FMEA Natural Gas Railroad Tender

Failure Modes and Effects Analysis (FMEA) is a qualitative, inductive process used to identify the effect of component failures on subsystems and systems. It is important to follow an established, standardized FMEA methodology to ensure that the FMEA process is sufficiently rigorous. There are several different FMEA methodologies; most adhere to a similar process, with the main differences stemming from the target industry, how the method handles varying degrees of design maturity and how the severity, probability and criticality are handled and prioritized.

Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 5580, titled “Recommended Failure Modes and Effects Analysis Practices or Non-Automobile Application,” is an appropriate methodology for this application. Specifically, a Product Design Hardware FMEA provides a top-down functional and interface FMEA based on the state of the developing technology and available information about the detailed design of the LNG rail vehicle.

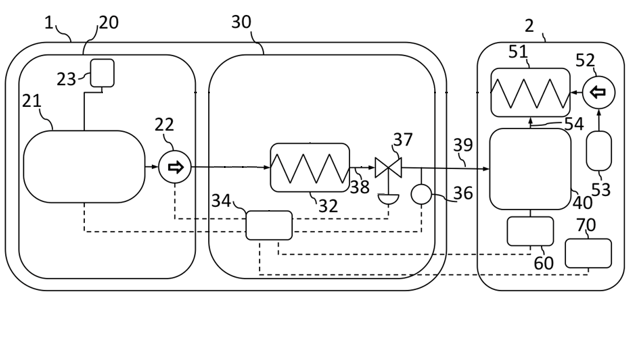
Information Basis may contain:

* System diagrams, system descriptions, system breakdowns, data sources, hazard checklists, failure mode models (lists),

**Diagrams & tables you will need for this exercise begin on next page.**

**Partial list of references:**

* SAE ARP 5580. Aerospace Recommended Practice-Recommended Failure Modes and Effects Analysis Practices or Non-Automobile Application. SAE International. Updated May 2012.
* MIL-STD-1629 A. Procedures for Performing a Failure Mode, Effects and Criticality Analysis. 1980.
* Reliability Information Analysis Center (RIAC), Non-electronic Parts Reliability Data (NPRD). Electronic database, U.S. Department of Defense. 2011
  + (1991 version located here: https://apps.dtic.mil/dtic/tr/fulltext/u2/a242083.pdf)
* Reliability Information Analysis Center (RIAC), Failure Mode/Mechanism Distributions (FMD). Electronic database, U.S. Department of Defense. 2013.
* LaFleur, C. B.; Muna, A. B.; Groth, K. M.; St. Pierre, M. & Shurland, M. “Failure analysis of LNG rail locomotives.” *Proceedings of the 2017 Joint Rail Conference (JRC2017),* The American Society of Mechanical Engineers (ASME), 2017

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System diagram: modified from Canadian patent. Full description of systems, parts, and interfaces provided in patent document.

|  |  |  |  |
| --- | --- | --- | --- |
| **FMEA ID#** | **System/part** | **FMEA ID#** | **System/part** |
| **1** | Tender car | **37** | Shutoff Valve |
| **2** | Locomotive | **38** | Piping and Fittings from Fueling System |
| **20** | LNG Storage sys. | **39** | Flexible Piping in Fueling System between tender and locomotive |
| **21** | Cryogenic storage tank | **40** | Engine |
| **22** | liquid fuel pump | **51** | Heat exchanger |
| **23** | Gas vent system | **52** | Heat transfer pump |
| **30** | Gas supply sys. | **53** | Reservoir |
| **32** | Vaporizer | **54** | Piping and Fittings from Cooling System |
| **34** | Cryogenic electronic controller | **60** | Engine controller |
| **36** | Pressure sensor | **70** | Locomotive controller |

**Failure Modes to consider for your assembly:**

* Premature operation
* Failure to operate at prescribed time
* Failure to cease operation at prescribed time
* Failure to meet functional specifications
* Failure conditions caused by the operational and maintenance environment

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **FMEA ID#** | **System/part** | **Description** | **Function** | **Parameters** | **Inputs** | **Outputs** |
| **1** | Tender car |  | Supplies fuel to locomotive |  |  |  |
| **2** | Locomotive |  | Propels train |  |  |  |
| **20** | LNG Storage sys. |  | Stores LNG |  | (Fill these in for your components) |  |
| **21** | Cryogenic storage tank | Industry standard ISO tank; Includes a fill receptacle and a pressure relief valve (PRV) | Stores LNG | 40ft ISO tank, 30,000 gal., 5% voidage, 18,125kg LNG, 12x2.5x2.5m; 304 stainless steel inner tank; carbon steel outer jacket; vacuum between inner and outer tank; max working pressure 8bar; 0.37% LNG evaporation rate; fluid: cryogenic LNG; |  |  |
| **22** | Low-pressure liquid fuel pump | Low-pressure liquid fuel pump | Transfers LNG from tank [21] to pump [31]. | Operational temp close to the boiling temp of LNG -- fluid does not vaporize in the pump |  |  |
| **23** | Gas vent system | Contains a burner, an accumulator, and a regulator | Accumulator captures gas vented from tank [21]; regulator controls flow rate to burner, burner burns gas to reduce greenhouse gas emissions |  |  |  |
| **24** | Pipings and fittings from fueling system | Pipe | Passes vent gas from tank [21] to Supplementary HX [33] | Assume 304 stainless steel; contains GNG |  |  |

