The Development and Introduction of Emerging Environmental Design Tools to Multiple Automotive Supplier Design Centers in Order to Provide a Differentiating Capability

by

Ennis Rimawi

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Submitted to the Department of Civil and Environmental Engineering and the Sloan School of Management in partial fulfillment of the requirements for the Degrees of

Master of Science in Civil and Environmental Engineering and
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in conjunction with the
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Abstract

"It is our belief that environmental concerns will be so central to [consumers'] purchasing decisions as to represent a threshold factor when they purchase a new car. Just as today's car buyers will not purchase a low-quality car, tomorrow's buyers will not buy a vehicle that is environmentally unsound."[1]

Leading European companies such as Phillips and Volvo are currently incorporating the environment as a parameter in the development of new products. In addition to minimizing the risk of impending regulation at the national and regional level, they are anticipating increasing market demand for "green" products. This is a result of both increased consumer interest and a greater availability of information. Eco-labels, a product label granted upon a product meeting an environmental standard, have already been introduced in several European markets.

The successful use of environmental tools during the product development process is becoming more significant. The Life Cycle Assessment methodology can be applied to quantify the environmental impact of a product, and thus provide a basis for making decisions that can minimize the environmental impact of a product. The methodology can applied to automotive components using a commercial software package, some customized data, and customized tools. This technology must be introduced and

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[1] Ward's Auto World. February, 1994, Vol. 30 ; No. 2 ; Pg. 26.

accepted in the product development environment in multiple, distributed, international, centers for the design of electrical distribution systems. Due to the state of the technology, limited, but valuable conclusions can be made concerning the tradeoff between product designs and materials. Additionally, the field work provides feedback by users on interface improvements to maximize the probability and efficiency of tool use.

This research was primarily conducted with the United Technologies Research Center in Hartford, Connecticut. Further research and field work was conducted over three months in Europe at the United Technologies Research Center in Aachen Germany, and three United Technologies Automotive design centers - Germany, France, and Spain. Chapter 1 establishes the increasing significance of environmentally friendly product design in the automotive industry. Chapter 2 describes the development and use of LCA tools to quantify the environmental impact of a product design. Chapter 3 describes the mutual adaptation process for technology transfer and a plan for applying it to the multiple UTA design centers. Chapter 4 actually summarizes the field work at each UTA design center. Chapter 5 provides recommendations based upon the field work and research. This includes specific recommendations for UTA, and general recommendations concerning the introduction, application, and improvement of DFE tools.

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Author's Note

The following points will be made in the thesis:

- Due to the existing and impending regulatory and market demand environments environmentally friendly product design is becoming a key differentiating capability in the automotive industry.
- Life Cycle Analysis tools can be developed and used to assess the environmental impact of a product design.
- Successful introduction to and application of these tools in multiple design centers can be achieved through a process of mutual adaptation.
- A sustainable capability requires further development of environmental data and software interface improvement.

This thesis does not attempt to fully capture 2.5 months of field work and 4 months of research, nor does it attempt to provide a comprehensive review of LCA, DFE, and technology transfer. It does provide a basis for further development of LCA software, technology transfer processes, and useful application of an emerging technology.

UTRC and UTA are proficient and successful organizations. Nothing in this document is a negative reflection of either organization, but rather a very positive reflection of their courage and learning in an area that is new and uncharted for most of the corporate world. Additionally, references in the thesis to UTA are actually references to UTA Europe. Additionally, I thank both organizations for their openness and interest in furthering knowledge development.

Acknowledgments

This thesis has been made possible with the continued support and motivation of my supervisor at the United Technologies Research Center, Mark Jaworowski. Knowledge and teamwork from Michael Niemczyk was critical to the project. Gerry Golden and Andre Verbeken provided their influential support. Martin Piech's assistance during the summer was invaluable. And ofcourse, I am grateful to Pam Amidon and Petra Keuter for their cultural support. Also, UTA for their enthusiasm and hospitality.

Professors Ehrenfeld and Eppinger have provided effective guidance, and allowed me to maintain perspective. We have all learned from this experience. Bill Hanson, the epitome of a change leader, has been responsible for a lot of truly valuable learning while at LFM. The innovative Leaders for Manufacturing Program itself has been instrumental in providing resources and a means for learning, I thank them for their support. And as always, Isam and Fairouz Rimawi for their sacrifices, their faith, and their never ending concern for my development and success.

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"It is our belief that environmental concerns will be so central to [consumers'] purchasing decisions as to represent a threshold factor when they purchase a new car. Just as today's car buyers will not purchase a low-quality car, tomorrow's buyers will not buy a vehicle that is environmentally unsound."[2]

1.1 The Effect of Government Regulation on the Automotive Industry Results in a Reversal of the Pattern of Innovation

The reaction to US and European government environmental regulation in the automotive industry has resulted in a reverse pattern of innovation. As Allen et al. note, "Government regulations, by establishing new criteria for defining a successful product or process, force innovation to occur, often in areas that have been long neglected by market or technological forces."[3] The initial industry reaction to regulation has been to add process steps. This is natural since catalytic converters, stack scrubbers, incinerators are quick, low investment solutions. As regulation is being internalized and becoming more demanding, quick-fix process solutions are becoming less feasible. Actually, publicity on the environment by consumer advocates and companies that are "ahead" are making the environment an attribute in consumer decision making. Stricter regulation and consumer demand, combined with industry's need to find lower cost solutions are driving companies to innovate. This depicts a trend from process change to process innovation, to product change, and finally product innovation. Because regulation is driving the change, we have a pattern that is the reverse the natural pattern of innovation.

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[2] Ward's Auto World. February, 1994, Vol. 30 ; No. 2 ; Pg. 26.

[3] Allen, Utterback, Sirbu, Ashford, Hollomon, "Government Influence on the Process of Innovation in Europe and Japan," Research Policy, North Holland Publishing Company, Vol 7, No.2, April 1978. p. 149.

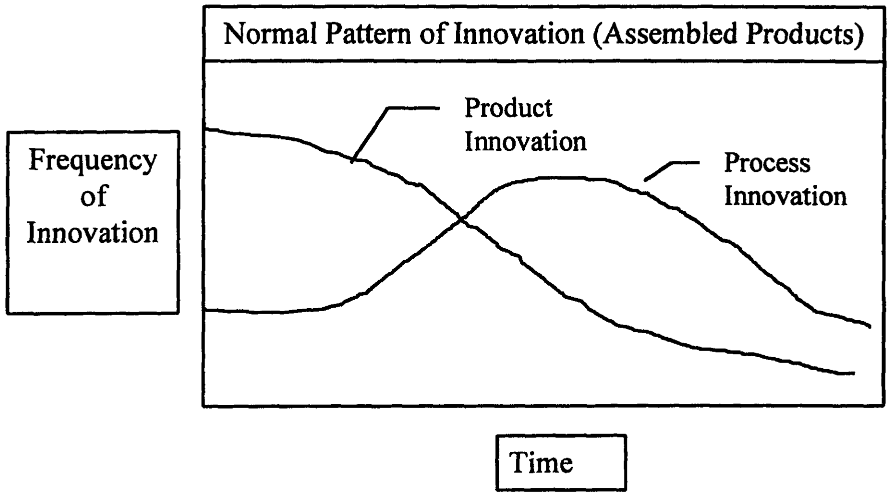

Figure 1: Normal Pattern of Innovation

The normal pattern of innovation for assembled products is depicted by a fluid stage, a transition phase, and a specific phase, with frequency of major innovation decreasing over time from stage to stage. Also in the early part of the transition phase, process innovation begins to occur in greater frequency than product innovation.[4] Regulation driven product and process specifications have resulted in a reversal of the normal trend in the automotive industry.

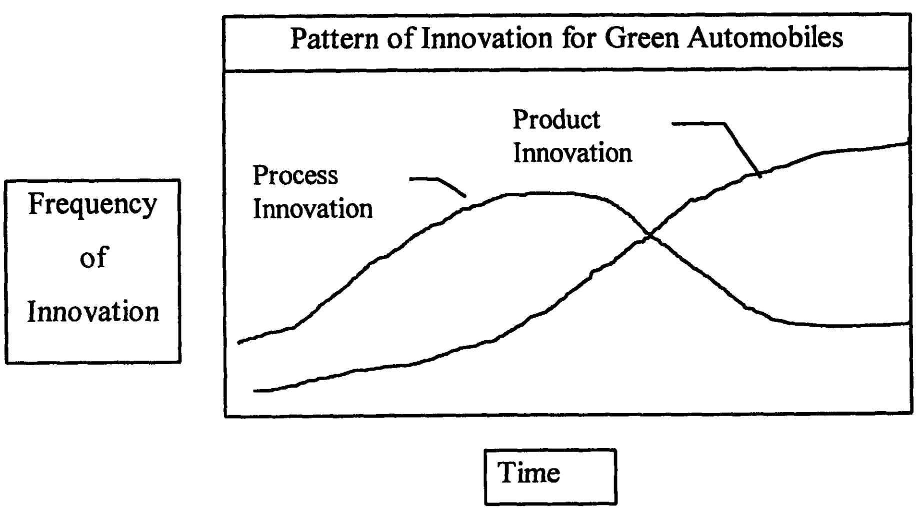

Figure 2: Pattern of Innovation for Green Automobiles

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[4] Utterback, James. Mastering the Dynamics of Innovation. (Boston: Harvard Business School Press, 1994), p. 130.

1.2 US and European Regulatory Environments

For many years, the question of automobile use has been inextricably intertwined with its environmental impacts.[5] In the US, a wide range of regulatory requirements link automotive performance and environmental impact. Fuel economy standards, which establish efficiency guidelines, and emission standards, which attempt to control air quality are premier among these regulatory regulations.

In Europe, additional regulatory emphasis has been placed on the impact of the automobile at the end of its service life. But regulation although with "good" intention, is not the most efficient driver for change. For instance in 1984, legislators in the Netherlands voted to impose a recycling fee on car owners so that disassembly would replace auto shredders. After 200 cars were dismantled it was discovered that shredding and dismantling result in the same amount of non-recyclable material, with dismantling costing more.[6]

As a reaction to inefficient regulation, the expectation of legislation is resulting in preemptive measures by automotive companies. Such preemptive measures would allow industry to attempt an efficient or "natural" solution with the hope of avoiding an impending inefficient solution imposed by government. [7]

1.3 United States and European Auto Recycling Strategies

US and European recycling strategies are different, but beginning to converge as regulation begins to converge, and a global market presence is becoming increasingly important.[8] The strategy of Japanese companies is not as visible as that of US and

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[5] Field, Clark, "Recycling of US Automobile Materials, A Conundrum for Advanced Materials," MIT, 3rd International ATA Conference, June 5-7, 1991.

[6] Marley, Michael. "Dutch shredders still needed for recycling; automobile shredders." American Metal Market, November 1, 1994, Vol. 102 ; No. 211

[7] Brooke, Lindsay ; Kobe, Gerry ; McElroy, John ; Sawyer, Christopher A. "Recycling: what's the problem?" Automotive Industries, September, 1992,Vol. 172 ; No. 9 ; Pg. 44.

[8] "Manufacturing for Reuse", Fortune, Feb. 6, 1995. p. 104.

European companies. Due to availability of information, only US and European companies have been documented. Documentation in Appendix A on Toyota's environmental plans indicates that they are pursuing a follower strategy.

1.3.1 Process Oriented Efforts

The Big Three are consolidating efforts to develop recycling technologies and strategies. Two umbrella organizations are coordinating much of the industry's cooperative research on recycling. The United States Council for Automotive Research (USCAR), formed by the Big Three automakers in June 1992, brings under one roof the various groups ("partnerships") they have set up to cooperate in solving generic technical problems involving materials, processes and environmental issues. One manifestation of such efforts is the Vehicle Recycling Partnership, a joint mechanism for facilitating innovation.[9] Part of this partnership is the Vehicle Recycling Center, where the alternative plastics, and the economics of recycling are being studied.

The Automotive Group of the SPI's American Plastics Council, the plastics industry's coordinating organization for automotive recycling research and information exchange, is entering its second year of existence with a doubled budget and substantial progress under its belt. The 41-member group is funding half a dozen major programs ranging from computer-modeling the automotive-scrap scenario in 2010 and dismantling cost studies on 57 cars to reviewing technical options for recovering and processing plastic scrap.[10]

Cooperative disassembly research programs among car companies, dismantlers and resin companies are widespread in Europe. However, BMW, VW and Ford have set up dismantling facilities of their own.[11]

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[9] Walkowicz, Don. "Vehicle recycling is a partnership; Vehicle Recycling Partnership formed to research ways of improving automobile recycling." Ward's Auto World. January, 1994
Vol. 30 ; No. 1 ; Pg. 11.

[10] "Ford and GE Research and Development announce they will join forces in 5 year, $10.8-million joint venture in composites." Business Wire. April 24, 1992.

[11] Ibid.

The governments are participating in the effort to drive innovation. For instance, the US Department of Commerce is supporting half the funding for five-year, $10.8-million joint venture program between Ford Motor Company and GE to demonstrate the ability to manufacture structural composite parts for automobiles. This is being done as part of the National Institute of Standards and Technology's "Advanced Technology Program." [12]

Although necessary, these process oriented efforts have limited impact on the cost of reducing environmental impact. As 70% of product cost is determined in the design stage, product oriented efforts will have the greatest influence on cost and environmental impact.

1.3.2 Product Oriented Efforts

The automotive OEMs and plastics suppliers are working together to resolve the recyclability issues of plastic components. The inherently low weight of plastics had traditionally led to proliferation of plastics in the automobile, but the complexity in material separation is driving plastic advocates to explore product design for solutions. Design teams must factor in recyclability when specifying plastics, plan parts for easier disassembly and material recovery, and use recycled plastics when feasible. Driven by the durables-recycling regulations in Europe and by the heat-up of the solid-waste issue here, US carmakers are ramping up their efforts to build "more environmentally responsible" vehicles. Their goal is to substantially reduce, if not eliminate the amount of plastics that goes to landfills from scrapped vehicle. To do this, they are developing design and material strategies that will make it easier to remove, identify and recover the plastics. [13]

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[12] Ibid.

[13] "Ford and GE Research and Development announce they will join forces in 5 year," $10.8-million joint venture in composites." Business Wire. April 24, 1992.

1.3.2.1 Standards

U.S. automakers along with their counterparts throughout the world have agreed on a system to identify the plastic used in all vehicle parts. A code identifying the type of plastic will be molded in or otherwise permanently applied to every part heavier than 3.5 ounces along with the long-standing practice of showing the part number. The coding system, based on the standard ISO abbreviations, is spelled out in the SAE J-1344 standard, which was recently modified to conform to the European practice of showing reinforcement and filler content also.[14] Also ISO 14000, the next level of global industrial certification has an environmental focus. Standards allow companies, governments, and consumers to speak in the same language. The next step is to have productive conversations.

1.3.2.2 Design Guidelines

Automakers have added recyclability as a basic consideration in all future component-design and material-selection decisions. To assist their engineers with this new requirement, the car companies have developed guidelines for general design practices and plastics selection. The Vehicle Recycling Partnership meanwhile is developing a set of guidelines to provide a uniform, industry-wide approach. Anticipating these trends, resin suppliers have been hard at work on concepts for designing assemblies to simplify their recycling. "In the past, designers have thought of parts consolidation mostly as a tool for cost reduction. Now, it's clear that integrated design also simplifies recycling because there are fewer materials in the assembly," says Greg Jones, leader, advanced design, manufacturing and assembly at GE Plastics' automotive application development center.

