MEYER BURGER

Automation in PV Manufacturing

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Increasing quality and reducing cost with automation in PV manufacturing

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ABSTRACT

The ultimate goal of PV manufacturing is to produce the highest quality of solar cells at the lowest possible cost. Translated into manufacturing requirements, this means that throughput, equipment uptime and yield must be continuously increased in a manufacturing environment while improvements and subsequent generations of products are implemented in parallel. Automation is a key element in understanding the relevant process behaviour, monitoring and controlling the process windows, ensuring stable processes, achieving the necessary product quality at all times, guaranteeing error-free production and promptly detecting any anomalies. Collecting and evaluating all of the applicable data, and controlling equipment performance with a high degree of complexity, rank among the challenges of automation. The general objective of automation is to move the *right material* at the *right time* to the *right place* and *process it correctly* – while controlling all of these steps in real time. The ability to do this in a reliable, predictable and flexible manner has a direct impact on factory performance. In this paper, the main components of automation will be described, and some ROI examples will be discussed for a PV manufacturing line.

Integrated automation is key

Today's production environments are highly complex. Intricate systems can only be managed through integration and interlinkage of all relevant elements, including processes, equipment, material flows and maintenance. Integration leads to networks. Networked systems have the ability to provide supra-summative intelligence. If the problem space is complex, then the solution space must also be complex: a mathematical problem with five unknowns requires five equations in the solution space. "Intelligence in automation is required at every node in the process; intelligence that is integrated with other nodes" [1].

Components of an integrated and automated manufacturing system

Manufacturing execution system (MES)

Anyone involved in the planning and control of manufacturing will already be aware of the requirements that exist in the areas

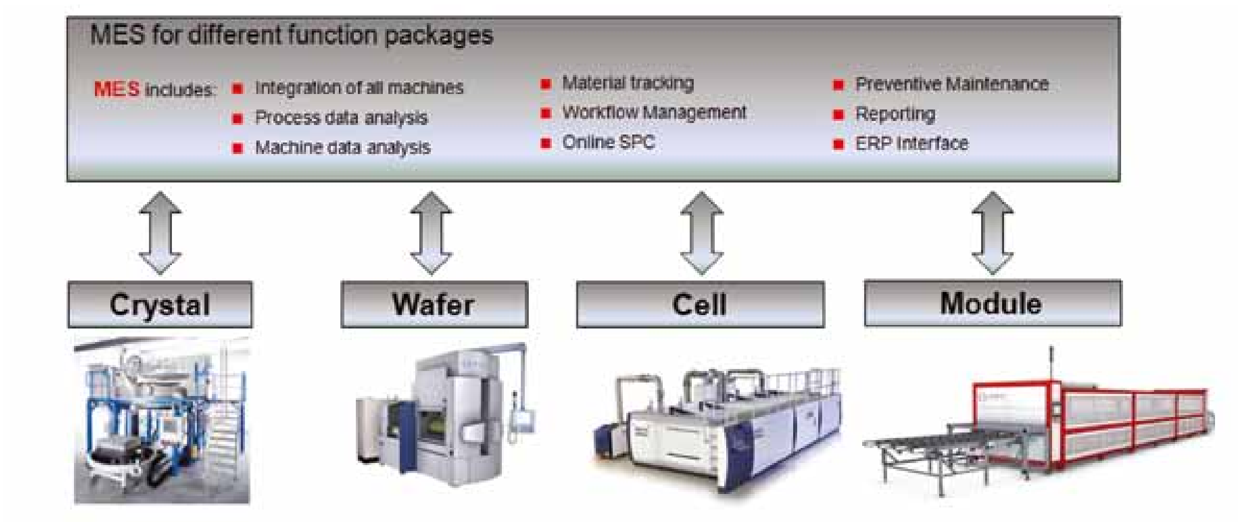

Figure 1. Integrated automation system for PV manufacturing.

of production planning and scheduling (PPS) and enterprise resource planning (ERP). The purpose of a PPS system is to support the user in the area of production planning and control and to optimize the management of data. ERP systems are used for order processing and for financial and personnel resource planning: they should therefore take into account the entire business process of the company.

