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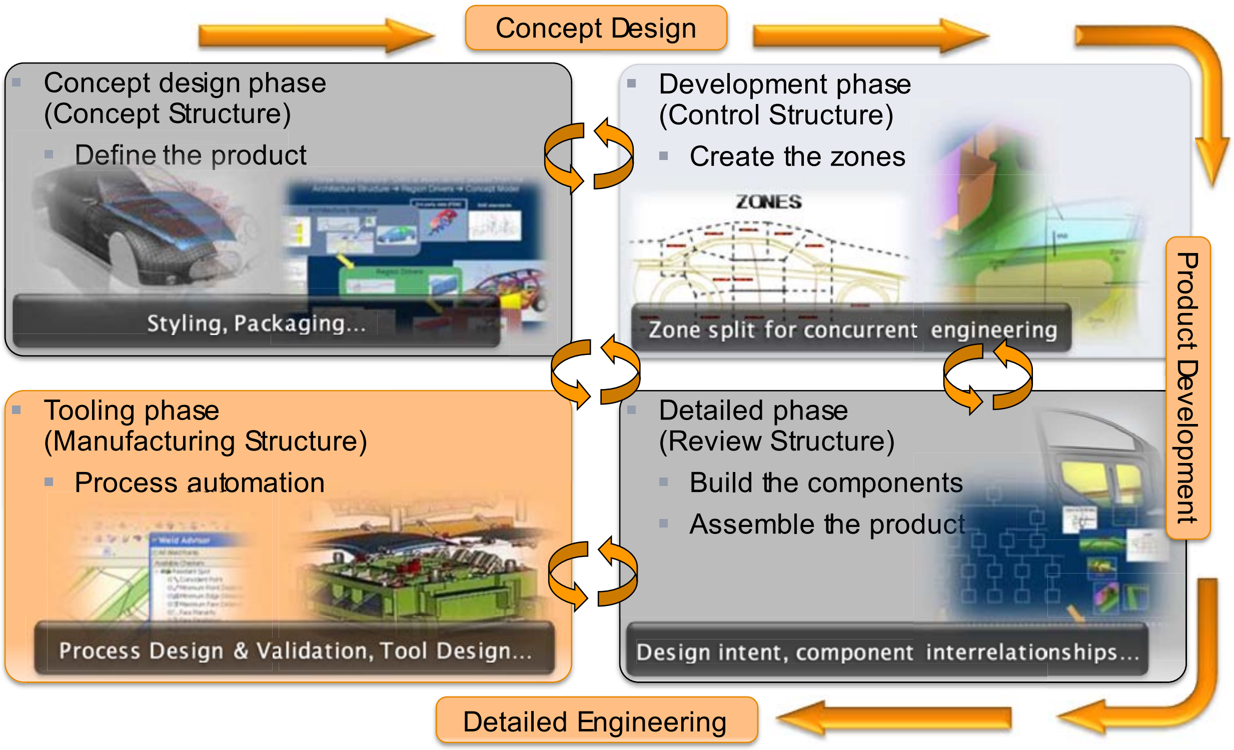
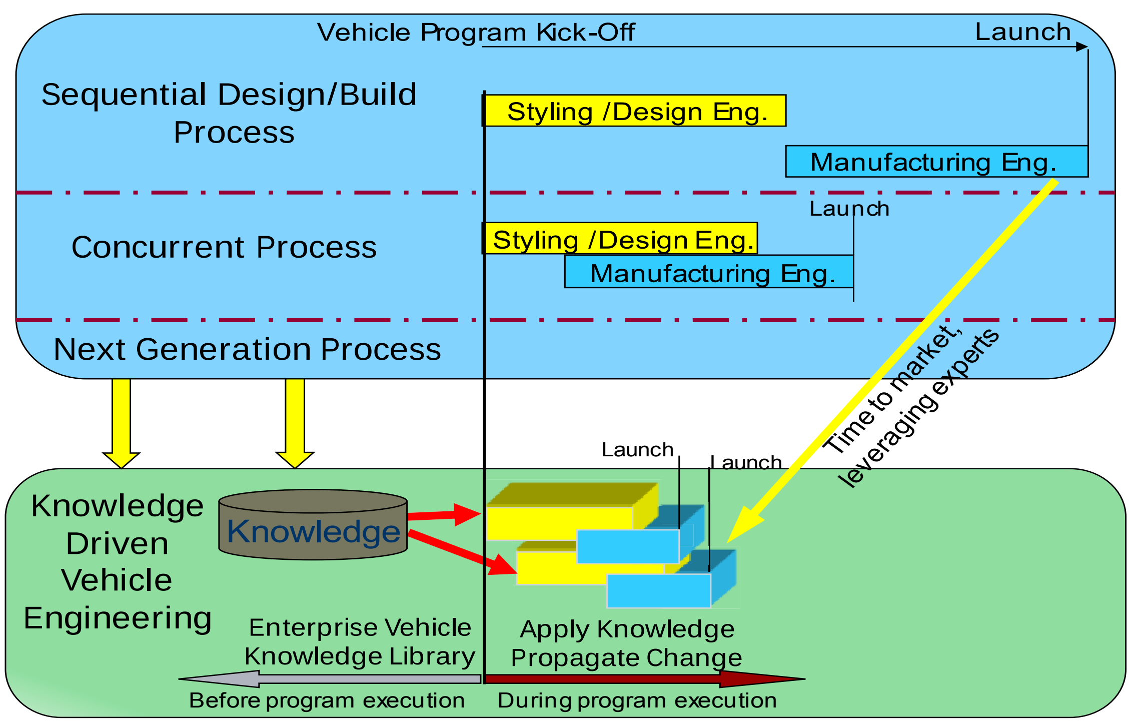
Knowledge-Driven Vehicle Development: Siemens PLM for Automotive Design

