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

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I. ABSTRACT

The environmental impacts of pre-consumer packaging in industry are often overlooked by decision-makers. Life Cycle Assessment (LCA) is a method of accounting for the environmental impacts of a product from cradle-to-grave, while Life Cycle Costing (LCC) quantifies economic impacts over the life cycle. Using GaBi4 software, we will conduct three LCAs and LCCs, evaluating the environmental burdens and economic impacts associated with three packaging system changes recently implemented at Toyota Motor Sales (TMS). Of these three comparative analysis, one will focus primarily on a change in packaging materials, another will focus on transportation route changes, and the third will evaluate the use of returnable shipping modules. We will present the results of the three case studies as A3 documents for TMS management. Based on the relevant parameters of these assessments, we will design a decision support tool for TMS packaging engineers. Using this tool, they will be able to quantify both the environmental and economic impacts of packaging options early in the design process. This tool will provide a way for TMS management to make efficient, informed decisions when comparing materials and size of a package, transportation mode, and end of life management.

II. PROBLEM STATEMENT

Package design decisions have numerous environmental impacts that manifest themselves throughout the life cycle of the product. These include environmental impacts from raw materials acquisition, manufacturing, transportation, and end of life. End of life impacts have received a significant amount of attention: as shown in Figure 1, municipal solid waste in the U.S. topped 245.7 million tons in 2005, and of this almost one third (76.7 million tons) can be attributed to consumer packaging and containers (EPA-MSW, 2005). Pre-consumer packaging from commercial or industrial sources is of a similar magnitude (Geyer, 2007).

![Figure 1 Products Generated in MSW, 2005 (Total Weight = 245.7 million tons), EPA MSW 2005](image-url)

Often overlooked, however, are the environmental impacts associated with packaging manufacture and package transport. Both require enormous amounts of raw materials, energy, and other resources while generating various forms of pollution. According to the Tellus Institute, “the environmental cost of production contributes 99% of the environmental harm….The problem of packaging facing the environment is not a problem related to disposal. It
is a problem of production…” (ILEA, 2007) Because of this lack of attention to the production and use phases of packaging, it is difficult for decision-makers to make informed decisions regarding packaging options.

For example, the manufacture of corrugated cardboard, one of the most commonly used packaging materials, is much more environmentally detrimental than the impacts associated with its disposal. Producing virgin cardboard requires timber harvest and transportation, kraft processing, forming, pressing and drying in the mill. Throughout this process, environmental impacts, including greenhouse gases, air pollution, water contamination, etc., are generated from the energy consumption and chemicals used in the manufacturing process. (Madehow.com, 2007)

III. BACKGROUND

A. Toyota
Engineers at Toyota Motor Sales are responsible for packaging and distributing over 110 million parts through their parts logistics operations every year, using both returnable and disposable packaging. Given the environmental impacts and high volume of pre-consumer packaging this generates, the TMS engineers are in a unique position to affect significant environmental improvements. Unfortunately, packaging engineers at TMS presently lack the requisite tools for making informed decisions and evaluating the environmental impacts of design options. This represents a significant information gap and opportunity for improvement, both financially and environmentally.
As TMS captures more of the American market each year, not only are overall vehicle sales growing, the number of accessories installed per vehicle is growing as well: 2006 saw a 12% increase per vehicle (McMullen, 2007). For accessories installed at TMS vehicle distribution centers, TMS controls all aspects of parts manufacturing, packaging, distribution and disposal (Figure 2). As such, TMS is in a position to affect all aspects of this process. Such capacity to modify the process is rarely so controlled, and presents fantastic opportunities for improving efficiency.

TMS has already recognized the intimate connection between packaging design, distribution processes, and the resultant resource use. TMS has made changes to its packaging design aimed at improving and streamlining the logistics process, and believes many of these changes have had the additional benefit of reducing environmental impacts. Their past efforts to increase efficiency have included implementing direct shipping from suppliers to vehicle distribution centers, using returnable shipping modules, and exploring the use of alternate packaging materials. This kaizen, or continuous improvement, was spearheaded by both the Environmental Coordination Office and Engineering Department of TMS. TMS believes these efforts have reduced greenhouse gas emissions, curtailed energy consumption, and diminished resource use. To date, however, that impact has not been adequately quantified and package designers lack the tools necessary to evaluate the environmental benefits of implemented changes, as well as the tools necessary to facilitate making informed decisions on design/distribution options in the future.

B. Life Cycle Assessment
A useful method for assessing the environmental impacts of a product is Life Cycle Assessment (LCA). LCA evaluates the environmental impacts of a product or process from a cradle-to-grave perspective. The main goal of LCA is to help identify opportunities to reduce environmental impacts throughout the system and to inform decision-makers about these opportunities. The systems approach is useful because decision-makers can track the impacts associated with different parts of a product’s life cycle – i.e. raw materials acquisition, manufacturing, use, and end of life. This information can then be used to change aspects of a product's life phase based on relevant environmental impact indicators (ISO 14040).

LCA is an objective technique using validated data, which quantifies materials and energy consumption, and allows decision-makers to evaluate and implement improvements (Sonneveld, 2000). LCA is a useful tool for many applications, ranging from product development to comparative environmental assessment (Zabaniotou, 2003; European Environment Agency, 2006).

The usefulness of LCA for analyzing the effects of packaging has been well documented. In fact, Huang (2004) asserts that “[m]ore than 40% of LCA studies published between 1970 and 1992 are estimated to be concerned with packaging materials.” The LCA style approach to packaging began in 1969. Driven by the increasing use of plastics and solid waste, the Coca Cola Company used the concept to quantify the consequences of its packaging choices (SOURCE). This was followed in the 1970s by concerns over how to reduce energy inputs. In the 1980s, the various aspects were brought together into a more “holistic view” that led to the establishment of LCA methodology. According to this methodology, a “packaging system not only needs to fulfill technical, economical and social requirements but also to minimize the impact on the environment” (Sonneveld, 2000).

