The standard, “ANSI/ASSE/ISO 31000 (Z690.2-2011) Risk Management—Principles and Guidelines,” can be applied to an entire organization, as well as to specific processes, activities or projects [ASSE, 2011; International Organization for Standardization (ISO), 2009]. The risk management process involves applying logical and systematic methods for communication and consultation throughout the process, as well as identifying, analyzing, evaluating and treating risk associated with any activity, process, function, project, product, service or asset. Monitoring and reviewing risk are key elements of the process, as are recording and reporting the results appropriately.

Prevention through design (PTD) addresses occupational safety and health needs in the design and redesign processes to prevent or minimize work-related hazards associated with the construction, manufacture, use, maintenance and disposal of facilities, materials, equipment and services. One goal is to educate designers, engineers, machinery and equipment manufacturers, SH&E professionals, business leaders and workers to understand and implement PTD methods and to apply this knowledge to the design and redesign of new and existing facilities, processes, equipment, tools and organization of work.

**Figure 1 ISO 31000 & Z590.3 Integration Suggestions**
ISO 31000 includes three main sections: Risk Management Principles (Clause 3); Framework (Clause 4) and Process (Clause 5). ISO 31000 is not one of the incorporated standards in “Prevention Through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes” (ANSI/ASSE Z590.3-2011) (ASSE, 2011). However, SH&E professionals can play a significant role in incorporating PTD principles into the risk management process.

PTD principles can be successfully integrated into ISO 31000 Clause 5. Clause 5 (Process) is one of the key sections of the risk management standard. A key component of the process is risk assessment (Section 5.4). According to the standard, risk assessment is an overall process of risk identification, risk analysis and risk evaluation. The authors see a direct link between the two standards. Section 7 of the PTD standard details the hazard analysis and the risk assessment process. Both standards also provide guidance on risk assessment techniques. The authors strongly believe that the PTD standard should be incorporated into ISO 31000 Clause 5. Suggestions for ISO 31000 and Z590.3 integration are presented here.

The authors believe that the initial risk, PTD Section 7.8, should be discussed before the selection of a risk assessment matrix.

SH&E professionals should learn how to develop tools and models to incorporate appropriate hazard identification and risk assessment techniques into the risk management process. The authors developed new tools based on the recommended risk assessment techniques referenced in both standards. Risk assessment tools were successfully used to demonstrate effective risk assessment methodology for new product development.

**PROJECT DESCRIPTION**

SH&E professionals face increased pressure to diversify their skills and to develop new risk assessment techniques. A small company requested a new product risk assessment and hazard evaluation. Their products are intended for export to the European Union. Therefore, their product needed to meet the requirements set forth in ISO standards. On the other hand, the product is manufactured in the U.S., and managers wanted to implement PTD principles. The authors developed new tools and successfully implemented the new PTD model to evaluate the product. The model allows different solutions to be evaluated and prioritized. The Excel-based tool helped the SH&E professionals, and a student team that assisted the authors, compare PTD-based design to an existing product that was not developed according to PTD principles. To satisfy the new product expectations and to gain support for SH&E improvements, the team needed to develop a new PTD-based risk assessment methodology.

### Table 1 Hand-Arm Vibration Sampling Data: Left Hand

<table>
<thead>
<tr>
<th>Tool or process</th>
<th>Vibration magnitude</th>
<th>Exposure points per hour</th>
<th>Time to reach EAV</th>
<th>Exposure duration</th>
<th>Partial exposure A(8)</th>
<th>Partial exposure points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool or process 1</td>
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<td>196</td>
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<tr>
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</tr>
<tr>
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<td>0</td>
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<tr>
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<td>0</td>
</tr>
</tbody>
</table>

**Table Instructions for use:**
Enter vibration magnitudes and exposure durations in the white areas. To calculate, press the Enter key, or move the cursor to a different cell. The results are displayed in the yellow areas. To clear all cells, click on the Reset button. For more information, click the HELP tab below.

