LIFE CYCLE DESIGN MANAGEMENT IN THE AUTOMOBILE SECTOR A FRAMEWORK

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INTRODUCTION

Many particular stages/impacts Life Cycle Assessment studies and some general life cycle perspective studies have been conducted in the automobile sector, as one of the most unsustainable social function. Because of its importance in automobile life cycle planning, the present study focuses its attention on the Original Equipment Manufacturer (OEM) and its role in improving the overall automobile eco-efficiency. In particular, we tried to build a general framework on design management, as a base for further researches on specific aspects.

1. AUTOMOBILE LIFE CYCLE

An automobile life cycle consists of the generic following stages:

- materials production;
- manufacturing and assembly;
- use and service;
- end-of-life management.

These stages are represented in more details in the process flow diagram in figure 1 http://www.leidenuniv.nl/interfac/cml/chainet/automlif.rtf
Key stakeholders over the life cycle are material suppliers, parts fabricators, Original Equipment Manufacturers (OEMs), customers, service and repair professionals, dismantlers, shredders, nonferrous processors, waste managers, regulators, insurers and investors and, as an extension, the environment.

2. AUTOMOBILE DESIGN MANAGEMENT

Two different areas can be considered in Design Management [Koudate, 1991]:

- Operation Management;
- Innovation Management.

The first one, as involved in the routine business process, works to satisfy the today's client, instead the second one, as involved in the future scenarios, works to satisfy the tomorrow's client. Then, Operation Management can make less improvement in the overall products' environmental impacts, than those achievable by Innovation Management. R&D, Marketing, Environment and Design functions afford Innovation Management in planning product life cycles, as it is represented in figure 2 http://www.leidenuniv.nl/interfac/cml/chainet/designmt.rtf
Today's LCA studies (as per ISO 14040 series) are just in an optical of Operation Management to improve product impacts obtained on the today's based LCA results. In the innovation process, in which no materials, manufacturing, use, maintenance and end of life are specified, the only useful tools can be guidelines and instructions (on paper or software) if previously tailored in the design process. These tools can help

designers in designing innovative product life cycles able to satisfy environmental needs.

3. INPUTS TO ENVIRONMENTAL DESIGN PROCESS

3.1 Life cycle stakeholder needs

It is recognized that the customer is not only the consumer, but there are different classes of customers [King, 1989]. With the goal of designing the life cycle, the marketing function has to consider all the stakeholders involved in the automobile life cycle because each of them has to earn a value in what is involved. For example the marketing function not always considers the dismantlers, shredders and nonferrous processors needs, even if their activities depend on the added value, as it is represented in Table 1.

Table 1: Retirement Value and Costs for a 1984 automobile

Stakeholder	Value and Costs	$/Vehicle
Dismantler	Fixed + Variable Costs	145
	Credit	215
Shredder	Fixed + Variable Costs	116
	Credit	125
Non-ferrous processor	Scrap Value	101

Source: Keolian et al., 1996

Customer needs individuated by the marketing function are usually translated into design requirements by the Quality Function Deployment (QFD) tool [Akao, 1978]. QFD refers to the organization that makes the design improvement effort possible and includes the charts that document the design process. This tool can be adapted to the environmental life cycle design management in two ways:

a) considering the environmental needs integrated in each life cycle customer class, achieving a better integration of environmental quality characteristics in traditional quality characteristic;
b) considering the environmental customer class, achieving a better consideration of life cycle impacts with respect to environmental quality characteristics.

A basic format of QFD Quality Table for the a) case considering the consumer customer at the automobile system level is represented in figure 3 http://www.leidenuniv.nl/interfac/cml/chainet/QFD.rtf

3.2 Life Cycle Technology

Technology can be defined as the ensemble of technical and organizational knowledge shared by technology community and practicioners. The importance recognized to technology for economic success is now extended to an environmental and life cycle perspective. In the following we synthetically describe the two most important activities R&D should manage to achieve innovative inputs to the design process.
The generic process of an innovative technology acquisition [Rogers and Shoemaker, 1971] usually follows these principle stages:

- Technological informative sources creation and enhancement, interested to supply useful information;
- Promotion and diffusion of preliminary information regarding specific technologies
- Desired source and technology identification and selection;
- Specific technology information acquisition, useful and sufficient to decide if acquire the specific technology or not;
- Organizations individuation owning the specific technology and selection of the organization able to supply at best technical and economic terms;
- Technical and organizational reengineering of organizational structure in the function involved in using the new technology;
- the selected technology buying and transferring;
- Acquired technology utilization and development of all necessary technical and organizational activities of supporting;
- Testing and final inspections.

