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Report

Statistical process control: Best practices in small and medium enterprises

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Abstract: Many developing countries have started to focus on quality in manufacturing industries including small and medium enterprises (SMEs) in Malaysia. Statistical Process Control (SPC) is one of the quality improvement practices companies employ to ensure the reliability of their products, thus increasing customer satisfaction. This paper aims to present the recent development of a computer-based SPC system to be used by operators or shop-floor workers to perform simple data analysis, as well as to enhance the efficiency of the improved process. Ideas and information concerning system development are generated through an in-depth case study at ten SME companies, featuring interviews, questionnaires and observation. The system, namely small and medium enterprises - statistical process control (SMEs-SPC), tends to focus on particular data sets, simple statistical operations and user groups. The findings show that the SMEs-SPC system is highly practical for quality data management and data analysis and has advantages over the manual SPC. Furthermore, it is suitable for users with a limited understanding of SPC and/or statistical background, highlighting the importance of SPC.

Keywords: statistical process control (SPC), small and medium enterprises (SMEs), system development

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INTRODUCTION

Small and medium enterprises (SMEs) have become an important sector for the growth of any country as they are the life blood of modern economy [1] and also contribute to innovation [2,

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3]. SMEs have been known to be a catalyst for economic growth as they are a major source of income and employment and consequently result in poverty reduction [4, 5]. Rahman et al. [6] argue that SMEs play a vital role in gaining a competitive advantage. Moreover, SMEs play a major role in total economic development both in developing and developed countries [7]. Generally, the long-term goals for SMEs are to maintain business competitiveness and to bring continuous profit. One of the fundamental ways of achieving this goal is the elimination or reduction of failure or waste including reworking, scrap, warranty claims, inspection tests, etc.

Statistical process control (SPC) is one of the quality control activities implemented to improve quality assurance programmes and Total Quality Management (TQM) practices through a process of monitoring, managing and analysing process performance [8, 9]. According to Gerard et al. [10], SPC is a method that has been used in industry since 1920 and approximately 80 per cent of companies have implemented SPC [11]. In practical terms, SPC is a statistical procedure that uses several control charts to detect any malfunction of a production process that could result in a poor-quality product [12]. Moreover, SPC can help to improve quality and productivity by reducing variations in a process [13]. To survive in a competitive market, all companies need to engage in SPC to ensure continual improvement.

Castagliola et al. [14] note that SPC is applied to assist practitioners in monitoring and controlling processes in manufacturing lines by detecting and removing assignable (special) causes of variation. Sharma and Kharub [15] emphasize that the process variation is the main course of quality problems that affect the process performance of SMEs. According to Bevilacqua et al. [16], SPC allows corrective action to be taken in a timely manner once a process has been identified as not meeting specifications. Previously, SPC has been implemented in numerous types of domain: the software industry [11], the health care sector [17], electrics and electronics [18], engineering, industrial and environmental applications [19], the production sector [20], the food industry [21, 22], the general service sector [23, 24] and the chemical industry [25]. It has also expanded to other non-manufacturing sectors including education and banking [26]. According to Abdolshah et al. [27], traditional quality concepts such as statistical quality control, SPC, zero defects and total quality management are crucial to companies in gaining a competitive advantage.

Moreover, SPC helps production employees to improve the quality of processes in their work environment. Statistical methods such as the ‘seven basic tools of quality’ offer valuable approaches that can be learned by everyone in an organisation [6]. Utley and May [28] note that quality control researchers first began to study the problem of monitoring and control related to variable data over 60 years ago. Since then, manufacturing disciplines have benefited from SPC tools in relation to decision making. For example, control charts and process capability measures aid in identifying the level of stability and performance of processes [16, 29]. According to MacCarthy and Wasusri [30], control charts are a powerful tool used in process control and improvement to manufacturing businesses. As pointed out by Yang and Yang [31] and Xue et al. [32], the main use of charts is to establish whether a process is in a controlled state, as well as to maintain the ongoing process during a production run. The use of control charts was first introduced by Shewhart in the 1920s and is commonly applied in large-scale manufacturing operations to trace special causes of variation present in processes [29, 33, 34]. Control charts make it possible to distinguish between special causes and common causes in manufacturing processes. However, White et al. [35] contend that control charts are intended to detect process change, not to improve or ensure product quality. MacCarthy and Wasusri [30] note that there is a need for user-friendly statistical SPC packages enabling companies to remain competitive in the business environment.

RESEARCH MOTIVATION AND OBJECTIVES

In keeping with recent developments, the manufacturing field has had to adopt advanced technology systems due to customer demand for low prices and the fast delivery of products [36]. Moreover, according to Caldeira and Ward [37], many SMEs need to implement new business approaches and adapt to new technologies to confront the changing global market. In a recent study conducted by Marri et al. [38], SMEs prefer to select advanced manufacturing technology and computer-integrated manufacturing systems as effective tools for reducing operating costs and improving manufacturing efficiency. Accordingly, existing computer software is frequently used in quality control to analyse industrial problems by assessing data quality, for example by means of SPC software packages. Das et al. [39] believe that the latest developments in software offer various additional statistical functions and advances in graphical display. Groeneveld [40] points to SAS, SPSS and Minitab as being the most widely used and effective statistical software packages in the academic, business and government sectors. Many extensive SPC software packages are widely available, such as STATPACK and spreadsheets which are used in firms engaged in plastics production and the manufacture of drinking bottles, and also by other companies to monitor the quality problem efficiently [41]. Nevertheless, such software involves understanding of commands which are not easy to learn, especially for users with little statistical knowledge. Thus, a systematic approach to the problem is needed, whether through educational programmes or practical training in SPC methods.

