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

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## 1 Introduction

The Maintenance Working Group (MWG) is the part of the Industrial Ontology Foundry (IOF) concerned with industrial maintenance. The MWG is currently focusing on a list of 18 relevant terms and their associated definitions and axioms. This document captures the group's work to date and questions that result from this work.

## 2 Relevant Terms

Table 1: IOF Maintenance Working Group Top 18 Terms

[1] Failure event
[2] Failure mode code
[3] Functional location
[4] Machine identifier
[5] Machine maintenance plan
[6] Maintainable item
[7] Maintainable item role
[8] Maintenance notification
[9] Maintenance notification trigger
[10] Maintenance schedule list
[11] Maintenance strategy type
[12] Maintenance task
[13] Maintenance work order record
[14] Material product production process
[15] Material product production process plan
[16] Restoring function process
[17] Structured maintenance task specification
[18] Structured maintenance trigger

## 3 Term Definitions and Axioms

This section contains subject matter expert (SME) definitions, formal definitions, first-order logic (FOL) axioms and FOL English translations for the MWG's top 18 terms. Whether they are complete and whether they were included in Towards a Reference Ontology for Maintenance Work Management (Hodkiewicz, Woods, Low 2020) i.e. the 'IESA paper' is indicated. Note that a

'complete' status should be understood as as indicating that the term's definitions are well developed and have been reviewed several times (rather than that they are absolute and not open to change). The terms are listed in alphabetical order.

## 3.1 failure event

**SME Def.** An event in which an item has a loss of ability to perform as required.
**Formal Def.** A BFO: terminal process boundary where some process which realizes the initial phase of a material product production process plan ceases.
**FOL Axiom.**

$instanceOf(z, FailureEvent, t) \equiv$
$\exists x, y, z, p(instanceOf(x, process, t) \wedge instanceOf(p, MaterialProductProductionProcessPlan, t) \wedge$
$realizesInitialPhaseOfPlan(x, y, p) \wedge terminalProcessBoundary(z, x))$

**FOL English translation.** A failure event z is equivalent to the terminal process boundary z of some process x where x realizes the initial phase y of a material product production process plan p.
**Status.** Complete, included in IESA paper.

## 3.2 failure mode code

**SME Def.** A set of codes used to describe the failure mode of a maintainable item.
**Formal Def.** An IOF:DescriptiveInformationContentEntity describing a failure mode.
**FOL Axiom.**

$instanceOf(x, FailureModeCode, t) \equiv$
$instanceOf(x, DescriptiveInformationContentEntity, t) \wedge$
$\exists y(instanceOf(y, FailureMode, t) \wedge IAO : denotes(x, y, t))$

**FOL English translation.** A failure mode code x is equivalent to a descriptive information content entity x such that there exists a failure mode y and x denotes y.
**Status.** Complete.

## 3.3 functional location

**SME Definition.** Describes a physical location where a maintenance task is actioned.
**Formal Def.** An IOF:DescriptiveInformationContentEntity that describes the location of a maintenance task.
**FOL Axiom.**

$instanceOf(x, FunctionalLocation, t) \equiv$
$instanceOf(x, DescriptiveInformationContentEntity, t) \wedge$
$\exists y, z(instanceOf(y, MaintenanceTask, t) \wedge instanceOf(z, SpatialRegion, t) \wedge$
$RO : locationOf(z, y) \wedge IAO : denotes(x, z, t))$

**FOL English translation.** A functional location x is equivalent to a descriptive information content entity x such that there exists a maintenance task y and a spatial region (0D, 1D, 2D or 3D) z. The location of y is z and x denotes z.
**Status.** Complete, included in IESA paper.

### 3.4 machine identifier

**SME Def.** A unique identifier or serial number of a machine or asset
**Formal Def.** An IOF:DescriptiveInformationContentEntity that uniquely identifies a machine.
**FOL Axiom.**
$instanceOf(x, MachineIdentifier, t) \equiv$
$instanceOf(x, DescriptiveInformationContentEntity, t) \wedge$
$\exists y(instanceOf(y, Machine, t) \wedge RO : denotes(x, y)) \wedge \forall z(RO : denotes(x, z) \rightarrow z = y)$
**FOL English translation.** A machine identifier x is equivalent to a descriptive content entity x and there exists a machine y and x denotes y. For all z, if x denotes z then z is equal to y.
**Status.** Complete, included in IESA paper.

