White Paper

Information management from engineering to the shop floor

Version 1.1
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Management summary

Nowadays, companies that operate globally are confronted with growing demands for flexibility and shorter development cycles. Among other things, this is due to the increasing complexity of products and the associated manufacturing processes. To cope with the increasingly demanding requirements, it is necessary to develop new standards and models for the uniform exchange of information throughout the entire product lifecycle. The project group PLIM (Production Lifecycle Information Management) brings together users from industry, system providers and service providers with a common vision of designing a universal information model throughout the entire product lifecycle. Practical use cases are discussed in joint workshops. These show how it is possible to flexibly adapt highly dynamic production systems in which human-robot collaboration is implemented. Development of detailed test suites for the use cases makes it possible for users and system providers to utilize the information model. Users can validate their processes and interfaces and system providers can use the test suites to further develop their products. Joint development ensures that the interfaces are harmonized in a targeted manner.

1 Project frame of reference and objectives

1.1 Mission and vision

To manufacture a product, a factory and a production line are needed, and this must be planned in advance. One key element in meeting the growing demands of production planning is the consistent use of information throughout the entire product development process. Achieving the closest possible cooperation between the production planning disciplines, both internally and with engineering service providers, requires an appropriate technical foundation for the exchange of product, process and resource models, including the links and relationships they contain. The basic objective is to specify an information model for the production lifecycle information, which will guarantee IT integration of the different domains.
1 TERMS OF REFERENCE AND OBJECTIVES

The current challenge is that, due to new technologies, the availability of data has increased in terms of both quantity and quality. Furthermore, evolved IT structures mean that information is distributed over a heterogeneous system landscape. There is a lack of standardized models and procedures for exchanging available information along the product lifecycle. This becomes particularly clear when production planning changes are made to existing machine configurations or when individual production machines are replaced within a production system.

Hence, there is an urgent need for joint efforts to:

- improve the continuous, end-to-end flow of information along the production lifecycle,
- implement the continuous, end-to-end flow of information in the event of changes to system configurations or working systems between the different company domains,
- ensure an automated flow of information from product development to production planning and production, and back from ongoing production to planning and product development.

This white paper has two objectives:

1. With the help of knowledge gained from the use cases, derive individual measures that are necessary to ensure a continuous, end-to-end flow of information within production and efficient information management.
2. Describe the current status of the use cases and provides a detailed insight into all aspects of production lifecycle information management. The white paper references the actors involved and the various levels that are to be mapped within the framework of the information model.

The PLIM working group has started to specify four concrete use cases*. This has been done with the aim of developing scenarios that are as close to real applications as possible and that demonstrate the advantages and possibilities of a digital information flow. The use cases that have been developed serve to visualize the information flow and also reveal fields of activity that need efficient information management. The work of the project group will result in a developed model that provides recommendations for digital production lifecycle information management.

The project group was established with the aim of identifying the standards for the exchange of information within dynamic production planning processes and, if necessary, to adapt these or develop additional standards that may be needed.

1.2 Interfaces in industrial companies

In the product development process, information relevant to products and production passes through different departments in the company. These fall into the three superordinate categories of development, production planning, and production. At present, information flows across departmental boundaries are often characterized by media discontinuities, specialized application interfaces, manual transmission or the creation of new information. Standardized data formats have become established in some domains, especially in product development, referred to below as “engineering”. But in the wider overall context of product development, which is characterized by differing system environments, a continuous, end-to-end flow of information is a challenge. This is particularly so because the information processes depend on the relevant functions in the different IT systems.

* see section 2.3
Figure 2 Information flow in product development (source: Prof. Dr. Oliver Riedel, ISW, Universität Stuttgart)

Figure 2 provides an initial overview of the areas under consideration. Even though the focus of the current use cases is on the interface between production planning and production itself, the information from engineering that describes the product is of course vital for all downstream departments. The system landscape is generally very heterogeneous, and the processing and administration of various different kinds of data is supported in each department. In engineering, the systems used for product data management (PLM systems) are well established in many companies and allow end-to-end processes within the department, usually on a single platform.

