Operating Engineers Risk-Based Regulatory Framework for Plant Rating and Attendance – Path 1

Summary Description of Plant Rating Calculations

Background

In November 2016, the Ministry of Government and Consumer Services (MGCS) and Technical Standards and Safety Authority (TSSA) brought together a volunteer panel of industry stakeholders with experience related to the Operating Engineers field to review Ontario's Operating Engineers Regulation (O. Reg. 219/01). The objective of this industry panel was to provide recommendations for MGSC's consideration to support revisions to modernize the Operating Engineers Regulation (O. Reg. 219/01) under the Technical Standards and Safety Act, 2000.

The industry panel met on seven occasions between November 2016 and February 2017 to discuss the following regulatory challenges relating to modernization of the Operating Engineers Regulation:

a) Prescriptiveness that places undue regulatory burden on industry;
b) Inflexibility around new technology with minimal or no reward for safety innovation;
c) Lack of regulatory clarity;
d) Regulatory compliance;
e) Inadequate labour supply for Operating Engineers; and
f) Low public knowledge of the Operating Engineers profession.

The industry panel proposed 25 recommendations to modernize the Regulation, reaching consensus on 23 recommendations. A key recommendation included the adoption of a risk-based regulatory framework for rating operating plants and determining staffing requirements. The approach would include two paths to regulatory compliance:

1. Path 1 - category-based approach by which registered operating plants will fulfill staffing and attendance requirements based on plant ratings developed scientifically.
2. Path 2 - site-specific risk-based approach by which regulated operating plants will develop and implement a regulator-approved Risk and Safety Management Plan (RSMP).

The Operating Engineers Risk Task Group was commissioned in March 2017 by TSSA, in collaboration with MGCS and the Operating Engineers Industry Expert Panel. The purpose of this Risk Task Group was to develop a risk-based regulatory framework for rating operating plants and regulating staffing requirements. This task group consists of nine members drawn from industry, TSSA and an external facilitator. The terms of reference for the task group are attached in Appendix A of this report.

Separately, an Advisory Group, largely comprised of the industry expert panel that proposed the 25 recommendations was retained for providing feedback and guidance on the work of this task group from a broader industry perspective.

This report presents a risk model for implementing the Path 1 approach, as recommended by this task group and later modified after extensive testing at TSSA. Readers interested in the rationale for the calculation of the plant rating can refer to the original task group report.

The Plant Score Equation

The plant score equation defines a plant's rating as the aggregate level of risk to a specific individual in a plant or within its immediate vicinity. A plant's aggregate individual risk is estimated as a product of the frequency of credible catastrophic events and the probability of consequence of fatality to the exposed individual resulting from those catastrophic events. The plant rating is adjusted by the modification factor weights relevant to the technology system, type of occupancy and exposure given the occupancy type, as applicable to plant.

This aggregate individual risk is in the units of 1 fatality/$10^{-x/year}$ and is compared against established risk tolerance criteria. For simplicity and ease of reference, the plant rating is calculated as the negative log of the aggregate individual risk.

The equation defining the aggregate individual risk of the plant and the plant rating is described as follows:

$$Risk_{plant} = \sum(F_{cce} \times P_{fd(cce)}) \times M_f \qquad (1)$$

$$Plant\ Rating\ (R_P) = -log(Risk_{plant}) \qquad (2)$$

Where,

- F_{cce} is the pre-established (reliable database provided) frequency of a credible catastrophic event associated with a technology sub-system, given a system and a sub-system combination.
- $P_{fd(cce)}$ is the probability of fatality associated with the credible catastrophic event adjusted using modification factors.
- M_f is a modification factor that is pre-assigned and reflects the variability in safety and risk across each of the technology systems, and the extent and types of exposure and occupancy to consequences (described later for each technology system).

There are two additional conditions:

- Where the total combined boiler power is greater than 60,000 kW, the Plant Rating is set to 2.99 at maximum; and
- Where the total number of pieces of equipment is greater than 40, the Plant Rating is set to 4.99 at maximum.