ARC Advisory Group



Integrated BIW Development Process



Progression of Body-in-White Development Process

Executive Overview

In order for the automotive manufacturers to remain competitive and claim a share of the market, they must be responsive to constantly changing demands, not only from their customers in terms of style and appeal, but from a market that is focused on the next generation of energy efficient and environmentally friendly vehicles. This implies that the product development process has to be accelerated in order to incorporate the latest trends from technology enhancements to winning consumer acceptance. Meeting these market challenges and global competition equates to significantly shorter development cycles which lead to more product launches and decreased time-to-market, all of which will lead to market share gain, profitable products, and ultimately customer satisfaction and loyalty.

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In the area of vehicle development car companies are beginning to realize the value of an end-to-end integrated approach to the overall process from vehicle concept, through engineering development, to production. The legacy sequential approach to vehicle development where body styling, structural engineering development, and manufacturing processes were separate functional disciplines and organizations that handed off each step of the process is giving way to a more integrated approach. Concurrent engineering methods have helped to merge concept, development, and manufacturing processes over the years, but the vision going forward is a knowledge driven vehicle engineering approach where knowledge-based reuse is widely adopted across all domains of vehicle development.

In recent years PLM suppliers to the automotive industry have been advocating an integrated and more holistic approach to body-in-white design, engineering, and production. The goal was to focus on common or standard vehicle designs that could be reused and modified to create new vehicle platforms and variants. While this approach has merit in that it fosters reuse and allows for an interrelated design/build process, it is incumbent upon the car makers to holistically adopt and implement this approach. Given that most car makers aren't in a position to replace their entire process, a modular approach to body design and engineering would appear to be an effective way to improve the process. A modular approach would allow all of the disciplines involved in body design/build process to use the tools and processes best suited for their particular function. The key to making this approach work is a standards-based interaction between each discipline.

The Evolution of Vehicle Design & Development

Development of complex mechanical structures such as automotive bodies has historically been an iterative and often sequential process beginning with concept and styling, progressing to detail design, test and analysis, tooling, and finally to the manufacturing processes. In the car body development process these stages are often accomplished in different departments, making the overall process from concept to production more protracted than necessary and accompanied by higher development costs.

Product designs have existed for as long as mass production has existed. Early on, in the manufacture of automobiles, as well as most products, there arose a division of intellectual labor whereby the design engineer was responsible for producing the design and the manufacturing engineer responsible for making the product. Because of this division, there is the likelihood for the product designer to work in vacuum unaware of manufacturing constraints. This functional separation and its resulting adverse affect on the design of the product and its producibility can have additional adverse affects on other functional domains within the development lifecycle such as tooling, production capability, and even maintenance. In the case of designing vehicle bodies, there is involved a chain of activities that have to be mastered across the entire product lifecycle. Development lead-time, final product performance, and quality are significantly affected by successful transitions through these lifecycle development phases.

