Enabling big data to increase output at NXP semiconductor operations

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Concise summary of this Operations Practice

Semiconductors are today part of almost all aspects of life. The back-end stage of the manufacturing process – encapsulating the chip into a plastic package, testing and packaging – is the most labour-intensive, and production efficiency has become one of the key focus areas of the company. NXP uses integrated productions lines for the assembly of discrete semiconductors. To monitor the status of its production lines, NXP developed an environment that collects state information of the machines producing chips. To continuously improve the throughput of the production lines in the NXP plant, problems need to be detected, analyzed and solved. This is where the Technical University of Eindhoven was called to assist NXP, in transforming big data into information, and to use that information to yield tangible results.

The designer from the Technical University of Eindhoven created Heads Up – a decision support tool to display data to users, using different perspectives and aggregation levels. The software does more than displaying information: Heads Up is able to perform simulations of the production equipment, based on a fluid flow model. This enables the user to analyze which machine errors contribute most to the line downtime – which is the crucial information needed to improve performance. The main reason for implementing the fluid flow model and simulation into the tool is to be able to do "what-if" analyses. Questions can be asked such as: "What is the output gain if a certain error type is solved?". In doing such simulations, it can be made clear where elimination of errors will bring the most gain.

The Heads Up software is in use by NXP and has enabled the company to increase productivity of the plant by several percent. This is a very significant result in terms of business value, brought about by the cooperation between NXP and the Technical University Eindhoven.

Key Terms

Big data, semiconductor manufacturing, operational efficiency.

Relevant for

Managers of companies with large amounts of operational data that can potentially be used to improve performance.
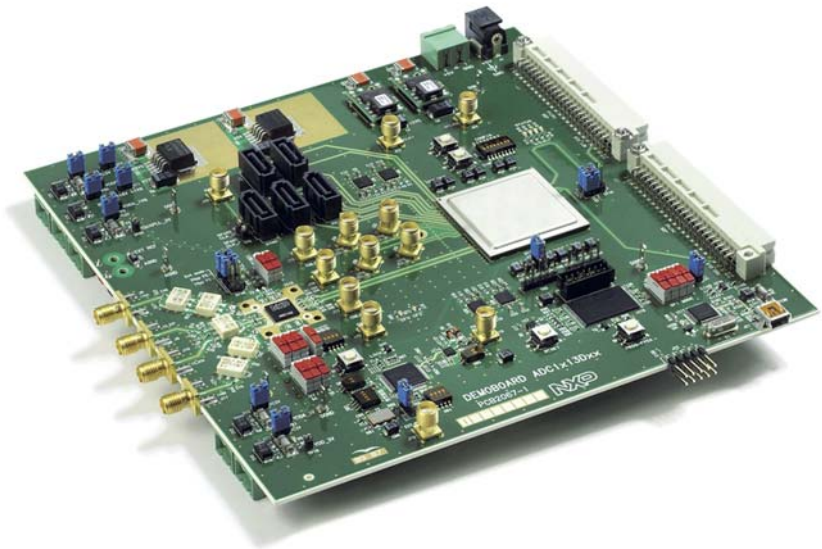
High tech production

Semiconductors are today part of almost all aspects of life. These small products are used in an ever growing number of devices, from smartphones to coffee machines, from self-driving cars to space rockets. One of the companies producing semiconductor products is NXP semiconductors, which specializes in the development and fabrication of High Performance Mixed Signal and Standard Product solutions. Their products are used in a wide range of areas, such as wireless infra, lighting, industrial applications, mobile technology, automotive, identification, consumer electronics and computing. NXP is a global semiconductor company that operates in over 25 countries and has over 3,300 employees in research and development. Some of NXP's products are depicted in Figure 1.

figure 1

A selection of NXP's products

A semiconductor chip is a tiny device, which contains a large number of components that process information. The manufacturing of these chips is a complex process that goes through a number of stages, with the front-end stage producing the silicon wafers and the back-end stage being responsible for cutting the chip out of the wafer, encapsulating the chip into a plastic package, testing the chip and preparing the chip for shipping.

The back-end stage of the manufacturing process is the most labour-intensive and is often performed in countries such as China and Malaysia, where labour costs are lower than in the United States, Japan, and Europe. Nevertheless, labour costs in China have been rising with more than 20 percent per year in the recent years. In addition to this, companies like NXP have to deal with fierce competition in the semiconductor industry. Therefore, production efficiency has become one of the key focus areas of the company. The aim of NXP's plants is therefore to maximize throughput of its production equipment with a constant quality level.