An example of a company that successfully used LCA to identify areas of improvement of a product’s life cycle, as well as to analyze environmental impacts, costs and quality of the product is, Alcan Composites. The company commissioned a study to compare the environmental impacts resulting from two automobile load floor materials: wood laminate and a new material known as Alucore. A new process for producing Alucore was also analyzed, for further comparison (Rebitzer, 2005).

Alcan chose to focus on four environmental impact indicators:

- Primary Energy Demand,
- Global Warming Potential (over 100 years),
- Waste generation
- Eco-indicator score without energy and global warming

The researchers chose primary energy demand and global warming because of their globally recognized importance. Waste generation was chosen because it addresses waste treatment and disposal processes, while the eco-indicator score is a weighted score that provides supplemental information not addressed by the other indicators (Rebitzer, 2005).
Alcan’s LCA ultimately enabled decision-makers within the company to evaluate and understand the environmental advantages of the new product over the old product. The results showed that the new load floor made from Alucore had a smaller environmental impact than the old wood load floor, and the new production process for Alucore further reduced environmental impacts. Based on the results of this case study, Alcan transitioned to manufacturing Alucore load floors. The company will continue to study the production data to determine potential savings in various stages of the product’s life cycle (Rebitzer, 2005).

IV. LITERATURE REVIEW

A. Packaging and the Environment

The relationship between packaging and the environment is complex and closely intertwined. Before a packaging engineer can even begin to consider the environmental properties of a packaging design, the engineer must accomplish the fundamental goal: “properly designed packaging” must protect the product from damage (Lee and Xu, 2005). Moreover, in the case of consumer packaging, the packaging itself may serve as a marketing tool, and thus must be attractive as well.

Yet as companies become cognizant of their role in creating environmental burdens, the opportunity to decrease these burdens through better packaging become clear. While packaging remains a necessity for transporting, storing and sometimes even in selling the product, it has also been targeted by some researches as “one of the most severely polluting activities” (Sonneveld, 2000). Because of the severity of the environmental burdens it generates, Sonneveld asserts that “[a] packaging system not only needs to fulfill technical, economical and social requirements but also to minimize the impact on the environment” (2000). There is consequently a need for decision-makers to focus not only on end-of-life issues, but to also incorporate distribution, marketing, and use phases into packaging design.

The idea of “sustainable packaging” and what this entails has emerged in recent years. The Sustainable Packaging Coalition has issued a working version of the term sustainable packaging. To quote, sustainable packaging:

- A. Is beneficial, safe & healthy for individuals and communities throughout its life cycle;
- B. Meets market criteria for performance and cost;
- C. Is sourced, manufactured, transported, and recycled using renewable energy;
- D. Maximizes the use of renewable or recycled source materials;
- E. Is manufactured using clean production technologies and best practices;
- F. Is made from materials healthy in all probable end-of-life scenarios;
- G. Is physically designed to optimize materials and energy;
- H. Is effectively recovered and utilized in biological and/or industrial cradle to cradle cycles (Sustainable Packaging Coalition).

Numerous studies have been conducted to analyze changes companies have implemented to increase the sustainability of their own packaging. Hekkart et al. conducted a study in Western Europe on consumer packaging in the beverage industry. They focused on improvements in specific types of beverage containers that resulted in reductions in CO$_2$ emissions (1999). To assess the improvements, the authors studied changes in the management of materials and
processes for consumer packaging. “Improved packages” were defined as meeting the following criteria: use of thinner materials, new product design that leads to a lighter package, product reuse, material recycling, and material substitution (Hekkert et al., 1999). These characteristics were considered to result in reduced CO₂ emissions.

Hekkert et al. went into more detail researching the effects of lighter packaging and reuse, individually and combined. Using a standardized glass beer bottle as an example in which the weight of the package could be reduced and the container could be successfully reused, they explain that with standardized sizes across the industry, consumers can easily return the bottle to producer A or producer B to be refilled and reused. The authors conclude that reducing the weight of the bottle and refilling the bottle resulted in a 5.6% reduction in CO₂ emissions. Further, if lighter packaging were used in all possible beverage containers that they researched, the cumulative CO₂ reduction would be 9%; if product reuse were implemented for all the containers studied, the cumulative CO₂ reduction would be 32% (Hekkert et al., 1999). The authors do note, however, that large scale implementation of reusable packaging can be a challenge. Reuse requires drastic changes to the current packaging procedures, such as reverse logistics and changes in consumer behavior (Hekkert et al., 1999). There is a limitation on weight reductions in packaging as well. Although thinner or lighter materials can reduce end-of-life waste and raw materials extraction, a potential drawback of reducing the mass/volume of packaging is the increased risk of product damage, which could increase the volume of solid waste at end of life (Lee et al., 2005).

Decreasing the environmental burdens of packaging may also be aided by increasing the number of times that packaging is used. Gonzales-Torre (2004) found that reusable packaging plays an important role in reducing the amount of raw materials used for production, in addition to minimizing pollution from solid waste. Reusable packaging has resulted in environmental improvement and cost savings for many large companies. Ford, John Deere, Harley-Davidson, Tyson, and others have found that they can move products “faster, better, safer, and more cost-effectively” with reusable packaging (Goetz, 2005). Goetz also asserts that because packages are available in standard sizes, they are easy to integrate into automated systems, which leads to less ordering time, no disposal costs, and faster receipt and inspection of deliveries, all of which aids in “lean manufacturing.” Achievements include savings of $10.9 million per year after an initial $16.3 million investment at one automaker; $12 million in disposal savings by GM between 1987 and 1992; and an elimination of 11 lbs. of waste per engine produced at Ford (Goetz, 2005).

