DIGITAL FACTORY ACCELERATION

Paperless production: The backbone of a digital factory

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Preface

In the past few years, Danish manufacturers have shown a significant interest in the Industry 4.0 agenda – now part of every innovation strategy - with the ambition of building a competitive advantage by capitalizing on it.

Nevertheless, it is clear how small- and medium-sized production companies (SMEs) often need practical support when it comes to identifying digital innovation opportunities and translating them into actual production performance improvement.

The Digital Factory Acceleration (DFA) programme – a three-year programme designed and executed by FORCE Technology and Aalborg University and co-financed by Industriens Fond – aims at providing this support. To extend its reach beyond the 21 companies that have the chance to directly join its projects, the Digital Factory Acceleration programme includes a number of articles where we present the key learnings that emerged through the programme.

This article presents the concept of paperless production, and how this emerged as a key backbone for the transformation towards a “digital factory”.

This article is part of the Digital Factory Acceleration programme, performed by FORCE Technology and Aalborg University and co-financed by Industriens Fond.

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The concept of paperless production

Paperless production is characterized as a backbone of the transformation towards a digital factory. One of the key root causes for the lack of digitalization in factory operations is how production companies – especially small- and medium-sized ones – extensively rely on the use of paper for sharing or collecting information across the production floor. This is particularly common for processes such as order release (i.e. when information concerning the order to be produced is collected on a paper which is following the order across production) and order control (i.e. when information concerning the processing of the order in each production station is registered manually on a piece of paper). This generates multiple issues:

- It causes inefficiencies across those processes, as operators and technicians need to manually retrieve or register data on paper
- It makes it challenging to feed back production data into other processes, such as production scheduling or warehouse management
- It makes it particularly complex to use historical data for follow-up analyses (e.g. to support continuous improvement of the processes), as data is stored on hundreds of papers
- It limits traceability across production, as it is not always possible to manually register the data required to ensure the traceability of a specific order

But if these are the limitations generated by paper-based production, then what is paperless production?

Definition

Paperless production - or paperless manufacturing - is the application of a completely digital system that enables the collection and sharing of information wherever and whenever it is needed, providing real-time workflow visibility without the use of paper.

Digital integration of information systems and physical assets across the organization

The goal of paperless production is to digitally replace all physical documents and equipment to administer and share them across production. For that, the system that enables paperless production needs to digitally integrate the information systems adopted at the different organization levels.

The international standard ISA-95 by the International Society of Automation provides detailed descriptions of the five different organization levels of the related aspects, roles and information systems *(ISA, Enterprise-control system integration, Part 1: Models and terminology (IEC 62264-1:2013))* which need to be integrated to obtain a control system that operates across the entire organization – such as a paperless production solution. The five levels and the related information systems that need to be digitally integrated are:

Level 4 – Business Logistics Systems (ERP, MRP), providing information that enables the execution of production activities, such as the definition of plant(s) schedule (material use, delivery, shipping) and the determination of the inventory levels.

Level 3 – Production Operation Management Systems (MES, Batch, LIMS, AM), providing information that regulates the execution of production activities and makes sure that they are performed at the right time in the right way, such as detailed scheduling, order dispatching, and assembly instructions.

Level 2 – Control Systems (SCADA, PLC, HMI), providing information that controls the execution of production activities, such as the monitoring of the order status and the supervision of production equipment (e.g. machinery and other automated systems) while processing the order.

Level 1 – Intelligent devices (vision systems, robots, sensors, meters), providing information concerning the execution of a specific production process, such as its processing parameters (e.g. temperature or force), and transmitting it to control systems, which will use them to control the execution of the process.

Level 0 – Production processes (batch, discrete, continuous), defining the type of activities that will be performed.

