Research on the Application of Real-Time Monitoring System for Manufacturing Quality of Industrial Production Based on Industrial 4.0

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1 Preface

As everyone knows, the Industrial 4.0 is the core of industrial intelligence-based manufacturing plant. In order to ensure the product quality, we must follow the modern quality concept, namely "quality comes from design and manufacturing, not from inspection." To reach the target of ensuring product quality, while reducing cost and improving efficiency, it is of great significance for such a large automobile manufacturing country like China to strengthen the stability of the production process, so it is very necessary to continue the implementation of statistical process control (SPC) which is a mature technology. Obviously, in order to be adapted to the rapid, small batch, customized production of intelligent manufacturing demand, we need to make full use of information technology, to optimize and expand the function of traditional SPC system.

Shanghai Volkswagen Powertrain Co., Ltd (VWPT), which was founded in 2005, has expanded from a plant to three plants (name as project 1, project 2, project 3), and has also experienced a series of production, promotion from EA111 to EA211 in a short term of 10 years (2006–2016). Varieties have increased from 3 to 5; in 2016, the volume reached 1.6 million units. In fact, VWPT is one of the most advanced worldwide engine production bases, both in production technology and manufacturing process. At present, the modern automotive industry as a representative of the manufacturing industry is carrying out Industrial 4.0 and "Chinese manufacturing 2025," and creating a transparent plant to achieve the enterprise intelligent manufacturing is a correct path, the so-called transparency, in essence, is integrated technology based on network, to make the various functional

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departments, operate with high effective interaction, which reflects the basic characteristics of the intelligent manufacturing.

As early as 4, 5 years ago, VWPT has worked together with Q_DAS company, which is a high level of professional statistical analysis software (DE) enterprises, and applied a real-time monitoring system in a plant network covering the production site, which has taken an important step to create a transparent plant, and to realize enterprise intelligent manufacturing. The "transparent" project is to establish a high level of quality information system according to the enterprise demand, with production site quality data visualization, data centralized management, backstage automatic analysis and assessment (CAMERA), and a series of advanced features. After several years of efforts, the implementation and completion of the transparent plant project, has not only greatly improved the production quality and operation level of the enterprise, also has provided a good example for the assembly plant, and many component plants in the domestic automobile industry, and different industries and enterprises which have similar needs.

2 The Change of Production Mode Request New Requirements for the Real-Time Monitoring System

The automobile engine, especially the small displacement automobile engine, as a typical product of modern manufacturing industry, since last 10 years at the end of the last century, its manufacturing process, mode of production, has changed greatly. As mentioned earlier, in order to meet the changing needs of today's automotive consumer market, and to be adapted to multi-variety, flexible production model, it is a necessity to improve the production process of real-time monitoring system functions. Taking the crankshaft production line as an example, over the years, the shaft grinding process is mainly consist of special grinding wheel cutting-type grinding machine, including the basic combination for processing line 5 gear shaft neck and neck connecting shaft for (respectively stage 1, 4 and stage 2, 3) equipment for each one. In the first line of the crankshaft in VWPT plant (see Fig. 1a), the three parts of the grinding machine are in the red circle.

The workpieces are transported in air through manipulator and get into the machine one by one. But in Project II, the tracking function of CNC grinder has occupied a dominant position in crankshaft grinding. Through the control program adjustment, it is convenient to be used for grinding various types of crankshafts, which has good flexibility. Due to the adoption of a single installation, all the main journal and connecting rod neck can be processed, and the efficiency and the precision can be improved. At the same time, since the technology scheme and layout use the fishbone which makes it easy to expand the production capacity (see many arrows in Fig. 1b), compared with the traditional linear layout shown in

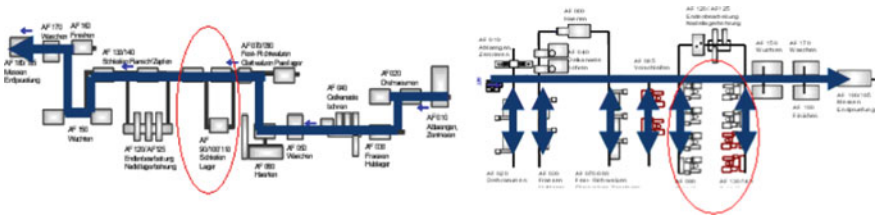

Fig. 1 Examples of the traditional and flexible curved axes

Fig. 1a, fishbone scheme improves the flexible level of the production line. It can be seen from Fig. 1b, in the past few years, the crankshaft has been built in the second line; the grinding process has reserved space to put another 8 sets of the same machine tool, and the graph shows that the actual number of grinding machine now is 6.