Figure 3 Systems in product development and their interfaces

However, it is possible that the first system interface will need to be overcome as soon as the product data is used in those systems that are geared to production planning. In the field of production planning, integrated IT systems that support all planning domains are less well-established than in the field of engineering. Production process planning can be carried out in the PLM systems or in separate, specialized software solutions. Resource planning is then often done in ERP systems. Once all the information for a production plan has been compiled, this information must be made available to production in suitable formats. In addition, interfaces to the company’s partners are also needed.

Moving on to manufacturing, the information needed for processing production orders must be transferred to the ME system used. If live production and the return flow of information is considered in the use cases, the hardware and the sensors it uses must also be taken into account.
2 Production Lifecycle Information Management

In the phases of product development already mentioned, different domains are involved in the use cases under consideration. These are included in a map of the various disciplines in order to be able to locate use cases in an initial step.

2.1 Relevant domains in the product development process

The product description covers CAD data, product functions and structures, specifications and other data objects. These are developed in various engineering domains and made available at a certain level of maturity. While simulation and calculation have a significant impact on product design, data from software development and electrical design is also required in production planning and production, e.g. for installing the electrical system or installing the software during production.

![Figure 4 Map of the disciplines under consideration](image)

Production planning can be subdivided into several domains: assembly planning, manufacturing planning, layout planning, logistics planning and, if necessary, structure planning. The product data, the available resources, and the processes to be planned must all be processed as information in the various domains. For example, the information from all planning domains flows into the production work schedule.

In the following, we shall discuss the transfer of planning data to production using the example of work scheduling for assembly. Production must use work scheduling during order processing in order to manufacture the product. Supported by the production system, orders are issued to the manufacturing and assembly disciplines and the production program is executed. In addition, there are other disciplines and departments, such as quality assurance and maintenance, which use the information from engineering and production planning.

Production is not only a consumer of information, but also generates its own information about the actual production processes. This information is not only important for common Industry 4.0 scenarios, such as predictive maintenance, but also for planning new products and production processes themselves. To this end, it must be possible for this information to be collected and fed back in an appropriate format. But, initially, the prerequisite for this is to identify what
information is required for what application. This applies both to information that necessarily flows from engineering through production planning into production and to information that flows back into the respective domains. This requires an overarching information model.

2.2 Levels in production lifecycle information management

Based on DIN 4499-3, a level model was developed. This is intended to clarify the classification of the elements under consideration, the procedure and the expectations of an information model.

The first level shows the classification in different departmental areas and the underlying domains. This detailed breakdown was presented in the map of the different disciplines, see Figure 4. The organizational aspects of the participating departments have been taken into account. However, these are of less relevance for the information model.

The second level looks at individual use cases. Definition of a uniform, generally valid process across all departments and domains represents a great challenge. The process under consideration must achieve a level of detail in which individual information objects can be identified. An approach involving specified use cases was therefore chosen in order to be able to identify and consider processes relevant to real-life practice. These represent sub-processes that may overlap in terms of information.

The third level represents a collection of information objects in the structural context in which they are used in the use cases. These are initially independent of the system or data format used. This means that the same information objects can be used in different use cases. Overlaiding the structurally linked information objects from several use cases results in an overarching information model which can grow as the number of use cases considered increases. The fundamental conception of an “open” information model also ensures general applicability and future extensibility. In a comprehensive form, this information model can map knowledge about the products to be manufactured, the necessary production processes and the production resources used. However, it makes considerable demands on the IT implementation.
The fourth level represents the data level. It contains the representation of information objects in real systems, proprietary or standardized data formats. The top-down approach across the processes and the overarching information model should allow identification of data formats which represent the information and reveal gaps where data formats have to be extended or additional requirements on systems are needed. This also takes account of the fact that in a real company, parts of the information model are already defined and therefore each use case requires separate consideration. To illustrate the interaction between the different levels of this model, the following example considers a smaller use case that can be used in the general scenarios. See Figure 5. The “Condition Monitoring” use case can be found at the interface between production planning and production control. At the information level, this use case makes use of a behavior model from production simulation and the real machine data from production. Machine data can, for example, be represented with OPC UA and the behavior model with the FMI data format and exchanged with partners in collaborative processes.

