Resilient Smart Connected Factory 4.0 Process Engineering – A RE4DY use-case approach

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Abstract
Europe's industrial sector leads in transitioning to a climate-neutral, sustainable circular economy, focusing on efficiency and reduced resource use through projects like Boost 4.0 and Productive 4.0. These initiatives leverage digital twins, AI, and digital threads to enhance competitiveness and foster human-centered, autonomous factories within collaborative ecosystems. The COVID-19 pandemic underscored the need for resilient manufacturing strategies against disruptions. European manufacturing must adopt innovative, proactive resilience features within digital strategies, utilizing technology for active resilience in Zero-X manufacturing processes. Within the European Commission-funded RE4DY project, the focus is on enhancing logistics for the automotive sector through AI and digital twins, aiming for autonomous internal supply chains and decision-making assistance. This involves predictive and adaptive logistics, learning from past events to optimize future actions, and ensuring material supply efficiency. The work presented here, is being validated at Volkswagen AutoEuropa in Portugal, and it represents a step towards automated, adaptive logistics ecosystems integrated with production.

Keywords
AI, Digital Twins, Zero-X Manufacturing, Autonomous internal supply chains, connected logistics

1. Introduction

Europe's industrial sector is at the forefront of driving the shift towards a climate-neutral and sustainable circular economy, aiming to become more productive while using less material and energy. Through pioneering projects like Boost 4.0 [1] and Productive 4.0, under the banners of EC Connected Factories and various clusters, the importance of leveraging digital twins, AI, and digital threads has become evident. These technologies are proving essential for gaining competitive edges throughout the product and process life cycles, supporting the development of human-centered, autonomous factories and fostering collaborative, circular industrial ecosystems [2]. A significant outcome of these collaborations is the creation of a unified big data factory model, compliant with RAMI4.0 and ISO 20547 standards, overseen by the Digital Factory Alliance [3]. This model is a cornerstone for integrating big data, manufacturing data spaces, and digital services into Zero-X manufacturing, marking a significant stride towards efficiency and sustainability.

The COVID-19 pandemic highlighted the fragility of global industries to sudden disruptions, revealing that traditional approaches to manufacturing resilience - often static and passive - are no longer sufficient [4]. As disruptions become more frequent and severe, the imperative for European manufacturing is clear: to stay competitive and sovereign, it must urgently embed innovative, proactive resiliency features into its data-driven digital manufacturing strategies. This involves embracing a once in-a-lifetime opportunity to leverage cutting-edge technology for building active resilience into Zero-X sustainable manufacturing processes [5]. The challenge is not just about using data to boost manufacturing efficiency; it's about ensuring the long-term competitiveness of the European manufacturing sector by fostering a digital agility that embraces data culture, secure digital

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platforms, and the harmonious integration of AI and automation with human expertise. As we move forward, the focus is on transforming the manufacturing landscape into one that is resilient, dynamic, and ready to face the challenges of tomorrow, ensuring that the European manufacturing sector remains a global leader in innovation and sustainability.

The work presented here, is framed within a European Commission-funded project, RE4DY – Manufacturing Data Networks [6], with the goals of Establish a framework for digital smart products & production value ecosystems in connected factories 4.0 and increase big data pipelines, data, digital thread and digital twin autonomy and interoperability. The work focus on one particular use-case scenario which is addressing the connected logistics for automotive sector.

AS/RS are Systems designed for Automated Storage and Retrieval of parts and items in manufacturing, comprehending a system of storage racks, conveyors, handling robots and Automated Guided Vehicles (AGVs). The complex network of the VW T-Rock logistics ecosystem is constantly changing. Therefore, the logistics specialist study on a daily basis the best solutions to optimize the processes as much as possible. Furthermore, the logistics specialists sustain the added pressure of having to seamlessly deliver parts to a virtually non-stop production assembly which on itself, could also suffer occasional deviations due to client demands. Currently, Volkswagen AutoEuropa uses manual sequencing for AS/RS, managing a huge amount of manufacturing data.

The entire process of unloading, placing the windows in the correct order, and transporting the racks to the Point of Fit (POF), are performed manually. The AutoEuropa Volkswagen is motivated to implement an automatic AS/RS Sequencing System for car glass assembly.