At this point, the process monitoring system is facing the problem: Through the grinding process in Fig. 1b, the sampling workpieces sent to the production side for checking are likely to have 14 different states, and if the check does not make a distinction and go on measuring, and deals with the workpieces' data according to the traditional approach, it has no means. Because at this time, if you want to judge and analyze whether the process is in control and stable measurement must be refined to one specification of the above over 10 conditions, only after recognizing the specific condition the targeted data processing is meaningful. Therefore, we must uniform the data format settings of those testing equipment that are related and provide quality information. This requires that need to be included in the quality data for evaluation in addition to the measurement value. Of course, depending on that the specific circumstances of the content will be different, but the modes of the data format are the same, then we will get the graph shown in Fig. 2 as a reflection of the operating process of the analysis of the situation. Different from the traditional SPC, the graph contains a number of curves, each corresponding to a specific situation, such as a machine tool or even more refined to a power head, or a corresponding part of the processing site. Having the refine dI monitoring system, we can recognize some abnormal phenomena that cannot be recorded in detail and targeted and take some actions according to the analysis and judgement. For example, tool wear occurs in the processing, only when a specific power head of a machine tool is targeted, analysis and measures can be worked out targetly (see Fig. 3), and if you do not use the data format set, we will not be able to timely adjust. As we see, the function of SPC needs to expand correspondingly with the change of technology and production methods.

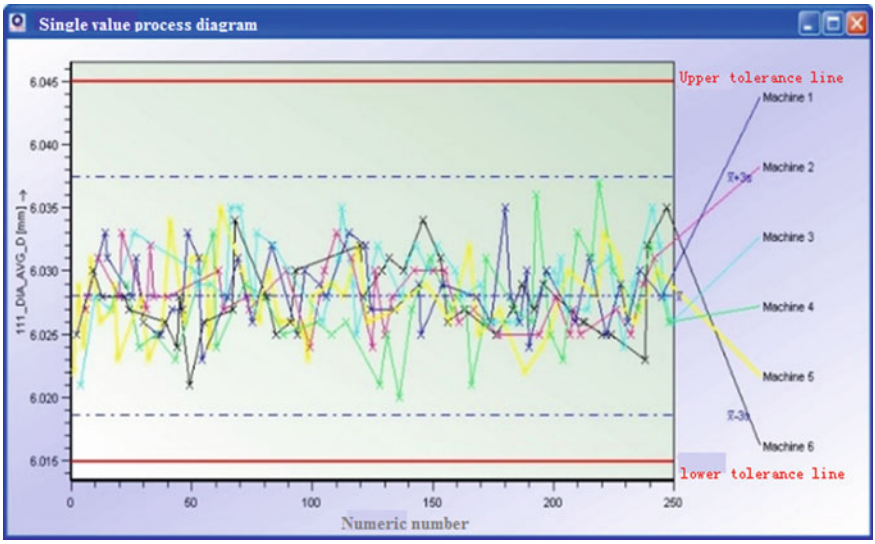

Fig. 2 It shows the detailed information related to the real-time monitoring of the process after the data format