Currently available ERP and PPS systems, however, do not manage the control of a manufacturing process. These software systems lack a reference to current events in production. To increase productivity, flexibility and competitiveness, this gap must be closed by using a manufacturing execution system (MES). An MES combines commercial order processing in ERP systems with control systems in automated production. It therefore links the transaction-oriented thought processes with the event-oriented actions of the company. The MES is a process-oriented production management system which is directly connected to automation and controls the production in real time. Nowadays, the MES forms part of an integrated factory automation solution.

For small- and medium-sized manufacturing environments, the MES must be a modular and scalable system that can keep pace with the growth of the manufacturing line. The core function of the MES automation system is work-in-progress (WIP) tracking. Additionally, it provides a central repository of process step sequences, product IDs, operation lists, routing information, etc. In PV environments, the MES automation system must provide:

- Web-based visualization of manufacturing for different user profiles, such as operations, process engineering and equipment maintenance
- User management
- Alarm management
- Order management
- Process control
- Integration of equipment
- Collection and analysis of equipment data and parameters
- Active recipe control
- Equipment performance management

The MES automation system must have the flexibility to integrate with a wide range of computer-integrated manufacturing (CIM) components, including tracking systems, material control systems and real-time dispatching and scheduling solutions. Fig. 3 illustrates the three different stages in the deployment from a passive MES to a fully integrated active automation environment that is controlled by an MES, based on manufacturing needs.

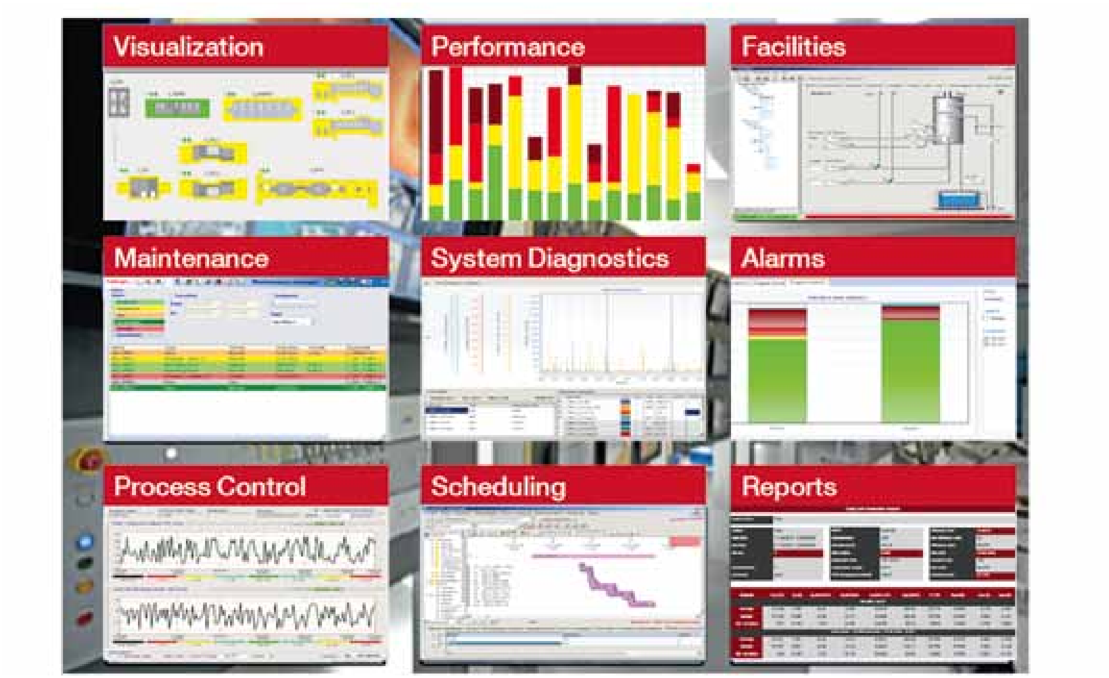

Figure 2. MES functions.

