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Mass Customization Manufacturing Solution for Cell Phone Production

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***Abstract* —Mass customization becomes a main production mode of the 21st century. This paper mainly proposes a kind of mass customization manufacturing solution, which has been applied into cell phone production successfully. Firstly, the cell phone production process is introduced. Then, the solution's production modes, namely, the four main phases (Marketing, R&D, Production, and Purchasing), the order processing, and MES architecture, are described. The results of mass customization, especially on the order and quality, are given out. Finally, conclusions are drawn out.**

***Key words* — Mass Customization; Manufacturing Solution; Cell Phone Mass Production; Manufacturing Execution System**

I. INTRODUCTION

1.1 Mass Customization Introduction

Marketing environment in new economic times calls for new production mode urgently. In 1970, Alvin Toffler, an American sociologist and futurist, gave his creative suggestion in his book *Future Shock* [1]: Provide customized products and services to meet customer's special requirements with the cost and speed of standard mass production. In 1987, at first time, Stan Davis named this type of production mode mass customization (MC) in his book *Future Perfect*. In 1993, B. Joseph Pine II wrote his book *Mass Customization: The New Frontier in Business Competition* [3]. Mass customization has a lot of different definitions. For example, Richard gave his definition [4]: mass customization is the method of "effectively postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network."

Since then, scientists of academic institutes have done a lot of researches on mass customization. Many giant companies from industries, like computer manufacturer Dell, computer and cell phone manufacturer Lenovo, and cell phone manufacturer Nokia etc. have done some successful practices of mass customization. In 1998, the market share of Dell computer increased about 54%, and its profit increased about 62%. In 1999, 50% of Dell computers were sold by using of E-business and mass customization. In 2001, Dell continuously broke its market and profit records when its competitors were losing their competences and market shares. In fact, it was "mass customization" strategy that contributed to Dell's core competences and success. Lenovo, Nokia, and many industrial manufacturers have similar success story, which are described in many media. In fact, mass customization becomes the main production mode of the 21st century.

Normally, the production modes of mass customization can be divided into four types: STO (sale to order), ATO (assemble to order), MTO (make to order) and ETO (engineer to order). In Table 1, we summarize the differentiation of mass production and mass customization clearly.

Table.1 Differentiation of mass production and mass customization

Mass production	Mass customization
low cost, stable quality, standard product	reasonable cost, high quality, customized product
long product life cycle	short product life cycle
production efficiency	product efficiency
high management cost for product variation	low management cost for product variation
production plan and execution is based on prediction, high storage	production plan and execution is based on customer order, "zero" storage
multi-level agent, marketing, promotion for product. Bad relationship with suppliers	direct marketing, "Blue Ocean" relationship with suppliers, and other partners
ignore many requirements of customers	fast response for customer's requirements
lost cost is focus. its 80% comes from high volume materials	80% of low cost comes from design phase and other aspects, not only from high volume.
production emphasis on capacity construction, cost and quality	production emphasis on outsourcing, core capability, and fast response
purchase emphasis on cost/ payment/ storage optimization	purchase emphasis on strategy cooperation
independent R&D	coordinate R&D and continuous improvement
logistics emphasis on distribution centre, transportation management	logistics is outsourced to 3rd partner
financial emphasis on cost and financial management	financial emphasis on value chain management

It is predicted that 30% of products will be customized in 2015. Some of them are transferred from mass production,

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Gang, Xiong (1969-) Research Professor of institute of automation, Chinese Academy of Science. Until now, more than 90 papers have been published and his major researches include intelligent control of complex system, parallel management system, the infomationization of enterprise, etc.
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like automobile industry and household appliance industry. Some of them are transferred from normal customization, like ship and industrial steam turbine. Furthermore, some other are transferred from batch mode, like machine tool industry and aviation industry. Currently, mass customization research and practice are developing very fast.

