Predictive discarding for sustainable Industry 5.0

The computer chip shortage has prompted Dr Geert van Kollenburg and his colleagues at Eindhoven University of Technology, the Netherlands, to find data-driven methods to optimise chip manufacturing processes. As part of the MadeIn4 project, they have developed a predictive discarding framework in which quality predictions from artificial intelligence (AI) algorithms are used to decide on whether to discard an unfinished product. This approach can improve both the profitability and sustainability of manufacturing processes. In line with Industry 5.0 goals, predictive discarding offers a way for humans and AI to work together to achieve sustainable manufacturing.

Our digital society relies on computer chips, but these chips are currently in short supply. As this is due to a combination of global events, the scarcity will remain for the foreseeable future. If the supply of chips is to meet the demand, chip manufacturing processes will have to be optimised in new ways.

PREDICTIVE DISCARDING

Nearly all manufacturing processes employ sensors that produce huge amounts of data relating to incomplete products and the conditions that are present during the production process. The use of artificial intelligence (AI) and machine-learning approaches can support this data-driven, high-volume manufacturing. Taking advantage of this, Dr Geert van Kollenburg and his colleagues at Eindhoven University of Technology in the Netherlands have developed 'predictive discarding'.

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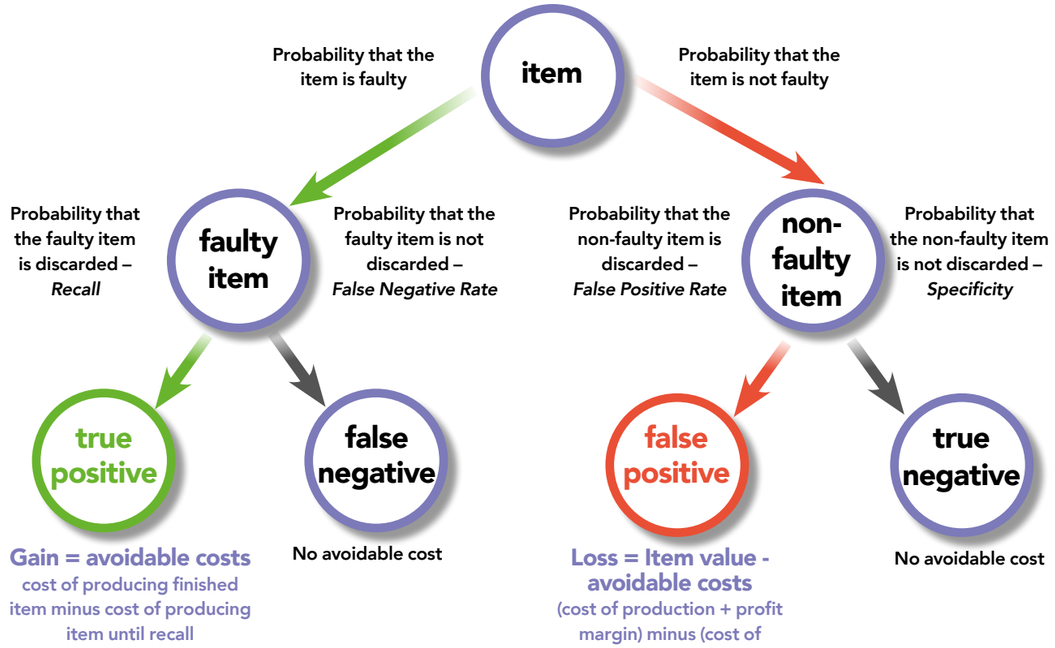
Predictive discarding combines industrial statistics and prescriptive analytics in a methodology that can be used continuously throughout the manufacturing process to predict whether a product will meet the required quality standard. If the model indicates that this quality standard is not going to be met, the unfinished product can be discarded without completing the manufacturing process. This significantly reduces the waste of resources, such as energy, time, and raw materials, which would otherwise be used to complete the faulty product. This simultaneously increases the throughput of factories and contributes to reducing environmental footprints.

COMPUTER CHIP SHORTAGE

Computer chips are manufactured in batches on thin wafers of semiconductor material. It takes three months to complete the hundreds of steps that make up the process. If too many faulty chips are detected on a wafer, all chips on that wafer are discarded. Manufacturers are, therefore, on the lookout for new ways to optimise their chip manufacturing processes. These production processes include systems that control production planning and monitor quality. They also collect data in real time. This makes predictive discarding an excellent fit for the industrial optimisation of computer chip production. In their papers, Van Kollenburg and his collaborators explain how, in addition to reducing the time required to produce a certain amount of good-quality chips, predictive discarding can contribute to the overall reduction of the carbon footprint generated by wafer manufacturing.



Schematic representation of the possible scenarios for predictive discarding, with the respective gains and losses provided under each outcome.