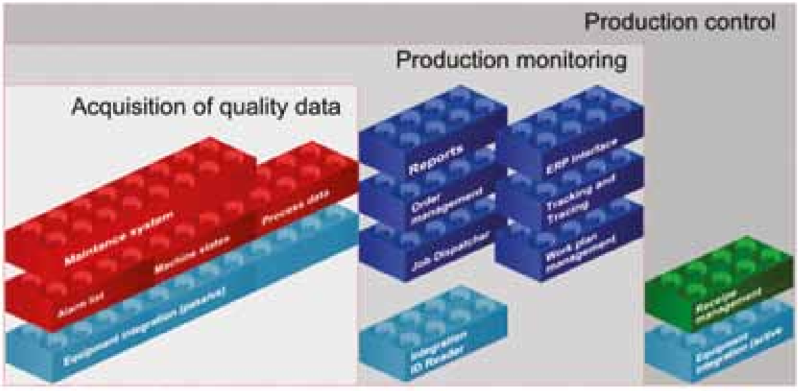

Figure 3. Expansion stages of an MES.

First expansion stage
Passive integration of equipment allows simple registration and analysis of equipment states, process data and alarms.

Second expansion stage
Extension for production monitoring supports integration of identification devices (such as radio-frequency identification – RFID) in order to track material in the production process. Integration with ERP allows the coordination of order management. Moreover, manufacturing jobs can be dispatched and manufacturing reporting is enabled.

Third expansion stage
Finally, at the third expansion level, the MES applies to all tasks in the entire production system. This means the equipment is actively integrated, including recipe management and remote control of the equipment via the MES. The PPS dispatches and controls the flow of material along the manufacturing line.

Equipment integration

Equipment integration should provide process control capability, with support for different tool, load port and carrier

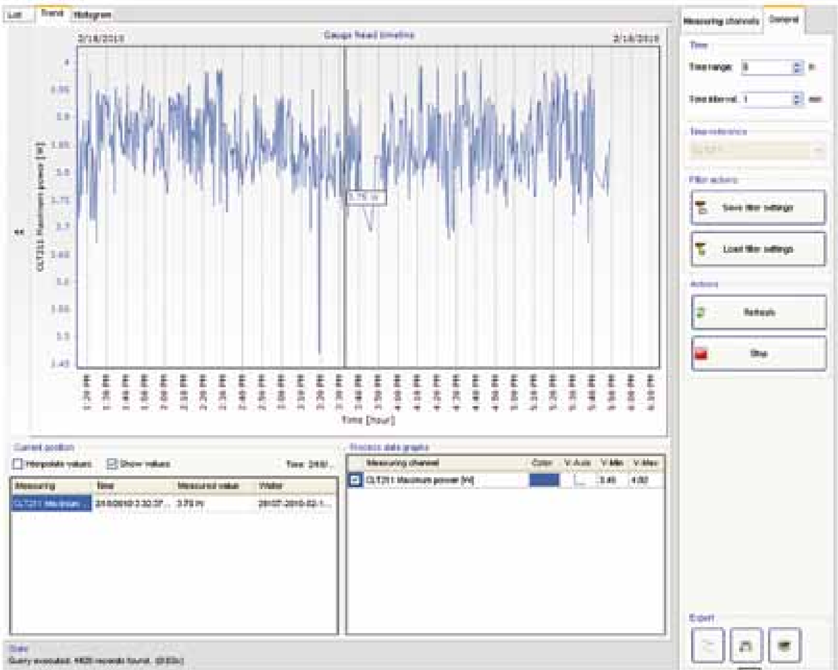

Figure 4. SPC with process data trending.

configurations as well as for varying wafer-flow throughputs. Tool control functions include alarm handling, recipe management, data storage, configuration/set-up information, material tracking and reporting. The tool controllers must offer standard industry communication interfaces for easy integration with factory networks. Standard PV equipment interfaces, such as PV02, must be supported. However, because of the variability of tools in the PV industry, there must also be support for other interface standards (such as OPC and XML). Tool controllers should support customization of individual tool applications and user interfaces.

Remote control

Remote control of equipment is a key element of automation. Standard commands that are communicated between the equipment and the automation environment are:

- Recipe selection and adjustment of recipe parameters
- Start/stop of manufacturing processes
- Pause/abort of process jobs

Additional commands may be necessary depending on the specific equipment requirements.

