White Paper


# prostep ivip White Paper

## Automated Functional Data Exchange
## in the Automobile Industry (FDX)
## A new data exchange format based on existing standards

FDX Project Group

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# Abstract

This prostep ivip / VDA White Paper has been devised by the FDX Working Group. The document presents a new standardized machine-readable data format for the exchange of functional data between OEMs and suppliers. Functional data refers to characteristic values, characteristic curves and characteristic fields for different parts and components. They are usually determined by physically or virtually created measurements.

The new standard enables parties to exchange their functional data in a highly structured way. The main goals of the standard are

- Harmonization of exchange of functional data between OEMs and suppliers.
- Improved quality and availability of functional data for CAE/simulation purposes
- Elimination of discrepancies in functional data between ordered and delivered data
- Reduction of misinterpretation of data during exchange and lifecycle
- More extensive automation in data generation, exchange, and processing

The FDX format is based on proven industry standards such as ASAM ODS, the corresponding data exchange format ATFX and the open-source Eclipse openMDM® application model.

# Disclaimer



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# 1 Introduction

## 1.1 Definition of Functional data

In our context functional data is representing the characteristic properties of (mostly) mechanical components. It describes as numerical information (e.g. values, curves and fields) how a component is working (→ the function). The information about the characteristic properties of components can be used to design and simulate the functionality of the component in virtual development.

Functional data typically are derived from discrete measurements in a continuous scope of definition. It can also be determined by simulation.

Functional data mean a reduction of the overall (physical/chemical/…) behaviour of a component/system with respect to the relevant effects. In combination with functional models (0D/1D/2D), functional data allow to describe complex systems with reduced and focussed modelling and calculation effort.

## 1.2 Meta Data Concept

The measurement, modeling and validation of components and properties lead (or requires) to a huge amount of descriptive data (so called meta data). The long-term traceability and interpretability of this data requires a standardized and flexible handling of it.

There are several reasons why meta data is so important: The most important one in the context of functional data is that engineers need to know the detailed description of a component and the way in which the functional data was measured, calculated or estimated. Without detailed meta data information, functional data loses its context and renders meaningless characteristics, curves, and fields.

## 1.3 Use of Functional data

Functional data is necessary in different process steps of the component design and validation phases, but even more in the development of systems, where functional data allow a reduction of complexity The quick calculation of such systems can only be realised by focussing on the relevant effects, e.g., by using ordinary differential equations (ODEs) with functional data linked to the coefficients of these ODEs.

Consider the example of a shock absorber: in many cases it is sufficient to reduce the function of the shock absorber to a force versus speed relation of the piston relative to the cylinder. The alternative is to model and simulate it as a combined finite element (FE) model and computational fluid dynamics (CFD) model with extensively more calculation time. This would not allow the application in e.g., a vehicle dynamics real time model.

### 1.3.1 Component Capabilities

As mentioned before functional data describes the characteristic properties and so the capabilities of a component. This includes the mode of functionality in the normal operational range and the way a component acts at the limits of its functionality. Engineers responsible for the component can add this data to other component describing data like geometric or materials data.

### 1.3.2 Parametrisation of Simulation

One of the challenges of defining and executing simulations is the parametrisation of it. The result of a simulation depends fundamentally on the data input quality. Therefore, a higher quality of functional data as input data leads to a higher quality of the simulation parametrisation and finally to a better simulation result.

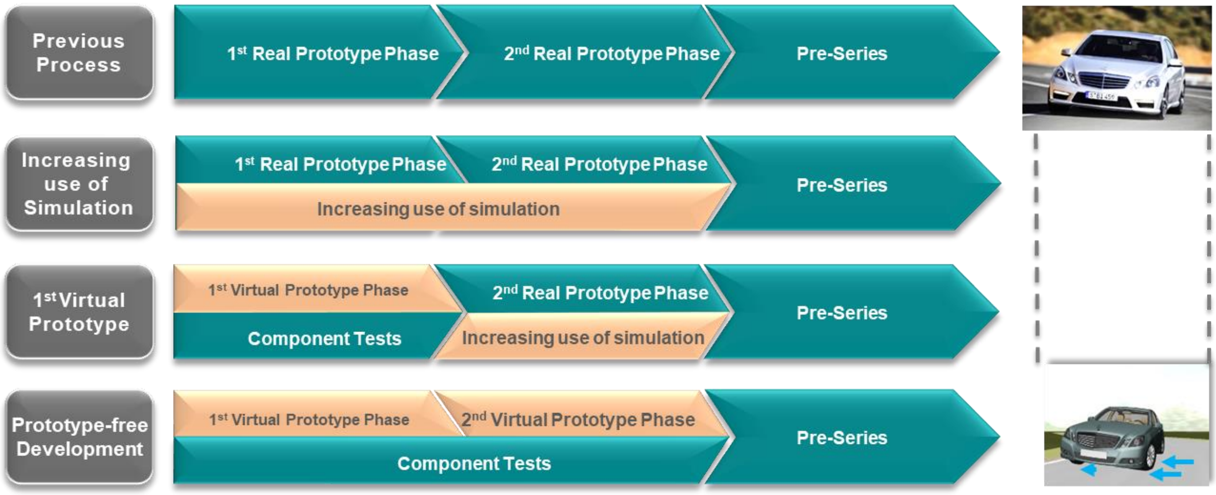
Quality in this context can be defined as the accuracy, but also as the significance: understanding, how and why a parameter was determined is essential to a qualified usage of simulation models.

The use of functional data as parametrisation data in the virtual development is the main topic in section 2.

# 2 Prototype Development

## 2.1 Evolution: From Real Prototype to Prototype-free Development

The following picture describes the evolution of classical physical testing using different development phases of a real prototype to physical-prototype-free development based on virtual prototypes.