As Castagliola et al. [14] and Jiao et al. [42] point out, the development of SPC through an online quality information system allows users to input data sets using the database, thus enabling them to disseminate problems and generate calculations using sample statistics and charts automatically, as well as share the system and information in real time. Computer-based SPC, or e-SPC, is widely used in organisations [13].

Currently, the development of online quality information system in SMEs is affected by the high costs of running such applications. According to Robson [43] and Hanif et al. [44], there are many basic statistical calculations and tools intentionally built into Microsoft Excel to perform a wide range of analyses as well as convert data into graphical figures such as pie charts, histograms and normal distribution. However, using Microsoft Excel also requires skill and training to understand the function names and syntax for each statistical operation [45]. Antony et al. [46] recognise that most organisations tend to develop control charts by using spreadsheet software or computer-based systems. However, several manufacturing firms continue to use a manual SPC approach (paper-based control chart) and the traditional SPC has a number of limitations such as the fact that few quality faults are detectable, there is the risk of human error and it is time-consuming [47]. According to Ahmed and Hassan [48], few manufacturing companies are able to use statistical tools effectively, and lack of education and training on how to use SPC hinders them from effectively applying the SPC tools and technique [20]. Up to this point, they continue to lag behind in the application of quality tools to quality improvements. Furthermore, there are few and limited SPC software programmes that can be effectively and appropriately used in the context of the constraints faced by SMEs, such as operators' skills level as well as other issues faced specifically by Malaysian SMEs.

Therefore, this study highlights specific tools associated with the SPC system development and covers several basic methods such as variable control charts, histograms and process capabilities. A previous study provided a presentation of the case study of companies and covered

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several significant areas such as the background of the companies, general aspects of SPC implementation, and problems with the SPC software and barriers to its use by associated companies [7]. This paper specifically explores the conception of a complete small and medium enterprises - statistical process control (SMEs-SPC) system and the validation methods employed to strengthen the usability of this tool. One key feature of the SMEs-SPC is the use of an online monitoring system for interaction between shop-floor workers and upper management, enabling them to engage in problem solving together. This is considered one of the core contributions of the research.

DEVELOPMENT OF SMEs-SPC SYSTEM

A case-study research typically involves a small number of cases which are not necessarily representative of the larger population [49]. In the first phase of the research, the case studies were conducted in 10 SME manufacturing companies located in Selangor, Malaysia. The types of industry involved were the automotive industry and the manufacturing of electronics, medical disposal devices, computer components, plastics and chemicals. The collection of ideas, information and data for the system development was undertaken through in-depth interviews, open-ended questionnaires and non-participation observation. A well-designed questionnaire was given to key personnel to seek further information concerning SPC practices. In the second phase, an in-depth case study of a selected automotive company was conducted to develop the proposed system, focusing on process characteristics, collection of existing quality data, process control sheets (paper-based control charts) and user groups involved in the process. The design and development of the SPC system also drew on consultations regarding company requirements and suggestions from academics. The last phase of the study focused on the validation of the system including assessment of the complete system in the selected company and other SME types compatible with the use of this system.

Conceptually, the SMEs-SPC system is integrated through a client database server with a graphic user interface using Visual Basic. All tools and object models in Visual Basic are used to access the database server. Based on the data stored in the database, Visual Basic is employed to compute or perform statistical calculations. The user interface provides the user with an intuitive graphic tool to analyse data through control charts and histograms. According to Rao [50], the database server known as MySQL (Structured Query Language) is supported by the administrative software to manage the entire database server, enabling functions such as browsing and dropping database objects, creating tables, and viewing, renaming, exporting and importing databases. Developing the SPC system through a main server application allows many users to use the same software, share the same data sets and share knowledge about capabilities, control limits, graphs and out-of-control events simultaneously. For example, users at the production site in the quality control division and in the top management can all interface with the system to share information and make instant decisions concerning problems with quality.

Figure 1 shows the schematic diagram of the operation of the system, illustrating the link between (a) the database server, (b) the administrative application assigned to manage the database and (c) the user workstations. The data on quality processes and on variability are not only used to identify the variation in the processes, but can enable the end users to compare the stability of performance across different times, values and processes.