1. Functional hierarchy of each level (on the left) and systems used for each level and related function (on the right)

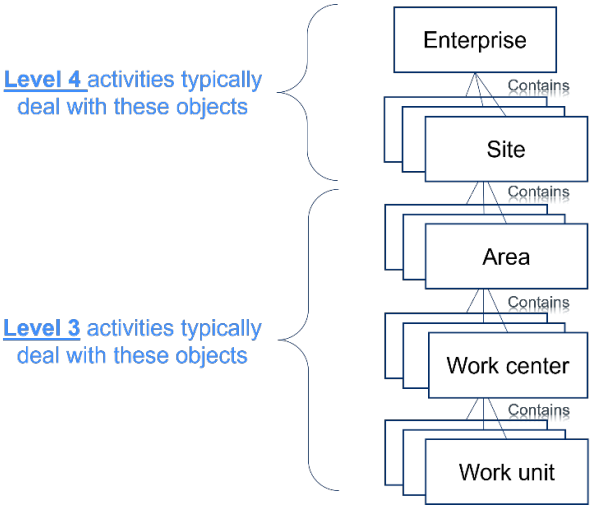
More specifically, it is important to consider that Level 4 and Level 3 include a multitude of physical assets that have to be considered hierarchically during the integration activities (i.e. "role-based equipment hierarchy").

Enterprise – Includes all the sites (i.e. production facilities) that belong to the company. The enterprise shares the responsibility for the type of products that will be produced (product family), the location of the sites where they will be produced and how they will be produced.

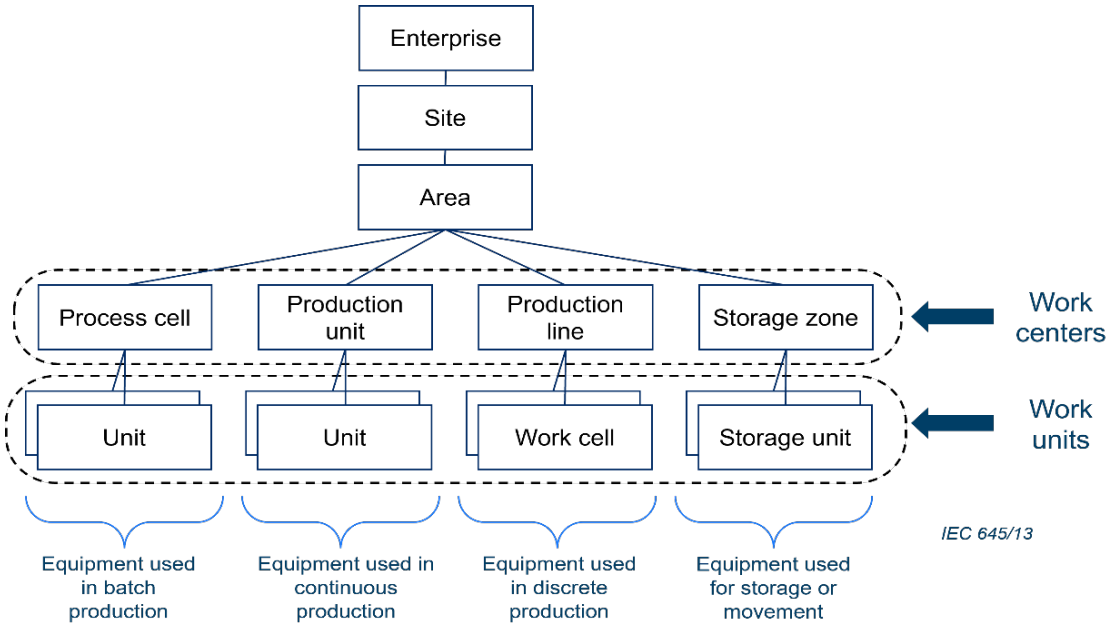
Site – Production facility in a specific geographic area which contains areas, work centers and work units (e.g. Hobro site). The Level 4 functions utilized within a site are supported by the ERP system and concern site management and site optimization.

Area – Group of one or more work centers responsible for executing the actual production processes (e.g. a packing or an assembly area). Level 3 functions (and in some cases Level 4 functions for planning and scheduling) are generally the ones supporting the operations within the area.