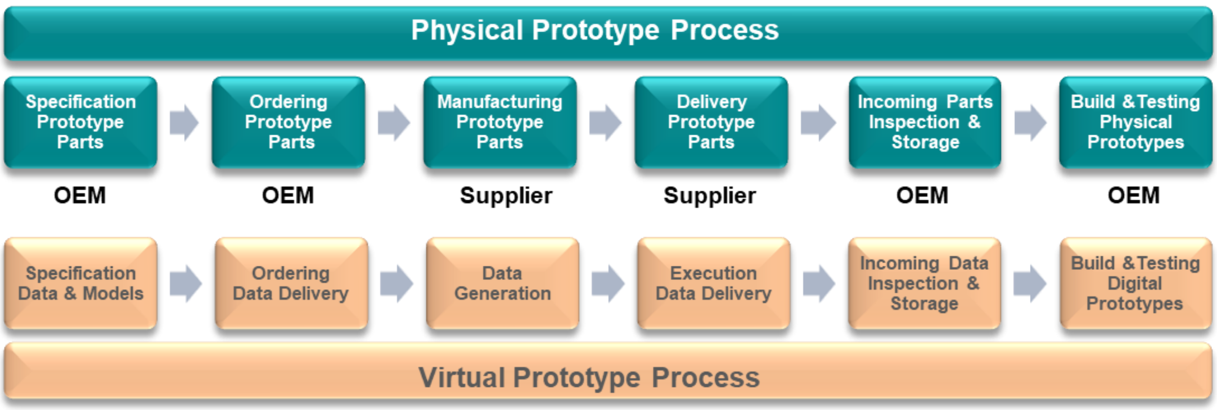



The increasing use of simulation in vehicle development is accelerated by the reduction of real prototype tests. The reasons for that are on one side the high costs of physical prototypes, but more and more the exponentially increasing need for tests and safety concerns: new ADAS and automated driving functions require considerably more tests, many of them in safety critical test conditions.

So the focus of physical testing is shifting to component tests as well as an increasing use of simulation during all development phases, because more and more physical prototype phases are replaced by virtual prototype phases including finally virtual prototypes and their descriptions. The ultimate goal of this transformation is a near physical-prototype-free vehicle development, which would limit/reduce the cost of development and validation enormously.

## 2.2 Protype Processes

As shown in the following picture the classical physical and the virtual prototype processes are similar:




The picture also shows that both – the physical and the virtual – process steps are requiring data exchange of functional parameters between OEMs and Tier-x suppliers or more common between customers and contractors. Functional parameters created in and determining the physical world must be also available in the virtual world.

## 2.3 Virtual Development

Virtual development needs different types of data for model-based systems engineering which includes model structure and model parameters. All process steps need parameters which must be stored and available on the customer and contractor side but also have to be exchanged between these two parties. The lack of a definition for standardized data and exchange format of functional data is one of the current problems in managing functional data. This issue is solved by using the FDX standard.

## 2.4 Requirements & Needs

Functional parameters are mainly determined by measurements in the physical, but as also in the virtual world.

Applying a MBSE approach requires a clear definition of functional data to be exchanged and communicated through the phases and levels of component and system design. On all levels, functional data are used to describe behaviour. Ambiguous usage of such data leads to double work and potentially to high cost for miscommunication.

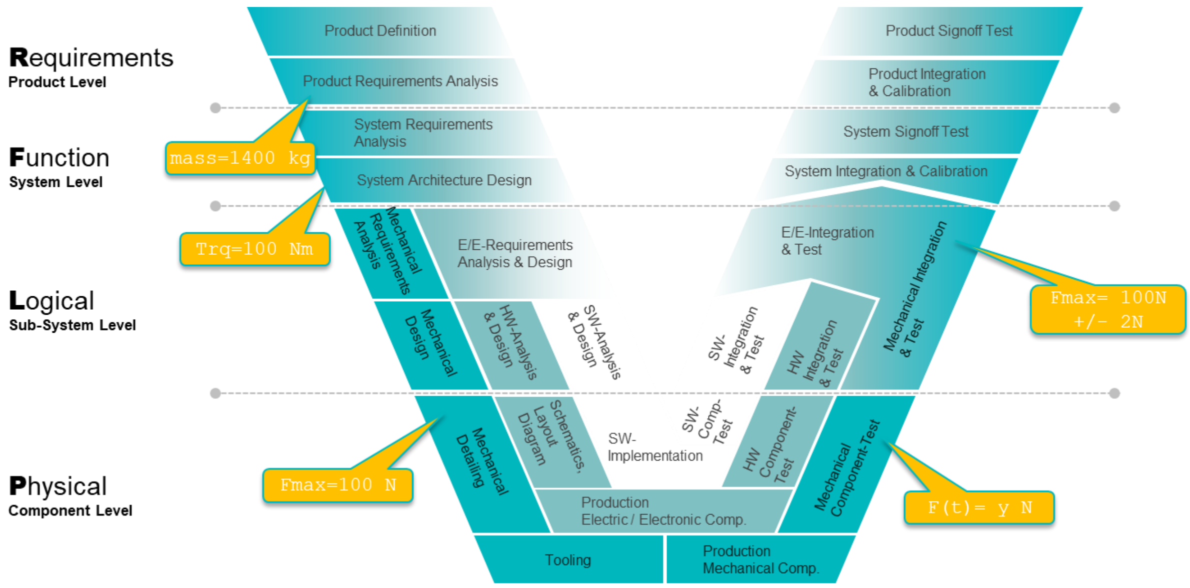



**Figure 2-1: RFLP architecture applied to the V-model**

### 2.4.1 Model Parameters Quality

Improve quality & availability of functional data for simulation/CAE

Parameters for a functional simulation are typically determined by a physical test. The observed effect in the real world contains all relevant information implicitly.

