

Maintenance Working Group: Terms, Taxonomy and First-order Logic Formalisation

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This is a working document that reflects the current state of the **IOF Maintenance Working Group** reference ontology terms and definitions.

1 Introduction

The maintenance working group is the part of the Industrial Ontology Foundry (IOF) concerned with industrial maintenance. Table 1 contains all top 25 maintenance terms from the maintenance working group. This document is prepared ahead of the 2019 IOF Meeting. It proposes where the terms in Table 1 could sit in the BFO Hierarchy along with first-order logic formalisation of each term and English definitions. Finally we identify a number of questions resulting from this work.

Top 25 Maintenance Terms

[1] Maintainable item	[14] State of degradation
[2] Maintainable item role	[15] Non-conformity
[3] Asset role	[16] Zero-dimensional failure event
[4] Failure mode	[17] Process of degradation
[5] Maintenance standard work specification	[18] Maintenance process
[6] Maintenance non-standard work specification	[19] Maintenance action
[7] Maintenance plan specification	[20] Maintenance strategy process
[8] Maintenance strategy specification	[21] Failure mechanism
[9] Maintenance schedule list	[22] Failure cause
[10] Maintenance strategy type	[23] Operating triggering event
[11] Failure modes and effects analysis specification	[24] Inspection triggering event
[12] State of failure component	[25] Maintenance notification
[13] State of failure machine	

Table 1: Table of Top 25 Maintenance Terms

2 Taxonomy

Figure 1 contains a fragment of the BFO taxonomy to show where the top 15 Maintenance terms fit.

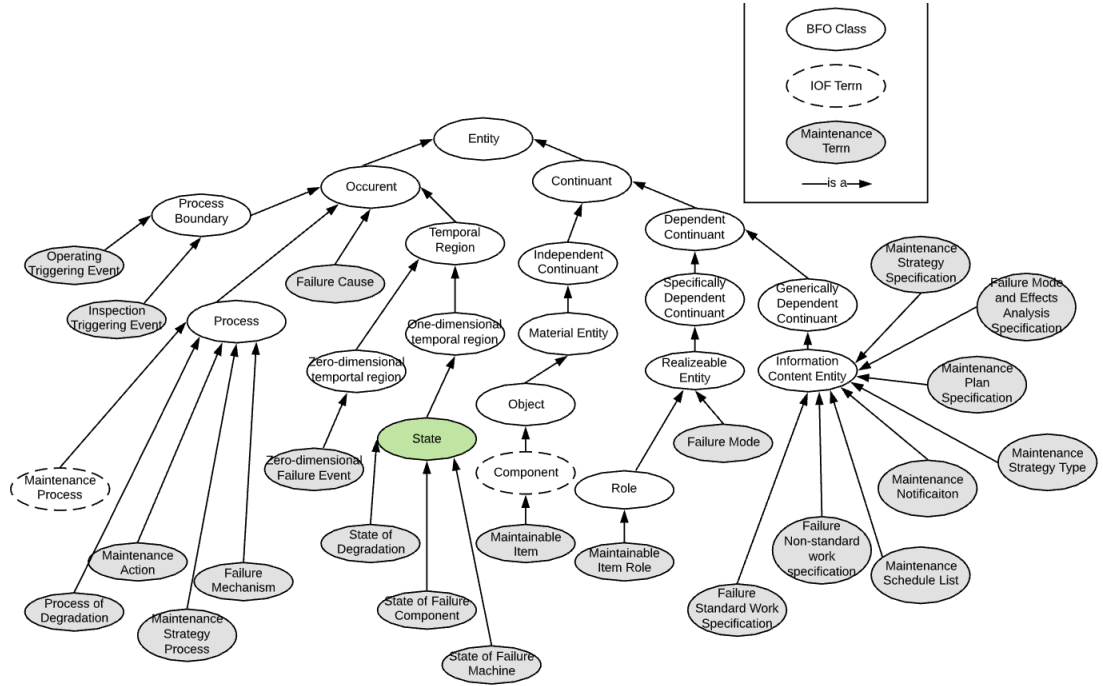


Figure 1: Taxonomy of Top 25 Maintenance Terms

3 OWL file

The maintenance working group has a working OWL file in a GitHub repository. The OWL file can be found at <https://github.com/uwasystemhealth/maintenance-ontology>. If you would like to access this ontology, please contact the author to be added as a collaborator.