Data collection

Data collection via conventional status variable and event report messaging is another key element of automation. Data should be collected at all levels of granularity (unit, lot, batch). For the process control type of data, the reporting of key process parameters (KPPs) is an essential tool in understanding the manufacturing process.

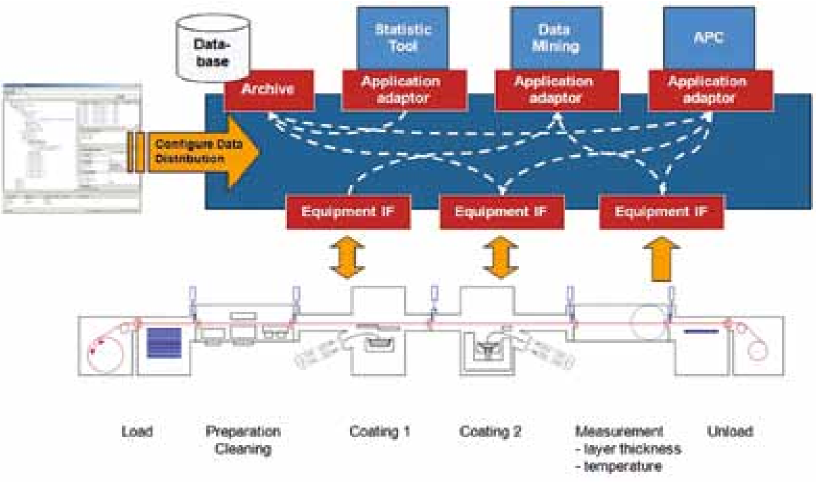

Figure 5. Feedback control loop.

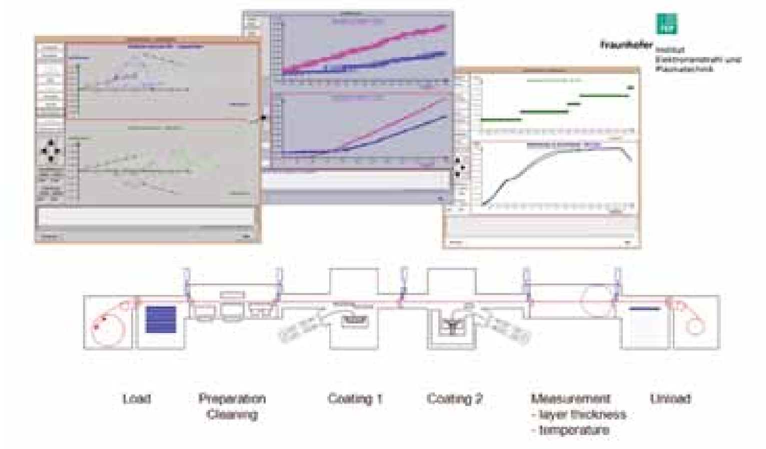

Figure 6. Process and control loop visualization.

Process programme management

Process programme/recipe management defines the functionality for the transfer of recipes (download and upload) and the sharing of management of those recipes between the host and equipment.

Automated equipment performance tracking

The equipment should support the storage of equipment state changes and associated timestamps, and the transmission of this information to the host computer.

Auto set-up

Automated set-up is the means by which the equipment allows the host system to audit the equipment configuration to ensure compliance with a standard equipment configuration. Additionally, the equipment must provide a mechanism for the host to set the equipment data. To support auditing and reconfiguration, the tool must display equipment data as both status variables and equipment constants.

Process data analysis

Statistical process control (SPC)

The MES collects process and metrology data and controls such data in real time. If alarm or hold limits are reached, specific events can be triggered, such as the distribution of alarm messages to a user group, or the setting of a lot on hold for further control steps or rework processes. Advanced integrated SPC systems can also analyze trends, process stability and quality on the basis of rules (e.g. Western Digital Rules).

Advanced process control (APC)

With integrated metrology, the automatically collected metrology data can be used to actively control process parameters – this is called advanced process control (APC). APC can be operated as feedback and feed-forward control loops.

