# Unlocking Zero-Defect Manufacturing with Genomics of Industrial Processes(TM)

How to optimise complex industrial processes, improve production quality and reduce waste

WHITEPAPER

# Contents

# Executive Summary

The Genomics of Industrial Processes(TM) is an innovative approach that aims to revolutionise quality control and defect prevention in industrial processes, offering a pathway to true zero-defect production. By treating events in the manufacturing process as discrete data quanta – akin to genes in biological systems – Genomics of Industrial Processes (GIP) identifies and sequences these events into "process genes." These sequences can then be analysed to predict and prevent defects before they occur, shifting manufacturers from reactive post-production inspections to proactive, real-time intervention.

One of the central advantages of the Genomics of Industrial Processes is its ability to use machine learning (ML) and artificial intelligence (AI) to manage and analyse vast datasets generated throughout production. These event-driven AI systems continuously monitor factors such as temperature, pressure, and material flow, allowing manufacturers to intervene and make adjustments before defects are introduced into the product. This real-time predictive capability is key to the effectiveness of GIP, and it goes beyond traditional machine learning techniques by offering data-efficient learning, faster model training, and greater focus on causal relationships rather than merely detecting correlations.

This whitepaper looks at the application of Genomics of Industrial Processes to a variety of industries, from semiconductor production to wastewater treatment, and the significant business benefits that it can unlock. These can include, but are not limited to, improved product quality, reduced waste, cost savings and increased efficiency.

The whitepaper then examines the potential challenges associated with the implementation of GIP such as data availability, system complexity and the integration of new technologies with legacy manufacturing equipment. Solutions explored include upgrading data acquisition systems, employing dimensionality reduction techniques and how to gradually introduce GIP as a modular system.

This whitepaper is essential reading for business and operations leaders looking for new advanced event-driven AI approaches to not only prevent defects in their production processes, but also unlock predictive maintenance, supply chain optimisation and sustainability efforts. By enabling manufacturers to reduce waste, increase efficiency, and lower costs, GIP represents a major advancement in industrial production methods.

# What is Genomics of Industrial Processes?

Genomics of Industrial Processes (GIP) is an innovative methodology that identifies and tracks events during complex processes by treating them as data, similar to how genes are treated in biological systems. Each event signifies a discrete system state change, and a series of these events form a chain analogous to a genetic sequence. Just as biological genes can predict traits or diseases, these 'process genes' can predict defects in processes typical of manufacturing or water & wastewater treatment.

The core idea behind the Genomics of Industrial Processes is that by understanding and mapping these event sequences, organisations can predict and prevent defects before they occur. This proactive approach stands in stark contrast to traditional reactive quality control, which often relies on post-production inspections and adjustments.

| | |
|---|---|
| **Event Tracking and Clustering**<br><br>Events during the industrial process are tracked and clustered into contiguous sequences, forming process genes. Each contains critical data about the system's input and output parameters at specific times, much like how a DNA sequence contains genetic information. | **Causal Links and Pathways**<br><br>These sequences of events form causal links between the system's state changes and the end product's quality. This information can be used to identify patterns that lead to defects, allowing manufacturers to intervene and adjust parameters in real time. |
| **Predictive Defect Identification**<br><br>By aligning process genes, manufacturers can predict defects before they occur. If a sequence of events is identified as a potential cause of a defect, the process can be adjusted to prevent that outcome, effectively disrupting the sequence of events leading to defective products. | **Markovian Process Chains**<br><br>The industrial process gene sequences follow a Markovian chain, meaning that the state of the system at any given time is dependent only on its previous state. This makes the system's behaviour both predictable and manageable. |

Figure 1: Key Principles of Genomics of Industrial Processes

## How is this different to traditional quality control methods?

Traditional quality control methods often rely on post-process inspections and statistical process control techniques. While these methods can identify defects, they do so only after the products have already been made, leading to wasted materials and resources. This reactive approach of making adjustments after defects are detected contrasts with preventing them proactively.

The Genomics of Industrial Processes focuses on real-time defect prevention. By continuously monitoring the system's events and parameters, the framework can detect potential defects before they occur. This proactive approach allows organisations across industrial sectors to intervene during their production processes, making adjustments that prevent defective products from being created in the first place. This shift from reactive to proactive quality control is a key factor in the success of zero-defect manufacturing.