4 Term definitions and Logic Formalisation

This section contains first-order logic formalisation of the axioms created by the maintenance working group. It also contains English definitions for each of the terms.

4.1 Taxonomy Formalisation

4.1.1 maintainable item subclass of component

$MaintainableItem(x) \rightarrow Component(x)$

4.1.2 maintainable item role subclass of role

$MaintainableItemRole(x) \rightarrow Role(x)$

4.1.3 asset role subclass of role

$AssetRole(x) \rightarrow Role(x)$

4.1.4 failure mode subclass of realizeable entity

$FailureMode(x) \rightarrow RealizeableEntity(x)$

4.1.5 maintenance standard work specification subclass of information content entity

$MaintenanceStanardWorkSpecification(x) \rightarrow$
 $InformationContentEntity(x)$

4.1.6 maintenance non-standard work specification subclass of information content entity

$MaintenanceNonStanardWorkSpecification(x) \rightarrow$
 $InformationContentEntity(x)$

4.1.7 maintenance plan specification subclass of information content entity

$MaintenancePlanSpecification(x) \rightarrow InformationContentEntity(x)$

4.1.8 maintenance strategy specification subclass of information content entity

$MaintenanceStrategySpecification(x) \rightarrow InformationContentEntity(x)$

4.1.9 maintenance schedule list subclass of information content entity

$MaintenanceScheduleList(x) \rightarrow InformationContentEntity(x)$

4.1.10 maintenance strategy type subclass of information content entity

$MaintenanceScheduleList(x) \rightarrow InformationContentEntity(x)$

4.1.11 failure mode and effects analysis specification subclass of information content entity

$FailureModeAndEffectsAnalysisSpecification(x) \rightarrow InformationContentEntity(x)$

4.1.12 state of failure component subclass of state

$StateOfFailureComponent(x) \rightarrow State(x)$

4.1.13 state of failure machine subclass of state

$StateOfFailureMachine(x) \rightarrow State(x)$

4.1.14 state of degradation subclass of state

$StateOfDegradation(x) \rightarrow State(x)$

4.1.15 non-conformity subclass of ?

$NonConformity(x) \rightarrow ?$

4.1.16 zero-dimensional failure event subclass of zero-dimensional temporal region

$ZeroDimensionalFailureEvent(x) \rightarrow ZeroDimensionalTemporalRegion$

4.1.17 process of degradation subclass of process

$ProcessOfDegradation(x) \rightarrow Process$

4.1.18 maintenance action subclass of process

$MaintenanceAction(x) \rightarrow Process$

4.1.19 maintenance strategy process subclass of process

$MaintenanceStrategyProcess(x) \rightarrow Process$

4.1.20 failure mechanism subclass of process

$FailureMechanism(x) \rightarrow Process$

4.1.21 failure cause subclass of occurent

$FailureCause(x) \rightarrow Occurent$

4.1.22 operating triggering event subclass of process boundary

$OperatingTriggeringEvent(x) \rightarrow ProcesBoundary$

4.1.23 maintenance notification subclass of information content entity

$MaintenanceNotification(x) \rightarrow InformationContentEntity$

4.2 Term Definitions and Formal Axioms

4.2.1 maintainable item

MaintainableItem = def. IOF:Component that has a MNT:MaintainableItemRole

$$\begin{aligned} instanceOf(x, MaintainableItem, t) &\equiv instanceOf(x, Component, t) \wedge \\ \exists r(MaintainableItemRole(r) \wedge bearerOf(x, r)) \end{aligned}$$

FOL English translation: A maintainable item x is equivalent to a component x and it is the case that there exists some maintainable item role r such that x is a bearer of r.