The adequate collection of the big data generated in the factory by all the systems, its appropriate serialization, management and utilization using AI and simulation techniques, will enable to create real time navigation plan to get an adequate Sequence Cells that will decrease the waiting time.

The main objective of the proposed work is to provide assistance in the decision-making to the logistics specialists about the best course of action depending on the production planned and depending on the inventory available for vehicle manufacturing. The approach to be proposed here, will address a more automated yet supervised generation of logistic processes scenarios driven by AI and digital-twins for simulation, enabling the possibility to analyze different concepts of warehousing, picking and line feeding, creating an autonomous internal supply chain, enabling human workers to fine tune, select and refine the scenarios proposed by RE4DY generative models. The ultimate goal is to validate the human centric generative design and planning of the intra-logistic process and cognitive product development framework.

The work to be addressed here will provide, to the logistics processes, predictive and cognitive/adaptive features that would support logistics specialist, to intervene in occasions when a bottleneck is identified. In such an event, this AI feature should assist the logistics specialist by offering alternative solutions to meet production demands. Additionally, this AI- based system should be able to learn from past experiences and manage effectively similar events automatically in the future. The use of AI for assistance in the decision-making process should provide the logistics specialist information about the best course of action depending on the production planned and depending on the inventory available for vehicle manufacturing. Such system will actively detect bottlenecks in the logistics supply chain thus, avoiding expensive running costs due to supplier shortfalls and other recurring incidents. With-in this approach, VWAE intends to pave the way towards an automatic warehouse adaptive logistics eco-system that should constantly be connected to the production areas, taking in all the information of the vehicles being manufactured and of the vehicles to be manufactured, thus, the AI system running the warehouse internal supply chain will know the optimal course of action to keep the production areas supplied with material. This AI system should also be able to proactively alert and assist the human operator to call for the optimum amount of stock and AGV's line feeding equipment, in order to keep inventory and line feeding costs to a minimum.

The scenario addressed here, is being currently being developed and validated at Volkswagen AutoEuropa (VWAE) automotive production pilot, located in Palmela, Portugal, more specifically the intralogistics sector.

2. Scenario

The Volkswagen Autoeuropa trial for RE4DY will focus on an internal logistics process called GT Process however, in order to understand properly how this process works there are a few concepts to grasp.

First thing to consider is that within the Volkswagen Group there are two main types of containers used for logistics processes. There are GLT (Großladungsträger) and KLT (Kleinladungsträge). GLT's are larger containers used for larger parts. KLT's are small size containers that usually carry smaller parts in a bulk format. The use case will focus on this container type. Smaller containers, like KLT, come from the supplier in bundles neatly stack together, the current designation for this configuration is GT: KLT Gebinde. Low runners parts go into shelve storage concept. The picking of the individual KLT's is done by a specific equipment to reach the different shelves: order pickers; High runners parts go into areas called Bahnhof. GT bundles with higher demand are located in this specific area because they need to be easily accessible by the operators in the tugger trains delivering parts from the warehouse to the assembly line.

The GT Process is the designation given to the process of picking high runners parts in the Bahnhof area. The key factor about this process is adaptability to marketing demands through monthly adjustments of the parts considered high runners. In other words, although the targeted production number is constant on a daily basis, the volume between the different model specs usually varies a lot due to external influences. These external influences most often relate to fluctuations of preferences in the market or to entropies on the supply chain of the suppliers of a plant.

The contents of this work will try to address 3 different business processes.

2.1. Autonomous / Automatic Planning

Monthly routine to extract and publish directly the optimum scenario to key stakeholders of the internal supply chain at Volkswagen Autoeuropa. Logistics planners are able to perform adjustments/study different scenarios and as soon as they validate the optimum scenario, the information flows digitally throughout the organization.

Information about the optimum scenario is clear to everyone and thus, each stakeholder knows which changes are required to achieve it.

These scenarios must be deployed effectively on a monthly basis for the best possible financial gains in the GT Process.