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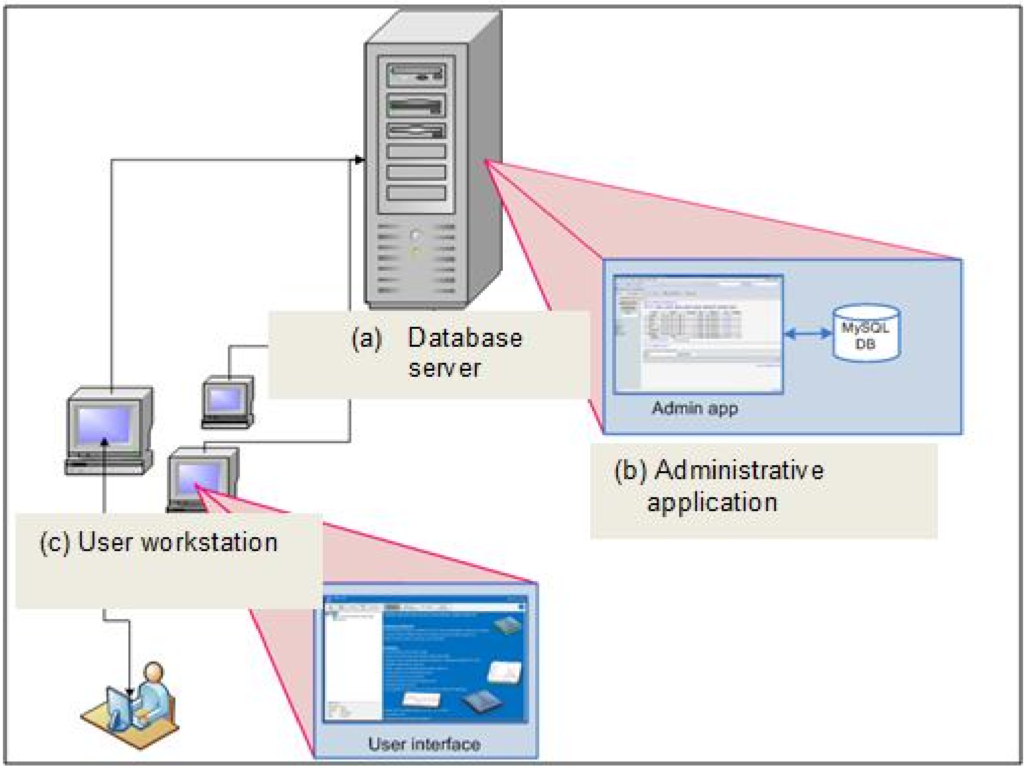

Figure 1. Operation system of SMEs-SPC

The details of data flow are shown in Figure 2. The design for SMEs is simple, unlike other commercial statistical software which tends to be complex. As can be seen from Figure 2, the administrative software relates to the generation of data input and typically uses six categories of table, viz. information of user, company name, folder name, characteristics of process and product, sample size (k) and frequency of subgroup (f), to differentiate data values and add variable information, as well as to assist in computing statistical operations. Under the administrative software, the SPC data processing manages the user's information and specific parameters to be used, such as process characteristics, type of control chart, sample size, time, date of entry, as well as classified user-defined control limits based on the respective table. Moreover, the SPC data processing organises data storage and finally passes results to the information system of SPC for the generation of graphs and process capability statistics, underpinned by statistical formulae.

FINDINGS AND ANALYSIS

The findings and analysis of this paper comprise three main aspects: first, the implementation of SPC in 10 companies; second, the development of the SMEs-SPC system; and third, the validation of SMEs-SPC by respondents from SMEs to meet user requirements.

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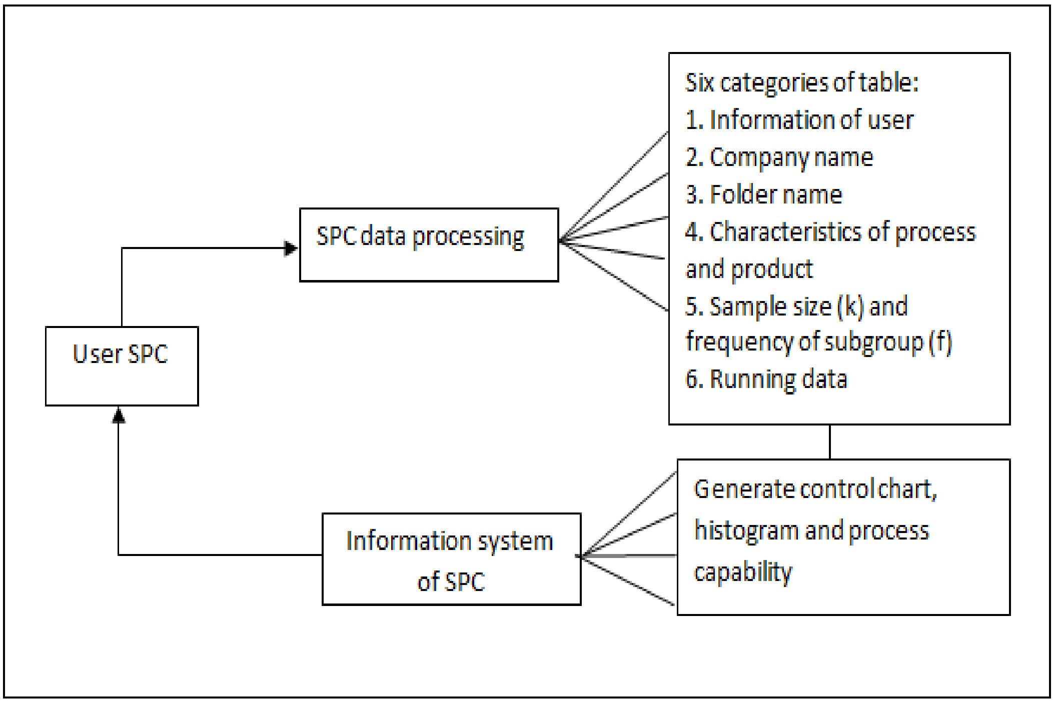