B. Existing Decision Support Tools for Packaging Designers
Given the vast room to cut environmental impacts through better packaging design, it is not surprising that many tools exist to enable packaging engineers to make educated decisions for packaging design. These tools vary considerably, ranging from detailed LCA based calculators to laundry-list time checklists of preferable packaging options.

One such tool is streamlined LCA, which is a simplified version of a full ISO compliant LCA. According to Lee et al., “industry is looking for a definitive, simple, relatively inexpensive and timely approach” when making decisions about packaging management (2005). In Lee et al.’s opinion, streamlined LCA (SLCA) can be used to most efficiently evaluate the environmental impacts of products (2005). The main advantage of SLCA is that it is flexible, easy to modify
and gives one number as the result (Lee et al., 2005). As such, SLCA is a great tool for management to use when comparing the environmental impacts of two or more products (Lee et al., 2005). However, there is no ISO or other accepted standards for SLCA, so methodology may vary from one study to the next leading to inconsistent findings.

Georgia-Pacific has established a “comprehensive cost-savings assessment program” to effectively pull together both economic and sustainability goals of the client company (Georgia Pacific, 2007). In this way, the tool is designed to link sustainability with business considerations. The Packaging Systems Optimization (PSO) tool now shows both attainment of sustainability goals and cost savings “gained by designing, distributing, and selling packages that meet sustainability objectives” (Georgia Pacific, 2007). I STILL DON’T UNDERSTAND HOW THIS TOOL FUNCTIONS.

EcoPackager, formerly made by Pre Consultants, was a streamlined LCA tool used to quickly compare the environmental impacts of different packaging systems (Royce et al., 2002). The goal of the software was quick results at a low cost, not an in-depth study. This software has since been replaced with more up-to-date programs, and Pre now offers several different LCA software packages. These include SimaPro, a full-scale LCA tool, and SimaPro Wizard, which allows untrained users to quickly build their own LCA. Not designed specifically for packaging, SimaPro Wizard nonetheless enables individuals not familiar with Life Cycle Assessment to “model and analyze products through a predefined question and answer tree” (Pré Consultants). The software prompts users at each step, offering choices of options. Though no background training is necessary to use the software, one employee in the company must understand the principles of LCA and be able to program wizards (Pré Consultants).

Wal-Mart Stores commenced a packaging scorecard to reduce packaging across its global supply chain, helping Wal-Mart and its suppliers improve packaging and conserve resources (Wal-Mart, 2006). The packaging scorecard is not LCA based, but is more a checklist. The scorecard is a measurement tool that allows suppliers to input information and measure their performance against other suppliers, based on specific metrics. The metrics in the scorecard evolved from a list of favorable attributes, known as the “7 R’s of Packaging”: Remove, Reduce, Reuse, Recycle, Renew, Revenue, and Read (Wal-Mart, 2006).

Developed by the Packaging Sustainable Value Network, a group of 200 leaders in the global packaging industry including suppliers, experts, and internal and external stakeholders (Wal-Mart, 2006), the following metrics are outlined for the packaging scorecard (the percent is the fraction of the total score assigned to each attribute):

- 15% will be based on greenhouse gas/CO2 per ton of production
- 15% on material value
- 15% on product/package ratio
- 15% on cube utilization
- 10% on transportation
- 10% on recycled content
- 10% on recovery value
- 5% on renewable energy
• 5% on innovation

Suppliers receive an overall score relative to other suppliers, as well as relative scores in each category (Wal-Mart, 2006).

On February 1 2007, Wal-Mart shared the packaging scorecard with its global supply chain of more than 60,000 suppliers. During a one year trial period, suppliers will be able to input, store and track data, learning and sharing their results. Beginning Feb. 1, 2008, Wal-Mart will begin to measure, rate and reward these suppliers against the scorecard (Wal-Mart, 2006).

C. Life Cycle Assessment as a Packaging Design Decision Support Tool
LCA may be used for public benefit to inform policy formation, or for private use to support decisions, improve company credibility and marketing, and to influence suppliers. As an assessment tool for determining the “environmentally best option to satisfy the essential packaging functions for the product in question,” LCA has strengths and weaknesses (Huang 2004; Royce 2002). On the positive side, the quantitative nature of LCA combined with the stringent methodological standards set by ISO standards makes LCA a reliable and transparent tool (Huang, 2004). These elements are requirements for being able to perform a critical review of any LCA study. In addition, LCA can be broadened to include financial elements such as cost and cost-benefit analysis. Both Australia and the European Union have used LCA in this capacity, to inform the development of packaging waste legislation (Royce, 2002).

The difficulties inherent in using LCA include: methodological gaps, software and database assumptions, drawing boundaries, availability of data, quality of data, and the potential to manipulate assumptions and boundaries to create a desired result (Royce, 2002; Miettinen et al., 1997; Sonneveld, 2000; Owens, 1997; Zabaniotou, 2003). Sonneveld also asserts that “LCA…reflects a specific moment in time” (2000). As technologies change and processes adapt, LCA results may no longer be accurate. The fact that LCA is an entirely quantitative tool is one of its primary limitations, because it lacks the capacity to analyze qualitative components such as human perceptions of environmental impacts (Huang et. al, 2004).

