Informing Packaging Design Decisions at Toyota Motor Sales Using Life Cycle Assessment

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1. SUMMARY

The environmental impacts of packaging manifest themselves at all life-cycle stages. From raw material acquisition, to package manufacture, distribution, recycling and land-filling, packaging systems deplete natural resources, consume energy, produce hazardous waste and emit pollutants. Additionally, each of these stages carries a financial cost. Driven by a desire to minimize financial costs and environmental burdens associated with the packaging of accessory and service parts, Toyota Motor Sales commissioned the Donald Bren School of Environmental Science and Management to build a life-cycle-assessment-based decision support tool to assist the packaging decision-making process. The *Environmental Packaging Impact Calculator* (EPIC) provides full Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) results that allow packaging designers to compare options in daily decision-making and choose environmentally preferable packaging systems. EPIC's heavy parameterization allows users to run a virtually limitless number of LCAs and LCCs using a single model. This parameterization also allows results to be calculated from minimal user inputs in a matter of minutes, requiring no pre-existing knowledge of LCA theory or methodology. Finally, EPIC distills LCA results into management actionable metrics, and provides the information early in the design process, when managers can affect downstream impacts by designing smarter packaging systems.

2. INTRODUCTION

Companies looking to improve the environmental performance of their products and supply chains must first generate the necessary information, and then move it into the hands of individuals in a position to affect change. Toyota Motor Sales (TMS) faced this predicament while trying to reduce the environmental burdens generated by packaging for their service parts and accessories. TMS packaging design engineers and logistics managers are in a position to decrease these environmental burdens through better design and shipping systems. However, they currently lack the information required to quantitatively assess and compare the impacts of packaging options and the expertise necessary to conduct the assessments and interpret the results.

In 2007 TMS commissioned the Donald Bren School of Environmental Science and Management to develop a tool that will allow TMS packaging engineers and logistics managers to perform complete Life Cycle Assessments (LCA) of packaging systems in a format and time frame that facilitates informed decision making during package design.

The recently completed *Environmental Packaging Impact Calculator* (EPIC) will support the packaging design decision-making process by providing real-time results of the life cycle environmental impacts and financial costs of proposed packaging options. Based on a highly parameterized model of the TMS packaging life cycle, EPIC users are able to input minimal data for packaging specifics, and immediately receive results for environmental performance and cost. EPIC is not a streamlined LCA; rather, EPIC performs full LCA and Life Cycle Costing (LCC), and translates the results into a format that allows packaging design engineers to incorporate findings into the packaging design process.

This article describes the development and intended implementation of the EPIC tool. It briefly presents background on the use and limitations of LCA in the packaging sector and TMS' environmental efforts regarding accessory and service part packaging to date. It outlines the scope and creation of the EPIC tool based on highly parameterized, TMS-specific data, and demonstrates how TMS plans to use EPIC in its packaging supply chain.

3. BACKGROUND

3.1. Toyota Motor Sales (TMS)

TMS is the sales and distribution company for Toyota in the United States. In addition to sales, marketing, and vehicle distribution, TMS is responsible for shipping accessories to TMS-operated installation facilities, and service parts to independently operated dealerships for vehicle maintenance and repair. The packaging used to protect these parts during transport is designed primarily by packaging engineers at suppliers, but is reviewed and directed by TMS packaging engineers. Both groups of packaging engineers collaborate to address issues with new and existing packaging.

Across TMS, the parts distribution operation (distributors of service parts) accounts for approximately 70% of all solid waste created, and a large contributor to that waste is packaging. For the TMS vehicle distribution centers (installers of accessory parts), total waste generation is smaller, but packaging accounts for an even higher proportion of waste generation. For the past five years, TMS has been focused on downstream waste management, achieving an average recycling rate of 90% at both parts distribution and vehicle distribution operations. There have also been several initiatives to reduce packaging purchasing through the use of returnable shipping modules (displacing expendable wood pallets and cardboard). TMS recognizes that packaging design affects a number of operations at TMS both environmentally and financially. However, adjustments have been driven by problem-solving, rather than a systematic approach of bringing information about those impacts back to the packaging engineers.

Several programs at TMS led to the desire for an LCA-based tool for packaging design. The first is the TMS Five Year Environmental Action Plan, which has targets for both reducing packaging and increasing recycling at TMS distribution centers. Initially, environmentally related efforts in packaging were initiated to meet these waste reduction and recycling goals, such as substituting materials that were difficult to recycle with ones that are easier (e.g. substituting cardboard build-ups for expanded polystyrene). But there was also a qualitative understanding that there were other additional environmental benefits (e.g. from reduced primary material production) and the possibility for trade-offs (e.g. return transportation of durable returnable shipping modules) from these changes. As packaging changes became more sophisticated and complicated, a method of evaluating all of the impacts was needed to determine if there was a net environmental benefit from the change.

A more recent driver for EPIC is a global initiative to track and reduce packaging and wrapping materials. The major Toyota companies in North America, Europe, and Asia are collaborating to reduce and harmonize packaging for all markets. This project focuses on both purchasing reductions and end-of-life management of packaging materials. TMS is piloting the use of LCA as a tool for addressing the goals of this global project.

Financially, there was also a recognition that packaging design affected downstream TMS costs (such as logistics, inventory, and waste management), but there existed no systematic way of passing that information back upstream (across several company divisions) to the packaging designer, where the costs are most easily addressed.

A TMS team, therefore, approached the Bren School of Environmental Science and Management at UC Santa Barbara with the proposal to develop a tool that:

- Assesses the life cycle environmental impacts of packaging in the TMS supply chain
- Assesses the life cycle costs of packaging to TMS operations
- Uses TMS-specific data
- Is usable by packaging engineers with little environmental or LCA experience
- Can be shared with supplier packaging engineers without revealing TMS' proprietary data

3.2. Life Cycle Assessment of Packaging

From the very beginning, the evaluation of product packaging played a major role in the development and application of life cycle assessment. According to Huang (2004) "[m]ore than 40% of LCA studies published between 1970 and 1992 are estimated to be concerned with packaging materials." Several milestones in methodology development and data collection, from Coca Cola's Resource and Environmental Profile Analyses (REPA) in 1969 to the life cycle inventories of the Swiss and German EPAs in the 1990s, were motivated by and concerned with the environmental impacts of packaging (Klöpfer 2006, BUWAL 1996, UBA 1995). While the scope of contemporary LCAs includes all imaginable kinds of products and services, the interest in packaging is undiminished, which can be attributed to the judgment that packaging is "one of the most severely polluting activities" (Sonneveld 2000).

