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## 1 - Análise ontológica do domínio, com identificação das entidades que tem identidade rígida, e as entidades dependentes (moments e relações)

Continuants

Ocurrents

Particulars

### *Predictive Maintenance and Health Monitoring System*

Let be a system responsible for **predictive maintenance** and **health monitoring** of a **facility**, such as an **oil** and **gas** extraction platform. This system may be considered as a part of the whole facility maintenance system and is composed by the **equipment** selected to be **monitored**, **sensors** that monitor the **physical quantities** and information necessary to predict the equipment's **condition** (**pressure**, **flow**, **electric current**, **voltage**, **vibration**, **temperature**, **noise**, **rust**, **abrasion level**, **integrity** of the **parts**, **iron filing level** in the bearing grease), a **supervisory system** that gathers these information and displays **alerts** whenever any of those **measurements** are out of the specified **range**, the **technical maintenance team** that **install** and **uninstall** the equipment, **execute maintenance actions**, **collect samples** (if needed) to **detect** any **anomalous condition** in the equipment, and a **maintenance engineering team** to **decide** wether and when is necessary any **maintenance intervention**.

In this example, there is 4 equipment selected to be monitored: **pump B-01** installed in the bottom of the oil well, the **electric motor M-01** that **drives** the pump **B-01** and **installed** attached to it, and their respective **spare** equipment: the pump **B-02** and the electric motor **M-02**. The technical maintenance team is composed by 4 technicians: **Jerry**, **Moacir**, **Marcos** and **Jeferson**. The maintenance engineering team is composed by 3 engineers: **Rafael**, **Caldas** and **Ulysses**. In this system there are real-time measurements in the supervisory system of the following physical quantities: the suction and discharge pressure of B-01, flow through B-01, B-01 and M-01 bearings vibration, **propelled petroleum** temperature, voltage and current of M-01. Once happens any alert in the supervisory system, the maintenance engineering team evaluates the necessity of stopping the operation or not so that the equipment can be brought to the platform for inspection and maintenance. Once the intervention is considered necessary, the maintenance engineering team opens an immediate **maintenance work order** in the **Computerized Maintenance Management System (CMMS)** and communicate the operation the need to **stop** the **running** equipment for maintenance. The **stopped** equipment are brought up to the platform, and the maintenance technician working in the current turn evaluates the equipment's general conditions (**rust**, **abrasion**, **integrity of the parts** of M-01 and B-01), collect **samples from the bearings grease from B-01 and M-01** and send them to laboratory analysis. The **out-of-order** equipment can be **fixed** or **replaced** by its **working** spare so that they can be **started** and the production reestablished. Then, the technician fill the maintenance work order data in the CMMS.

The maintenance engineering team have access to the information gathered by the real-time sensors, as well as the reports generated by the maintenance technical team. They also use specific **maintenance engineering softwares** to make predictions. So, if needed, a **maintenance notification** is opened in the CMMS, and the discovered **anomaly** will be treated along other maintenance pendencies (either **preventive** or **corrective**).

Continuants:

- Facility: BFO:object aggregate
- Equipment: BFO:object
- Oil: BFO:object
- Gas: BFO:object
- Petroleum: BFO:object
- Sensor: BFO:object
- Physical quantity: IAO:physical\_object\_quality
- Condition: quality
- Pressure: IAO:physical\_quality
- Flow: IAO:physical\_quality
- Electric current: IAO:physical\_quality
- Voltage: IAO:physical\_quality
- Vibration: IAO:physical\_quality
- Temperature: IAO:physical\_quality
- Noise: IAO:physical\_quality
- Rust: IAO:physical\_quality
- Abrasion\_level: IAO:physical\_quality
- Integrity: IAO:physical\_object\_quality
- Part: BFO:object

- Iron\_filing\_level: IAO:physical\_quality
- Bearing: BFO:object
- Grease: BFO:object
- Supervisory\_system: IAO:software\_application
- Alert: IAO:software\_method
- Range: IAO:'one dimensional cartesian spatial coordinate datum'
- Technical\_maintenance\_team: BFO:object\_aggregate
- Sample: BFO:'fiat object part'
- Anomalous condition
- Maintenance\_engineering\_team: BFO:object\_aggregate
- Pump: BFO:object
- Electric\_motor: BFO:object
- In\_service: quality
- Spare: quality
- Measurement: IAO: 'measurement datum'
- CMMS: IAO:software\_application
- Running: quality
- Stopped: quality
- out-of-order: quality
- working: quality
- Normal: quality
- Maintenance\_engineering\_software: IAO:software\_application
- Maintenance\_work\_order: IAO:document
- Maintenance\_notification: IAO:document
- Anomaly: BFO:disposition

Considering:

Sortal: type of object that is able to carry a uniform principle of identity, persistence and counting for all its instances [1].

