New visions towards zero defect manufacturing

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The European Commission, through Horizon 2020, supports projects developing advanced technologies for the manufacturing industry. These projects have different objectives, target industries and employ very specific methodologies and approaches; nevertheless, in most cases, projects share a common goal: increase efficiency, reduce waste, boost competitiveness and lower costs for European manufacturers, particularly small and medium companies.

Among these virtuous examples, some projects aim at an even more specific goal: reach excellence in manufacturing through zero defect production.

This challenge led some of the best research centres, the most innovative SMEs and important industrial players to create consortia around different project ideas. In this article, it will be possible to discover in detail the work carried out by three projects active in the field of zero defect manufacturing. On the one hand, two European innovation projects dealing with the development of next-generation zero defect manufacturing processes STREAM-0D and Z-FACT0R. On the other hand, QU4LITY, as a European lighthouse innovation project, provides the foundation for cutting-edge digital manufacturing platforms and enablers supporting the operation of such advanced ZDM decision support and control loops. The three projects reconcile in the ZDM cluster and share similar goals and visions. This article was created in cooperation and aims at encouraging common dissemination activities to share knowledge and spread the results of EU-funded research and innovation projects.

STREAM-0D: looking for the perfect industrial product

STREAM-0D (www.stream-0d.com) is a European-wide project which has the ambition to tackle one of the main challenges of the manufacturing industry: reaching a zero defect production. STREAM-0D's consortium worked towards the integration of simulation models in the manufacturing process: the idea is to link simulation models and instruments that can perform measurements of physical parameters in order to monitor the simulations and the overall production process in real-time. The

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high-level goals of the project are to:

- increase product quality with low variability, reduce scraps and shift production towards a zero defect manufacturing approach
- reduce product development cycles, increasing the reconfigurability of the production line
- reduce manufacturing cost.

The STREAM-0D solution performed the integration between models and the production environment through the use of reduced-order modelling (ROM) techniques: these represent the key technology because they allow the transformation of detailed, complex, computationally expensive simulation models into modern abaci that instantaneously provide the output responses for a given set of inputs. Additionally, ROMs can be run in simple platforms (laptops, tablets and even smartphones).

However, due to the complexity of certain processes, ROMs sometimes failed to reproduce some of their inherent variability. Data-driven models, which are based on real data measured in-line, completed and expanded the process information provided by the ROMs.

The blend of these two approaches allowed the STREAM-0D solution to predict and adjust the output of the production, reducing the variability and the number of defective parts.

The solution has been implemented and demonstrated in the production line of a series of industrial settings all in the automotive sector; they represent different factory types and production methods and, specifically:

- tapered roller bearings (Fersa Bearings, Spain)
- body/door mounted seals (Standard Profil, Spain)
- brake actuation units (ZF, Germany)

- **Fersa Bearings:** Tapered roller bearings are composed of four main components, all of them metallic: inner ring, outer ring, rollers and 'cage'. The most critical parts of the assembly process, from the point of view of the bearing performance, are the machining of the raceways in the rings. In fact, they typically have a 'T' geometry that must be checked for every unit to avoid flaws responsible for the concentration of local pressure that might lead to the bearing failure. Within the STREAM-0D project, a simulation model (ROM) of a bearing component, able to predict the exact dimensions as a function of the temperature, was developed. In addition, a data-driven model complemented the ROM also to identify, through machine learning algorithms, potential defects and failures.
- **Standard Profil:** The primary function of the body/door-mounted seals is to provide water and soundproofing between the door and the vehicle body. Since these seals are highly visible, they need to have a high-quality visual appearance and also allow doors to be closed with minimal effort. In fact, they are made of rubber or TPE and metallic, or glass fibre hoops and are produced in high-tech co-extrusion lines (extruders, ovens, plasma units for surface treatment and visual inspection systems are used). Within the project, the production process (extrusion) of a rubber profile has been simulated. Specifically, the simulation predicted the evolution of the shape and curing degree of the profile as it was being pulled along the line, through the curing ovens and other stations.
- **ZF:** The standard car braking system uses the motor admission vacuum source to amplify the driver's force, transforming it into hydraulic power in the brake cylinder. The main aim of the actuation unit is to combine the driver's force and the force provided by the vacuum in a controlled way. The manufacturing process consists of an assembly process of a number of subcomponents, which are metal, plastic and rubber parts. STREAM-0D introduced in ZF's manufacturing process a simulation model of a brake booster able to predict and adjust some final key indicators of the booster (such as the pedal feeling).