Even though packaging remains a necessity for containing, protecting, storing, and sometimes even selling products, there is a growing consensus that due to the severity of the environmental burdens packaging generates, "[a] packaging system not only needs to fulfill technical, economical and social requirements but also to minimize the impact on the environment" (Sonneveld 2000). Today, it is common sense that the sheer volume of packaging waste is but one aspect of the problem, which has to be assessed in the context of the environmental impacts from material production, package manufacturing, distribution logistics and end-of-life management activities. This is why LCA is the ideal methodology to identify and evaluate the trade-offs between life cycle stages and environmental concerns.

Nonetheless, LCA remains under-utilized because of the large time and resource investments required to collect and analyze data, and because of the complexity of LCA methodology itself (Cooper and Fava 2006). Firms look for clear, cost-effective and timely approaches when making decisions about packaging management, and traditional LCA appears poorly suited for this task (Lee and Xu 2005). A comprehensive LCA can take months to prepare, cost thousands of dollars, and provide data on only one product rather than the suite of options that are of interest to decision-makers.

Nevertheless, examples of companies using LCA to improve packaging design do exist. McDonald's used comprehensive LCA to help managers make environmentally-informed decisions regarding packaging options in the 1990s. McDonald's collaborated with the Environmental Defense Fund (EDF) to assess the environmental and cost tradeoffs of packaging options for their sandwiches (Svoboda, 1995). McDonald's was particularly interested in assessing their clamshell polystyrene packaging, due to intense public criticism of McDonald's use of polystyrene (Svoboda, 1995). Franklin Associates Ltd. performed a comprehensive LCA on the various packaging materials available to McDonald's, including polystyrene, paper, paperboard, and quilt wrap (Svoboda, 1995). While the joint task force of McDonald's and EDF successfully achieved their goals of comparing possible packaging options, they did not obtain a decision support tool for continuous improvement that would enable them to conduct LCAs for future packaging decisions. McDonald's management would have to rehire consultants to conduct LCAs for any future decisions regarding packaging alternatives, costing them significant time and resources for each LCA.

Not surprisingly, companies frequently opt to use simplified assessment tools that offer quick, approximate results with minimal time and effort required. For example, Wal-Mart Stores recently implemented a packaging scorecard to reduce packaging impacts across its global supply chain, helping Wal-Mart and its suppliers improve packaging and conserve resources (Wal-Mart 2006). The packaging scorecard allows suppliers to input information and measure their performance against other suppliers based on the "7 R's of Packaging": Remove, Reduce, Reuse, Recycle, Renew, Revenue, and Read (Wal-Mart, 2006). Suppliers receive an overall score relative to other suppliers, as well as relative scores in each category (Wal-Mart, 2006).

Georgia-Pacific has developed the *Packaging Systems Optimization* (PSO) tool, which the company offers as a consulting service to their clients (Georgia Pacific, 2007). With a goal of effectively pulling together the economic and sustainability goals of client companies, PSO uses an LCA-like "systems approach" to measure the environmental impacts and costs throughout clients' supply chains. PSO shows both attainment of sustainability goals and cost savings "gained by designing, distributing, and selling packages that meet sustainability objectives" (Georgia Pacific, 2007).

While both the Wal-Mart scorecard and Georgia-Pacific PSO provide valuable insight, they also exhibit significant limitations. Wal-Mart's scorecard is limited in that it provides no quantification of results and no assurance that environmental improvements will be achieved. The system is essentially a 'best practices' summary, incapable of capturing trade-offs between environmental impacts at various lifecycle stages or differentiating between material choices. It is also narrowly limited to packaging decisions, and provides no guidance on logistics issues, such as altering shipping routes. Additionally, Wal-Mart's scorecard must allow greater marketing discretion, because the tool assesses primary packaging. With primary packaging, package design decisions must be consider the value added of marketing and aesthetic design features, which are difficult to measure and largely subjective. Consequently, decisions at this scale must not be too narrowly constrained by any model. These constraints prevent Wal-mart's tool from providing quantification of results.

Georgia-Pacific's PSO tool provides greater lifecycle and logistics support than the scorecard, but is provided as a consulting tool to its clients, rather than as an internal decision-support tool. While large decisions clearly warrant extensive analyses such as those supported by PSO, it is the small decisions which are too often overlooked, but which taken together can have profound impacts.

EPIC's goal is to combine the ease of use of the Wal-Mart scorecard with the robust and comprehensive LCA analysis of Georgia-Pacific's PSO. EPIC allows the user to measure and aggregate environmental impacts and breaks down the impacts by use phase and impact category. As such, EPIC is able to function as an internal decision-support tool aimed at the day-to-day small decisions TMS managers encounter. In particular, the EPIC tool focuses on secondary packaging—that which protects a product during transport but plays no role in the marketing of the product. As such, the only variables that are necessary to consider are the cost, and whether the package fulfills its duty to protect the product.

Like PSO, EPIC does not force the user to make decisions based on environmental considerations alone. Rather, EPIC provides full costing and environmental impacts of packaging options, and displays results as a clear comparison. If there is a discrepancy between the cost and environmental performance, the user can make the final decision after weighing the tradeoffs.

4. SCOPE OF THE EPIC TOOL

In order to reconcile the requirements of TMS with the demands of life cycle assessment, the Environmental Packaging Impact Calculator (EPIC) was designed to produce full LCA results from limited user input and expertise. EPIC was crafted with the explicit goal of creating a simple, user-friendly interface operable by packaging engineers wholly unfamiliar with LCA theory and practice. In just minutes, EPIC quantifies and assesses the life cycle environmental impacts and financial costs of packaging systems at TMS. As such, EPIC can be used as a decision support tool for packaging engineers to use ‘on-the-fly’ early in the packaging design process. While the EPIC interface was designed to be user-friendly, the tool rests on a fully articulated LCA model of the TMS packaging system built in PE International’s *GaBi 4* software package. EPIC thus generates robust scientific analysis and translates it into management-actionable measures.

Given the specialized role of packaging design engineers at TMS and its suppliers, their knowledge of the entire TMS packaging system is inherently limited. They are responsible for package design elements such as material choice and package dimensions, but exert no further control over the rest of the packaging life cycle. Packaging engineers cannot be expected to have in-depth knowledge of the entire logistics network, end-of-life processing, or characteristics of individual facilities throughout the supply chain.

