Interest Group „Digital Plant“:

White Paper for the Use of Standards based Data Communication Methods in Automotive Industry

Accelerating Simultaneous Development of Products and Manufacturing Resources

Version:	*1.0*
Status:	***Final PDTnet version***
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Date:	*July 2003*
Distribution:	*PDTnet*

History

Version	Status	Authors	Changes
0.1	Draft	M. Ungerer , PROSTEP	Creation
0.2	Review V.	M. Ungerer , PROSTEP	June 18 meeting results
1.0	Final (PDTnet)	M. Ungerer , PROSTEP	Final Report for PDTnet

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Contents

PREAMBLE

The Interest Group Digital Plant was initiated by PDTnet. Due to the high interest the work is continued as a ProSTEP iViP Working Group. This document describes the results reached at the end of PDTnet. It is aimed as versioned document containing requirements and results of the IG Digital Plant. Due to its character of a „living document“ it will be extended and completed gradually according to the progress of the IG Digital Plant work within ProSTEP iViP. Some chapters will be supplemented later.

Third parties are kindly invited to provide their comments and additional requirements to the IG Digital Plant.

1 Background and Motivation

In the world-wide automobile industry one of the goals is to reduce development time and costs. The complete development and simulation of the manufacturing resources and factories for a new product on a computer is the first step towards achieving this goal. The computer model of the "digital plant" can be used to perform trials and calculations for which expensive physical trials are still needed today. This computer model is created by the combined effort of a number of developers using different Data Creation systems.

Due to the fact that each system defines its own data format the communication process along the computer-aided process chain today is tackled by duplicate data creation, redundant data management and expensive data conversion processes.

In order for the vision of “Digital Plant” to become reality, a neutral representation of the digital plant is needed, which can be processed by all the partners involved irrespective of data creation system used. This is why the car industry has been investing a great deal of time and money in the development and application of the neutral product data description in accordance with ISO 10303 (STEP) for several years.

However, the standardized data model is only one precondition to allow data sharing, exchange and transfer in a heterogeneous data creation systems environment. A common understanding about processes and operations creating and processing product and manufacturing data as well as standardized implementation methods are required in addition.

In addition, an increasing portion of engineering development work is given out by OEMs to suppliers. This requires a stronger integration of processes, information and systems between OEM and supplier. In order to cope with this, various IT solutions were developed during the last years. They can be generally classified into four groups:

- Asynchronous file-based data exchange
- Data integration based on Web-clients
- Synchronous data sharing
- Small-sized concepts and solutions, that are based on the techniques listed above.

Encouraged by the progress made with the “digital car” vision, automotive companies started to continue this work in the production planning area. Starting with a PDTnet application project between SCANIA and ABB, the Interest Group “Digital Plant” was initiated.

This paper provides an overview on the factory processes, discusses the data requirements and emphasizes the relevant standards. It also presents a concept how the concept can be brought into praxis.

In a nutshell, the goals of the Interest Group are:

- Preparing solutions for the integrated development of products and manufacturing resources
- Enabling and accelerating the collaboration between vehicle manufacturers and manufacturing equipment suppliers
- Providing access to actual product, resource and process data in a heterogeneous system environment (PDM, CAx, process and manufacturing resources planning systems)
- Enabling the coupling of systems
- Driving vendors to develop interfaces

- Establishing flexible and comprehensive data communication based on international standards