Plant Attendance Requirements

As the plant rating is calculated on a logarithmic scale, the staffing requirements are obtained by segmenting the staffing categories with equal divisions:

Table 1: Staffing requirements based on Plant Rating.

Class of Operating Engineer Required	Plant Rating range
1st	< 3
2nd	3 – 3.66
3rd	3.66 – 4.33
4th	4.33 – 5
Unattended	> 5

As per rule 12 of the *Alternate Rules for Ontario Regulation 219/01*, the chief officer reserves the right to change a plant's staffing requirements, whether by revising the formulas, factors, methodologies, risk rating ranges or corresponding staffing requirements set out in this document or by overriding the staffing requirement dictated by the risk rating if deemed necessary for a particular plant. The precise parameters of the calculation (see below) will be periodically reviewed and updated as necessary.

Calculation Details

Modification Factors

The base failure frequencies for credible catastrophic events and consequences are based on failure rate databases that are then modified to account for various design features. The modification factors are intended to adjust the risk value based on either the likelihood of failure or the probability of a fatality for each variation. For example, if a refrigeration plant is run using a non-toxic/non-flammable (class A1) refrigerant, its potential range for fatal exposure (limited to overpressure due to rupture, thermal effects, or asphyxiation due to displacement of air) is much less than it is for a similar sized system using a flammable and/or toxic refrigerant (e.g. ammonia class B2). In this case, the modification factor for ammonia is much higher than for the more benign non-toxic/ non-flammable refrigerant to account for the consequence exposure.

There are two types of modification factors considered:
a) Frequency modification factors; and
b) Consequence modification factors.

Frequency Modification Factors

The frequency modification factors are meant to increase or decrease the selected top event frequencies based on the design, presence of guarded controls, type of fuel (if applicable), and number of equipment on the premises, as described below:

Design
This criterion primarily represents the age, adequacy, material type, material length for piping, and/or state of obsolescence of the design of the equipment as relevant to each of the technology systems. The base frequency for the credible catastrophic event obtained from the databases, regardless of the equipment, is assumed to apply to the most modern, safest design (modification factor of 1), while those representing the other classes are assigned modification factors with higher orders of magnitude indicating higher failure frequencies.

Presence of Guarded Controls
This modification factor simply reflects the presence or absence of guarded controls (less the requirement for being hard-wired) accepted within the current regulation. The absence of a guarded control would have a modification factor reflecting a higher failure frequency.

Fuel Type
Relevant only to boilers, this modification factor assumes the properties of the fuel type (e.g. flammability) increase the probability of the credible catastrophic events related to fuel system/furnace failures. The fuel types considered for the boiler design include:
- Flammable Liquid
- Flammable Gas
- Solid
- Electric
- Black Liquor

Consequence Modification Factors

It is assumed that, irrespective of the type of credible catastrophic event, the worst-case scenario would always lead to a fatality. The consequence modification factors are therefore set at an upper limit of 1 and reduced based on the type of occupancy of the public receptors and their proximity to exposure, represented in the amount of material or charge and the temperature and/or pressure of the charged fluid. The modification factors agreed upon by the task group, as described, above include the following:

Occupancy
This factor represents the conditional probability of occupancy within the potentially impacted area for a specified individual. Ontario's Operating Engineer plants are currently located at locations with the following occupancy types:

- Power Producers/Utilities
- Petro/Chemical
- Production Industries
- Manufacturing Industries
- Medical
- Academic
- Food Process
- Public Services
- Commercial
- Residential
- Agriculture

Working Fluid
The working fluid may carry the potential risks of scalding, flashing, burning, BLEVE or poisoning, depending on type, flammability or toxicity properties or operating temperatures, among other properties. Examples of materials considered in the model include water above and below 212°F (100°C), steam, thermal oil, refrigerants, natural gas and organic fluids used in organic rankine cycle systems.

The working fluid modifier is a surrogate for a conditional probability of exposure to a hazard for a specified individual that results in a probability of fatality of 1, given occupancy.