The work carried out during the three-and-a-half-year lifespan of the STREAM-0D project allowed the consortium to verify the feasibility of this approach: in addition to ROMs, the introduction of DDMs and in-

Figure 1: STREAM-0D project partners

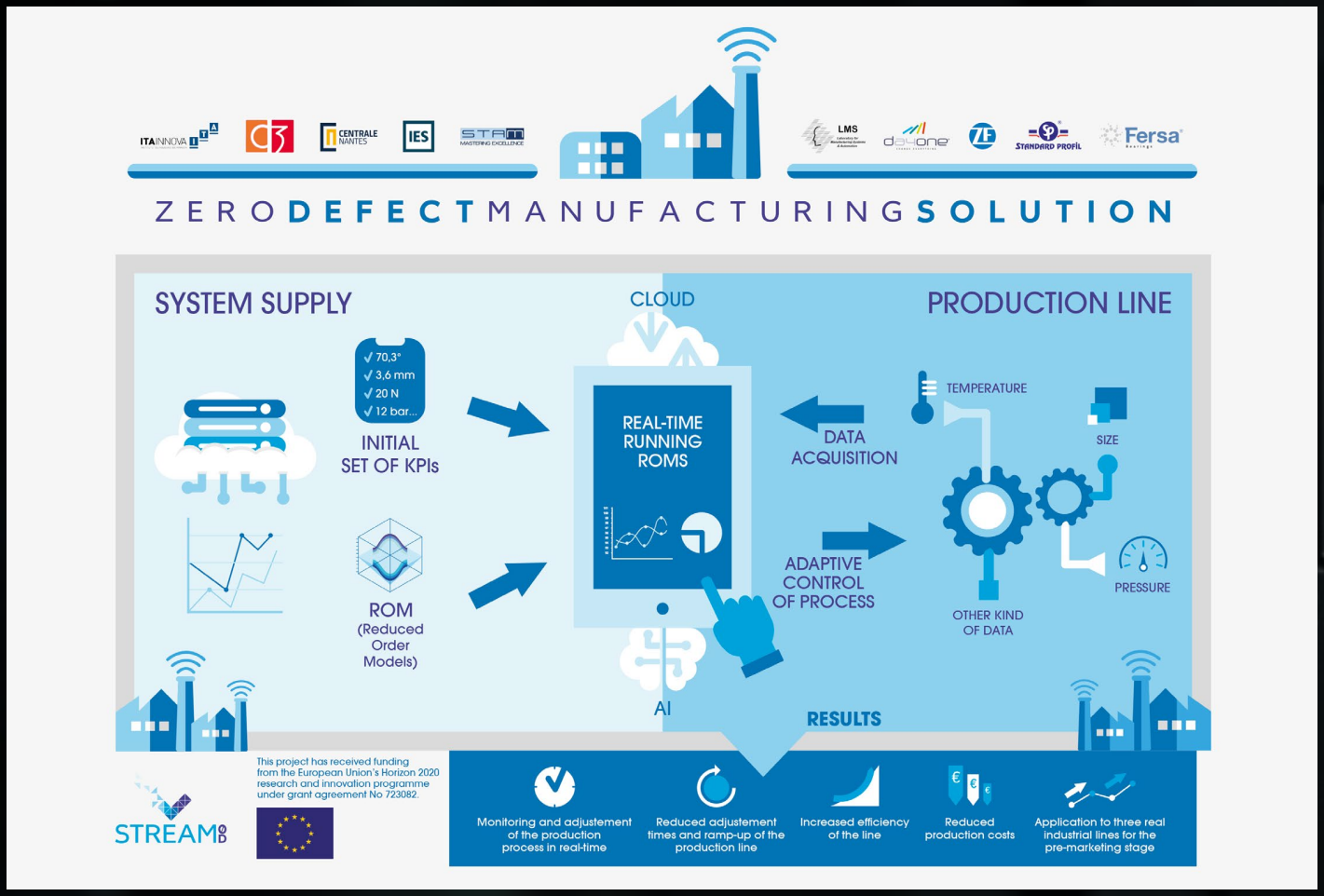

Figure 2: Infographic representing how the STREAM-0D solution works

line recalibration methods proved to be essential to fine-tune the manufacturing process and achieve a reduction in scraps, increase reconfigurability and obtain an overall reduction of costs.