Work center – Group of one or more work units (e.g. a packaging line, part of the packing area). The work centers have very well-defined capabilities and capacities,



2. Role-based equipment hierarchy (ISA, Enterprise-control system integration, Part 1: Models and terminology (IEC 62264-1:2013))



3. Examples of work centers and work units (ISA, Enterprise-control system integration, Part 1: Models and terminology (IEC 62264-1:2013))

and these are used as input for Level 3 functions (e.g. order dispatching, workflow generation) and Level 4 functions (scheduling, inventory management).

Work unit – Unit composing – together with other units – a work center (e.g. a pick-and-place robot, part of a packaging line) and most often communicating with Level 3 functions (MES).

Through the integration across all the organization's levels (and of their information systems) and the related hierarchy of physical assets, it is possible to enable the digitalization (and often the automation) of the activities that are crucial for supporting and controlling production, ensuring its efficiency and effectiveness.

Which information shall be exchanged across which organisation levels to enable paperless production?

Information exchange for paperless production

Paperless production is based on the exchange of information across Level 4 - Business Logistics Systems - and Level 3 - Production Operation Management Systems – to support real-time automated decision-making. The transferred information is clustered into five groups.

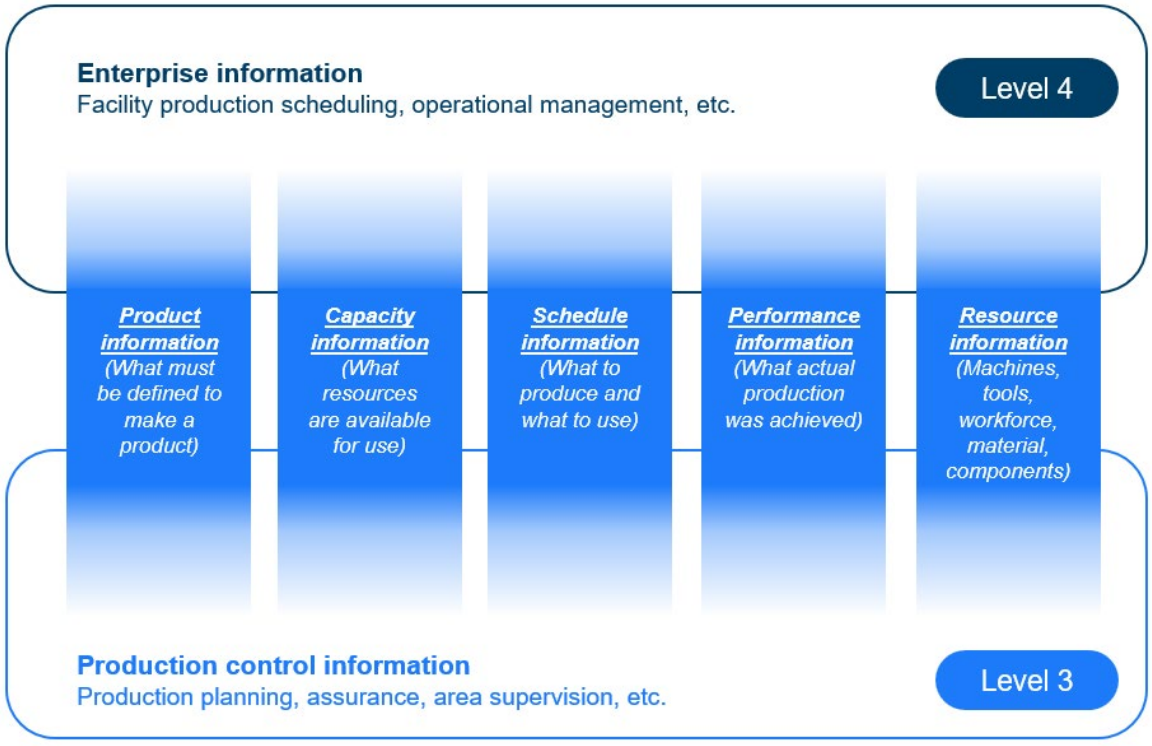
The first group of information concerns product information. This contains production rules, a bill of materials (BOM) and a bill of resources. The production rules are defined as the information required to manufacture a specific product, and include the Standard Operating Procedures (SOP) (e.g., Step 1: turn on the machine and set it up according to the incoming order specifications), the assembly steps and the standard operating conditions (e.g. the RPM in the mixing machine should range between 100 and 120). The BOM incorporates all the needed raw materials, intermediate materials, parts, subassemblies, and consumables required to produce a product. The bill of resources (a superset of the BOM) includes all the resources involved in the manufacturing of a specific product such as personnel, equipment, materials, energy and consumables (e.g. Step 1 requires 2 employees running machine x for 30 minutes, 6 planks of wood, 10 ml of lubricant and 1 carton box to store the processed product).