> The functional separation of design and build activities can have adverse affects on other domains within the development lifecycle such as tooling, production capability, and even maintenance.

Moving From Sequential Design/Build to Concurrent Engineering

The inherent deficiencies of the “throw it over the wall” design/build engineering mentality gave rise to the concept of concurrent engineering. The introduction of concurrent engineering concepts and methods fostered the notion that the product design and the manufacturing processes that enabled the producibility of the design needed to be accomplished concurrently. The idea was that all product design needed to incorporate constraints imposed by the manufacturing processes and the capability of available production equipment and facilities. Typically, design engineers are primarily focused on the product's performance and functionality (fit, form, and function) and generally do not take manufacturing process design and constraints into consideration. Depending on which manufacturing processes are available, these constraints may be formalized into a set of rules or procedures that should be considered during the product design process, or more informally conveyed through individual experience and expertise.

As improved production methods are introduced and implemented into the overall production process, it become important for knowledge about the new methods and processes to have a direct influence on the product design. In essence, knowledge about these new and improved production processes must be made available to the design engineer. The preferred method which is indicative of the next generation of concurrent engineering is a knowledge-driven approach where constraints, methods, best practices, design and process rules, and general expertise are captured as a knowledge base that enables re-use and the propagation of best design/build practices.

Re-Thinking the Overall Design/Build Process for Body-in-White

Modern automotive body design has been accomplished by a multitude of Computer Aided Design (CAD) tools since the early 80s, and today there is a variety of these tools that range from sketching and styling, geometric bodies for detail design, test and analysis simulation for product testing, digital manufacturing simulation tools for building virtual production systems and work cells. Many of the early CAD design tools originated in the automotive and aerospace sectors as well as later product test (CAE) tools. The automotive industry represents one the largest users of PLM today with major manufacturers typically using a full portfolio of tools across the design/build lifecycle.

Even with the use of current state-of-the-art 3D development tools and collaborative PLM environments, the design, test, validation, and manufacture of a car body structure continues to consume an inordinate amount of time. At the same time, demands for shorter development times continue to rise.

A more integrated and streamlined process is needed to enable a continuous and collaborative flow from concept and styling through detail design development, tooling, and ultimately the body-in-white production assembly process. The vision and intent for body-in-white design/build is to create a robust development process for complex mechanical structures and apply it across the overall process through the stages of concept, development, detail design, and tooling.

Complex structural products such as automotive bodies are typically made of hundreds of components joined together. While a monolithic design is ideal from a structural perspective, it is virtually impossible to economically manufacture complex structures such as body-in-white components in a single piece. In some industries such as aerospace manufacturing, the trend is to consolidate multiple machined parts of a complex assembly into a single machined part. While this may represent significantly improved structure for aircraft manufacture and cost savings through high speed machining, this economic and production model could not be applied to automotive production, as the cost would be prohibitive in all but specialized markets. Because of this body-in-while production will remain assemblies of smaller sized components with simpler geometry that are, for the most part, produced by stamping and forming processes.

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It follows that conceptual stage designers and perhaps detail development stage engineers would need to determine a set of components by decomposing the product geometry of the entire structure. In most discrete industries (automotive, aerospace, industrial & agricultural equipment, high tech & electronics, etc.) decomposition schemes that consider geometry, functionality, and manufacturing processes are used. However, these types of decomposition schemes are usually non-systematic and depend primarily on the designer's domain expertise and experience, which may present certain producibility problems during the manufacturing process creation and production stage: 1) Issues around joining and fastening methods specified by the designer that do not meet desired structural or stiffness requirements of the assembled structure. 2) Issues of producibility where designed components and parts cannot be produced or assembled in an economically feasible manner.

Generally, these types of build issues are directly related to the component and join configuration in the body-in-white build phases, and usually occur in the production environment. Solving these manufacturing process issues early in the concept and design stages through process design validation and applied simulation technology can prevent costly and time consuming iterations later in the production stages. Moreover, introducing more systematic methods that enables a continuous and collaborative flow from product definition and structure concept to product development and structure control will allow consideration of the overall structure characteristics and enable the producibility and a body-in-white assembly with enhanced structural and stiffness characteristics.

