

IPC-2591-Version 1.3

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Connected Factory Exchange (CFX)

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Connected Factory Exchange (CFX)

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Connected Factory Exchange (IPC-CFX)

1 SCOPE

This standard establishes the requirements for the omnidirectional exchange of information between manufacturing processes and associated host systems for assembly manufacturing. This standard applies to communication between all executable processes in the manufacture of printed board assemblies – automated, semiautomated and manual – and is applicable to related mechanical assembly and transactional processes.

1.1 Purpose With the growth and acceptance of digital modeling and practices in manufacturing, the lack of a holistic Industrial Internet of Things (IIoT) standard for the transfer of information between machines, systems and processes has become a severe limitation to the growth of digitization and computerization in the electronics manufacturing industry, inhibiting technology innovations such as Industry 4.0 and Smart Factories being available to all companies in the industry, regardless of size, sector and location.

This Connected Factory Exchange (CFX) standard provides a true “plug and play” Internet of Things (IoT) communication environment throughout manufacturing, where all equipment, manufacturing processes and transactional stations can communicate with each other without the need for the development and use of bespoke interfaces. CFX-enabled equipment and solutions from different vendors work seamlessly together.

There are many types of users of this CFX standard, including equipment vendors, solution providers, in-house information technology (IT) groups, etc. The many types of data included in CFX are used in different ways depending on the application; for example, closed-loop feedback systems, live production dashboards, traceability (IPC-1782), manufacturing execution systems (MES) control, lean supply chain management, active quality management, production control, etc.

As CFX data is fully omnidirectional, any CFX endpoint connection can consume data as well as create it. As an illustration, consider the scenario in which a single machine from a certain vendor is connected in-line with other machines from different vendors. CFX messages are sent from the single machine to other machines in the line, and to host systems such as MES. The single machine can also receive CFX messages from all other machines in the line, as well as from the host systems in order to optimize the machine operation and enable the vendor of the machines to create added-value functionality, such as to support machine-specific Industry 4.0. In this way, a smart, digital, Industry 4.0 factory will be comprised of many different Industry 4.0 computerization applications, each of which can be provided by different suppliers, at the machine, line, site and even enterprise levels, all working together, sharing data seamlessly through CFX.

This CFX standard supports the concept of big data by including data of different types from across the factory, including performance, materials, resources, users, quality events, product tracking, etc., all of which can be combined to create a big-data environment. CFX, therefore, provides many kinds of added value opportunities to the whole manufacturing operation, including, for example, improving operational efficiency and productivity, quality and reliability, agility and responsiveness. This CFX standard helps organizations ensure that end users/consumers will receive products and services that meet or exceed their expectations and in the timeliest and most economically viable method.

1.2 Application of This Standard This standard defines the communication protocol and content across all assembly production processes, irrespective of type or method of operation. It can also be applied to transactional operations. There are no restrictions in terms of product classification sector, size of operation or location. Surface-mount technology (SMT) production is not required to be a part of the factory. Though intended to support all aspects of printed board production, the use of CFX can be extended downstream to include, for example, mechanical assembly, personalization, packing and shipping, as well as upstream to include, for example, electrical and mechanical subassemblies.

1.3 CFX and the Hermes Standard This CFX standard is complementary to IPC-HERMES-9852. The Hermes Standard, as an advanced, intelligent Surface Mount Equipment Manufacturers Association (SMEMA) standard replacement, provides near-instant line control, passing information about production units as they pass down the line. CFX provides vertical messaging that is complementary to Hermes.

1.4 Updates to This Standard The IPC Connected Factory Exchange Initiative Subcommittee intends to make frequent incremental revisions to this standard to support additional machines and processes. Version updates are identified by version number and the change (added, removed, etc.), so the reader can easily identify changes in each version. See Figure 1-1 for an example of this version change tracking using a portion of the CFX.Maintenance table of this standard as an example.

Appendix A also provides an itemized version history.

All messages in this standard apply to IPC-2591, Version 1.0 and subsequent versions, unless otherwise stated.

Table 7-5 CFX.Maintenance Messages		
Name	Type	Description
GetResourceInformation	RR	This Request message requests detailed resource information about a single endpoint, as specified by its CFX handle. The response includes information regarding the endpoint's resource and subresources that may undergo maintenance operations. – <i>Added v1.3</i>
GetResourceMaintenanceAndService	RR	This Request message requests detailed resource maintenance information about a single endpoint, as specified by its CFX handle. The response includes information regarding the endpoint's maintenance, counters, errors and verification that are relevant for the decisions around the execution of the maintenance operations. – <i>Added v1.3</i>

Figure 1-1 Version Change Tracking Example

1.5 Definition of Requirements The words **shall** or **shall not** are used in the text of this document wherever there is a requirement for materials, preparation, process control or acceptance.