Assembly Interfaces:

Cryogenic storage

tank

21

Gas vent system

23

Low pressure

liquid fuel pump

22

LNG

(refueling)

Evaporated

GNG

LNG

Power

LNG to Vaporizer 32

Ignition spark

Combustion air

Combustion emission

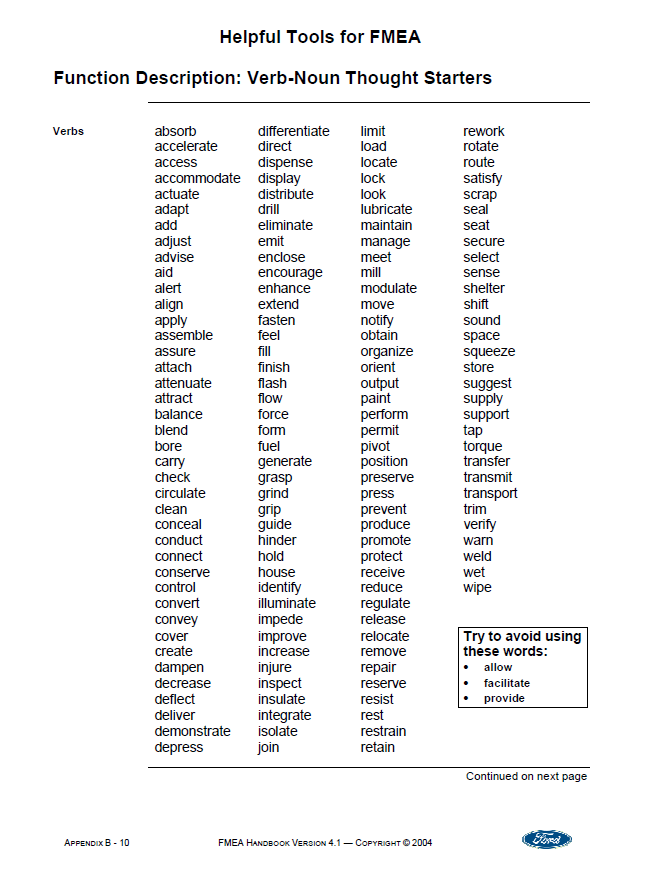
Control

Signals from

Cryogenic

Electronic

Controller 34





System description Table part 2 to fill in.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ID #** | **RIAC Index Term** | **Total Hours (million hrs)** | **Number of Failures** | **Failure rate per million hours** |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

**Some data from FMD-2013, Failure Mode/Mechanism Distributions, RIAC, 2013:**

**(Assume the failure rates are the same for all failure modes of a component; your assembly likely contains several components, though).**

|  |  |  |  |
| --- | --- | --- | --- |
| **RIAC Index Term** | **Total Hours (million)** | **Number of Failures** | **Failure Rate per Million Hours (lambda)** |
| Brake, Hydraulic | 0.092874 | 0.5 | 5.38 |
| Tank, Liquid, Fuel | 0.779 | 20 | 25.67 |
| Valve, Relief | NA | NA | 11.43 |
| Pump Assembly, Fuel Tank | 0.365464 | 11 | 30.10 |
| Duct, Gas Purge | 0.365464 | 2 | 5.47 |
| Igniter | NA | NA | 3.70 |
| Pump Assembly, Fuel Tank | 0.365464 | 11 | 30.10 |
| Heat Exchanger, Assembly | 0.071472 | 0.5 | 7.00 |
| Igniter | NA | NA | 3.70 |
| Controller (Summary) | NA | NA | 0.16 |
| Accumulator Assembly | 0.365464 | 0.5 | 1.37 |
| Sensor, Pressure | 12.614224 | 12 | 0.95 |
| Regulator and Shutoff, Valve Pressure | 0.365464 | 0.5 | 1.37 |
| Heat Exchanger, Assembly | 0.071472 | 0.5 | 7.00 |
| Pump, Cooling System | 0.071472 | 0.5 | 7.00 |
| Reservoir Assembly | 0.142944 | 0.5 | 3.50 |
| Pipe and Tubing, Pipe | 249.681568 | 1353 | 5.42 |
| Pipe and Tubing, Tube | 905.095684 | 273 | 0.30 |

|  |  |
| --- | --- |
| **Probability Class** | **Failure Rate per Million Hours or Million Track Miles** |
| High (H) | >10 |
| Medium (M) | 1-10 |
| Low (L) | <1 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Probability Class** | High | M | H | H |
| Medium | L | M | H |
| Low | L | L | M |
|  |  | 1 | 2 | 3 |
|  | Risk matrix | **Severity Class** | | |

|  |  |
| --- | --- |
| **Severity Class** | **Definition** |
| 1 | No potential release of LNG or GNG |
| 2 | Potential leak or small scale release of LNG or GNG, e.g. leaking seal, breach of line carrying vented GNG |
| 3 | Potential for catastrophic release of LNG or GNG, e.g. rupture of storage tank |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  | 8 | 9 | 10 |  |  |  |  |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | **Failure Effects** | | | 11 | 12 | 13 | 14 |
| **Failure Mode ID** | **Unit Level** | **Assembly Level** | **Item/ Functional Identification** | **Function** | **Failure Modes and Causes** | **Failure Mode Model** | **Local Effects** | **Next Higher Level** | **End Effects** | **Severity Class** | **Item Failure Rate λp** | **Probability Class** | **Risk matrix level** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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