Through parameterization, EPIC is able to predict all of these logistic and end-of-life management values based on the information that packaging engineers *do* know, and then calculate full LCA results. Therefore, EPIC was built to function entirely from what limited information packaging engineers have available. This includes:

- number of parts per package

- weight of the part being packaged
- weight of materials used for the packaging
- purchase price of the packaging
- type of shipping module
- number of packages that fit in each module
- shipping route: standard or direct
- starting TMS parts center
- distance from supplier to starting parts center
- type of part: accessory or service
- destination of the accessory part
- distance from supplier to the destination facility

Using these inputs, EPIC calculates cradle to grave LCA results for the entire life-cycle of the packaging system, including phases well beyond package engineers' purview. Specifically, the EPIC system boundary encompasses all life cycle stages required to fulfill an ISO 14040 compliant LCA. Although TMS is not directly responsible for raw material extraction and other related activities, these have been included within a cradle-to-gate approach at the production phase. In sum, the boundaries include all elementary and intermediate flows at each stage in
Figure **1**:

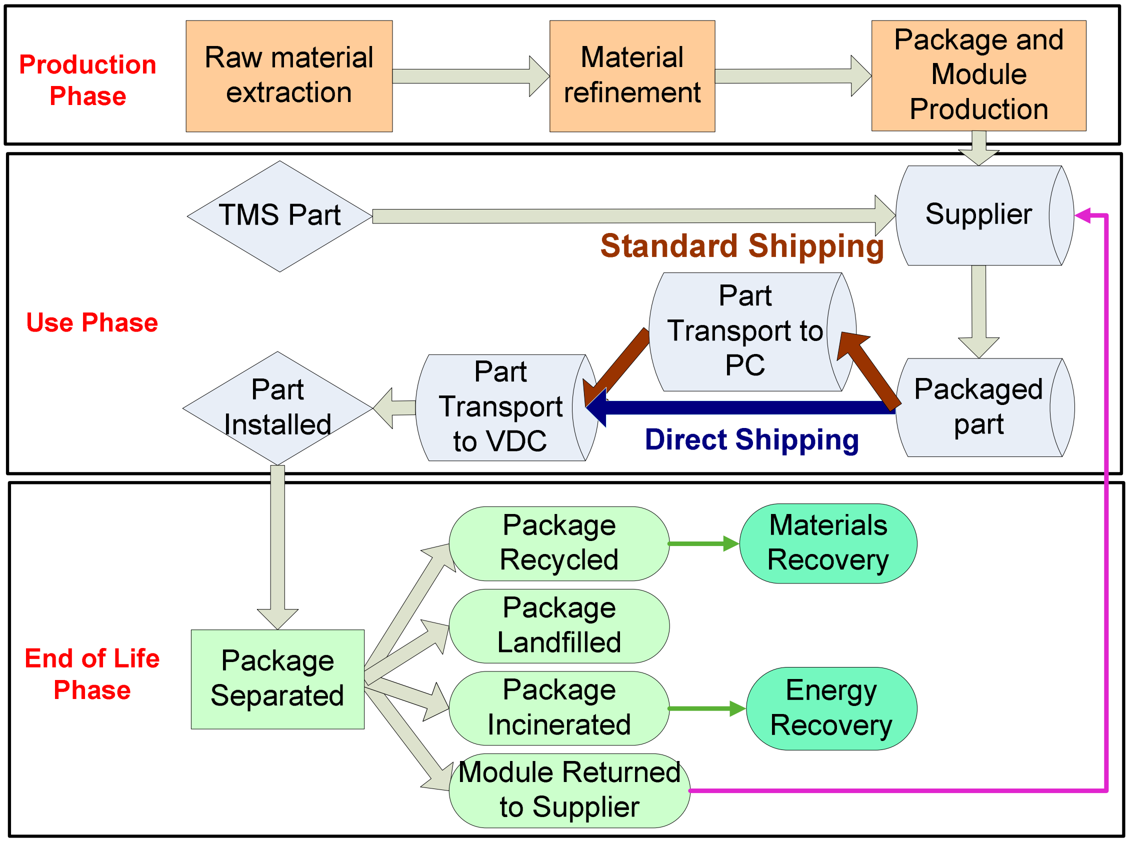


Figure 1. The EPIC system boundary

After extensive deliberation and consultation with TMS, the one life cycle phase that is omitted from EPIC is the inventory stage. Inventory activities, such as energy required to power the storage facility or move parts within the facility were not incorporated because they were not predicted to have a significant effect on the results of the comparison between packages. For example, if Package A required significantly less storage space than Package B, then the TMS storage facility would still require the same amount of energy to light and cool the space. Additionally, the difference in cost of labor during the inventory phase between two packages was considered negligible; therefore, it was not included into the model. Lastly, decisions about the expansion of facilities, due to an increasing amount of inventory, for example, do not influence packaging design. TMS will not make a decision on a package design in order to avoid having to expand their storage facilities to accommodate their growing inventory. Thus, the environmental impacts associated with expanding the facilities—whether they are positive or negative—are not accounted for in this model.

The functional unit of the model is defined as *the transportation and protection of one part from supplier to final destination*. The reference flow, therefore, is all of the packaging necessary and logistics components used to achieve the functional unit. Because most TMS suppliers ship parts to multiple final destinations, EPIC calculates values such as distance and recycling based on a weighted average of characteristics at the specific final destination facilities for a given product.

Traditional LCAs are built for a single static product system, and the reference flow can be calculated and hard-wired into the model. However, EPIC is designed to run a virtually limitless number of LCAs based on varying packaging systems; the individual components of the reference flow, therefore, have to be adjustable in EPIC as well. To achieve this flexibility, EPIC was built on a highly parameterized platform. Based on only the data supplied by packaging design engineers, EPIC calculates the functional unit and reference flow through a cascading series of referential parameters.

5. INVENTORY MODELING

EPIC's major strength is its ability to minimize user effort by automatically adjusting dozens of parameters, values and settings based on a few user inputs. The LCA model underlying the EPIC interface includes options for all packaging materials, shipping modules, and transportation routes and modes used by TMS. When an EPIC user inputs values for the relevant parameters, only the necessary portions of the underlying model are activated. For example, the user may input that a particular package requires 2 kg of corrugated cardboard and 0.2 kg of high density polyethylene (HDPE). These two materials and their accompanying impacts will be activated, while all other materials remain set to zero.

To achieve this flexibility, EPIC contains two kinds of parameters. The first category is '**Free Parameters**,' which represent user-defined inputs. Some free parameters include the weights of various packaging materials, the facility to which a packaged part is first sent, the type of shipping module used, and the percentage of parts to each facility.