In addition, resin suppliers have come up with design concepts that reduce recycling costs by using compatible combinations of plastics in multimaterial assemblies. Instrument panels, bumper-fascia systems, door panels, seats, and interior trim have

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[14] Ibid.

received particular attention.[15] Such strategies will lead to an increased supply of recycled material. The equivalent situation for steel was resolved with the Electric Arc Furnace, a technological innovation that allowed significantly more recycled steel to reenter the market.[16] Plastic suppliers are beginning to find new ways to reintroduce recycled plastics into the market.

1.3.2.3 Recycled Content Plastics

Another area of progress is the availability of recycled-content plastics. Car designers are being encouraged to substitute recycled plastics for all-virgin grades, when feasible. "Feasible" means no compromise in component specifications and little or no extra cost compared to virgin grades.[17] Such trends bring us incremental steps closer to the "closed loop" materials paradigm, in which material extraction serves as a secondary supply of raw materials. The benefits of such a system are intuitive, but life cycle assessment tools quantify the impact of material extraction and other processes on the environment.

1.3.2.4 Life Cycle Assessment Tools

Methods of assessing environmental impact are being introduced into the design stage of product development. GM seems to be the leader among the Big three in utilizing such tools.[18] But, the nature of the environmental regulations in Europe have resulted in a more extensive use of such "accounting methods" by design centers in Europe.

For example, a cooperative Swedish industry effort has lead to the Extended Producer Responsibility System (EPS). This 'environmental accounting' system, incorporated into software, quantifies the environmental impact of design decisions in

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[15] Ibid.

[16] Field F., Ehrenfeld J., Roos D., Clark J., Automobile Recycling Policy: Findings and Recommendations (DRAFT), IMVP - MIT, Davos, Switzerland; Feb. 1994. p. 14.

[17] "Ford and GE Research and Development announce they will join forces in 5 year, $10.8-million joint venture in composites." Business Wire. April 24, 1992.

[18] Ibid.

terms of Environmental Load Units (ELU's). Thus a choice of a 30kg aluminum hood is expanded into environmental implications resulting from extraction of bauxite, to distribution, to processing, to recycling, to effects of weight in the usage stage of the car. These impacts range from effects on the ozone layer, to human discomfort from smog. Values are developed for each of these impacts, and the result is one number quantifying the environmental impact of making a 30 kg aluminum hood. Of course, certain assumptions must be made about source of energy, and the value of human life, but the Swedes have established a starting point for valuing intangibles.

Companies like Daimler Benz have also developed environmental impact software, but have not ventured into the "subjective" side. They stop at the point of accumulation of harmful chemicals resulting from extraction, processing, and disposal. These are depicted in kg of molecules such as CO. As a result one would have flexibility in ranking alternatives.

These environmental impact methodologies are important since they go beyond regulation avoidance, but allow for holistic environmental assessment for proactive, not reactive, product changes.

It is interesting to note that stricter auto recycling regulation in Europe gives European companies, especially Germany, an advantage in the US. For example, in the United States, only BMW of North America has a takeback plan for its models sold here.[19]

1.3.2.5 A Note on a European Companies' New Competitive Advantage

German and Swedish companies have been especially fervent in pursuing environmentally safe products. The combination of non-availability of resources, high levels of government participation, and environmentalist culture are driving design for the environment into the mainstream of company activities. "R&D teams from the Ruhr to

[19] American Metal Market, September 10, 1992, Vol. 100 ; No. 176 ; Pg. 2.

the Black Forest set their world class intelligence, human and artificial, to work on the problem."[20] Companies like BMW, Mercedes, and Volkswagen have set a target of over 90-percent recyclability for their new model cars.

> When recycling becomes obligatory throughout the Continent, as inevitably it will, German car companies can sit back in their recycled seats and watch the competition play catch-up. **For German car makers, becoming the leaders in auto recycling is a win-win situation**. Or maybe they've just cottoned onto what autophiliacs have known for years: **That old Beemer is just too valuable to throw away.**[21]

The French are also developing recycling initiatives. Peugeot/Citroen have initiated a joint program aimed at "zero waste."[22] Additionally, Austrian car dealers are ready to take back autos ready for scrap pile as part of a voluntary recycling agreement.[23] See Appendix A for Toyota's environmental strategy.

1.4 US Market Response to the Environment

In a recent automotive survey of US consumer preferences, fit-and-finish was the most important attribute of an automobile. This was not the case before the "Toyota - roll the marble along the uniform gap between body panels" commercial. This illustrates the ability of a company to actively affect market response to its capabilities. Most recently, Cadillac placed a two page ad in the New York Times touting the environmental friendliness of its new model. Dodge and Plymouth Neon and BMW are also running

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[20] Menagh, Melanie. "Achtung, baby: Germans perfect the recyclable car." Omni, October, 1992 Vol. 15 ; No. 1 ; Pg. 22.

[21] Ibid.

[22] Marley, Michael. "French car recycling starts early." American Metal Market, May 29, 1992, Vol. 100 ; No. 104 ; Pg. 9

[23] Marley, Michael. "Austria car dealers to take back autos ready for scrap pile; voluntary recycling agreement." American Metal Market, September 10, 1992, Vol. 100 ; No. 176 ; Pg. 2

environmental ads.[24] In an effort to maximize the benefit (or minimize loss) from environmental regulations, companies are using the "green" image as a product feature. This, and an increase in environmental consciousness is leading to a market pull for environmentally safe products. Such a market pull will supplement incentive for product innovation.

Unfortunately, some companies are taking advantage of the market's interest and the lack of available information to fool consumers into thinking that products are environmentally safe. .[25] But, although skeptical of "green scam," consumers are changing their behavior Some automobile experts predict that environmental considerations one day will rival benchmark selling points such as power, performance and price.[26] That day may be sooner than many expect.

Wards Auto World argues that indoctrination of children in school and through TV and movies will change their attitudes and buying habits permanently.[27] An A.D. Little report supports this:

> "It is our belief that environmental concerns will be so central to their purchasing decisions as to represent a threshold factor when they purchase a new car. "Just as today's car buyers will not purchase a low-quality car, tomorrow's buyers will not buy a vehicle that is environmentally unsound."[28]

By the year 2000, 7.7% of potential car buyers will have grown up with environmental messages in their childhood, representing about 15 million potential car buyers, based upon Bureau of the Census population estimates, A.D. Little says. By the year 2010, 26.7%, or 57 million, potential car buyers will come from the

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[24] Fussell, James A. "The New 'Green' Machines; Automakers Are Touting The High Recyclability Of New Cars. But Environmentalists Are Skeptical." The Orlando Sentinel, July 7, 1994 , Pg. F1.

[25] Ibid.

[26] Ibid.

[27] "Recycling air bags shapes up as next big challenge and automobile factory recycling." Ward's Auto World, February, 1994, Vol. 30 ; No. 2 ; Pg. 26.

[28] Ibid.

environmentally educated generation, says Maritz Marketing Research Inc. in Toledo, OH.[29]

As standardized forms of environmental assessment and labeling emerge, "green scam" will decrease. Currently the Blue Angel is being used in Germany to indicate environmentally safe products. This is impacting consumer decisions.[30]

1.5 An Environment for Change

Stricter environmental regulation, increasing cost of raw materials, and consumer demand for environmentally safe products are driving companies to become more innovative. Initial corporate reaction was with incremental improvement. Such improvements have decreased cost, but not suitably. Now, it is becoming more evident that innovations are necessary to meet demand. For instance, auto weight has been decreasing incrementally as a reaction to fuel efficiency regulation in the US.[31] This is done by substitution of lighter materials or thinner parts for existing steel parts, but not redesigning the car for lighter materials like plastics/composites or aluminum. Such changes are not a reflection of major innovation.

1.5.1 Process Innovation

Process innovations are developing at the system and sub-system levels. Recycling technologies have improved, examples include the aluminum body panel assembly process, electric arc furnaces, and lead-acid battery recycling. [32] But cost models and environmental impact models show that the auto use stage is more significant than the recycling or disposal stage. The cost model shows that assuming present recycling methods, the present value of the recycled car is $30 to $60, while the present cost of gasoline for auto usage is $15,000 to $19,000.[33] The following table provides

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[29] Ibid.

[30] Green Products by Design, Office of Technology Assessment, Congress of the United States, 1992, p.12.

[31] Field, F. and Clark, J., "Recycling of US Automobile Materials, A Conundrum for Advanced Materials," MIT, 3rd International ATA Conference, June 5-7, 1991.

impact information per life cycle stage.[34] The drivers for the dramatic difference in ELU's during the usage stage are weight and energy efficiency.

Environmental Load Unit Calculation for Mid-Size Automobile			
Material	*Disposal*	*Manufacturing*	*Usage*
Steel	39 ELU's	44 ELU's	4,112 ELU's
SMC+Alum	231 ELU's	62 ELU's	2,748 ELU's
SMC+Steel	225 ELU's	63 ELU's	3,429 ELU's
Aluminum	50 ELU's	44 ELU's	2,152 ELU's

Figure 3: ELU Calculation for an Automobile

This implies that, although recycling is important, the areas of greatest improvement are weight and alternative propulsion systems. Weight changes have resulted from incremental, material substitution and component optimization strategies (see Appendix B.) Propulsion system efficiencies have also been incremental.

1.5.2 Product Innovation

"...improvements to the conventional spark-ignition engine are following the law of diminishing returns: gains have become incremental and are costing more to attain. To reduce automotive pollution, we need to consider a radical change of propulsion system."[35]

Lovins and Lovins argue that if existing innovations in advanced materials, software, motors, power electronics, microelectronics, electricity storage devices, and manufacturing are integrated, a discontinuous jump (10 times) in fuel efficiency can be

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[32] Worden, Edward. "Cost vs. cleanliness in processing used batteries". Metal Technology Quarterly. American Metal Market. April 5, 1994, Vol. 102 ; No. 64 ; Pg. 11A.

[33] Based on Cost Model for MIT course TPP123 with Field and Clark. Assumes gas at $4/gallon, 10% cost of capital, 10 yr. car life, 12,000 miles per year. The ranges were based on various materials selected.

[34] This is based on a version of the Swedish EPS system presented in MIT course TPP123, Spring 1995.

[35] Wilson, G; "Turbine Cars," Technology Review, Feb/March 1995.

achieved.[36] The reaction of the steel industry supports the inevitable arrival of the hyper car. Similar to the reaction of the gas lamp industry to electric lamps[37], the steel industry has responded to plastics by improving the base material and coating steel sheets to give steel plastic-like anti corrosive, low weight characteristics.[38]

The market is taking over as the driver of fuel efficiency and weight improvements, and environmental friendliness. This is sensible as the economic advantages of efficiency and environmental safety are becoming apparent. "The forces behind this newfound environmentalism have more to do with return on capital than with return to nature."[39] As we head up the reverse pattern of innovation, it makes sense that the normal initiator of innovation, the market, becomes the final driver of product innovation for an initially regulation driven product and process pattern of innovation. It is a matter of time as the market drives innovation to change one of the largest entrenched institutions of the world, the automobile industry. Application of the Life Cycle Assessment methodology during product design can facilitate this product innovation.

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[36] Lovins, A. and Lovins, L.; "Reinventing the Wheels," The Atlantic Monthly, January 1995. p. 75

[37] Utterback, James. Mastering the Dynamics of Innovation., 1994.

[38] Field, F. and Clark, J., "Recycling of US Automobile Materials, A Conundrum for Advanced Materials," MIT, 3rd International ATA Conference, June 5-7, 1991. p 4

[39] "Manufacturing for Reuse", Fortune, Feb. 6, 1995. p. 104.

2. The Development and Use of LCA Tools to Assess the Environmental Impact of a Product

'Clean', 'green', and "environmentally correct" are abstract terms used with little discrimination to describe a product or process as environmentally friendly. This is generally done without a standard method of measurement. Traditionally, the above terms are used based upon a product's recyclability, recycled content, disassemblability, or non-toxicity. But the product's impact on the environment is much broader in scope than these terms imply. A product's life cycle extends from material extraction, manufacturing and distribution; to use; and finally through disposal.

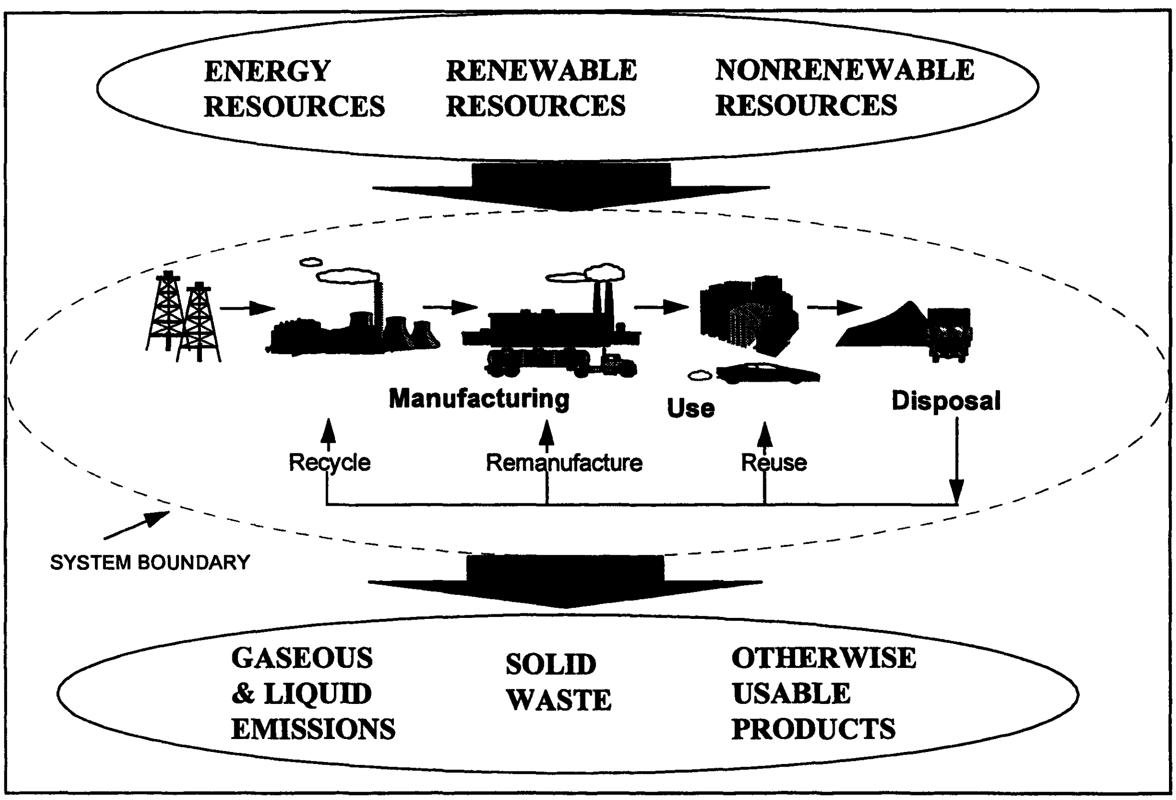

Figure 4: Product Life Cycle Diagram

Much recent emphasis has been on the disposal stage since it often creates a very visible and quantifiable impact. However, the disposal stage may not create the product's most significant environmental impact. A holistic, structured approach to life cycle assessment is necessary because impacts may take several years or even decades to become visible, and impacts may be indirect or affect others rather than ourselves. But our holistic understanding of environmental impacts is limited.