Figure 2. Data flow diagram

The case-study approach adopted could differentiate between the case companies in relation to the level of SPC adoption, type of SPC software, and problems and advantages of the application. It also identified the input and requirements of SMEs to develop the SPC tool. The initial results (Table 1) revealed that only five companies – A, B, E, G and I – fully utilised the SPC software or SPC system. Companies C and J were using manual methods (paper-based control charts) and companies D, F and H developed control charts or graphs using Microsoft Excel. Of those companies that fully implemented SPC, only companies E and G used an online SPC system to monitor process control. Company G was closest to implementing an ideally effective SPC application; hence it greatly enhanced the process performance, reduced customer complaints to the minimum level, and reduced time, paper consumption and human error throughout its processes. Companies C and J (automotive industries) were found to have many deficiencies and problems in SPC implementation amongst shop-floor workers; the application of SPC at company C and J were subjected to certain limitations such as human error and effects of delays in relation to data measurement, data entry, chart plotting and calculation of control limits.

Our previous study [6, 7] identified typical problems associated with using SPC and the barriers that may prevent Malaysian SMEs from adopting the SPC software or systems effectively. One of these are that the implementation of SPC systems is more difficult in SMEs than in other firms because smaller companies are not able to afford high-technology systems (hardware, software, networking and security) due to the high costs involved. Thus, some companies continue to use simple control charts based on paper (manual method). As already mentioned, a number of key problems were also found in the first phase of the study, such as the lack of efficiency in quality data management, the inconsistent formatting and the inability to disseminate information on time. Other barriers to the effective implementation of SPC are the lack of commitment and support from top management and the lack of awareness of SPC as a powerful problem-solving technique. Furthermore, the lack of training and education is also a major factor in the failure of SPC implementation.

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Table 1. Companies in the case study and types of SPC software/system used

Company	Type of company	Type of SPC software/system
A	Automotive	Minitab
B	Medical devices	SPC XL 2000
C	Automotive	Manual
D	Plastics	Microsoft Excel
E	Electronics	e-SPC
F	Chemicals	Microsoft Excel
G	Automotive and electronics (computer components)	Online SPC database
H	Automotive	Microsoft Excel
I	Automotive and electronics	QC calculation
J	Automotive	Manual

Based on the above, SPC implementation can be considered to be at a moderate level in Malaysian SMEs. The first phase of the study ended with the selection of company J to collaborate in developing the system. Based on this collaboration, it was apparent that the system developed would have to be simple to operate and offer ease of use for low-level workers. The development of the SMEs-SPC aimed to address the problems and drawbacks of other systems and approaches identified in the first phase of study. Thus, the system was designed to make use of graphics and employ buttons to access key features rather than requiring the users to do so manually. For users, it is easier use buttons to generate calculations, graphs and reports. For example, they can set their own control limit values and select control chart rules to suit the company requirements. As mentioned earlier, this system is intended to be used by a wide range of users at different levels in the SMEs. Thus, the users are given a simple introduction to the system, its key features, objectives and application of X-bar (average) and R (range) charts, X-bar and s (standard deviation) charts, and histograms, as shown in Figure 3. Moreover, the system contains several novel features and provides guidance and information aided by the 'help' button, as shown in Figure 4. These guidelines make use of a few key concepts in statistics to facilitate the understanding necessary to use the system.

The graphic interface provided in the system is one of its advantages in performing systematic calculations. Figures 5-8 address certain features available to the user, expressed in each interface. First, the user is requested to complete some information to register as a means of protecting confidential data, as shown in Figure 5. When first using the system, the user should input raw data or quality data into the system to have statistical analyses performed quickly and the recorded data will be displayed in a data table as illustrated in Figure 6.

According to Taylor and Shouls [51], SPC comprises control chart rules which identify an out-of-control condition through an abnormal pattern. In some cases the system employs colour coding (either red or yellow) to signal an out-of-control condition based on control chart rules and provides feedback on any event by suggesting action disseminated via email. This aspect is of great importance in providing information on problems at the site in real time. The results (graphs and limit calculations) are then displayed in either a text or image form as shown in Figure 7. This should identify whether the variation that has occurred is in control or out of control. The system also performs calculations to determine the process capability. Figure 8 illustrates the overall

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performance report, which includes control charts, histograms and capability studies, which can be saved as an electronic file and printed for reference.