### Table 2 Hand-Arm Vibration Sampling Data: Right Hand

<table>
<thead>
<tr>
<th>Tool or process</th>
<th>Vibration magnitude</th>
<th>Exposure points per hour</th>
<th>Time to reach EAV</th>
<th>Exposure duration</th>
<th>Partial exposure A(8)</th>
<th>Partial exposure points</th>
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</thead>
<tbody>
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<td>Tool or process 1</td>
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<tr>
<td>Tool or process 3</td>
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<td>0</td>
</tr>
<tr>
<td>Tool or process 4</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Tool or process 5</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>

**Table Instructions for use:**
Enter vibration magnitudes and exposure durations in the white areas. To calculate, press the Enter key, or move the cursor to a different cell. The results are displayed in the yellow areas. To clear all cells, click on the Reset button. For more information, click the HELP tab below.
The purpose of this project was to determine noise levels, hand and arm vibration risk and potential particulate matter (PM) exposure from a normal production unit. The risk assessment evaluation included a sound level meter, hand and arm vibration instruments and a PM measurement system. The evaluation was conducted during simulated work activities.

“Projecting a green image,” reduced hand and arm vibration, reduced noise levels and reduced air pollutants emission all played a substantial part in the decision-making process.

Methods

A new decision-making model was developed to evaluate a new product intended for export. This research identified potential areas of SH&E professional involvement in the decision-making process. The authors developed a new PTD model that incorporates risk assessment, hierarchy of controls and future-state risk reduction. The model follows define, measure, analyze, improve and control (DMAIC) logic. Separate tools were developed for each phase. For instance, brainstorming and preliminary hazard analysis (PHA) were used in the “Define” phase. A modified bowtie diagram, risk assessment matrix and failure mode effect analysis (FMEA) were used in the “Measure” phase.

Applicability of FMEA tools to prioritize hazards and to modify procedures was used to demonstrate and quantify risk reduction after the proposed SH&E improvements. Hand and arm vibration, noise levels and air pollutant emissions were evaluated.

To demonstrate the applicability of the PTD model integration into the ISO 31000 risk management process, the authors evaluated two different products as discussed in the following case study.

Results

ISO 31000, PTD, FMEA and risk assessment methodologies, as well as a new model, are estimated

<table>
<thead>
<tr>
<th>PM Exposure Measurements</th>
<th>Respirable particles 4 μg/m³</th>
<th>Total PNOR μg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used Dust Containment System</td>
<td>72.45</td>
<td>81.53</td>
</tr>
<tr>
<td>New Dust Containment System</td>
<td>91.8</td>
<td>107.12</td>
</tr>
<tr>
<td>No Dust Containment System</td>
<td>118.275</td>
<td>161.7</td>
</tr>
<tr>
<td>No Bag</td>
<td>296.95</td>
<td>367.63</td>
</tr>
</tbody>
</table>

Figure 2 Dust Exposure Measurements in μg/m³

Figure 3 Dust Exposure Measurements in mg/m³
to significantly reduce the ergonomics injuries, noise levels and air pollutants of the product evaluated in this case study. Similar benefits are possible with products made in the U.S. but intended for the European Union market. Possible SH&E practitioners’ involvement in the process was evaluated.

**Hand & Arm Vibration Evaluation**

Three industrial vacuum cleaner units were evaluated using the VibTrack/HAVSense system. HAVSense is an autonomous vibration dosimeter that records the operator’s exposure to hand and arm vibration. HAVSense provides monitoring that satisfies the requirements of the European directive 2002/44/EC (European Agency for Health and Safety at Work, 2002). The directive was issued in June 2002 and defines the minimum safety and health requirements regarding the exposure of workers to the risks arising from physical agents (vibration) and forms the sixteenth individual directive within the meaning of Article 16(1) of Directive 89/391/EEC. European Directive 2002/44/EC establishes minimum requirements, in particular the fixing of lower values for the daily vibration exposure limit. The European directive acknowledges the potentially damaging consequences of vibration for human health and gives maximum levels of vibration exposure.

The HAVSense sits between the second and third fingers of either hand. The topside rests over the fingers. The underside rests under the fingers and is pressed by the fingers against the operating surface. The HAVSense was placed comfortably inside a protective glove for data collection (Photo 1, p. 18).

Exposure data were downloaded directly to a computer via the docking station. To calculate the exposure, the team used the British Health and Safety Executive (HSE) hand-arm vibration exposure calculator. The assessment of the vibration exposure is calculated in relation to a standardized 8-hour daily exposure value A(8). After establishing the A(8) value, this should be compared with the exposure action and limit values. Different units could be compared based on the daily exposure action value (EAV) and the daily exposure limit value (ELV).