Environmental Tools

Several forms of tools assist in making DFE decisions. Tools range from informal design guidelines which provide advice, to structured methodologies which support decisions with analysis such as LCA. Following is an list of common design guidelines:

- label all plastic materials > 50g
- materials x, y, z can be used together
- design products in disassemblable modules
- do not use Cadmium
- minimize product weight

Design guidelines are easy to use and can be effective, but do not provide product specific advise and may suggest contradictory actions. Analytical tools require more time, but provide more accurate information. Life Cycle Assessment is the most widely used analytical tool for supporting DFE decisions.

2.1 Life Cycle Assessment

Life-Cycle Assessment is a method to evaluate the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth.[40] There are three steps in the methodology:

1. Inventory Analysis: Identification of energy and resource inputs, and emission and product outputs.

[40] LCA: Inventory Guidelines and Principles, US-EPA, Feb.1992, p.xi

2. Impact Analysis: Quantification of the consequences to the environment.
3. Improvement Analysis: Evaluation and implementation of opportunities to reduce environmental burdens.

The diagram below illustrates the steps used to quantify the environmental impact of a product.

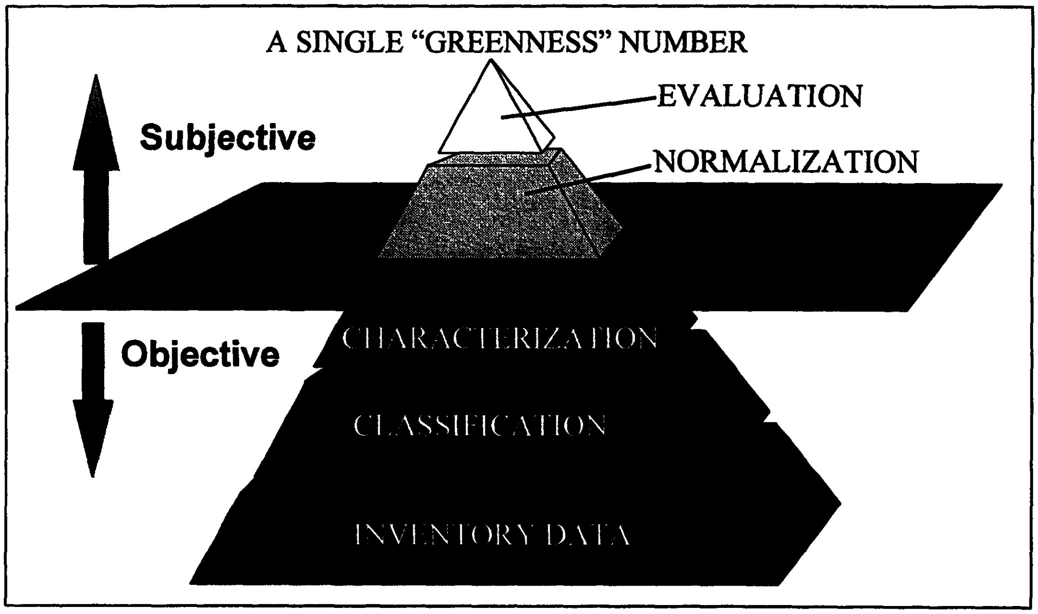

Figure 5: Stages of Quantifying Environmental Impact

Like the "explosion" of the Bill of Materials of a product, the first step in LCA involves the explosion of the resources used and emissions created during the entire life cycle. This lengthy list of substances and their quantities (i.e. tons of copper ore and kilograms of CO_2 per unit of the product) is the **inventory data**. Inventory data (inputs and outputs) are classified based upon the types of impact to the environment. A common set **classifications** is as follows:

- Eutrophication
- Ozone Depletion
- Ecotoxicity
- Greenhouse Effect
- Acidification
- Solid Waste
- Summer Smog
- Human Toxicity

Any one substance may have an effect on more than one classification category. So, the different substances are accumulated in the various classification categories.

The next step is **characterization**, in which each classification category is quantified in units of a single reference substance. For example, Greenhouse Effect is measured in equivalent kilograms of CO_2. Therefore a substance like methane, which contributes to the Greenhouse Effect, is given a CO_2 equivalent based upon its relative contribution to the Greenhouse Effect. Below is a table showing the reference material and a sample of equivalents for each classification category. This is based upon the Swiss CML Method.

Impact Classifications, Reference Materials, and Sample of Equivalents

Classification	**Reference Materials (units)**	**Sample Equivalents**
Eutrophication	Phosphate (kg)	*Air*: NO=0.02, *Water*: NH_3=0.33
Ozone Depletion	CFC-11 (kg)	*Air*: methylbromide=0.6
Ecotoxicity	Cobalt, Cromium (kg)	*Water*: Cd=200,Pb=2,Hg=500
Greenhouse Effect	CO_2 (kg)	*Air:* N_2O=27, methane=11
Acidification	SO_2 (kg)	*Air*: HCl=0.88, NO_2=0.7
Solid Waste	weight (kg)	*Solid*: all wastes=1
Summer Smog	ethylene (kg)	*Air*: methane=0.007
Human Toxicity	isopropanol, benzene, 1,2,dichloroethane (kg)	*Air*: CFC-113=0.022 *Water*: Cd=2.9, flourine=0.041

Figure 6: The emissions from the manufacturing, use, and disposal of the product are translated into effects for each impact category. The effects are aggregated in units of the reference material for each impact category.

At this point in the LCA, we have quantified the product's impacts in terms of standard reference materials. The above steps are fundamentally rooted in science. The next steps are more subjective

The next step is to **normalize** the data so that we understand the significance of each impact, for example 10 kg of CO_2 with regard to the Greenhouse Effect. This gives us a relative measure of a products impact upon an effect. For instance, with regards to the Greenhouse Effect, it may take 10 million kilograms of CO_2 to change the average temperature on Earth by 1 degree Celsius. The 10 kg emissions of CO_2 from the wire harness will provide $1x10^{-6}$ of the emissions necessary to produce the representative effect. We then assign weights to the impacts so that we can compare them to each other, and thus **evaluate** the entire product. We subjectively evaluate a 1 degree change in temperature compared to an effect on human health as described by the Human Toxicity Effect. These weights allow us to reach a single "**greenness**", or total impact, number. In addition to the subjective nature of these final steps, there is little consensus to date upon the proper weights or values. For this reason, some companies base decisions upon the characterization data, but not data that is further processed.

The ultimate value is the quantification of a products environmental impact. Thus a direction for improvement is established, based on science, but potentially influenced by subjective or specialized interpretations of the impacts. The illustration below depicts the iterative nature of applying such a design tool.

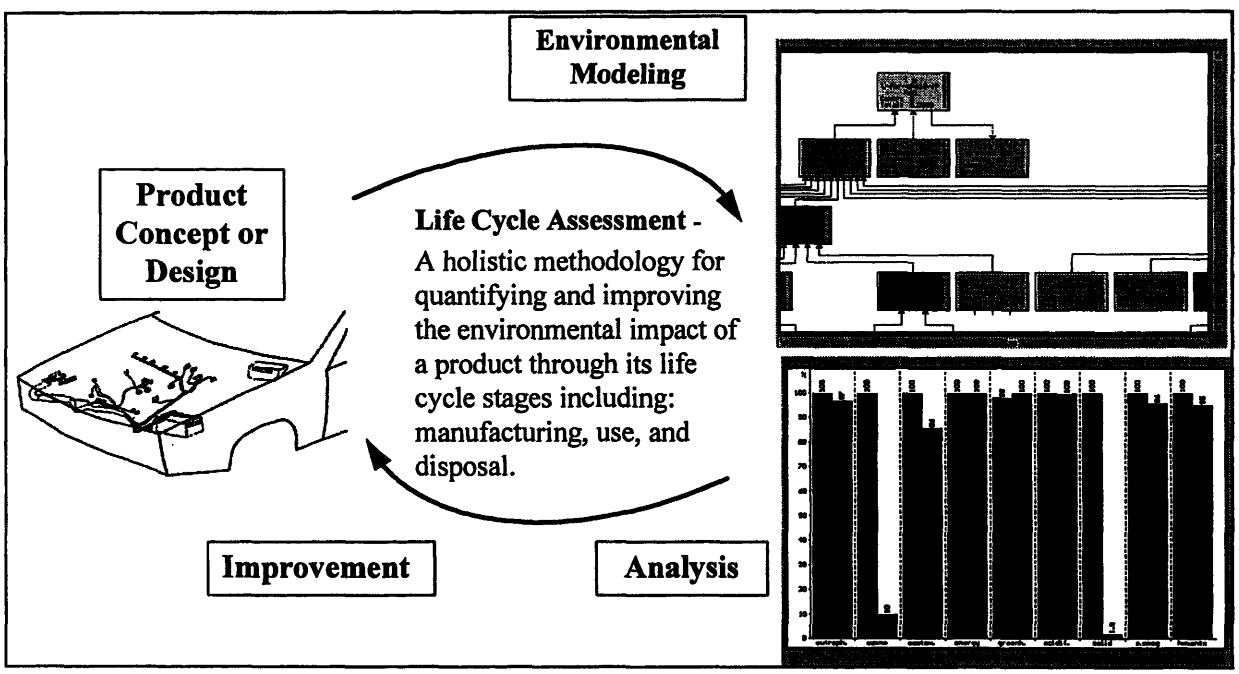

Figure 7: The Design Improvement Process

2.2 Status of Technology

Methodologies for the assessment of environmental impact are relatively new, and thus the technology is not fully developed. Assuming the use of an LCA methodology, the technology can be separated into two primary components environmental data and an interface for processing the data.

2.2.1 Environmental Data

The quality and availability of environmental data has been an impediment to the application of LCA. The quality of an LCA is only as good as the information upon which it is based, yet the application of data quality assessment procedures is by no means widespread, uniform, or rigorous.[41] Since data collection and presentation standards have not been established, comparisons from various sources for various materials are questionable unless data collection procedures and data quality are transparent.

Additionally, data is difficult to obtain. There are several sources of data. In a survey completed by Vigon and Jensen, six types of data were identified: aggregated/ company-specific, industry averages, technology/trade associations, peer-reviewed literature, book/statistical abstract, and on-line databases.[42] By far the most used data source is internal company data. This reflects the lack of published studies containing useful data. To support this, most if the respondents to the survey commented on the sparseness of data for some areas.

Below is a chart comparing data for the same material, PVC. This chart shows the translation of the PVC inventory data into environmental impacts. The results are relative to the higher impact for each effect, thus one bar is always at 100%. The lesson is that data for the same material can be very different per the source of the data. In this

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[41] Vigon, Jensen. "Life cycle assessment: data quality and databases practitioner survey," Journal of Cleaner Products, 1995, Vol. 3, No. 3, p. 135.

[42] Ibid., p. 138.

example, the left bar is PVC data from Buwal, and the right bar is PVC based on data from the European Plastics Society.

Comparison of PVC Data from Two Different Sources

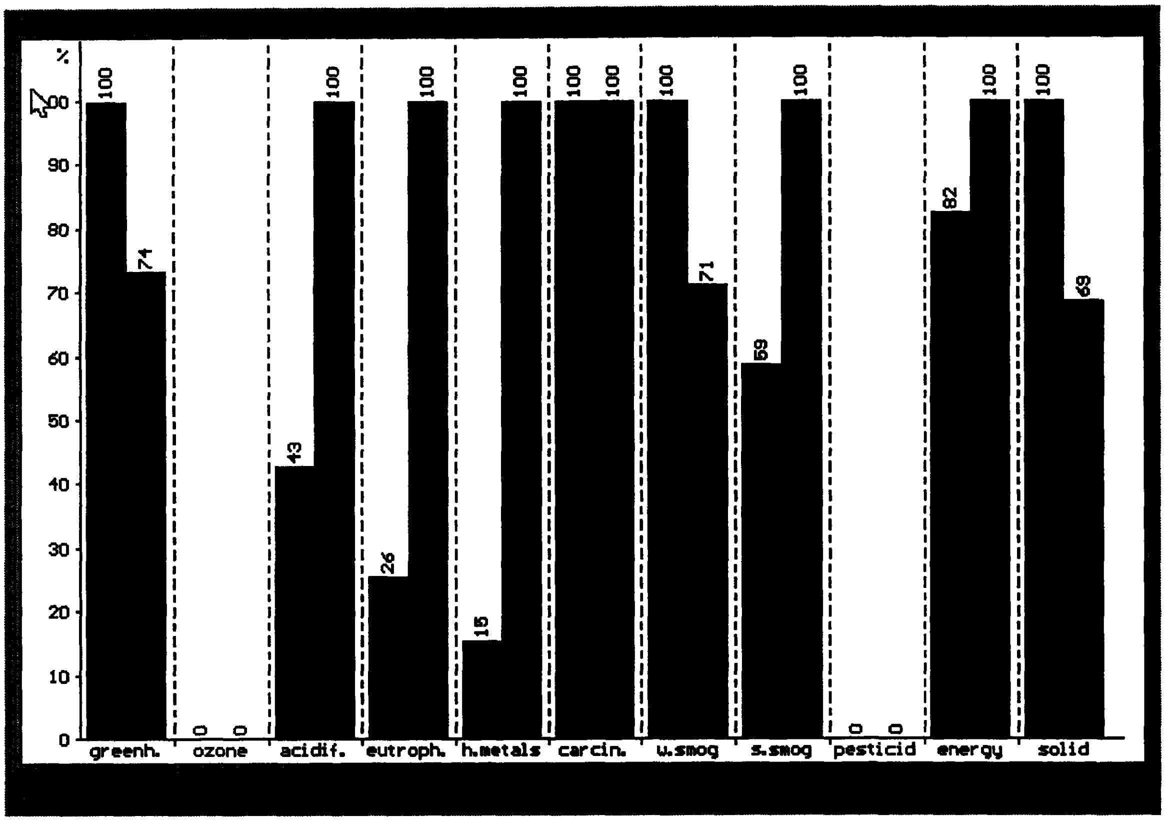

Figure 8: Comparison of PVC Data from Two Different Sources

Until data standards are developed, used, and enforced; data reliability will be an issue in comparing the environmental impact of products, processes, and materials. As a result, practitioners compensate by being cautious in drawing conclusions.[43] A measure of data reliability may help guide practitioners when comparing data, but a standard must developed for this measure as well. Additionally, product level error propagation analysis could provide information on the marginal benefit from additional detailed data

[43] Ibid., p. 135.

collection. Currently Jaworoski of UTRC and Wallace at MIT are conducting joint research in error propagation analysis.

2.2.2 Data Processing Interface

The ultimate objective of using LCA for improving product designs, is just that - using LCA's. The value of an LCA analysis is a function of its quality and its application for decision making. If the LCA quality is excellent, but it is not used by the designer, then no the value is negative because it becomes a wasted resource. Assuming that the data issues are resolved; designers under cost, time, and quality pressures require a "usable" tool. The term "usable" is defined differently by designers and current practitioners (usually environmental specialists). Designer's interest are centered around three primary themes:

1. searchability (flexibility)
2. compatibility
3. simplicity

These themes all imply speed. They will be addressed in detail based upon field work in Chapter 5.