In *feed-forward* loops, if the measurement does not meet the specification, the next production step (rather than the previous one) will be adjusted to make a correction. For example, if the product is a fraction thicker than expected, the next step might function to etch away the extra material [2].

A *feedback* loop exists if, in a completed manufacturing process, metrology data is used to compare the result with a specified target. If there has been any deviation, the previous process is immediately adjusted so that the device which is made next will be closer to the specification.

The example given in Fig. 5 shows a multi-chamber deposition tool in a coating plant. Layer thickness is measured by separate metrology equipment at the end of the manufacturing line. All process and control loop parameters can be displayed with charting tools as analytical methods for continuous improvements (Fig. 6).

Virtual metrology (VM)

State-of-the-art product quality control is based on product monitoring and feedback control as discussed in earlier sections. The metrology operations are quite expensive and time-consuming, so it is preferable to not measure every substrate. A subset of substrates is measured at a metrology station, and this metrology data is assumed to be representative of the rest of the substrates. This technique is known as virtual metrology (VM).

As explained earlier, a huge amount of data is collected in the process steps. One problem is to decide which data are important and which are not. The next step is to generate a mathematical model that describes how the process data will develop over time. Fig. 7 shows, by means of an example of an MBT of a cell line, how precise the calculation of metrology data by VM can be.

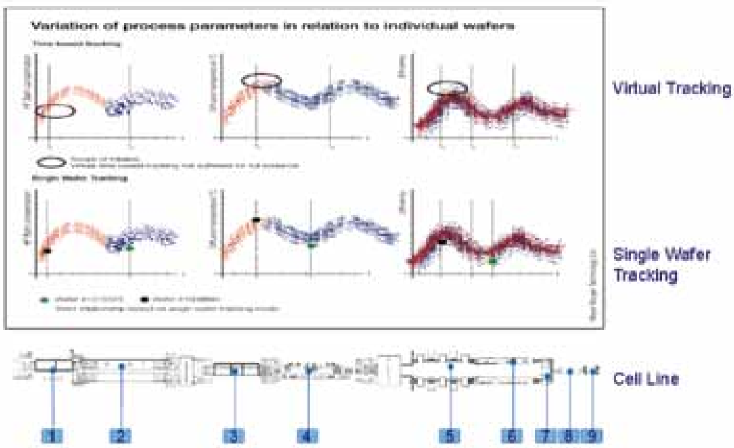

Figure 7. VM within a cell line.

Example of ROI by addressing the needs of PV wafer manufacturing

Cropping process

The precision achieved through angular accuracy and evenness increases the yield in the subsequent wafering process by up to 1.5%. Advanced cutting technologies, combined with quality checks performed on the silicon crystal, are automatically passed on, increasing the manufacturing quality in wafering by ensuring that the cropping saw is correctly positioned on the ingot. Saw control needs to be simplified, kerf loss prevented and the number of cropping operations minimized.

Fig. 8 shows how the use of the MES increases the output of wafers by monitoring quality issues in the raw material and during crystallization. APC with feedback run-to-run algorithms for tester results and recipe parameters for wire saws increases the yield of wire saws dramatically while preventing misprocessing and optimizing cut results. Overall, the wafering yield at one customer of AIS Automation was increased by 7% using an integrated approach for the MES with equipment integration and APC.

Wafering process

Flawless wafering is ensured by material tracking, recording wire usage and coordinating the residual saw length. The MES/automation environment must provide assistance by the monitoring of slurry quality and the optimum provision of all consumables and supplies (slurry, wire guide rolls, etc.).