By selecting the measurement equipment, time and place, the information is reduced, so that data acquisition is representing only a small window to reality.

During data analysis this information is even further reduced – whether intentionally or accidentally.

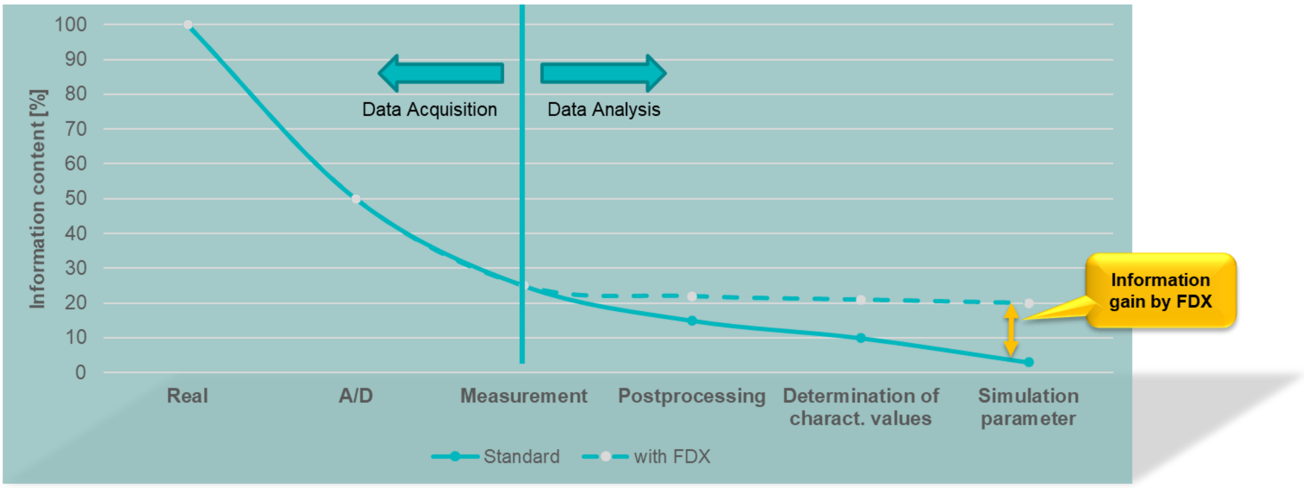



**Figure 2-2: Loss of information from reality to usage**

FDX cannot prevent the loss of information during data acquisition, but it can reduce the loss in the analysis phase by maintaining clarity – with metadata and a clear definition of component specific detail knowhow. By this, additional knowledge is generated.

FDX creates an opportunity to improve quality and availability of functional data for design and simulation. This is not limited to functional simulation as also classical CAE has a need for functional data.

### 2.4.2 Uniform Data Formats & Exchange

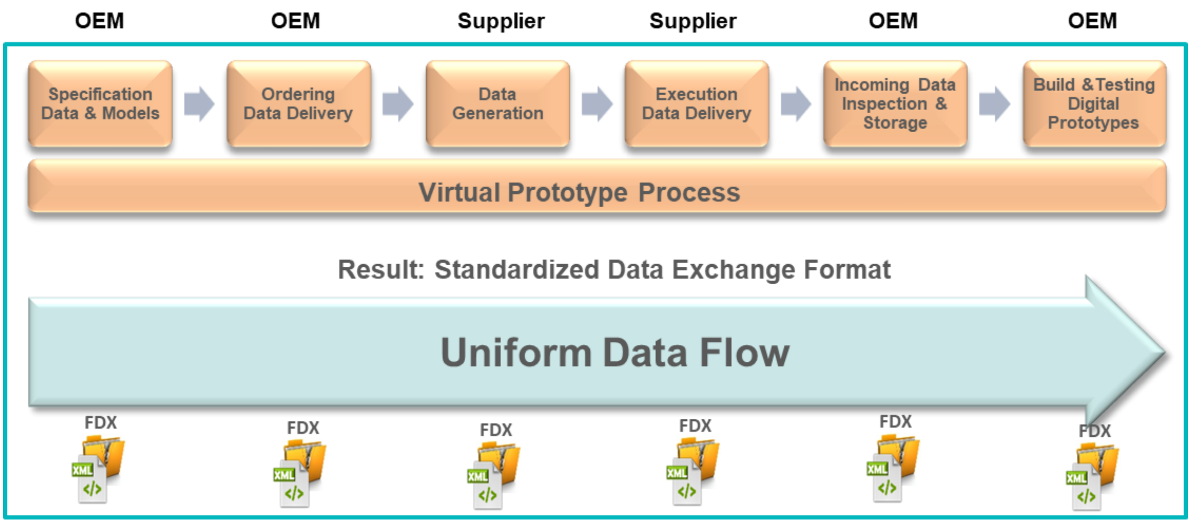



**Figure 2-3: Standardized exchange along the development process**

Building physical or virtual prototypes is a complex task that has well defined steps, which include different partners – internal or external.

At the start requirements that shall be fulfilled are defined.

All communication steps in between bear the risk of misinterpretation. So, any means to reduce miscommunication is essential.

OEM and Tier1/2 have identified that a uniform, standardized data exchange format is needed in this situation.

In addition to the format, a lightweight process for order and delivery is essential to accompany the exchange process.

Both means enable an easy and automated integration into the existing data management solutions.