### 3.5 machine maintenance plan

**SME Def.** A plan for the maintenance of a machine over its life cycle that documents actions required and when those actions should occur.
**Formal Def.** An IOF:Plan that describes maintenance actions to be taken for a machine and that identifies the MNT:MaintenanceTriggeringEvent for the machine.
**FOL Axiom.**
$instanceOf(x, MachineMaintenancePlan, t) \equiv$
$instanceOf(x, Plan, t) \wedge$
$\exists x1, x2, \ldots, xn, \forall i(instanceOf(xi, MaintenanceAction, t) \wedge partOf(xi, x)) \wedge$
$\exists y, z(instanceOf(y, MaintenanceTriggeringEvent, t) \wedge denotes(x, y) \wedge instanceOf(z, Machine, t) \wedge bearerOf(z, y))$
**FOL English translation.** A machine maintenance plan x is equivalent to a plan x such that there exists a set of maintenance actions xi (for x1 to xn) where all xi are parts of x and x describes the maintenance triggering event y for a machine z.
**Status.** Complete.

### 3.6 maintainable item

**SME Def.** A component or grouping of components on which maintenance is actioned.
**Formal Def.** An IOF:MaterialArtifact that has a MNT:MaintainableItemRole.
**FOL Axiom.**

$instanceOf(x, MaterialArtifact, t) \equiv instanceOf(x, Component, t) \wedge \exists r(MaintainableItemRole(r) \wedge bearerOf(x, r))$
**FOL English translation.** A maintainable item x is equivalent to a material artifact x and there exists some maintainable item role r such that x is a bearer of r.
**Status.** Complete.

### 3.7 maintainable item role

**SME Def.** This class is necessary to recognise that a single machine or component can play a number of roles depending on perspective. For example, it has an asset role with a cost in an accounting system, a part role in a purchasing system, and a maintainable item role in the maintenance management system.
**Formal Def.** A role that inheres in some IOF:Component that has the capability to serve as the output of some MNT:MaintenanceProcess.
**FOL Axiom.**
$instanceOf(x, MaintainableItemRole, t) \equiv instanceOf(x, Role, t) \wedge \exists y, w, z(instanceOf(y, Component, t) \wedge bearerOf(y, x, t) \wedge hasCapability(y, w) \wedge \forall z(realises(z, w) \rightarrow (instanceOf(z, MaintenanceProcess) \wedge hasSpecifiedOutput(z, y))))$
**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.
**Status.** Incomplete.

### 3.8 maintenance notification

**SME Def.** Documentation used to notify the maintenance planners about a non-conformity
**Formal Def.** An IOF:DirectiveInformationContentEntity describing a non-conformity.
**FOL Axiom.**
$instanceOf(x, MaintenanceNotification, t) \equiv instanceOf(x, DirectiveInformationContentEntity, t) \wedge \exists y(instanceOf(y, NonConformity, t) \wedge denotes(x, y, t))$
**FOL English translation.** A maintenance notification x is equivalent to a directive information content entity x and it is the case that there exists a non-conformity y and x denotes y.
**Status.** Complete.

### 3.9 maintenance notification trigger

**SME Def.** Needs work
**Formal Def.** Needs work
**FOL Axiom.**

Needs work
**FOL English translation.** Needs work
**Status.** Incomplete.

### 3.10 maintenance schedule list

**SME Def.** A maintenance schedule contains a list of actions to be performed in a specific period of time, for example a weekly maintenance schedule.
**Formal Def.** An IOF:Plan describing a list of MNT:MaintenanceAction(s) to be executed in a defined period.
**FOL Axiom.**

$$instanceOf(x, MaintenanceScheduleList, t) \equiv$$
$$instanceOf(x, Plan, t) \wedge$$
$$\exists x1, x2, \ldots, xn, \forall i(instanceOf(xi, MaintenanceAction, t) \wedge partOf(xi, x))$$

**FOL English translation.** A maintenance schedule list x is equivalent to a plan x such that there exists a set of maintenance actions xi (for x1 to xn) where all xi are parts of x.
**Status.** Incomplete.