## The role of AI and ML in Genomics of Industrial Processes

A critical component of GIP is the use of machine learning (ML) and artificial intelligence (AI) algorithms to analyse the vast amounts of data generated during the manufacturing process. By training these algorithms on historical data, the system can learn to recognise patterns and predict defects based on previously observed sequences of events.

For example, AI/ML models can use data generated by industrial imaging and photonics throughout the manufacturing process to predict the likelihood of defects based on factors such as temperature, pressure, humidity and contamination levels.

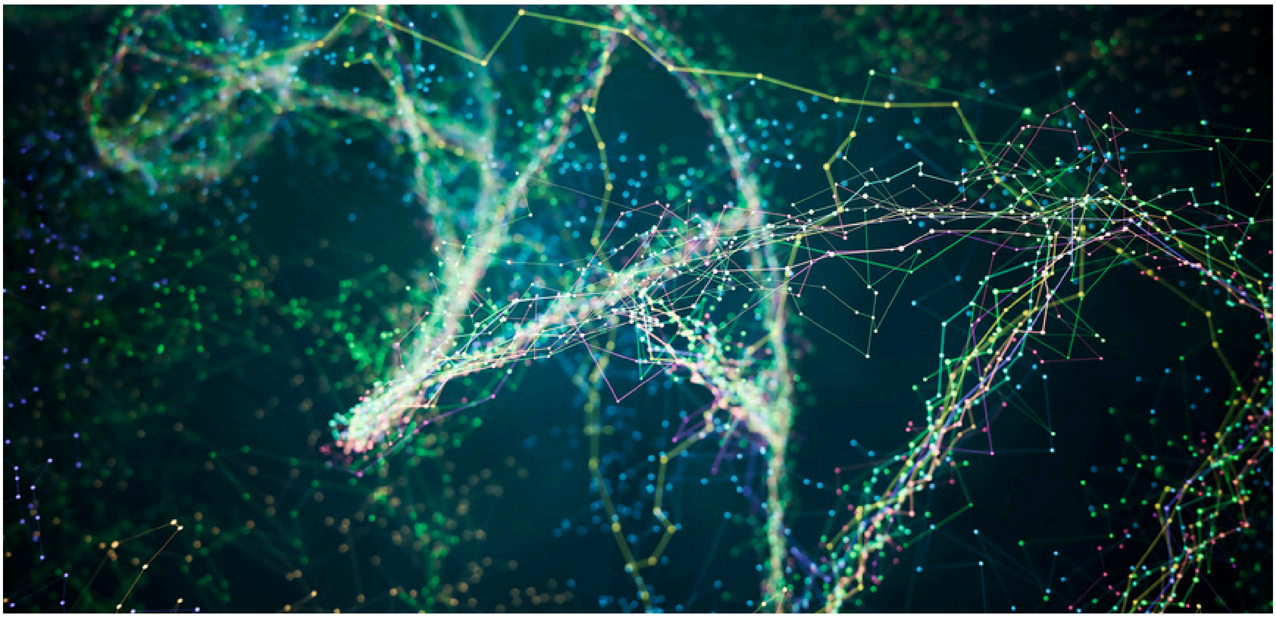
By analysing the relationships between these factors and the resulting product quality, the AI/ML models can use GIP to identify sequences of events likely to lead to defects. These predictive capabilities are essential for the successful implementation of event-driven AI use cases as they allow manufacturers to take corrective actions in real-time.

# GIP versus classical ML techniques

While traditional machine learning techniques such as random forest regression, k-nearest neighbours (kNN) and multilayer perceptron (MLP) networks have been widely used in industrial applications, they have limitations when it comes to real-time defect prediction. These methods often require large amounts of labelled data to train models effectively, which can be challenging in manufacturing environments where defects are potentially costly but rare.

Genomics of Industrial Processes offers several advantages over these classical ML-based techniques:

1. **Data-Efficient Learning**: Unlike traditional methods, which require large datasets, GIP can work with smaller datasets by focusing on event sequences and their causal relationships. This allows for more efficient learning and faster model training.
2. **Real-Time Decision Making**: Classical machine learning models typically require offline training, meaning they must be retrained periodically as new data becomes available. In contrast, Genomics of Industrial Processes operates in real-time, continuously updating its models based on new data and making immediate adjustments to prevent defects.
3. **Dimensionality Reduction**: The GIP framework incorporates dimensionality reduction techniques, such as rank-order clustering, to simplify the input data and focus on the most relevant factors. This reduces the computational complexity of the system and allows it to make faster, more accurate predictions.
4. **Causal Understanding**: Traditional machine learning models often struggle to provide insights into the underlying causes of defects. GIP, by contrast, is explicitly designed to identify the causal links between events, allowing manufacturers to understand why defects occur and take targeted actions to address the root causes.