The second group of information concerns capacity information. This includes the production capacity of each element (personnel and equipment) included in a site/area/work center and is expressed as the number of units (e.g. bottles) that a site/area/work center can produce under a given amount of time (hour, shift, day). Changeover, scheduled maintenance, and production stop times should be also accounted for, as they directly affect the production rate. This information can be collected through devices that monitor the production performance and enable the MES to create and optimize a production schedule accordingly. Historical capacity data is used to understand capacity fluctuations and spot inefficiencies, supporting continuous improvement activities.

The third information group concerns schedule information. This group covers the information associated with the execution plan of the production runs defining which products to produce and which resources to utilize to manufacture the product. These are taking into consideration the production/quality parameters (product information) that have to be followed. The information utilized is the chronological order of operations (order prioritization based on criteria such as deadlines, customer priority, production efficiency, etc), the resource availability (listing of the resources needed for production and their availability), the capacity planning (ensuring that the demand can be covered by the site/area/work center capacity during a specific period) and the lead times of the production processes.

The fourth group specifies the performance information. The information included in this cluster covers elements such as the type and quantity of the produced product (e.g. 300 glass bottles), the amount of material that is consumed to fulfil the production (e.g. 200 kg of glass), the resources utilized in that timeframe (e.g. one 8-hour shift of 6 employees working in 1 production line containing 4 work units). It is of major importance to underline that production metrics can be adjusted and evaluated based on the needs of the organisation, production, supply chain, etc. For instance, the organisation's interest could lie in developing a Key Performance Indicator (KPI) displaying the quantity of defective output, contrary to the production manager who might want to measure all output quantity to assess the site's production capabilities.

Finally, the fifth group concerns resource information. This contains information about the available resources (personnel, materials, equipment, etc) and the produced/consumed materials during the run *(ISA, Enterprise-control system integration, Part 1: Models and terminology (IEC 62264-1:2013))*.



4. Information exchange between Level 4 & Level 3 to enable paperless production (figure inspired by MESA International)

Paperless production as a backbone of the digital factory

The deployment of digital solutions enabling paperless production brings significant changes not only in production but across the whole factory, supporting, enhancing and/or automating human activities. This makes it possible to unlock new levels of efficiency for the factory.

From a general perspective, there are several functions enabled by paperless production, and particularly supported by the introduction of a MES (Level 3) and its integration with the other organization's levels and information systems. These are described in the following.

Instant retrieval of digital documents across the production facility - In a modern factory, the plant manager uses the MES to collect product information such as production rules, bill of materials and bill of resources from the ERP system whenever a new order or batch arrives at the factory. The MES is also supporting the dispatching of such orders/batches on the production floor through integrated HMIs, reducing the time required to transmit such information as well as potential errors.

Efficient scheduling and management of resources - The MES is used to generate detailed production schedules, starting from the initial plan made in the ERP system. In fact, the MES is managing the complexity behind matching the incoming orders, their delivery requirements, the correct resources (e.g. machines, tools, workforce and materials), their availability status (current and future) and the processing requirements. In addition to that, the MES can also reassign resources in real-time from one process to the other in the case of unexpected events or change of order priority, by quickly updating the schedule. Other than reducing the planning time and making it less dependent on the experience of the single planner, this ensures the effectiveness of the plans, which maximises the site's capacity by consistently finding the optimum across all the variables that need to be considered.