### 3.11 maintenance strategy type

**SME Def.** Maintenance strategy types are defined by reliability centred maintenance process and include strategies such as run-to-failure, preventative replacement and restoration, failure finding and predictive maintenance.
**Formal Def.** An IOF:DescriptiveInformationContentEntity describing the MNT:MaintenanceStrategyType to manage a specific MNT:FailureMode.
**FOL Axiom.**

$$instanceOf(x, MaintenanceStrategyType, t) \equiv$$
$$instanceOf(x, DescriptiveInformationContentEntity, t) \wedge$$
$$\exists y, z(instanceOf(y, MaintenanceStrategyType, t) \wedge$$
$$instanceOf(z, FailureMode, t) \wedge denotes(x, y, t) \wedge denotes(x, z, t))$$

**FOL English translation.** A maintenance strategy type x is equivalent to a descriptive information content entity x such that there exists a maintenance strategy type y and a failure mode z and x denotes both y and z.
**Status.** Incomplete.

### 3.12 maintenance task

**SME Def.** A task involving replacement, repair, inspection or service of a maintainable item.
**Formal Def.** An IOF:Task that takes some MNT:MaintenanceWorkOrderRecord as an input and is a temporal part of some process where a maintainable item's required function is restored.
**FOL Axiom.**

$instanceOf(x, MaintenanceTask, t) \equiv instanceOf(x, Task, t) \wedge$
$\exists y, z(instanceOf(y, MaintenanceWorkOrderRecord, t) \wedge inputOf(y, x)$
$\wedge instanceOf(z, RestoringFunctionProcess, t) \wedge RO : hasTemporalPart(z, x))$
**FOL English translation.** A maintenance task x is equivalent to a task x which has some maintenance work order record y as input and is a temporal part of some restoring function process z.
**Status.** Complete, included in IESA paper.

### 3.13 maintenance work order record

**SME Def.** A record in the computerized maintenance management system describing the need for a maintenance action.
**Formal Def.** An IOF:DescriptiveInformationContentEntity that describes some MNT:Maintenance Action and is realized in response to a MNT:Maintenance Notification Trigger or a MNT: StructuredMaintenanceTrigger
**FOL Axiom.**
$instanceOf(x, MaintenanceWorkOrderRecord, t) \equiv$
$instanceOf(x, DescriptiveInformationContentEntity, t) \wedge \exists y, z, p(instanceOf(y, MaintenanceAction, t)$
$\wedge RO : inputOf(x, y) \wedge instanceOf(z, MaintenanceNotificationTrigger, t) \wedge$
$instanceOf(p, StructuredMaintenanceTrigger, t) \wedge (RO : realizedInResponseTo(x, z) \vee$
$RO : realizedInResponseTo(p, z))$
**FOL English translation.** A maintenance work order record x is equivalent to a descriptive information content entity x and there exists some maintenance action y and x isAbout y. It is realised in response to either a MaintenanceNotificationTrigger z or a StructuredMaintenanceTrigger p.
**Status.** Complete, included in IESA paper.

### 3.14 material product production process

**SME Def.** Needs work
**Formal Def.** Needs work
**FOL Axiom.**
Needs work
**FOL English translation.** Needs work
**Status.** Incomplete.

### 3.15 material product production process plan

**SME Def.** Needs work
**Formal Def.** Needs work
**FOL Axiom.**
Needs work
**FOL English translation.** Needs work
**Status.** Incomplete.

### 3.16 restoring function process

**SME Def.** Needs work
**Formal Def.** Needs work
**FOL Axiom.**
Needs work
**FOL English translation.** Needs work
**Status.** Incomplete.

### 3.17 structured maintenance task specification

These are fixed interval restoration and replacement, inspection and condition based maintenance work orders which are generated automatically by the computerised maintenance management system based on maintenance strategies. They have a standardised format.
**Formal Def.** An IOF:TaskSpecification describing a desired MNT:MaintenanceAction.
**FOL Axiom.**
$instanceOf(x, MaintenanceWorkOrderSpecification, t) \equiv$
$instanceOf(x, TaskSpecification, t) \wedge$
$\exists y(instanceOf(y, MaintenanceAction, t) \wedge denotes(x, y, t))$
**FOL English translation.** A maintenance work order specification x is equivalent to a task specification x and it is the case that there exists a maintenance action y and x denotes y.
**Status.** Incomplete.

### 3.18 structured maintenance trigger

**SME Def.** Needs work
**Formal Def.** Needs work
**FOL Axiom.**
Needs work
**FOL English translation.** Needs work
**Status.** Incomplete.