The second category of parameters, '**Fixed Parameters**,' is pre-programmed into EPIC's underlying model. Fixed Parameters can either be **constant** information (e.g., the number of shipping modules that fit on a truck), or dependent functions formed from other parameters (**dependent fixed parameters**). Examples of fixed parameters include:

- weight of each module (constant)
- number of each module that fit on a truck (constant)
- % of non-recycled waste that is incinerated (dependent)
- cost of transportation (train and truck) (dependent)
- cost of modules (constant)
- cost of end-of-life processes (dependent)
- types of materials recycled, incinerated, and landfilled at each facility (constant)

EPIC's dependent fixed parameters are analogous to Excel equations that reference other cells. Dependent fixed parameters have pre-set data that is activated, de-activated or scaled by other parameters. For example, the percent of soft plastic in the packaging system that will be recycled is the sum percent of parts going to facilities that recycle soft plastic. Similarly, the distance a package is transported is calculated as a weighted average of the distances to the facilities to which that part travels. In this case, rather than a simple sum of percentages, it is the sum of each percentage, multiplied by the distance to that facility, with unused facilities registering as zero.

All data for free and fixed parameters is based on information obtained directly from TMS. Free parameters are input by the EPIC user. Constant and dependent fixed parameters have been programmed into EPIC using data gathered from site visits, database review, system analysis and interviews with TMS environmental, packaging, and logistics managers.

The ultimate purpose of parameterization is to activate and scale the relevant processes and materials involved in the life cycle of a single package. Figure 2 shows an example of how these parameters interact to make EPIC run. Steel used to make shipping modules, a '**Process Flow,**' is specifically what generates environmental impacts. The actual amount of steel required to achieve the functional unit ('**Mod_Steel_Use**') is a function of numerous parameters, both free and fixed. The EPIC user enters the free parameters, ‘**MU_Module**’ and ‘**Parts_Per_Module**,’ activating the kind of shipping module used (MU) and how many packaged parts fit in that module. These free parameters trigger the constant fixed parameter, ‘**MU_Module_Weight**,’ adding in the weight of that module. This figure is then divided by the parts per module as input by the user, to arrive at the amount of that particular module necessary to transport one part. Finally, to determine the amount of module produced and disposed of for this single trip, ‘**Mod_Steel_Use**’ divides the amount of module necessary to transport one part by the lifetime uses of an MU module (in this case, the lifetime uses of an MU module is **120**). This amount is linked to the Process Flow, informing the quantity flow of a cradle-to-gate ‘steel’ process in the model.

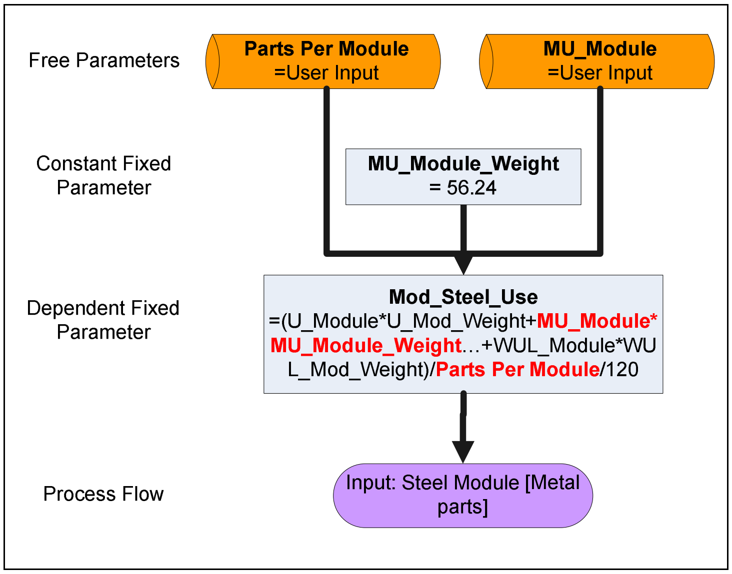


Figure 2. Parameters underlying steel use for shipping modules.

The individual inventory processes used in EPIC are contained within the *GaBi 4* software package and accompanying data sets, used to create EPIC’s underlying model. PE International, the company that manufactures *GaBi 4*, is an industry leader in life cycle assessment, and all processes contained in *GaBi 4* are fully vetted through external review and analysis. The processes chosen for EPIC were selected because they most accurately represent the specific materials, trucks, and processes used in the TMS packaging system. Geographic location and age of the data also contributed to selection when multiple options for a single process or material were available. When *GaBi 4* did not contain cradle-to-gate inventory data appropriate to the TMS system, plans capturing the requisite processes and inventories were built in *GaBi 4* and nested within the larger model. In one case, the process for a particular material—lumber— was not available in *GaBi 4*, so the process inventory for ‘rough, dry lumber’ was imported from U.S. LCI Database (NREL, 2008) an outside life cycle inventory database (i.e. not *GaBi 4*).

All together, EPIC contains complete inventory data for the following material and process classes:

- Cradle-to-gate process inventories for all materials used in packaging
- Cradle-to-gate process inventories for all materials and processes used to make shipping modules and pallets
- Inventories for truck and train transportation processes
- Recycling, incineration, and land-filling process inventories specific to each packaging material
- Inventories for all production processes assumed to be displaced by recycled or incinerated materials

By linking the inputs from packaging engineers to the parameterized inventory model, EPIC is able to calculate a full life cycle inventory of the specified packaging system.

6. IMPACT ASSESSMENT

Just as EPIC was built to simplify the user input requirements, EPIC also distills pertinent results into outputs usable by managers. This process, illustrated in Figure 3, required that inventories first be analyzed according to normalized environmental impact indicators. EPIC uses the CML 2001 suite of environmental impact indicators.

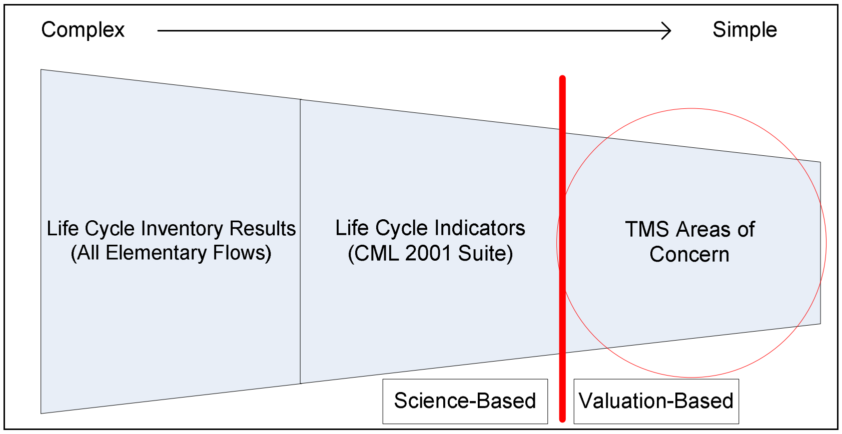


Figure 3. Distillation of Life Cycle Inventory Results into TMS Areas of Concern

However, even the CML 2001 impact indicator results were determined to be too scientifically abstract for the day-to-day decisions that packaging engineers face. Consequently, it was decided that the impact indicator results and several inventory results (lead, mercury, hexavalent chromium, cadmium, net resource consumption and net energy consumption) would be further distilled into TMS' five major areas of environmental concern, as identified in TMS' Environmental Action Plan and 2006 North American Environmental Report (Toyota, 2006) (Table 1).