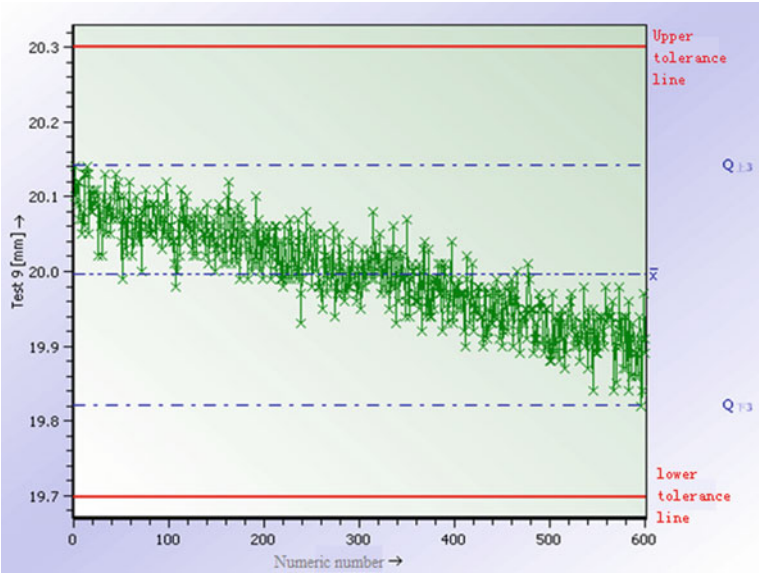

Fig. 3 Analysis and processing of the tool wear

3 The Necessity and Main Configuration of the High-Level Network Real-Time Monitoring System

Shanghai Volkswagen Powertrain Co., Ltd is a representative mainstream enterprise in the past 10 years with the rapid development of the domestic automobile industry, and the continuous expansion of production capacity, its number of measuring points, and online inspection devices on the floor is increasing rapidly. But since these measurement points (and the online inspection tools) are added along with the construction of the production workshop, it brings the following problems:

- The source of measurement data is fragmented: Measurement points are spread across the entire enterprise production area of three plants (in the three large combined plants), and it takes a lot of manpower and time to get all the data on the site;
- The measurement data are isolated from each other: The data from each measurement point is stored in a different computer format in its own computer;
- The measurement data cannot be shared: Since there is no established network communication between the existing measurement points, so if you need to access data, the only way is to collect the data on each measurement point. It is very troublesome, and also it is of low efficiency and easy to make mistakes;
- The measurement data information cannot be timely feed backed to the management departments (or supervisor): Due to the scattered measured points, once the measured value exceeds the control line, or the instability of the data occurs. It takes a long time for on-site quality staff to analyze the data and take countermeasures and feedback.
- To solve the actual situation, lack of operation personnel quality consciousness: Because the field operators are not able to see the fluctuation of the measured data visually and real-time process capability index, it is difficult to change the trend of the production process to make prediction and judgment. It is more difficult to adjust in time.

In order to improve the above problems, and based on the Volkswagen global transparent factory building suggestion, Shanghai Volkswagen Powertrain Co., Ltd plans to set up a real-time network monitoring system for manufacturing quality, automatic analysis, and evaluation system with field data visualization, centralized management, background data automatic evaluation system (CAMERA system). The function of the system should be able to meet the following requirements:

1. to provide advanced statistical process control theory and methods, to reduce the deviation in the production process, so as to improve production efficiency;
2. by better quality data visualization and human–computer interaction, to improve engineers and relevant personnel's working efficiency, to improve the sensitivity of field personnel for quality data, and to make timely feedback on production possible;

3. to achieve the centralized storage, management, and analysis of quality data from the production site in the whole plant;
4. to provide a standard statistical analysis and evaluation strategy for the management system, processing and assembly equipment acceptance, and process capability evaluation of the measurement system;
5. to be able to provide a comprehensive solution for automatic data entry, visualization, statistical analysis, data management, data display, data distribution model of automatic selection, evaluation, and quality information archiving.

So, what are the characteristics of the mass production data from the production site? The data from the production site have two kinds: One kind is the production site inspection; for example, Marposs measuring device placed next to the production line in three different plants in the workshop, they are divided into manual Marposs measure and important station automatic Marposs measuring machine (most of them placed near GROB machining center). The other is all kinds of precision measurement room testing equipment, such as Hexagon's CMM three coordinate measuring machine, Mahr's MFK form and position tolerance meter, Hommel's roughness meter, etc. (Fig. 4 left three/data sources) the goal of the project is to measure all of these results of the measuring instrument and to save production data not only as reference paper, but also save data to the database, the engineer in responsibility can do real-time analysis, while the manager can get to know the real-time quality of products, such as OEE data through the Web page (Fig. 4 in the database connection), meanwhile the measurement results on the Web page will be displayed on the big screen in the production field, which makes

