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Performance Measurement for Environmentally-Conscious Manufacturing[1]

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Abstract

Environmental performance measurement is a key corporate challenge in an era of global competition, rapid technological change and increasing concern for the environment, health and safety. Industry has made major strides in reducing environmental burdens associated with products and processes. This paper describes an approach to tracking toxic releases and associated risks over time based upon the data of the Toxics Release Inventory (TRI) and relevant toxic indices. We provide examples for companies, an industry, and products. We discuss how this environmental performance methodology can be used in green design and manufacturing efforts.

1. Introduction

Due to regulations, consumer demand and public pressure, environmental issues have become very important to industry. According to a recent study by Price Waterhouse [PW 95], 40% of the surveyed 445 corporations have board-level responsibility for environmental issues and 73% conduct environmental audits. More and more companies publish annual environmental accounts similar to financial reports. Increased ecological awareness is especially true for multinationals that have to comply with a variety of regulations in different parts of the world. For example, a U.S. computer manufacturer that wants to sell its product in Germany has to comply with a rigorous take-back legislation for packaging. Parts of its final product may have been made in Australia which has its own set of regulations. This manufacturer may try to practice the same environmentally-conscious design ("green design") and manufacturing in the U.S., as well as in all the countries where it has operations. Global trade and manufacturing require a thorough understanding of the environmental aspects of all the stages of manufacturing, use and disposal of a product. Without a comprehensive and universally understood system of environmental performance measurement of industrial activities, achievements are unclear and goals are vague.

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2. Environmental Performance Measurement

For many years, life cycle assessment or analysis (LCA) has been an emphasis. Many hoped that all products and processes would be analyzed by the methodology, and the environmental stakeholders would eventually be able to decide on the basis of LCA which product or process is better in environmental terms. Unfortunately, this will not happen any time soon. For one thing, there is no agreement on how the LCA methodology should be formulated or applied. The few complete or pseudo-complete LCA studies conducted so far have sometimes featured contradicting, inconsistent and arbitrary boundaries or assumptions. They all took considerable time and resources to complete [Portney 94]. Rather than providing tools for informed decision-making, they caused confusion or lead to incorrect conclusions. Clearly, there is a need for a different approach in assessing the life cycle environmental burdens of products and processes.

There have been attempts to develop a better system. For example, the Volvo Car Corporation have devised an Environment Priority Strategies for Product Design (EPS) system that uses Environmental Load Units (ELUs) to index the environmental impacts of materials used in a car, over the lifetime of the product [Graedel 94]. Some companies use a case-by-case approach to characterize how "green" is their product. While all these efforts have merit, a number of problems obstruct their practicality. The environmental performance measurement scheme is usually specific to the company's activities, thus it cannot be used to compare companies or benchmark the best industrial practice. The day-to-day implementation is often carried out by a handful of experts, making the system's universality and practicality questionable. The science and techniques behind these systems are often vaguely defined. Complete and reliable data is seldom available to expand the use of the environmental performance measurement method to all the products or processes of the corporation, much less to other companies or industrial sectors.

Fundamentally, there are three main goals in designing for the environment:
- minimize use of non-renewable resources
- effectively manage renewable resources
- minimize toxic releases to the environment.

We focus on the third goal here. Many materials used by industry, especially in manufacturing, are highly toxic and hazardous when released to the environment. Companies have to install costly equipment to contain them and prevent their release to the environment. Disposal of hazardous materials is expensive. There is a danger than toxins may leak or explode and result in ecological tragedy. Companies have to make sure that a product containing toxic materials gets disposed of in a safe manner, or else liabilities may start to haunt the corporation and cost them dearly.

In addition, Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986 requires many manufacturing firms to report the discharges and transfers of more than 650 toxic chemicals to the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI) [TRI 92]. These reports contain discharges to air, water, land and underground, and show quantities that are sent to off-site disposal or recycling. The TRI summaries have been made public since 1987, and have provoked widespread attention.