Photo Credit: Modified from Figure 1, van Kollenburg et al (2022), 10.1080/09537287.2022.2103471

MISALIGNMENTS AND END-PRODUCT QUALITY

The accurate alignment of each layer within a wafer is critical and closely monitored throughout the manufacturing process. The research team trained classification models to use misalignment measurement data collected from just one layer of a wafer to predict the result of an electrical test that is used at the end of the process to determine the quality of the completed wafer. They discovered previously unknown relationships between misalignments and the quality of the end products that can inform the decision of whether to continue manufacturing a wafer or discard it. Moreover, they demonstrated how predictive discarding could use these relations to reduce resource consumption that would otherwise be wasted completing faulty wafers.

PREDICTIONS ARE NOT PERFECT

Predictions are not always perfect, so it is possible that even when predictive discarding is used, false positives occur, and some good-quality products will be discarded. Likewise, false negatives can occur, and some poor-quality products make it through to the end of the production process. In both cases, resources are wasted. This led the researchers to investigate when predictive discarding can benefit manufacturers and to identify which conditions are required for its successful adoption.

The sooner a faulty product can be recalled and discarded from the manufacturing process, the greater the resource savings. In economics, the costs of resources already used are referred to as 'sunk costs'. These should not affect the decision-making process. The costs of the resources needed to complete a product are referred to as 'avoidable costs', and these can be saved if the correct decision is made.

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WHEN IS PREDICTIVE DISCARDING BENEFICIAL?

The researchers use a combination of avoidable costs, numbers of correct and incorrect decisions, and profit margins to calculate the benefits of predictive discarding. Two sensitivity analyses were performed to identify the conditions under which predictive discarding is beneficial. The first examines the relationship between the proportion of correct discards (recalls) and false discards (false positive rates) based on machine learning predictions. The second analysis studied the relationship between the false positives and profit margins. This revealed that even when recalling 50% of all products, predictive discarding could reduce the total resource consumption by 9% if the decision to discard is made early on in the manufacturing process.

PRACTICAL APPLICATION

The team demonstrates the benefits of predictive discarding using the publicly

Predictive discarding is an asset for manufacturing and production control.

available SECOM data set. This data set is made up of 591 process variables that were captured throughout the production of 1,567 wafers, with 104 (approximately 7%) of the wafers failing the final quality test.

A simulation study was carried out on the SECOM data set. Usually, classification models with recall of 10% are considered insufficient. The researchers observed, however, that correctly identifying any faulty products could lead to substantial benefits if avoidable costs are high. They validated the results using a Monte Carlo procedure that replicated the empirical analysis 100 times, with each repetition using a different training/testing split of the data set to ensure that the results were not mere chance findings.

IMPROVING SUSTAINABILITY

The research team showed that merging data analytics with resource awareness through predictive discarding can reduce the total amount of resources, including time, required to produce computer chips. Of course, many critical faults in manufacturing processes are already known by the manufacturer and the people responsible for process and quality control. The use of AI in quality predictions can help the decision-making process in discarding faulty unfinished products by finding previously unknown combinations of factors that affect the quality. The research revealed that even if AI can find weak relations between process measurements and end-product quality, the overall sustainability of a manufacturing process improves if the decisions are made early enough in the process. Implementing predictive discarding can thus improve the availability of chips in a resource-friendly way, as fewer resources are used to complete faulty chips.

Investment of manufacturers in resource-aware data-driven methods can improve both the profitability and the sustainability of manufacturing processes.

TRANSITIONING TO INDUSTRY 5.0

Complementing the human contribution to manufacturing processes with AI is a fundamental step in the evolution to Industry 5.0. This research shows that including resource consumption in data-driven techniques can optimise the decision-making process. The researchers believe that investment of manufacturers in resource-aware data-driven methods can improve both the profitability and the sustainability of manufacturing processes.

Van Kollenburg and his collaborators present predictive discarding as an asset for manufacturing and production control. Implementing predictive discarding requires only limited resources and its benefits can be explored with data that are already available from standard process measurements. They conclude that 'predictive discarding may therefore become standard practice in Industry 5.0, where AI and humans work together to achieve sustainable production.'

Behind the Research

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Research Objectives

Dr Geert van Kollenburg and colleagues developed the predictive discarding framework.

Detail

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Bio

Dr Geert van Kollenburg is a researcher at Eindhoven University of Technology and is an Industry 5.0 ambassador. He focuses on data-driven approaches to improve industrial sustainability. His work includes research on process analytics, structural equation modelling, chemometrics, handheld spectroscopy, and water pollution.

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Personal Response

What plans do you have for the future development of the predictive discarding framework?

"We are working to develop resource-aware machine learning algorithms that continuously adapt to changes in the environment and in the market. You can imagine that profitability depends on fluctuating market prices. In periods with a surplus of green energy, manufacturers may want to increase production capacity to ensure sustainable production. If a prediction model can incorporate all this information in real time, this can help the decision-making process enormously. The main goal is to ensure that manufacturing necessary goods is done as sustainably as possible."