

Fig. 10. This displays the results on averages on this control chart.

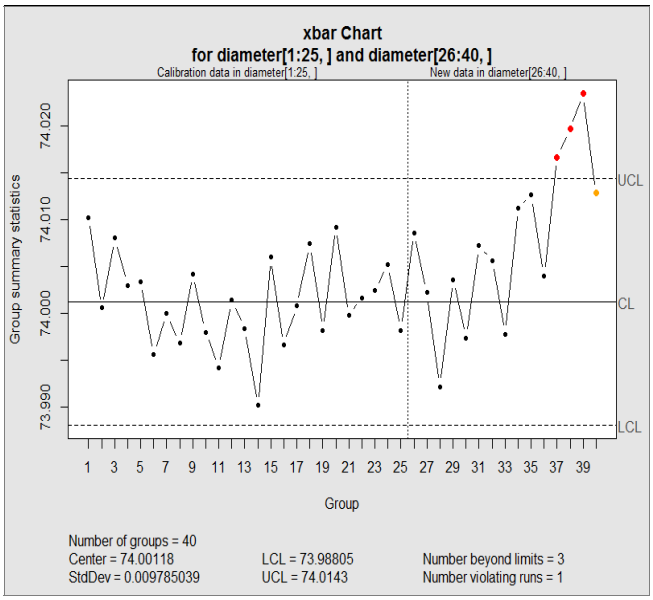

Fig. 11. The diagnostic phase and control chart monitoring phase on averages.

In Phase II on Fig. 11, which starts in the 25th group, it is possible to verify three points (37º, 38º and 39º), as well as the upper control limit, which characterizes a process as being out of statistical controlled.

In Fig. 12 and 13 there are CUSUM control charts, both for individual measurements run on the Quality Control menu /CUSUM Chart and Quality Control/. In this application, the data utilized is based on individual temperature measurements in Celsius degrees of a chemical compound as described in [17].

The process is considered as statistically controlled in Fig. 12 as well as in Fig. 13, as none of the points have exceeded the control limits.

Besides the previously presented charts, the package is even enabled to construct (R) amplitude charts, on variability (S) and for p, np, c, and u type attributes.

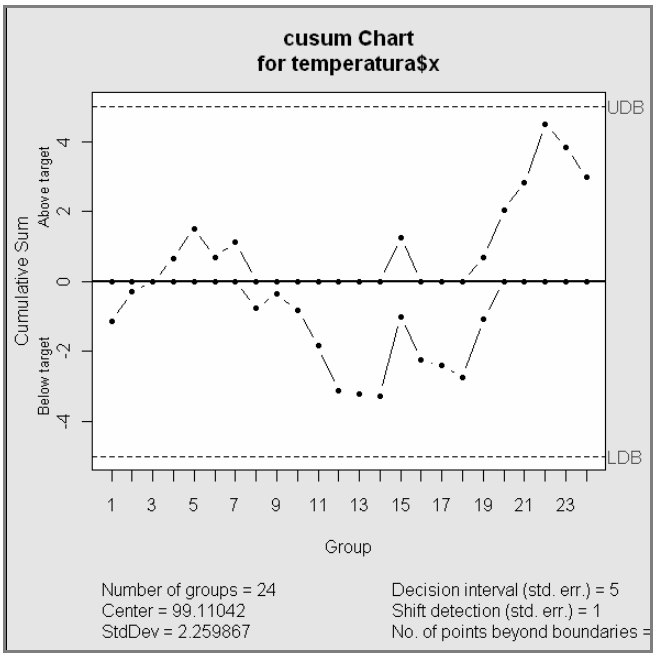

Fig. 12. CUSUM control chart.