2.1.1. Expected Results

The expected results from item 1 are to relief planners of mundane tasks required in the planning and communication stage when updating the GT Process. The logistics system updates for the current ERP scenario and then, the planner validates and deploys the optimum part selection for the GT Process, followed by an automatic communication mechanism to inform all key stakeholders of the update process and on how to proceed for the deployment of the optimum GT Process. The communication routine after each update must be easy to follow and deployed with significant automatic triggers to ease the process information flow, all the way from the planner until it reaches the shop floor.

From the deployment of this process planning, one can expect significant gains in time throughout each stakeholder involved in the process. This is possible thanks to an increase in digitalization and communication actions automatically triggered to the key stakeholders.

Additionally, operational reaction times decrease and systems adaptability to unstable logistics environments increases.

2.2. Shop floor Implementation

Efficient communication to the stakeholders on shop floor level with digitalization to enable direct remote updates through e-papers. This is to smooth the operation by displaying clear information to all members of the operational team: from the ones responsible to coordinate and physically implement changes and to the ones responsible to move and deliver the parts from the warehouse to the point of fit.

Considerable reduction on the planning process since it is no longer required from the logistics planners to update the process physically on the shop floor. With the deployment of e-papers, updates to the process are achievable remotely.

2.2.1. Expected Results

Speedy updates are useless without a strong support on digitalization and communication to the shop floor. Thanks to the use of E-Papers there is a significant increase in digitalization in the procedure of updating the GT Process. With these devices, upon the moment the system updates, the stakeholders from planning to shoo floor are immediately aware of the new optimum scenario. Additionally, during a transitional stage, it displays the current and new part number allocated to a given location on the bahnhof, thus training and informing the operation of these changes with significant preparation time.

The benefits for this use case come from the preemptive update and communication to the operational team on the shop floor through a sophisticated communication methodology thus, shortening reaction times by informing and training the operational team, as soon as the decision is known within the higher hierarchy of the organization.

2.3. Resource Optimization

After the definition of the optimal scenario of parts in the GT Process then it is time to optimize the resources required to deliver those parts.

Upload new scenario of GT Process into the simulation tool and analyze the time required for each route and overall equipment efficiency. Test different scenarios, aim for the best financial solution. Introduce ML based on historical data, to explore these scenarios as accurately as possible.

2.3.1. Expected Results

Resource optimization on the logistics system at Volkswagen Autoeuropa is complex. With the aid of a simulation tool, one can expect quick studies of multiple scenarios with high degree of confidence. Therefore, the GT Process is an excellent stepping-stone to start with this initiative.

The expected result is to enable quick process/resource optimization starting with a simpler process (GT Process) and then move on to the entire Logistics system.

In the near future, where all logistics processes are within a digital twin/simulation tool, it would be possible to test multiple scenarios to accommodate the demand fluctuations and disruptions affecting the logistics system. This would be that the optimal scenario is constantly being pursued resulting in significant financial gains within the logistics ecosystem as well as increasing the robustness of the entire chain by shortening planning time, making the whole process much more agile and adaptable to internal/external factors.

3. Results

Monthly routine to ingest data, extract and publish insights directly the optimum scenario to key stakeholders of the internal supply chain at Volkswagen Autoeuropa (specific process is GT Process). Logistics planners are able to perform adjustments and study different scenarios and as soon as they validate the optimum scenario, the information flows digitally throughout the organization. Information
about the optimum scenario is clear to everyone and thus, each stakeholder knows which changes are required to achieve it. For the GT Process, in order to extract the best possible financial gains, the optimal scenario must roll out effectively on a monthly basis following customer and marketing tendencies, which result in different consumption trends of part numbers per week.

Currently, these updates are possible although they are not automatic nor streamlined. There is a considerable effort to account for when communicating changes to the logistics service provider. In the future the process will include an automatic / autonomous update with overarching communication to the logistics service provider thus, releasing logistics planners time for other tasks.

The first exploratory results to report are about the development data workflows using the Data Analytics and Visualization Environment to apply the required transformations in the logistical costs dataset regarding the GT process and another to make the calculations on what the optimal GT process configuration is with the latest data. autonomously configure the ideal part numbers for the GT Process. These workflows after creation can be automated to run as soon as there is new data, calculate the changes and distribute this information.

Figure 1. Optimal GT workflow

The example below shows the financial savings of the optimal GT Process calculated by an early version of the script applied to the logistics master data file from November 2022.