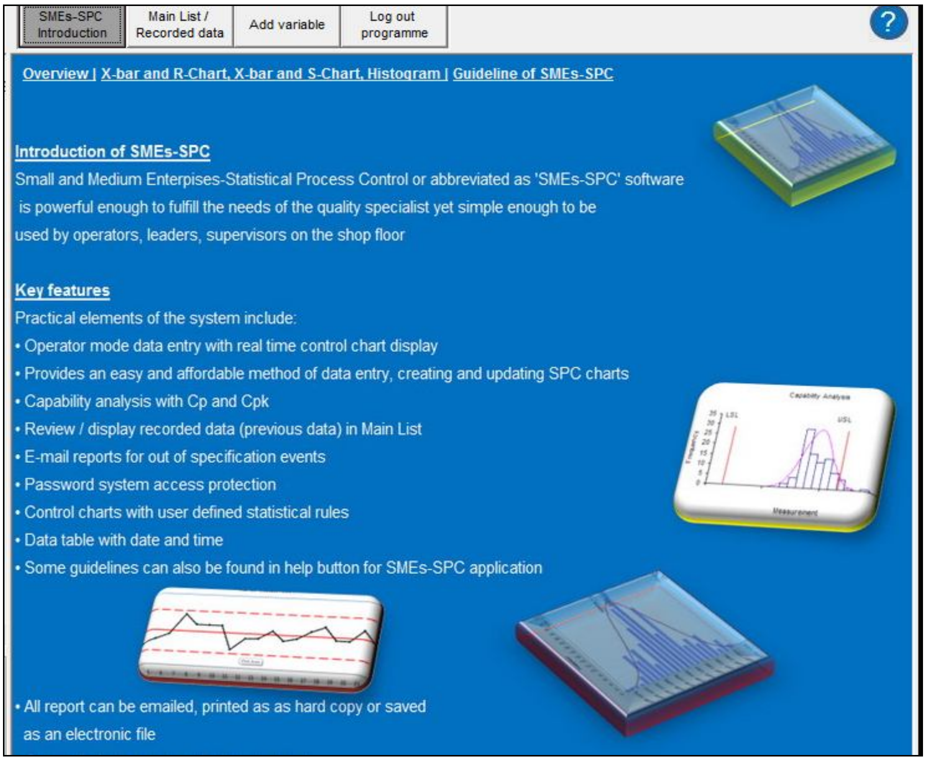

Figure 3. Introduction to SMEs-SPC

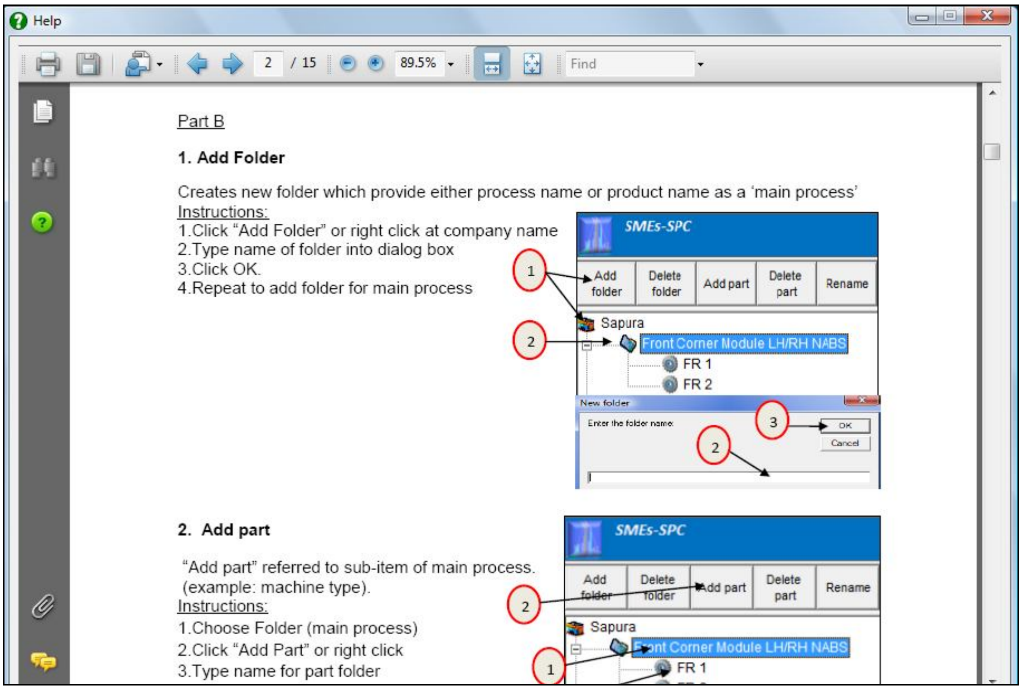

Figure 4. Guidelines (help) for using SMEs-SPC system

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Figure 5. User registration

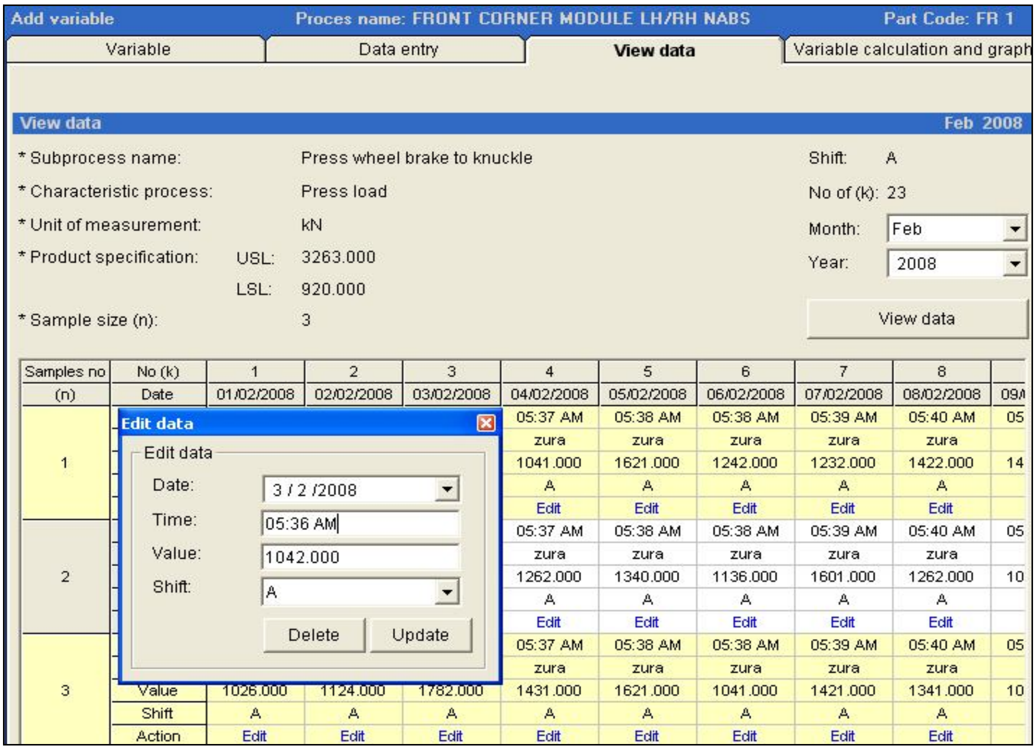

Figure 6. Example of data entry and data table

Another important feature of this system is that, unlike commercial software, it is not based on a spreadsheet or tabular format and does not require functions or syntax to conduct statistical calculations. Also, the instructions given using the help button are user friendly and easy to understand at all levels. The