**Exposure Action Value**

Whenever an operator is subjected to vibration exposure A(8) exceeding the EAV at 2.5 m/s., the employer must conduct a risk assessment of the operation and introduce control measures. For more details, see Directive 2002/44/EC and member state legislation.

**Exposure Limit Value**

In any event, workers shall not be exposed above the ELV (5.0 m/s.).

Results revealed that the right hand of the operator is exposed slightly more than the left hand.

British HSE hand-arm vibration exposure calculations made by the survey team for left hand exposure are shown in Table 1 (p. 19) (Health and Safety Executive, n.d.).

HSE hand-arm vibration exposure calculations for right hand exposure made by the survey team are shown in Table 2 (p. 19).

There was a difference in the vibration measurements for the right and left hands. The difference could be explained by the fact that the operator is right-handed. The design of the units could be another contributing factor.

The operator should not operate/run an industrial vacuum cleaner for more than 3.1 hours based on right hand exposure.
hand exposure alone. Right hand exposure is considered a worst-case scenario.

**Noise Measurements**

The same units were evaluated for noise exposure. The sampling was conducted based on 2000/14/EC requirements.

OSHA sets legal limits on noise exposure in the workplace in the U.S. These limits are based on a worker’s time-weighted average (TWA) over an 8-hour day. With noise, OSHA’s permissible exposure limit (PEL) is 90 dBA for all workers for an 8-hour day (OSHA, n.d.).

The OSHA standard uses a 5 dBA exchange rate. This means that when the noise level is increased by 5 dBA, the amount of time a person can be exposed to the new noise level (now 95 dBA) to receive the same dose is cut in half (4 hours).

NIOSH has recommended that all worker exposures to noise should be controlled below a level equivalent to 85 dBA for 8 hours to minimize occupational noise-induced hearing loss (NIOSH, n.d.). NIOSH also recommends that the exchange rate be 3 dBA.

British HSE noise regulations also require specific action at certain action values (Health and Safety Executive, 2005). These relate to:

- **Lower exposure action values:**
  - daily or weekly exposure of 80 dB;
  - peak sound pressure of 135 dB.

- **Upper exposure action values:**
  - daily or weekly exposure of 85 dB;
  - peak sound pressure of 137 dB.

Levels of noise exposure, or exposure limit values, must also not be exceeded:

- daily or weekly exposure of 87 dB;
- peak sound pressure of 140 dB.

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**Figure 6 FMEA & RPN Worksheet**

<table>
<thead>
<tr>
<th>Part or Process Name</th>
<th>Trash Pick</th>
<th>Suppliers &amp; Responsibility</th>
<th>Prepared By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trash leaves collection</td>
<td>Ergo injury</td>
<td>Wrist injury</td>
<td>3 Design 3 Admin 3 9 27</td>
</tr>
<tr>
<td>Trash leaves collection</td>
<td>Hands and Arms</td>
<td>HAVS</td>
<td>4 Vibration 2 Admin 3 8 24</td>
</tr>
<tr>
<td>Trash leaves collection</td>
<td>Noise</td>
<td>Hearing loss 3 Improper Exhaust Design 1 None 3 3 9</td>
<td></td>
</tr>
</tbody>
</table>
None of the tested units exceeded the 85 dBA noise level.

**PM Exposure Measurements**

Two units were tested for PM emissions using a DustTrak DRX PM measurement system. The purpose of the test was to evaluate the PM levels approximately one meter from the dust collection system.

**Occupational Size-Selective Criteria & Particles Size Sampling**

Occupational safety and health professionals have traditionally sampled for two particulate size fractions: total or respirable (OSHA, n.d.).

Total particulate includes both respirable and non-respirable particles, a.k.a. particulates not otherwise regulated (PNOR). OSHA PEL is 15 mg/m$^3$ (15,000 μg/m$^3$) TWA.

Respirable particulate includes only the smaller particles than can penetrate to the alveolar or gas-exchange region of the lung. PNOR respirable fraction, OSHA PEL is 5 mg/m$^3$ (5,000 μg/m$^3$) TWA.

At this time, OSHA and MSHA still use total and respirable particulate size fractions for regulatory standards and compliance monitoring.

The company’s engineering unit designed a special filtering dust containment system to reduce the PM emissions.