2.3 Description of the use cases
The prostep ivip project group PLIM has investigated the use cases outlined below and described them in detail at the process level. Each use case is described in detail at the process level.

Figure 6 Representation schema for the detailed processes

The following process schema is used throughout to represent the abbreviated processes. The color orange represents engineering sub-processes. Production planning processes are shown in blue, virtual validation processes in green and production processes in red.

2.3.1 Use case dynamic capacity planning and effects analysis
The dynamic capacity planning and effects analysis use case is intended to enable the production planner to carry out a dynamic analysis of the effect on capacity for the entire production program as a result of changes in the process or in the planning of a new product in the system.

A production program containing approximately 500 released production plans is assumed. The production program is planned for one week in the ERP system and is implemented using MES. However, the situation on the shop floor changes dynamically. For example, a production worker uses machine A for a sub-process, although machine C was planned for the process. It is also possible that a resource is unavailable. As a result, available capacities can shift and systems can be overloaded or underutilized. Downstream processes can also be affected.
A capacity analysis is triggered, for example, by a change in the planned quantity or by scheduling a new product or product variant on a production line (see Figure 7). The production planner now uses information from engineering and live production. A changed engineering BOM (eBOM) is sent from engineering. Information about current production orders and allocated resources is made available from production. This data informs the planner about the real production processes on the shop floor.

Change planning is based on production plans that have already been released. The updated engineering BOM details the process steps of the production process. This leads to the manufacturing BOM (mBOM). This involves planning the required capacities. The effect on the production program can now be calculated on the basis of the assignment of the process steps to resources and the information on the actual use of the resource from production. The information flow from production back to planning is crucial in this context. The controlling MES must return the conditioned sensor and process data to the planning system in a suitable form.

More accurate decision support can be put in place by considering this information about actual production. Dynamic planning simulation with effect analysis also becomes possible within the framework of the overall production program. This also supports buffer planning and the avoidance of bottlenecks.

Figure 7 Simplified process for the capacity planning and effects analysis use case
2.3.2 Use case dynamic re-sequencing

The dynamic re-sequencing use case is aimed at the point on the shop floor where disruption to the planned production processes leads to the need to make adjustments to the production orders. These adjustments almost always encompass the adjacent and downstream process steps, including the planned use of resources. They thus have a long-term impact on the planned and scheduled workflows. This is generally compounded by inadequate IT coverage of the actual progress of production at the workstation, production system or production cell, so that data and information on the actual status are not fully recorded. Thus, there is no transparency in respect of the actual progress. One of the consequences of this is that the identification of disruptions is often delayed and the appropriate reaction to disruption comes too late.

This use case addresses this issue. The dynamic and rapid re-planning of the production process or the re-sequencing of the work tasks including the associated impact are to be identified, analyzed, executed and documented in order to minimize the undesirable side effects described above and to maximize the effectiveness of the entire production process.

Within the scope of this use case, the production-related information model resulting from the work of the prostep ivip association should lead to end-to-end and automated consideration of the production processes, early detection and anticipation of disruption, and adaptive optimization of the workflows. The concrete objective is the dynamic process planning and sequencing of work packages and quantities based on the latest information from production about currently available equipment, resources (employees), components and process times. These are made available to the people involved in the process, such as the shift scheduler or the production planner.

A production-related information model such as this enables and promotes a continuous, end-to-end exchange of information between the heterogeneous IT applications involved in the production process. In addition to the information from the work processes, the relational links to the necessary resources and the associated product data play a crucial role. On the basis of the visible effects of changes to manufacturing processes, the information model provides strategic and operational support in the process of both arriving at and finally taking a decision. It supports the identification of current business weaknesses, such as the lack of harmonized data, inconsistent data, heterogeneous data landscapes, gaps in the information flow between operational phases or teams, etc.

The installation of a "mixing unit" for fresh air in a passenger aircraft, as shown in Figure 8, is used as an example for the use case. This is installed manually in the fuselage of the aircraft by two production specialists over two shifts over a 16-hour period (cycle time: about 8 hours per cycle). The installation space is very limited and the production staff therefore have very little room to move. In addition, the parts to be installed are unwieldy and heavy. The installation process can be delayed by unexpected disruptions ("nonconformities" / NCs) such as damage in upstream process steps, missing components or work still to be carried out, etc.