results of SPC data processing based on structured query language are placed into result tables using standard formatting and labelling. Figure 9 illustrates the result table processed by means of the structured query language database in company J. The result tables are stored in the main process folder (Figure 9a) and the part folder (Figure 9b) and show the running data, i.e. specifications, target, data values and other aspects (Figure 9c). Another enhancement in this system is the possibility of creating final reports that contain image files and results in text.

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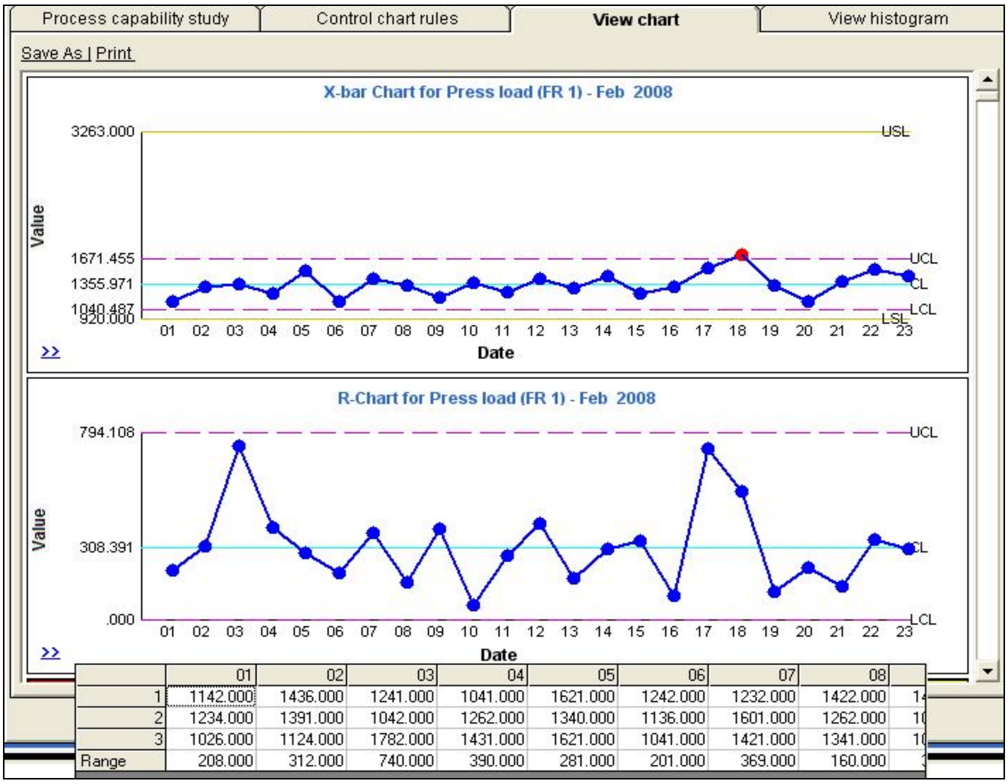