Some research has been conducted to address this dichotomy between qualitative and quantitative analysis, and how it influences LCA results. Huang and Ma (2004) explore the integration of quantitative and qualitative assessments, based on the idea that the two approaches do not always lead to similar results. Quantitative analyses may leave out important normative influences, such as the feelings and motivations of decision makers. Quantitative assessments may include LCAs, cost benefit analysis, material flow analysis, while qualitative assessments may include interviews, observations, case studies, and subjective reports. The researchers use cluster analysis to create a framework combining quantitative (LCA) and qualitative (analytic hierarchy process—AHP) analysis for environmental assessments. Using soft drink packaging materials as a test case to evaluate the framework process, the researchers conclude that LCA and AHP do not yield consistently similar results. Given this discrepancy, and to ensure that considerations that are not easily quantified (such as???) are included, both qualitative and quantitative information should be taken into account when evaluating environmental impacts (Huang et al., 2004).
The question of ‘weighting’ is also important to consider when considering LCA as a packaging design decision support tool. It is often difficult to interpret LCA results with the purpose of informing decision-makers. Miettinen et al point out that “the most environmentally friendly product is obvious only when all the eco-balances have exactly the same [impact categories] and one of the products is best in all of them…This is rarely the case” (1997). Therefore, as a decision analysis tool, LCA must acknowledge subjective issues early on, and can also benefit from valuation (“weighting”) which incorporates specific concerns of decision-makers. Unlike standard LCA indices, weighting wraps multiple categories, such as resource depletion, human health impacts and ecological impacts, into one “score” for each alternative. The relative weighting of these categories depends on: “(1) how serious the problem is generally perceived to be, and (2) how much the alternatives in the particular study differ in this attribute” (Miettinen et al., 1997). On the other hand, weighting automatically adds a level of subjectivity to the study, and moves the analysis away from purely quantitative results.

Despite these concerns, there do exist numerous case studies where LCA has successfully led to informed packaging decisions. Zabaniotou and Kassidi (2003) chose Life Cycle Assessment as a tool to compare the environmental effects of egg packaging. The study emphasized the benefits that proper packaging design can induce, including significant energy savings, reduction in raw materials, reduction in solid waste generation and other decreased environmental impacts. This is particularly true given the massive volume of packaging produced and consumed in the U.S. and elsewhere every year. Their LCA compares egg packaging made from polystyrene to packaging made with recycled paper and found that, although each form of packaging was superior in some impact categories, the overall environmental impacts of polystyrene in this case were worse than those of recycled paper. The study also brings attention to the influence of factors such as importing packaging, recycling, and the underlying function that the packaging is meant to perform (Zabaniotou, 2003).

A study by Ross and Evans (2003) found that recycle and reuse strategies for plastic based packaging products yielded significant environmental benefits. The researchers used LCA to compare two forms of refrigerator packaging: original packaging using virgin materials of expanded polystyrene (EPS) and a polyethylene (PE) bag, versus a new packaging system using recyclable/reusable EPS and PE materials with a high-impact polystyrene (HIPS) coating. In addition to recycle/reuse impacts, the HIPS coating also made overall packaging more durable, allowing a 20% decrease in the weight of the other packaging components. The LCA concluded that the environmental impacts of the new system were less for all impact categories because of its lighter weight and component recycling and reuse. In particular, the energy required for production of virgin material was much higher than the energy required to recycle. Interestingly, however, the environmental impacts attributed to transportation energy were negligible, when evaluated against overall energy consumption of the system (Ross, 2003).

V. OBJECTIVES

This project ultimately aims to create a decision support tool to be used internally by TMS design engineers specializing in the packaging and distribution of post production options (accessories installed at TMS-owned vehicle distribution centers). As intermediate steps, we will
also perform thorough, comparative life cycle assessments on several specific changes implemented by TMS. These will serve the dual purpose of providing valuable information to TMS, and providing a means of verifying the accuracy of the final decision support calculator.

A. Formal LCA
A formal LCA will be conducted to assess the environmental and cost impacts of three recent package system modifications. The first will focus on a re-design of the packaging used to ship vehicle spoilers. The old packaging consisted of cardboard, foam, and rubber. The new package consists of only cardboard and cohesive kraft paper. Given the smaller dimensions and higher potential recyclability of the new package, it is presumed that this package leads to less environmental impacts. Our comparative LCA will test this hypothesis and quantify any improvements.

We will conduct additional comparative LCAs focusing on distribution network changes (shipping floor mats directly to vehicle distribution centers by circumventing parts centers and parts distribution centers) and use of returnable containers.

B. Decision Support Tool
Because formal LCAs require software expertise, are time consuming and are information intensive, it is unrealistic to expect TMS design engineers to conduct LCAs as part of the decision process. The calculator that this group creates will attempt to capture greater than 90% of the results and accuracy of a formal LCA with less than 5% of the required time and information to be provided by the design engineers. As such, it will serve as a true on-the-fly decision support tool that can be used early in the design process to inform packaging design decisions.

Finally, for the calculator to gain widespread implementation it must not only require a minimum time commitment, but also must require no specific environmental expertise while being simple to operate. We will therefore develop a graphic user interface such as Excel Visual Basic for Applications or GaBi I-report. Although the interface must be simple and efficient, it must also provide engineers the ability to modify the calculator in the future to incorporate emerging technologies, distribution changes, and materials.

We will further promote implementation by developing training and documentation materials to accompany the calculator. Like the calculator itself, these materials will be streamlined, but complete, and will be comprised of a user manual and one-day on-site tutorial.