The NXP chip assembly factory

The developments in the semiconductor market urged NXP to seek an answer to basic but essential questions regarding its manufacturing process: what is the current status of production, where do problems occur, which problems are these, what can we do to solve them, and which problems should we solve first and what can we gain if we solve those problems? Because the NXP backend factories are highly complex, the answers to these questions are not easy to find.

NXP uses integrated productions lines for the assembly of discrete semiconductor products. At the plant in China where this best practice was implemented, 32 production lines are active, each containing nine machines. More than 100 million transistors and diodes per day are produced on these lines. A production line consists of the following machines:

• 4 die-bonders called ADAT machines
• 4 wire bounders called Phicom machines
• 1 Multi Plunger (MP) machine

These nine machines are separated by 8 finite buffers which can buffer a few minutes of production. The machines and buffers are connected via a production tape, which is like a small conveyor belt with 4 tracks, holding the products.

AWACS data gathering

To monitor the status of its production lines, the NXP Industrial Technology and Engineering Center (ITEC) developed an Advanced Warning And data Collection System environment (AWACS) that collects state information of the machines producing chips. It collects timestamped state events of the equipment that can have the following values: Production, Down or Standby. The possible states and sub-states are indicated in Figure 2.
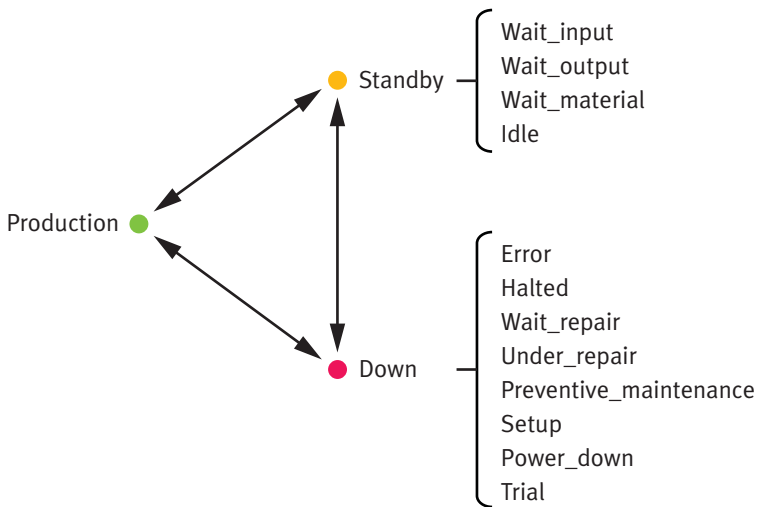
figure 2

Possible states and sub-states

The state Production means that the machine is up and running. The standby state indicates that the machine could technically be running but there is an issue with the material flow. The Down state indicates a technical issue with the machine, or that the machine is down for maintenance or a trial. Below the sub-states in Figure 2 there are hundreds of more detailed codes. Using the timestamps that are also provided by AWACS, a chronological series of up- and downtimes per piece of equipment can be put together.

Big Data volumes

To continuously improve the throughput of the production lines in the NXP plant, problems need to be detected, analyzed and solved. As indicated above, NXP has already been using equipment status monitoring tools for decades. Such monitoring tools should enable NXP to find answers to the question where improvement efforts should focus to get the highest productivity improvements. However, there is an enormous challenge that must be overcome, as the amount of monitoring data captured every day equals to about 26 Gigabytes. Manually scanning and filtering this data is a massive task for any reasonable pool of business analysts.

Furthermore, the machine data cannot be analyzed in an isolated manner, as machines are connected with each other via a tape and buffers. It is therefore not trivial to predict what happens to the whole line output if a specific error is solved on an individual machine. This is inherent to the complexity of semiconductor production. Hence, the scale of operations in the factory, and the structure of its production equipment, makes it hard for NXP to pinpoint the most urgent problems that lead to the most downtime.

The problems that NXP is facing in analyzing its data are typical for situations where big amounts of data are available. Although large promises have been worded on using data to make better decisions, combining a large amount of data with computing power does by itself not yield usable results. Instead, a model should guide the analysis of data and the simulation of possible scenario's. This is where the Technical University of Eindhoven was called to assist NXP, in transforming big data into information, and to use that information to yield tangible results.

Heads up

As the analysis of data starts with an effective visualization of the data to users, the designer from the Technical University of Eindhoven created a decision support tool to display the data to users, using different perspectives and aggregation levels. The software system developed was called Heads Up: it aims to visualize the state data of the machines, and in addition to that, simulate possible outcomes.