Figure 7. Example of control charts

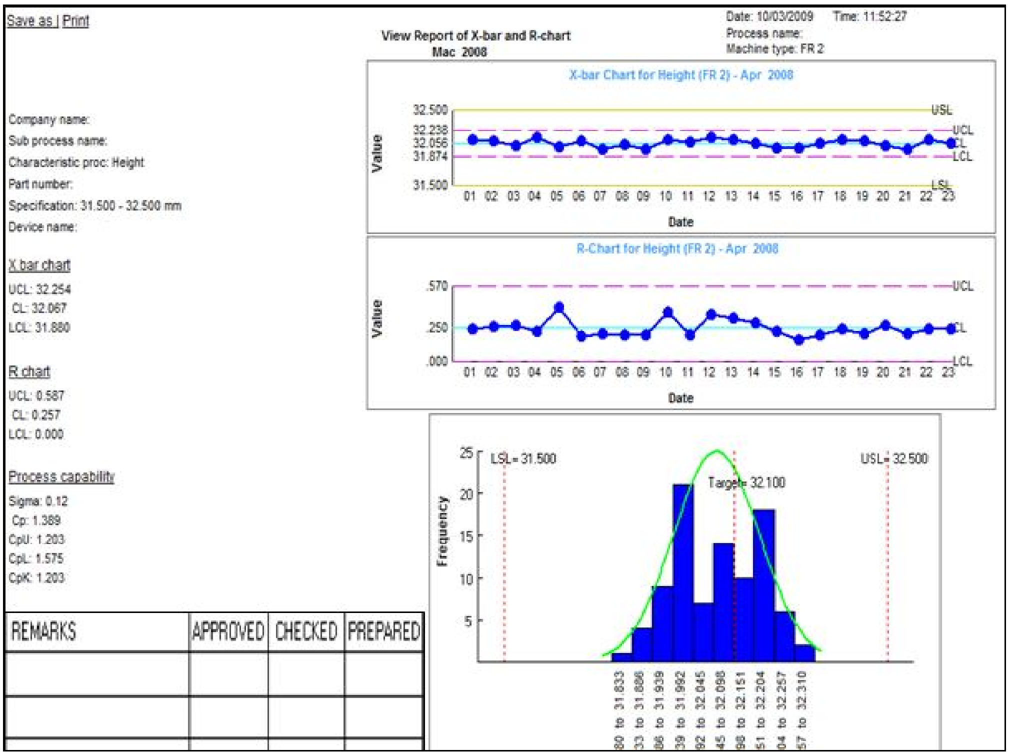

Figure 8. Example of monthly report

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FolderID	Name	Operator	CompanyID	Status	DeleteBy	DelDate
18	TEST1	zura	4	1		0000-00-00

(a) Main process folder

CompanyID	Value	Date	Time	EnteredBy	Shift	n_index
4	1234	2008-12-01	06:39:00	zura	A	1
4	1245	2008-12-01	06:39:00	zura	A	2
4	1235	2008-12-01	06:40:00	zura	A	3
4	1124	2008-12-02	06:40:00	zura	A	1
4	1256	2008-12-02	06:40:00	zura	A	2
4	1567	2008-12-02	06:40:00	zura	A	3
4	2100	2008-12-03	06:42:00	zura	A	1
4	2300	2008-12-03	06:42:00	zura	A	2

(b) Part folder

PartID	PartNo	Target	CpkTarget	Date	Operator	CompanyID
6	825763/64	0	1.33	2008-12-10	zura	4
7	825763/64	0	1	2009-01-08	zura	4
8	825763/64	0	0	2009-01-08	zura	4

(c) Running data

Figure 9. Example of result tables

Based on our research, the calculations and SPC operations required by SMEs are relatively basic, e.g. control charts (X bar-R charts and X bar-s charts), histograms and process capability indices. A report on the process performance is presented in such a way that it allows users to provide progress reports to customers each month. It should be noted that this interface application only enables users of the SMEs-SPC system to conduct simple statistical analyses. The plotted X-bar and range charts based on the data from company J are shown in Figure 10 (analysed by the SMEs-SPC system) and Figure 11 (validated by Minitab software). This demonstrates that the results and graphs generated by SMEs-SPC are similar to those derived from Minitab software. An important issue is the way in which the statistical operations are calculated: the SMEs-SPC system uses three decimal places whereas the Minitab software uses four decimal places. However, results of the calculations performed using SMEs-SPC approximate almost exactly those shown in the Minitab figures.

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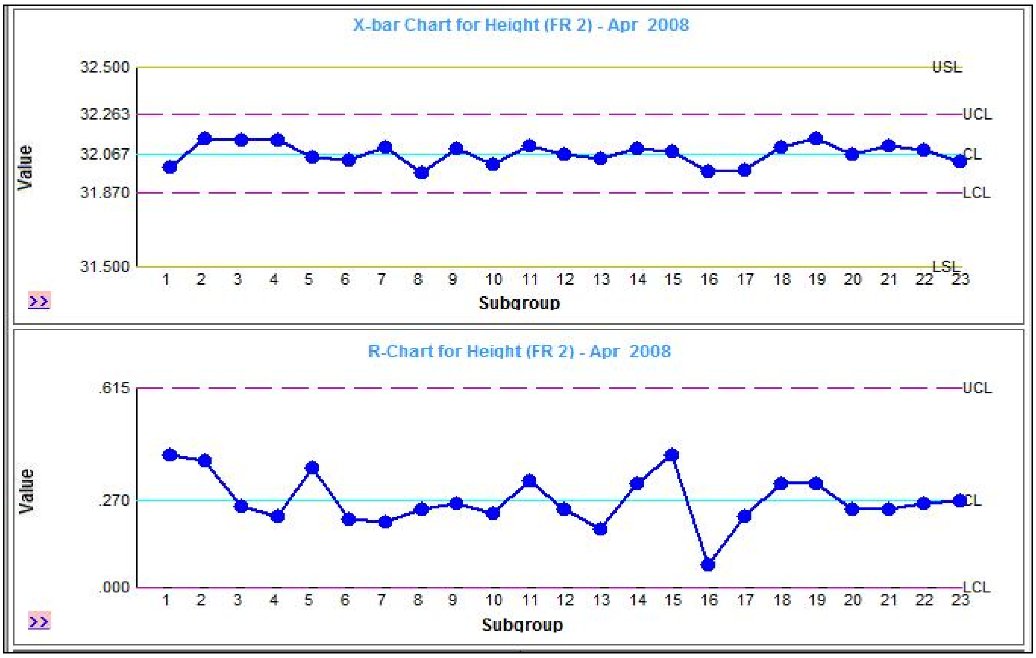