Table 1: Assignment of LCA Impact Categories to TMS Areas of Environmental Concern

Impact Indicator Categories, and Inventory Flows	TMS Area of Concern
CML 2001, Global Warming Potential	Climate Change
CML 2001, Abiotic Depletion Net Energy Consumption Net Resource Consumption	Resource Depletion
CML 2001, Human Toxicity Potential CML 2001, Terrestric Ecotoxicity Potential CML 2001, Freshwater Aquatic Ecotoxicity Potential CML 2001, Marine Aquatic Ecotoxicity Potential	Human Health and Toxicity
CML 2001, Acidification Potential CML 2001, Photochemical Ozone Creation Potential CML 2001, Ozone Layer Depletion Potential	Air Pollution
Lead, Mercury, Cadmium, Hexavalent Chromium	Substances of Concern

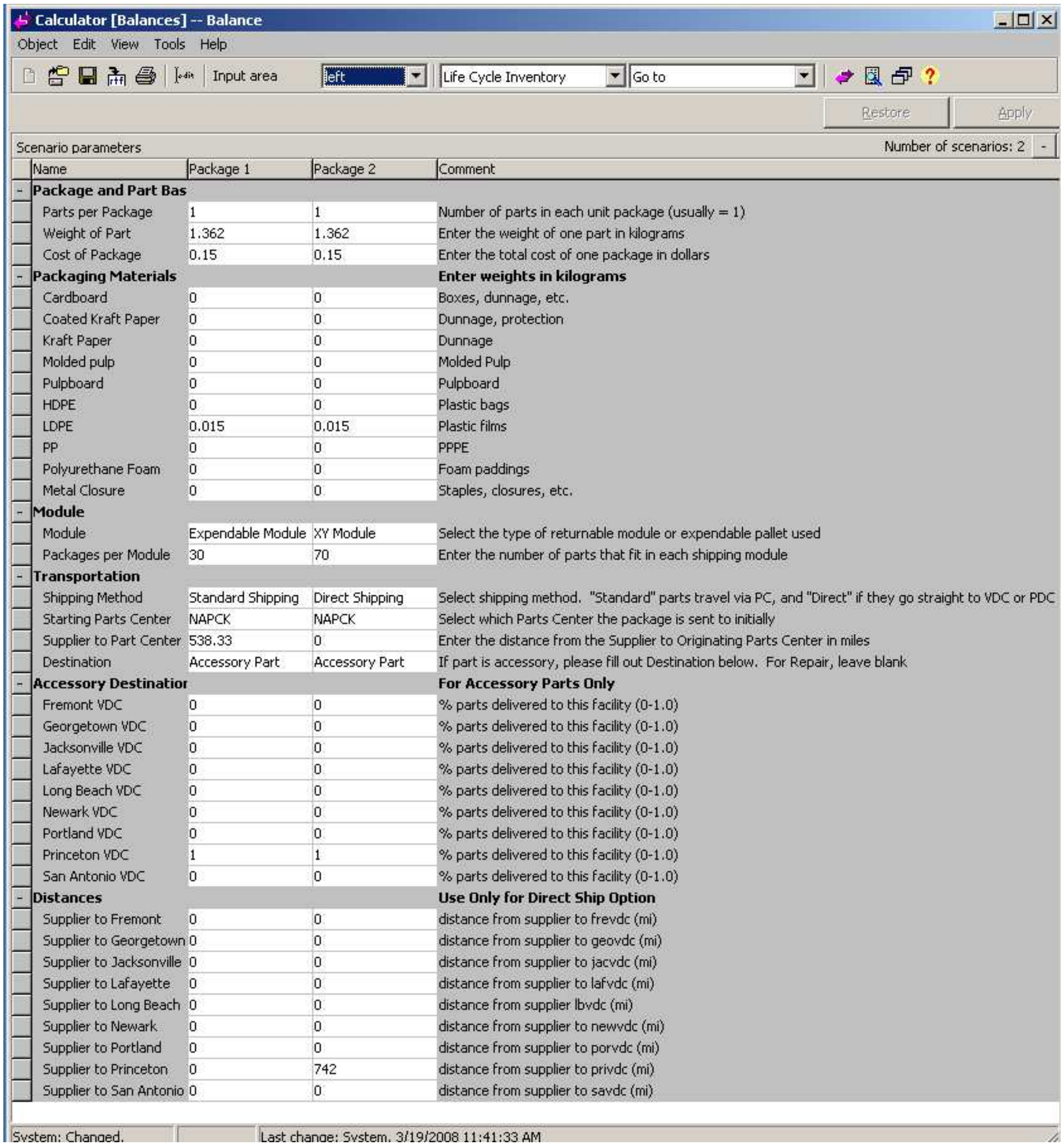
Based on requests from TMS Environmental Management, the impact indicator categories that comprise each area of concern are given equal weight. For example, the EPIC score for ‘Climate Change’ is comprised entirely of normalized *CML 2001, Global Warming Potential* results; whereas the score for ‘Air Pollution’ is comprised of equal parts normalized *CML 2001 Acidification Potential,* normalized *CML 2001 Photochemical Ozone Creation Potential*, and normalized *CML 2001 Ozone Layer Depletion Potential.*

The assignment of impact categories into TMS areas of environmental concern inherently moves the LCA results away from purely scientific and towards value-based assessments. According to ISO 14044, weighting is optional, and “weighting steps are based on value-choices and are not scientifically based” (ISO 14044, 2006). If weighting is used in LCAs, the data and indicator results (pre-weighting) should be provided along with the weighted results, so the audience can understand the methods behind the valuation (ISO 14044, 2006). TMS deemed weighting a necessary step in order to allow non-experts to interpret LCA results with the purpose of informing decisions. Further, by allowing environmental managers to hard-wire educated valuation into EPIC, TMS is able to ensure that valuation is codified company-wide and determined by those with an environmental background.

7. EPIC INTERFACE

The EPIC interface, which was created using PE International’s *I-Reports*, sits on top of the underlying TMS packaging system model. Obscuring the view of the actual model, it nonetheless draws its results directly from the model. Consequently, the simplified EPIC interface does not present the results of a streamlined LCA, but rather provides full LCA and LCC results.