Visualization of state information is based on the idea that different users in the factory want to look at the data in different ways. The challenge for the designer was to aggregate and filter the data such that this was achieved. Furthermore, the user should be able to customize the way the user sees the data. The functional structure of the Heads Up tool is depicted in Figure 3.
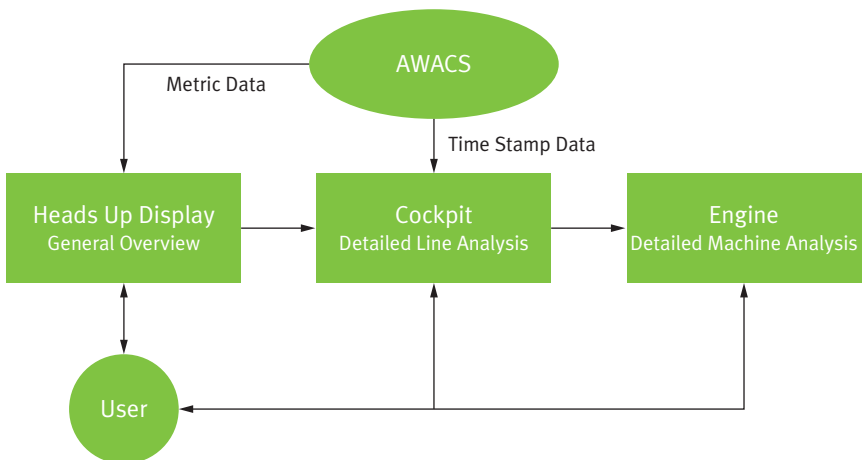

figure 3

Structure of Heads Up

The three elements displayed in Figure 3 represent the different levels of information in Heads Up: the general production level, the line level and the machine level, respectively. Users can easily drill down from a higher level to a

lower level using the Graphical User Interface (GUI). To illustrate this principle,
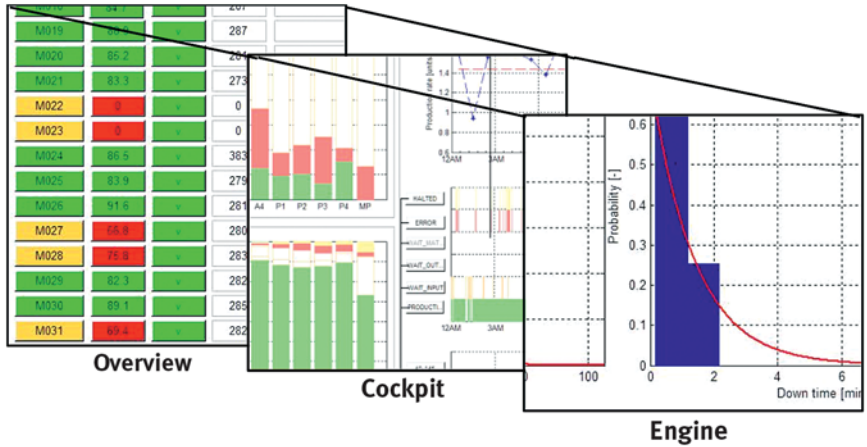Figure 4 shows the three views of Heads Up.

figure 4

Heads Up displays

The main objective of the general **overview** is to give a quick answer to the
question: how is the production doing, where should we potentially focus our
attention? The overview shows production lines with main indicators, and when a
production line is not running well – i.e. it has a high number of errors or
downtime – the indicator of the line turns red. The user can easily select the
problematic line and go to the **cockpit** view for that line. This view contains state
charts, Gantt charts and trend graphs, to provide insight in the recent history of
the line where the user is zooming in. The **engine** view displays equipment specific
information that is used by maintenance engineers and technicians.

Fluid flow simulation

Heads Up is a powerful visualization tool that already helps NXP to quickly analyze its equipment, yet the software does more than displaying information. Heads Up is able to perform simulations of the production equipment, based on a fluid flow model. This enables the user to analyze which machine errors contribute most to the line downtime – which is the crucial information needed to improve performance. In other words, it answers the question: when we solve this error, how much uptime for the whole line do we gain? Answering this question is essential for efficient error resolution, as there are too many errors to solve them all – prioritizing errors is essential.