The word “should” reflects recommendations and is used to reflect general industry practices and procedures for guidance only.

Line drawings and illustrations are depicted herein to assist in the interpretation of the written requirements of this Standard. The text takes precedence over the figures.

1.6 Order of Precedence The contract **shall** take precedence over this standard, referenced standards and drawings.

In the event of conflict, the following order of precedence applies:

1. Procurement as agreed and documented between user and supplier.
2. Master drawing, design brief or tech pack reflecting the user's detailed requirements.
3. When invoked by the customer or per contractual agreement, this standard.

When documents other than this standard are cited, the order of precedence **shall** be defined in the procurement documents. The user can specify alternate acceptance criteria.

1.6.1 Conflict In the event of conflict between the requirements of this standard and the applicable drawing(s) and documentation, the applicable user-approved drawing(s) and documentation govern.

Some examples of documentation include the contract, purchase order, technical data package, engineering specification or performance specification. In the event of a conflict between the text of this standard and the applicable documents cited herein, the text of this standard takes precedence. In the event of conflict between the requirements of this standard and drawing(s) and documentation that has not been user approved, this standard governs.

1.6.2 Clause References When a clause in this document is referenced, its subordinate clauses apply, unless the requirement references specific subordinate clauses.

1.7 Measurement Units This document, and all CFX messages and data structures, use SI (metric) units throughout.

1.8 Acronyms See Appendix B for a list of acronyms used in this standard.

1.9 Terms and Definitions Other than those terms listed below, the definitions of terms used in this standard are in accordance with IPC-T-50.

1.9.1 Activity An action performed by an endpoint in the course of performing its function. There are many different types of activities that may be performed, depending on the specific function of the endpoint. Activities may be value added (such as placing components on a printed board), or non-value added (such as a tool change by a pick-and-place machine).

1.9.2 Component The component is a single instance of a bulk material, such as a resistor, capacitor, integrated circuit (IC), etc. Bulk components are normally supplied in material packages.

1.9.3 Dashboard An information management tool used to track key performance indicators (KPIs), metrics and other key data points relevant to a business, department or specific process. Through the use of data visualizations, dashboards simplify complex data sets to provide users with at-a-glance awareness of current performance.

1.9.4 Data Integrity Maintaining and ensuring accuracy and consistency of data over the data's entire lifecycle. Data integrity is a critical aspect to the design, implementation and usage of any system which stores, processes or retrieves data.

1.9.5 Endpoint A participant in a CFX network, which is a software instance that can both send and receive CFX messages. Each endpoint is a software program associated with a particular machine or process, used to exchange information related to the operation.

1.9.6 Factory Resource A physical location, machine, tool or device within the factory that performs any sort of function.

1.9.7 Lane A corridor within an endpoint down which production units flow through a series of production stages (see 1.9.23). Many endpoints only have one singular lane, but multiple production lanes on a production line are possible and supported by CFX.

1.9.8 Lock A process lock, or locked process, is one in which the endpoint must not continue any active operation.

1.9.9 Material Carrier The material carrier is the mechanism by which a material package is located for use at an endpoint. In the case of SMT, for example, a feeder is a common example of the material carrier.

1.9.10 Material Chain A set of two or more material packages connected together (i.e., by splicing them together).

1.9.11 Material Location Identifies a specific location on an endpoint where material packages may be loaded or otherwise mounted (perhaps employing a material carrier to do so). For example, a single feeder slot on a feeder bank of a pick-and-place machine is a single material location.

1.9.12 Material Package Material package refers to the physical mechanism in which bulk materials are supplied (e.g., on a reel, in a box or bag or on a tray). A single material package represents one singular package of material (one reel, one box, etc.) and is identified by a unique identifier that is typically labeled on to the package.

1.9.13 Material Traceability The ability to verify the history, location or application of an item by means of documented recorded identification.

1.9.14 Materials For purposes of this standard, all physical and nonphysical items which are combined together to create a final assembly.

1.9.15 Operator A production operator who can actively work at an endpoint or is responsible for its operation.

1.9.16 Process Endpoint (Station) An endpoint associated with a production process of any kind, whether automated or manual. Normally referred to as a station.