3. Toxicity-Weighted Emissions

A major problem has been the simplistic interpretation of the TRI data. Media have reported the total chemical discharges of companies, without specifying what chemicals had the firm released, and how toxic they were. If we use a commonly available measure of toxicity, the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values-Time Weighted Average (TLV-TWA) [ACGIH 94], it turns out that some chemicals on the TRI list of 650 reportable chemicals are highly toxic, while others are not. For example, based on their TLVs, one pound of sulfuric acid is 262 times more toxic to human health than one pound of methanol. By using the TLVs, we are assuming that the ecological damage these chemicals may cause if discharged to the environment is proportional to the adverse health effects that may occur if humans are exposed to more than the threshold quantities of the chemical, denoted by TLVs. The Threshold Limit Values are given in mg/m^3. A lower TLV indicates a more toxic chemical. Unfortunately, not all the TRI chemicals have TLVs established for them.

We propose a methodology that weights TRI emissions by their toxicity, using the ACGIH TLVs. The system is elaborated in [Horvath et al. 95]. In effect, we are taking the pounds of chemical emissions and multiplying them by a weighting factor, equal to $TLV_{Reference}/TLV_{Chemical}$. The $TLV_{Reference}$ is chosen to be 1 mg/m^3, the same value that sulfuric acid and other chemicals on the TLV list have. Therefore the resulting toxicity-weighted emissions index, the CMU-Equivalent Toxicity (CMU-ET), can be viewed as equivalent to pounds of sulfuric acid released to the environment. By summing the CMU-ETs calculated for the company's individual TRI chemicals, we arrive at the CMU-ET for the company. We can normalize companies of different size by dividing the CMU-ET by the pounds of chemicals on the company's TRI discharges list, but only for the chemicals that have a TLV index (EPA-TRI_{TLV}). We call this the Toxicity Ratio.

In the following, we will illustrate the use of the toxicity-weighted emissions indices as a management and design tool through several examples.

4. Examples

Table 1 shows the CMU-Equivalent Toxicity indices and the Toxicity Ratios for two motor vehicles manufacturers, calculated using 1992 air emissions [TRI CD-ROM 92]. (Since the TLVs are related to inhalation, we used only the companies' air emissions.) The number of TRI chemicals they reported in 1992 are comparable: 60 for the first company and 54 for the second. However, the first company released more than 30 million pounds in those 60 substances (EPA-TRI), about 30% more than the other. Sixteen chemical substances on the first company's TRI list, and 13 on the second firm's did not have a TLV available for them, so their EPA-TRI_{TLV} values are less than their EPA-TRI numbers.

	EPA-TRI [10^4 lb]	EPA-TRI$_{TLV}$ [10^4 lb]	CMU-ET [10^4 lb]	Toxicity Ratio
Motor Vehicles Manufacturer #1	3,092	2,397	97	0.04
Motor Vehicles Manufacturer #2	2,194	1,749	26	0.01

Table 1. Comparison of two motor vehicle manufacturer's toxic discharges.

The first company is the worst in all respects. Its toxicity-weighted emissions amount to about 970,000 pounds of sulfuric acid equivalent, almost four times the CMU-ET of the second firm. The Toxicity Ratio reflects this disparity.

The CMU-ET can be used to help companies decide which chemicals it should spend resources on reducing. In the case of the first motor vehicles manufacturer, as much as 41% of the CMU-ET is accounted for by the releases of chromium compounds. Another 14% is attributable to the emissions of lead compounds. Although these two groups of chemical compounds account for only 0.08% of the total, unweighted air releases of the first company's TRI chemicals (EPA-TRI), combined they are responsible for 55% of the company's equivalent mass of toxic releases (CMU-ET). Similarly, the second firm's CMU-ET is made up 33% by weighted releases of cobalt compounds and 23% due to discharges of chromium compounds, although these two TRI chemical compound groups account for a mere 0.01% of the corporation's EPA-TRI. Without toxicity weighting, the companies may not know which chemicals pose the largest environmental threat on their emissions list. It makes not much sense for the first company to reduce the emissions of xylene (the top mass released with 9.07 million pounds and almost 30% of the EPA-TRI) when it accounts for only 2% of the CMU-ET.

The toxic emissions indices can help designers decide which chemical substances pose a potential environmental hazard in their products or processes. They can then design these chemicals out, reduce their use to a minimal level, or substitute them with a less toxic material that performs the original material's function.