Ridgity: A property is rigid if it is essential to all its possible instances; an instance of a rigid property cannot stop being an Instance of that property in a different world [2].

Quality: a trope classified under a quality type, which is an intrinsic trope type that are directly associated with a quality structure.

#### **Rigid Sortals:**

- Equipment: BFO:object
- Oil: BFO:object
- Gas: BFO:object
- Petroleum: BFO:object
- Sensor: BFO:object
- Part: BFO:object
- Bearing: BFO:object
- Grease: BFO:object
- Pump: BFO:object
- Electric\_motor: BFO:object
- Maintenance\_work\_order: IAO:document
- Maintenance\_notification: IAO:document
- Supervisory\_system: IAO:software\_application
- Supervisory\_system: IAO:software\_application
- Maintenance\_engineering\_software: IAO:software\_application
- Maintenance\_work\_order: IAO:document
- Maintenance\_notification: IAO:document

#### **Moments:**

- Pressure: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: pump
- Flow: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: pump
- Electric\_current: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: electric\_motor
- Voltage: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: electric\_motor
- Vibration: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: equipment
- Temperature: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: equipment
- Noise: IAO:physical\_quality – inheres in: equipment
- Rust: IAO:physical\_quality – inheres in: equipment
- Abrasion\_level: IAO:physical\_quality – inheres in: equipment
- Integrity: IAO:physical\_object\_quality – inheres in: equipment
- Iron\_filing\_level: IAO:physical\_quality – inheres in: grease

- inventory\_status: IAO: quality – inheres in: equipment
- maintenance\_status: IAO: quality – inheres in: equipment
- operational\_status: IAO: quality – inheres in: equipment

#### **Relações estruturantes:**

##### **Subsumption:**

- grease is an object;
- sensor is an object;
- person is an object;
- petroleum is an object;
- oil is an object;
- part is an object;
- gas is an object;
- equipment is an object;
- bearing is a part;
- pump is an equipment;
- electric\_motor is an equipment;
- sample is a fiat\_object\_part;
- facility is an object\_aggregate;
- team is an object\_aggregate;
- technical\_maintenance\_team is a team;
- maintenance\_engineering\_team is a team;
- physical\_object\_quality is a quality;
- operational\_status is a quality;
- installation\_status is a quality;
- maintenance\_status is a quality;
- physical\_quality is a physical\_quantity;
- physical\_quantity is a physical\_quality;
- physical\_quality is a physical\_object\_quality;
- morphology is a physical\_object\_quality;
- pressure is a physical\_quality;
- noise is a physical\_quality;
- mass is physical\_quality;
- flow is physical\_quality;
- iron\_filing\_level is physical\_quality;
- voltage is physical\_quality;
- vibration is physical\_quality;
- electric\_current is physical\_quality;
- temperature is physical\_quality;
- abrasion\_level is physical\_quality;
- rust is physical\_quality;
- integrity is physical\_quality;
- discharge\_pressure is a pressure;
- suction\_pressure is a pressure;
- not-broken is a integrity;
- broken is a integrity;
- employee is a role;
- engineer is a employee;
- technician is a employee;
- fixing\_equipment is a planned\_process;
- measurement is a measurement\_datum;
- measurement\_datum is a measurement;
- measurement is a data\_item;
- measurement\_datum is a data\_item;
- scalar\_measurement\_datum is a measurement\_datum;
- vibration\_measurement\_datum is a scalar\_measurement\_datum;
- mass\_measurement\_datum is a scalar\_measurement\_datum;