2.3 SimaPro Software

In an evaluation of several software packages (commercial and proprietary), SimaPro was chosen as the most suitable for the field work. SimaPro, although not perfect, was designed with the designer in mind; additionally it is available in English. The software is produced by a Dutch environmental consulting company, PRé Consultants.

2.3.1 Data

LCA and DFE software packages contain environmental data modules. The number and quality of the modules vary. The data modules in SimaPro were primarily derived from publicly available data, mostly from European institutions.

2.3.2 Methods

Several methods for quantifying a products are available for use. As illustrated in section A, the Dutch EcoIndicator Method, and the Swiss EcoPoints Method are available in SimaPro 3.0.

2.3.3 Analysis

Analysis can take the form of numerical, bar charts, and tree diagrams. Additional forms of data representation must be conducted through other software tools.

2.4 Creating tools and customizing SimaPro for Automotive Components

Custom data and supporting tool development were necessary to apply SimaPro to automotive wire harness analysis. The closed architecture nature of SimaPro made this work extensive.

2.4.1 Data module development

Pre-field work data collection for the development of a fuel module and a copper module was necessary. The fuel module was derived from data in the Swiss ETS document. Data was found for both fuel production and fuel use emissions based upon a European average fuel mix. The copper module was developed with an extensive literature search.

A data translation flaw when converting a German data table into English revealed the need for a mass balance feature in the software. A simple mistake resulted in increase of an emission by a power of 10. A tree diagram analysis indicated that an error existed. To find the source of the error, 8 hours were spent conducting a mass balance. A mass balance is simply the comparison of the mass of the inputs versus the mass of the output for a specific data module. The greater the complexity and detail of the data module, the more extensive the mass balance. Due to the nature of the technology, only strong imbalances are worthy of investigation. Daimler Benz's rule of thumb is plus or minus 15%. In the case with the fuel module, a 46% discrepancy existed. This was traced back to the source, in this case with water input to the process was not balanced with the water output. Water was one of over 200 substances, but was detectable due to the magnitude of water use. An automatic mass balance feature would have been valuable as an automatic data module checking feature. But, if the imbalance was due to a mistake in the entry of the mercury data by a power of 10, it may not have been noticeable since the amount of mercury in a process is usually negligible with regards to the mass of the entire module.

2.4.2 Support Tool Development

To model an electrical distribution system using an LCA software package, once has to provide information concerning the material makeup, the use, and the end of life of a product. The inputs to the passive LCA software packages of today necessitate the entry of three forms of data: material type, material mass, and process. If one assumes that the environmental data for all materials and processes is present, modeling is reduced to quantifying material mass. In the manufacturing stage, this implies knowing or estimating the individual material mass of a complex system. For the use stage, this implies understanding the fuel consumption as a function of product weight, since it is the fuel consumption (in liters) that causes the primary environmental impact.

2.4.3 Mass Calculators

Designers think in components, not materials. When designing a wire harness, a designer chooses components based upon functional or cost requirements, sometimes the performance of a component is based upon the existence of a certain material - but overridingly, the material composition of a component by weight is not the first thing on a designer's mind. A 12-gauge, high heat wire; a 12-way, small waterproof connector, or a part number 3679495KZ may imply a certain material content, but in no way breaks down the material composition necessary to model the component using the LCA software. Ideally, the software database is populated with all the possible components and subassemblies necessary to create a final product. But there will always be circumstances when new components must be modeled by the designer. These circumstances arose in the field. For instance when modeling the harness of a competitor, very little information is available.. Also, with regards to small complex components, such as connectors - their influence on the overall environmental impact of a wire harness is minimal, and one can argue that a quick estimate is 95% as valuable as a detailed compositional analysis. This is especially true during the early design, or concept phases when everything is an estimate. As a result, custom spreadsheets were developed to support the calculation of component mass. To form of mass calculators was based upon the significance of the component, and the availability of information.

If a component was deemed significant from its potential environmental impact, and a print of the component was available, calculation based upon decomposition was feasible. This process involved decomposing the component into subcomponents of the same material, then calculating the volume of these subcomponents based upon the print and manufacturing variance. Thereafter the average specific gravity of the material was used to calculate the probable mass of the material. This was done for wires since they composed 40-80% of the mass of wire harnesses, and also contained heavy metals in the form of stabilizers or flame retardants.

Estimation was used when the size, complexity, variety, and environmental impact of the product was such that decomposition based calculation would be too time consuming and provide minimal marginal benefit. For example, this was the case for connectors. A wire harness could contain several hundred types of connectors which compose less than 5% of the harness mass, and about the same percentage of the product's environmental impact. The estimation system was based upon a actual data. For connectors, a random sample of 20 connectors were taken. Each connector was physically taken apart, and its various subcomponents were weighted. Subcomponents include: waterproof housing seals, waterproof wire seals, terminals, housings, and body. The mass of these subcomponents was sufficiently correlated with the outer dimensions of the connector. As a result, one could estimate the material composition of a connector based upon the outer dimensions provided in a print, or even a actual part weight if a sample was available.

2.4.4 **Fuel Consumption Calculator**

For automotive products, an overwhelmingly significant stage of the product life cycle is the Use Stage. The primary input for the Use Stage of the product life cycle is liters of fuel consumed. More so than material composition, this information is not at the forefront of a designer's mind, and is not easily accessible. But it is easily estimatable when actual data is not available, and when certain assumptions are made. Sovran's equation was used as a bases for the Fuel Consumption Estimator. Below is a description of the process used to validate the underlying relationship used in the calculator: for each percentage of mass reduction, there is approximately a half percent reduction in fuel consumption. The mathematics is illustrated below:

Sorvan's simplified model for energy consumption in a car is used to estimate effects of weight reduction. (in this analysis (1983), fuel consumption during unpowered deceleration is not included.)[44]

Main Sovran equation:

$$ET_c = u_c M r_0 + w_c M + v_c C_d A + AC_c + ID_c + BR_c \qquad (1)$$

ET_c - total energy as a function of a driving cycle

u_c, w_c, v_c - constants specific to a driving cycle

r_0 - rolling friction coefficient

C_d - drag coefficient

A - frontal area of a car

AC_c - losses due to accessories

ID_c - losses due to idling

BR_c - losses during breaking

M - car mass

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[44] Source: Some Evidence on Determinants of Fuel Economy as a Function of Driving Cycle and Test Type, Danilo J.Santini and John Anderson, Argonne National Lab, SAE 9310804; 1993

Assuming constant values for AC, ID, and BR the variability of the energy use around its mean value is a function of mass (exemplified analysis for an EPA urban drive cycle follows.):

Ω_0- average energy for Sovran vehicle on the EPA urban cycle

M_0 - average mass of a car

(2) $\Omega_0 = M*(0.37/M_0)*\Omega_0 + M*(0.17/M_0)*\Omega_0 + 0.2\Omega_0 + 0.1\Omega_0 + 0.07\Omega_0 + 0.09\Omega_0$

or:

(3) $\Omega_0 = M*(0.54/M_0)*\Omega_0 + 0.46\Omega_0$

A change of energy use due to change of mass from M_0 to M_1 can be written as:

(4) $\Delta\Omega = \Delta M*(0.54/M_0)*\Omega_0$

Because energy use is directly proportional to a fuel consumption the equation (4) takes on the form:

(5) $\Delta MPG = \Delta M(0.54/M_0)*MPG_0$

ΔMPG - change in the fuel consumption

MPG_0- original fuel consumption

Note that for an EPA highway driving cycle, an "influence coefficient" (0.54 in eqs.3-5) would be 0.32.

Figure 9: Sovran's Equation to Calculate Fuel Consumption

The fuel consumption calculator is in the form of an Excel spreadsheet. The inputs to the calculator are total car mass and mass of wire harness, and the output is liters of fuel consumed. It is flexible such that basic assumptions like driving cycle and miles per car lifetime can be adjusted as customer's assumptions vary.

3. Multiple Site Technology Introduction and Application

"Technology never fits perfectly into the user environment."[45] A process of mutual adaptation was necessary for the successful introduction of the LCA tools into the multiple wire harness design centers. The technology introduction stage became an extension of the technology development as the users, their environment and processes were incorporated into the technology. This process of adaptation is especially necessary when in a distributed, multinational environment.

3.1 Technology Transfer and Mutual Adaptation

Bases upon 12 in depth case studies of new technology introductions into large organizations, Leanord-Barton argues that the initial introduction of a new technology is the most critical stage of technology development.[46] Initial implementation is an extension of the invention process, it is dynamic and thus is a process of mutual adaptation. Mutual adaptation is an iterative process of organizational and technological convergence. Just as "forecasts are never right," technology never fits into the user environment.

3.1.1 Technological/Organizational Misalignment

Leanord-Barton's study revealed that misalignments always occurred in one of the following three areas:

- technical requirements,
- delivery system,
- and user organizational performance criteria.

Technical requirements refers to the specifications of the technology. Does the technology provide what it is meant to provide at the technical level? This refers to attributes such as accuracy of information and type of information. Does the tool design

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[45] Leanord-Barton D., Research Policy; "Implementation as Mutual Adaptation of Technology and Organization," Volume 17, Issue 5, October, 1988, p. 251

[46] Ibid.

team, and even the user, understand the process within which the technology will be used? Is this process rational? It would be a challenge to answer "yes" to all of the above questions, but it is critical to do so for sustainable use of a technology.

Delivery system refers to the proper support equipment, and access to the support equipment. For a computer application this implies, operating system computability, memory capacity, supporting software availability, and computer accessibility. This is critical for the users, the tool developers, and the maintainers.

User organizational performance criteria refers to both explicit performance measures, and implicit performance requirements. A technology must help the user, it must add value. This has certain implications on cost, time, and quality of the technology. Additionally, the technology must be easy to use. This refers to computer interface, training, manuals, etc. And to help institutionalize the use of the technology, there must be some visibility associated with use. this implies connecting the technology with existing measures so that the user is rewarded by use. For example, the output of the technology could be part of design approval or part of the deliverable to the customer.

Given that misalignment will always happen, correction is inevitable. Correction is accomplished by altering the technology and/or the environment. The management of the implementation becomes critical.[47] The first step is the awareness that technology introduction is a process of mutual adaptation. This awareness must be present in the mind of the transfer team, and the users.

3.1.2 Significance of Original Definition

The better the original definition of the process, the less disruptive and costly the adaptation cycles. The adaptation takes place at the user site after most of the development is complete. the better the user environment is understood during project definition and technology development, the less adaptation required. This implies that understanding customer requirements ensures a greater probability of success, faster, and with less cost. User input into the technology development process is therefore critical to

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[47] Ibid.

more efficient technology transfer. There are several means to accomplish this end, including:

- following the TQM based concept engineering process,
- developing an advisory user design group, or
- including users in the technical design team.

It is possible that the nature of an organization does not allow such user input. In such a circumstance it is ever more important for the technology developers to understand the perspective of the user indirectly by activities such as; simulating the user environment, having a user background, getting input from users in a similar environment, and understanding previous cases in which similar technologies were introduced.

3.2 Company Organizational Background

United Technologies Automotive Europe is a regional division of United Technologies Automotive (UTA). UTA itself is one of several operating companies that form the United Technologies Corporation. The United Technologies companies are relatively independent. UTA is decentralized within itself. The field work took the form of a technology transfer project. The United Technologies Research Center (UTRC) was to develop and introduce LCA capabilities to the UTA Europe design centers.

3.2.1 UTA Europe's Primary Product

A wire harness, or more formally - an electrical distribution system, is an increasingly critical and complex part of an automobile. As the number and sophistication of electronic devices (such as ABS, navigation systems, engine controls, etc.) in autos grow, the wire harness must also grow in functionality. A wire harness ranges in weight from 40 to 60 lb., and contains thousands of components. 50-80% of the weight of the wire harness is derived from the wires themselves, thus making copper the most abundant material by mass in a harness. The copper is insulated by a flexible plastic material (usually PVC) compounded with stabilizers (usually lead) or flame retardants. Wires are connected to each other and to electrical devices by connectors and terminals.

Fuse boxes and junction boxes serve as central connection points. Plastic shielding and tape is used to protect the wires and devices from heat, water, rocks, etc. Additionally, printed circuit boards are becoming more common as they provide intelligence to the harness and thus allow for a reduction in the number of wires, and greater functionality. Below is a sketch of an engine harness, a subsection of the entire wire harness.

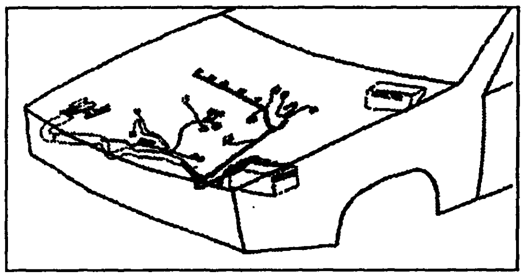


Figure 10: Engine Wire Harness Subassembly

3.2.2 Organizational background

The multiple European design centers are highly focused and responsive to their customers, and thus have a relatively strong level of autonomy. Each center has some type of advanced group and a core product design group that report to the engineering manager, in addition to a sales/marketing group. Inter-design center interaction is minimal below the engineering manager level, except when a design center is sourcing components of a harness to another design center. The Spain design center also provides wire harness components, and is thus involved with the other design centers at the component level.

3.2.3 Customers and relationships

Specific product development responsibility and processes are dictated by the customers and the relationships with the customers. As customers may vary per company, some design center autonomy is inevitable. Varying customers also implies different specifications and subcomponents per customer, as well as different CAD systems. As Eastern principles of closer relationships with suppliers become more prevalent, the nature of UTA's involvement with its customers is changing. A previously "build to print" relationship is being superseded by more supplier involvement much earlier in the design process. This implies more time and power to influence product design, and thus use product design as a differentiating capability.

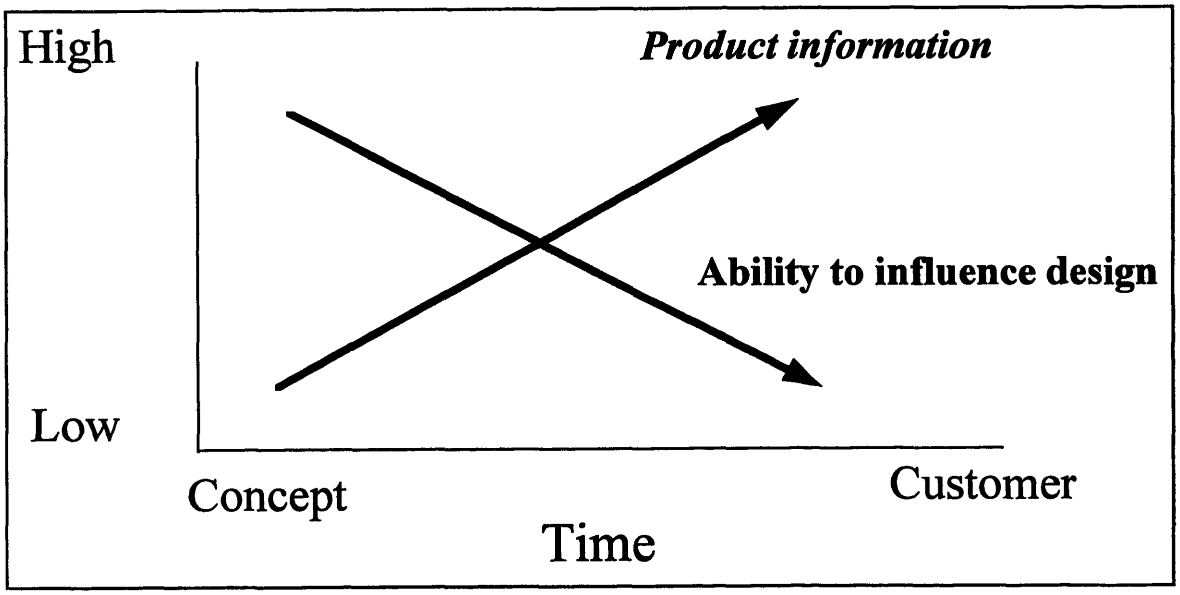


Figure 11: Influence and Information vs. Time Tradeoff

3.2.4 Product Development Process

The supplier's product development responsibility begins between four to two years before production. As noted above, there is a trend in beginning responsibility earlier. This implies input into the conceptual design of the product. The following step is a more detailed design, followed by iterations of prototypes and design changes, and finally production. As in the diagram above, the most important decisions are made earlier in the process. System technology choices such as multiplexing are made at the beginning, with subcomponent level decisions made at the end.