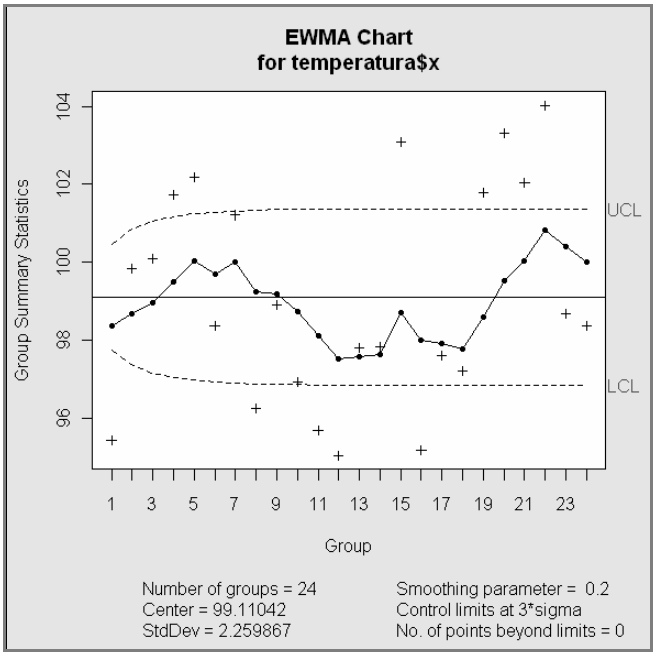

Fig. 13. EWMA control chart.

B. Applications using RExcel

The imported data from the spreadsheet used to generate the Shewhart type control chart are based on the machining process for a metallic bathroom part industry, located in southern Brazil. In this process, the internal flush valve body is machined in order to fit and insert the rubber o-ring inside for sealing the part [29].

Access the Data/Import data/From Excel menu to access (import) available data from Excel, Access, or dBase data set

files, input the name for creating the new data set and locate the Excel file in the computer where the data are contained. The enabled data set will be displayed in the Data set field.

The commands from the data importing process from the Excel file are displayed on the first line on the script window of the R Commander screen as shown in Fig. 14. As *RExcel* does not enable the user to manipulate data in the Data set field after being imported from an Excel file, it is necessary to save it in the RExcel file format and load it again. The command used for saving the data resulting from the action on the Data/Active Data Set/Save Active Data Set menu, will be displayed on the last line in Fig. 14.

Access the Data/Load data set menu to load the saved data set and select the file from the disk. As soon as the data set is loaded, it will be displayed in the Data set field on the RExcel screen, as the enabled data set, as displayed in Fig. 15. Click the right mouse button and select the "Get Active DataFrame" option to view the data set directly in RExcel as shown in Fig. 15 and then select the "Get Active DataFrame" option.

Fig. 16 displays the Shewhart type control chart on the machining data. The user just has to insert the current R chart, by clicking the right mouse button to display the chart generated straight from the Excel spreadsheet. Notice how the average is higher than the control limit in sample 23 and therefore, it is sufficiently far from the justified process average to investigate and discover a special cause and resolve the problem.

As the plugin used does not enable the user to directly construct a sample in the collection phase representative of the data in order to define the control limits (Phase I - diagnostic) and the process monitoring phase by way of the specified control limits from the previous phase (Phase II - monitoring), this chart was generated based on the command presented on the RExcel screen in (Fig. 17), which was run by using the "Run code" command, when right clicking the mouse button on the typed command.

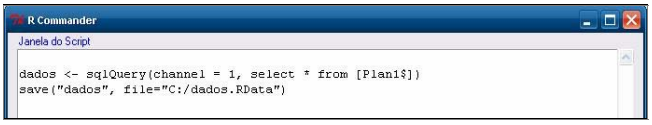

Fig. 14. See the Rcmdr screen with the commands run by RExcel

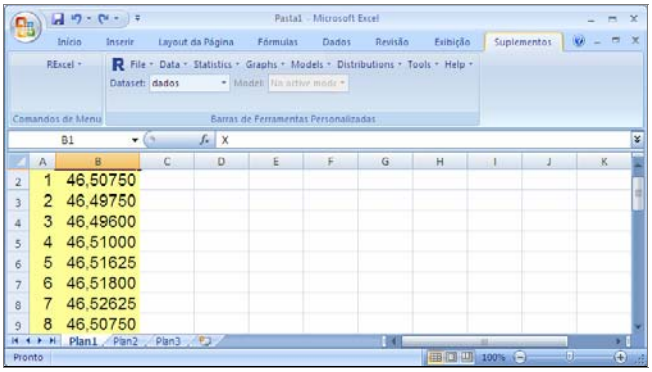

Fig. 15. See the machining process on the flush tank valve body.