# Use Cases: Applications of GIP in Industry

From optical wafer inspection in the semiconductor industry to effluent treatment processes in the wastewater industry, Genomic AI enables organisations to detect and predict defects, providing detailed analysis and classification of defects, and ultimately to take prompt corrective actions – increasing productivity, improving quality and reducing waste.

## The business benefits of advanced AI-driven industrial process

The most immediate benefit of GIP is the reduction in defective products. By predicting and preventing defects in real-time, manufacturers can reduce waste and improve overall product quality. This not only reduces the cost of scrapped products but also enhances the company's reputation for producing high-quality goods.

The Genomics of Industrial Processes framework allows for real-time adjustments during the manufacturing process, which leads to greater efficiency. Instead of waiting for post-production quality checks to identify defects, the advanced AI system continuously monitors and adjusts parameters to ensure optimal performance. This reduces downtime and increases the overall speed of production.

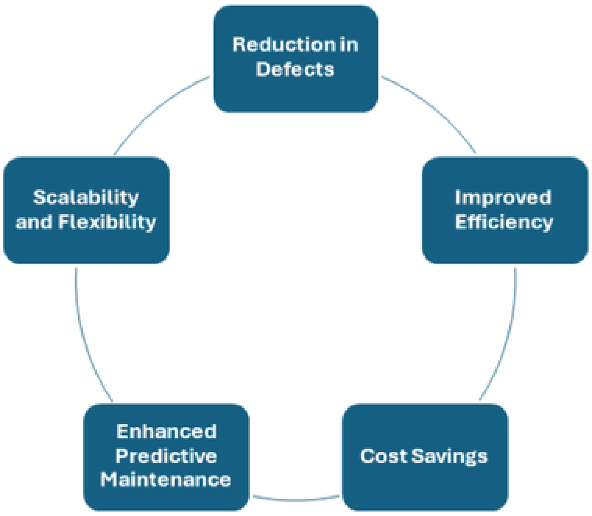



Figure 2: The business benefits of GIP

In turn, fewer defective products and a more efficient production process result in significant cost savings. These savings come not only from reducing waste but also from minimising the need for manual quality control interventions. In addition, process genomics can help manufacturers avoid costly recalls by ensuring that products meet quality standards before they leave the factory.

The GIP approach can therefore also be applied to predictive maintenance, allowing manufacturers to identify potential equipment failures before they occur. By monitoring the system's events in real-time, GIP-driven solutions can predict when a machine is likely to fail, allowing for timely maintenance that prevents costly breakdowns.

GIP is highly scalable and can be applied to a wide range of manufacturing environments. Whether in semiconductor production or larger-scale manufacturing operations, Genomics of Industrial Processes provides a flexible and adaptable solution for quality control and defect prevention.

The Genomics of Industrial Processes approach can therefore also be applied to predictive maintenance, allowing manufacturers to identify potential equipment failures before they occur. By monitoring the system's events in real-time, GIP solutions can predict when a machine is likely to fail, allowing for timely maintenance that prevents costly breakdowns.

The GIP framework is highly scalable and can be applied to a wide range of manufacturing environments. Whether in semiconductor production or larger-scale manufacturing operations, Genomic of Industrial Processes provides a flexible and adaptable solution for quality control and defect prevention.

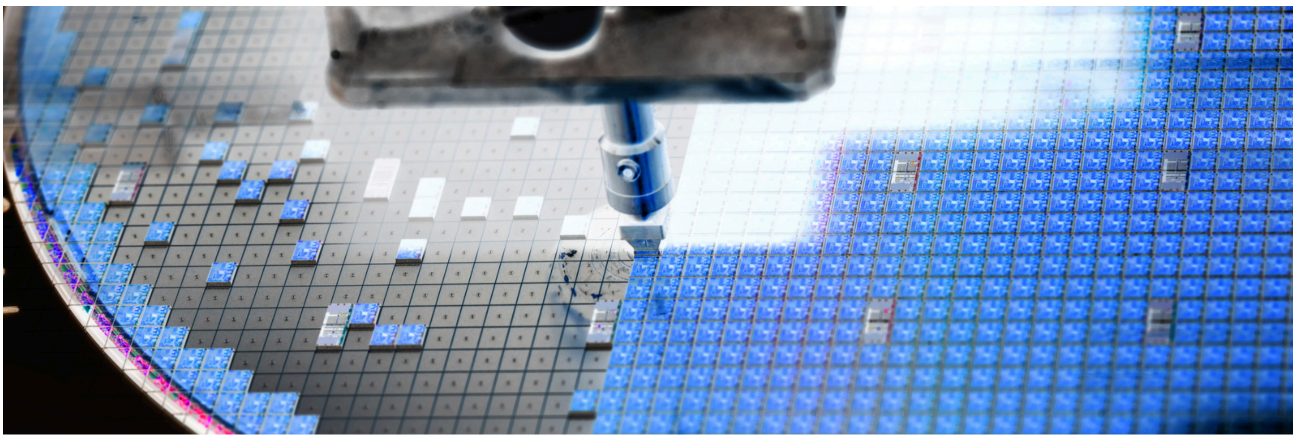
## Case Study: GIP in the semiconductor industry