1.9.17 Production Unit A singular instance of an item that is being produced via a production process. For printed board assembly, a single printed board would be considered a production unit. A single panelized printed board layout may contain multiple printed boards / production units on one single panel. For final assembly, the uppermost assembly would also be considered a production unit itself, perhaps containing one or more subassemblies, which are themselves production units produced by a different, previously executed process.

1.9.18 Recipe A set of instructions, data or documentation used to control or guide the activity at an endpoint. For an SMT machine, this would be the set of files that form the machine program.



1.9.19 Root The highest level in the structure, above level 1.

1.9.20 Setup A list of materials and tools that are required to be in place in specific locations at a station.

1.9.21 State (Production State) This refers to the state or mode of operation of a station. Possible states vary by process type, identified by the process state model.

1.9.22 Station (Process Endpoint) An endpoint associated with a production process of any kind, whether automated or manual.

1.9.23 Stage An area or zone within a Production Station endpoint in which added-value work is performed.

1.9.24 Subassembly An assembly that will become a material of another assembly, whether they are made in the same environment as their peers in the hierarchical product bill of materials (BOM) or transferred from outside as materials.

1.9.25 Symptom An indication that something may be wrong with a production unit under test.

1.9.26 Tool An item used by a person or automated endpoint in the course of performing a particular function. Examples of tools used by humans would be wrench, hammer, screwdriver, etc. Examples of tools used by automated endpoints would be stencil or squeegee (for a stencil printer), head or nozzle (for a pick-and-place machine).

1.9.27 Transactional Endpoint An endpoint associated with a production process that manages or transacts, rather than being associated with an operational process. A transactional endpoint is usually a piece of software that performs some type of visibility or control function, such as a material logistics terminal.

2 APPLICABLE DOCUMENTS

2.1 IPC¹

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits

IPC-1782 Standard for Manufacturing and Supply Chain Traceability of Electronic Products

IPC-HERMES-9852 The Global Standard for Machine-to-Machine Communication in SMT Assembly

2.2 ECMA International²

Standard ECMA-262 3rd Edition ECMAScript Language Specification

2.3 International Organization for Standardization (ISO)³

ISO 8601:2004 Data elements and interchange formats—Information interchange—Representation of dates and times

2.4 SEMI⁴

SEMI E58-0703 Automated Reliability, Availability, and Maintainability Standard (ARAMS): Concepts, Behavior, and Services

SEMI E10-0814E Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM) and Utilization

1. www.ipc.org

2. www.ecma-international.org

3. www.iso.ch

4. www.semi.org

3 GENERAL REQUIREMENTS

3.1 Guidance on the Use of This Standard This standard is comprised of two parts:

- 1) The first part is this document.
 - 2) The second part is available online, which describes the detailed technical specification of messages and data structures.
- The combination of both parts forms the complete documentation of this standard.

3.1.1 Technical Reference The link to the technical reference part of the standard is www.connectedfactoryexchange.com/CFXDemo/sdk.

This link can also be used to access the CFX software development kit (SDK).

3.1.2 Application Reference This CFX standard has a dedicated website that provides up to date information about the standard, applications and supporters. Information is also posted about any updates that may be made to the CFX messaging as the scope expands to cover additional and new technologies. Visit www.ipc-cfx.org.

3.2 Users of CFX There are many kinds of CFX endpoints that perform different purposes and roles within the overall CFX network. Each of them is able to create and receive CFX messages.

3.2.1 Automated Assembly Processes A CFX endpoint can be created as part of the software package that exists as part of or together with an automated machine process. This can be applied as a standard part of the machine software or as an optional extra. CFX native support is expected to be built into new machines that appear on the market and provided where practical for machines currently supported in the market. In certain environments, where multiple physical machines are managed within a specific single-vendor-provided software environment, the vendor software can provide a single access point for CFX communication, through which messages will flow as if directly to the machines. This emulation facility allows machine vendors to utilize CFX in line applications as well as machine applications.

The native CFX interface represents a single data exchange mechanism to provide information about the machine operation to users of the machines, replacing the need for additional proprietary interfaces.

Where there is no practical way to provide CFX native support, machine vendors and third parties may consider the use of a simple inexpensive external hardware which can act as a CFX endpoint. It is connected to the machine through a combination of legacy native interface support and additional sensors and switches as required.