VI. SIGNIFICANCE

The formal LCA process will provide important information regarding the environmental and cost advantages of the spoiler packaging. It will allow package designers to promote their work to managers, and more importantly, will provide valuable lessons on how environmental impacts can be further minimized.
Using the calculator, TMS will be capable of assessing the environmental impacts of packaging design on demand; this capability can fundamentally change the way TMS packaging engineers approach design decisions. TMS will become more nimble in its design process, and more efficient and less resource consumptive with respect to packaging materials and distribution processes. These improvements will decrease the environmental impact of parts packaging and distribution.

In particular, the following issues may be affected:

- Impacts from packaging materials (raw material extraction, refinement/manufacturing impacts, material cost/assembly cost, etc.)
- Effects of product transport (shipping cost, fuel consumption, GHG emissions, air pollution emissions, return transport of returnable containers/use of back-hauls, compatibility with returnable containers)
- Efficiency of inventory space use at distribution centers (utility usage, warehouse expansion needs, etc.)
- Waste Management Impacts (recycling, incineration, landfill)

The project should illustrate the linkages between packaging decisions, environmental impacts, and financial consequences. There is also the potential to provide a model to others in the industry who would like to make similar improvements. The long term benefits of this project have the potential to raise standards in the automotive industry for informed environmental and business decisions.

VII. APPROACH

The work of creating a functional calculator for the Toyota packaging engineers will require a thorough understanding of the materials, processes, limitations, and possibilities of the distribution system. Targeted LCAs will be used as case studies to explore the system, gather necessary data, and familiarize the team with TMS operations. Finally, these LCAs will provide a means of verifying the accuracy of the final calculator.

We will conduct LCAs to assess and compare environmental impacts of three recently updated packaging systems at TMS. (See Objectives) We will use GaBi4 software to execute LCA and Life Cycle Costing (LCC) of the systems, and to create a model of the current TMS packaging process.

A. Life Cycle Assessments:
We will perform our LCA based upon the standards in the International Organization for Standardization (ISO), sections 14040 & 14044. Our analysis will be performed based on the four phases included in the ISO 14040 framework exhibited in Figure 1:
1) Goal and Scope Definition Phase
During this phase we will explicitly state and justify the overall aim or objective of the studies. The goal for the LCA/LCC for all three systems is to compare environmental and cost impacts of old vs. new packaging systems. The intended use of the data is to provide our audience (TMS environmental managers and packaging engineers) with information to make environmentally informed packaging decisions. Comparative assertions will not be disclosed to the public.

While determining the scope for each LCA we will establish the function of the system, functional units, and system boundaries. This includes the temporal, spatial, and technological coverage of the systems being analyzed. The scope will be defined to facilitate direct comparison between before and after performance of the systems.

2) Life Cycle Inventory Analysis Phase
During this phase, the team will collect all necessary data. This will involve searching for quantitative data on material and energy inputs, as well as waste and emissions outputs, within system boundaries. All data will come from TMS environmental and packaging managers under a non-disclosure agreement. To embrace Toyota’s *Genchi Genbutsu* methodology, we will begin by touring salient facilities. Such facilities will include the TMS Corporate headquarters, TMS Environmental Coordination Office, product suppliers (Asahi glass), TMS Parts Distribution Center, and Toyota’s Long Beach Vehicle Distribution Center. The team will meet with packaging and distribution associates to understand the system, materials, and processes. Specific data collected on those tours and through future communication will include, but not be limited to:

- materials inventory
We will enter pertinent information into GaBi4 to create inventories for each analyzed system, as well as determined an appropriate allocation method.

3) Life Cycle Impact Assessment Phase
During the Life Cycle Impact Assessment (LCIA) phase we will use the assembled data to evaluate the magnitude and significance of the environmental impacts imposed by TMS systems. LCIA is a process by which flows to and from the environment are classified and characterized according to their relative contribution to various environmental problems. As such, it provides a means of comparing the impact of separate systems according to a common metric. Generally, the impact categories relate to the specific issues with which the client is concerned. Our client has specified that the areas they are most concerned with are greenhouse gases, air pollution and toxicity—particularly substances of concern such as lead, mercury, hexavalent chrome, and cadmium.

To capture these concerns, and because they are the most accepted standards in the scientific community, we will use the CML2001 standards to compare environmental impacts of different implementations. The CML2001 standards we will use include, but are not limited to:

1. Acidification potential (AP) [kg SO2-Equiv.]
2. Abiotic resource depletion (ADP) [kg Sb-Equiv.]
3. Ecosystem toxicity WE NEED TO PUT IN THE EXACT NAMES (3 OF THEM)
4. Global warming potential (GWP 100 years) [kg CO2-Equiv.]
5. Human toxicity potential (HTP inf.) [kg DCB-Equiv.]
6. Ozone layer depletion potential (ODP, steady state) [kg R11-Equiv.]
7. Photochemical ozone creation potential (POCP) [kg Ethene-Equiv.]

It is likely that more indicators will be evaluated, but the precise indicators will emerge in response to TMS primary concerns. In order to understand the magnitude of differences between two systems, it may be necessary to normalize our data relative to some reference information (ISO 14044).

4) Interpretation Phase
During this phase we will test the LCIA evaluation for completeness, sensitivity, and consistency. We will then draw conclusions, address limitations and make recommendations to TMS. To be in accordance with ISO 14044 standards, the following will be specifically addressed (ISO 14044):

- the results
- assumptions and limitations associated with the interpretation of results, both methodology and data related
- data quality assessment
• full transparency in terms of value choices, rationales and expert judgments

The faculty group advisor and advisory panel will also conduct a critical review during this phase.