4.2.2 maintainable item role

MaintainableItemRole = def. A role that inheres in some IOF:Component that has the capability to serve as the output of some MNT:MaintenanceProcess

$$\begin{aligned} instanceOf(x, MaintainableItemRole, t) &\equiv instanceOf(x, Role, t) \wedge \\ \exists y, w, z(instanceOf(y, Component, t) \wedge bearerOf(y, x, t) \wedge hasCapability(y, w) \wedge \\ \forall z(realises(z, w) \rightarrow (instanceOf(z, MaintenanceProcess) \wedge \\ hasSpecifiedOutput(z, y)))) \end{aligned}$$

FOL English translation: A maintainable item role x is equivalent to a role x such that there exists a component y that is a bearer of the maintainable item role x and has capability w. Any maintenance process z that realises w has specified output y.

4.2.3 asset role

MaintainableItemRole = def. A role that inheres in some IOF:EngineeredSystem that has the capability to serve as the output of some UNK:ValueAddingProcess

$$\begin{aligned} instanceOf(x, AssetRole, t) &\equiv instanceOf(x, Role, t) \wedge \\ \exists y, w, z(instanceOf(y, EngineeredSystem, t) \wedge \\ bearerOf(y, x, t) \wedge hasCapability(y, w) \wedge \forall z(realises(z, w) \rightarrow \\ (instanceOf(z, ValueAddingProcess) \wedge has - specified - output(z, y)))) \end{aligned}$$

FOL English translation: An asset role x is equivalent to a role x such that there exists a component y that is a bearer of the asset role x and has capability w. Any value adding process z that realises w has specified output y.

4.2.4 failure mode

FailureMode = def. A BFO:RealizableEntity that is the result of a MNT:FailureMechanism through which the MNT:StateOfFailure occurs.

$$\begin{aligned} \text{instanceOf}(x, \text{FailureMode}, t) \equiv & \text{instanceOf}(x, \text{RealizableEntity}, t) \wedge \\ & ((\exists y, w(\text{instanceOf}(y, \text{FailureMechanism}, t) \wedge \\ & (\text{instanceOf}(w, \text{StateOfFailureComponent}, t) \wedge \text{precedes}(y, w, t)) \vee \\ & (p, z(\text{instanceOf}(p, \text{FailureMechanism}, t) \wedge \\ & (\text{instanceOf}(z, \text{StateOfFailureMachine}, t) \wedge \text{precedes}(p, z, t)))) \end{aligned}$$

FOL English translation: A failure mode x is equivalent to a realizable entity x such that either,

1. there exists a failure mechanism y, a state of failure component w and y precedes w.
2. there exists a failure mechanism p, a state of failure machine z and p precedes z.

4.2.5 maintenance standard work specification

MaintenanceWorkOrderSpecification = def. An IAO:InformationContentEntity describing a desired MNT:MaintenanceAction

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceWorkOrderSpecification}, t) \equiv & \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) \wedge & \\ \exists y(\text{instanceOf}(y, \text{MaintenanceAction}, t) \wedge \text{denotes}(x, y, t)) & \end{aligned}$$

FOL English translation A maintenance work order specification x is equivalent to an information content entity x and it is the case that there exists a maintenance action y and x denotes y.

4.2.6 maintenance non standard work specification

MaintenanceNonStandardWorkSpecification = def. An IAO:InformationContentEntity describing a desired MNT:MaintenanceAction created when a MNT:MaintenanceStandardWorkSpecification for the same MNT:MaintenanceAction does not already exist

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceNonStandardWorkSpecification}, t) \equiv & \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) \wedge \exists y(\text{instanceOf}(y, \text{MaintenanceAction}, t) \wedge & \\ \text{denotes}(x, y, t)) \wedge (\text{denotes}(x, y, t) \exists z(\text{instanceOf}(z, \text{MaintenanceStandardWorkSpecification}, t) \wedge & \\ \text{denotes}(z, y, t))) & \end{aligned}$$

FOL English Translation A maintenance non-standard work specification x is equivalent to an information content entity x such that x denotes a maintenance action y. If x denotes y then there doesn't exist a maintenance standard work specification z such that z denotes y.