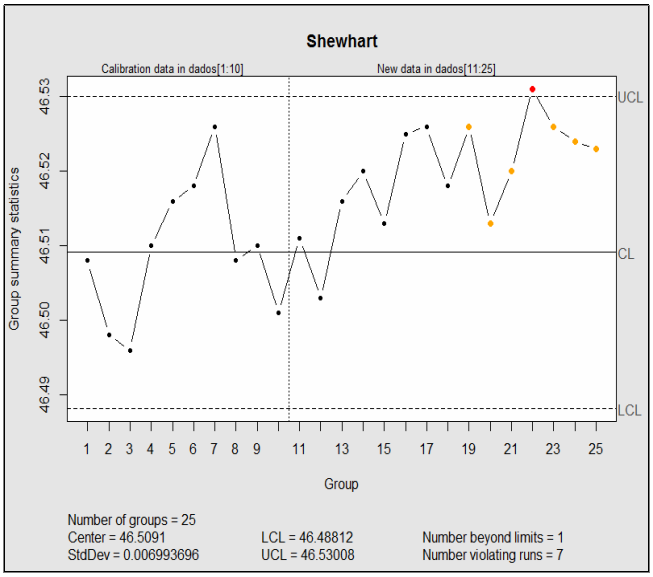

Fig. 16. See the Shewhart control chart showing the average on the machining process (diagnostic phase and monitoring phase).

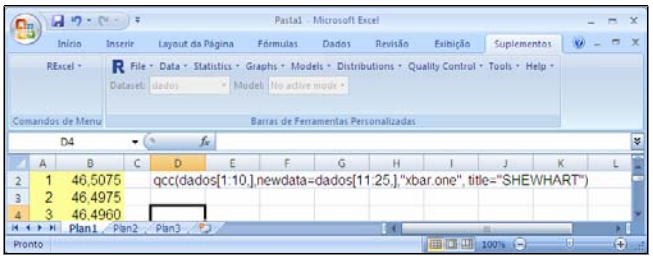

Fig. 17. See RExcel with the commands for generating Phases I and II of the Shewhart control chart on the average

Look at how it is so simple to construct the CUSUM and EWMA charts using the plugin, as it is just necessary to access the specific menu and select the variable for plotting, as shown in Fig. 18. Fig. 19 displays the CUSUM control chart for phase I and phase II, as it is also necessary for the user to intervene by typing the commands as shown here on lines 17 and 18 on the spreadsheet in Fig. 18.

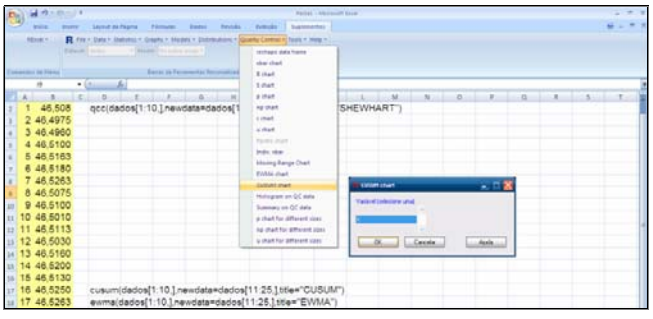

Fig. 18. RExcel displays the commands for generating a CUSUM chart for the average.

A EWMA chart can be constructed in a similar way, as displayed in Fig. 20. The behavior of the process reveals changes when the data are analyzed using the CUSUM and

EWMA control charts as shown in Fig. 19 and 20, respectively.