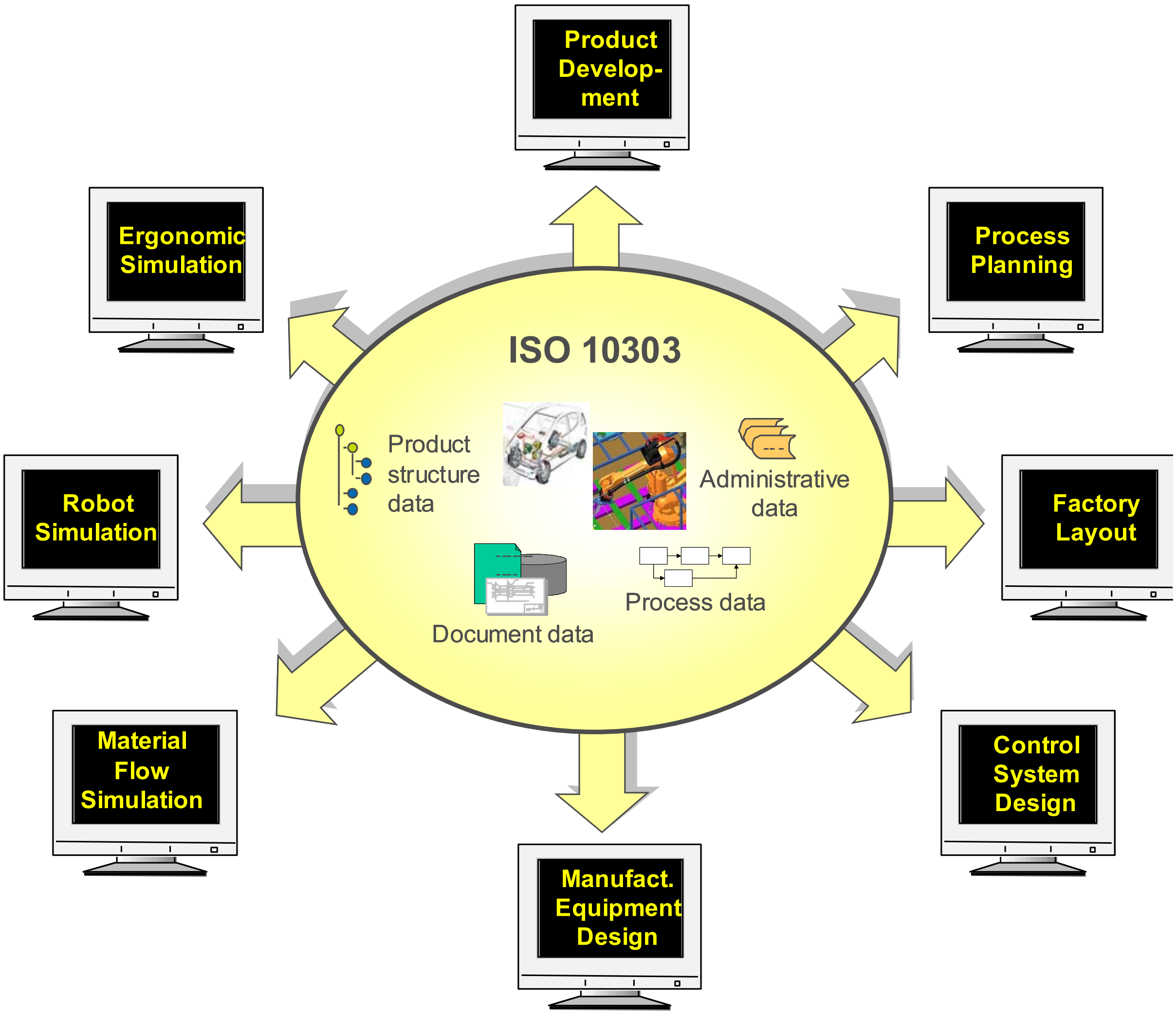


Figure 1: OEM – Supplier and In-house Downstream Process Communication

To reach these goals the following approach will be taken:

- Definition of application and system scenarios for the exchange of product and resource data (resource data: product data of manufacturing equipment)
- Definition of use cases
- Definition of recommendations for the use of ISO 10303 and related standards for the exchange of product and resource data
- Definition of implementation guidelines

2 General Scope and Approach

This White Paper covers four main topics regarding the integrated product development and manufacturing:

- Factory development processes
- Data requirements
- Manufacturing standards
- Guidelines to deploy the standards

The work addresses the whole manufacturing area, starting with Body in White processes and continuing in a later phase with power train, machining, assembly, etc.

The factory development processes which are subject to this paper are described in section 3. In section 4 the data requirements are discussed. Section 5 gives and overview on the relevant manufacturing standards and how they relate together. Section 6 outlines how guidelines for the application of these standards in automotive industry can be structured. Whereas section 7 deals with the guidelines for implementers.

3 FACTORY DEVELOPMENT PROCESSES

3.1 HIGH LEVEL APPLICATION ACTIVITY MODEL (AAM)

Several activities are carried out during the development of a manufacturing system/subsystem, from the development of a product to the validation and approval of a particular solution. These activities are related and interrelated through the flow of information between them. The information flow is important to understand in order to understand how the development of a manufacturing system can be supported by standards for information representation and exchange. The following activities have been identified, see also Appendix B:

- develop product,
- plan process,
- design factory layout and internal logistics,
- design manufacturing equipment,
- design control system, and
- validate solution.