4.2.7 maintenance plan specification

Definition needs further work.

4.2.8 maintenance notification

MaintenanceNotification = def. An IAO:InformationContentEntity describing a MNT:Non-conformity

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceNotification}, t) &\equiv \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) &\wedge \\ \exists y(\text{instanceOf}(y, \text{NonConformity}, t) \wedge \text{denotes}(x, y, t)) \end{aligned}$$

FOL English translation: A maintenance notification x is equivalent to an information content entity x and it is the case that there exists a non-conformity y and x denotes y.

4.2.9 maintenance strategy specification

MaintenanceStrategySpecification: def. An IAO:InformationContentEntity describing the MNT:MaintenanceStrategyType to manage a specific MNT:FunctionalFailure.

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceStrategySpecification}, t) &\equiv \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) &\wedge \\ \exists y, z(\text{instanceOf}(y, \text{MaintenanceStrategyType}, t) \wedge \\ \text{instanceOf}(z, \text{FunctionalFailure}, t) \wedge \text{denotes}(x, y, t) \wedge \text{denotes}(x, z, t)) \end{aligned}$$

FOL English translation: A maintenance strategy specification x is equivalent to an information content entity x such that there exists a maintenance strategy type y and a functional failure z and x denotes both y and z.

4.2.10 maintenance schedule list

MaintenanceScheduleList: def. An IAO:InformationContentEntity describing a list of MNT:MaintenanceWorkOrderSpecification to be UNK:Executed in a defined period.

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceScheduleList}, t) &\equiv \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) &\wedge \\ \exists x_1, x_2, \dots, x_n, \forall i(\text{instanceOf}(x_i, \text{MaintenanceWorkOrderSpecification}, t) \wedge \\ \text{partOf}(x_i, x)) \end{aligned}$$

FOL English Translation: A maintenance schedule list x is equivalent to an information content entity such that there exists a set of maintenance work order specification x_i (for x_1 to x_n) where all x_i are parts of x .

4.2.11 Maintenance strategy type

MaintenanceStrategyType = def. An IAO:InformationContentEntity resulting from a maintenance strategy development process for a MNT:MaintainableItem

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceStrategyType}, t) \equiv & \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) \wedge & \\ \exists w, z(\text{instanceOf}(w, \text{specifiedOutput}) \wedge \text{hasCapability}(x, w) \wedge & \\ \forall z(\text{realises}(z, w) \rightarrow (\text{instanceOf}(z, \text{MaintenanceStrategyDevelopmentProcess}) \wedge & \\ \text{hasSpecifiedOutput}(z, x)))) & \end{aligned}$$

FOL English Translation: A maintenance strategy type x is equivalent to an information content entity x and it is the case that w is some specified output and x has capability w . If z realises w then z is maintenance strategy development process with specified output x .

4.2.12 failure mode and effects analysis specification

FailureModeAndEffectsAnalysisSpecification = def: An IAO:InformationContentEntity that is the specified output of some UNK:FmeaActivity

$$\begin{aligned} \text{instanceOf}(x, \text{FailureModeAndEffectsAnalysisSpecification}, t) \equiv & \\ \text{instanceOf}(x, \text{InformationContentEntity}, t) \wedge & \\ \exists w, z(\text{instanceOf}(w, \text{specifiedOutput}) \wedge \text{has} \neg \text{Capability}(x, w) \wedge \forall z(\text{realises}(z, w) \rightarrow & \\ (\text{instanceOf}(z, \text{FmeaActivity}) \wedge \text{hasSpecifiedOutput}(z, x)))) & \end{aligned}$$

FOL English translation: A failure mode and effects analysis specification x is equivalent to an information content entity x and it is the case that w is some specified output and x has capability w . If z realises w then z is a FMEA activity with specified output x .