B. Life Cycle Costing
The GaBi4 software package includes a feature to perform an analysis of the total costs to Toyota for the three systems. We will calculate total costs of each process, which will include costs from all phases of the packaging lifecycle, including natural resource extraction, manufacturing, use, and end of life. This will require unit costing at each stage that will be done concurrently with LCA.

C. Packaging Calculator
The ultimate and enduring product of this project is the creation of a computer interface tool (‘calculator’). We will extract pertinent information from the GaBi model into an Excel Visual Basic for Applications, GaBi I-report, or other interface. The calculator will be a parameter-based tool which allows packaging engineers to analyze the environmental impacts of various packaging options. Parameters that designers will be able to manipulate will include, but not be limited to: product material, dimensions/weight, transportation mode and route, potential for reuse/recycling. After entering the desired parameters the calculator will give the engineer the results of the impact categories and overall unit cost.

The calculator will be pre-programmed with a comprehensive list of potential parameter choices, encompassing both standard and emerging materials and processes. These will be researched in the industry literature and through communication and information-sharing with Toyota designers in the United States, and potentially in Japan and Europe.

The accuracy of the decision support tool will be verified by answering the same three questions targeted by the formal LCAs:

• What have been the greenhouse gas, resource extraction, and other improvements associated with TMS’ recent re-design of spoiler packaging?
• What is the reduction in greenhouse gas emissions from a supplier shipping parts directly to a Vehicle Distribution Center instead of through the part distribution network?
• What have been the environmental benefits or costs of TMS’ increased use of returnable shipping modules?

An important feature of the calculator will be its transparency. As new materials or systems emerge, users will be able to update the underlying data sets to incorporate these changes into the calculator. The team will create a user manual to accompany the calculator, which will provide guidance on both the use and update of the software.

VIII. MANAGEMENT PLAN

A. Group Structure and Responsibilities
Each group member has been assigned specific jobs, and it is each member’s responsibility to carry out the tasks associated with those jobs. The role of project manager will be shared by all members, who will take a leadership role and contribute their expertise when applicable. The administrative responsibilities are as follows:

**Coordination Manager (Michelle Corti):**
- Point of contact for faculty advisors, external advisors, and clients
- Ensure that the group is meeting all deadlines
- Arrange and schedule meetings
- Record minutes at weekly meetings

**Data Manager (Tim Kidman):**
- Maintain and manage project’s electronic folders
- Maintain and manage project’s mailing list
- Install specialized software required on the project’s designated computer

**Financial Manager (Claire Early):**
- Manage purchasing and expenditures
- Keep track of all transactions and the team account balance
- Prepare agendas for weekly group meetings

**Web Manager (William Lee):**
- Develop, maintain and manage web site
- Maintain hard copy files related to the project
- Maintain updated project tasks and deadline file

**B. Weekly meetings**
The project team will meet twice a week on a regular basis. One meeting will last for one hour with all student members present, as well as the faculty advisor, Roland Geyer. The other meeting will be a group work session to discuss progress and to collaborate without the faculty advisor. Meetings will be scheduled via Corporate Time by Michelle Corti. Group members are expected to keep their Corporate Time up to date to facilitate scheduling. Claire Early will email the agenda to all group members the day before the meeting, so they may add agenda items. Michelle will draft minutes and post a digital summary of the meeting in the “Minutes” file of the GP folder.

**C. Data Management**
In order to maintain all electronic data and information, the group has created an electronic folder that contains all project information. This folder is divided into subfolders which include the research itself, administrative issues, and information pertaining to the client. The last of these subfolders will be accessible only by the group members in order to preserve the confidentiality of the information.

**D. Web Site Management**
The group will construct a web site for the project. It will be maintained by the website
manager and will contain information about the project proposal, goals, team members and advisors, background, links to information resources, and any other information approved by the client representative. The site will be developed and begin operating June 1, 2007. The web site address will be: http://www.bren.ucsb.edu/~toyota.

E. Systems to Ensure Deadlines Are Met
The Coordination Manager is charged with keeping track of deadlines and group milestones and communicating important dates to the group via e-mail. At each weekly meeting, progress updates from each project member will be given and upcoming deadlines will be announced and tasks will be assigned. It is vital that the tasks and due dates be clearly defined.

F. Conflict Resolution
To help avoid conflict, responsibilities will be equally distributed among group members. If a certain responsibility becomes too burdensome, other group members will come forward to take on more responsibility. Communication about conflict is encouraged, and any problems are expected to be discussed privately. Both praise and constructive criticism are welcome for all members through the duration of the project. The group should be able to resolve most issues internally; however, if the conflict cannot be settled among group members, we will turn to our advisor as a mediator. As this project is a learning experience for all involved, egos should be set aside, and an atmosphere of respect, trust and openness should be maintained.

IX. DELIVERABLES

- An analysis of the three questions raised in the Objectives section in the form of A3 documents, summarizing the project findings most relevant to TMS managers.
- A “calculator” that packaging engineers will use to compare different packaging designs and options, quantitatively showing both environmental and economic impacts of those options.
- A report on the calculator’s development providing transparency that will allow for future changes or improvements.
- Documentation and a training program on the use of the calculator.

X. MILESTONES

Spring 2007
- Literature review
- Write project proposal
- Gather necessary data from TMS
- Conduct one (or more) comparative LCAs
- Create website
- Appoint External Review Committee and Advisory Board

Fall 2007
- Conduct LCAs on transportation route and shipping module changes
• Create packaging design calculator
• Write draft of final report
• Write calculator documentation

Winter 2008
• Defend project
• Submit draft of final report to faculty advisor
• Submit information for group project presentation program
• Submit final report, project brief, and project poster
• Present final report to the public

Below is a general timeline for the project. A project management file will be developed to ensure all tasks are completed in a timely manner.