At present, no information on the progress of production is recorded in the MES during the installation process. Reports on processed work orders are currently made on a weekly basis when an order is completed, and do not include any intermediate status or progress information. Furthermore, installation of the mixer unit is not broken down into the actual detailed work steps in the work schedule, but is instead stored as a single work process. This means that any knowledge about the installation of the unit resides exclusively with the production specialists responsible for installation.
In future, this process, complete with the progress information and the detailed work instructions, is to be stored digitally in the work schedule. If the work schedule is available in a form that can be processed by a computer, it can interact with data from other systems using suitable data interfaces. This allows the knowledge required to install the mixer unit to be made available to the production specialists. In the target process, detailed SOIs (standard operating instructions) are to be introduced for each work step. These are to be presented visually to the production specialist and the confirmed progress recorded in a process progress model (e.g. in the MES). Tools such as handheld devices, sensors, smart glasses, etc. can be used to display work instructions and record progress.

In order to be able to realize the target process as described, suitable conditions must be created for the collection, administration and storage of dynamic and static data and information. All data is to be collected and processed in a single OT (operational technologies) backbone (shop floor IT / production IT). This includes sensor data, machine data, operational data, etc. Additional static information can be derived from the PLM systems and the MES, e.g. the BOM, the product structure, the product definition, the virtual validation information, etc. Additional information from the ERP systems such as resource data, measurement data, orders etc. is also available.
Figure 9 Processing steps in the dynamic re-sequencing use case

Figure 9 shows a simplified process diagram in which the individual operations are brought together with the associated data and information flows. Assembly is carried out exclusively in the fuselage of the aircraft. Work operations that can be performed in sequence or in parallel are identified and documented using gateways. The necessary resources and skills of the production specialists are stored for each process step. A progress report/measurement is defined. In addition, instructions for the implementation of each process step are defined and prepared and are validated and stored after completion of a work step. The SOIs are intended to act as progress indicators. This information is then passed on to an MES, where it is aggregated and processed and a report issued.

2.3.3 Use case versatile, hybrid assembly system at the Institute for Production Systems (IPS)

The use case versatile, hybrid assembly system at the Institute for Production Systems addresses holistic and automated data exchange from planning through (virtual) commissioning to live production. Holistic data exchange of this kind is of particular importance against the backdrop of increasing demands on the adaptability of production systems as a result of the growth in the number of different variants. For the purposes of simulation, a highly adaptive cyber-physical production system (CPPS) has been set up in the Training Center of the IPS. Pumps are currently being assembled on this production system as part of a collaborative assembly process in which humans and robots act in close cooperation.
There are other drivers of change in addition to the large number of variants mentioned above. These can be divided into six superordinate categories, which have an impact on the areas of commissioning, production and service in the product lifecycle. These categories are:

- a change to the product,
- a change in technology,
- an adaptation of the production program,
- an improvement project that is to be implemented,
- a continuous improvement process,
- and the sharing of best practice methods.

In a modern production environment, it is important to be able to react flexibly and directly to each of these changes. This affects both the adaptation of the data for the virtual representation of the production system and the actual design of the real system.
With regard to the concrete use case described, this means that the change drivers of the robotic cell as described must be monitored and managed by consistent manufacturing change management (MCM). Each of these six levels of changes triggers a series of follow-on steps. These follow-on steps must also be based on consistent and valid data. The use case that was set up at the IPS deals specifically with modification of the product that is to be manufactured.

The first step is an impact analysis to assess the effects of the introduction of the new product on the system. This allows identification of the critical processes and resources of the robot system. The success of this impact analysis depends on a consistent, end-to-end information model, so that effects from all participating domains are taken into account. This is followed by elaboration of the necessary adaptations to the cell. These adaptations affect both the real and the virtual system. Serious problems are encountered in this step if there is a lack of data consistency. Thus, for example, there is a risk that if a change is made exclusively to the real system without taking the virtual representation into account, obsolete data will be used in future planning. The direct feedback of real changes into a digital information model allows shadow libraries to be avoided. The production adaptations that need to be made and recommended must then be worked out. For example, it is conceivable that there could be adaptations to the control mechanisms and to the individual interactions between humans and machines.