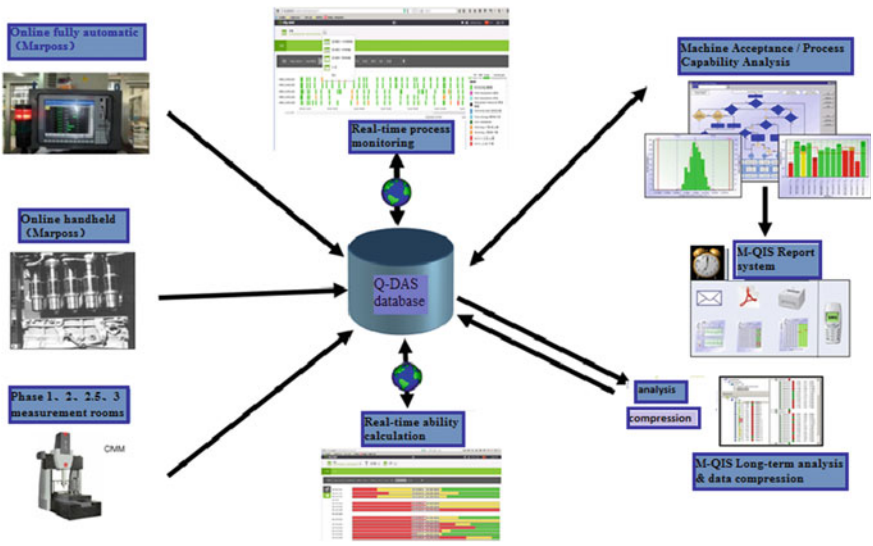

Fig. 4 Schematic diagram of data transmission in real-time monitoring system for networked manufacturing quality

production staff have a more intuitive understanding of the overall production quality and also, can make a more quick response (such as shutdown, tool change). If there is any doubt about the results of the field measurement, they can use the qs-STAT software interface to retrieve the data from the database to analyze (Fig. 4 on the right) for long-term production, not only the current quality data need analysis, but also these "big data" are required to predict the future trend of production quality, to avoid problems. So in the design of the whole system, we need to set up all kinds of automatic reporting tasks by means of M-QIS (lower right), and through these regular reports, the quality trend production process can be controlled by enterprises management departments, to guide the future direction of our continuous improvement.

Apparently, by the data acquisition and processing in this way, it is not enough to only rely on measuring check value provided by line. It cannot fully reflect the running status of the flexible production process, and surely, it is difficult to implement effective monitoring. In addition, as mentioned above, now enterprises pay more attention to product quality tracking and tracing. After taking a series of measures, marking two-dimensional code on the key parts has been more and more common (see Fig. 5), which contains a batch, type, blank manufacturer plant, mold tool number information, etc. In many enterprises of Volkswagen system, since many code marking stations are placed in the final inspection of the workpiece, the two-dimensional code will also contain some information obtained through inspection; for example, two-dimensional code marking on the crankshaft in the contains the journal grouping results obtained, and the measurement data of inspection can provide all measurement data of the workpiece under a certain state. It is not only necessary for workpiece evaluation, but also very valuable in the tracking of product quality by enterprises. In recent years, chip technology of RFID RF (based on the application of automatic identification device for contactless electronic data) is also becoming more and more common, and RF signal automatically recognizes the target and gets access to relevant data; identification does not need manual intervention. It is applicable to all kinds of environment. The system consists of an electronic chip, data read–write device, and control management software: Electronic data chip which is attached to a data carrier identification object on the part has small volume and lightweight, waterproof, anti-oil, high-temperature and high-pressure resistance characteristics. The electronic data chip is usually mounted on the machined workpiece by means of threaded fasteners, and Fig. 6 is a typical example. When it enters the working magnetic field, it can accept the RF signal sent by the reading and writing device. Similarly, the RF signal emitted by the read–write device is provided with a carrier, and the information can be written into the electronic data chip. Under normal circumstances, the basic information from the production line parts is as follows:

(1) The basic information—including the part number (sometimes the drawing number), blank factory code, production plant code, blank batch, on-line time, etc.;

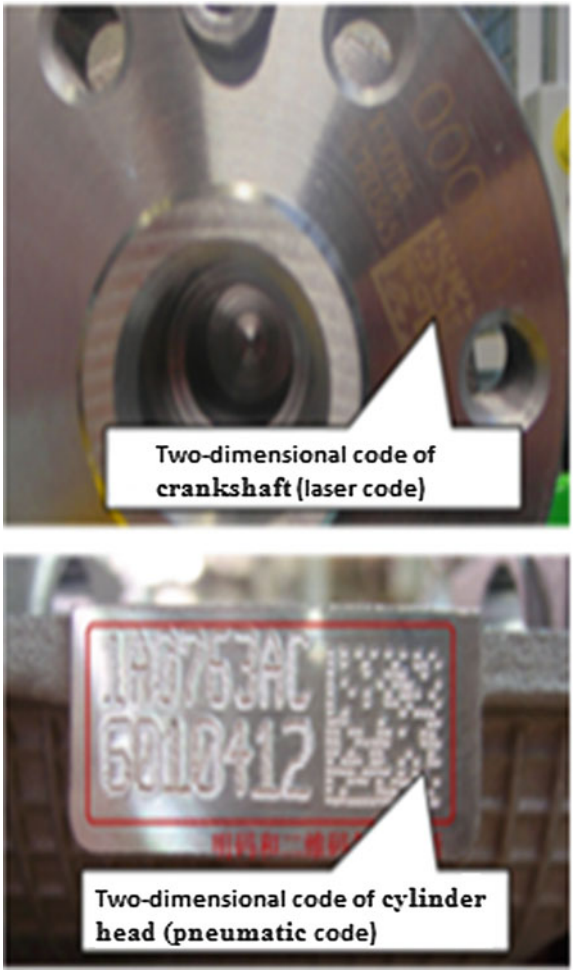

Fig. 5 Two-dimensional code on the surface of the workpiece

(2) The manufacturing information—the workpiece is reflected by machining state and each process information, which is actually the most important content that record and storage, including information such as machine tools, equipment number, the spindle (fixture) number: processing information, i.e., parts in the procedure (state qualified or not is rework or not, processing date and time, if it belongs to the sampling parts, test results are OK or not); if it is online measurement procedures, such as connected to the cylinder block and cylinder head production line's sealing test (leakage test assay) process, the measured results will be written to the electronic data chip at this time.

Fig. 6 Workpiece in the feeding station with electronic

4 Based on qs-STAT Enterprise Edition Statistical Analysis Software to set up the Whole Plant Network Process Monitoring System

Companies follow the Volkswagen "Transparent Factory" concept, in the implementation of the project, based on qs-STAT Enterprise Edition statistical analysis software from q-DAS company, the establishment of manufacturing quality monitoring system networking site in the whole company, and then making own

personalized customization, optimization, generates quality information real-time monitoring manufacturing data network. The system covers all the production lines in the three plants (the 3 connecting rods, the 4 curved axes, the 3 cylinder block, the 3 cylinder head, the 1 axis of the cams, and 2 housing lines). As mentioned earlier, the quality information from the production site contains:

(1) production line process;
(2) high precision instrument in the measurement room;
(3) at the end of line 100% final inspection.

According to the requirements of VWPT, the system will meet the needs of three levels (line operators, responsible engineers, and relevant managers), as shown in Fig. 7.

The line operator (located in the left side Fig. 7) can observe the fluctuation data through the monitor at any time, control the production process of the station, and all production measurement room can quickly feedback measure data to the production site through the network after checking the parts.

After getting the feedback data, the line operator can make adjustments in time, and if there are special fluctuation, it can feedback to quality management personnel immediately, which reduces the TP and TQ sectors workload, and also improves the data transmission efficiency and timeliness. The data will also be sent to the central quality database after recognized by the line operator, for engineers to query and analyze.