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<thead>
<tr>
<th>Task</th>
<th>Apr</th>
<th>May</th>
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**XI. BUDGET**

The Bren School provides a budget of $1,400 for group Toyota to complete the project. The budget is allotted in the following manner: $1,200 for the entire project span to cover any needs of the project, and $200 toward printing. The telephone will be used to communicate with our client, external professionals, and advisory members. The travel cost provides transportation reimbursement to visit facilities or conference attendance. The expense of presentation $300 is set aside for the printing of the final poster and other expenses associated with the final presentation. The category “miscellaneous” catches other unplanned expenses. The group evaluates the necessity and the financial manager executes the administration.

<table>
<thead>
<tr>
<th>Descriptions</th>
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<tr>
<td>Printing</td>
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<td>Food and entertainment</td>
<td>$300</td>
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</tbody>
</table>
### XII. STAKEHOLDERS

- Environmental Coordination Office: packaging; coordination, recycling
- North American Parts Operations (NAPO) Packaging: packaging design
- NAPO Logistics Operations: parts shipping
- NAPO NPO (North American Parts Center California, Los Angeles Parts Distribution Center): parts warehousing
- TLS LBO: vehicle logistics support
- TLS Vehicle Distribution Centers (Long Beach VDC): accessory installation, vehicle logistics

### XIII. CLIENT

Toyota Motor Sales  
Ryan McMullan  
Environmental Resource Specialist  
Environmental Coordination Office  
Toyota Motor Sales  
(310) 468-4883  
Ryan_McMullan@toyota.com

### XIV. REFERENCES

5. [http://www.epa.gov/msw/facts.htm](http://www.epa.gov/msw/facts.htm), 2007 May 9  

11. [http://www.deq.state.or.us/lq/pubs/docs/sw/packaging/LifeCycleInventory.pdf](http://www.deq.state.or.us/lq/pubs/docs/sw/packaging/LifeCycleInventory.pdf) 2007 May 15


21. McMullen, Ryan. 2007 Personal Correspondence


GLOSSARY

A3 document: the document format TMS uses to summarize and circulate information; an 11”x17” sheet of paper

Allocation: partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO 14044)

Category indicator: the amount of impact potential a process has with respect to a certain impact category (Geyer, ESM 282 1.24.07)

Characterization models: The chain of physical, chemical and biological events in the natural environment that link a particular elementary flow to a particular impact category is called an environmental process. For each impact category, the characterization model models all relevant environmental processes (to a greater or lesser extent). (Geyer, ESM 282 1.24.07)

Characterization factor: factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator (ISO 14044)

Consumer packaging: the final packaging that envelops a product at the point of sale

Cradle-to-grave: the life cycle phases from raw material extraction through end-of-life

Cradle-to-gate: the life cycle phases from raw material extraction through primary materials production

Critical review: process intended to ensure consistency between a life cycle assessment and the principles and the requirements of the International Standards on life cycle assessment (ISO 14044)

End-of-life: the life cycle phase following the use phase. Typical end of life options are reuse, recycling, land filling, or incineration

Environmental aspect: element of an organization’s activities, products or services that can interact with the environment (ISO 14044)

Environmental impact indicator: Category of environmental impact such as ‘Global Warming,’ ‘Eutrophication,’ or ‘Ozone Depletion’

Environmental impacts: Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services. (Service Canada, http://www1.servicecanada.gc.ca/en/cs/fas/as/sds/appd_sds03.shtml)

Functional unit: quantified performance of a product system for use as a reference unit (ISO 14044)

Genchi genbutsu: “(現地現物) means "Go and see for yourself" and it is an integral part of the Toyota Production System. It refers to the fact that any information about a process will be simplified and abstracted from its context when reported. This has often been one of the key
reasons why solutions designed away from the process seem inappropriate.”
(http://en.wikipedia.org/wiki/Genchi_Genbutsu)

**Goal:** The Goal of the LCA states and justifies (Geyer, ESM 282, 1.10.07)
- the aim or objective of the study
- the intended use of the results (application)
- the initiator (and commissioner) of the study
- the practitioner of the study
- the stakeholders of the study (interested parties)
- intended users of the study (target audience)
- mention if one objective is ‘comparative assertion disclosed to the public’

**Impact category:** class representing environmental issues of concern to which life cycle inventory analysis results may be assigned (ISO 14044)

**Impact category indicator:** quantifiable representation of an impact category (ISO 14044)

**Input:** product, material or energy flow that enters a unit process (ISO 14044)


**Kaizen:** (改善)“Japanese for ‘change for the better’ or ‘improvement’; the English translation is ‘continuous improvement’ or ‘continual improvement…’” (http://en.wikipedia.org/wiki/Kaizen)

**Life Cycle:** consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (ISO 14044)

**Life Cycle Assessment (LCA):** compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14044)

**Life Cycle Costing:** “A life cycle cost analysis calculates the cost of a system or product over its entire life span.” (en.wikipedia.org/wiki/Life_cycle_costing)

**Life Cycle Inventory Analysis:** phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (ISO 14044)

**Life Cycle Inventory Analysis Result:** outcome of a life cycle inventory analysis that catalogue the flows crossing the system boundary and provides the starting point for life cycle impact assessment (ISO 14040)

**Life Cycle Impact Assessment:** phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO 14044)

**Life Cycle Interpretation:** phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations (ISO 14044)
Nemawashi: (根回し) “in Japanese company culture is an informal process of quietly laying the foundation for some proposed change or project, by talking to the people concerned, gathering support and feedback, and so forth. It is considered an important element in any major change, before any formal steps are taken, and successful nemawashi enables changes to be carried with the consent of all sides.” (en.wikipedia.org/wiki/Nemawashi)

Output: product, material or energy flow that leaves a unit process (ISO 14044)

Pre-consumer packaging: packaging used for transportation of an item, protection and other purposes, not including the final consumer packaging.