3.1.1 DEVELOP PRODUCT

In the *Develop Product* activity the specification of the product, i.e. what is to be manufactured, is developed. The product specification includes such things as product structures and geometries.

3.1.2 PLAN PROCESS

In the *Plan Process* activity the specification of the process (process plan), i.e. how the product is going to be manufactured, is developed. A process plan specifies the manufacturing processes of the product, including assembly sequence and process operation structure.

3.1.3 DESIGN FACTORY LAYOUT AND INTERNAL LOGISTICS

The *Design Factory Layout and Internal Logistics* activity results in specifications of the shop floor and the flow of material. These specifications include structures and geometry of shop floor and media installations, such as where particular machine cells are located and the flow of material between these machine cells.

3.1.4 DESIGN MANUFACTURING EQUIPMENT

In the *Design Manufacturing Equipment* activity the manufacturing equipment specifications are developed. These include structure, geometry, and kinematics of the manufacturing equipment.

3.1.5 DESIGN CONTROL SYSTEM

The *Design Control System* activity results in specifications of how the manufacturing system and internal logistics are controlled. These specifications define the different control system modules that are needed, such as physical device controls, robot programs, and PLC programs.

3.1.6 VALIDATE SOLUTION

In the *Validate Solution* activity the different solutions created in the previous activities are validated. That is, they are analyzed and tested against the set goals and criteria. Hence, such things as the developed product, process plan, factory layout and internal logistics, manufacturing equipment, and control system are analyzed and tested by for example calculation or simulation. Solutions that fulfill the goals and meet the criteria are approved; solutions that do not are either rejected or result in change requests.

The change requests are then considered in an activity outside the scope of the AAM Appendix B. Decisions are made that may result in change orders that affect concerned activities in the AAM.

3.2 PROCESSES FOR BODY IN WHITE CONNECTIONS

A common understanding of Body in White Connection processes and the standardization of the related information and data exchange is required both for the cooperation between product development and production planning and to the downstream processes like CAE.

Whereas standards like STEP in principal support and provide solutions guidelines for the application of these standards are missing. This has the risk, that proprietary solutions based on specific CAD systems will be established, how it is currently pushed by some system vendors.

There are already activities started by users to bring these proprietary solutions to standards. Just to mention here the GACI. GACI analyzed the current situation and stated:

- OEM-Internal PDM-specific structures are ignored and therefore the created items are incompatible to the internal PDM processes and to the international standard STEP
- This leads to data exchange scenarios which are system dominated and do not conform with international standards like STEP
- In this context it is a severe deficit that STEP offers no working specification for the fasteners stuff
- The working group is charged with the task to define a STEP conformant specification of all process steps and their relevant entities important in the process chain of welding and setting fasteners downstream to the definition of robots and assembly lines for this work

4 Data requirements

The input and output data required for the involved systems is described in a data exchange matrix in Appendix C. In the following subsections more information and a short description on the information types and on the systems is given.

4.1 Definition and description of information types

- **Product Structure as designed**: product structure from a design view including part identification, properties, assembly structures and transformations
- **Product Mix**: How many of which product in which configuration to produce
- **Product Structure as manufactured**: Static view on the manufacturing structure
- **Assembly Sequence**: Detailing of the “Product Structure as manufactured**”** ny adding information in which sequence different parts are put
- **Connections**: Connection between parts, e.g. welding gluing, bolt connection, etc.
- **Assembly Path**: Geometric path to put things together
- **Part Geometry**: Geometric model of a part, e.g. a CATIA model file, VRML file
- **CAD model structure**: Structuring of geometric models within CAD systems
- **Resource Geometry**: Geometric model of machinery, production equipment, fixtures, tools, e.g. a CATIA model file, VRML file"
- **Resource Structure**: Structure of manufacturing systems
- **Process Structure**: connection between parts, resources, operations and factory area both from product and a factory view
- **Material flow**: what goes when to where including storage
- **Kinematics**: description of the kinematics behavior and structure ("how to move")
- **Movements**: Dynamic behavior
- **Shop Floor Structure**: Structure of the building excluding the manufacturing equipment
- **Shop Floor Geometry**: Description of the geometry of the building
- **Media & Installations Structure**: Structure of installations like fresh/waste water, process water, electricity, heating, air conditioning, communication, etc.
- **Media & Installations Geometry**: Description of the geometry of the installation
- **Part tolerances and features**:
- **Control system modules**: specifications of how the manufacturing system and internal logistics are controlled; specifications that define such things as physical device controls, robot programs, and PLC programs.