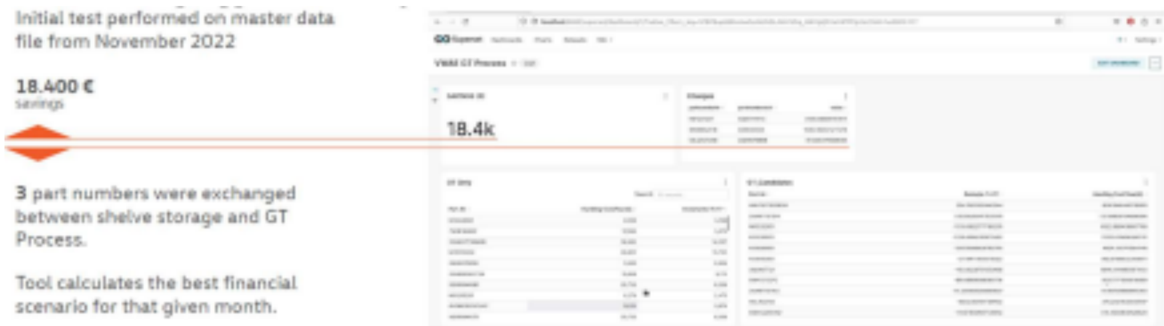

Figure 2. configuration optimal part number configuration on GT Process

After the definition of the optimal scenario of parts in the GT Process then it is time to optimize the resources required to deliver those parts. The logistics planners, upload new scenario of GT Process into the simulation tool and analyze the time required for each route and overall equipment efficiency. They test different scenarios setting their target for the best financial solution. At this phase, the introduction of Machine Learning based on historical data, is key to expose these optimal scenarios as accurate as possible. Currently the assembly area is divided into 3 main zones, and the planning of routes do not account for sophisticated optimization or integration of routes. Calculation / analysis is done manually by the logistics service provider.

In the future, planning of routes is done through sophisticated process simulation using machine learning, this leads to optimization of line-feeding assets and thus financial savings on the whole internal logistics supply chain at Volkswagen Autoeuropa. Thanks to track and trace technology we can see the operation of line feeding assets in unexpected areas. The detection and correction of these events will obviously, translates into inefficiencies and opportunities of improvement.

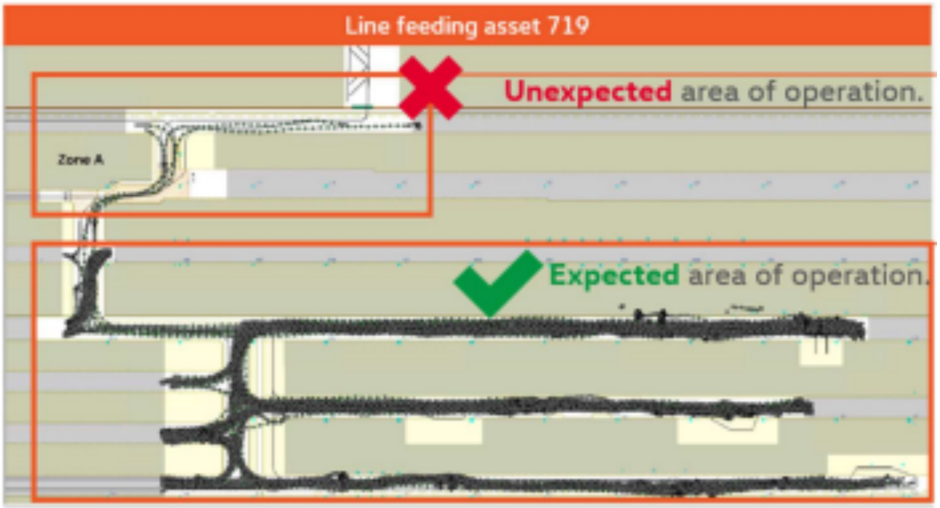

Figure 3. Operation analysis of line feeding asset

This initial study/result will set the bedrock for further analysis of asset performance, which ultimately will result in fleet optimizations in the internal logistics supply chain. This project is ongoing and the next steps are focused on introducing AI models where they can be applied, whether in forecasting future production or in route optimization.

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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