3.2.2 In-House Manufacturing Solution Development CFX provides a single interface for any specialist or bespoke internal manufacturing IT projects, related to enterprise resource planning (ERP), MES, product lifecycle management (PLM), etc. Multiple-point solutions can exist on the same CFX network, each providing niche functionality in a common data environment. CFX messaging promotes the ability for point-solutions to communicate effectively through the option of inclusion of complete information sets in messages.

3.2.3 MES Software Solutions Many areas of CFX work in context within a defined factory environment. MES systems provide the infrastructure around the various aspects of CFX messaging in a single environment, to gain the maximum value from CFX. This does not exclude the use of in-house developed point solutions, which can coexist with MES solutions on the CFX network.

3.3 Software Development Environment CFX endpoint software is created in a choice of development environments. Any language and platform may be used. The default environment is based on Windows, for which an SDK is provided. It is updated in line with the latest CFX specification updates. To access the SDK, visit www.connectedfactoryexchange.com/CFXDemo/sdk.

SDKs for other software development environments are encouraged, supported by members of the IPC Connected Factory Initiative Subcommittee. News and information about these are announced on the CFX website (www.ipc-cfx.org) when available.

3.4 CFX Support Declaration This CFX specification allows the CFX developer to choose the areas of the CFX specification that are appropriate for support based on the nature and capabilities of the machine, process or solution that is being developed. It is essential that the level of support for CFX topics is clearly shown to end-users, as they select their CFX

endpoints as part of their overall CFX-based operation. These capabilities should also be detailed when requested by the CFX messaging system. See 6.1.1 for guidance on support declaration and 6.5 for CFX messaging requirements by equipment type.

4 CFX STRUCTURAL OVERVIEW

CFX communication consists of three key elements:

- Content – the definition and meaning of data to be encoded
- Encoding – the way in which data are encoded ready for transportation
- Transport – the messaging mechanism and infrastructure

CFX combines all three of these elements to create a true plug and play standard.

4.1 Primary Transport Layer: AMQP v1.0 The primary transport layer for CFX messages is Advanced Message Queuing Protocol (AMQP) v1.0 (www.amqp.org). All CFX endpoints must implement support for the primary CFX primary transport layer. Versions of AMQP prior to v1.0 are not compatible with CFX.

AMQP was originally developed by the financial industry to facilitate the reliable processing of secure financial transactions across broad geographies. Over the years, its footprint in the computerized world and IoT space has grown well beyond the bounds of the financial industry, and its natural qualities of high-reliability and secure message transmission make it an ideal fit for CFX.

The use of AMQP as the primary transport protocol also greatly eases the burden of equipment makers and factory-level system providers as they implement their CFX support by eliminating most of the development effort needed to send and receive CFX messages. Equipment providers need not understand, nor worry, about the complexities of message routing and subscription management. Routing architectures can be as simple or complicated as needed.

This CFX standard does not dictate any specific message AMQP v1.0 routing infrastructure, such as specific message brokers, queues, exchanges, pub/sub subscription management, etc. The specifics of message routing are at the discretion of the factory-level system provider. Numerous open-source AMQP software development toolkits are freely available. Additionally, there are numerous message routing systems (message brokers, cloud IoT message buses, message-oriented middleware, etc.) that support the AMQP v1.0 wire protocol, both easing the burden of factory-level system providers and providing them greater flexibility in their implementations.

The use of alternative transport layers is technically possible and may be applied in special cases, though this requires implementation in addition to the primary transport layer for all parties concerned.

4.1.1 CFX Message Channels CFX messages are exchanged through AMQP 1.0 protocol using one or more channels. A single endpoint may be configured to exchange messages through multiple channels. There are three types of channels:

• Event Channels

CFX endpoints publish event messages to these event channels. In most cases, the recipient of event channel messages is an AMQP v1.0 broker or host software, such that the messages can be received by any subscribed endpoints. Event channels are used to publish all event type messages, as well as broadcast requests messages. The network address (URL) and AMQP target (typically identifying an exchange on a message broker) of event channels must be preconfigured as part of the initial CFX configuration for each endpoint. Event channels remain active at all times while the endpoint is active and participating in a CFX network. Each CFX endpoint should be preconfigured to publish events to at least one event channel. Additional event channels may be configured as required.

• Subscription Channels

CFX endpoints may also be configured to receive unsolicited events and broadcast responses from one or more sources. The network address (URL) and AMQP source (typically identifying a queue on a message broker) of subscription channels must be preconfigured as part of the initial CFX configuration for each endpoint. Subscription channels remain active at all times while the endpoint is active and participating in a CFX network. Each CFX endpoint should be preconfigured to receive broadcast requests from at least one subscription channel. Additional subscription channels may also be configured as may be required.