Refer to the middle part of Fig. 7. Since the whole system support analysis of different stage of production process, engineers in responsibility on site in the early stage, according to production process and process, make the appropriate directory file and edit the corresponding detection device, so that the quality assurance and technical engineers in responsibility can easily reach the aim of filtrating and tracing

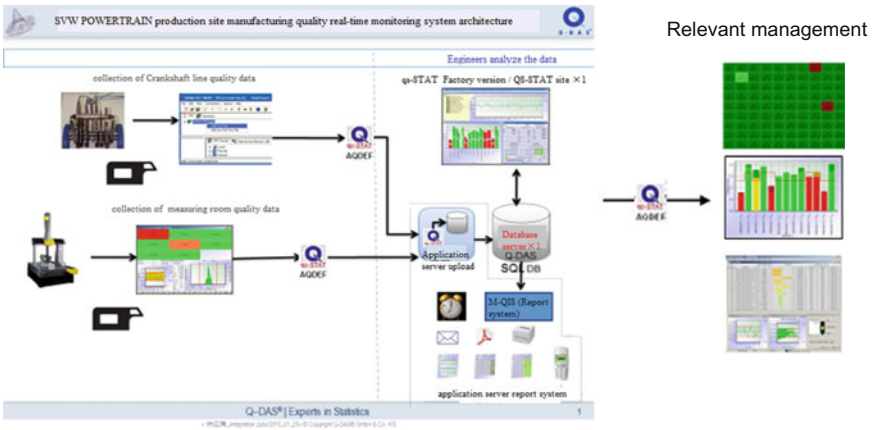

Fig. 7 Framework of real-time monitoring system for manufacturing quality with three layers of data visualization

data. At the same time, the system also allows engineers quickly analyze the corresponding short-term and long-term process capability by analyzing the quality data acquired from measure points; of course, the site supervisor engineers can also monitor production quality trend through the monitoring module, so that any problem can be treated in time.

Right side of Fig. 7 corresponds enterprise management; in accordance with the site supervisor engineers present, automatic report system can periodically obtain measure data from the corresponding automatic central quality database and generate standard SPC report. And the report can be viewed through e-mail or the form of public SkyDrive. Chy-STAT WEB web system works out a query page, as long as the relevant management leaders of the enterprise have a certain understanding of the system. They can monitor the quality of the whole plant at any time through any network-connected PC terminal.

5 Based on Whole Process of the Network Monitoring System, in the Whole Plant Improve the Quality of Real-Time Monitoring

After three years of hard work, the measurement point in the entire workshop production line and the four production measuring room has been equipped with network, using qs-STAT statistical analysis software as monitoring system, to achieve the effective control of the whole production process manufacturing quality. This set of new monitoring system uses Firefox Web browser as a software platform, to avoid the tedious software installation and configuration process, so that everyone can easily use the Q-DAS software to observe and monitor the whole plant's quality data. And it also has the following advantages: (1) to report regularly, to avoid complex preparation on product scrap, process and equipment capacity, OEE and stability; (2) online KPI; (3) easy and intuitive user interface; (4) with Q-DAS statistical core, to ensure the perfect statistics.

Further study also shows that for a long-term and continuous production, it not only requires analyzing the quality of current data, but also handling the "big data" for the future production process of quality trend forecast, in order to avoid the quality problems of products manufacturing. So in the developed system, through the M-QIS (see Figs. 4 and 7 in the lower right below) all kinds of automatic reporting tasks are set up, through which the production process trend can always be grasped and controlled, and the direction of the enterprise's continuous quality improvement in the future is guided. Today, the most used in Powertrain Assembly is the "monitoring module" and "capability module" of the whole system. The former can monitor real-time measurement result in a specific time, a specific production line, as well as a specific production equipment and so that it can statistic and display the actual production indicators. In the monitoring module, the data and varieties of charts of the measured parts can be retrieved at any time (see Fig. 8a–c) and can be read by a click on the report, and you can also send the