4.2 Definition and description of systems (functions)

- **CAD system**: system used to define geometry and kinematics. Used for product design, tool design, machine and equipment design. Adaptations for work shop layout planning where less model accuracy is required.
- **Calculation systems**: system used to evaluate dimensions and selection of material. Used for product design, tool design, machine and equipment design.
- **Process planning systems**: system used to define manufacturing process (assembly sequence or machining operation sequence, time estimation). Used for process planning and preparation.
- **Programming systems**: system used to create control code. Used for programming of NC machine tools, robots or handling equipment, coordinate measurement machines and PLCs.
- **Discrete event simulation systems**: system used to evaluate material flow, capacity, lead time.

- **Equipment simulation systems**: system to evaluate programmes and equipment (i.e. NC machine tools, robots, coordinate measurement machines
- **Process simulation systems**: system to evaluate part design, process selection and parameters and sometimes tool design (i.e. casting process, stamping process, cutting process). Used for process planning when defining the product.
- **Human simulation systems**: system used to evaluate ergonomic aspects and time estimation.

5 Manufacturing Standards

Naturally, not one standard can cover the whole area for information representation and exchange. The probably scenario include several standards that cover different parts. A number of current standards (IS) and standards that are under development are presented in Figure 2. They are presented in a product lifecycle perspective, i.e. when during the lifecycle of a product different can standards be applied.

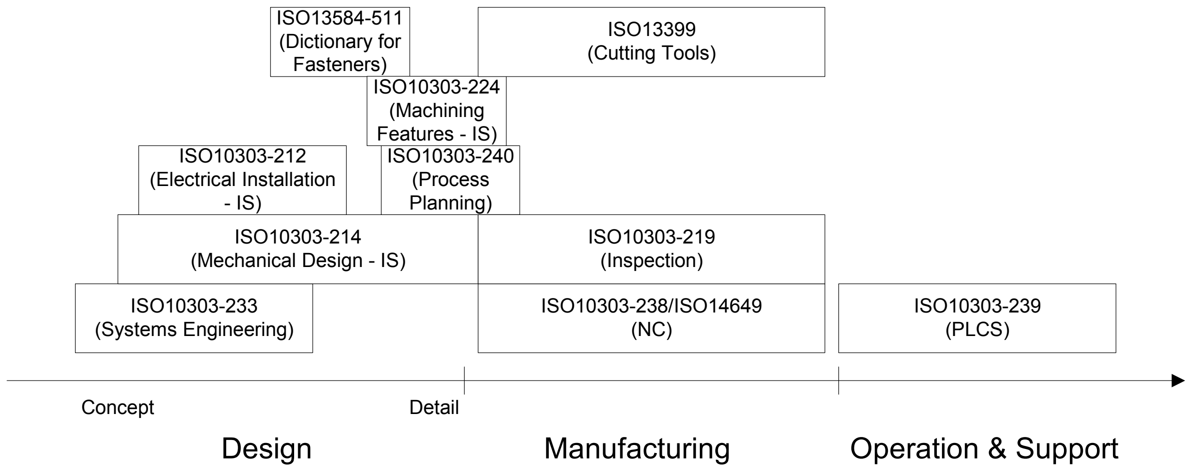


Figure 2: Standards from a product lifecycle perspective.

If a manufacturing system is considered to be a product, it is developed and sold by someone, the same standards apply to manufacturing system development, cf. Figure 3. An interesting aspect here is the operation and support phase of the manufacturing systems that coincides with the manufacturing phase of the product. Consequently, manufacturing aspects need to be considered during product design and vice versa. This issue is even less developed than that of representing information along the line of one lifecycle.