Collaboration between humans and robots is the crucial aspect of the described use case and must be the absolute focus in all areas of decision-making during the investigation. The process steps described result in a pool of data and an understanding of the process under changed production conditions. From this, possible scenarios for production can be derived and elaborated. The co-existence of the real and virtual systems permits comparison and evaluation of the different production scenarios and potential adaptations of the robot cell. The last step in the process chain is the analysis and creation of the mBOM. All the process steps described can be sequenced in a similar manner for the other five change drivers.

Figure 11 shows a process diagram illustrating the aggregated workflow. When the product to be manufactured is changed, the requirements list must be adjusted. As described above, this is followed by an impact analysis, which is used as the basis for adapting the production system. If production specifications that cannot be implemented arise during adaptation of the real system or reprogramming, this information is fed back to allow adjustments to be made to the requirements list. The modified production setup must be updated in the virtual version and adapted on the basis of the existing IT structure.
The detailed description of the use cases has shown how flexibly they can react to external changes. The use cases presented by the prostep ivip association’s PLIM group demonstrate how a flexible adaptation of highly dynamic production systems in which human-robot collaboration is implemented can be achieved in a joint effort between system providers, users and service providers. The main thrust of the group’s work is on the design of homogeneous IT systems for the provision of information over the entire product lifecycle, even beyond the described use case. Future work of the group will complement and extend this use case.

2.3.4 Use case "Smart Factory 4.0" demo cell at Fraunhofer-IPK

The "Smart Factory 4.0" demo cell use case looks at a holistic approach to the automated flow of information from the design of the product to be manufactured to actual production and production monitoring.

The Fraunhofer IPK Smart Factory 4.0 demonstrates a manufacturing cell which is in turn part of a line that manufactures user-definable products. Currently, a disc that can be used as a coaster is milled, including a customer-defined logo and slogan. Users can also choose between several different raw materials.

The fundamental idea behind the system is to explore the concept of the digital factory twin. To this end, a bi-directionally linked kinematics and material flow model of the production system has been provided in Siemens PLM Mechatronics Concept Designer.

The basic idea of production, namely to manufacture a product, involves the following 4 steps:

1. product engineering
2. manufacturing planning
3. virtual commissioning
4. manufacturing execution

Step 1, the engineering of the product, is carried out in this demonstration cell by recording the production request in the form of ad-hoc customer-specified engraving on the product and the material selected. A CAD component of the product is generated on the fly and stored in a product data management system. This forms the basis of the product twin, which is later enriched with production data after production sub-steps, such as milling, have been completed. As a result, process information, and ultimately the actual status as delivered, are recorded on the basis of the ideal nominal geometry. This takes account of today’s need for highly individualized products, which also have to be maintained throughout their service life and supplied with (tailored) spare parts.

In the second step, production planning, planning decisions as to which blank is to be used, and hence where the placement robot must go and what paths the milling machine has to travel, are made on the basis of product requirements such as engraving and material. In future enhancements, basic manufacturing strategies will then be planned automatically on the basis of available manufacturing processes and their manufacturing cells in the factory. The G code for the milling machine is generated using an automatically controlled CAM module and then sent to the machine tool. It is essential to ensure data consistency, regardless of the machine used.

In the third step, virtual commissioning, a simulation using the digital factory twin is carried out to determine whether production as requested is feasible and whether the control code, currently limited to a product-specific G code, leads to the desired result and is compatible with the physical limitations of the production system. As part of this, the process time is calculated in advance.
In the fourth step, production execution, the production components are controlled with the aid of a programmable controller and synchronized with the digital twin of the system at a frequency of less than a second. This is done with OPC data exchange. The prerequisite for this is, of course, a neutral description of all components of the system and their control units on the basis of an OPC interface definition. In addition, the statuses of the system are provided on the OPC server for evaluation on SCADA systems. Power consumption and wear are determined and in future serve as a basis for quality predictions and maintenance decisions.