The characteristics of high volume semiconductor production lends itself to be modelled in a fluid flow model, because a large number of products is assembled on high-speed flow lines in a roll-to-roll process. Although strictly speaking this is a discrete process, the large volume allows this process to be viewed as a continuous flow. The limited buffer capacity that exists between the machines is also typical for fluid flow systems. Hence, the fluid flow modelling assumption is feasible in this environment: the products literally flow through the equipment. The individual product granularity is not required for throughput calculations.

The advantage of a fluid flow simulator lies in its proven simulation efficiency: running "what-if"-scenarios takes far less time than in discrete product simulations. At the same time, the simulation model carefully describes the interactions between the machines in the flow line, and the effect on overall line performance of system characteristics such as buffer capacities, machine production rates, and mean and variability in machine up and down times. Therefore, the simulator provides a powerful tool to support decision making in flow line configuration.

Validation

To validate the fluid flow model, the simulation results have been compared to historical data. The focus of the validation process has been on how accurate the model was able to predict the throughput of the production equipment. The validation has been carried out by a series of simulation experiments – comparing the simulated output with the actual output, while varying the number of shifts for different data gathering periods. The results show that the simulation model accurately predicts the output, especially for data periods with more than one shift. This is due to the fact that the throughput is "more random" over short periods, and there are only few up and down time realizations available for fitting phase-type distributions. For longer data periods, it is seen that on average the simulated predictions are quite accurate – typically the deviation is not more than 5%. There are situations though where the model might be less applicable, such as when atypical, long power-down states occur.

Validations of models similar to the one described here have been made in other environments as well, such as packaging lines at Heineken. Such lines also process a large number of discrete products and have to deal with finite intermediate buffers to absorb disruptions.

Improving output

The main reason for implementing the fluid flow model and simulation into the tool is to be able to do "what-if" analyses. Questions can be asked such as: "What is the output gain if a certain error type is solved?". To answer this question, the chronological list of up and down times is modified by assuming that it is possible to solve all errors of this specific type. A new timeline can thus be created with the projected uptime under the assumed elimination of the error type. The throughput gain is now calculated by comparing the simulated throughput based on the *modified* up and down times to the simulation throughput based on the *original* up and down times. In doing such simulations, it can be made clear where elimination of errors will bring the most gain. The table below shows a possible analysis.

Date	17-04-13		19-04-13		28-04-13	
Machine	Error type	Gain [%]	Error type	Gain [%]	Error type	Gain [%]
1	28-702	0.11	40-702	0.02	28-552	0.00
2	30-709	0.18	40-702	0.06	30-703	0.00
3	30-34	0.07	40-703	0.05	30-703	0.14
4	28-702	0.22	40-703	0.04	30-703	0.00
5	40-144	0.14	40-145	0.04	40-351	0.00
6	40-145	0.05	40-356	0.61	40-135	**1.91**
7	40-359	0.04	40-135	**1.10**	40-144	**1.93**
8	40-139	**1.74**	40-356	0.88	40-144	0.00
9	20-165	0.06	20-177	0.16	20-177	0.00

table 1

Analysis of productivity gains

One could also look at the effect of removing multiple error types on multiple machines.

Future applications

The next step in the development of the Heads Up tool is to allow users to create "mini-companies", i.e., the ability to create user specialized views which focus on a small section of the factory or on a single product type. By doing so, each factory employer can create a view in which all relevant information with respect to their responsibilities is shown.

The Heads Up software has been primarily designed as decision support system. However, in the future, it may be extended with data mining algorithms for job shop scheduling, quality control, fault diagnostics and condition based maintenance. Furthermore, for more general data mining applications, there are possibilities for:

- product traceability enhancement by integration of batch assembly data with shop floor control systems
- searching for correlations between product deficiencies and machines errors by integration of batch test data and assembly data
- enhancement of the SAP Production Maintenance module by adding root-cause information to errors.

The Heads Up software is in use by NXP and has enabled the company to increase productivity of the plant by several percent. This is a very significant result in terms of business value, brought about by the cooperation between NXP and the Technical University Eindhoven.