### 2.4.3 Process Quality & Data Requirements

**Overall:**

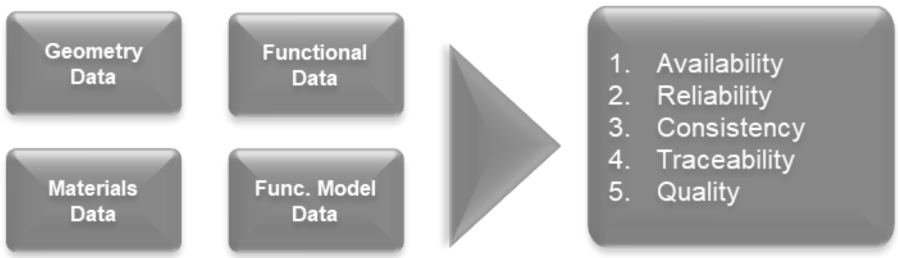



**Figure 2-4: Requirements for data exchange**

**General requirements for a reliable and sustainable data exchange in this context are:**

- High process quality and security: Automated data exchange is powerful but can be very critical if quality is not sufficient. That is why a process with high quality and reliability (& security) is mandatory.
- Internationalization: For a wide usage in the global partners networks an approach is required that is compatible to different languages
- Low operating costs: Data exchange on a standardized base is not a unique selling proposition, that companies would heavily invest in. So, it has be simple to introduce and maintain such a solution with respect to tool integration and daily usage (e.g., training)

**OEM specific Requirements:**

- Acceptance from suppliers
- Consistent component description
- Flexibility and expandability

**Supplier specific:**

- Consistent use by many OEMs
- Protection of intellectual property
- Efficient creation of exchange objects

**Conclusion:**

- Accepted Uniform Data Model and Data Exchange Format is needed
- Software Solutions to support exchange process are necessary

# 3 FDX Format as the Solution

The prostep ivip FDX group works on the requirements and needs which are described in the last chapter. Let's start the description of the solution with a short summary

- FDX defines an exchange standard for functional data which is based on well-known industry standards and contains high level of industry state-of-the-art technical details
- Based on these standards, FDX allows to define the meta data description of components and systems as well as the definition of the way the functional data for these components/systems were created and determined
- All users, who are involved in the functional data order/delivery process, use the same high-quality data

## 3.1 Technical Details of FDX

FDX data exchange is organized in the FDX zip container: All related data and files are bundled, so that only one file is exchanged.

### 3.1.1 Underlying Standards

The most important part of the FDX Zip Container (*.fdxc) is the "Exchange file" in the ATFX format. The data format is XML-based and defined by the industry standardisation group ASAM e.V.. The ATFX itself is part of the ASAM ODS (Open Data Services) standard.

The second industry standard, which is used in the FDX context, is openMDM® (open Measured Data Management). openMDM® is an ASAM ODS based model template on which domain specific ASAM ODS based application models could be developed and defined. The reusing of well-established standards increases the acceptance of the data format and allows the use of existing ASAM ODS compliant applications.

The FDX application model is an openMDM® based application model for the exchange of functional data. openMDM® is provided by Eclipse foundation in the MDMBL project.

### 3.1.2 ZIP Container Structure

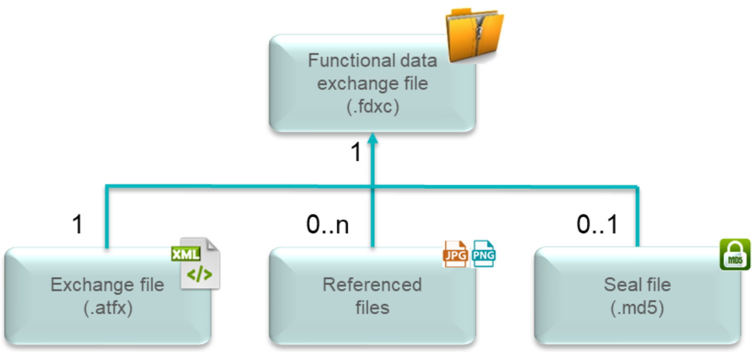



**Figure 3-1: FDX Zip Container Structure**

### 3.1.3 Exchange file

The ATFX file of a FDX zip container includes the meta data description and a generic description of values, curves and fields. By describing the data in a detailed way and the creation of rule-based dependencies between attributes, there is a reducing room for interpretation and misunderstanding on sending and receiving side. And since the ATFX file includes the information about the data model, every ATFX complaint application can manage the exchanged functional data.

The data model, which is provided by the FDX group, is an overall model for different types of components with the possibility of divisibility into several sub-scopes. The model is not fixed - users of FDX (usually the customers) can strip down the data model and can expand the model by adding customer-specific information blocks.

The following picture describes the structure of the ATFX exchange file for customer / contractor data request and data delivery.