This approach can be referred to as an *assembly synthesis* set of design/build methods, which constitutes a systematic approach where the design entire geometry is decomposed to components, structural zones, and joining and fastening methods. Since joints are often structurally inferior to components, it important the decomposition and joint allocation are done in an optimal fashion, such that the reduction in structural performances (e.g. stiffness) is maximized while achieving economical production processes and assembly methods.

Integrating the Body-in-White Development Process

The primary job of an automotive style designer is to take a concept for a proposed vehicle and define the product from the perspective of style, i.e. develop a creative and conceptual rendering of the vehicle based on criteria such as the class of vehicle (mid-sized sedan, sports car, SUV, etc.) required, market demographics, geographic regions, or niche markets. Creating a style concept that is appealing and attractive while embodying the basic criteria and function of the car is the intent and mission of the concept designer. Often the constraints on the concept design are not levied until the design is passed on to the developmental phase of detail body design. These constraints can involve structural requirements, ability to manufacture the body-in-white components, tooling requirements, and even manufacturing equipment resources availability.

> The constraints to vehicle development can involve structural requirements, ability to manufacture the body-in-white components, tooling requirements, and even manufacturing equipment resources availability.

To anyone in the car business body styling defines the essence of the vehicle in terms of its uniqueness, distinctiveness, and ultimately, the vehicle's appeal to the consumer. Automotive body stylists are perhaps one example of designers who need a high degree of conceptual freedom, but in today's high precision production environment, must also deliver the highest possible geometrical accuracy. They need design and styling tools at their disposal that allow for complete creativity, but also provide assurance that their design can be manufactured. Moreover, this points to the need to have an unrestricted and bi-directional work flow between the concept and styling phase and the developmental design activity, through the manufacturing process and tooling phase, all the way to production assembly.

The development process for a new vehicle model should be a collaboration and orchestration between the various disciplines needed to bring the new model into production. Generally, a new model development program begins with a team consisting of the stylist, detail engineering, manufacturing engineering, tooling, and marketing and sales. The criteria for the new model are identified and the stylist commences the development process. Even at this early stage, detail structural designers can work concurrently to define certain fundamental structure design features based on known non-variable requirements such as roof pillars, basic door requirements, and other basic body join requirements for components.

The stylist uses freeform shape molding applications such as Siemens PLM's NX Shape Studio to create the style and shape of the car body. Additionally, these styling applications allow the designer to render the body shape into Class A surfaces that the detail designer can use to design body components. Class A surfaces define the visible surfaces of the vehicle. This can include the exterior skin of the vehicle—body sides, hoods, doors, fenders, etc., as well as interior surfaces. These are a set of freeform surfaces of high quality that represent the transition from freeform styling to smooth mathematically defined surfaces of near perfect aesthetical reflection quality. Class A surfacing complements the prototype modeling stage by reducing design time and increasing control over design iterations.

It is at this stage that constraints can come into play that will have an effect on the original concept design. The style and shape of the vehicle may have to be altered and revised to meet structural and stiffness requirements, as well as occupant and other system packaging at this stage. If the concept design phase and the detail development phase disciplines and activities are not closely linked together in terms of a common and integrated design platform, the process can be highly reiterative, lengthy, and costly. Moreover, the assembly process should be considered early in the product definition and development stages, so as to reduce or eliminate downstream issues with the tooling and production assembly phases.

Integrating the Body-in-White Workflow: Design, Manufacturing Process, and Production Assembly

It has been researched, analyzed, and demonstrated by manufacturers across multiple industrial verticals that a segregated engineering discipline approach to product development usually inhibits a smooth design/build work flow, as well as increasing time to product launch. Integration of the complete body-in-white development lifecycle that involves design collaboration between the concept and detail design function through inter-part associativity between shape styling and component design is one of the most direct ways to accelerate this process.

In recent years PLM suppliers to the automotive industry have been advocating a monolithic approach to body-in-white design, engineering, and production. The goal was to create a parametrically driven library of common or standard vehicle designs that could be reused and modified to create new vehicle platforms and variants. While this approach has merit in that it fosters reuse and allows for a more end-to-end design/build process, the actual implementation of this approach has been constrained because very few car makers have gone in this direction.