Once a technology based architecture is chosen at the beginning of the design process. Thereafter, the engineer usually begins to conceptualize the various wire layouts based upon the location of the electrical devices, the power and signal requirements of the electrical devices, physical car body constraints, and temperature and other environmental constraints (such as exposure to water, engine heat etc.). All of this is done while trying to minimize cost and maximize reliability. Increasingly, the designer has influence over some of the above constraints, but the nature of the product minimizes this influence. The complexity of the designers responsibility necessitates an easy to use technology, which is carefully presented, if the designer is to include environmental friendliness as a design parameter.

3.3 Technology Introduction Process

Technology introduction is the period with the highest probability of failure during the technology transfer process. In the spirit of TQM, market-in rather than product-out; there was an attempt to conduct early user interviews and thus incorporate as much user feedback into the LCA tools before actual introduction. Due to organizational and geographical constraints, early voice of the customer collection was not feasible. Background research and simulating the user environment were the primary customer input mechanisms during initial technology development. As noted earlier, spreadsheets were developed to support LCA use, and a convincing presentation was prepared to maximize user learning and interest.

In the spirit of mutual adaptation, correspondence with upper management was used to ensure the availability of the delivery system, and increase visibility of the project to provide a formal incentive - atleast enough to allow for an initial visit. Additionally, before entering the user environment, information/ benchmarking sessions with PRé Consultants and Philips were conducting in the Netherlands. The purpose was to understand historical LCA software introduction strategy and experiences. With the expectation of a large feedback cycle, and in an effort to generate user ownership - introduction was planned in two phases for each of three design centers. Phase I being a two day customer requirements, customer education session. Engineering managers, marketing managers, and designers would be interviewed, and given presentations about environmental trends, the strategic nature of DFE, and a demonstration of the software. The Phase I sessions would be followed by one week of off-site technology development. Phase II would be composed of 2 week sessions at each design center working with teams of designers to conduct environmental analysis of product designs - actually using the software, real-time. This would allow for training of engineers, and productive analysis of existing/future products. The following diagram captures the structure of the process.

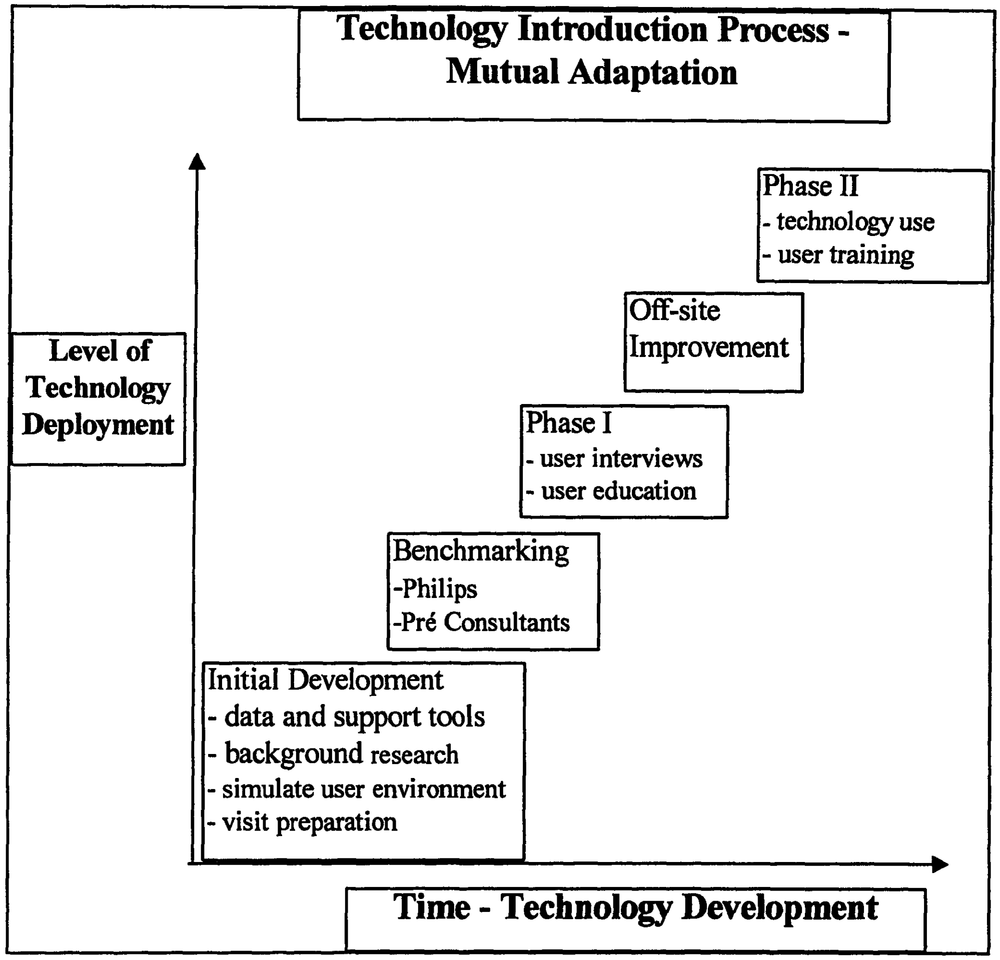


Figure 12: Technology Introduction Process

3.3.1 Initial Development

Beyond the data entry and support tool development, efforts were directed towards preparing for on-site introduction. This involved interviews with persons who understood the user environment and presentation development. The was done to minimize misalignment in technology specifications (the first potential source of technology misalignment per Leanord-Barton's study), and maximize the value to the user. Direct correspondence with the user sites concerning the availability of sufficiently equipped computers and the strategic intent of UTA was used to minimize the other two of the three potential sources of misalignment - delivery system inadequacy and lack of user performance incentive.

3.3.2 Phase I: Presentation and User Requirements

The plan for Phase I involved two types of interaction with the users. The interviews were a format to collect information and understand the user. The presentations, a format to generate interest and educate.

1. A total of four to eight 1-hour interviews with each of the following: engineering manager, marketing managers, and 2-3 designers. A structured interview process was planned to provide input into a modified concept engineering process.
2. One or two 2-hour presentations to designers and managers. The presentation was designed to foster interest and educate.

This was the plan, but the process of mutual adaptation began early.

3.3.2.1 Inform and Gain Buy-in

The structured user interviews turned into two-way learning sessions. To establish context for the interview and the relatively new topic, the interviews also became a forum for discussing the competitive dynamics of the industry, and the potential strategic advantage which an environmental tool can provide. At times part of the presentation was given in the interview to develop interest, and occasionally a user would request a demo of the software during the interview. The specific nature of the Phase I visits varied per site, based upon personality, cultural, and OEM customer differences. This is documented in Chapter 4.

The presentation was designed to generate interest and then educate. Therefore the initial portion of the presentation was general and strategic in nature, followed by a more technical explanation of the technology and its applications. Following is the presentation format:

1. Environment and competitiveness. (General, UTAE customers, UTAE)
2. What is Design for the Environment?
3. Types of tradeoffs and methods of evaluation.
4. SimaPro software and other tools.
5. Technology transfer
6. Sustaining an advantage.

User receptivity ranging from initial reluctance to mild acceptance evolved into moderate acceptance to enthusiastic support. Appointments were anxiously made for the Phase II visits. Delivery system availability was confirmed, and management buy-in facilitated user visibility and incentive. User information was collected, user buy-in was developed, and user psychology was prepared for the incorporation of the environment as a differentiating capability for an automotive supplier.

3.3.3 Phase II: Analysis and Training

Phase II involved the returned to the user site with an improved system in order to use the system with designers on wire harness designs. This is "on the job" training of the site champion and designers. During use feedback is incorporated to further adapt the system. In-the-field adaptation was most extensive at the first site, and in retrospect more time should be spent a the first implementation site for this reason.

3.3.3.1 Areas of Technology Development at User Site

User input was critical in understanding further environmental information needs, developing an appropriate component naming convention that reflects the concept design thought process, and further development of support tools for quantifying the composition of components. Additionally, the process of populating the component database was initiated; this allowed for quicker wire harness modeling at future sites. Challenges arose when environmental information did not exist for certain materials or processes. Additionally, varying customer standards and sources of wireharness information produced complexity in wireharness modeling and analysis.

3.3.3.2 Modeling, Analysis, and Results: an Example

This example is taken from one of the design center sites. The environmental emissions data are from various sources, and the product modeled was significantly altered to protect proprietary design concepts. X Car is a fictitious name used in the example. SimaPro Version 3.0 software was used for the analysis.[48] The example is presented to:

- illustrate the process of conducting a life cycle assessment;
- show the analysis which an LCA provides;
- show the differences using two systems of evaluating impact; and
- illustrate comparison of two scenarios, traditional disposal versus complete recycling.

In the current disposal scenario, the plastic insulation which contains heavy metals is usually landfilled. The LCA shows the relative impact of the disposal stage to the other two stages, manufacturing and use. The analysis provides direction for the allocation of resources to minimize the environmental impact.

X Car Bodysill Harness Analysis

The wire harness assembly includes several types of components and subassemblies, including:

- cables or wires (conductor and insulator to transfer power and signals)
- connectors (structural plastics to provide support/housing for terminals)
- terminals (conductors which interface between wires, sources, and devices)
- tubes and channels (plastics for protection of wires)

Figure 2 lists the components in the harness assembly. In constructing the inventory, descriptive component names are used to provide the information necessary for a designer to quickly find the component type and select a specific component to meet functional requirements. For example, w-.35M2,PVC-A,.22 describes a wire with a $0.35mm^2$ conductor cross section, which meets the customer's M2 functional specification, with a PVC compound A insulator 0.22 mm thick. Similarly, t-s,CuZn,Sn4,320255078 represents a small terminal composed of a Sn_4 coated CuZn

[48] SimaPro Software is a popular LCA software package produced by PRé Consultants in Amersfoort, The Netherlands.

alloy, with part number 320255078. The list of materials and subassemblies that describe the assembly is the product-specific input to the analysis.

Wires	Connectors, Tubes, and Channels	Terminals
w-.35M2,PVC-A,.22	321660144	t-s,CuZn,Sn4,320255078
w-.6M2,PVC-A,.28	321766347 (PA66)	t-s,CuZn,Sn4,320255573
w-1.0M2,PVC-A,.3	321755050 (PA66)	t-s,CuSn,Sn4,320271216
w-1.4M2,PVC-A,.32	320350093,PA66	t-s,CuSn,Sn4,320271224
w-2.0M2,PVC-A,.38	320453442,PA66	t-s,CuSn,Sn4,320271240
	329954234,PA66	t-s,CuSn,Sn4,320271257
	329980064/72,PP	t-s,CuSn,Sn4,320271273
	329981286/94,PP	t-s,CuSn,Sn8,320260441
	329920912,PP+20Talc	t-s,CuSn,Sn8,320260458
	517929006,PP+20Talc	t-s,CuZn,Y108,271323
		t-s,CuMg,Sn3-285190
		t-s,CuMg,Sn3-285216

Figure 13: The X-Car, bodysill harness includes 27 different components or subassemblies.

The scope of the analysis extends from raw material extraction to end-of-life disposal. This means that resources consumed and emissions generated are accumulated for the entire life cycle of the product. The material information used is a combination of aggregate data based upon theoretical estimates and industry-average data based upon commercial studies. Information concerning component composition is based upon an actual wire harness design.

Two Scenarios

The base scenario for the X Car bodysill harness life cycle makes the following assumptions:

1. Manufacturing: The harness assembly data from raw material extraction to component assembly is included in this stage.
2. Use Stage: The average fuel mix gasoline consumption for the average European automobile is used to estimate the emissions during the Use stage of the life cycle. 18.77 liters are used based upon the weight of the product. The environmental impact of making the fuel, and burning the fuel are included in this stage.
3. Disposal Stage: This reflects the traditional fate of a wire harness. The conductor materials are recycled, while the plastics including any additives are landfilled. For simplicity, transportation, shredding, and separation processes are not reflected.

The modified scenario assumes full recycling in the disposal stage. This implies that the plastics with additives are 100% recycled. Comparison of these scenarios is significant since it will illustrate the difference in the environmental impact resulting from automotive plastics recycling, in context of the entire product life cycle.

Results

The charts below show the translation of the wire harness inventory data into environmental impacts using two methods of analysis. The results are relative to the total impact for each effect, thus each bar adds up to 100%. The same environmental information in units of substances (kilograms of CO_2) is used as inputs to the Dutch method and the Swiss method of analysis. Both methods translate the inventory data into units of reference material for each classification of impact category, however slightly different impact categories (and thus reference materials) are used.

In both methods, the characterization of the life cycle indicates that the Use stage is dominant, followed by the Manufacturing stage, and with the Disposal stage having the least impact. For most categories, the Disposal stage has a negative impact since credits are granted for the recycling of copper as this offers an alternative to copper extraction, but does require electricity.