1.2 Literatures Review

The 1st World Conference on Mass Customization and Personalization was held in 2001, and has been held once every two years [5]. The Workshop MCP 2005 was held in China. The 2009 World Conference on Mass Customization & Personalization Took Place in Helsinki, Finland. In 2004, a Chinese scholar, Dan Bin published his book *Mass Customization: To build up the core competence of your enterprise* [6]. Elizabeth et al. suggested a queuing model of delayed product differentiation [7]. Cao et al. proposed an interactive service customization model [8]. Finnish scholar Jari described how to implement mass customization in electronics industry [9]. More literature reviews can be found from Giovani's paper [10].

With the support of Chinese 863 High-Technology Development Foundation in 1998, the author Xiong [8] started his research on "Intelligent Production and Optimized Scheduling System Based on Push/Pull Production Mode used in Process Industry". "Mass production" is Push production mode, what is made will be sold. "Customization" is Pull production mode, what will be sold is made. Pull Production Mode is mainly used, and Push Production Mode compensates it, and their advantages are combined to meet the requirements of "Mass Customization". Those research achievements were applied into the industrial practice in one global cell phone manufacturer.

The paper mainly gives out a kind of mass customization manufacturing solution of cell phone production. Firstly, the cell phone production process is introduced. Then, the solution's production mode, the main phases, the order processing, and manufacturing execution system (MES) architecture are described, and it results in mass customization's order and quality. Finally, conclusions are drawn out.

II. CELL PHONE PRODUCTION PROCESS DESCRIPTION

Every customer wants to buy his/her unique electronic products, such as cell phone and laptop, which are composed of hardware platforms, software platforms, user interfaces, and accessories. Hardware platforms have different types of components, such as Wireless Local Area Network (WLAN), Blue Tooth (BT), Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Code Division Multiple Access 2000 (CDMA2000), Wideband Code Division Multiple Access (WCDMA), Time Division-Synchronous Code Division Multiple Access (TD-SCDMA), and Worldwide Interoperability for Microwave Access (WiMax); software platforms have different Operating Systems like BlackBerry 4.3, Palm 5.4, Symbian 9.2, and Windows Mobile 6 etc., and different Operators include China Mobile, Vodafone, O2, Orange, T-Mobile, Verizon Wireless, AT&T Mobility, and TeliaSonera etc. User Interfaces have different languages like English, Chinese, Spanish, Germany, Finnish etc., and accessories consist of charger, battery, memory cards, data cables, hand free ear phone, user manual etc.

To meet those requirements, cell phone production process can be arranged like Fig.1.

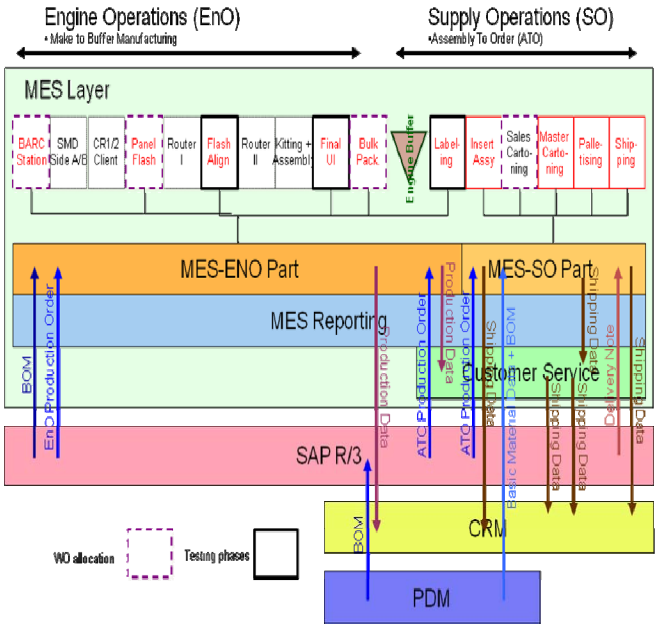

Fig.1 Cell phone production process

In ATO (assembly to order) mass production mode, the whole cell phone production process is composed of engine operations (ENO) part and supply operations (SO) part. MES-ENO part mainly manages engine operations phases; MES-SO part mainly manages supply operations phases. MES is applied to collect, analyze and report the production data of ENO and SO about product material, order, quality, and status etc. Its detail is described as follows.