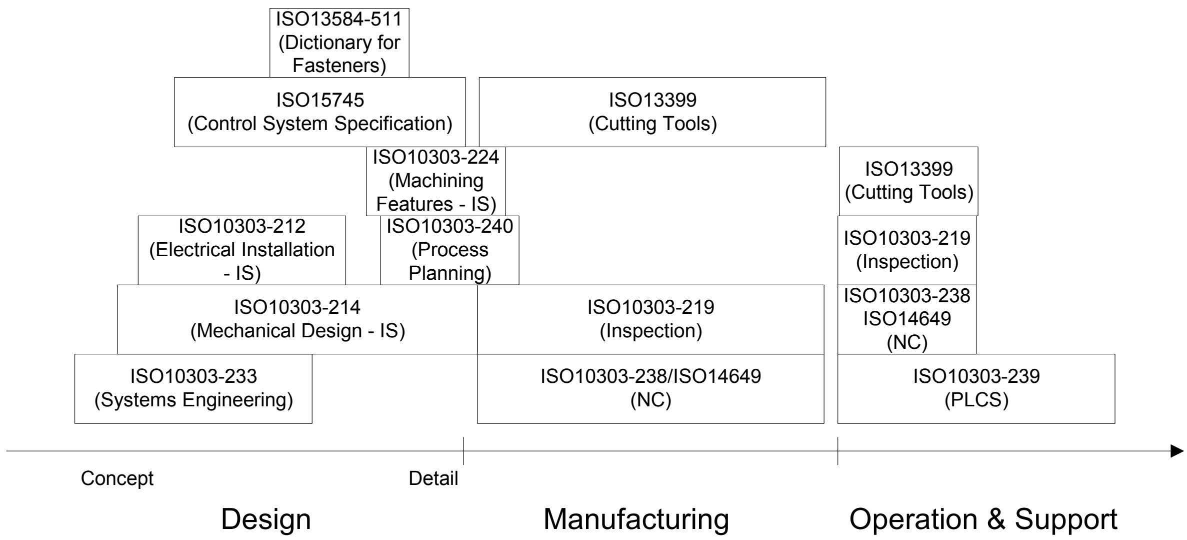


Figure 3: Standards from a manufacturing system lifecycle perspective.

5.1 ISO 10303-212: Electrotechnical Design and Installation (AP212)

The application protocol for Electrotechnical design and installation, or AP212, was published in February 2001. This part specifies an application protocol for the design and installation information of electrotechnical equipment used in plants, industrial systems and vehicles. The description includes various characteristics of the design, such as functional aspects, physical aspects or the aspects related to the installation of the equipment.

5.2 IS0 10303-214: Core data for Automotive Mechanical design processes (AP214)

The application protocol for Core data for automotive mechanical design processes, or AP214, was published in February 2001. This part describes the information required for automotive mechanical design processes, but have been proved to be applicable for any type of mechanical product, including products in the aeronautical industry. The information requirements are specified according to functionality, application objects, and application assertions.

Note: ISO 10303-203 (AP203) is not mentioned here because it can be considered to be a subset of AP214. The harmonization efforts between AP203 and AP214 (and AP212) have resulted in the so called PDM-Schema.

5.3 ISO 10303-219: Inspection (AP219)

This application protocol 219, which is in its development phase, addresses the importance of dimensional tolerances of mechanical parts and the activity of dimensional measurements. The scope of this application protocol is to enable interoperability of systems and software that operate around the execute-analysis interface.

5.4 ISO 10303-224: Machining Features (AP224)

The application protocol for machining features, AP224, is an international standard. This application protocol identifies specific characteristics of part shape used in manufacturing. These characteristics are used to define manufacturing features. The purpose of manufacturing features is to facilitate the identification of manufacturing shapes that are human and computer interpretable. Manufacturing features allow information about the shape to be used for decision in computerized process planning systems.

5.5 ISO 10303-233: Systems Engineering Data Representation (AP233)

The application protocol for systems engineering data representation, or AP233, is in its development phase. This part of ISO 10303 specifies the exchange and sharing of design and configuration control product information belonging to the design and validation phases for a system. AP233 supports the exchange of data during systems engineering including technical aspects, such as the systems functional and physical architecture, and management issues, such as validation and verification procedures.

5.6 ISO 10303-238/ISO 14649: STEP-NC (AP238/ISO14649)

The application protocol for STEP-NC, AP238, is an ISO Committee Draft. STEP-NC is an application protocol for numerical controlled machines and associated processes, including the scope and information requirements defined by the ISO 14649 Data model for computerized numerical controllers. ISO 14649 describes machining processes with respect to a part, including part geometry, manufacturing features, sequencing of operations, associated process parameter, and tool requirements. The scope of STEP-NC includes mechanical parts for manufacturing, manufacturing process descriptions, the AS-IS and TO-BE shapes of a mechanical part, manufacturing features of a part, manufacturing tolerance requirements of a part, tool paths for machining operations, manufacture of mechanical products using manufacturing processes defined in ISO 14649.