• Request/Response Channels

CFX endpoints may dynamically create request/response channels with which to communicate directly with another CFX endpoint without the need to go through a broker or host. This mechanism is used for time-critical issues such as

where, unlike a broadcast message, a response from the specific targeted endpoint is a requirement. Request/response channels are created on an on-demand basis as needed, when one CFX endpoint wishes to send a request type message to another. The channel remains open for the lifetime of a single request/response transaction and then terminates.

The diagram in Figure 4-1 illustrates the many ways in which a CFX network with a complex set of channels can be created.

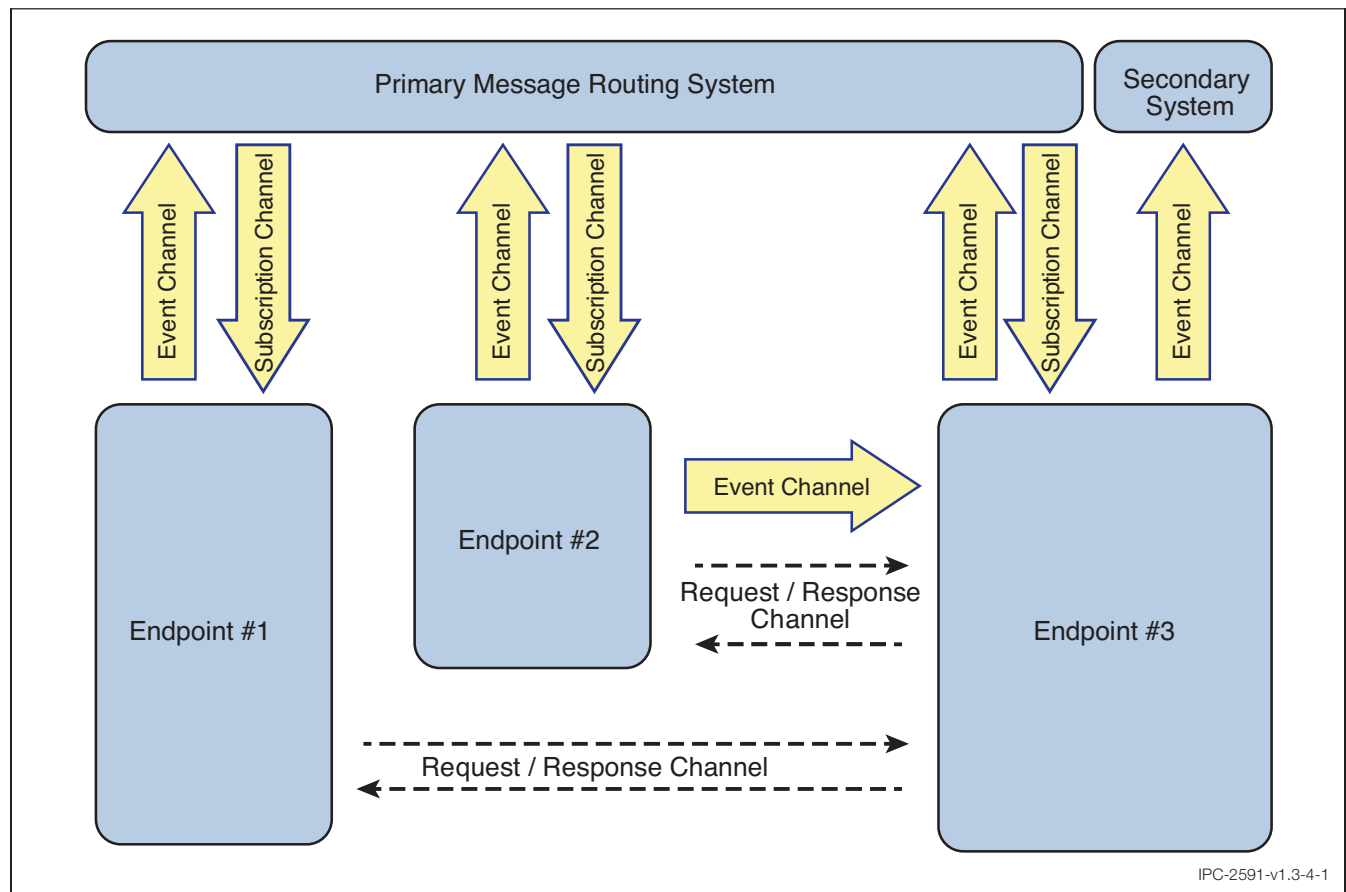


Figure 4-1 CFX Channels Between Endpoints

In Figure 4-1, all three endpoints have been configured to publish their events to the same factory-level message routing system. Additionally, endpoint #2 has been configured to also publish its events directly to endpoint #3.