In order to act as a decision support tool, EPIC calculates side-by-side results of two packaging systems. As a comparative tool, EPIC easily allows variation in material choice, shipping routes, and shipping modules. To operate EPIC, the user enters free parameter data for the two packaging systems. Figure 4 shows an example of how the questionnaire appears. The data inputs required by EPIC intentionally mimic the data TMS management requires from packaging engineers prior to finalizing a package design, and, therefore, require no additional research from engineers.



Input area: left

Life Cycle Inventory

Go to

Scenario parameters

Number of scenarios: 2

Name	Package 1	Package 2	Comment
Package and Part Bas			
Parts per Package	1	1	Number of parts in each unit package (usually = 1)
Weight of Part	1.362	1.362	Enter the weight of one part in kilograms
Cost of Package	0.15	0.15	Enter the total cost of one package in dollars
Packaging Materials			**Enter weights in kilograms**
Cardboard	0	0	Boxes, dunnage, etc.
Coated Kraft Paper	0	0	Dunnage, protection
Kraft Paper	0	0	Dunnage
Molded pulp	0	0	Molded Pulp
Pulpboard	0	0	Pulpboard
HDPE	0	0	Plastic bags
LDPE	0.015	0.015	Plastic films
PP	0	0	PPPE
Polyurethane Foam	0	0	Foam paddings
Metal Closure	0	0	Staples, closures, etc.
Module			
Module	Expendable Module	XY Module	Select the type of returnable module or expendable pallet used
Packages per Module	30	70	Enter the number of parts that fit in each shipping module
Transportation			
Shipping Method	Standard Shipping	Direct Shipping	Select shipping method. "Standard" parts travel via PC, and "Direct" if they go straight to VDC or PDC
Starting Parts Center	NAPCK	NAPCK	Select which Parts Center the package is sent to initially
Supplier to Part Center	538.33	0	Enter the distance from the Supplier to Originating Parts Center in miles
Destination	Accessory Part	Accessory Part	If part is accessory, please fill out Destination below. For Repair, leave blank
Accessory Destinatior			**For Accessory Parts Only**
Fremont VDC	0	0	% parts delivered to this facility (0-1.0)
Georgetown VDC	0	0	% parts delivered to this facility (0-1.0)
Jacksonville VDC	0	0	% parts delivered to this facility (0-1.0)
Lafayette VDC	0	0	% parts delivered to this facility (0-1.0)
Long Beach VDC	0	0	% parts delivered to this facility (0-1.0)
Newark VDC	0	0	% parts delivered to this facility (0-1.0)
Portland VDC	0	0	% parts delivered to this facility (0-1.0)
Princeton VDC	1	1	% parts delivered to this facility (0-1.0)
San Antonio VDC	0	0	% parts delivered to this facility (0-1.0)
Distances			**Use Only for Direct Ship Option**
Supplier to Fremont	0	0	distance from supplier to frevdc (mi)
Supplier to Georgetown	0	0	distance from supplier to geovdc (mi)
Supplier to Jacksonville	0	0	distance from supplier to jacvdc (mi)
Supplier to Lafayette	0	0	distance from supplier to lafvdc (mi)
Supplier to Long Beach	0	0	distance from supplier lbvdc (mi)
Supplier to Newark	0	0	distance from supplier to newvdc (mi)
Supplier to Portland	0	0	distance from supplier to porvdc (mi)
Supplier to Princeton	0	742	distance from supplier to privdc (mi)
Supplier to San Antonio	0	0	distance from supplier to savdc (mi)

System: Changed.

Last change: System, 3/19/2008 11:41:33 AM

Figure 4. Screenshot of EPIC user input screen

Running a comparison between two packaging models through the EPIC tool takes under five minutes.

Because of the simplicity of the graphs, a rough interpretation of the results can take as little as a few seconds. Once the data has been input, user hits he ‘Apply’ button and is immediately provided the option of viewing the results of the comparison in four different formats: Life Cycle Results, Life Cycle Stage Results, Life Cycle Inventory and Life Cycle Impact Assessment. Each page gives progressively more detailed information about the environmental impacts and financial costs associated with the packaging design choices.

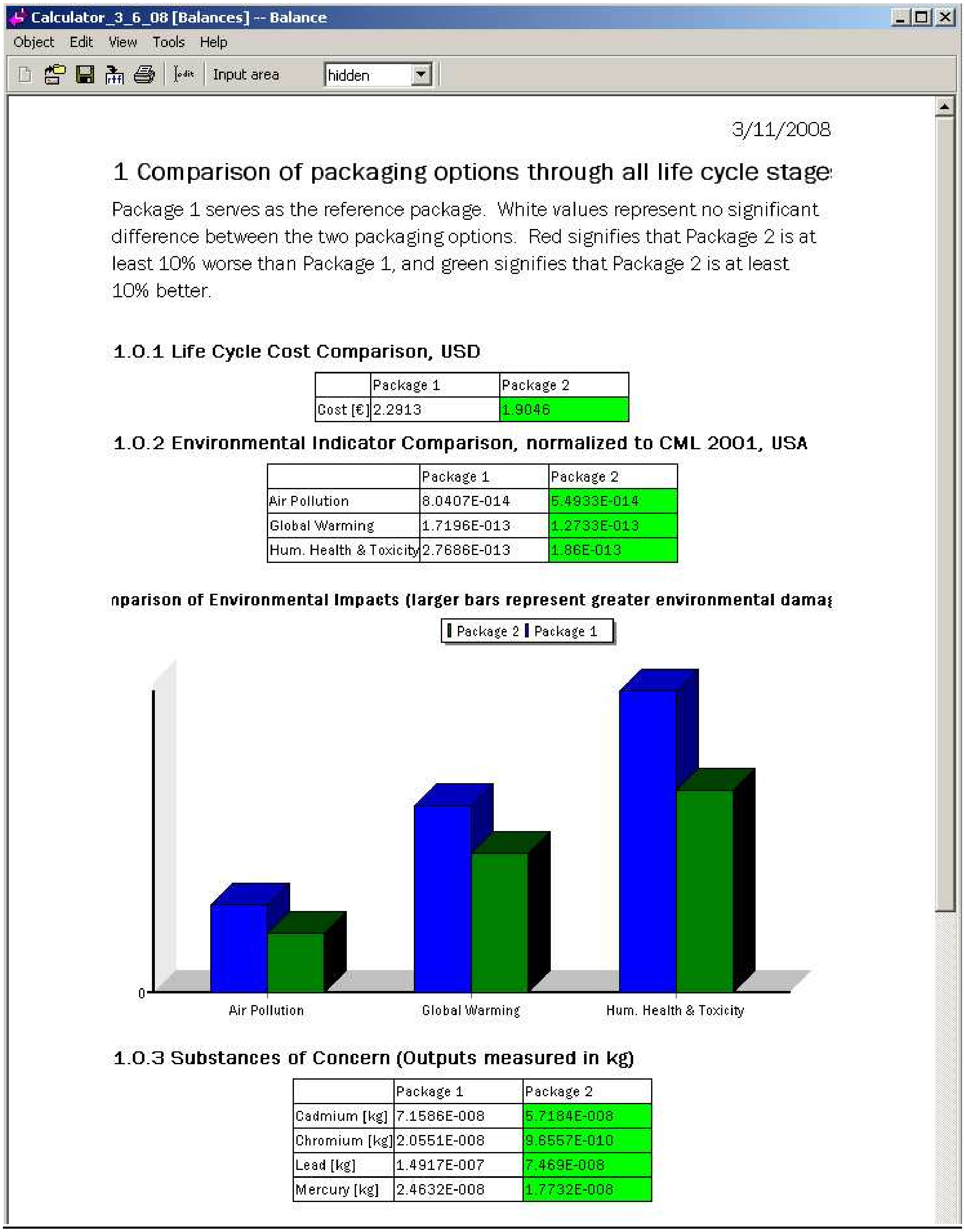
The *Lift Cycle Results* page gives the most basic and easily understandable results for both the LCA and LCC (see Figure 5), and will be referenced most commonly used by EPIC users. The results are divided into the following sections:

- **Life Cycle Cost Comparison (USD):** a table showing the total cost of the two packaging options over the course of their lifetimes, including materials, manufacturing, transportation, logistics, and end-of-life.

- **Environmental Indicator Comparison:** a table and histogram showing the environmental harm the two packaging options cause with respect to three of TMS’ targeted environmental areas of concern: Air Pollution, Global Warming and Human Health and Toxicity. Results are normalized to U.S. data.

- **Substances of Concern:** a table and histogram showing the impacts of the packaging options on TMS’ four substances of concern: cadmium, hexavalent chromium, lead, and mercury (measured in kilograms).

To facilitate analysis, EPIC displays color coded results. Green signifies that Package 2 results are at least 10% better than Package 1 results; red signifies that Package 2 results are at least 10% worse. If the difference is less than 10% in either direction the results are not highlighted, though values are still displayed.



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1 Comparison of packaging options through all life cycle stage

Package 1 serves as the reference package. White values represent no significant difference between the two packaging options. Red signifies that Package 2 is at least 10% worse than Package 1, and green signifies that Package 2 is at least 10% better.

1.0.1 Life Cycle Cost Comparison, USD

	Package 1	Package 2
Cost [€]	2.2913	1.9046

1.0.2 Environmental Indicator Comparison, normalized to CML 2001, USA

	Package 1	Package 2
Air Pollution	8.0407E-014	5.4933E-014
Global Warming	1.7196E-013	1.2733E-013
Hum. Health & Toxicity	2.7686E-013	1.86E-013

nparison of Environmental Impacts (larger bars represent greater environmental damag

1.0.3 Substances of Concern (Outputs measured in kg)

	Package 1	Package 2
Cadmium [kg]	7.1586E-008	5.7184E-008
Chromium [kg]	2.0551E-008	9.6557E-010
Lead [kg]	1.4917E-007	7.469E-008
Mercury [kg]	2.4632E-008	1.7732E-008

Figure 5. Life Cycle Results page, which shows the results for Life Cycle Costing, Air Pollution, Global Warming, Health and Human Toxicity, and Substances of Concern.

In addition to providing aggregated scores for each TMS Area of Concern, EPIC also provides results differentiated by life-cycle stage: package and module manufacture, transportation, and end-of-life. Packaging engineers and logistics managers can determine which life-cycle stage contributes the most to environmental or cost burdens, and make strategic changes that maximize improvements while reducing effort and cost.

Additionally, EPIC provides a full Life Cycle Inventory and Life Cycle Impact Assessment. These sets of results will likely not be used by packaging engineers, but provide the capacity for TMS environmental managers to conduct ISO 14040/14044 compliant LCAs.

As with any tool, there is a possibility that user error could occur. To ensure the robustness of EPIC, a sensitivity analysis of the model's parameters was conducted. The analysis assessed impact on final LCA results in the CML suite of indicators that result from minor errors in user input values (package material weights and percent of parts to each final location). For one case study a Monte Carlo analysis using GaBi4's sensitivity analysis feature was performed. The bounds of uncertainty were defined as plus or minus ten percent for those parameters that may see higher rates of user error, and 1000 iterations were run. The results, shown in Figure 6, indicate that the model is not sensitive to minor user input errors for any particular parameter. Qualitatively, the results did not change for any environmental impact category evaluated.