## 4 OWL Ontology

The terms listed in Table 1 are captured in a Protégé file available at `https://github.com/uwasystemhealth/IOF_Maintenance_Working_Group_Public/tree/IESA-2020-snapshot`. We use the prefix MNT, which stands for maintenance. This MNT ontology uses classes imported from the IOF ontology and is aligned to the top-level ontology Basic Formal Ontology (BFO).

# 5 Potential Terms

## 5.1 stasis of failure of maintainable item

**SME Def.** Needs work
**Formal Def.** A X:Stasis in which some MNT:MaintainableItem endures and is developing one or more failure modes.
**FOL Axiom.**
$instanceOf(x, StasisOfFailureMaintainableItem, t) \equiv instanceOf(x, Stasis, t) \wedge \exists y, w(instanceOf(y, MaintainableItem, t) \wedge instanceOf(w, Requirement, t) \wedge \neg(meets(y, w))$
**FOL English Translation.** A stasis of failure maintainable item x is equivalent to an stasis x where for some maintainable item y and requirement w, y does not meet the requirement.
**Status.** Incomplete.

## 5.2 stasis of degradation of maintainable item

**SME Def.** Needs work
**Formal Def.** A X:Stasis in which some MNT:maintainableItem endures and is developing one or more failure modes.
**FOL Axiom.**
$instanceOf(x, StasisOfDegradation, t) \equiv instanceOf(x, State, t) \wedge \exists y, w, z(instanceOf(y, Component, t) \wedge \neg(instanceOf(w, FailureMode, t) \wedge instanceOf(w, FailureMode, t') \wedge precedes(t, t'))$
**FOL English translation.** A stasis of degradation maintainable item x is equivalent to an IOF stasis x such that for some component y:

1. there is no failure mode at t
2. there is a failure mode
3. t precedes t'

**Status.** Incomplete.

# 6 Appendix

This section contains a summary of the September 2019 state of the MWG's reference ontology terms and definitions. Note that the terms which were the MWG's focus in September 2019 are different to the terms which are its current focus. This is because the MWG has decided to focus on terms core to the maintenance domain, and wait to collaborate with other working groups on terms which are relevant across domains.

| **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 2: IOF Maintenance Working Group Top 25 Maintenance Terms

## 6.1 Relevant Terms

## 6.2 Taxonomy

Figure 1 contains a fragment of the BFO taxonomy to show where the top 25 maintenance terms fit.