The two request/response channels shown in the diagram are ad-hoc. They need not be preconfigured and may be opened and closed by the requester as required. Any CFX endpoint may, at any time, solicit a direct request to any other CFX endpoint.

4.1.2 Channel Configuration Each CFX endpoint should permit end-users to configure any number of event and subscription channels. Additionally, endpoints **shall** permit end-users to enable or disable the transmission of specific CFX topics for each event channel, as well as specific messages within any CFX topics that are configured as enabled.

It might be that in a particular deployment, some of the event content is not needed by any consumers. Filtering messages at the source prevents unnecessary information from cluttering the network and message routing infrastructure.

4.1.3 CFX Message Types Table 4-1 summarizes the CFX message types.

4.1.4 CFX Compression Beginning with IPC-2591, v 1.1 (SDK v 1.1.11 and later), the ability to apply compression to message data is supported. As of IPC-2591, v 1.2, compression is applied by default. Compression reduces the size of message data. The amount of compression varies by data type and content. This is enabled by default when using the CFX SDK.

4.1.5 CFX – AMQP Message Properties Beginning with IPC-2591, v 1.2, all CFX messages transmitted via AMQP 1.0 protocol **shall** include the information in Table 4-2 in the AMQP message and message application properties.

Table_4-1 Types of CFX Messages

Type	Flow	Recipient
Event	Publish (Outbound Flow)	Any Number of Recipients
Request	Source -> Destination	One Targeted Recipient
Response	Destination -> Source	Originator of Request
Broadcast Request	Source -> Destination(s)	Any Number of Recipients
Broadcast Response	Destination(s) -> Source(s)	Any Number of Recipients

Table 4-2 CFX – AMQP Message Properties

Type	Name	CFX Population
AMQP Property	message-id	CFXEnvelope.UniqueID
	user-id	<< Not Populated >>
	to	CFXEnvelope.Target
	subject	CFXEnvelope.Source + “.” + CFXEnvelope.MessageName *Default value. Can be customized if desired.
	reply-to	CFXEnvelope.Source
	correlation-id	CFXEnvelope.RequestID
	content-type	application/json; charset="utf-8"
	content-encoding	gzip (If using gzip compression, otherwise not populated)
	absolute-expiry-time	<< Not Populated >>
	creation-time	CFXEnvelope.TimeStamp
	group-id	<< Not Populated >>
	group-sequence	<< Not Populated >>
	reply-to-group-id	<< Not Populated >>
AMQP Application Property	cfx-topic	Fully qualified topic name of message contained in CFXEnvelope. (e.g., If MessageName is CFX.Production.WorkStarted, cfxtopic = CFX.Production)
	cfx-message	CFXEnvelope.MessageName
	cfx-handle	CFXEnvelope.Source

4.2 Encoding: JSON

The encoding of data in CFX refers to the format in which data fields and structures are written in CFX messages.

JavaScript Object Notation (JSON) (www.json.org) is a lightweight data-interchange format. It is easy for humans to read and write, and it is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language, Standard ECMA-262 3rd Edition.

All encoding within CFX must comply with UTF-8 as defined by the Unicode Standard (www.unicode.org/standard/standard.html).

4.2.1 JSON Data Types The following data types are used with JSON data structure and messaging:

- **Enum:** The data element must be one of the allowable choices as defined in an associated list.
Note: The English language will be used for enumeration data.
- **Integer:** A whole number; for example, “123.”
- **Numeric:** A number, represented by, for example, “1.23” or “12.65E3” (no commas, just one decimal point as required); maximum precision is 15 digits.
- **String:** A sequence of characters; for example, “Hello CFX.” The maximum length of a string is 2,000 characters, except where noted.
- **Date/Time:** Represented in ISO 8601 format, with mandatory time zone included. Fractional seconds are optional (i.e., “2018-09-15T15:53:08+05:00”).
- **String Lists:** RFC 4180 compliant comma delimited list of multiple strings. Note: Strings containing commas must have them enclosed by parentheses.
- **Boolean:** “1” (True) or “0” (False)