Automated control of production - The MES can manage the flow of production across the production facility by dispatching jobs to the different processes. For example, the system can send a job list like "Produce 2 batches of 1000 Liters each at 1 pm" and then translate the job lists into operational commands for selecting, starting and moving units of work. In other words, the MES can start and facilitate the movement of the units to be produced across the different processes which are controlled by control systems such as PLC and SCADA.

Collection of digital data in real-time - The MES can collect production data such as sensor readings, equipment states, event data, operator-entered data, transaction data, operator actions, messages, process data, operation logs and calculation results from models. These are used for more precise decision-making on the production floor, quantification of KPIs, condition-based or predictive maintenance and optimizing processes.

Sustainability - By continuously monitoring the production processes, the MES can assess in real-time energy and material consumption as well as generated waste. This data can be used for supporting continuous improvement initiatives to improve energy and material efficiency. In addition to that, the ability to track sustainability parameters such as energy and material consumption provides significant support for sustainability reporting activities (e.g. ESG reporting), whether they are performed to comply with legislative requirements or with customer requirements.

Improved service level - The digitization of workflows increases the level of transparency in production, providing customers with the possibility to ask for specific information concerning the status of their order in production as well as with full traceability of their products once delivered. Moreover, the increase in production efficiency is leading towards a reduction in the delivery lead time.

Flexibility and scalability - The MES system provides customized solutions that can adapt to production needs. On one hand, if the company starts producing a new product variant for a customer (e.g. having to change or include new processes), the MES platform allows for smooth adjustments. Through it, the current workflow can be changed, and the new quality checks and production parameters can be updated without disrupting ongoing operations. On the other hand, when production needs to be scaled up (e.g. due to increased demand), the additional areas, work centers or work units can be easily integrated into the existing platform.

In practice, these functions help our factories in their transition towards a more efficient and sustainable “digital factory”. The removal of paper and the enabling of such functions facilitate (and innovate) some of the most crucial factory operations, such as the translation of sales inputs into a structured production order, the definition of the production schedule, the communication of a released order on the production floor, the tracking of the order and its processing and quality information across every production step, the management of the inventory, the management of maintenance activities and the integration of all the necessary information for the preparation of the shipping activities.

Figure 5 portrays a vision of the “Digital Factory”, showing how its operations can look like when supported by a paperless production system.

5: Vision of the Digital Factory

1. **Sales:** The customer is placing the order through a web application. Once submitted and confirmed by the sales responsible, the order is automatically registered in the ERP (Enterprise Resource Planning) system.
2. **Planning**: The ERP system automatically establishes the plant schedule based on the available resources across the enterprise. Aligning with the plant's MES (Manufacturing Execution System), the system automatically generates the optimal production schedule based on delivery time, processing needs and material requirements. This is then confirmed by the planning responsible. The planning responsible uses the VSP (Visual Production Scheduler) to fine-tune the production schedule.
3. **Purchasing:** After the order registration, the necessary bill of materials is booked and subtracted from the stock. When the stock level of a component drops below the minimum threshold (defined according to the demand forecast and supply lead time), the planning responsible receives a notification and places the purchasing order through the EDI (Electronic Data Interchange) system integrated with the ERP.
4. **Dispatching:** The production schedule is automatically shared on HMIs (Human Machine Interfaces, such as PCs, tablets or large touchscreens) located on the production floor, along with specific order information and production instructions to support the technicians and operators in their activities.
5. **Order tracking:** The status of the order is continuously tracked by the MES, which communicates with machines, IoT devices and tracking tools used by the operators (such as RFID solutions or barcode/QR scanners). This enables both the evaluation of production performance, full traceability across production and support for ESG reporting activities.
6. **Quality control:** The quality of the produced items is assured by automated or semi-automated quality control systems or by monitoring production parameters and their deviations through the use of AI, triggering quality inspections only when needed. In both cases, quality control systems are integrated with the plant MES and quality data is collected and registered to ensure traceability.
7. **Inventory management:** When components need to be picked/delivered in the warehouse, the responsible receives location details on the HMI and uses tracking tools (such as barcode/QR scanners or RFID solutions) to register the handled items. The interconnection between the tracking tools, the MES, and the WMS (Warehouse Management System), makes it possible to keep the stock level continuously updated.
8. **Maintenance:** Non-critical maintenance activities are organized by a CMMS (Computerized Maintenance Management System), which assigns jobs according to the date and the actual use of the equipment. Critical equipment, instead, is subject to a condition-based or predictive maintenance policy: key parameters (such as power, temperature or vibration) are continuously monitored to identify upcoming failures, and when deviations or failure patterns are identified the maintenance responsible is notified.
9. **Shipping:** When an order is ready to be shipped, the delivery responsible uses tracking tools (such as barcode/QR scanners) to register the shipment in the ERP system and, if necessary, retrieve additional information for the delivery. Relevant information and invoice details are sent via EDI (Electronic Data Interchange) to the customer.