Z Prime has successfully demonstrated the application and benefits of process genomics in a case study involving quality control in the semiconductor manufacturing industry. Z Prime's GIP-driven solutions allowed the manufacturer to map the precise events that lead to defects in the product.

Specifically, the system monitored glue droplet formation during the production process and predicted whether a droplet would meet production specifications. By monitoring the system's events and parameters in real-time, the system was able to predict and prevent defects that could lead to product failure.

The event-driven AI system achieved a zero-defect rate in the production of glue droplets. This not only improved the overall quality of the products but also reduced waste and lowered production costs. The success of this case study demonstrates the potential of process genomics to revolutionise quality control in manufacturing.

The result was a significant reduction in defective products and an overall improvement in process efficiency. The ability to detect and correct defects in real time allowed for more precise control over the production process, leading to fewer discarded products and lower production costs.



# How to implement GIP into industrial processes

To successfully implement GIP, organisations must undertake a series of essential steps. The first involves data acquisition and monitoring, where real-time systems are established to track key events and parameters throughout the manufacturing process. This requires the installation of sensors to measure important inputs such as temperature, pressure and material flow.

Once the necessary data is collected, the next phase is event clustering and sequence mapping. At this stage, the event-driven AI system analyses and groups related events, sequencing them into the process genes. This step involves examining the relationships between various events and mapping the sequences that either lead to successful production outcomes or result in defective products.

With the identification of process genes complete, manufacturers can then apply predictive analytics. Here, machine learning algorithms are utilised to analyse historical data, identifying patterns that may lead to defects. These analytics enable manufacturers to forecast the likely outcomes of the production process, improving their ability to pre-empt issues.

When a potentially defective sequence is detected, the system can intervene by making real-time adjustments to the process. These adjustments may include altering machine parameters, modifying material inputs, or changing aspects of the production environment to prevent defects from occurring.

Finally, GIP is designed to be an ongoing, continuously improving system. As more data is gathered, the system becomes increasingly adept at predicting defects and making the necessary adjustments in real-time. Over time, this leads to greater efficiency and reliability in the production process.


Figure 3: Implementation of GIP in Manufacturing

# How to address implementation challenges in complex environments

While the potential benefits of Genomics of Industrial Processes are significant, there are several challenges associated with its implementation in complex manufacturing environments. These challenges include data availability, the complexity of (and integration with) existing industrial systems and manufacturing processes, and access to expertise in data analytics within the workforce.

| | |
|---|---|
| **Challenge: Data Availability**<br>To effectively predict and prevent defects, GIP requires real-time access to accurate data on system inputs and outputs. In some manufacturing environments, the necessary sensors and data acquisition systems may not be in place, making it difficult to implement the GIP framework. | **Solution**<br>Manufacturers can overcome this challenge by investing in modern data acquisition technologies, such as optical sensors and real-time monitoring systems. By upgrading their infrastructure to support real-time data collection, manufacturers can ensure that they have the necessary data to implement Genomic AI solutions effectively. |
| **Challenge: Complexity of Industrial Systems**<br>Many manufacturing processes are highly complex, with numerous variables and interactions that can impact product quality. Capturing and analysing all of these factors in real time can be challenging. | **Solution**<br>GIP addresses this complexity by using dimensionality reduction techniques to focus on the most critical factors affecting product quality. Additionally, the use of machine learning algorithms allows the system to handle complex relationships between variables and make accurate predictions based on real-time data. |
| **Challenge: Integration with Existing Systems**<br>Implementing process genomics may require integrating the system with existing manufacturing equipment and control systems. This can be a complex process, particularly in older facilities that rely on legacy equipment. | **Solution**<br>To facilitate integration, process genomics can be implemented as a modular system that operates alongside existing equipment. Manufacturers can gradually introduce the framework into their operations, starting with specific processes or machines, and expand its use as needed. |
| **Challenge: Training and Expertise**<br>Successfully implementing process genomics requires a certain level of expertise in data analytics, machine learning, and industrial systems. Manufacturers may need to invest in training for their staff to ensure that they can effectively operate and maintain the system. | **Solution**<br>Manufacturers can address this challenge by partnering with experts in process genomics and data science. By working with consultants or technology providers, manufacturers can gain the necessary knowledge and support to implement the system and train their staff. |