5.7 ISO 10303-239: Product Life-Cycle Support (PLCS, AP239)

The application protocol for Product Life-Cycle Support (PLCS), or AP239, is in its final development stage. PLCS aims to represent the exchange of information related to product support. It ensures that the support information that is generated when a product evolves can be exchanged, shared, and archived throughout the product life-cycle. The four key areas of PLCS are: Support Engineering, Resource Management, Configuration Management, and Maintenance and Feedback.

Note: In the context of manufacturing systems the manufacturing system is considered to be the product that needs support in its operational phase.

5.8 ISO 10303-240: Process Planning (AP240)

The application protocol for process planning, AP240, is an ISO Committee Draft. This application protocol defines the context, scope, and information requirements for digitally represented process plans for numerical control and manually machined parts. Included in this application protocol are the relationships that exist between the different process plan data items as well as the relationships that exist between these data items and the product definition data. Product definition data includes data items from design process such as geometry, surface finish and machining tolerance.

5.9 ISO 13584-511: Reference Dictionary for Fasteners

The reference dictionary for fasteners is in its development stage. This part of ISO 13584 specifies the reference dictionary for all parts described in the various ISO mechanical fastener standards, together with their descriptive properties and domain of values. This part contains a reference dictionary with definitions and identification of classes of fasteners, data element types that represent properties of fasteners, and domains of values for describing the data element types.

5.10 ISO 15745: Open Systems Application Integration Framework

The open system application integration framework, ISO 15745, is in its development stage. The framework provides the means to specify the integration of automation components within a manufacturing application, integration of multiple manufacturing applications, and integration of a manufacturing application and an information system to support and control the manufacturing application.

5.11 Overview of Data Types and Related Standards

Following is an overview of subsets of selected standards that can represent the information types represented in the AAM in Appendix B.

Note: That the information types are the same as in the data exchange matrix, cf. section **Appendix C**. Hence, it is possible to identify which standard(s) that may be used for a particular system.

- **Product structure as designed - AP214**-S1+S2+S3+S6+PR1 UoF.
- **Product mix (planning targets) - AP214**-S7+PR1 UoF.
- **Product structure as to be manufactured** - *See Product structure as designed*.
- **Assembly sequence - AP214**-S1+S2+S3+S6+S7+S8+PR1 UoF.
- **Connections/fasteners - AP214**-S1+S2+S3+S6+S7+S8+PR1 UoF; **ISO13584-511**.
- **Assembly path - AP214**-S1+S2+S3+S7+S8+PR1+ G1/G2/G3/ G4/G5/G6/G7/G8/E1 UoF.
- **Part geometry** - **AP214**-G1/G2/G3/G4/G5/G6/G7/G8/E1 UoF.
- **CAD model structure** - **AP214**-E1/S2 + G1/G2/G3/G4/G5/G6/G7/G8 UoF.
- **Resource geometry** - *See Part geometry*.
- **Resource structure** - *See Product structure as designed*.
- **Material flow** - **AP214**-S1+S2+S3+S6+S7+S8+PR1 UoF.
- **Kinematics** - **AP214**-S1+S2+S3+S6+PR1+K1 UoF.
- **Movements** - **AP214**-S8+PR1 UoF.
- **Shop floor geometry** - *See Resource geometry*.
- **Shop floor structure** - *See Resource structure*.
- **Media and installations geometry** - **AP212**-installation + site + product_structure + physical_connectivity + properties + classification UoF.
- **Part tolerances and features - AP214**-T1+FF1+FF2+FF3 UoF; **AP224**-part_model + shape_representation_for_machining + manufacturing_feature + feature_definition_item + feature_profile UoF.
- **Control system modules** – ISO15745.

6 APPROACH TO DEVELOP RECOMMENDATIONS

The approach to develop recommendations is part of the ProSTEP iViP work and not yet available.

7 IMPLEMENTATION SCENARIOS/GUIDELINES

The approach to develop recommendations is part of the ProSTEP iViP work and not yet available.