Life-Cycle Impact of the Bodysill Harness by Impact Category using Two Different Evaluation Methods

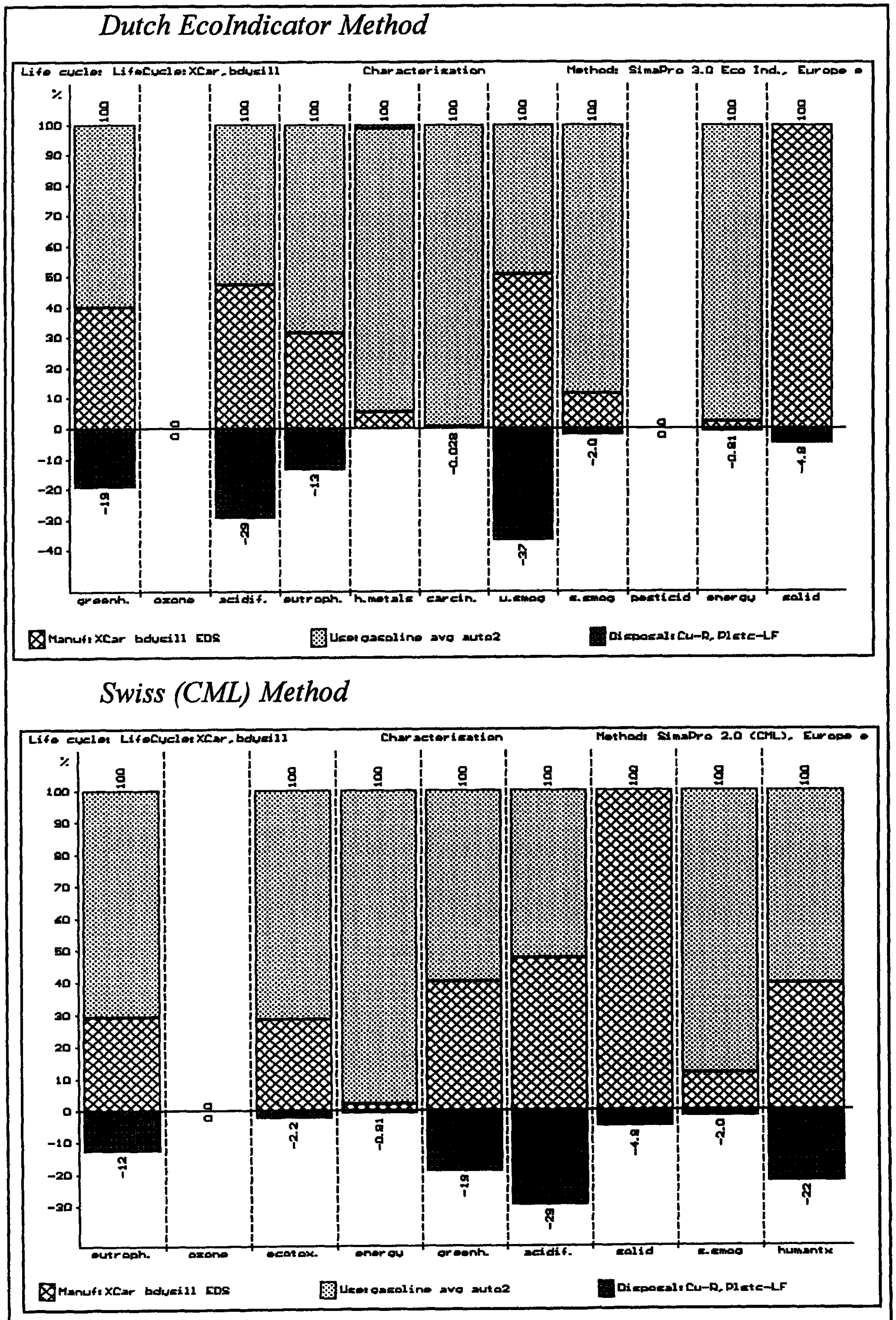


Figure 14: LCA Using Two Different Evaluation Methods. The above methods show similar results when converting inventory data into impacts. Each bar shows the relative contribution from the Manufacturing, Use, and Disposal stages. Summer and winter smog, carcinogens, heavy metals, and pesticides in the EcoIndicator Method replace eco and human toxicity in the CML Method.

Sensitivity Analysis

To understand the relative environmental impact of a single product component, one can compare that component with the entire product. In traditional wiring systems, wires or cables usually contribute the most to the product's total environmental impact. This is because the wires comprise between 40-70% of the weight of an electrical distribution system, thus effecting fuel consumption. Also, most wire insulation materials contain heavy metals such as bromide (flame retardant) and lead (stabilizer). There is also significant impact from the production of copper, but since copper is traditionally recycled (as in the base case) - the impact is credited. Below we see the relative impact of one wire type to the entire bodysill harness. This wire is 21 meters long and weighs 675 grams, 40% of the bodysill harness weight.

Comparison of Bodysill Harness with One of its Components: 21 meters of 1.5mm^2 Wire.

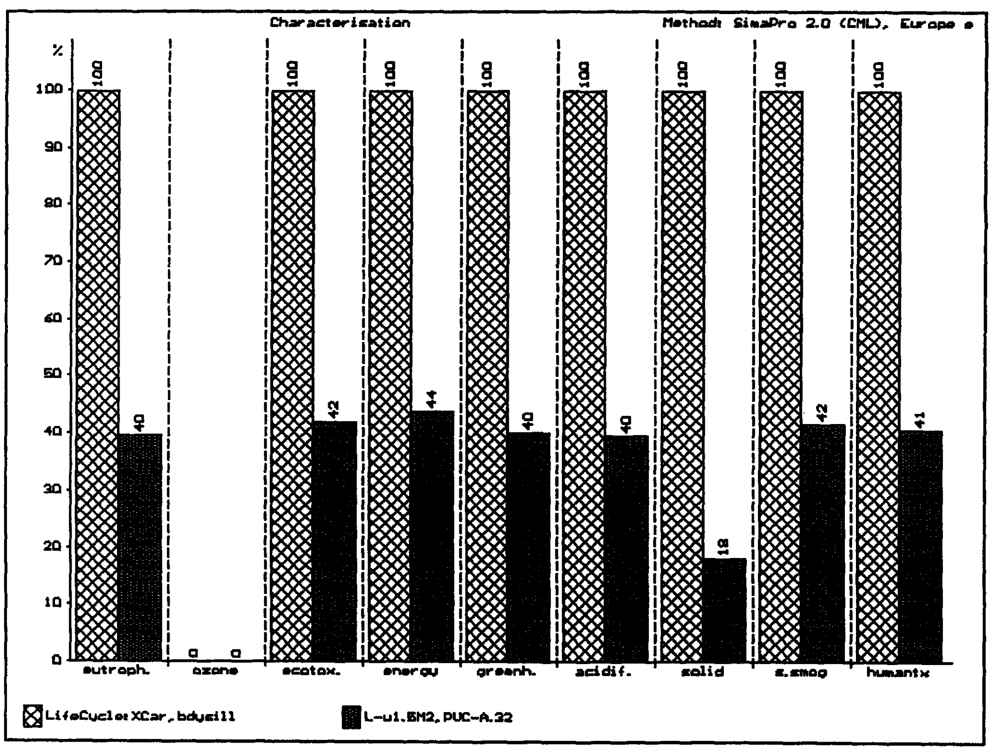


Figure 15: Harness subsection versus One Wire. **In many if the Impact Categories, the 1.5mm^2 wire has a significant effect on the environmental impact of the entire bodysill harness.**

In all life cycle stages, the components with the greatest contribution to environmental impact are the wires. This is true for the Base Case scenario. By conducting further analysis on the wire, one can see that during the Assembly Stage, the copper in the wire has a dominant effect; while during the Use Stage, wiring contributes the greatest weight to the system; and in the Disposal Stage, it is the additives to the wire insulation which have the greatest impact on the environment.

Scenario Analysis

Finally we compare the base case scenario in which the plastics are landfilled with the modified base case which assumes full recycling of plastics.

Comparison of Scenarios in which Plastics are Landfilled vs. Plastics Recycled

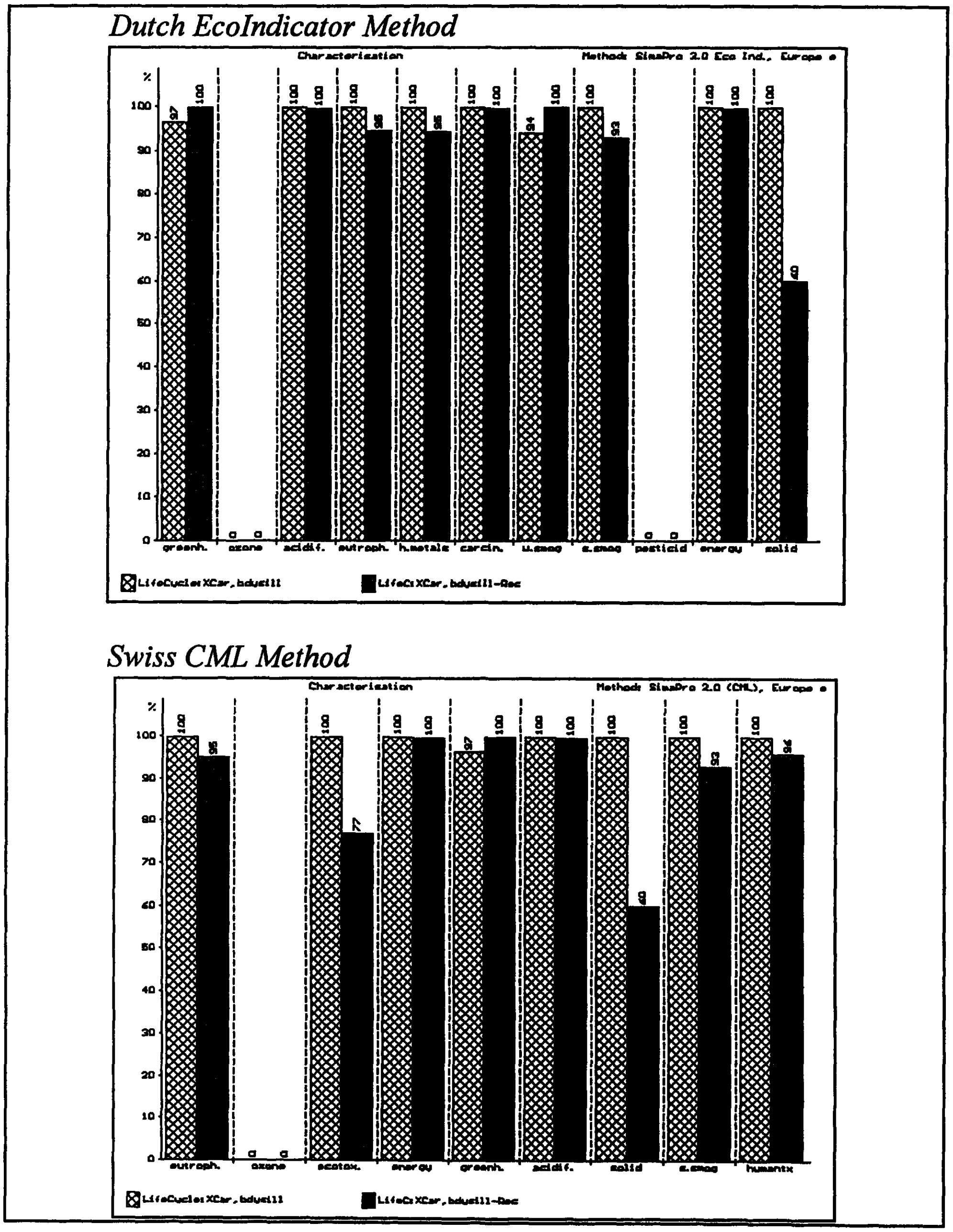


Figure 16: Comparison of Scenarios Plastics Landfilled vs. Plastics Recycled. **The CML Method is more sensitive to the difference between the two scenarios. With the CML Method, recycling all plastics shows significantly less impact on Acidification and Solid Waste.**

When we quantify the impact of full recycling, we see that the reduction in environmental impact is not significant relative to the impact of the product's life cycle. In most categories there is marginal improvement, with solid waste showing the greatest improvement. One can quantify other scenarios which result in greater improvement and thus find alternatives to full recycling.

3.3.3.3 Conclusion: Wire harness Example

Below is a list of conclusions formed based upon the analysis.

- The LCA shows that wires are a significant contributor to the life cycle impact of a traditional wire harness.
- Research, development, and engineering resources should be reallocated to reflect the significance of the overall weight of wires.
- Recycling plastics provides a significant improvement in environmental impact in only two categories, and thus environmental strategies primarily based upon recycling should be reconsidered.
- The impact of a product is dependent upon the evaluation methodology used.
- Company, national, industry, or global standards for assessment are necessary for a complete holistic assessment of a product's impact.

4. On-site Progress Summaries

All four Electrical Distribution System design centers, UTA France, Germany, Spain, and the UK, received a Phase I visit. The engineering manager, several marketing managers, and several design engineers were given a presentation of the methodology and a demonstration of the software. Interviews were conducted to obtain input on UTAE environmental tool requirements, and to understand the UTAE business practices. Each site was enthusiastic about the project and looking forward to developing this new technical capability. Phase II was conducted at UTA France, Germany, and Spain.

Following is the general status at each of the design centers:

- Awareness: Several designers (6-10) and the advanced engineering manager at each site have a general understanding of the LCA methodology, the capabilities of the environmental tools, and advantages of using such information in making design decisions and in presentation to customers.
- Tool Availability: All three design centers have SimaPro3.1 software installed. Also, all have supporting documentation and spreadsheets to assist in quantifying electrical distribution systems.
- Training/Preliminary Analysis: 1-3 designers at each site have modeled and conducted preliminary analysis of an EDS subsystem for training. An additional 1-3 designers/engineers have provided close support and monitored the progress.

Notes:

1. Time to model an EDS system depends on the complexity of the system, the availability of product data, the number of new components to be defined, and the availability of environmental data. A simple harness section at the first site took two weeks, a more complex harness section in France took only one hour to model. The dramatic decrease in modeling time was due to the availability of product data (length of wires etc.), and the use of existing components from other harness models. In the

first case, each wire length had to be individually calculated, and each of the components had to composed from scratch.

2. Environmental data on Additives, PBT, and printed circuit boards are not available, estimates or substitutes were used when applicable. This implies that detailed analysis cannot be conducted on all components. But very high level analysis, and analysis of specific components (for which data is available) is valuable.

4.1 UTA Germany: Phase II Summary

Dates on site: September 25 - October 6

Champion:. Advanced Engineering Manager (direct report to Engineering Director, high involvement in advanced programs)

Primary Contact: Advanced Engineering Manager

Secondary Contact: Advanced Engineering Supervisor

Projects

Modeling and analysis of a Door Harness. Information was scarce since this was not a UTA product, but UTA was providing a concept for the next program. Most of the two week period was spent creating spreadsheets to quantify the materials in the Harness, and modeling components with incomplete information. Close support was provided by the two engineers in the Advanced Engineering group, each of the two engineers were given approximately 8 hours of direct training.

Door Harness Project

Sources Data: Experience, German specifications (DIN), print.

Scope: Everything was modeled "ground up". Estimates were used often as specific product information was not available. Also, the insulation additive estimates for disposal were not estimated in Germany, this was done at the next site.

Time: 2 x 4 hour sessions describing the model and software. 2 hours developing the naming system for components. 2 additional hours per day understanding EDS drawings and specifications.

Preliminary Results: As in other sites, the use stage has the most significant impact and the disposal stage has the least significant impact. In all the stages the components with the greatest contribution to environmental impact are the wires. Reducing the cross section of one wire resulted in a significant reduction in environmental impact - more than that generated by recycling the insulation. Charts of analysis and implications of preliminary results are in a separate document.

Next Steps

UTA Germany would like to use the analysis in a presentation to OEM. The primary objective would be to communicate UTA's new capability, but also contribute to OEM's supplier requirements and environmental strategy. Also UTA Germany expressed strong insight into the long term use of the software. The Engineering Director, as well as several engineers inquired about the compatibility of SimaPro with their existing CAD systems (especially for importing bill of materials information). Also of great interest was environmental data and component data exchange between design centers.

Reflection

UTA Germany is interested in the technology, they feel it will eventually be very valuable. For now, they would like to use it in order to demonstrate engineering capability. UTA Germany expressed interest in leading coordination between design centers with regards to environmental tools. Also UTA Germany is in a leading environmental country, environmental data collection and research on methodology in Germany is stronger than the nations of other design centers. This office could serve as a environmental process and product technology center for UTA Europe.