The two charts in Fig. 9 show the total thickness variation (TTV) before and after automation is implemented. There is clearly a significant reduction in the variation around the optimum for the

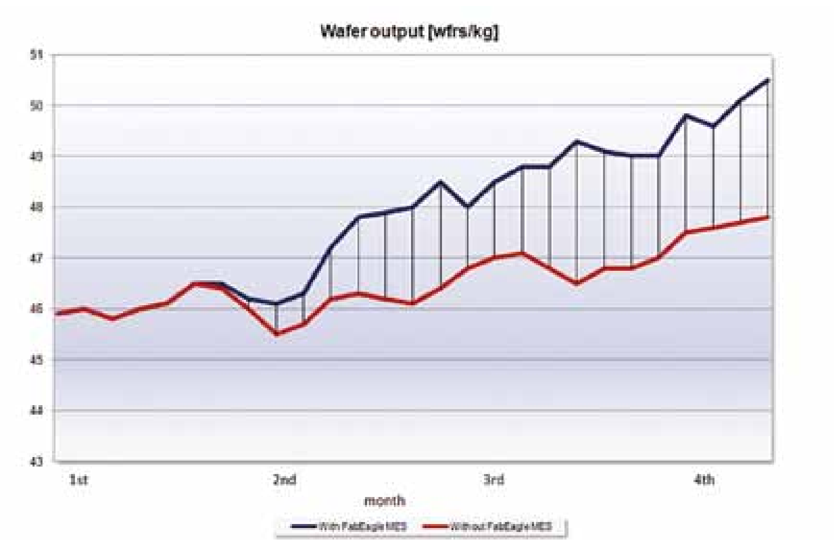

Figure 8. Increase in wafer output when APC is used in cropping.

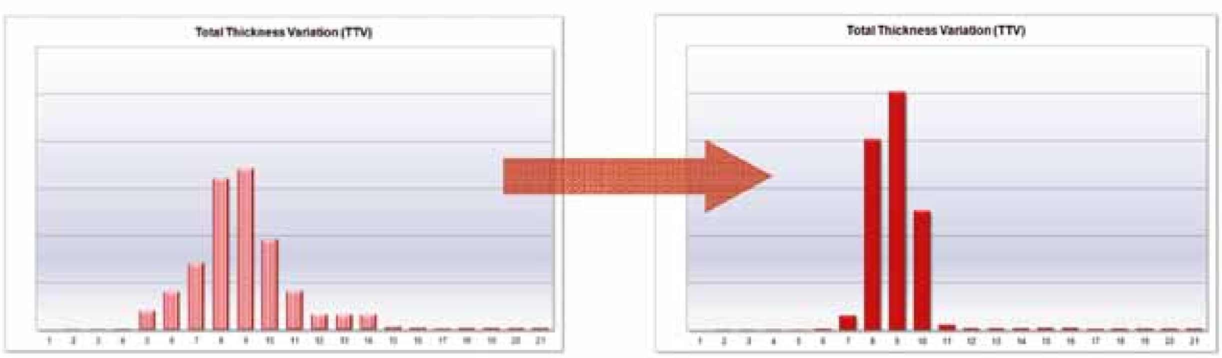

Figure 9. Comparison of TTV before and after deployment of automation.

process. Automation helped to limit the process windows while continuously observing process parameters and conditions for the equipment and supplies such as wire and slurry.

Example for ROI – optimization of manufacturing parameters

Equipment performance monitoring

The analysis of equipment performance becomes essential as production lines in the PV industry grow to dimensions that can no longer be adequately monitored by humans. An automated collection of tool-related data is now part of the MES functionality and forms the basis for planning and improvement processes. Data provided by the equipment include status information, alarms and a set of events indicating the current tool activity.

Continuous observation of equipment performance is of great importance when working towards tracing and optimizing production. The MES can be used to collect the status information for the machines directly from the tools and calculate the relevant performance indicators. These indicators are then presented graphically to allow in-depth analysis of machines and machine clusters.

In the example shown in Fig. 10, the area manager for wire saws was challenged to reach a target of more than 92% overall productive time for all saws within a one-year time frame. He achieved his goal by continuously monitoring the uptime, set-up time, maintenance cycles and utilization of his machines. The key to his success lay in optimizing the set-up procedure and reducing unnecessary maintenance time for the saws. Every morning, he pulled reports from the MES to obtain in-depth details about each downtime along with set-up times for each shift. He challenged his team to improve and be efficient, and he challenged the machine vendors to eliminate all machine-dependent errors.

After one year the total uptime for the equipment was increased to a level above 98% and the productive time to more than 92%. In total, the area manager gained more than 9% productive time on his equipment, thereby significantly increasing throughput and wafer output. This example illustrates that continuous observation using an MES is the key to maintaining and improving production performance.