Barcode (BARC) station phase is the 1st variation point for the module production. The modules are attached to the 1st work order level (WO_1) for the first variation. A barcode label is printed and attached to every printed wire boards (PWB) on the panel. One panel usually contains 4, 6 or 8 PWB's. A unique production serial number (PSN) is generated for every module. The PSN is printed on the barcode label. Basic information about the module is created and saved into the database.

In SMD A/B phase, components are inserted to A- side (top) and B- side (down) of the printed wire boards.

CR (change request) 1/2 client phase is to read the barcode label with a barcode reader, and monitoring. If modules have a CR or agamid alarm, the unit will be stopped at the 1st test phase.

Panel flash phase is basic product code (BPC) attachment client, which is the 2nd variation point for the unit (Basic Product). Basic product code, which comes from work order, is given to the unit, and is attached to the 2nd work order level (WO_2). BPC defines for example the color of the cover.

In flash alignment phase, the test phase, core flash file is flashed and programmed into the unit, and then the unit is tested online and test results are saved into MES.

In kitting client phase the PSN is read from escort memory, and work instructions are presented in pictorial form, and an alarm is evoked when the basic product code changes.

Final UI (user interface) is a phase to test the user interfaces related functions.

Labeling phase is a test phase too, language flashfile (PPM) is flashed into the unit. This is the 3rd variation point for the unit (product), the unit gets a product code from work order, and an ESN is attached to work order level 3 (WO_3). Type label is printed.

The units are sent to and packed in distribution centre (DC) either in bulks, or if the line is equipped with inline packing, they are packed at the end of the line.

When SO lines are separated from ENO lines, the Engines will be packed and sent to Engine buffer.

After the engines are opened again on another SO line, its ENO's related data is retrieved from the databases of MES. When every check is passed, the engine will be assembled into phone product, be flashed UI software, and then tested.

In sales cartooning phase, every phone is finally packed into its own sales carton according to customer's requirements. The fixed number's (like 12) sales cartons are packed again into one master carton. Many master cartons are packed into one pallet. And then, those pallets are shipped out of production lines for transportation.

In fact, the giant cell phone manufacturers have many partners, such as Sanyo supplies battery, Exel provides for logistic services, Ibiden supplies PWB, Verso supplies accessories，Elcoteq provides PWB and engine, Foxconn provides for low end phone. A perfect supply chain can make 400-500 millions cell phones every year.

Now, the story below becomes fact: Every morning, customer orders are collected and transferred to factories, the cargo transports all necessary "materials" from suppliers' storages to cell phone factory. Enterprise Resource Planning (ERP) and MES help factory arrange suitable workers, production lines, and the time for the phone's making to fulfill the order according to the customer's requirements. In the afternoon, all phone products are made and shipped to the cargo waiting outside. In the evening, all those phones are transported to different customers all over the world. The response time from the customer's order creation to phone receiving can be as short as several days. The customer order can be as small as only 1. The storage of material and product can be as small as "ZERO". Mass customization is fully realized.

The MES, together with SAP R/3 ERP, customer relationship management (CRM), and product database management (PDM) etc., composites of the IT systems realize the mass customization. The four layers of data management of ERP and MES are described as Fig.2. First, nearly all related data, like material resource plan (MRP), part lists, sales orders, production order, scheduling, releasing, deliveries etc. are collected to assure the 2nd step. Then, mass customization production is mainly executed by strict and accurate order and version management. After that, data is used for analyzing, reporting, and archiving etc. Nearly all kind of data can be collected and managed for different purposes.