The automotive industry has adopted the concept of the common vehicle platform that can spawn multiple models, but they have not pushed the notion of common body components and standardized vehicle design templates down to the level of body-in-white development. One of the obstacles to the adoption of this approach is simply that the process of designing and developing BIW surfaces and structures is usually rigidly divided between the various design, engineering, and production organizations. This makes it inherently difficult to define common processes, much less common templates and tools that would be used cross-functionally.

BIW Development Requires a Modular Approach

This development workflow must continuously progress through manufacturing process design and tooling through to assembly production. Each of the four functional areas: concept, development, manufacturing/tooling, and assembly represent distinct modules that involve specific design tools, engineering disciplines, and methods required for each phase of developmental process. The preferred intent is to integrate these functional areas through a modular approach that would allow the various design, engineering, and manufacturing disciplines to use processes and tools best suited for their particular function. However, the important caveat to this modular approach is the requirement and inclusion of a standards-based method of collaboration between the functional areas to deal with maturing and changing designs, engineering alternatives, and how changes are implemented.

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Once the body-in-white development process is initiated in the concept phase, the work flow should not be confined to linear sequential progression, but must be bi-directional and collaborative between all modules. Today, the design process is often distributed globally, and often includes multiple engineering organizations, suppliers, and other stakeholders. Additionally, the suppliers and other partners may use different design tools and in some cases, incompatible systems, but collaboration must take place for the design to be completed. This drives the need for an open, standards based approach to collaboration where tools like Siemens JT format can play a significant role. By using a format like JT, collaboration can happen regardless of where geometry was authored.

Manufacturing process design and validation and tool design are functional areas that would benefit greatly from seamless model exchange and common process templates. Body components that will be produced through a stamping process will require manufacturing process planning and tool design for the stamping and form dies. The body-in-white assembly process is typically a spot welding joining process performed in an automated robotic welding workcell. Using today's Digital Manufacturing simulation technology such as Siemens PLM's Tecnomatix 3D simulation applications, the production functions these robotic welding workcells can be virtually simulated with digital models of the body-in-white components as the work pieces. The kinematic motion and other control functions in the workcell can be virtually validated and commissioned using this Digital Manufacturing technology. In this production assembly phase, design intent and component interrelationships can be validated against the detail engineering design as a part of the integrated product development process.

Knowledge-Driven Vehicle Engineering

Today most advanced CAD systems are based on features, parametric modeling and associative design environment concepts. These types of systems evolved into a combination of parametric and associative CAD or feature-based CAD. Applied to car body design this approach spawned the concept of the archetype, a set of logical and parametric features of an object or system that can be used to build the specific or relative CAD model. In the body-in-white development environment these archetypes became body component templates that detail designers could use to develop body structures to apply to conceptual shape designs. This means that a concurrent engineering approach could also be used where the detail engineer can develop basic body component structures as the body styling and shapes are being designed.

Parametric, Feature-Based, and Direct Modeling Approaches All Support Knowledge Reuse

In 3D CAD model development today there are three basic design approaches: parametric, feature-based, and direct or history free modeling. All three approaches have their pertinence to the development process, and are beginning to be used in combination, although each approach has its supporters and detractors usually based on specific design requirements and established engineering methods.

In essence, parametric or history- based modeling provides a rigid modeling environment in which a history tree records the details of each geometric entity or feature as they are created. Parametric modeling uses parameters such as dimensions, geometric-based features, material attributes, shape formulas, and reference surfaces to define a model. The parameter may be modified later, and the model will update to reflect the modification. Typically, there is a relationship between parts/components, assemblies, and drawings. A part can consist of multiple features, and an assembly consists of multiple parts. Assemblies and sub-assemblies are used in installations leading to completed products, all of which is predicated on a hierarchical history-tree design structure that product engineering has used long before the advent of digital design.

Related to parameters, but slightly different are constraints. Constraints are relationships between entities that make up a particular shape. For a body-in-white panel the sides might be defined as being parallel, but of the different length. These parameters allow shape modification according to certain constraints and control the propagation of design changes. Parametric modeling is very powerful, but requires more skill and design experience in model creation. A complicated model for a machined or formed part may have multiple features, and modifying an early feature may cause later features to fail. Skillfully created parametric models are easier to maintain and modify. Parametric modeling also lends itself to design re-use which represents an important element to any design engineer initiating a new design.