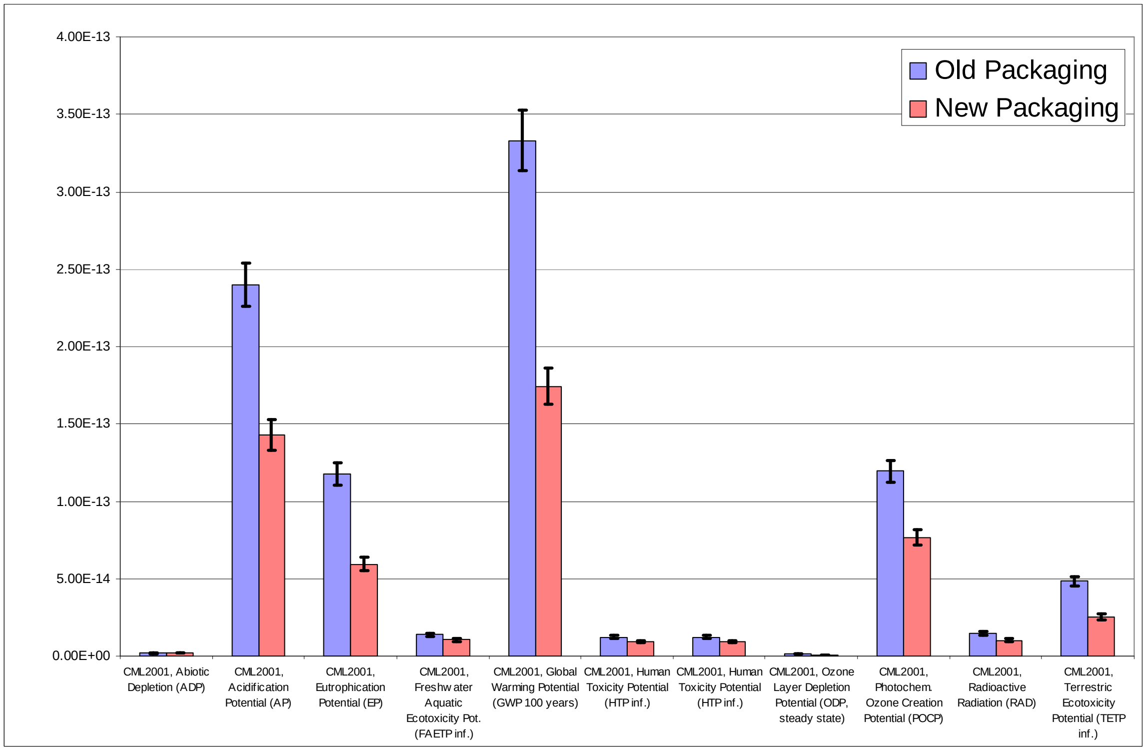

Figure 6. Sensitivity analysis of user input parameters

In addition to providing visual simplicity, the EPIC interface also protects TMS' proprietary information. EPIC is built to keep all proprietary data hidden from the user in a virtual 'black box.' The model, calculations, and data itself are concealed within the software, allowing the tool to safely reflect proprietary TMS information while simultaneously protecting it. As a result, EPIC can be shared with independent partners and any other TMS affiliated packaging engineers that design package systems.

8. IMPLEMENTATION

Currently, suppliers submit packaging designs and a packaging information sheet to the TMS packaging group for review and information sharing. The information sheet lists several details about the packaging, but contains no environmental or life cycle assessment. The TMS packaging group then reviews the packaging design and suggests adjustments or alternatives as necessary.

TMS plans to implement the EPIC Tool on two levels within existing procedures. The first is to distribute the EPIC tool with the existing Supplier Guidebook. To harmonize the procedures, the packaging information sheet that independent suppliers normally fill out will be reformatted to mimic the input to the EPIC Tool. The EPIC results from final packaging design and alternative designs will be submitted with the packaging information sheet. The second level is use of the EPIC tool by the TMS packaging engineers, logistics managers, and environmental managers, for internal planning and evaluation of packaging changes and options, as well as communicating the benefits and changes from packaging improvements. This will add environmental considerations alongside other packaging considerations in an existing framework.

9. CASE STUDY

To reduce environmental impacts and life cycle costs, TMS changed the shipping route and module used to ship Sequoia model floor mats in 2007. EPIC has been used to determine whether the new Sequoia floor mat packaging system did, indeed, lead to reduced environmental impacts and costs.

Previously, floor mats were individually packaged in low density polyethylene plastic bags, and shipped in expendable shipping modules made of cardboard, wood, and nails, through the standard TMS supply chain route (supplier to national parts center to vehicle distribution center.) After the change, floor mats continue to be individually packed in the low density polyethylene bags, but are now shipped in reusable shipping modules made of high density polyethylene plastic, along a direct shipping route (supplier to vehicle distribution center.) The modules are then shipped back to the supplier after use.

Given these circumstances, the following user inputs ('independent parameters') were entered into EPIC (Table 2):

Table 2. EPIC data inputs for the change in Sequoia model floor mat packaging.

	Package 1	Package 2
Package and Part Basics		
Parts per Package	1	1
Weight of Part (kg)	1.362	1.362
Cost of Package ($)	$0.15	$0.15
Packaging Materials		
LDPE (kg)	0.15	0.15
Module		
Module	Expendable Module	XY Module (Plastic)
Packages per Module	30	70
Transportation		
Shipping Method	Standard Shipping	Direct Shipping
National Parts Center (if standard ship)	NAPCK	n/a
Supplier to Part Center distance (if standard ship)	538.33	n/a
Destination	Accessory Part	Accessory Part
Accessory Destination		
Princeton VDC (%)	100%	100%
Distances (if direct ship)		
Supplier to Princeton (miles)	n/a	741.61

The independent parameters input in Table 2 trigger dependent and constant parameters built into EPIC's underlying TMS supply chain model. 'Expendable Module,' activates underlying parameters specifying that expendable modules cost $20, and are used once and then recycled. 'XY Module' (plastic) activates relevant background data that plastic module are used two to three times per month, have a life expectancy of five years, and cost $160. Each of these costs is scaled according to the number of parts in that module and the number of trips each module completes in its life. Further, logistic parameters are activated, such as those indicating that a filled standard TMS truck (53') holds 120 expendable modules or 78 plastic returnable modules. End-of-life parameters are also calculated, including one specifying that the vehicle distribution center to which all floor mats are shipped, Princeton VDC, recycles 100% of wood pallets, paper, low and high density polyethylene plastics, and landfills all remaining waste.

EPIC results confirm that the new packaging system does reduce environmental burdens in all five 'Areas of Concern,' including an 88% reduction in lead use, 89% reduction in mercury, and an 80% decrease in human health and toxicity potential. The new packaging system also generates a cost savings of $0.72 per floor mat. Table 3 provides a comprehensive list of LCA and LCC results.

Table 3. LCC and LCA results for the change in Sequoia model floor mat packaging. LCA Results for the 3 Areas of Concern have been normalized to U.S. Data.

	Package 1	**Package 2**	**Percent improvement**
Life Cycle Cost			
Cost [$]	$1.29	$0.58	55%
LCA: 3 Areas of Concern			
Air Pollution	2.07E-14	1.18E-14	43%
Global Warming	5.01E-14	2.93E-14	41%
Hum. Health & Toxicity	7.08E-14	1.44E-14	80%
Natural Resource Depletion			
Resource Use (kg)	3.41E+00	1.58E+00	54%
Substances of Concern			
Cadmium [kg]	2.53E-08	1.25E-08	51%
Chromium [kg]	2.07E-09	2.88E-09	-39%
Lead [kg]	1.63E-07	1.93E-08	88%
Mercury [kg]	6.05E-09	6.60E-10	89%

Analysis of Life Cycle Stage results show improvements in almost all life cycle stages. Among the notable Life Cycle Impact Assessment results, EPIC shows that the new packaging system results in a decrease in carbon dioxide equivalent (CO2eq) of 0.6 kg, per floormat set. Given that TMS sold over 9 million vehicles in 2007, if a similar gain could be made for each vehicle, this decrease would be estimated to lead to overall reductions of over 5,000 metric tons of CO2eq.

10. CONCLUSION

EPIC's highly parameterized format allows packaging design engineers at Toyota Motor Sales to run full Life Cycle Assessments and Life Cycle Costing for a virtually limitless number of packaging options. Its simple, easy to use interface reduces the chance for user error, and improves the flow of environmental information through the TMS packaging supply chain such that packaging design engineers will be able to actively base design decisions on robust scientific information. TMS views implementation of EPIC as an important step in establishing a quantitative component in their efforts to green their supply chain, as well as a unique opportunity to integrate science with progressive management strategies.

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