4.2.13 state of failure component

StateOfFailureComponent = def. A IOF:State in which some IOF:component endures and does not meet a requirement

$$\begin{aligned} \text{instanceOf}(x, \text{StateOfFailureComponent}, t) \equiv \text{instanceOf}(x, \text{State}, t) \wedge & \\ \exists y, w(\text{instanceOf}(y, \text{component}, t) \wedge \text{instanceOf}(w, \text{Requirement}, t) \wedge & \\ \neg(\text{meets}(y, w)) & \end{aligned}$$

FOL English translation: English Translation: A state of failure component x is equivalent to an IOF state x where for some component y and requirement w, y does not meet the requirement w.

4.2.14 state of failure machine

StateOfFailureMachine = def. A IOF:State in which some IOF:machine endures and does not meet a requirement

$$\text{instanceOf}(x, \text{StateOfFailureComponent}, t) \equiv \text{instanceOf}(x, \text{State}, t) \wedge \exists y, w (\text{instanceOf}(y, \text{Machine}, t) \wedge \text{instanceOf}(w, \text{Requirement}, t) \wedge \neg(\text{meets}(y, w)))$$

FOL English translation: A state of failure machine x is equivalent to an IOF state x where for some machine y and requirement w, y does not meet the requirement w.

4.2.15 state of degradation

StateOfDegradation = def. A IOF:State in which some IOF:component endures and is moving towards non-conformity.

$$\text{instanceOf}(x, \text{StateOfDegradation}, t) \equiv \text{instanceOf}(x, \text{State}, t) \wedge \exists y, w, z (\text{instanceOf}(y, \text{Component}, t) \wedge \neg(\text{instanceOf}(w, \text{nonConformity}, t) \wedge \text{instanceOf}(w, \text{nonConformity}, t') \wedge \text{precedes}(t, t')))$$

English Translation: A state of degradation x is equivalent to an IOF state x such that for some component y:

1. there is no non-conformity at t
2. there is a non-conformity
3. t precedes t'

4.2.16 non-conformity

Definition needs further work.

4.2.17 zero-dimensional failure event

Need to discuss formalisation

4.2.18 process of degradation

Definition needs further work.

4.2.19 maintenance action

MaintenanceAction = def. A BFO:Process to perform work on an IOF:Component according to a MaintenanceWorkOrderSpecification.

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceAction}, t) &\equiv \text{instanceOf}(x, \text{Process}, t) \wedge \\ \exists y(\text{instanceOf}(y, \text{MaintenanceWorkOrderSpecification}, t) \wedge \text{inputOf}(y, x)) \end{aligned}$$

FOL English Translation A maintenance action x is equivalent to a process x such that there exists a maintenance work order specification y and y in an input to x.

4.2.20 maintenance strategy process

MaintenanceStrategyProcess = def. A BFO:Process to produce a MNT:MaintenanceStrategySpecification

$$\begin{aligned} \text{instanceOf}(x, \text{MaintenanceStrategyProcess}) &\equiv \text{instanceOf}(x, \text{Process}) \wedge \\ \exists y(\text{instanceOf}(y, \text{MaintenanceStrategySpecification}, t) \wedge \text{isSpecifiedOutput}(y, x, t)) \end{aligned}$$

FOL English translation: English Translation: A maintenance strategy process x is equivalent to a process x and there exists some maintenance strategy specification y and y is the specified output of x.

4.2.21 failure mechanism

Definition needs further work.

4.2.22 failure cause

Definition needs further work.