4.2 UTA France: Phase II Summary

Dates on site: October 16 - October 25

Champion:. Advanced Methods Manager (direct report to Engineering Director, high involvement in advanced programs)

Primary Contact: Expert Engineer (reports to advanced method manager, highly respected by engineers and management)
Secondary Contact: Special Studies Engineer (conducts benchmarking studies, and collects data on material content in EDS)

Projects

There were three projects at UTA France.

- Engine Harness
- ABS Harness
- Traditional Fuse Box

The modeling and analysis for each EDS or component was done in multiple 3 hour sessions with 100% involvement from one engineer from the respective design team and support from another engineer or engineering supervisor (40% involvement). All of the designs are based on existing UTA France products.

Project 1 Engine Harness

Primary Designer Involved: Engine Cable Engineer

Support: Expert Engineer

Sources Data: Bill of Materials, experience, supplier documentation of cable specifications, calls to suppliers.

Scope: cables, channels, and tubes were modeled completely; representative connectors and terminals were used from another harness.

Time: 5 x 3 hour sessions were necessary, most of the time was spent quantifying the material weights of the various cables. Plus 1 hour introduction.

Preliminary Results: As in other sites, the use stage has the most significant impact and the disposal stage has the least significant impact. In all the stages the components with the greatest contribution to environmental impact are the wires. Charts of analysis and implications of preliminary results are in a separate document. Alternative designs involved decreasing copper cross-section but upgrading to a higher functionality (thermal) insulator to compensate for the increased heat generated.

Project 2: ABS Harness

Primary Designer Involved: Electrical Car Engineer

Support: OEM Engineer

Sources Data: Bill of Materials, experience, product design, supplier documentation

Scope: Both OEM able specifications are very similar so the same cables were used for both. Another OEM's connectors were used. Actual OEM tubes and channels were modeled.

Time: 1 hour modeling, 1 hour introduction.

Preliminary Results: As in other sites, the use stage has the most significant impact and the disposal stage has the least significant impact. In all the stages the components with the greatest contribution to environmental impact are the wires. Charts of analysis and implications of preliminary results are in a separate document. Alternative designs involved decreasing copper cross-section but upgrading to a higher functionality (thermal) insulator to compensate for the increased heat generated.

Project 3: Traditional Fuse Box

Primary Designer Involved: Plastics Engineer - Components Group

Support: Supervisor Components Group

Sources Data: Bill of Materials, product design, experience.

Scope: connectors and housing were modeled; connector-specific terminals were used.

Time: 3 x 3 hour sessions were necessary, plus 1 hour introduction

Preliminary Results: As in other sites, the use stage has the most significant impact and the disposal stage has the least significant impact. In all the stages the components with the greatest contribution to environmental impact are the wires. Charts of analysis and implications of preliminary results are in a separate document. Our recommended alternative design involved an increase in the glass fiber content of the fuse box housing so that the housing could be made thinner, and weigh less.

Next Steps

UTA France would like to use SimaPro to model the EDS for a new program. UTA France has concept responsibility, and design and manufacturing responsibility potential. The concept design for competitive bidding by UTA France and other suppliers. UTA France feels that some environmental analysis of the EDS will differentiate UTA's engineering capability, and appeal to OEM's emerging interest in the environment. More information about OEM's environmental interest (mostly recycling) is in a brochure distributed to all suppliers. The only concrete measurable they have been give to date are cost targets (40% below traditional cost). Use of environmental tools could help justify lower cost solutions like maintaining the use of PVC compound as an insulator. UTA France need assistance planning the full implementation, use, and development of environmental tools.

Reflection

UTA France is interested in the technology, they feel it will eventually be very valuable. For now, they would like to use it in order to demonstrate engineering capability. The size and culture of this design center is conducive to quick implementation. If interested, UTA France can use a new technology very quickly. They want the capability, but are not structured to allocate resources to develop the data in the software. Therefore they will need some guidance on use and data development.

4.3 UTA Spain: Phase II Summary

Champion: Manager of Research Engineering.

Primary Contact: Research Engineer

Project: Body Sill (right side) EDS subsystem

We modeled this system using specific information research engineer had collected. We left out the PBT components. Data was in the easiest form for entry: weight per material.

Wires, we added the insulator material (in grams) to copper (in grams), this is a change from the previous format in which wire was measured in meters. The insulator material is a subassembly since it is really a compound. We decided to make it a subassembly so that a change in the "im-PVC-A 1 gram " subassembly will automatically be reflected in all the wires that use that material. This is a change in format from Cologne and France, but was made to make things more flexible after discussion with the cable manufacturing engineer from the UTA MAI Cable Facility. The wire extrusion process is added when making the wire, not during the compounding. Also we added copper wire directly to the wire, to allow for faster data entry. For the PVC insulation compound below, we used therephtalic acid as a substitute for the plasticizer. The lead is partially altered zinc data, and does not include the process of going from ingot to additive. The lubricant was not added it comprises 0.1% of the mass.

Terminals: we also changed format since we had more information, and to make things more flexible. Previously the subassemblies were the materials added directly: copper, tin etc. Here, the subassembly is a terminal material (tm), and the weight in grams is entered. The process is "terminal generic", a copy of another process that already existed in the database (some real data is being collected, see below under other).

Other components: Complete descriptive data was not readily available for the "other" OEM components, so we entered data using the available part number and material weights. For connectors, we added terminals separately. Previously terminals were added as part of a connector. This change was due to circumstances, the previous format is better for concept development, this format is suitable for modeling an existing design from a Bill of Materials.

Primary Designer Involved: Research Engineer
Support: OEM EDS lead engineer, spent 4 hours with us understanding software, looking at analysis, and helping us understand design.

Preliminary Results: As in other sites, the use stage has the most significant impact and the disposal stage has the least significant impact. In all the stages the components with the greatest contribution to the environmental. impact are the wires. Charts of analysis and implications of prelim results will be sent separately to minimize the size of this file.

Other (Data Collection)
Insulation: Cable facility engineer is very interested in developing our data on insulation materials. He will be going to another country soon to speak to an OEM environmental manager about cable. He will present UTA's status as being aware of LCA and using Tools, having some tools, and having very preliminary analysis. Cable facility engineer offered to request information from suppliers of additives.

Terminals: A 2 hour session with the Terminals/Connectors design manager led to meetings with 2 terminal and connector engineers. The engineers will collect some data on energy consumption for the stamping of terminals in MAI, he will forward this information to the research engineer. Also, they will request manufacturing information from terminal materiel suppliers - rolling/plating copper alloys. With regards to terminal design, weight minimization is already a design objective, and materials such as cadmium are being phased out of terminal design.

Next Steps

UTA Spain would like a long term plan developed for full implementation and use of the Environmental tools, and a plan for development of environmental data. They would like this plan and the preliminary analysis from the project to be presented to the Engineering Director.

In discussions with the champion, it was decided that it is too early for systematic use of the tool on programs. But rather, a cross-functional Environmental Design Guideline Team should be put together and trained. They would conduct specific analysis and develop product specific design guidelines - for example quantifying the tradeoff between a heavier clean material terminal vs. a lighter, but less clean material terminal.

Reflection

The Research Engineering Manager is very committed to this effort, he has already invested some of his team's time in doing some data collection and entry before Phase II. Also UTA Spain has enough interest and resources to play a role in environmental data collection. The level of adoption is contingent on Engineering Director approval and a structured plan.

5. Recommendations

The application of LCA tools to improve product designs can provide an automotive supplier with a differentiating capability. The development and introduction of such a technology must be adaptive due to the infancy of the technology, and the pressures in the user environment. As the technology improves, sufficiently accurate and quick analysis will allow designers to make tradeoffs which will minimize environmental impact. Until then, such tools are still very valuable for certain types of analysis, user education, and as a basis for future development. This chapters presents recommendations, the nature of the technology dictates different types of recommendations. Recommendations for UTA's applications, general LCA use, and further DFE software development should provide a basis for advancement for this increasingly significant field.

5.1 UTA Environmental Design Needs

The introduction of the LCA tool to UTA Europe design centers provides them with a unique capability, which must be further developed. UTC as a whole has an opportunity to play a leadership role in this field. UTC, UTRC, UTA, and other operating company efforts can be coordinated to efficiently provide UTA with a sustainable differentiating capability. Areas of development are addressed in the following sections.

5.1.1 Data Collection

Short term and long term efforts in obtaining the environmental data to conduct analysis of an entire Electrical Distribution System are necessary. Short term efforts should be aimed at acquiring manufacturing emissions and disposal emissions estimates for high priority materials, processes, and components.

1. Cable insulation additives: especially bromide flame retardant, antimony oxide co-flame retardant, lead stabilizer.

2. Plastic materials: PBT, TPE (thermoplastic elastomer).
3. Printed circuit boards: scaleable data.
4. Irradiation process: used to crosslink polyethylene for XLPE insulation production.

Long term efforts could be directed at :

1. Acquiring more accurate information for high priority materials, processes, and components noted above.
2. Developing manufacturing emissions and disposal emissions estimates for lower priority materials, processes, and components:
    - Plasticizers, processing lubricants, fillers
    - Copper alloys for terminals (including production of sheet), plating (Tin, Gold, Silver).
    - Elastomers
    - Terminal production (primarily stamping)

Sources of data include:

1. Academic institutions like Buwal and University of Delft develop and sell data.
2. Industry associations like the Plastic Waste Management Institute part of the European Plastics Association develops and makes available data.
3. Suppliers can be pressured to divulge or release pertinent data.
4. Customers such as Volvo have an interest in the consistent use of data and may have or assist in acquiring standardized data.
5. UTA operations can be a source of data, process information resides at manufacturing sites such as UTA Spain (MAI) which compounds and extrudes cable insulation, stamps terminals, and injection molds connectors.
6. Industry partners such as Philips are interested in data exchange. These can provide an excellent source of data, experience, and credibility.

5.1.2 Analysis and Guidelines

An effective method for broadly introducing environmental analysis to designers is through the generation of specific design guidelines based upon analysis using LCA software. This is especially helpful when for designers who are not trained to use LCA software, and in situations where there is little time for program specific modeling. Studies comparing insulation materials, fuse box technologies, connector materials, and terminal types would provide information and direction for designers during the design process.

5.1.3 UTAE Design Center Coordination

Design centers are interested in coordinating data collection and modeling of subassemblies. They are also interested in learning about innovative solutions and analysis conducted at other sites. This would maximize their learning and the benefit they can provide to their increasingly global customers. This is essential for maintaining consistent environmental data.

Additionally, coordination would be valuable in influencing suppliers - including:

- Material and component suppliers for data collection.
- Environmental data suppliers, coordinating the evaluation, purchasing, collection, and entry of new data.
- Software supplier, pressuring PRé Consultants to incorporate the changes which are most important to UTA.

Another area of coordination is in the influence of government, EU, and industry environmental policy.

5.1.4 UTC Coordination

General data, software, and policy issues are also relevant to other UTC companies. Central coordination of generally applicable data, methodologies, and resources would be an efficient method to develop DFE practices. Philips strategically uses central coordination in areas that conducive to such a structure (see Appendix C).

5.1.5 Regulatory Policy, Technology, and Market Trends

UTA Europe does not have functional expertise in LCA or environmental studies applied to product and process design. UTA Spain's Research Engineering Group is beginning to focus on this area, but I do not think they will allocate sufficient resources, or have access to the right information. Monitoring and presenting existing and expected regulatory policies, technologies, and market (consumer and OEM) trends to UTA design centers is valuable in sustaining a UTA capability in environmental friendly design.

5.1.6 Training

All UTA designers require general environmental awareness, understanding of a product's impact on the environment, and training on the use of environmental tools during the product development process.

5.1.7 Management

Efforts in data collection, development of analysis and guidelines, software improvement, UTA coordination, UTC coordination, training, and monitoring DFE trends need to be managed. A structure must developed so that these efforts are progressing and are coordinated. There are multiple options for such an effort, ranging from a distributed effort, to centralized UTA Europe or UTA coordination.

5.1.8 Institutionalization of Technology

Most of the recommendations above address development of the DFE capability. One can assume that the value of the capability will institutionalize it, but other mechanisms for institutionalization should be established to facilitate long term leadership in the application of DFE methodologies. This implies actions such as:

- formal incorporation of the environmental friendliness parameter in design reviews,

- integration of environmental design capability with marketing and sales efforts - this creates a "pull" effect from the OEM,
- design team performance measures based upon product improvement,
- incorporating some of the organizational change necessary to adapt to the technology,
- and the creation of mechanisms for designers to provide feedback concerning the value and ease of use of the software.

It is evident from UTA personnel, industry literature, some OEM actions, and government signaling that being a leader in the capability to understand and design environmentally friendlier products provides a business advantage. Done properly, a small investment will yield a significant long term return..

5.2 Introduction of DFE Tools

The introduction of emerging environmental tools is best done with an iterative, adaptive process. The need for intra and inter-company standards may dictate certain limits to the adoption of the technology, but nonetheless, it is the final user that has the power to incorporate the technology into the product development process. Some simple lessons follow:

- Understand the user.
- Obtain user buy-in.
- Educate the user.
- Understand the user's customers.
- Ensure the availability of and access to the delivery system.
- Elevate the visibility associated with use.
- Gain management buy-in.
- Train by doing as much as possible.
- Develop a long term implementation plan for the user organization.

5.3 Application of DFE Tools

With all the weaknesses associated with an emerging technology, it may be difficult to maximize the value of use. "Don't think of what you can't do, think of what you can do," may be the appropriate advise.

- The mere understanding of DFE by users is progress, the environment is now consciously a parameter.
- Having the capability in-house is also a strength, a step towards the inevitable.
- The development of product-specific design guidelines is a simple way to educate designers, and guide product development. These guidelines would be based on LCA studies.
- The development of a simple scoring systems (as with Philips) would provide a method for quick product analysis. In this case, the appropriate scoring system(s) must be chosen, or dictated by the customer.
- Use analysis for directional guidance, rather than detailed recommendations, especially if it is based on estimated data.
- Directly compare products if data is at a similar level of accuracy.
- Use DFE tools and analysis as early as possible in the design cycle.

5.4 Tool Improvement

DFE software, although sufficient, leaves much to be desired. The currently small market for such products dictates lower development budgets, but this may be a hidden blessing. Usually, proprietary software is more difficult to develop, and much more difficult to change. Software developed using commercial applications such as Visual Basic (see Winter and Shah, 1996) can be developed quickly, and most importantly can be altered easily. Such open architecture systems allow for the integration of other software applications, which makes automation of data entry and report generation automatic and flexible. Whether such an open architecture system is developed or not, below are software attributes which have been deemed important by designers and managers.

5.4.1 Searchability (flexibility)

All of the subassemblies for a project reside in a list in alphabetical order. As complexity increases (thousands of components) and when designers have limited information - finding the right component will become very time consuming and frustrating. Furthermore, this could lead to double entry and inconsistent modifications. During concept design, a designer has descriptive information about a component, while during redesign or detailed design a designer has a part number (usually a customer part number, not a standardized UTA part number).

- The component (subassembly) and environmental databases should be flexible and thus searchable based on any attribute (part number, component type, material etc.
- This search capability should be somewhat fuzzy to allow for comparison of similar data.