- noise\_measurement\_datum is a scalar\_measurement\_datum;
- temperature\_measurement\_datum is a scalar\_measurement\_datum;
- electric\_current\_measurement\_datum is a scalar\_measurement\_datum;
- flow\_measurement\_datum is a scalar\_measurement\_datum;
- voltage\_measurement\_datum is a scalar\_measurement\_datum;
- pressure\_measurement\_datum is a scalar\_measurement\_datum;
- iron\_filing\_measurement\_datum is a scalar\_measurement\_datum;
- measurement\_unit\_label is a datum\_label;
- vibration\_unit is a measurement\_unit\_label;
- electric\_current\_unit is a measurement\_unit\_label;
- iron\_filing\_unit is a measurement\_unit\_label;
- flow\_unit is a measurement\_unit\_label;
- noise\_unit is a measurement\_unit\_label;
- voltage\_unit is a measurement\_unit\_label;
- pressure\_unit is a measurement\_unit\_label;
- temperature\_unit is a measurement\_unit\_label;
- anomaly is a disposition;
- alert is a software\_method;
- maintenance\_engineering\_software is a software\_application;
- supervisory\_system is a software\_application;
- cmms is a software\_application;
- range is an one\_dimension\_cartesian\_spatial\_coordinate\_datum;
- maintenance\_notification is a document;
- maintenance\_work\_order is a document;

**Part-of:**

- facility has\_part equipment;
- facility has\_part sensor;
- facility has\_part part;
- team has\_element person;
- petroleum has\_subquantity gas;
- petroleum has\_subquantity oil;
- part is component of equipment;
- engineer is element\_of maintenance\_engineering\_team;
- technician is element\_of technical\_maintenance\_team;

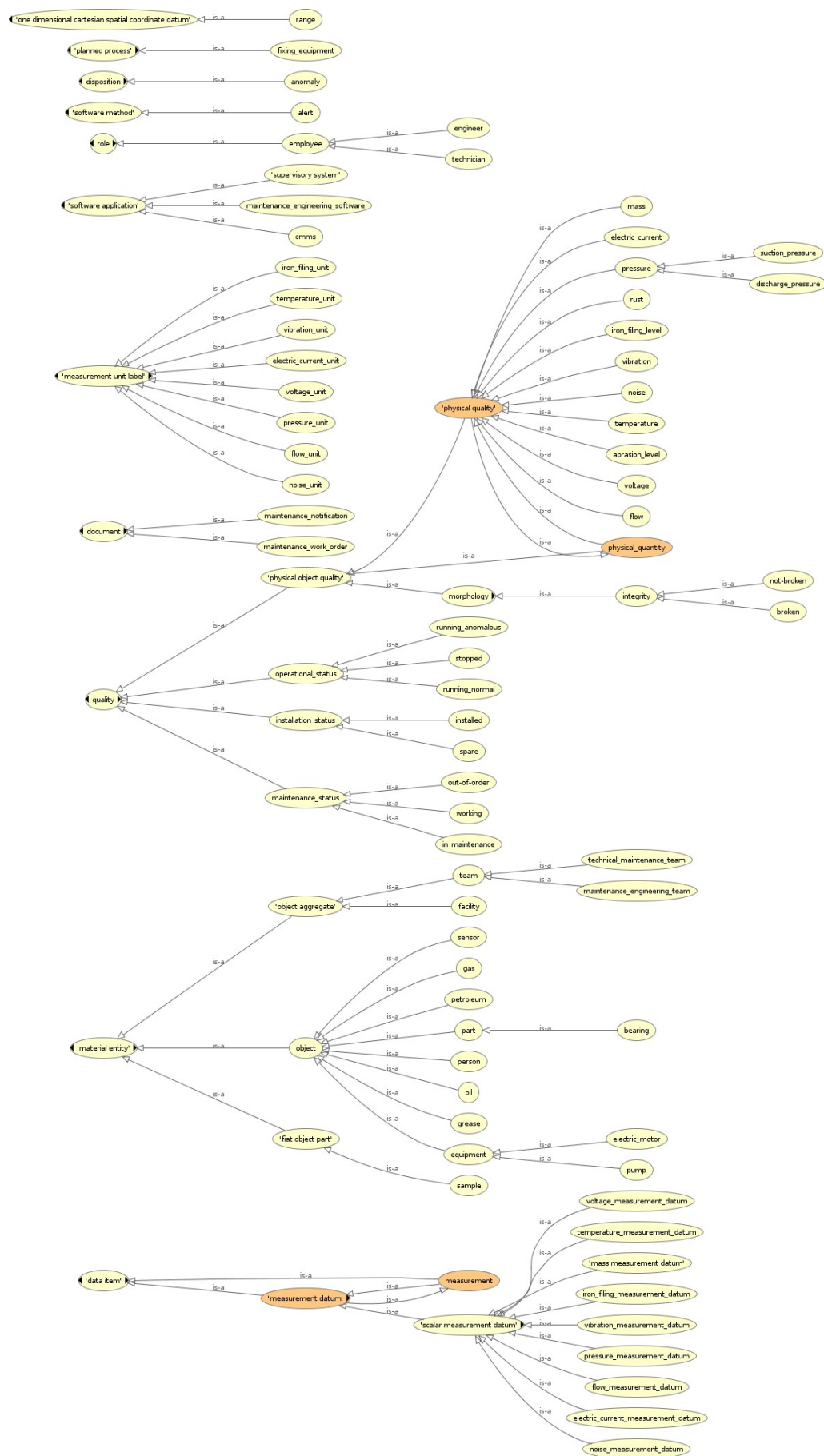
2- Defina um processo para ser modelado e de que forma afeta entidades continuantes (criando/destruindo entidades, alterando suas qualidades, modificando papéis). Lembrem-se que uma instancia de processo é identificada pela detecção da modificação que causam nas instancias dos continuantes.