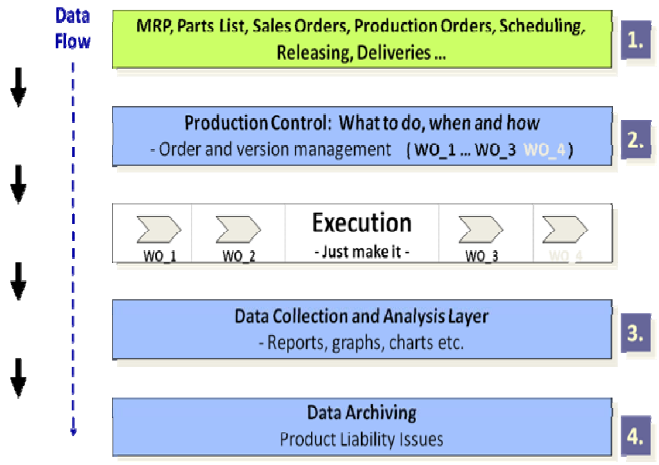

Fig.2 Four layers of data management of ERP and MES

III. THE MASS CUSTOMIZATION MANUFACTURING SOLUTION

There are six different production modes to realize the customized manufacturing of cell phone (Fig.3), i.e. buy to order (BTO), make to oder (MTO), assembly to order (ATO), ship to order (STO), customer to order (CTO). ATO and CTO are the latest modes mainly to realize mass customization. The detailed descriptions of ATO and CTO are shown as Fig.4.

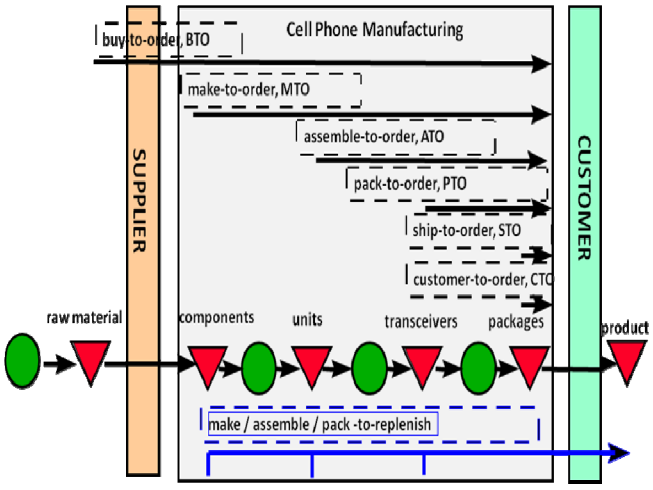

Fig.3 Customized manufacturing modes of cell phone

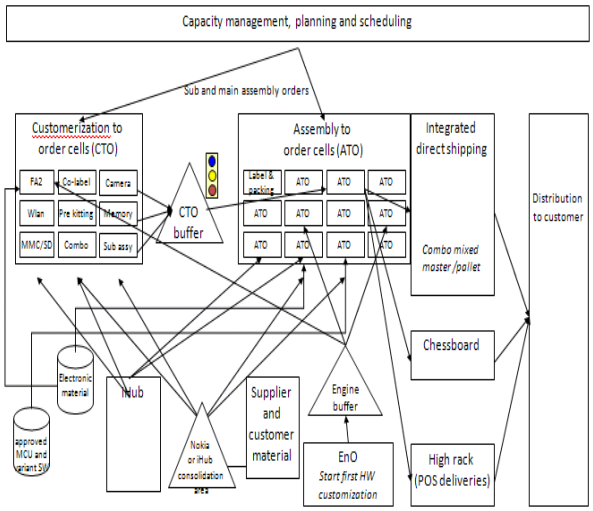

Fig. 4 ATO and CTO of cell phone manufacturing

3.1. The Main Phases of Mass Customization

To realize the mass customization in a cell phone enterprise, there are about four main phases (Fig.5) involved normally, i.e. marketing, R&D, production, and purchasing.