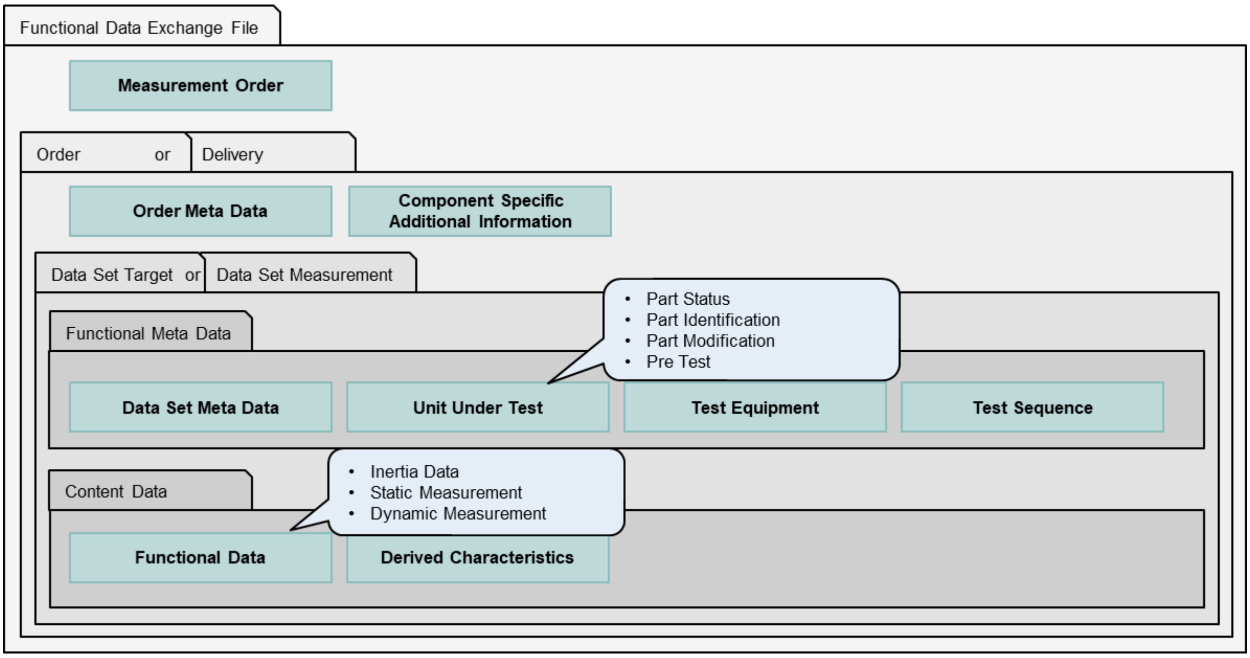



**Figure 3-2: FDX ATFX Data Structure**

On the top level the FDX ATFX file includes overall information about the measurement (functional data) order and additional descriptive information about the component. Usually some of the information already exists on the customer side, some of the information is created and added by the contractor. The partition between customer and contractor data is drawn from order to functional meta and content data.

The customer defines the order and functional data, which includes detailed information about the component (unit under test), the equipment and the way the functional data has to be created. In addition, the customer can add value, curve and field information as requirement or other specifications for the contractor. The contractor completes the meta data information and adds the determined functional data.

### 3.1.4 Example Data

The following examples are based on the FDX Recommendation Part 3.1 for Elastomer Bushing:

Part / Component specific information (Part Type):

- Conventional
- Hydraulic
- Slot Bushing
- Bushing with voids
- …

Test sequence specific information (Test programs):

- Amplitude Sweep
- Medium Load Sweep
- Frequency Sweep

- Measurement with Oscillating Excitation (more detailed)
  **Mutually exclusive parameters for defining the maximal excitation velocity:**
  - Revolution Value (for eccentric test benches)
  - Frequency Value together with Signal Shape definition
  - Max. Velocity Value together with Signal Shape definition

  **Mutually exclusive sets of parameters for defining the maximal load values:**

  Parameters for translational excitation within the force regime:
  - Force Start Value
  - Force End Value

  Parameters for rotational excitation within the force regime:
  - Moment Start Value
  - Moment End Value

  Parameters for translational excitation within the displacement regime:
  - Displacement Start Value
  - Displacement End Value

  Parameters for rotational excitation within the displacement regime:
  - Angle Start Value
  - Angle End Value

Content Data (Functional Data - Static Force Displacement Characteristic Curve)

- Measurement results are described by following vectors:
  - Time
  - Velocity
  - Displacement
  - Force
  - Temperature
  - Hysteresis Loop Counter
- Plot: Force against Displacement

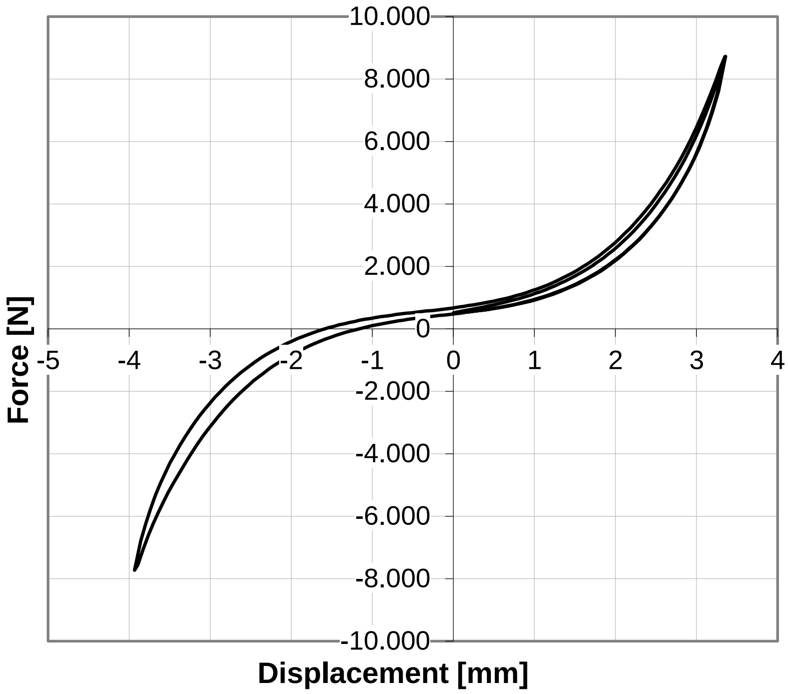



**Figure 3-3: Example plot (Force against Displacement)**

### 3.1.5 Referenced files

Additional artefacts could be added to the FDX zip container. These documents ("Referenced files") are helping customer and contractor to understand the exchanged data in a better way.

### 3.1.6 Seal file

A seal file indicates whether the content of the FDX zip container is validated. It contains a checksum over all files. The seal file mechanism will be implemented at a later stage.

## 3.2 Use Cases

### 3.2.1 Component Capabilities

In the cooperation process between OEM and Tier 1 or Tier 1 and Tier 2 tests for components/systems are regularly agreed upon. This was the motivational use case for FDX: To clarify, what is expected (which tests are performed in which configuration) and what was actually tested (deviation from request, metadata on test setup, tested unit…) sometimes differ and transparency about these deviations is required.