Appendix A IDENTIFICATION OF AREAS FOR FURTHER INVESTIGATION

This appendix will briefly introduce areas that have been identified as week or none existing in the standards. It may also be that the standard itself is sufficient to support the information requirements but that the particular standard, or part of the standard, has not been tested to verify its applicability.

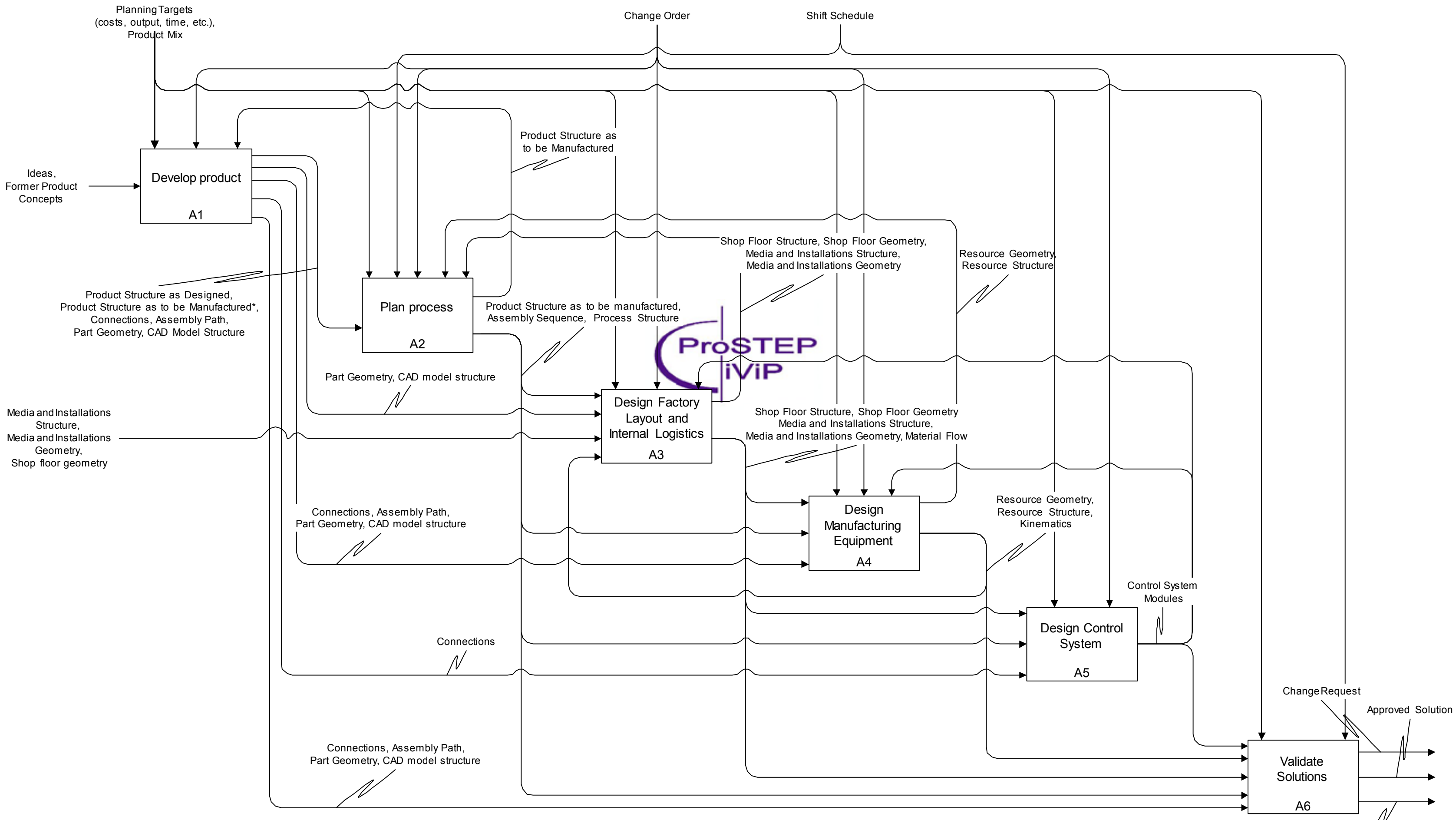
A.1 MATING DEFINITION IN ISO 10303-214 (AP214)

For body-in-white operations, AP214 has an interesting mechanism that have the capability to represent how two or more things are mated to realize an assembly. That is, the focus of the mechanism is on the definition of how the different parts are physically joined together. However, this mechanism is not yet thoroughly tested and from a body-in-white and weld spot perspective it seems to need more elaboration. This must, of course, be investigated further.