Processo a ser modelado: fixing\_equipment, modelado no Protégé.

Definition: The process of repairing an equipment out-of-order so that it can be able to work normally. The installation status is changed from out-of-order to working after the process is complete.

3- Construa o modelo conceitual especializando a BFO (entidades materiais), a RO (relações), a IAO (artefatos de informação, se for o caso), e outras ontologias necessárias.  
Feito no Protégé.

Figure 1: Print da árvore com a visão geral do modelo na BFO



4- Definição das entidades. Os itens a. até e. são definidos como annotations properties no Protege, enquanto o f. são object properties. Descreva as entidades com:

- a. Label (nome que a entidade será referenciada)
- b. Definição semi formal (pode ser descritiva, não precisa ser em Lógica, mas atente para a precisão)
- c. URL da fonte ou referência bibliográfica
- d. Sinônimos (se houver)
- e. Exemplo de uso
- f. Relações de disjunção ou equivalência com outras entidades, se houver.

Feito no Protégé.

5- Definição dos momentos das entidades definidas e, quando tiverem estruturas de valores, descrição dos quality domains.

Moments:

- Pressure: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: pump
- Flow: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: pump
- Electric\_current: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: electric\_motor
- Voltage: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: electric\_motor
- Vibration: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: equipment
- Temperature: IAO:physical\_quality – quality structure: 'scalar measurement datum' – inheres in: equipment
- Noise: IAO:physical\_quality – inheres in: equipment
- Rust: IAO:physical\_quality – inheres in: equipment
- Abrasion\_level: IAO:physical\_quality – inheres in: equipment
- Integrity: IAO:physical\_object\_quality – inheres in: equipment
- Iron\_filing\_level: IAO:physical\_quality – inheres in: grease
- inventory\_status: IAO: quality – inheres in: equipment
- maintenance\_status: IAO: quality – inheres in: equipment
- operational\_status: IAO: quality – inheres in: equipment

6- Definição das relações. Inclua no seu modelo pelo menos uma relação do tipo descritiva interna, descritiva externa, não-descritiva interna, não-descritiva externa. Para cada uma descreva:

- a. Label (nome que a entidade será referenciada)
- b. Definição semi formal
- c. URL da fonte ou referência bibliográfica
- d. Características da relação
- e. Exemplo de uso
- f. Relações de disjunção ou equivalência, se houver.

**Descritiva interna: heavier\_than**

**Descritiva externa: driven\_by**

**Não-descritiva interna: higher\_than**

**Não-descritiva externa: component\_of**

7- Definição de relações mereológicas. Inclua no seu modelo pelo menos uma relação do tipo component-of, subquantity-of e element-of.

Relações e suas inversas:

**element\_of / has\_element**

**subquantity\_of / has\_subquantity**

**composed\_of / composed\_by**

8- Definição de instâncias suficientes para validar o modelo.

Feito no Protégé.

9- Descrição das informações ou inconsistências que podem ser extraídas com os raciocinadores do Protege. Em modelos pequenos, as inferências podem não mostrar muita informação útil, mas anotem inconsistências encontradas no processo de criação da ontologia.

Inconsistências:

- Ao tentar atribuir 'specified\_range' como uma qualidade de 'physical\_quality': não havia sido respeitado o domínio e range da relação.