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**Figure 7 Current-State Risk Assessment**

- **Hazards**: Calculated Risk Factor: go to exit; Calculate Risk Factor: fire alarm.
- **Prevention Ladders**: fire injury, PM exposure, hearing loss.
- **Recovery/Prevention Measures**: exit, high tumour rate, lost time/lost productivity.

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**Figure 8 PTD Hierarchy of Controls**

- **Current State**: Prevention through design using hierarchy of controls, elimination.
- **Future State**: Better handle design, polyurethane dampers.
- **Levels**: Engineering Controls, administrative controls, personal protective equipment, financial value.
pollution and operators’ exposure. Results are presented in Table 3 (p. 20) and Figure 2 (p. 20).

Figure 2 (p. 20) visualizes the results. The used dust containment system is the most efficient. It provides reduced operator exposure and is more protective of the environment. The new unused dust containment system is also effective. However, it might be concluded that the collection efficiency increases with accumulation of the particles on the inner surfaces of the filtering bag.

The sampling results indicate potential operator exposure is well below occupational exposure limits. After a careful evaluation of the results, the team developed a new PTD model. The model follows DMAIC logic (Popov & Zey, 2012) (Figure 4, p. 21).

During the define phase, PHA was performed for hand-arm vibration, noise and PM exposures. Figure 5 (p. 21) shows the current-state PHA.

Risk priority number (RPN) can be calculated using a standard FMEA and RPN worksheet.

A bowtie risk assessment diagram was prepared based on the initial limited hazard analysis. Figure 7 (p. 23) presents the current-state risk assessment.

The PTD hierarchy of controls (Figure 8, p. 23) was used to develop suggestions for engineering controls. A better handle design was suggested. Polyurethane

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**Figure 9 Future-State FMEA**

<table>
<thead>
<tr>
<th>Part or Process Name</th>
<th>Suppliers &amp;</th>
<th>Prepared By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design/Mfg Responsibility</td>
<td>Model Date</td>
<td>FMEA Date</td>
</tr>
<tr>
<td>Other Areas Involved</td>
<td>Engineering Change</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process Operation, Function or Purpose</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>SEV</th>
<th>Potential Cause(s) of Failure</th>
<th>OCC</th>
<th>Current Controls Evaluation Method</th>
<th>PE</th>
<th>S*O</th>
<th>RPN</th>
<th>Rec</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trash leaves collection</td>
<td>Ergo injury</td>
<td>Wrist injury</td>
<td>3</td>
<td>Design</td>
<td>3</td>
<td>Admin</td>
<td>3</td>
<td>27</td>
<td>New Do</td>
<td></td>
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<tr>
<td>Trash leaves collection</td>
<td>Hands and Arms HAVS</td>
<td>Vibration</td>
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<tr>
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<td>Noise</td>
<td>Hearing loss</td>
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<td>Improper Exhaust Design</td>
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<td>None</td>
<td>3</td>
<td>3</td>
<td>New mod low RP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| SEV| Severity; OCC = Occurrence/Probability; PE= Prevention Effectiveness. |
Dampers could reduce vibrations, and a new muffler and lower RPMs could further reduce noise.

Future-state FMEA and RPN were calculated based on PTD improvements (Figure 9).

Future-state bowtie risk analysis was prepared based on future state RPNs (Figure 10, p. 26).

Additionally, residual risk reduction (R3) was calculated. SH&E improvements resulted in a 52.6% (SxP) and 85% (RPN) risk reduction (Table 4, p. 26).

Where risk factor is severity times probability, and RPN is severity times probability and prevention effectiveness.

The authors have used R3 methodology and Liberty Mutual’s formula to calculate percent reduction (Liberty Mutual, 2010). The R3 rating scale provides for numerical ratings that may be assigned to three key characteristics—frequencies (F), likelihood (L) and severity (S)—when a particular area of risk is evaluated (Liberty Mutual, 2010). However, the authors feel confident that the same formula can be used to compare risk reduction for three or more hazards.

**Conclusion**

SH&E professionals can play a significant role in product development. PTD can be successfully integrated into the ISO 31000 risk management process. The project described in this article led to management’s decision to approve the new product design, which will result in reduced ergonomic injuries, lowered emissions and improved operator productivity. These changes should also enhance the company’s ability to sell its products in Europe.

It was concluded that PTD tools could be successfully incorporated in the risk management process. Such a process could be used effectively to develop and present a business cases for SH&E interventions.

**References**


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