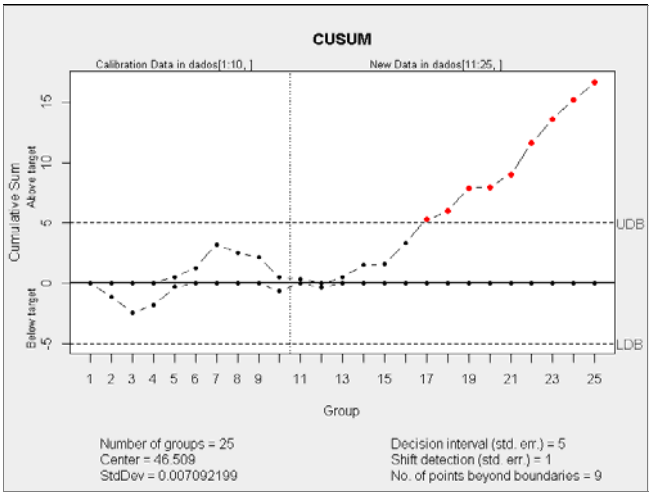

Fig. 19. See the diagnostic phase and monitoring phase on the CUSUM chart.

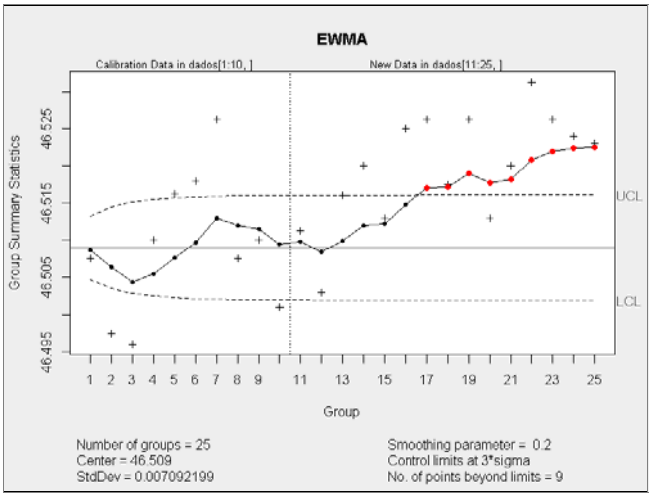

Fig. 20. The diagnostic and monitoring fases of the EWMA chart.

As is verified on the Shewhart control chart in (Fig. 16), the uncontrolled process indication occurs in sample 22 and is stabilized after that point. Beginning in the analysis obtained by the CUSUM control chart, the process does not return to a stable situation after sample 17, when it exceeds the upper control limit. Another consideration is it is possible to identify an increasing trend of the process average.

C. Application using RStudio

For the graphic applications of CUSUM control (Fig. 21) and EWMA (Fig. 22) for the average, which are presented in Fig. 17, data from [30] were used which are also available in R in the Devore7 package.

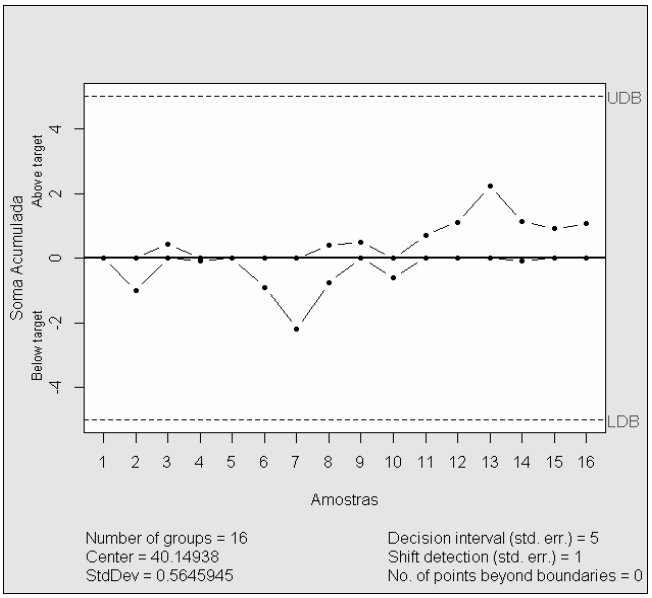

Fig. 21. CUSUM control charts on the weight of charcoal.