4.2.23 operating triggering event

OperatingTriggeringEvent = def. A BFO:ProcessBoundary in the operation of a IOF:ManufacturingProcess that begins a MNT:MaintenanceProcess

$$\begin{aligned} \text{instanceOf}(x, \text{OperatingTriggeringEvent}, t) &\equiv \text{instanceOf}(x, \text{ProcessBoundary}, t) \wedge \\ \exists y, z(\text{instanceOf}(y, \text{MaintenanceProcess}, t) \wedge \text{instanceOf}(z, \text{ManufacturingProcess}, t) \wedge \\ \text{precedes}(x, y) \wedge \text{precedes}(z, x)) \end{aligned}$$

FOL English translation: An operating triggering event x is equivalent to a process boundary x such that for some maintenance process y and some manufacturing process z, and x precedes y and z precedes x.

4.2.24 inspection triggering event

InspectionTriggeringEvent = def. A BFO:ProcessBoundry of an UNK:InspectionAction that begins a MNT:MaintenanceProcess

$$\begin{aligned} \text{instanceOf}(x, \text{InspectionTriggeringEvent}, t) \equiv & \text{instanceOf}(x, \text{BFO} : \text{ProcessBoundry}, t) \wedge \\ \exists y, z (& \text{instanceOf}(y, \text{MaintenanceProcess}, t) \wedge \text{instanceOf}(z, \text{InspectionAction}, t) \wedge \\ & \text{precedes}(x, y) \wedge \text{precedes}(z, x)) \end{aligned}$$

FOL English translation: An inspection triggering event x is equivalent to a process boundary x such that for some maintenance process y and some inspection action z , and x precedes y and z precedes x .

5 Outstanding Questions and Comments

- "State" is not a IOF term, should we be using it?
- Maintenance Process is an IOF term, therefore perhaps we do not need to include it in our top 25 maintenance terms. What should we replace it with. There are a dew terms that have been labelled "UNK" in our spreadsheet. Perhaps we should use one of those.
- It is unclear where the term "Non-conformity" sits in the hierarchy. Also, should we use this or "Malfunction"?
- In the definitions, it is unclear how FailureCause and FailureMechanism are different from one another.
- In the IOF top-down group, they are using a relationship called hasRole where we are using bearerOf from the relations ontology. We should probably use hasRole to match the top-down group but we need to have a good idea of what that means.
- The definition of maintainable item role changed slightly to include the idea of a "capability" to serve as an output of a maintenance process. I think we should also consider that it could serve as an input or an output of a maintenance process.
- The IOF top-down group has no realizable entities that we can use as an example. Therefore FailureMode should be reviewed. Note that the logic for failure mode does not match the formal definition that was defined in the spreadsheet.
- For the terms that are information content entities, is the "denotes" relationship descriptive enough to define the term properly?
- State of failure component has used a relationship called "meets". However, we have no defined this. Is there a more appropriate relationship?

- State of failure component and state of failure machine both need a class called Requirement but this is not defined. One option would be to make use of non-conformity instead of using requirement.
- The term InspectionAction is required for inspection triggering event. However, it has not been placed in our taxonomy.
- In the current top 25 terms spreadsheet, the asset role definition is under review. To move forward, we have added the concept of a ValueAdding-Process but this has not yet been defined.
- The definition of FailureModeAndEffectsAnalysisSpecification requires the concept of FMEA Activity but this has not been defined.
- In the definition of MaintenanceStrategyType, we are assuming that “for a MNT:MaintenatableItem” will be already defined in the definition for MaintenanceStrategyDevelopmentProcess.
- The first order logic for MaintenanceNonStandardWorkSpecification does not necessarily capture that the document is ‘created’ in a particular instance. However, it does capture that maintenance non-standard and standard work specifications for the same action don’t exist together.
- Formal logic definition for MaintenanceScheduleList does not capture “to be executed in a defined period”. However, it does capture that a MaintenanceScheduleList contains a MaintenanceWorkOrderSpecifications as parts.
- In the logic definition for StateOfDegradation, we are unsure about use of precedes(t, t'). Should we introduce two Zero-dimension temporal regions into this definition.
- The logic definition for maintenance action assumes that “on a component” is covered in the definition of MaintenanceWorkOrderSpecification. Furthermore, the logic definition says that specification is an input to the process, is this correct?