Primary packaging: “Packaging material that is in direct contact with the product. It is generally composed of glass, or rigid or flexible plastics, and must keep the product stable until the expiration date.”

http://www.intota.com/multisearch.asp?strSearchType=all&strQuery=primary+packaging

“Primary packaging is the material the first envelops the product and holds it. This usually is the smallest unit of distribution or use and is the package which is in direct contact with the contents” http://en.wikipedia.org/wiki/Packaging

Process: set of interrelated or interacting activities that transforms inputs into outputs (ISO 14040)

Process energy: energy input required for operating the process or equipment within a unit process, excluding energy inputs for production and delivery of the energy itself (ISO 14044)

Raw material: primary or secondary material that is used to produce a product (ISO 14044)

Reference flow: measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit (ISO 14044)

Scope: The Scope of an LCA study defines (Geyer-ESM 282, 2007):
- temporal coverage (specific or averaged data)
  - spatial coverage (specific or averaged data)
- technology coverage (specific or averaged data)
- coverage of economic processes (initial system boundaries)
- coverage of environmental interventions and impacts
- mode of analysis (Attributional versus Consequential LCA)
- level of sophistication

Secondary packaging: Material used primarily to give additional physical protection to the outside of a proximity package. E.g. cardboard boxes, padded bags, polythene wrap. (Electrostatic Solutions, Ltd., http://www.static-sol.com/ESD_Guide/technical/definitions.htm)

Sensitivity analysis: systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study (ISO 14044)

System: (product system) collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product
**System boundary**: set of criteria specifying which unit processes are part of a product system (ISO 14044)

**Transparency**: open, comprehensive and understandable presentation of information (ISO 14044)

**Waste**: substances or objects which the holder intends or is required to dispose of (ISO 14044)
APPENDIX B.

WEEKLY TIMELINE

Spring 2007

7th 5/14-5/20
1. Summary of literatures reviewed
2. editing proposal
3. begin building Gabi4
   a. request data from TMS specifically
   b. define function unit, reference unit, system boundary
   c. pre-draft flow
   d. install Gabi4 and check DB
4. Draft proposal to Roland
5. email external advisors
6. invite extra Bren professors (Magali Delmas)

8th 5/21-5/27
1. spoiler GaBi all relevant data built
2. confirm extra advisors

9th 5/28-6/3
1. spoiler GaBi all relevant data built
2. spoiler GaBi4 analysis
3. Website done
4. email proposal to external advisors

10th 6/4-6/10
1. spoiler GaBi4 analysis done
2. Proposal review meeting
3. proposal signed by Roland
4. Turn in final proposal to Bren

Summer
Data gathering: transportation routes and shipping modules LCA

Fall 2007

1st 9/27-9/30
1. Spoiler LCA write up
2. Conduct transportation routes and shipping modules LCA
3. Data gathering for transportation routes, shipping modules, and floor mat LCA
2\textsuperscript{nd} 10/1-10/7
1. Final spoiler LCA due
2. Conduct transportation routes, shipping modules, and floor mat LCA
3. Build Gabi models for both
4. Meet with packaging engineers to discuss calculator format and metrics

3\textsuperscript{rd} 10/8-10/14
1. Transportation routes and shipping modules, and floor mat LCA write up

4\textsuperscript{th} 10/15-10/21
1. Transportation routes and shipping modules, and floor mat LCA due
2. Build the calculator
3. Begin draft progress report
4. Progress meeting scheduling

5\textsuperscript{th} 10/22-10/28
1. Build the calculator
2. Progress report

6\textsuperscript{th} 10/29-11/4
1. Build the calculator
2. Progress report
3. Meet with packaging engineers to get feedback about calculator

7\textsuperscript{th} 11/5-11/11
1. Build the calculator
2. **Progress meeting** with advisors and external advisors

8\textsuperscript{th} 11/12-11/18
1. Build the calculator
2. final report

9\textsuperscript{th} 11/19-11/25
1. Final report
2. Final calculator review by packaging engineers

10\textsuperscript{th} 11/26-12/2
1. Calculator done
2. Submit progress report to Roland

Winter 2008

1\textsuperscript{st} 1/7-1/13
1. Final report
Informing Packaging Design Decisions at Toyota Motor Sales Using Life Cycle Assessment

2\textsuperscript{nd} 1/14-1/20
1. Final report

3\textsuperscript{rd} 1/21-1/27
1. Project defense presentation powerpoint

4\textsuperscript{th} 1/28-2/3
1. Project defense Presentation Practice

5\textsuperscript{th} 2/4-2/10
1. Project defense presentation
2. Draft of final report due to faculty advisors

6\textsuperscript{th} 2/11-2/17
1. Final report revision

7\textsuperscript{th} 2/18-2/24
1. Final report revision

8\textsuperscript{th} 2/25-3/2
1. Final report revision
2. Final Report Project Brief Preparation
3. Project Poster Preparation

9\textsuperscript{th} 3/3-3/9
1. Final report due
2. Projection Poster preparation
3. Final Report Project Brief due
4. Project preparation power point preparation

10\textsuperscript{th} 3/10-3/16
1. Final report signed by Roland
2. Final report submitted and archived to the Bren School
3. Projection preparation power point due
4. Projection preparation practice
5. Project Poster due

\textbf{Spring 2008}

Public presentation of Final Report
- Submit information for group project presentation program