The data are related to the weight of charcoal for barbecue restaurants. The charcoal is packaged in several sizes of bags. The largest is around 40 pounds (1 lb ≈ 0.4536 kg). The data are organized into 16 samples of size n=4. The ten first weights were collected at a normal distribution N(μ = 40, σ = 0.5). Starting with the sample number 11, the average was scaled up to μ = 40.3.

The CUSUM control chart in Fig. 21 has defined the reference value as k = 0.5 (this parameter is related to the change magnitude), control limit h = 5. Since the EWMA chart in Fig. 22 has been configured to λ = 0.2 (a smoothing constant which defines the weight expressed for previous observations) and, L=3 (the width of the control limits). These values are the cusum ( ) and ewma ( ) default functions of the qcc package, used in this reference.

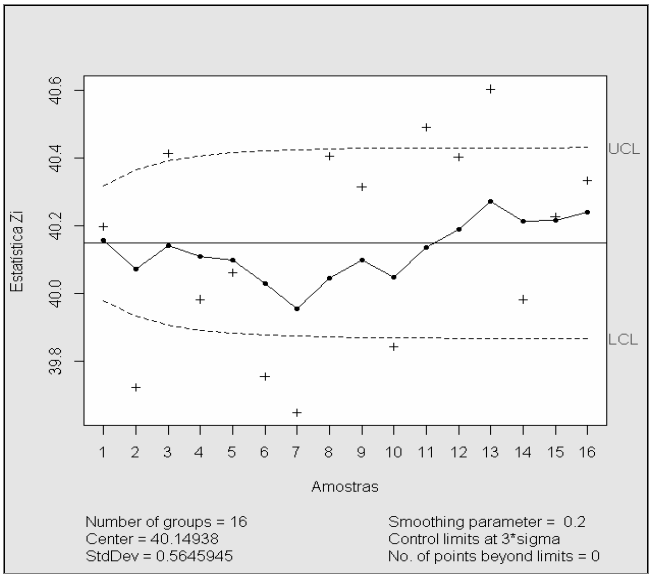

Fig. 22. EWMA control charts on charcoal weight.

The commands used for the construction of the CUSUM and EWMA control charts are displayed in Fig. 23. On line 2 is the command for the Devore7 installation package which contains the application data for Fig. 21 and 22.

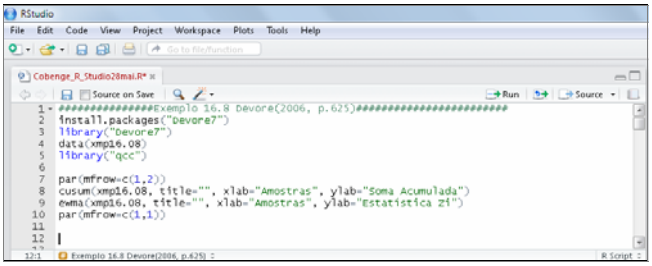

Fig. 23. The RStudio Source Screen for the application.

The Devore7 activation packages are on lines 3 and 5 [31] and qcc respectively. The packages can also be activated by selected them as in the case of the qcc package in Fig. 24. The command lines 8 and 9 display the construction of the CUSUM and EWMA control charts respectively.

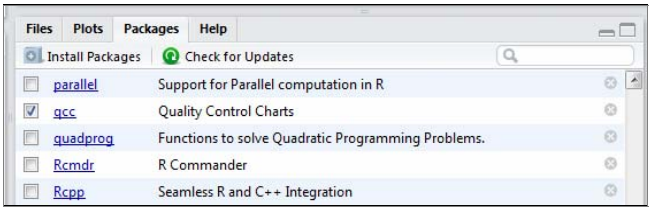

Fig. 24. The RStudio interface screen for installing and activating the packages.

The installation of the packages can also be done directly by clicking the Install Packages button on the Packages tab, as shown in Fig. 24.