Explanation for: electric_current EquivalentTo owl:Nothing		
1)	electric_current SubClassOf 'has quality' some specified_range	In 26 other justifications ?
2)	'has quality' Range quality	In 10 other justifications ?
3)	quality SubClassOf 'specifically dependent continuant'	In 10 other justifications ?
4)	specified_range SubClassOf 'one dimensional cartesian spatial coordinate datum'	In 26 other justifications ?
5)	'one dimensional cartesian spatial coordinate datum' SubClassOf 'cartesian spatial coordinate datum'	In 5 other justifications ?
6)	'cartesian spatial coordinate datum' SubClassOf 'data item'	In 5 other justifications ?
7)	'data item' SubClassOf 'information content entity'	In 11 other justifications ?
8)	'information content entity' SubClassOf 'generically dependent continuant'	In ALL other justifications ?
9)	'specifically dependent continuant' DisjointWith 'generically dependent continuant'	In ALL other justifications ?

- Ao atribuir 'engineer' como um 'role' de 'employee': não havia sido respeitado o domínio e range da relação.

Explanation for: engineer EquivalentTo owl:Nothing		
1)	engineer SubClassOf 'role of' some employee	In ALL other justifications ?
2)	'role of' InverseOf 'has role'	In ALL other justifications ?
3)	'has role' Domain 'independent continuant'	In ALL other justifications ?
4)	employee SubClassOf role	In NO other justifications ?
5)	role SubClassOf 'realizable entity'	In 1 other justifications ?
6)	'realizable entity' SubClassOf 'specifically dependent continuant'	In 1 other justifications ?
7)	'independent continuant' DisjointWith 'specifically dependent continuant'	In ALL other justifications ?

10- (Não obrigatório) Verifique se existem ontologias no mesmo domínio e derivadas da BFO, com código OWL, que possam ser reusadas no seu trabalho.

Sim, existem 2 ontologias de manutenção encontradas e que poderiam ser utilizadas, porém não sem prejuízo da descrição anteriormente feita.

Uma delas é a ontologia de manutenção da IOF (<https://www.industrialontologies.org/maintenance-wg/>) ([https://github.com/uwasystemhealth/IOF\\_Maintenance\\_Working\\_Group\\_Public](https://github.com/uwasystemhealth/IOF_Maintenance_Working_Group_Public)), porém muito focada no processo de gestão da manutenção. Ainda está claramente em construção, com muitos termos ainda não classificados (existe um grupo de trabalho discutindo isto periodicamente) e algumas definições que parecem incompatíveis com a IAO (por ex.: CMMS). Como eram poucos termos que poderiam ser facilmente reaproveitados, optou-se por não utilizá-la neste momento.

A outra trata-se da ontologia do projeto Z-BRE4K, específica para manutenção preditiva. Especializa a ontologia da IOF, detalhando o processo de manutenção preditiva. Trata-se de uma ontologia bastante desenvolvida, que traz a abordagem gerencial (inclusive descrevendo prestadores de serviço e fornecedores de peças). A descrição do processo de manutenção preditiva é feita com base em modos de falha, suas causas e efeitos e criticidade das falhas, associando cada modo de falha a um componente, de acordo com a metodologia de manutenção centrada em confiabilidade. Não foi encontrado até o momento o arquivo .owl da ontologia, apenas a descrição da mesma em pdf. Não entra em detalhes de equipamentos, ficando a cargo de cada empresa participante do consórcio especializar para cada caso. São apresentados casos de 2 empresas (<https://www.z-bre4k.eu/wp-content/uploads/2020/12/Z-BRE4K-semantic-modelling.pdf>). Por esta razão e pela incompatibilidade entre a abordagem que já vinha sendo utilizada no estudo de caso do TF optou-se por não utilizá-la neste momento. No entanto, trata-se de uma boa alternativa para ser reutilizada no restante do projeto de mestrado, bastando para isto ter os estudos de manutenção centrada em confiabilidade dos sistemas selecionados.

References:

[1] - Guizzardi, G. and Zamborlini, V., 2014. Using a trope-based foundational ontology for bridging different areas of concern in ontology-driven conceptual modeling. *Science of Computer Programming*, 96, pp.417-443.

[2] - Guarino, N. and Welty, C.A., 2004. An overview of OntoClean. *Handbook on ontologies*, pp.151-171.

[3] - Fonseca, C.M., Porello, D., Guizzardi, G., Almeida, J.P.A. and Guarino, N., 2019, November. Relations in ontology-driven conceptual modeling. In *International Conference on Conceptual Modeling* (pp. 28-42). Springer, Cham.