What to do with these learnings

Paperless production emerged as one of the most relevant concepts to present and discuss with the SMEs involved in the Digital Factory Acceleration programme, and this article presents an overview of the paperless production concept, the information and physical systems that should be interconnected to enable it, the information that should be shared across these systems and of how paperless production can increase production efficiency by significantly innovating the factory operations.

The suggestion is to use this article to reflect on how different factory operations are performed today and on which are the “missing links” between the different organisation’s levels and information systems (described above) for enabling a “paperless production”.

Of course, what we proposed is an “ideal” vision of a paperless production and showcases how paperless production can act as a backbone of a digital factory. We are well aware of the fact that every factory is different and has different constraints and needs. This is why you should use this knowledge to build a vision for your factory, answering the following questions:

- How should our processes look like? (e.g. the inventory should be automatically updated once orders are released in production)
- Which information should be shared across the systems) (e.g. order information and bill of material and inventory levels)
- Where is this information located? (e.g. in a printed paper and in the warehouse management system)
- Which systems should be integrated and where do we miss a digital system to enable the integration? (e.g. a Production Operation Management Systems – Level 3 - such as a MES connecting area, work centers and work units)

This will help you outline a clear vision for your digital factory - a necessary building block before starting to talk about technology solutions.

About the programme

The Digital Factory Acceleration (DFA) is a three-year program, aiming at supporting Danish small- and medium-sized production companies (SMEs) in improving their production performance through digital innovation.

The programme consists of two phases: the Digital Factory Mapping phase – focused on identifying production improvement opportunities, quantifying their potentials and formulating an activity plan to capture them - and the Digital Factory Realization phase – focused on finding technology solutions to implement the activity plan and on coordinating the implementation activities if needed.

The programme is co-financed by Industriens Fond which is covering, for all the 21 companies joining it, 60% of the cost of the consultancy hours they receive from FORCE Technology consultants, while Aalborg University is responsible for translating the experience gained from the programme into generalizable knowledge to better understand and support digital innovation in SMEs.

If you are interested in joining the program as a small- and medium-sized Danish production company, you can contact Michele Colli (Head of Digital Production, mic@forcetechnology.com) or Jens Ulrich Nielsen (Chief Consultant, jeun@forcetechnology.com). If you are interested in including the Digital Factory Acceleration programme in an industry event, you can contact Iryna Møller (Administration, imo@forcetechnology.com) or Lennart Oleg Larsen (Head of Sales, lol@forcetechnology.com).

Xenofon Apostolou
M.Sc.
Specialist
FORCE Technology, Digital & Sustainable Innovation
apos@forcetechnology.com
+45 4262 7352

Michele Colli
Ph.D., M.Sc.
Head of Digital Production
FORCE Technology, Digital & Sustainable Innovation
mic@forcetechnology.com
+45 4262 7185