Figure 10. X-bar chart and range chart results for knuckle and brake disc height by SMEs-SPC

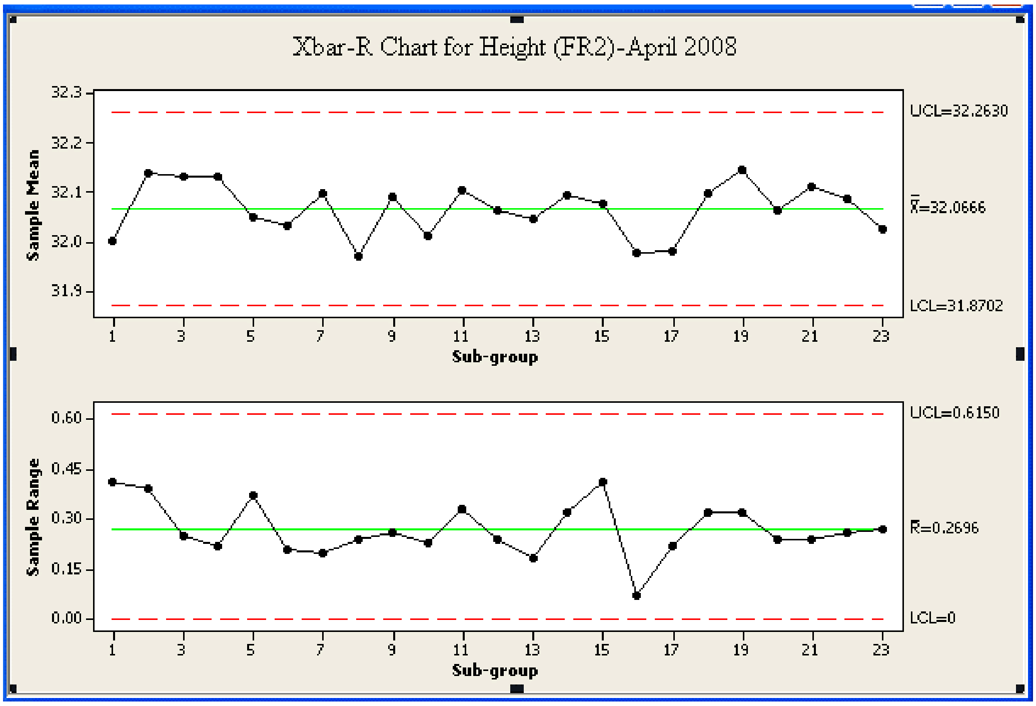

Figure 11. X-bar chart and range chart results for knuckle and brake disc height by Minitab software

The final stage in the development process was the assessment of the SMEs-SPC system by respondents from company J and other SMEs. According to the final reviews by respondents after completing the development phase, this system is suitable for application in automotive companies and provides education in SPC starting from a basis of little statistical training. The SMEs-SPC allows users to share the system, data and information with flexibility in time and space. The graphic interface provided in this system is sufficiently simple to allow a quick and easy analysis, which can facilitate timely and correct decisions in solving quality problems. The respondents from other SMEs found the basic analytic tools very encouraging, considering that they would allow those from different educational backgrounds to participate in the process of analysis. They believed that the system as a whole would be highly practical for application in production sites. Nevertheless, to increase the sensitivity of analyses and prevent any inconsistencies in the results derived by other SMEs, as well as to ensure that the system would fulfil the need of multiple users, it was considered that flexibility, usability and applicability should be addressed with greater rigour. Table 2 shows the specifications for the SMEs-SPC system that is compliant with the main requirements of company J and other SMEs.

Table 2. SMEs-SPC specifications in compliance with SMEs' requirements

Type: X-bar and R charts	•
User-friendly operation and multiple users	•
Suitability for low-level education	•
Systematic data storage	•
Automatic generation of graphs	•
Automatic calculation of process capabilities	•
Automatic data retrieval and update	•
Ease of checking recorded data processes	•
Recorded information and quality data characteristics based on process, machine, product name, etc.	•
Rapid analysis of data	•
Presentation of complete report	•

CONCLUSIONS

The introduction of the SMEs-SPC system as a tool would greatly enhance the SPC in SMEs. The use of this latest system is expected to assist in overcoming common quality problems and should thus be supported by upper management levels.

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