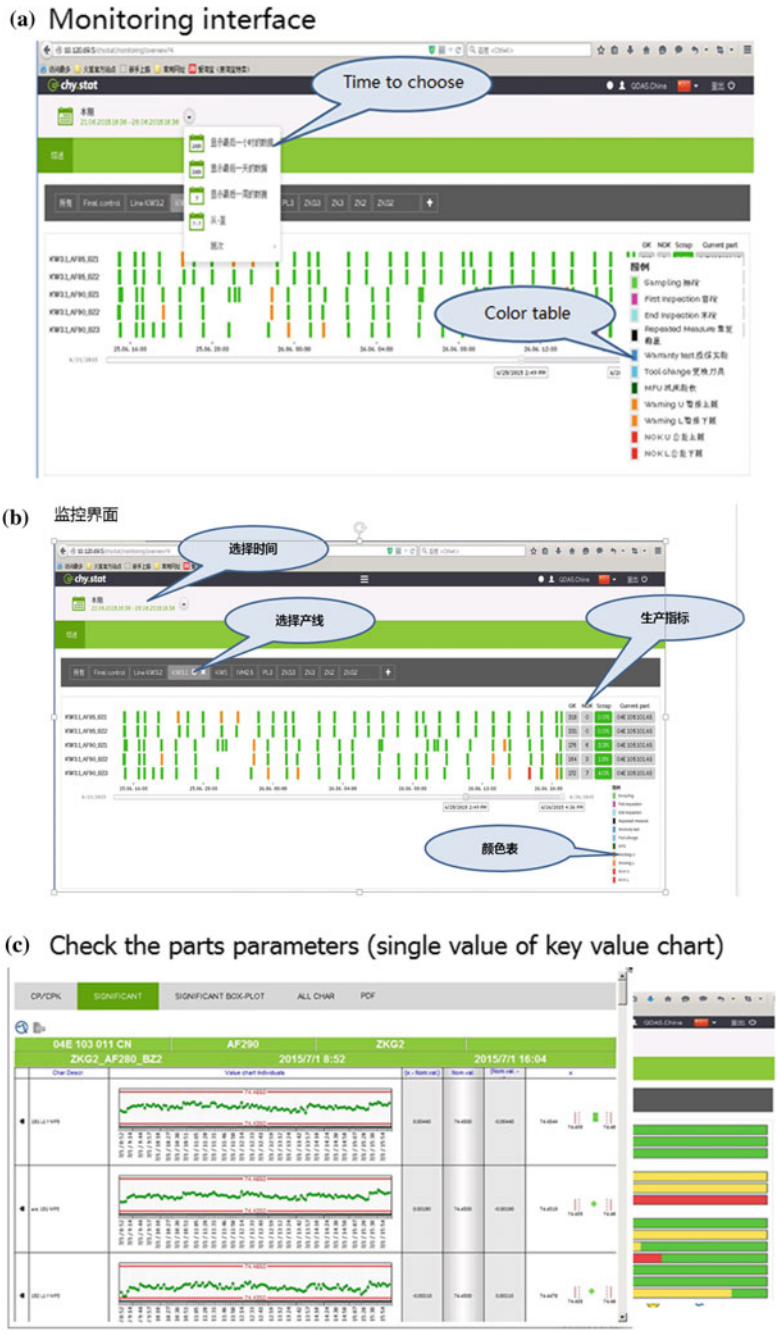

Fig. 8 **a** from the monitoring module in the system work monitoring interface 1, **b** from the monitoring module in the system work monitoring interface 2, **c** from the monitoring module in the system work monitoring interface 3

above interface to other related people. Either the basic line operator or the managers can easily distinguish between these colors to detect whether the work is in accordance with the requirements, and whether the results can fulfill the requirements. If the engineers on site need to do further analysis, you can click on a specific color column in Fig. 8 page, that is, to get more detailed information. Of course, you can also save the data in the form of DFQ alone for further analysis.

"Module" can take a shift as a unit, and calculate and evaluate the ability of each shift, each production line each process, so that each line foreman and the director has an intuitive understanding of the quality of the actual production capacity. Through the analysis of the capacity of these processes, we can adjust the production line or shift, etc., targetedly. Of course, the above two modules will eventually combine with other modules of the Q-DAS system to work together, such as the O-QIS module that ensures the complete input of additional information of measured data, the qs-STAT module used to do more statistical analysis on the data. After all, in the Web system you can only see a relatively simple icon; more icons need to be displayed on a more professional tool (Fig. 9).