Charge
Charge refers to the amount of process material that would be released at a point. This suggests that, the more process material that is released, the greater the release duration and impact range of the hazard, therefore increasing the likelihood of an exposure. In the case of boilers, this would equate to the volume of water released, while for refrigeration systems, the total charge (in pounds/kilograms) that could come in direct contact with the exposed individual in the event of a failure. In the case of compressor system leaks, the power rating and storage inventories are used to estimate release.

In addition, where electrical hazards are relevant and apply, the voltage in the system would impact the probability of a fatality largely due to electrical contact or arc flashing.

Power Rating
The power rating of a plant (measured in kilowatts) is the total energy output, represented by operating parameters such as pressure, temperature and volume. The risk model assumes that units with higher power ratings have a greater consequence factor in the event of a catastrophic failure.

Number of Equipment
This represents a complexity factor, which assumes that the presence of more equipment on the location increases the chances of the credible catastrophic event by a factor equal to the number of pieces of equipment.

Calculating the Plant Rating

The plant rating is determined by summing the risk associated with a list of failure events for each type of equipment. For each failure event, not all of the modifying weights apply. The tables below describe which weights apply for which events.

Table 2: Rules for calculating the risk of failure events for boilers.

Top Event	Frequency Modification Factors			Consequence Modification Factors				Complexity Factor
	Fuel Type	**Presence of Guarded Controls**	**Design**	**Working Fluid**	**Occupancy**	**Charge**	**Power Rating**	**No. of Equipment**
Pipe System Failure	Always 1	Always 1	Always 1	Apply weights	Apply weights	Always 1	Always 1	Always 1
Tube Break	Always 1	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Total equipment count
Shell Break (Missile)	Always 1 except for firetube (For firetube, apply fuel type weights)	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Total equipment count
Furnace Failure	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Total equipment count
Auxiliary System Failure	Always 1	Always 1	Always 1	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count
Turbine Failure	Always 1	Always 1	Always 1	Always 0.1	Apply weights	Always 1	Apply weights	Total equipment count

Table 3: Rules for calculating the risk of failure events for compressors.

	Frequency Modification Factors	Consequence Modification Factors					Complexity Factor
	Presence of Guarded Controls	**Occupancy**	**Power Rating**	**Working Fluid**	**Voltage**	**Weight of Material**	**No. of Equipment**
Pipe System Failure	Always 1	Apply weights	Always 1	Apply weights	Always 1	Always 1	Always 1
Pressure Vessel Failure	Always 1	Apply weights	Always 1	Apply weights	Always 1	Apply weights	Total equipment count
Electrical Flash/Contact	Always 1	Apply weights	Always 1	Always 1	Apply weights	Always 1	Always 1

Reciprocating Compressor Failure	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Always 1	Total equipment count
Rotary Compressor	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Always 1	Total equipment count

Table 4: Rules for calculating the risk of failure events for refrigeration equipment.

	Frequency Modification Factors		Consequence Modification Factors				Complexity Factor
	Presence of Guarded Controls	**Design**	**Occupancy**	**Charge**	**Refrigerant Type**	**Voltage**	**No. of Equipment**
Pipe System Failure	Always 1	Always 1	Apply weights	Apply weights	Apply weights	Always 1	Always 1
Pressure Vessel Failure	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count
Electrical Flash/Contact	Always 1	Always 1	Apply weights	Apply weights	Apply weights	Apply weights	Always 1
Evaporator Failure	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count
Condenser Failure	Always 1	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count
Sealed Pump Failure	Always 1	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count (not hermetically sealed)
Reciprocating Compressor Failure	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count
Rotary Compressor	Apply weights	Apply weights	Apply weights	Apply weights	Apply weights	Always 1	Total equipment count

Base Frequencies

The tables below give the base frequencies (F_{cce} in equation 1) for each event.

Table 5: Base Event Frequencies for Boilers.