QU4LITY: the digital manufacturing platform for smarter and connected zero defect manufacturing processes

QU4LITY (https://qu4lity-project.eu/) EU Lighthouse project enables a radical shift from the state-of-the-art production quality methods to the disruptive **autonomous quality (AQ)** concept (end-to-end intelligence and automation). QU4LITY will leverage the **digital continuity enablers** for modular, composable and federated ZDM digital manufacturing platforms operation.

Thus, QU4LITY will enable manufacturers and solution providers (including SMEs) to adopt **innovative manufacturing solutions for ZDM**.

The project started in January 2019, and it will end in March 2022, with a total budget of €19.5 million. It involves 45 EU-based partners (see Figure 3) as a joint effort of European leaders in cutting-edge digital manufacturing technologies, ZDM equipment, platforms and processes, and top European research, academic and institution providers of innovation management services for digital manufacturing (i.e. manufacturing-related DIHs).

Any European manufacturing company has a constant need to strive for excellence and sustainability. This requires producing top quality goods, being highly efficient in terms of costs and resources, while

Figure 3: QU4LITY project partners

being extremely responsive to market and customer needs, and using and offering creative and innovative solutions. However, due to increased product mass customisation and the proliferation of global flexible manufacturing networks, scalable first-time-right manufacturing is also becoming increasingly complex. **Future flexible production scenarios for mass customisation of multi-reference small batch production jeopardise the perception-control-actuation loop productivity under the conventional automation approach.** With new product features, new manufacturing processes and techniques will emerge, which in turn will call for an evolution of quality control and quality assurance procedures capable of effectively dealing with the inherent variability of Factory 4.0 manufacturing processes. Traditional quality control models such as TQC, end-of-line SPC, or in-line multi-stage quality control solutions are not fully capable of dealing with the dynamism of such new manufacturing scenarios. QU4LITY does not call for abandoning such well-established and sound quality control methods, but on the contrary, calls for extending such methods with a **multi-dimensional, multi-stage and systematic framework for cognitive collaborative quality assurance** throughout an entire supply chain. Thus, QU4LITY will enable the development and implementation of **novel zero defect manufacturing (ZDM) control systems with cognitive capabilities, and new information flows** capable of reacting to unpredictable situations, to plan their further actions, and to learn and gain experience from previous manufacturing processes, i.e. cognitive automation.

QU4LITY brings quality control to new levels of automation, adaptation, actuation, cognition and collaboration. QU4LITY is proposing to spread intelligence across the various levels of the smart connected factory (field, edge, factory and cloud) with suitable digital continuity enablers (networking, computing, analytics and visualisation enablers) that are able to meet the volume, variety, and velocity of ZDM decisions in the shop floor.

Figure 4: Autonomous Quality "One-Stop-Shop" Platform Assets

QU4LITY provides to factories and manufacturing equipment vendors a 'one-stop-shop' platform for a comprehensive assessment of autonomous quality processes and digital continuity enablers– see Figure 4. QU4LITY standards alignment, open API support, common software-defined reference model and trusted industrial quality data space allows unique and tailored ZDM strategies implementation.

Through an ecosystem of orchestrated open platforms, containerised software components and digital continuity enablers across all phases of product and process lifecycle, QU4LITY leverages advanced autonomous decision and control loops— i.e. multi-stage deep process analytics, digital twin orchestration and simulation-based control, embedded intelligence and real-time control and augmented human centred decision support capabilities. In fact, autonomous ZDM equipment and factory operation are essentially conditioned by the ability of future cognitive systems to implement and interoperate feedforward and feedback quality control loops at multiple levels in a cost and time-effective manner and to achieve the right balance among process automation and human interaction. **The ultimate autonomous factory transformation goals are (1) to improve the quality of manufacturing decisions, (2) to reduce the time to decision and (3) to make things happen as planned/predicted.** The actual deployment of ZDM solutions in the autonomous factory depends and relies upon the concurrent design and effective deployment of ZDM processes coupled with the implementation of advanced digital decision workflows supported by effective information flows.