6 Real-Time Monitoring and Automatic Reporting System for the Whole Plant

By Use of the previously described optimized, recognizable data processing and analysis system, the department managers, and even responsible leaders, can easily observe and monitor the production process according to their own needs,. and can handle it when necessary. The main steps are the relevant professionals with qs-STAT statistical analysis software, use quality database, to obtain the overall monitor on the process after data processing from the production line and assembly line through comparison and filtering, etc., and then judge the operation situation of the production process, and analysis, to find out the problems in the process. It depends on the specific circumstance to decide which method to use to complete the steps. In normal condition, it is up to production site engineers and full-time quality assurance personnel, to be responsible for the implementation of the daily monitoring, using a targeted state of real-time monitoring. In addition to the monitor of the field operator through the control box in the test table at any time, the monitor can be realized from the system terminal set on site selectively.

Figure 10 on the left shows the needs to call out the required instructions, and after that, the monitoring page and content can be selected as needed, the right is an example. As for the use of M-QIS automatic reporting system, daily, weekly, and monthly reports and other customized reports can be sent to relevant departments and relevant functions through the electronic documents and can be designed or expressed in various forms according to the actual needs. The daily report and the weekly report can be used as shown in Fig. 11a as a process analysis report, and weekly and monthly reports summarize through the tolerance utilization and

Fig. 9 **a** from the system ability module work monitoring interface 1 **b** from the system ability module work monitoring interface 2

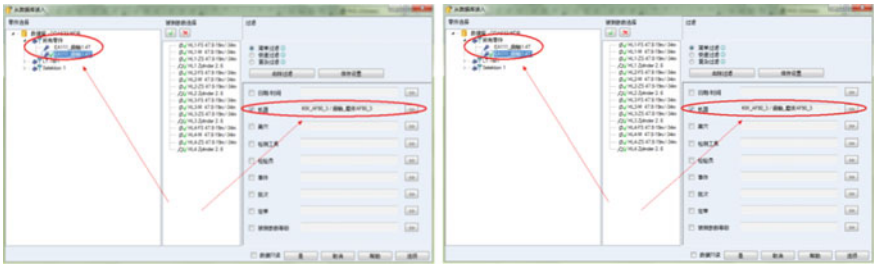

Fig. 10 Production site monitoring system terminal has a selective representation of the page pattern

Fig. 11 **a** Example of analysis report selected in daily, weekly 1. **b** Example of analysis report selected in daily, weekly, and monthly 2

process analysis results (see Fig. 11b left and right), and Cp/Cpk trend charts and other forms, so that it can intuitively reflect and state the production process of a period of time, as the base to optimize production and improve process.

7 Conclusion

Shanghai Volkswagen Powertrain implements the "transparent plant" project, as an example of the successful application of the enterprise version qs-STAT statistical analysis software. As a result of the combination of automobile, especially cars, the growing demand for personalized products for the consumer market, and thus in the implementation of the project, it both talk around the greatest degree of adaptation and to meet the multi-types, flexible production targets, And further use the contemporary information and network technology, to optimize and expand the traditional SPC system. And then through the improvement of "qs-STAT Enterprise Edition statistical analysis software" function, a whole plant network and real-time manufacturing quality monitoring system is completed, which not only includes function of automatic data entry, data visualization three-tier structure, statistical analysis, data management, but also provides a data distribution model's automatic selection, a variety of capacity assessment, and the quality of information archiving the requirements of enterprises. It can be called as a comprehensive solution.

The last thing to mention is that the German Volkswagen (headquarters) hoped to copy the Czech Republic's Volkswagen Group's engine plant's lately completed, "transparent plant" project content which shows good results, intactly to Shanghai Volkswagen Powertrain. They may also be out of "good intentions." They hope that we can avoid some detours, since our domestic understanding of this ability is one-sided. After communication with Czech factory (by sending engineers out, and inviting them in), we recognized that there are big differences between the two plants, and "copy" is impossible and meaningless; we must do it based on our own feature. The final fact is after closely and unremitting efforts made by the Chinese engineers of both sides, a satisfying solution is finally provided to all sides after three years.

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