Credible Catastrophic Event	Frequency
Pipe System Failure	1.65E-04
Tube Break	1.50E-04
Shell Break (Missile)	4.00E-06
Furnace Failure	8.97E-06
Auxiliary System Failure	5.00E-04
Turbine Failure	5.00E-03

Table 6: Base Event Frequencies for Compressors.

Credible Catastrophic Event	Frequency
Pipe System Failure	1.00E-04
Pressure Vessel Failure	5.00E-06
Electrical Flash/Contact	1.00E-06
Reciprocating Compressor Failure	1.40E-05
Rotary Compressor Failure	2.96E-06

Table 7: Base Event Frequencies for Refrigeration Equipment.

Credible Catastrophic Event	Frequency
Pipe System Failure	1.65E-04
Pressure Vessel Failure	4.00E-06
Electrical Flash/Contact	1.00E-06
Evaporator Failure	4.00E-06
Condenser Failure	4.00E-06
Sealed Pump Failure	1.00E-04
Reciprocating Compressor Failure	1.40E-05
Rotary Compressor	2.96E-06

Frequency Modifiers

The following tables give the frequency modifiers.

Table 8: Modifiers for Guarded Controls (applicable to all equipment types).

Design	Weight
None	50
Guarded Controls Present	1

Table 9: Modifiers for Fuel Type (boilers).

Design	Weight
Indirect/Electric	0.1
Liquid	1
Gas	10
Solid	500
Black Liquor	1000

Table 10: Modifiers for Design (boilers).

Design	Weight
Safest in class (Low volume)	1
Moderate (Packaged/Field Erected/Water Tube)	10
Aged Design (Fire Tube - Locomotive)	100

Table 11: Modifiers for Design (refrigeration equipment).

Design	Weight
Self-contained	1 (0.1 for Sealed Pump or Compressor Failure)
Indirect and Built Up	2 (0.1 for Sealed Pump or Compressor Failure)
Direct and Built Up	2 (1 for Sealed Pump or Compressor Failure)

Consequence Modifiers

The following tables give the consequence modifiers.

Table 12: Modifiers for Occupancy (applicable to all equipment types).

Occupancy	Weight
Medical, Residential	1
Academic, Public Services	0.81
Commercial	0.36
Power Producers/Utilities, Petro/Chemical, Production Industries, Manufacturing Industries, Food Process, Agriculture	0.27

Table 13: Modifiers for Working Fluid (boilers).

Working Fluid	Weight
Water < 212 F (100 °C)	0.01
Thermal Oil	0.05
Steam	0.1
Water > 212 F (100 °C)	1
Flammable or Toxic Fluids	1

Table 14: Modifiers for Charge (boilers).

Gallons of Fluid	Weight
< 75	0.1
75 – 1000	0.5
> 1000	1

Table 15: Modifiers for Power Rating (boilers).

Power Rating	Weight
LWV < 15,000 kW	0.01
< 600 kW	0.1
600 kW – 12,000 kW	0.4
12,000 kW – 30,000 kW	1
> 30,000 kW	10

Table 16: Modifiers for Power Rating (compressors).

Power Rating	Weight
< 37 kW	0.01
37 kW – 112 kW	0.1
> 112 kW	1

Table 17: Modifiers for Working Fluid (compressors).

Working Fluid	Weight
Non-flammable and non-toxic	0.01
Flammable and non-toxic	0.1
Non-flammable and toxic	0.1
Flammable and toxic	1

Table 18: Modifiers for Voltage (compressors and refrigeration equipment).

Voltage	Weight
≤ 240 V	0.001
240 V – 600 V	0.1
> 600 V	1

Table 19: Modifiers for Weight of Material/Charge (compressors and refrigeration equipment).

Weight of Material/Charge	Weight
< 100 lbs	0.01
100 lbs – 10,000 lbs	W/10,000 (where W is the amount in lbs)
> 10,000 lbs	1

Table 20: Modifiers for Refrigerant Type (refrigeration equipment).

Refrigerant Type	Weight
A1/A2L	0.02
A2	0.03
B1	0.04
A3	0.06
B2/B2L/B3	1