Some of the inherent deficiencies of geometric model design have led to a more focused feature-based modeling approach. Geometric entities (edges, lines, curves, and solid primitives) alone sometimes do not convey the design intent as well as a feature (holes, pockets, bosses, and specific shapes) can. Moreover, features add a new dimension to the concept of reuse since common features can be incorporated into many models. A feature can convey specific portions of a model that are of particular significance to design intent as well as denoting a subset of shape primitives. Features can be thought of as building blocks for the product definition and can represent the engineering design intent of the geometry of the part or assembly.

Direct or history-free modeling basically removes the constraints associated with parametric modeling and allows the designer to make geometric and dimensional changes to specific parts and assemblies without "breaking" the history tree of the model. Removing the tightly bound associativity aspect of the parametric approach frees the designer to make direct, on the fly changes to parts, components, and sub-assemblies such as dimensional changes, and moving or altering features (holes, support elements, extrudes, pockets, etc.). Direct or explicit modeling, as it is sometimes referred to, is more concerned with the geometry or topology of the model, rather than in the order in which features were added. This approach is ideal for making innovative changes and improvements to products without a lot of up front planning that a parametric model would require.

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Additionally, direct modeling systems are well known for their ability to import models from other CAD systems more directly. However, the trade off here is that these imported models lose their intelligence because many direct modeling applications strip out the history and parametric data. This represents advantages and disadvantages for both parametric and history-free approaches. A history-based modeler can have difficulty dealing with imported models; in contrast, a direct modeler is getting unintelligent data. There has emerged a hybrid approach where attributes of direct and history-based modeling are combined. Here the designer can incorporate parts and features into existing models and add history as they go.

Conclusions & Recommendations

The automotive industry clearly faces some formidable challenges today. Given a global economy that is sharply defining a consumer market that is retracting as well as focusing on very specific needs, car makers must be able to meet a new set of market demands while remaining competitive. One strategy that the automotive manufacturers are using to attract new buyers is to concentrate on niche markets that define consumers with very specific wants and needs. Typically, vehicle production runs for these niche markets are small, placing even more emphasis on a very efficient and effective development process, as well as flexible and adaptive production systems. If the overall vehicle development process from concept to launch cannot meet cost and time-to-market requirements, the chances of leveraging a particular niche market is diminished much less being able to realize any profits.

Additionally, as the global automotive industry makes the shift to new generations of energy efficient and alternative energy vehicles, design/build development activity will not only increase significantly, but will have to move to new levels of knowledge driven design, engineering, and production methods. Car makers will need to adopt a more end-to-end holistic approach to their overall vehicle development process, not only to meet market demands, but to significantly improve their entire concept to launch development lifecycle.

Re-thinking their overall development process and adopting knowledge driven approaches and the tools that enable this approach can assure that new concepts will be engineered and produced in a timely and cost-effective way to meet market demands. Knowledge and innovation are the keys to future vehicle development, but only if they can be applied a repeatable and strategic driven approach across all programs. An end-to-end standards-driven development process that leverages all of the knowledge from each organization is the best way for car makers to rapidly develop the range of new models needed for the next generation of automobiles. Siemens PLM appears poised to lead the automotive manufacturers in this direction.

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Acronym Reference: For a complete list of industry acronyms, refer to our web page at www.arcweb.com/C13/IndustryTerms/

API	Application Program Interface
B2B	Business-to-Business
BPM	Business Process Management
CAGR	Compound Annual Growth Rate
CAS	Collaborative Automation System
CMM	Collaborative Manufacturing Management
CPG	Consumer Packaged Goods
CPM	Collaborative Production Management
CRM	Customer Relationship Management
DCS	Distributed Control System
DOM	Design, Operate, Maintain
EAM	Enterprise Asset Management
ERP	Enterprise Resource Planning
HMI	Human Machine Interface
IOp	Interoperability
IT	Information Technology
MIS	Management Information System
OpX	Operational Excellence
OEE	Operational Equipment Effectiveness
OLE	Object Linking & Embedding
OPC	OLE for Process Control
PAS	Process Automation System
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
RFID	Radio Frequency Identification
ROA	Return on Assets
RPM	Real-time Performance Management
SCM	Supply Chain Management
WMS	Warehouse Management System

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