Test data exchange has long been established, but the quality of data and metadata is depending on many factors and has not been paid enough attention to in the past, as it is important to avoid error prone transformations.

By using FDX, the focus of this exchange can be on the actual performance of the unit under test.

The ordering party can easily verify the capabilities of the components and ensure that the requirements are met.

### 3.2.2 System design

In an early phase of development system design by simulation supports the detailing of requirements.

For example, a detailed multi body simulation can define the target damper force curve, that shall be used as a reference for the component design by the supplier. By specifying this target curve, the expected behaviour of some functional aspect during the detailed design can be linked to the requirements. This clear link is often lost in the past in the agreement and execution of the process, limiting traceability.

### 3.2.3 Parametrisation of Simulation and Physical Tests

Functional data are the decisive input to make a simulation model a realistic representation of a specific system/component. Many simulations, especially in the integration and validation phase, rely on such parameters. Yet as there are different models for different purposes, it is mandatory to exactly understand the meaning of measured functional data to map them to simulation parameters. This can be done if relevant metadata are available – FDX ensures that.

For a simulation task, simulation parameters can be requested in FDX format (e.g. specifying the required number of breakpoints) and the delivered FDX can easily be applied to the simulation model to run the simulation task with efficiency and confidence – the parameters are credible. This avoids misinterpretations and duplicate communication.

## 3.3 Harmonizing Data Exchange

### 3.3.1 Order and Delivery Process

Order and delivery – OEM <-> Supplier

Prerequisite to a successful collaboration based on a standard like FDX is clear communication and agreements in the contract phase. The exchange format and content have to be specified, so that both partners know the format, understand the benefits and implications of its use. This is described in detail in “Smart Systems Engineering Reference Process”.

In this phase, it is possible to make adaptions to the content of FDX: additional metadata can be defined between both parties, metadata can be removed, specific rules can be agreed upon…

In the execution phase, the typical workflow is as shown in Figure 3-4:

The data requestor describes the needed data in the FDX format (this is done by tool support) and creates an order that is then sent to the data supplier (the data exchange layer is flexible, not defined in FDX).

The data supplier then checks and accepts the order. In the next step the tests/simulations are executed to generate the required data (e.g., on a test rig). These data are then converted into FDX standard (if the data generator is not providing the data directly) and the delivery is finalised (e.g., approval, controlling). Now it can be sent back to the requestor, who validates the data by the metadata that the delivery is as expected. If the quality is confirmed, the data are ‘onboarded’ into the requestor’s system (e.g., PLM, TDM) and can be used for its intended purpose.

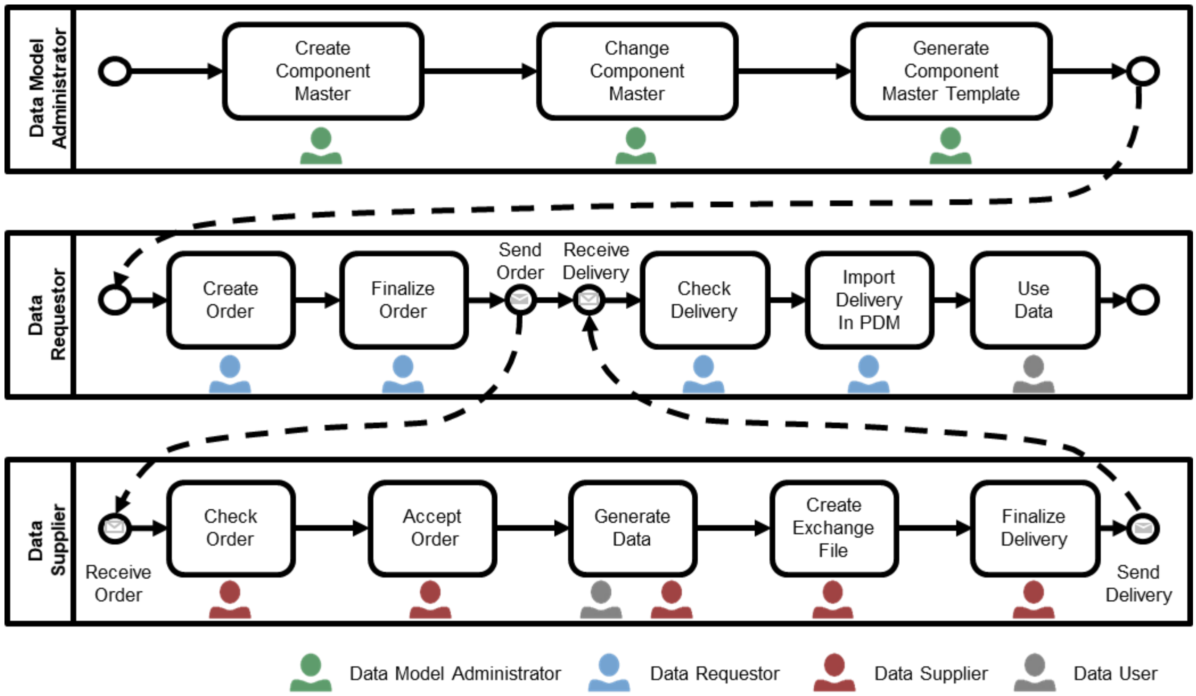



**Figure 3-4: FDX order and delivery process**

### 3.3.2 Traceability

According to ISO/IEC/IEEE 24765:2010 traceability is defined as

*Discernible association among two or more logical entities, such as requirements, system elements, verifications and tasks.*

This is an important aspect in the exchange between partners of different companies and even different departments, especially with different focus (e.g., test and simulation).