QUALITY 4.0 will trial autonomous ZDM strategies and control loops in nine manufacturing process and five plug and control manufacturing equipment lighthouse pilots in seven sectors that drive the European manufacturing economy, i.e. automotive (Continental, Kolektor, ThyssenKrupp), aeronautics (Airbus, +GF+),

railways (Mondragon, Fagor) automation and machine tool (Siemens, Danobat, GHI, Fagor, Prima Industrie) and smart home appliance (Whirlpool, Philips) factories. Additionally, QU4LITY ZDM model for connected smart factories is enriched from inception by one sector that addresses traditional industries (ceramics (Vista Alegre – RiaStone)).

Figure 5: Z-Fact0r project partners

Zero defect strategies for smart factories: three different applications of the Z-Fact0r system

Z-Fact0r EU project aims to optimise production processes, introducing real-time monitoring systems and predicting defects/errors. Through the implementation of the multi-stage system that relies on a machine learning algorithm, Z-Fact0r aims to the eradication of defects in manufacturing, providing a better quality of products, increased flexibility and reduced production costs, providing the zero defect production within Industry 4.0.

The project started in October 2016, and it will end in March 2020, with a total budget of €4.2 million. It involves 13 EU-based partners, representing both industry and academia, that have ample experience in cutting-edge technologies.

Z-Fact0r is a zero defect manufacturing system, which is applicable to factories and multi-stage production lines as a holistic framework both to new and existing manufacturing lines, achieving zero defects productions. It aims to address the changing customer needs by integrating them in the process, allowing re-tuning of the manufacturing line in order to meet the desired targets.

This framework envisages considering all the multi-stage manufacturing lines as a whole, identifying which parameter causes diversion from the initial targets and leads to defects. Thanks to the five intertwined zero defect strategies (i.e. Z-PREDICT, Z-PREVENT, Z-DETECT, Z-REPAIR and Z-MANAGE) the overall solution is expected to contribute to a spectacular improvement in the overall performance and reliability of the targeted multi-stage manufacturing systems and in the production agility, as a fast response to continuous adjustments in production targets, facilitating the adoption of risk-based thinking at an enterprise level by supporting faster and better decision-making at shop floor.

The Z-Fact0r system has been studied, developed and tested on three use cases from different industry sectors: electronics, metals, together with shaving processing, mechanical processes and metal treatment. The end users involved in Z-Fact0r demonstration activities are:

- **Microsemi Semiconductor Ltd** — a wholly-owned subsidiary of Microchip Technology Inc. which is a leading semiconductor supplier of embedded control solutions. The semiconductor components are a high-value product, so a small percentage change in yield can make a significant difference to waste costs. The process chosen to evaluate the Z-Fact0r system involves the placement and glueing of very small die/components with conductive paste into a laser-cut cavity since it represents a crucial point in the overall process. Thanks to the Z-Fact0r project, Microsemi would improve this process and finely control the amount of glue being dispensed into the cavity. Optical inspection, along with trend monitoring, plus the prediction of the usability of the glue are all factors that help with improvements.

- **DURIT** — developers and producers of precision tools and engineers components made of tungsten carbide bonded with cobalt. They are intensive users of precision grinding, milling and turning operations, particularly for the final stages of hard metals' wear tooling for numerous industrial applications. Surface finishing, including surface roughness, dimensional tolerances and structural integrity must meet precise standards that are met by continuous measuring and quality control. The production process is based on powder metallurgy, so any non-quality is very