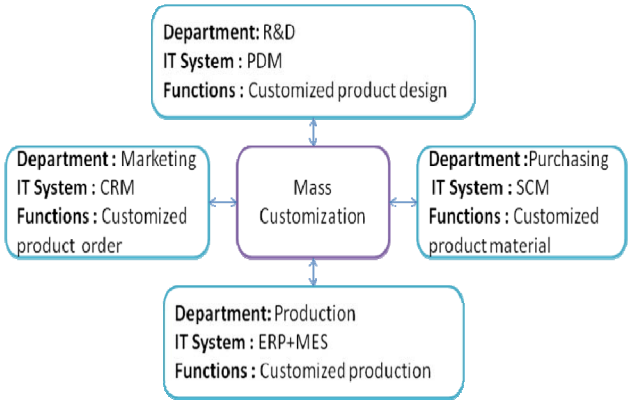

Fig. 5 Four phases of mass customization

[1]. Customized product order

To meet the mass customization's requirements from marketing department, existing CRM is modified, where the product specification, order and requirements are recorded, and transferred to R&D department for product design, production department for product making, and purchasing department for material preparation. At the same time, the customer can create- his own product order, and track every phases of its processing, until receiving the product. The extensible function of CRM is to realize the whole product lifecycle management.

[2]. Customized product design

To meet the mass customization's requirements from product R&D department, existing PDM is modified, where the customized product is designed according to the customized product order and requirements. After enough hardware components and software components are made and accumulated, their combination can create as many variations as needed; the customized product design can easily be executed.

[3]. Customized product material

To meet the mass customization's requirements from material department, existing supply chain management (SCM) is modified, where the correct product material is purchased at the correct time, quantity, quality and price to meet the production requirement and reduce the storage. To realize full lifecycle management of material quantity and quality from every supplier, and to transfer material's data to production department, marketing department, and customer department, correspondent feedbacks are necessary to improve the purchasing quality and efficiency.

[4]. Customized production

Customized production is such production mode that the customized product is made by assembling the existing parts and components only after the customized product order is received. To meet the mass customization's requirements from production department, existing ERP and MES are modified to a mass customization production management system shown as Fig.6, and the system is used to fulfill the targets:

1) Solution can meet the requirements of product order as small as only 1, or as big as millions.
2) Production profits still can be made even when product order quantity is as small as only 1.

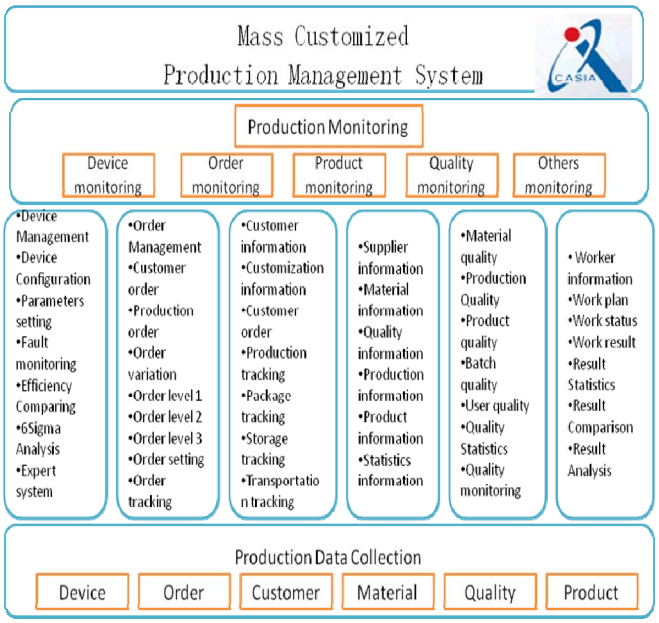

Fig. 6 Main functions of
mass customization production management system

3.2. The Order Processing of Mass Customization

The order processing is the main tool to realized mass customization. An example on the customized production is particularized. In MES of the cell phone manufacturer, current work order structure has four work order levels (Fig.7), and one level means one variation point:

[1]. Work order level 1 (WO_1) is for manufacturing modules. Its variation number is between 10 and 50.
[2]. Work order level 2 (WO_2) is for manufacturing basic product codes. Its variation number is between 20 and 100.
[3]. WO_3 (Work order level 3) is for manufacturing product codes. Its variation number is between 50 and 100.
[4]. WO_4 (Work order level 4) is for sales package. Its variation number is between 20 and several hundreds. Unit is attached to work order in every variation point. Work order attachment routine is dynamic and follows the last work order priority sequence at each variation point. If a unit fails at a certain test phase, it is removed from work order and next unit in line will dynamically replace it.