A.2 WELD SPOTS IN ISO 13584-511

The ISO 13584-511 define a dictionary for fasteners including rivets, bolts, screws, nuts, etc.. However, weld spot, which is an important type of fastener within the automotive industry, is not included. For the utilization of the reference data dictionary for fasteners within the automotive industry it is important that the types of fasteners included in the dictionary is extended to, for instance, weld spot.

Appendix B HIGH LEVEL APPLICATION ACTIVITY MODEL (AAM)



Explanation: Product Structure as to be Manufactured* is a high level, not yet determinde, product structure as it is to be manufactured.

Appendix C DATA EXCHANGE MATRIX

Id	Data	Explanation	Information types	System: Product Development (PD)	Process Planning (PP)	Factory Layout (FL)	Control System Design (CS)	Manufacturing Equipment design (ME)	Material Flow Simulation (MF)	Robot Simulation (RS)	Ergonomic Simulation (ES)
				whole product development process including DMU, CAE, etc.	connecting products, resources and processes	geometrical definition of building and production process	systems controlling materials flow and production systems	design of machinery, tools and production equipment including electrical design, hydraulic			
1	Product Structure as designed	Design view	ID, properties, hierarchy, variants, transformation of subparts, classifcation	out	in						
2	Product Mix	How many of which product in which configuration to produce	variants, variance, frequency	in	in	in	in	in	in		
3	Product Structure as manufactured	Static view on manufacturing structure	ID, properties, hierarchy, variants, transformation of subparts, classifcation	in/out	in/out	in	in	in	in	in	in
4	Assembly Sequence	in which sequence are different parts put together more detailing of the PS as	ID, properties, variants, classifcation, sequence, related manufacturing system		out	in	in	in	in	in	in
5	Connections	Connection between parts, e.g. welding glueing, bolt connection, etc.	ID, position and orientation,related parts, related resources, related process data, classification, properties	out	in		in	in	in	in/out	in/out
6	Assembly Path	Geometric path to put things together	related part(s), properties, related resources	out	in			in		in/out	in/out
7	Part Geometry	Geometric model of a part e.g. a CATIA model file, VRML file	geometry, level of details	out	in(visual)	in		in		in	in
8	CAD model structure	Structuring of geometric models within CAD systems	ID, properties, hierarchy, variants, classification, files	out	in(visual)	in		in		in	in
9	Resource Geometry	Geometric model of machinery, production equipment, fixtures, tools	geometry, level of details		in/out	in/out		out		in/out	in/out
10	Resource Structure	Structure of manufacturing systems	ID, properties, hierachy, transformation of subparts, classifcation		in/out	in/out	in	out	in	in/out	in/out
11	Process Structure	connection between parts, resources, operations and factory area both from product and a	ID, properties, hierachy, sequence, related resources, related products/parts, related connections related areas (shop floor)		out	in	in	in	in	in/out	in/out
12	Material flow	what goes when to where including storage	related parts, properties, related resources, related operations			out	in	in	in/out		
13	Kinematics	description of the kinematic behaviour and structure ("how to move")	structure, joints, controller logic			in		out		in/out	in/out
14	Movements	Dynamic behaviour	sequence of joint angles and translations, acceleration, speed, starting time		out	in/out	out			in/out	in/out
15	Shop Floor Structure	Structure of the building excluding the manufacturing equipment	ID, properties, hierachy, transformation of subparts, classifcation		in/out	out		in	in	in	in
16	Shop Floor Geometry	Description of the geometry of the building	external/internal geometry, level of details		in	in/out		in	in	in	in
17	Media & Installations Structure	Structure of installations like fresh/waste water, process water, electricity, heating, air conditioning,	ID, properties, hierachy, transformation of subparts, classification		in	in/out	in	in		in	in
18	Media & Installations Geometry	Description of the geometry of the installation	external/internal geometry, level of details		in	in/out	in	in		in	in
19	Part tolerances and features										
20	Control System Modules	Specification of how the manufacturing system and internal logistics are controlled	specifications of physical device controls, robot programs, PLC programs			in	out	in	in	in	