# Future use cases for GIP

The potential applications of GIP extend far beyond quality control in manufacturing. As the technology continues to evolve, it could play a critical role in other areas of industrial operations and across sectors where complex processes can be co-optimised to address often competing challenges of efficiency and quality with sustainability and circularity.

1. **Predictive Maintenance**: By monitoring the sequences of events that lead to machine failures, GIP solutions can be used to predict when equipment is likely to break down. This allows manufacturers to perform maintenance before a failure occurs, reducing downtime and extending the life of their equipment.
2. **Supply Chain Optimisation**: GIP can also be applied to optimise supply chain operations. By analysing the sequences of events that lead to delays or disruptions in the supply chain, manufacturers could identify bottlenecks and inefficiencies and take corrective actions to improve the flow of materials and products.
3. **Sustainability**: As sustainability becomes an increasingly important priority for manufacturers, GIP can help reduce waste and energy consumption. By identifying the sequences of events that lead to inefficiencies in production, manufacturers can optimise their processes to minimise resource use and reduce their environmental impact.
4. **Digital Twins**: The concept of Genomics of Industrial Processes aligns closely with the emerging trend of digital twins, which are virtual representations of physical systems. By incorporating GIP into digital twin models, event-driven AI enables manufacturers to create highly accurate simulations of their production processes, test different scenarios and optimise performance in a virtual environment before making changes in the real world.

**Z Prime Genomic AI Platform™**
Z Prime provides an advanced AI system for manufacturing and process industries to embrace digital transformation and Industry 4.0 initiatives.

**The Z Prime Genomic AI Platform solution** is an advanced AI system that co-optimises industrial efficiency and quality in combination with sustainability and circularity in a single system to enable balanced decision-making for Operations and Investments.

The industry-agnostic Genomic AI platform collects multiple sources of data and uses advanced AI and ML to turn data into a real-time digital replica of an industrial organisation. This enables insights and advanced decision support systems including predictive simulation and co-optimising of operational and environmental objectives.

Using sophisticated analytics, Z Prime Insights™ software solutions leverage the data provided by the Z Prime Genomic AI Platform to provide deep insights and predictive simulations across multiple concurrent areas of an Enterprise including productivity, efficiency, quality, inventory and environmental impact.

Learn more about the Z Prime Genomic AI Platform here: https://zprime.ai/products/

# Conclusion

Genomics of Industrial Processes represents a sector-agnostic approach to quality control and defect prevention industries such as manufacturing and water & wastewater treatment. By treating events as data quanta and mapping them into process genes, organisations can predict and prevent defects in real-time, leading to a zero-defect production process.

The ability to monitor and adjust complex processes proactively using advanced AI solutions offers significant advantages over traditional quality control methods, including reduced waste, improved efficiency and cost savings.

As industries continue to adopt data-driven technologies, GIP will play an increasingly important role in optimising manufacturing operations. From predictive maintenance to supply chain optimisation, event-driven AI solutions will enable manufacturers to achieve higher levels of quality, efficiency and sustainability, positioning themselves for success in the competitive global market.

**Further Reading:**

*The Genomics of Industrial Process Through the Qualia of Markovian Behavior*
By Morad Danishvar; Alireza Mousavi; Sebelan Danishvar
Published: IEEE Transactions on Systems, Man, and Cybernetics: Systems (Volume 52, Issue 11)

https://ieeexplore.ieee.org/document/9717302

## Contact Us

For more information, please visit **zprime.ai**

**UNITED KINGDOM**

The Charter Building
Uxbridge, London
UB8 1JG
UK

**GERMANY**

Maximiliansplatz
17 80333, Munchen
Germany

**UNITED ARAB EMIRATES**

Office 3003
Prism Tower
Business Bay, Dubai
UAE