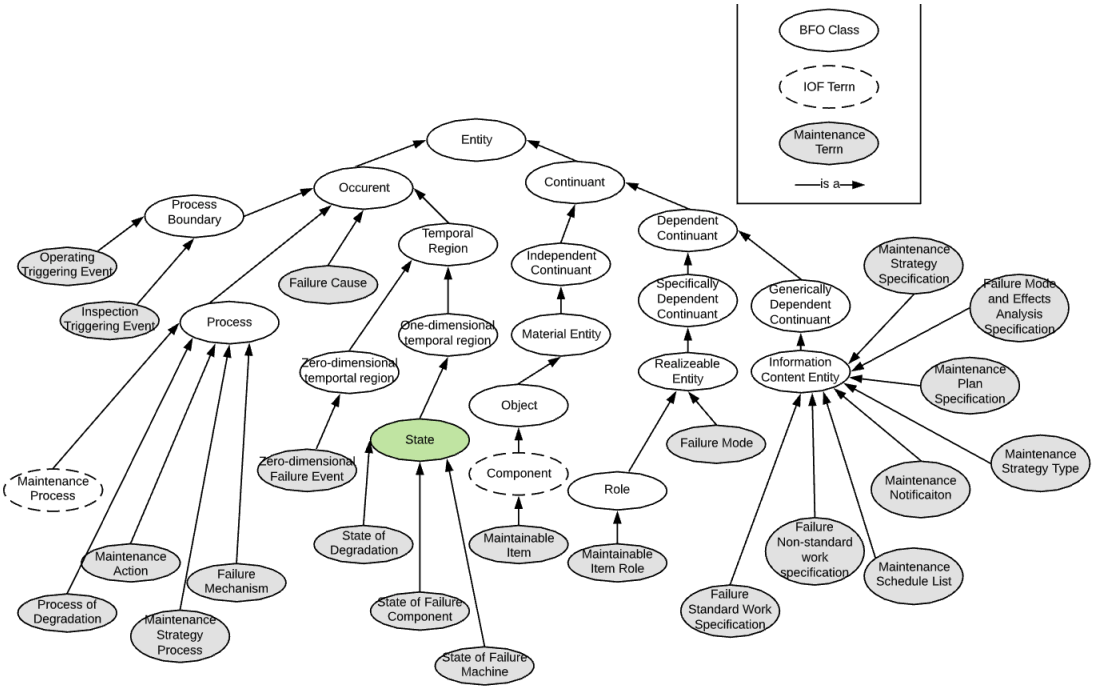


Figure 1: Taxonomy of Top 25 Maintenance Terms

## 6.3 Taxonomy Formalisation

### 6.3.1 maintainable item subclass of component

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

### 6.3.2 maintainable item role subclass of role

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

### 6.3.3 asset role subclass of role

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

### 6.3.4 failure mode subclass of realizeable entity

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

### 6.3.5 maintenance standard work specification subclass of information content entity

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

### 6.3.6 maintenance non-standard work specification subclass of information content entity

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

### 6.3.7 maintenance plan specification subclass of information content entity

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

### 6.3.8 maintenance strategy specification subclass of information content entity

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

### 6.3.9 maintenance schedule list subclass of information content entity

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

### 6.3.10 maintenance strategy type subclass of information content entity

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

#### 6.3.11 failure mode and effects analysis specification subclass of information content entity

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

#### 6.3.12 state of failure component subclass of state

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

#### 6.3.13 state of failure machine subclass of state

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

#### 6.3.14 state of degradation subclass of state

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

#### 6.3.15 non-conformity subclass of ?

$NonConformity(x) \rightarrow ?$

#### 6.3.16 zero-dimensional failure event subclass of zero-dimensional temportal region

$ZeroDimensionalFailureEvent(x) \rightarrow ZeroDimensionalTemporalRegion$

#### 6.3.17 process of degradation subclass of process

$ProcessOfDegradation(x) \rightarrow Process$

#### 6.3.18 maintenance action subclass of process

$MaintenanceAction(x) \rightarrow Process$

#### 6.3.19 maintenance strategy process subclass of process

$MaintenanceStrategyProcess(x) \rightarrow Process$

#### 6.3.20 failure mechanism subclass of process

$FailureMechanism(x) \rightarrow Process$

#### 6.3.21 failure cause subclass of occurent

$FailureCause(x) \rightarrow Occurent$

#### 6.3.22 operating triggering event subclass of process boundary

$OperatingTriggeringEvent(x) \rightarrow ProcesBoundary$

#### 6.3.23 maintenance notification subclass of information content entity

$MaintenanceNotification(x) \rightarrow InformationContentEntity$

## 6.4 Term Definitions and Formal Axioms

### 6.4.1 maintainable item

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

$instanceOf(x, MaintainableItem, t) \equiv instanceOf(x, Component, t) \wedge \exists r(MaintainableItemRole(r) \wedge bearerOf(x, r))$

**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.

### 6.4.2 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

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

**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.

### 6.4.3 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

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

**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.

#### 6.4.4 failure mode

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

$$instanceOf(x, FailureMode, t) \equiv instanceOf(x, RealizableEntity, t) \wedge ((\exists y, w(instanceOf(y, FailureMechanism, t) \wedge (instanceOf(w, StateOfFailureComponent, t) \wedge precedes(y, w, t)) \vee (p, z(instanceOf(p, FailureMechanism, t) \wedge (instanceOf(z, StateOfFailureMachine, t) \wedge precedes(p, z, t)))$$

**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.

#### 6.4.5 maintenance standard work specification

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

$$instanceOf(x, MaintenanceWorkOrderSpecification, t) \equiv instanceOf(x, InformationContentEntity, t) \wedge \exists y(instanceOf(y, MaintenanceAction, t) \wedge denotes(x, y, t))$$

**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.

#### 6.4.6 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

$$instanceOf(x, MaintenanceNonStandardWorkSpecification, t) \equiv instanceOf(x, InformationContentEntity, t) \wedge \exists y(instanceOf(y, MaintenanceAction, t) \wedge denotes(x, y, t)) \wedge (denotes(x, y, t) \exists z(instanceOf(z, MaintenanceStandardWorkSpecification, t) \wedge denotes(z, y, t)))$$

**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.

#### 6.4.7 maintenance plan specification

Definition needs further work.