Let's assumption:

WO_1 variation number =20
WO_2 variation number =50
WO_3 variation number =50
WO_4 variation number =200

Then the work order variation of the four levels can create a product variation number as big as 20*50*50*200=1,000,000 = ten millions!!

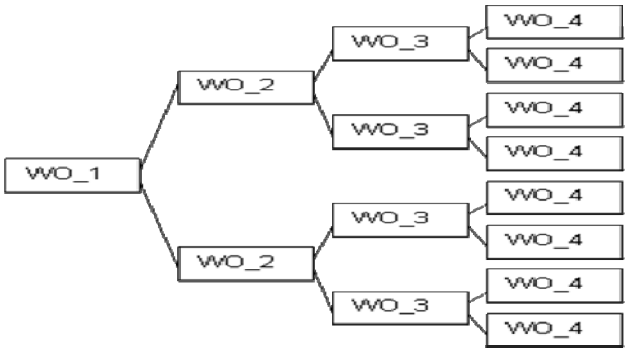

Fig.7 The Order Variation of Mass Customization

Work order has the following status codes at each work order level:

[1]. PENDING (in queue)- work order is pending in queue means it is waiting to be processed;
[2]. ACTIVE - work order is in process;
[3]. CLOSED - work order is completed and closed;
[4]. LOCKED (in edit) - work order is being modified;
[5]. ATTACHMENT STOPPED - unit attachment to work order is stopped;
[6]. HOLD - work order is put on hold (paused) status;

A module is linked to a phase order. Phase orders define all mandatory and optional phases that a unit travels through the production. Previous mandatory phase must be ensured on completion before the module can enter its next phase. Unit can return to any passed phase in order to re-run phase.

3.3. The Architecture of MES

The technical architecture of MES can be described as Fig.8. Its service oriented architecture (SOA) 3-tier structure includes client, middleware, functions and database (DB). Product data and production data are collected, and saved into the database, and then the system can provide different reporting functions. System intelligence (business logic) is built into individual functions or services. Functions communicate with Oracle DB. Tuxedo middleware knows where the services (functions) are, how to call them, how to deal with parameter interfaces, and how to arrange different calls to different function servers. Clients on the production line calls Tuxedo middleware with the service name and parameters, to perform the wanted function(s). The clients can be machine client (like tester) or user client.