1. Looking back from a final artefact to its history:

Especially for providing evidence in final validation or certification situations it is important to be able to show, where a result/decision came from.

**Physical test**: Starting with a test result, it is important to understand, what components and test equipment were used to create this result. A test has several key elements that influence the result. The test unit(s) used is of course a main element. But it is also important to understand, which test rig and test adapters were used, their history and calibration status, test environment conditions, …

**Simulation**: Starting with a simulation result, it is important to understand, what artefacts and data were used to create this result. A simulation has several key elements that influence the result. The model used is of course a main part.

This use case is typically relevant in the validation and verification (V&V) process.

2. Understand cumulative knowhow:

Components/systems improve over time and many versions of a component are created - based on experience and improvements in development or modelling. So, a system (model) can be understood only when its history is clear (who did what why, based on which assumptions and constraints). This is even more relevant in the area of functional models, when a component/system is reduced to key functionality and the choice of parameters (functional data) is critical.

This is true for all kinds of usages.

## 3.4 High Process Quality

In general, the exchange process must be reliable and always lead to credible data. This is enabled by the usage of established standards, a simple process schema, and detailed definitions (attributes clearly explained).

Furthermore, an internationalization is necessary for international data exchange to avoid misinterpretations due to different languages.

With a wide coverage of tools that can handle this standard in the future, the operating costs will remain low.

**OEM specific Requirements:**

An OEM exchanges data with many suppliers. It is therefore mandatory to have an efficient process that can be applied to all of them and that helps to standardize project execution in large teams. Yet that has to be agreed on and supported by the partners.

There will always be the need for some specific agreements, so the standardized exchange needs to have enough flexibility (e.g., if some attribute is not relevant or known) and should be expandable (e.g., if a new component has an additional attribute).

Starting the exchange on such a new standard is not a given and requires a proactive acceptance by all parties involved, as only then FDX can unfold its potential.

**Supplier specific Requirements:**

One main objective for the suppliers for using a data standard is the wide acceptance and use by many OEMs as only this will justify the initial investment into the FDX tool infrastructure and processes. Supporting different data formats for different OEMs increases operating costs for the supplier.

Developing new, innovative products is a key success factor for any supplier. To protect the intellectual property of the supplier, data formats must be flexible enough to adjust for these requirements for example through bilateral adaptions with a specific OEM, without aspects of this information having to directly go into the data exchange standard.

As cost pressures apply especially to the supplier side, creating and handling of a standard data format must be easily and efficiently possible. Low initial costs, high degrees of automation and low operating costs for data transformation and handling tools are key objectives.

- Consistent use by OEMs
- Protection of intellectual property
- Efficient creation of exchange objects

## 3.5 Link to prostep ivip standards

### 3.5.1 SysML

The SysML project group is examining how the modeling language could be adapted and developed to achieve full industrial applicability of SysML in the context of model exchange in the future. Especially the topic of parameter management has been identified as a rising challenge, in which FDX can be of help.

At the interface model to real world data FDX could provide data and parameters based on the underlying SysML models.

### 3.5.2 Smart Systems Engineering

The Smart Systems Engineering (SmartSE) project group publishes recommendations for process design, promotes technical standards for the cooperative development of complex mechatronic systems, and supports the creation of transparency regarding systems engineering objects.

Enabling collaborative development and validation of complex products by simulation along a multi-tier supply chain includes the usage of FDX data to increase the simulation (process) quality.

An example of how to use FDX in the Credible Simulation Process (CSP) has demonstrated the good compatibility and how FDX can complement CSP.

### 3.5.3 Standardization Strategy Board and Digital Data Package

The objective of the Standardization Strategy Board (SSB) project is to achieve end-to-end coverage of the business objects and interfaces required in the collaborative systems engineering (CSE) processes and to achieve this on basis of system engineering relevant IT standards to realize the vision of a digital twin based on systems engineering IT standards.

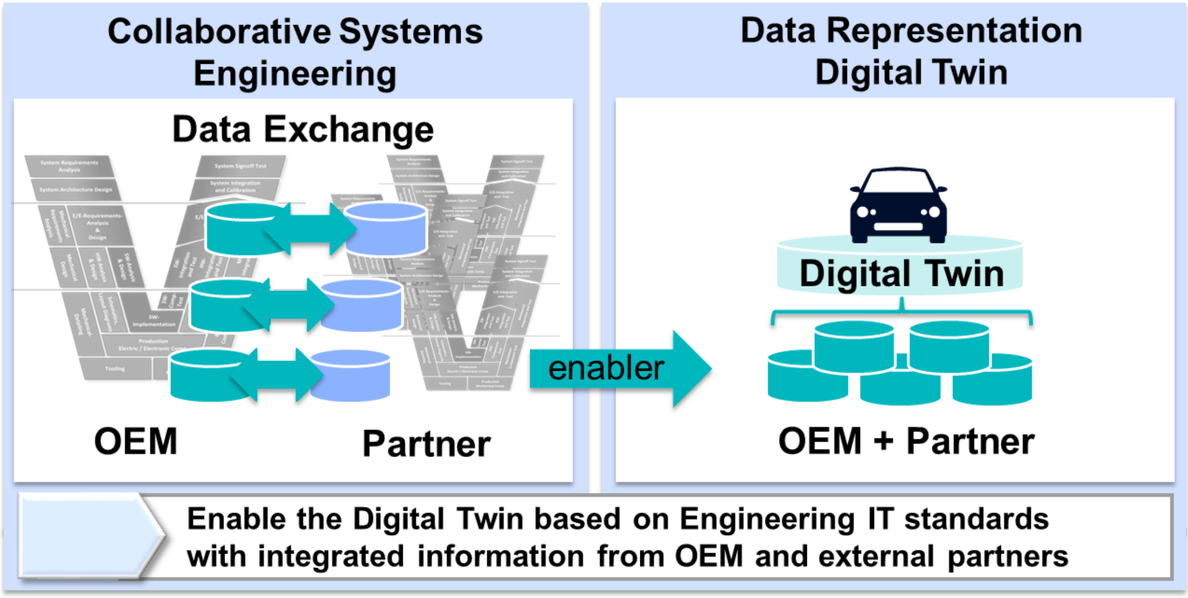



**Figure 3-5: Digital Twin**

Together with the project group Digital Data Package (DDP) the CSE group focus on the integrated exchange of engineering data across different standards and processes (e.g., simulation, verification and validation). The FDX standard is one of the data packages that provides necessary information about the capabilities of components.