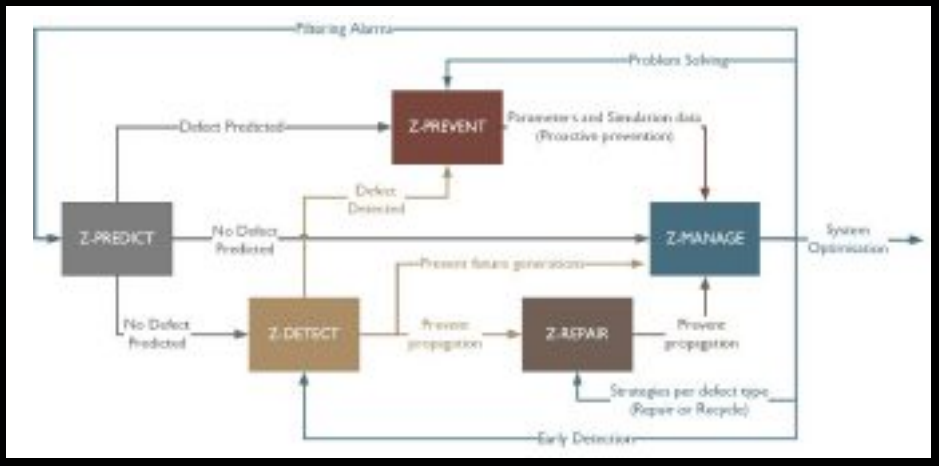

Figure 6: Z-Fact0r five strategies and its synergies

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costly as the recycling process can only be done by specialised companies. More than 70% of overall rejections registered are attributed to these operations. The objective of DURIT is to adopt and implement a predictive system to monitor online the quality of the parts, register the data and predict quality deviations resulting from systematic errors and improper machine operation.

- **NECO**, part of the TIVOLY Group, designs, manufactures and sells cutting tools and associated products and services. They design and realise in particular, tapping and threading tools that require a complex, high precision sequence of manufacturing operations, from bulk stock to final precision grinding. NECO aims to develop a strategic competitive advantage by **preventing defects and the error propagation**, being able to deliver highly complex, customised cutting tools in the shortest possible delivery time at reduced production cost. With information about geometrical and functional features of the tool, thanks to the deployment of 3D metrology, NECO would enhance its processes towards a zero defects scenario.

The Z-Fact0r consortium has built an innovative solution with advanced features such as an autonomous and self-adjusted early-stage inference engine for **real-time inspection** and **control at the shop floor**. The system includes new approaches to real-time optimisation algorithms using machine learning techniques in order to prevent future failures, malfunctions/abnormalities, and obtain better predictive performance. It represents a complete monitoring solution for every manufacturing process that could be seamlessly integrated, able to adjust and think ahead to avoid non-productive activities, thus moving towards the Industry 4.0 and zero defect.

Conclusions

All ZDM cluster projects deal with zero defect manufacturing, trying to ensure the best quality standards at a reduced cost and time in order to be effective on the market and gain a significant competitive advantage.

The different solutions are designed to be integrated at the shop floor level and also to have positive effects on whole companies' processes.

The three projects have the common ultimate goals to improve the decision-making process related to manufacturing quality issues and to be able to predict erroneous manufacturing behaviours to have a non-stop production process.

While STREAM-0D project aims to achieve ZDM processes thanks to real-time monitoring simulations based on mathematical models, Z-FACT0R project output is the development of a strategy to allow the prediction, prevention and management of quality issues thanks to 3D metrology allowing for real-time monitoring. QU4LITY project broadens its project scope, aiming at achieving the digital continuity of product and process lifecycle, enabling the ZDM strategies to become more autonomous and better suited to future flexible manufacturing lines.

SUMMARY

This article was created in cooperation between STREAM-0D, QU4LITY and Z-Fact0r projects. These three projects reconcile in the Zero Defect Manufacturing (ZDM cluster) and share similar goals and visions: increase the efficiency of the manufacturing processes, reduce waste, boost competitiveness, lower costs for European manufacturers and ultimately reach excellence in manufacturing through zero defect production. STREAM-0D and Z-Fact0r, on the one hand, deal with the development of next-generation zero defect manufacturing processes. On the other hand, QU4LITY provides the foundation for cutting-edge digital manufacturing platforms and enablers supporting the operation of such advanced ZDM decision support and control loops. The article aims at providing an insight on the activities of the three projects, encouraging and promoting at the same time the benefits of joint dissemination activities between EU-funded projects.

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FUNDING

STREAM-0D and Z-Fact0r have received funding from the European Union's Horizon 2020 research and innovation programme respectively under grant agreements no. 723082 and no. 723906.

QU4LITY is co-funded by the Horizon 2020 Framework Programme of the European Union Under grant agreement no. 825030.