D. A brief comparison

Regarding the utilization of the RcmdrPlugin.qual package in Rcmdr, some limitations have been verified, such as: phase I and phase II are not automatically performed, which means that it is necessary to type the commands on the script screen window; and it does not evaluate process capacity; nor does it evaluate if the data are auto-correlated. Eventual changes on the charts, for example, the title and legends are not direct, and this requires typing specific commands. It is possible to generate reports only in LaTex, a text editor.

RExcel extends the Excel spreadsheet functionalities to the R interface, which can definitely be used as a language for statistical computing.

For students who are familiar with Microsoft Excel, or a user who is used to working with data in files in the Excel format, it is possible to run R directly within an Excel spreadsheet, from the RExcel application.

Excel spreadsheets in a certain way can be a comfort zone for some users, but frequently it is necessary to run a more robust tool. Thus, to supply this gap, the user can take advantage of the simplicity of Excel jointly with the robustness of R, in RExcel. Besides the facility of jointly using these two tools, RExcel includes a single file installer package that will install R and all the other software required for running it.

Some limitations of RExcel are related to the generated charts, which are not automatically incorporated in an Excel spreadsheet, as they require some specific commands to perform this task. Besides that, these charts are not automatically updated, as it is necessary to repeat some actions when changing data. But, as [9] explains this peculiarity will be changed in future versions of RExcel.

The RStudio interface is much more user-friendly when compared to the standard R version. The window divided into four screens is more appealing to the student, as it facilitates discovery while exploring its resources. This is the case, for example of the installation procedures and package activation, enabled on the Packages tab on the lower right part of the screen

The auto-complete resource on the Console facilitates typing commands and thereby avoiding typing mistakes. The differentiation of the command based on color facilitates organization and searching for any given command along the script.

A criticism on editing a data set (matrixes, vectors) as it is not possible to perform this on the Workspace tab, as it only is enabled for viewing. Thus, these changes can be performed on the Console screen by using commands. Changes on the Workplace tab are only possible for numerical and function type data.

It is possible to generate reports based on results in LaTeX (in Rcmdr and RStudio) and HTML (in RStudio).

It is important to emphasize that the programming interface is one of the main attributes of R. It comes from the principal that each user can be a programmer. Thus, the engineering student can go much further than just “selecting and clicking”.

In our opinion, the RStudio and Rcmdr interfaces provide an advantage in this way as compared to RExcel, as the execution of the scripts is simplified due to the windows.

V. CONCLUSION AND FINAL CONSIDERATIONS

This paper has explored some of the characteristics of the R interfaces through the applications of advanced control charts, as they can be used for teaching SPC The demonstrations herein exploited are not just for the fields of engineering and technology courses, but any field interested in quality statistical control of processes.

But the main positive points of using R, no matter which interface is chosen, goes beyond this. It is possible to simulate controlled and uncontrolled situations and thereby provides the student an ample view of any phenomenon. Likewise, it is possible to simulate auto-correlated processes and evaluate adherence of any given distribution. And charts are not considered by the majority of commercial packages, such as multiple variable charts, as this is possible in the R

packages, providing a broad range of statistical analyses and more specialized studies.

As suggestions for future research work, it would be important to enlarge the scope of this research and include other SPC packages, such as: RcmdrPlugin.qcc [22], and packages including (DOE) Design of Experiment and Six Sigma methodology in such a way as to evaluate overall quality engineering. Similarly, investigating the applicability of the R program based on commercially available software as STATISTICA and SPSS, which is already possible. It is important to synthesize, and analyze real experiences using these interfaces in the classroom

In conclusion, all the analyzed R interfaces are good resources for facilitating the learning process in classrooms and academic research papers. However, the *RStudio* interface is considered the most appropriate for teaching SPC, which is the purpose of this research work, as it provides a more-user-friendly interface similar to commercial statistical software programs, without restraining its programming functionalities. It is important to highlight the following: there still needs to be further development in control charts, since the efficiency of these applications for successful teaching and learning Statistical Quality Control depends on this choice.

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