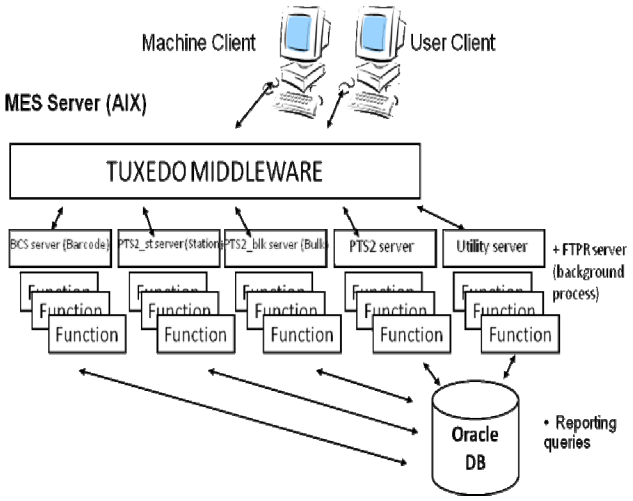

Fig. 8 Technical architecture of MES

IV. THE SOLUTION'S RESULTS

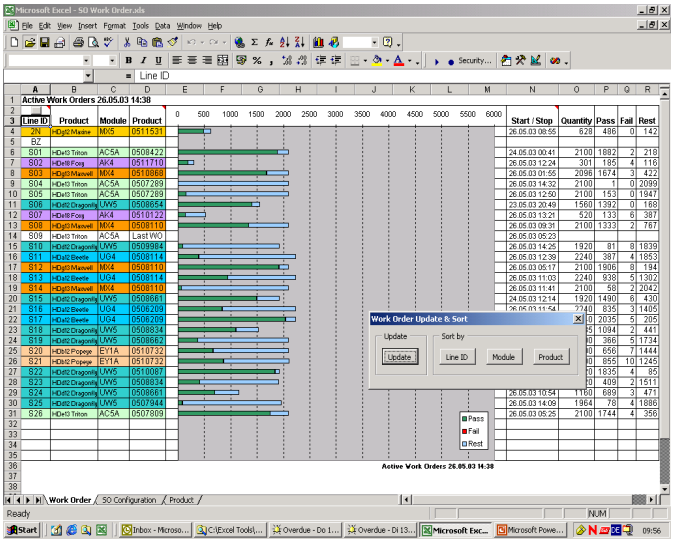

Fig.9 Work order monitoring of customized production

The solution described above is one of the main success factors of cell phone manufacturers. Some examples are given. Fig.9 mainly provides work order

online monitoring function of customized production, where all active orders are listed. For every work order, its production line, product code, and module code are shown, and its total quantity, pass quantity, and fail quantity are summarized.

Fig.10 mainly provides production quality online monitoring function of customized production, where all failed PWB, modules, units, engine and phone are tracked and analyzed to find out the root reasons nearly real time. The statistical process control (SPC) analysis mainly uses the six sigma method and tool.

The root reason can be from the "material" quality from suppliers. If so, the whole batch of the material will be stopped to use, and retrieved. Business bargain will start with the supplier. The material can be like battery, PWB, monitor, chips, etc.

The root reason can be from the production line. For example, some machine's parameters are not adjusted or calibrated correctly. If so, the production will be stopped to repair the machine in trouble, and all products made by the machine will be retrieved.

The root reason can be from the production worker , too. For example, a worker is careless or tired, and then mistakes are made. If so, the worker's work will be stopped and retrieved.

And all kind of quality, quantity, and status data can be compared between different time, different production lines, different materials, different workers, different factories to find possible mistakes, exception, and problem etc. And then, the production quality and efficiency can be improved continuously.

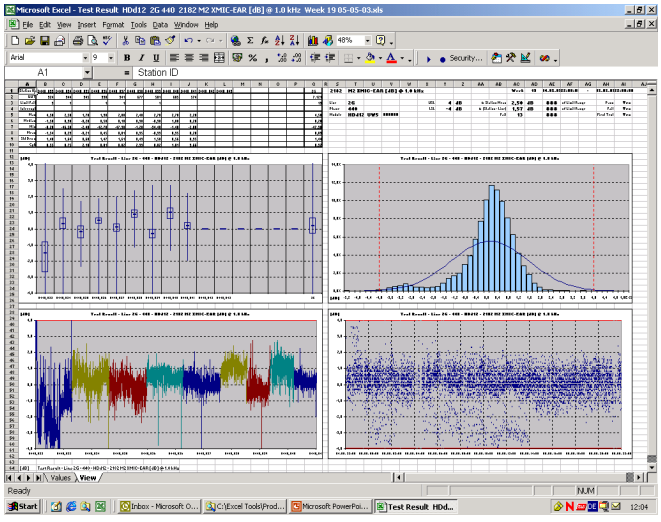

Fig.10 Production quality monitoring

MES can support the production speed as high as 7 seconds per phone in one factory. MES itself is also with high quality. For example, its service availability can as high as 99.97%, i.e. less than 3 hours unplanned break every year.

V. CONCLUSIONS

In this paper, a kind of mass customization manufacturing solution is given out for cell phone production, which has been successfully applied into a giant cell phone manufacturer. The solution can easily be practiced to other cell phone manufacturers, also can be applied to other electrics products manufacturers, like laptops, and can be referenced by other mass customization industries, like furniture industry and clothing industry.

With the help of the academic researchers and their achievements, the solution will be improved and optimized to fulfill different situations and requirements.

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