5.4.2 Compatibility

This is the most significant issue raised by engineering managers. For long term use of such systems, they must be compatible with other design center systems.

- Interface with 3rd part databases. UTA design centers would like to maximize efficiency by directly importing Bill of Material data into SimaPro. SimaPro only allows for the import of text files of a specific format.
- Updating data and projects between design centers. UTA design centers would like to leverage data and modeled components from other design centers. SimaPro has the capability to import projects or data, but this is limited - for instance if the same subassembly is detected in both databases, the update is canceled.

5.4.3 Simplicity of Use

In quantifying the value of DFE, one of the variables is time needed to accomplish a task. Simplicity of use minimizes time, anxiety, and errors.

- Data entry should be easy, and a mass balance feature should check environmental data.
- The software should run on the same platform as other software which designers use.
- The user interface should be icon based, and intuitive.

5.4.4 Flexible Scoring

As scoring systems evolve, standardize, and fragment, a system must be flexible in the incorporation of any values the customer wants to attribute to components or data. Shah and Winter (MIT Thesis, Process of Design For Environment Within Global Manufacturing Companies, 1996) developed such a tool using commercial software applications (Access and Visual Basic) in a fraction of the time necessary for proprietary system development.

- Allow for a rating of the accuracy of data.
- Accommodate any scoring system. This is especially useful if customers begin to dictate the scoring system. This could include price as one of multiple scores. Several designers and marketing managers asked that product/component price be included in an ideal system.

5.5 Conclusion

LCA software introduction and use at UTA provided evidence of the potential for quick technology transfer and value creation with an emerging tool. The institutionalization of any technology must involve development or advancement of that technology, whether one is a leader or follower in that technical field. Long term institutionalization is the real creation of a differentiating capability. Customers seem to remember the first supplier to offer a new capability.

6. Appendices

6.1 Appendix A: Toyota's Recycling Plans

In 1990, Toyota Motor Corporation (TMC) established a Recycling Committee to oversee all such corporate activity. This committee became part of the newly formed Environmental Committee in 1992. With its high-level management leadership, the committee's activities and recommendations are easily implemented within the corporation.

Short-term (3 years or less) programs of the committee include:

* establish guidelines for reduction in use of non-recyclable materials,
* develop technologies to use recovered waste materials,
* develop pollution-free technologies to recover energy from combustible waste, and develop recycling technologies jointly with suppliers and research groups.

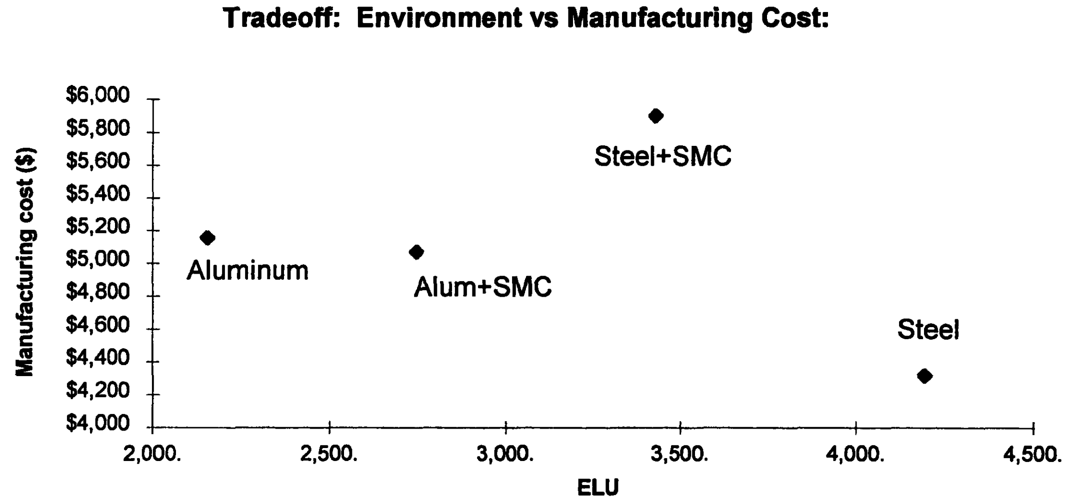
Long-term (4 years or more) committee programs are:

* implement design for recycling practices,
* develop components and processes using recycled materials,
* develop more easily recyclable materials and components,
* reduce overall number of materials used in vehicles, and
* develop efficient, clean energy recovery technologies.

Activities already underway in support of these programs are:

* marking of plastic parts with identification codes,
* planning and developing as many recycling technologies as possible,
* seeking cooperation of supplier companies,
* monitoring U.S. and European recycling trends,
* analyzing Germany's post-use vehicle regulations, and
* investigating adaptability of design for recyclability and optimal material selection practices.

6.2 Appendix B: Effect of materials on environmental impact and manufacturing cost, assuming traditional structure and propulsion systems.[49]



[49] Based on Cost Model and Environmental Impact Model (EPS) for MIT course TPP123 with Field and Clark. Assumes gas at $4/gallon, 10% cost of capital, 10 yr. car life, 12,000 miles per year. The different pointes were based on various materials selected for BIW structure.

6.3 Appendix C: Benchmarking Philips Environmental Design Experience

A full day session was spent with Mr. Philip White, a champion for environmentally friendly design within the Philips Corporate Industrial Design Organization in the Netherlands. The following transcript provides some background information followed by Philip's process for promoting design for the environment within its divisions.

Benchmarking session with PHILIPS

Philip White
Product Designer
PHILIPS Corporate Industrial Design
PHILIPS International B.V.
The Netherlands

Date: August 23, 1995
Notes By: Ennis Rimawi, UTRC

Philip White has a BS in Mechanical Engineering, and a degree in Industrial. He is from the US, and has been working in the Netherlands for Philips for 5 years.

Philips Corporate Design (PCD), a centralized corporate industrial design office, was formed during Philips' last major reorganization, a reaction to diminishing market share. Since most Philips products are consumer products, they decided that all new concepts would evolve from a central industrial design group. This also allows for more effective implementation of centralized design policies.

Company Background

Three corporate offices actively contribute to design for the environment efforts. The PCD, the Center for Manufacturing Technology, and the Environmental Office are involved with SimaPro and the EcoIndicator Method (a system for evaluation developed by a consortium of Dutch companies). The Environmental office, composed of 15 persons, is most involved in the effort, they contribute with policy decisions and high level management support.

PCD has a very close relationship with the product divisions and has a structure to communicate with them. They are directly involved with product design in all product divisions. PCD also makes guidelines for designers on methods. They feel that SimaPro and the Eco-Indicator method are most accurate tools for making decisions. They also advocate the use of higher level tools for other decisions like by using aggregate values for materials per material weight. Assumptions are made about the average impact per product with given materials, for example x EcoIndicator points per pound of microprocessor. Environmental coordinators raised several questions about the data to be used for evaluation. Philips finally helped develop and agreed to use EcoIndicator system.

The definition of significant improvement for Philips is a minimum of a 20% lower EcoIndicator score. Philips has an eco-label for televisions in Holland. But some companies are afraid of an environmentally conscious reputation. Even a good reputation means more publicity, more exposure, and thus closer inspection.

Current Methods of Promoting DFE in Philips

In general, the three corporate groups are promoting DFE with education, and by supplying information and decision tools. Mr. White is not aware of any specific performance measures that support DFE.

Also, the Product Divisions have extensive DFE manuals. A brief overview of a Philips TV Division manual showed that they focus on guidelines, specific materials, and use EcoIndicators to evaluate impact. The manual was 80-100 pages long.

Historically, there have been independent purchases of SimaPro from various individuals and groups at Philips. Now, the Environmental Office will coordinate purchases. The Environmental Office and the Fabrication. Technology Office will each have multi-user versions.

PCD: Mr. White is the environmental expert in the PCD group. To promote DFE he does the following:

1. Evaluate design concepts for other industrial designers.
2. Conduct aggregate or specific product analysis and present findings to divisions, this includes specific information and guidelines.
3. Diffuse DFE principles and tools throughout the PCD organization.

For example, he conducted a study to compare housing materials for TV's. He then presented a pie chart showing the environmental. load of product to the design engineers and product managers.

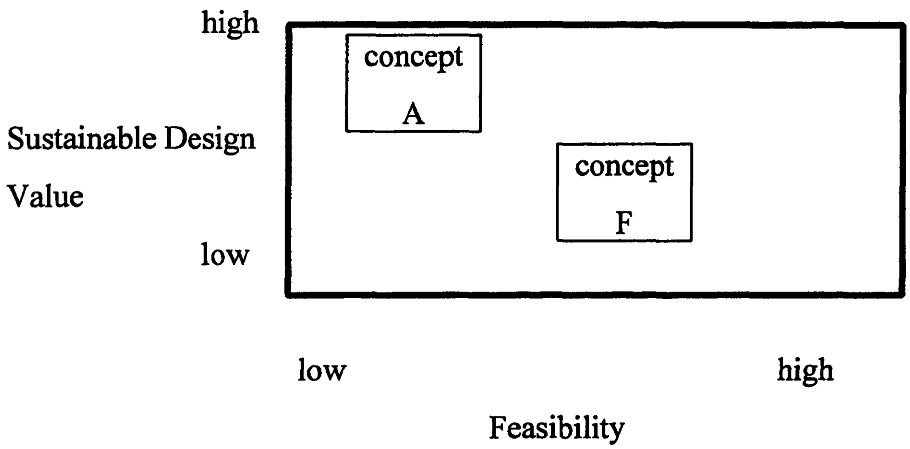
Redesign and Concept design require separate DFE processes.

1. Redesign

Analyze the design, and develop a proposal for reducing the biggest loads. Present this proposal and conduct market and economic studies.

2. Concept

Comparative information is helpful here. Several alternatives are generated, and their feasibility is determined in a workshop using a matrix similar to the one below.



More specifically, product designers go to corporate office with concept sketches and description, PCD then replies with priorities, dangers, etc.

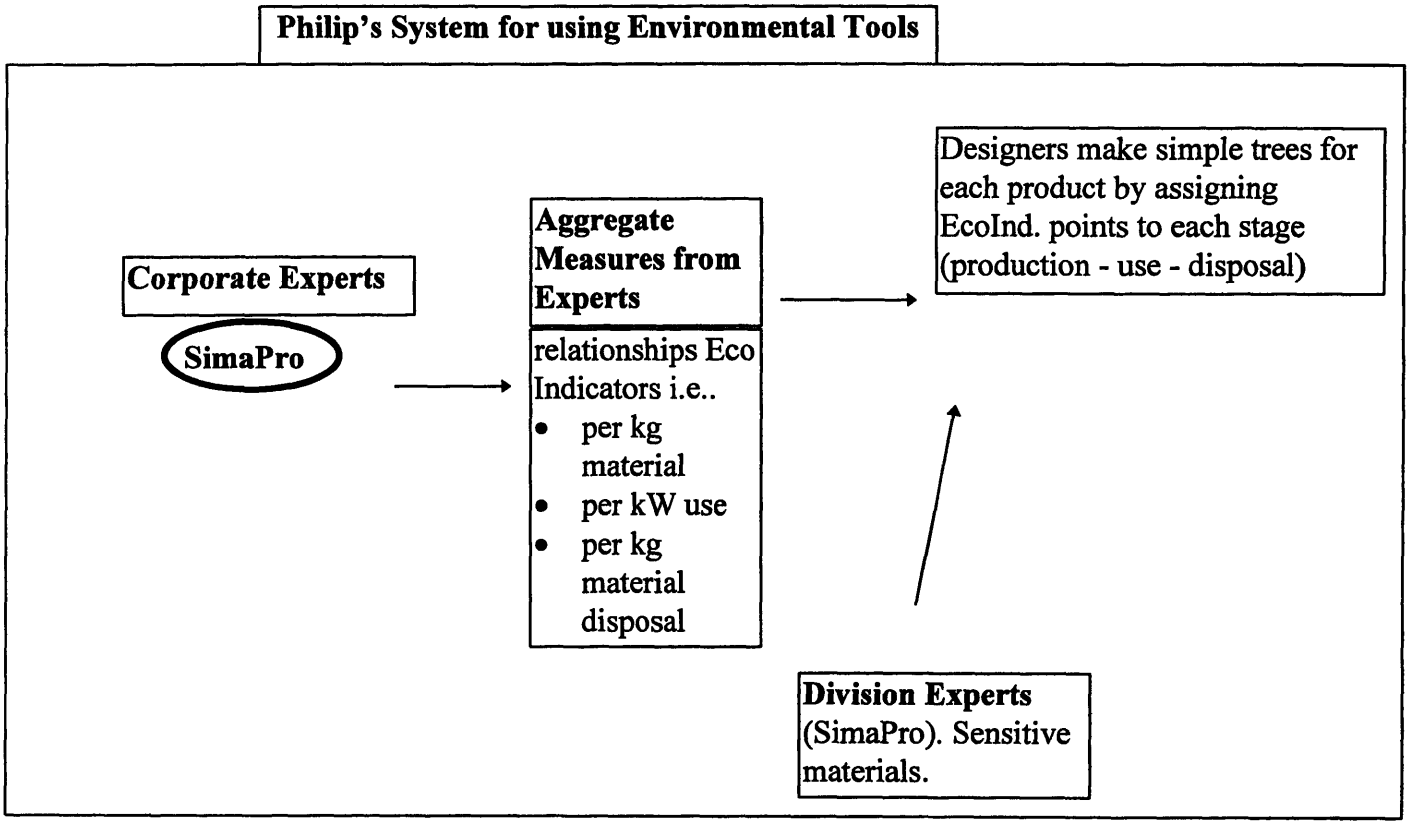
Mr. White will publish a DFE manual for all the designers in the PCD group. This report will include: design tools, information sources/references, expert contacts, and design objectives.

The Center for Fabrication (manufacturing) Technologies develops data bases or purchases them from ETH. But sometimes to avoid complication, they multiply weight for electrical components by copper to develop a best estimate for the components. Also, Phillips acquires a great amount of information from suppliers.

Environmental office is conducting workshops. These workshops revolve around special projects as demonstrations for designers. They last two to three days. Additionally, the Environmental. office is working with technology developers (designers at the product division.)

Environmental Data Management at Philips

The figure below is a representation of Philip's environmental data management system. This system may have been, or be modified at any time.



Certain parts of the system are centralized, and others decentralized based upon availability of information, secrecy, and cost.

Centralized: Methodologies; and general data especially disposal, energy, and transportation information.

Decentralized: Proprietary information, and project specific information. Also, information may also be shared between divisions with related interests.

EcoIndicators can be exchanged more easily than inventory data since EcoIndicators partially hide sensitive data.

A procedure/system is necessary within the design stage, to initiate the development of EcoIndicators for new materials. Designers are "stuck" if they do not have a process for initiating development of impact values for new materials.

UTAE Specific Advice:

- None of the methods are perfect but something is better than nothing.
- Lead styrate in PVC has more impact than PVC itself.
- Actual PVC Incineration is not clearly understood.
- A smaller and stronger thermoset part may have less impact than a larger, recyclable thermoplastic part due to the reduction in weight.
- An electronic regulator is usually friendlier than the user paying for additional fuel.

Information Sources

Mr. Philip White will give a presentation at the New Mexico Industrial Society of America Conference, 12-15th of Sept.

Best Practice companies: Volvo, Phillips, Xerox, German Automotive industry, can find more in eco-design conferences, Unilever has LCA data on most of their products.

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