## 3.6 Reference Implementation of FDX Standard

### 3.6.1 EXOKNOX$^{free}$ Tool

EXOKNOX is a product family for functional requirements management, data exchange and data management. With EXOKNOX$^{free}$ a software tool free of charge is available with the goal to enable and support data exchange using the FDX format. EXOKNOX$^{free}$ is a rich client application written in Java which does not require an installation and therefore runs without administrator privileges. The software provides different editors for FDX content, an integrated order management, different ways to efficiently fill in data from external sources, automated quality checks and the capability to handle foreign FDX-compliant data models (the latter from version 1.2 and higher). In a data-driven approach EXOKNOX$^{free}$

gets updated regularly with new content and versions of the FDX standard. The software is available with English and German internationalization, by configuration it can be extended to more languages.

A download link can be requested either on https://exoknox.com or by writing an email to info@exoknox.com.

### 3.6.2 openMDM® application

openMDM® is a vendor-neutral open-source software platform for the efficient implementation of data management solutions based on the ASAM ODS standard. The platform can ingest FDX data, measured and simulated data coming from different sources and file formats. In addition to FDX, the formats range from simple CSV files to specific binary formats for special areas of application. Of course, application-specific combinations and modifications of such file formats are possible as well. The various data formats are harmonized by means of openMDM® and thus made interpretable and comparable in the long term. Powerful functions for navigation, search, visualization and data exchange make it easy to use the data across departments and locations. An object-oriented API ensures controlled access to the data for different user groups and simplifies the integration of vendor-specific tools. This allows to reuse measured and simulated data between different teams and tools, improving collaboration.

A demo or test system of openMDM® can be requested by writing an email to michael.plagge@eclipse-foundation.org.

### 3.6.3 ATFX compliant applications

The FDX format bases on the data exchange format ATFX, which is part of the industry standard ASAM ODS. This enables software providers to efficiently implement the recommendations of the FDX working group and make functional data available in a uniform manner in a variety of test and simulation tools. A wide range of tools available on the market already provide powerful importers and exporters for the ATFX format today. The respective implementations can be considered as mature and stable. The further dissemination of those ODS-compliant tools all over the world is currently becoming apparent.

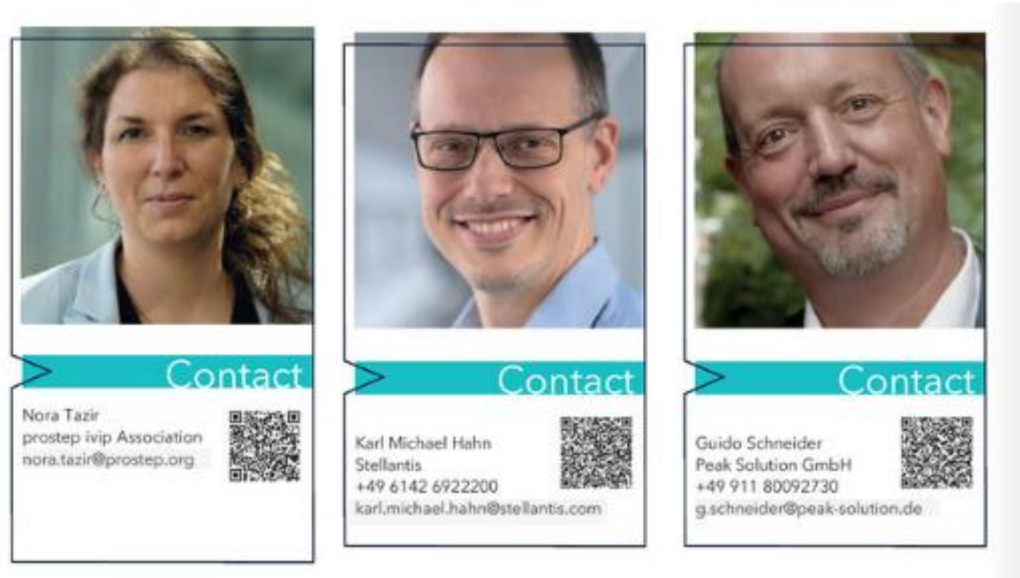
By sending an email to info@peak-solution.de, tool providers can discuss their questions regarding the technical implementation of FDX with leading ASAM ODS specialists and test the interoperability of their products with other solutions.

# 4 About prostep ivip

The prostep ivip Association is an international association that has its headquarter in Darmstadt, one of Germany's top locations for science and research. The association has committed itself to developing innovative approaches to solving problems and modern standards for product data management and virtual product creation.

It bundles the interests of manufacturers and suppliers in manufacturing industry as well as IT vendors, in close cooperation with research and science institutes, to provide its members with the long-term competitive advantages that more efficient processes, methods and systems provide.

# 5 Contact us




# 6 References

prostep ivip FDX Recommendations: https://prostep-ivip-e-v.github.io/FDX/

ASAM ODS Standard: https://www.asam.net/standards/detail/ods

openMDM® Homepage: https://openMDM.org/

openMDM® Eclipse project: https://projects.eclipse.org/projects/automotive.mdmbl