Conclusion

The Heads Up software is a data mining tool with an integrated fluid flow simulation model to do "What-if" analysis. The fluid flow simulation model can accurately simulate the production line behaviour of NXP assembly lines. The combination of 'big data'-mining and increased intelligence by use of simulation has proven to be an effective and valuable tool within daily manufacturing operations. It enables the factory maintenance crew to better focus their attention and set task priorities. Preliminary results show that the NXP assembly plant in GuangDong China has gained several percent in Overall Equipment Efficiency (OEE) thanks to the implementation of the software.
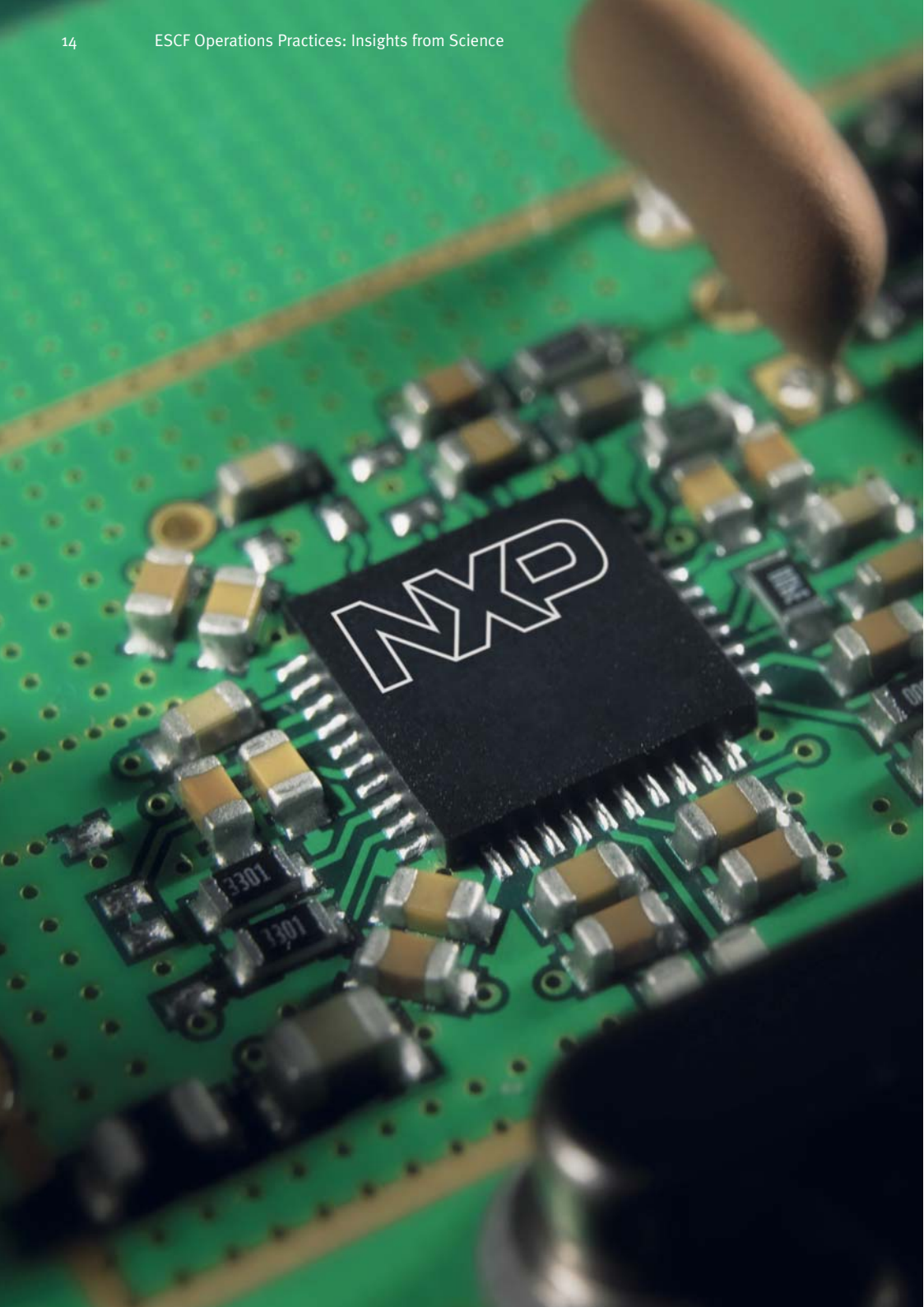
Reference

- Wilschut, T., Adan, I. J. B. F., & Stokkermans, J. (2014). Big data in daily manufacturing operations. In *2014 Winter Simulation Conference (WSC'14,Savannah GA, USA, December 7-10, 2014). (pp. 2364-2375)*. Institute of Electrical and Electronics Engineers Inc.. DOI: 10.1109/WSC.2014.7020080

The scientific paper about this project that was presented at the 10th International Conference on Modeling and Analysis of Semiconductor Manufacturing 2014 was granted the Best Paper Award.

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