#### 6.4.8 maintenance notification

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

$$instanceOf(x, MaintenanceNotification, t) \equiv$$
$$instanceOf(x, InformationContentEntity, t) \wedge$$
$$\exists y(instanceOf(y, NonConformity, t) \wedge denotes(x, y, t))$$

**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.

#### 6.4.9 maintenance strategy specification

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

$$instanceOf(x, MaintenanceStrategySpecification, t) \equiv$$
$$instanceOf(x, InformationContentEntity, t) \wedge$$
$$\exists y, z(instanceOf(y, MaintenanceStrategyType, t) \wedge$$
$$instanceOf(z, FunctionalFailure, t) \wedge denotes(x, y, t) \wedge denotes(x, z, t))$$

**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.

#### 6.4.10 maintenance schedule list

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

$$instanceOf(x, MaintenanceScheduleList, t) \equiv$$
$$instanceOf(x, InformationContentEntity, y) \wedge$$
$$\exists x1, x2, \ldots, xn, \forall i(instanceOf(xi, MaintenanceWorkOrderSpecification, t) \wedge$$
$$partOf(xi, x))$$

**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 xi (for x1 to xn) where all xi are parts of x.

#### 6.4.11 Maintenance strategy type

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

$$instanceOf(x, MaintenanceStrategyType, t) \equiv$$
$$instanceOf(x, InformationContentEntity, t) \wedge$$
$$\exists w, z(instanceOf(w, specifiedOutput) \wedge hasCapability(x, w) \wedge$$
$$\forall z(realises(z, w) \rightarrow (instanceOf(z, MaintenanceStrategyDevelopmentProcess) \wedge$$
$$hasSpecifiedOutput(z, x))))$$

**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.

#### 6.4.12 failure mode and effects analysis specification

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

$$instanceOf(x, FailureModeAndEffectsAnalysisSpecification, t) \equiv$$
$$instanceOf(x, InformationContentEntity, t) \wedge$$
$$\exists w, z(instanceOf(w, specifiedOutput) \wedge has-Capability(x, w) \wedge \forall z(realises(z, w) \rightarrow$$
$$(instanceOf(z, FmeaActivity) \wedge hasSpecifiedOutput(z, x))))$$

**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.

#### 6.4.13 state of failure component

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

$$instanceOf(x, StateOfFailureComponent, t) \equiv instanceOf(x, State, t) \wedge$$
$$\exists y, w(instanceOf(y, component, t) \wedge instanceOf(w, Requirement, t) \wedge$$
$$\neg(meets(y, w))$$

**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.

#### 6.4.14 state of failure machine

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

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

**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.

#### 6.4.15 state of degradation

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

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

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'

#### 6.4.16 non-conformity

Definition needs further work.

#### 6.4.17 zero-dimensional failure event

Need to discuss formalisation

#### 6.4.18 process of degradation

Definition needs further work.

#### 6.4.19 maintenance action

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

$$instanceOf(x, MaintenanceAction, t) \equiv instanceOf(x, Process, t) \wedge \exists y(instanceOf(y, MaintenanceWorkOrderSpecification, t) \wedge inputOf(y, x))$$

**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.

#### 6.4.20 maintenance strategy process

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

$$instanceOf(x, MaintenanceStategyProcess) \equiv instanceOf(x, Process) \wedge \exists y(instanceOf(y, MaintenanceStrategySpecification, t) \wedge isSpecifiedOutput(y, x, t))$$

**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.

#### 6.4.21 failure mechanism

Definition needs further work.

#### 6.4.22 failure cause

Definition needs further work.

#### 6.4.23 operating triggering event

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

$$instanceOf(x, OperatingTriggeringEvent, t) \equiv instanceOf(x, ProcessBoundry, t) \wedge \exists y, z(instanceOf(y, MaintenanceProcess, t) \wedge instanceOf(z, ManufacturingProcess, t) \wedge precedes(x, y) \wedge precedes(z, x))$$

**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.

#### 6.4.24 inspection triggering event

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

$$instanceOf(x, InspectionTriggeringEvent, t) \equiv instanceOf(x, BFO:ProcessBoundry, t) \wedge \exists y, z(instanceOf(y, MaintenanceProcess, t) \wedge instanceOf(z, InspectionAction, t) \wedge precedes(x, y) \wedge precedes(z, x))$$

**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.

### 6.5 Outstanding Questions and Comments

- "State" is not an 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 few 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 an 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 a FMEA Activity but this has not been defined.
- In the definition of MaintenanceStrategyType, we are assuming that "for a MNT:MaintenanableItem" 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 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?