The “Smart Factory 4.0” demo cell provides an example demonstrating that there are continuous, end-to-end paths for providing and forwarding information through all stages of product development. In future, investigations will look at what alternative paths resulting from the different formats of the IT tools used in the individual steps will lead to success, and what media discontinuities have to be bridged by converters or even new standards.
3 Outlook

The PLIM project group has set itself the goal of not only providing theoretical insights, but also of making such knowledge tangible with the assistance of the use cases developed. The case studies that are currently available and that have been described above represent a first step towards hands-on experience.

3.1 Test suite application concept

In the processes under consideration, different information is exchanged across domain boundaries. The exchange of information presents challenges for which there is currently no IT support or insufficient IT support. In order to analyze these interfaces more precisely, a proven concept from the prostep ivip Implementer Forums will be used, namely the specification of test suites. These will be developed in order to test the interface processors of the various vendors for defined data formats (e.g. JT, STEP) and to improve data exchange iteratively.

Figure 13 Example: Test suite of the CAx Implementer Forum
The challenge for the PLIM project group is to transfer this concept to the process of a superordinate use case. The focus here is on consistent, end-to-end design of the interfaces, which enables the flow of information between the individual levels. For example, it is currently not possible to automatically transfer data from production back to the planning system within the context of the IPS use case. In order to be able to perform this data exchange automatically, the individual areas must be closely integrated, from product engineering right through to manufacturing execution. In the IPS use case, a possible test suite could look like this, for example: As early as the planning phase of the product, data is automatically exchanged with the system so that system restrictions can be taken into account as soon as possible. Before the start of real-world commissioning, the test suite is executed virtually in order to identify initial weak points. The results of this analysis are automatically imported into the planning system. The same applies to real-life production execution, where the system is able to automatically return real changes of the setup (failure of individual system components). Thus, the virtual representation can be adapted and any necessary workflows can be initiated in the production process.

3.2 Call for Action

In a production environment that is subject to ever more rapid change, driven by faster development and the pursuit of flexibility, consistent and valid information is an indispensable, competition-critical commodity for any manufacturing company. At the same time, companies face the challenge of sensibly filtering and processing the rapidly increasing amount of data in order to derive added value from the availability of this data. The objective of the Production Lifecycle Information Management project group is to help companies build a consistent, end-to-end information model that allows a consistent, end-to-end flow of information throughout the product lifecycle. Furthermore, approaches must be established to ensure the long-term maintenance and further development of the model. In order to achieve this goal, it is necessary to survey the current status of existing IT systems and processes together with the users to allow identification of the need for action and any gaps in integration. Existing test suites are to be further developed on the basis of the resulting insights. The primary focus here is on improving data integration. Interested user companies have the opportunity to actively participate in developing the information model. In particular, there is the possibility of participating in the development of a cross-system, end-to-end information model, which will help to further develop existing data formats, to design in-house processes more consistently and to react more flexibly and quickly to changing environmental conditions in the future.
## Glossary

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<thead>
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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
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<td>CPPS</td>
<td>Cyber Physical Production System</td>
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<td>EBOM</td>
<td>Engineering Bill of Materials</td>
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<tr>
<td>ECAD</td>
<td>Electrical Computer-Aided Design</td>
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<tr>
<td>Engineering</td>
<td>Product development domain</td>
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<td>ERP</td>
<td>Enterprise Resource Planning</td>
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<td>FEA</td>
<td>Finite Element Analysis</td>
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<td>FMI</td>
<td>Functional Mock-up Interface</td>
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<td>mBOM</td>
<td>Manufacturing Bill of Materials</td>
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<td>MCAD</td>
<td>Mechanical Computer-Aided Design</td>
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<td>MCM</td>
<td>Manufacturing Change Management</td>
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<td>MES</td>
<td>Manufacturing Execution System</td>
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<td>OPC</td>
<td>Open Platform Communications</td>
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<td>Operational Technologies</td>
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<td>Production Lifecycle Information Management</td>
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<tr>
<td>PLM</td>
<td>Product Lifecycle Management</td>
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<tr>
<td>PPC</td>
<td>Production Planning and Control</td>
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<tr>
<td>Production Planning</td>
<td>Planning for the production (product, process and resources) of a product, not including the planning of order-driven batches</td>
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<td>SCM</td>
<td>Supply Chain Management</td>
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<td>Standard Operating Instructions</td>
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