Using the toxicity-weighted emissions indices, we can compare companies of different size, but we can also track their environmental performance over time. At the moment, TRI data is available for the period 1987-1992. In the following example illustrated in Table 2, we show the performance of the industrial sector under the Department of Commerce's primary Standard Industrial Classification codes 3711, 3713, 3714 and 3715 (Motor vehicles (passenger cars and trucks), and Truck and bus bodies, trailers, and motor vehicles parts) [TRI CD-ROM 92].

	1987	1988	1989	1990	1991	1992
EPA-TRI [10^4 lb]	13,645	12,310	12,583	10,193	8,697	8,578
EPA-TRI_{TLV} [10^4 lb]	11,685	10,218	10,656	8,486	7,194	6,948
CMU-ET [10^4 lb]	497	339	550	319	196	190
Toxicity Ratio	0.04	0.03	0.05	0.04	0.03	0.03

Table 2. Toxic emissions trends of an industry (SIC 371).

This industrial sector has made major strides to reduce its air emissions: they dropped by about 37%, from 136 million pounds to 86 million pounds. The pounds of toxicity-weighted emissions (CMU-ET) have decreased by 62%, from 5 million pounds to 1.9 million pounds. However, the Toxicity Ratio has only slightly decreased, indicating that more improvements are needed regarding the average toxicity of used chemicals. The improvement has been continuous, except for 1989. There may have been a large increase in production that year, or a change in technology.

The toxicity-weighted emissions indices can be calculated for products as well. However, product material compositions are rarely made public due to matters of trade secret. Nevertheless, designers using the tool presented herein can perform the environmental performance assessment of their company's products. Use of less toxic materials, of course, means a more environmentally friendly product with a lower CMU-ET and Toxicity Ratio. In the future, it may be expected that independent experts will be given access to different product material lists and will be able to compare products of different companies.

To illustrate the use of toxic emissions indices for products, we weighted by toxicity the masses of pollutants emitted in the production of one ton of linerboard manufactured from virgin materials and recycled materials, respectively [Tellus 92]. (Linerboard is defined as the facing material of a corrugated container or of a solid fiber box.) Substances on the pollutants list are both TRI and non-TRI chemicals. Six chemicals do not have TLVs, three of which are common to both lists. Table 3 presents the results.

	Linerboard from virgin materials	Linerboard from recycled materials
EPA-TRI [lb]	2.36	0.13
EPA-TRI_{TLV} [lb]	2.21	0.04
CMU-ET [lb]	0.18	0.11
Toxicity Ratio	0.08	2.75

Table 3. Comparison of two products' toxicity-weighted emissions indices.

One ton of linerboard made from virgin materials results in 2.36 pounds of effluents, as much as 18 times the mass of pollutants ~~required to make~~ a ton of linerboard from recycled materials. The equivalent mass of toxic releases (CMU-ET) is about 64% more for the virgin linerboard than it is for the recycled linerboard. Indeed, in terms of toxic effluents, using the latest TLV indices [ACGIH 94], linerboard made from recycled materials is more environmentally friendly. The Toxicity Ratio, however, is higher for the recycled linerboard because the effluents in this process are more toxic on average.

5. Conclusion

The proposed toxicity-weighted emissions indices, the CMU-ET and the Toxicity Ratio, differ from the existing and proposed environmental performance measures in several aspects.

- They are calculated by a transparent, computer-based tool that is easily implemented as part of the design for the environment and the environmentally-conscious manufacturing efforts.
- They have an underlying data base accessible by all environmental stakeholders.
- Although reliability is a concern [Horvath et al. 95], the format of the data is consistent across industry.
- The CMU-ET and the Toxicity Ratio can be used on a variety of analysis levels: facility, company, county, state, industry, product.
- Interpretation of the toxic emissions indices is objective and straightforward.
- International environmental performance measurement may be possible in the future. (Encouraged by the success of the U.S. EPA's Toxics Release Inventory, Canada will issue its first toxic discharges inventory report next year [NPRI 92]. Other countries are expected to follow suit.)
- They make possible informed decision-making and optimal allocation of resources.
- The methodology is complete and ready to be widely implemented.

6. References

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