Material tracking

Since the beginning of the PV industry, a crucial requirement for users has been material tracking. The main reason for this is related to PV producers with less experience in production who are establishing very new production processes. In addition, the raw material price of solar wafers makes any misprocessing very cost-intensive. In recent years the profit from the production of solar modules has fallen dramatically. Any loss of material, or even of quality, lowers the resulting profit of the production line. Keeping both aspects under control is the key factor in surviving the present price war.

All data related to the material are monitored by the MES automation system during every step of the production process. The path taken by each material item is predicted by building software models for the machines and processes in the MES automation system. All collected data are connected to the material ID.

The result is data sets ready for correlation analysis using the MES automation database. The number of records in the database is currently in the billions, demanding high-performance database systems. However, even in a modern

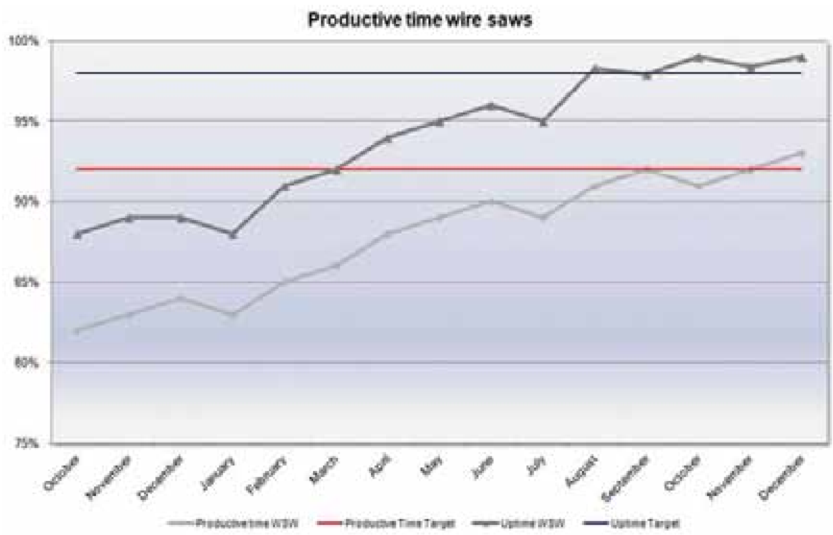

Figure 10. Improvement of productive time for Meyer Burger wire saws with automation.

Figure 11. Material tracking in combination with the MES improves cell efficiency.

mass-production factory, the material is still individually tracked. Accordingly, for each of the hundreds of thousands of wafers or cells produced every day in such a factory, the entire history and all of the process data are stored with the real or virtual material ID. This database is the foundation for analyzing production, optimizing the processes and providing enough input for data mining to pave the way for improved processes and control loops in production.

Summary

Integrated automation in manufacturing allows quality to be increased and cycle time to be reduced. The entire manufacturing system – including the ERP, MES, PPS, equipment and process data analysis tools – must be seamlessly integrated.

Advanced methods for data analysis, such as feed-forward or feedback loops with APC, improve process control, and, in conjunction with VM, the scope of the metrology tools (and their costs) can be kept under control. ROI can be achieved by improving the process control as well as the tracking and planning capabilities provided by the MES environment.

All of these solutions should be able to grow to keep pace with a particular manufacturing process. This is only possible, however, through the use of a modular MES based on a modern, extendable software architecture.

References

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[2] Kaften, C. 2012, "A guide to Industrial Revolution 4.0", *PV Magazine* (November).

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Jochen Kinauer is Director of Sales and Business Development at AIS Automation Dresden GmbH, a company within the Meyer Burger Group with headquarters in Dresden, Germany, and operations around the globe. AIS Automation specializes in equipment automation as well as MES installation, and has completed more than 70 MES installations and automation projects worldwide. Jochen previously worked as a project manager for several hardware and software automation projects in the PV and semiconductor industries. He is leader of the Silicon Saxony 450mm and RFID Cluster and holds a degree in electrical engineering, controls and automation from the Technical University of Munich.