The principal technologies in an automobile life cycle are shown in Table 2.

Table2: Principal Technologies

• Metalworking	• Combustion engineering
• Glass technology	• Manufacturing automation
• Rubber technology	• Presswork
• Controls engineering	• Metal cutting
• Mechanical engineering	• Painting technology
• Assembling and disassembling operations	• Electronic engineering
• Welding	• Electric engineering
• Technology of synthetic materials	• Remanufacturing technology
• Technology of material recycling	

Adapted from Lowe, 1995

3.3 Environmental needs

Last but not least, environmental needs enter in the design process as environmental corporate policies, strategies and objectives, basic environmental design guidelines [Canadian Standard Association, 1995] and LCA databases (1). In order to have a representation on the need to develop an environmental design process, environmental needs from U.S. literature are synthetically expressed in the latter.

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(1) The italian database for LCA (project manager: R. Scialdoni) is ready and going to be officially presented.

a) Materials production

The automotive industry is among the most resource intensive of all major economic system: in USA it represents at least one-third of the consumption of iron, lead, platinum and synthetic and natural rubber. Further on, a US- built car in 1994 had steel accounted for 54.8% of the vehicle by weight, iron 12.9%, plastics 7.7%, fluids 6.0%, aluminium 5.7% and rubber 4.2% [AAMA, 1994]. In # 4.3 we describe the role of Innovation Management in achieving aggregate reductions in environmental burdens improving the life cycle impacts by design practices/requirements.

b) Manufacturing and assembly

Motor vehicle, car bodies, vehicle parts and accessories waste and emissions in this life cycle stage account for 62% of all releases and transfers of the whole transportation equipment [US EPA, 1992]. About a half of the cited 62% are occurred by painting and coating operations. In General Motors, packaging for assembled vehicle was estimated about 25 lbs, whose about 41% is recycled, 43% landfilled and 11% combusted with energy recovery [Williams, 1995]. Average energy intensity to manufacture a typical Ford vehicle is about 7500 BTU/lb. [Sullivan, 1995].

c) Vehicle use and service

Resource depletion for automobile use includes product component (all the replacement parts: tires, hoses, wipers, lights, belts, filters, batteries, etc.), process component (fuel, fluids and associated packaging, highway infrastructure), distribution component (packaging associated with replacement parts). But the most serious environmental issue facing the automobile is surely its enormous consumption of non-renewable energy. For instance, in 1992, USA transportation accounted for 65.1% of the total USA petroleum consumption and automobile consumed 58% of USA total transportation [Davis, 1994]. The primary air pollutant from the use stage of the automobile life cycle include Carbon monoxide (CO), Nitrogen oxides (NO_X), particulate matter less than 10μ (PM-10), Sulphur dioxide (SO_2), Volatile organic compounds (VOC) and lead. Table 3 shows that (except SO_2 and PM-10) highway vehicles contribute significantly to total American emission.

Table 3: Total American Emission (Millions of Short Tons), 1994

Sector	CO	NO_X	VOC	SO_2	PM-10	lead
Highway Vehicles	61.1	7.5	6.3	0.3	0.3	0.0014
Total national	98.0	23.6	23.2	21.1	45.4	0.0050
Percent of total	62.3	31.9	27.2	1.4	0.7	28.0

Source: US EPA, 1995

The most significant impacts on vehicle maintenance are the too often no environmental friendly behaviour of the automobile shop repairers and waste management of used tires. In this last field the principles tier manufacturers are involved in improving the reutilization of used tires.

d) End-of-life management

The automobile retirement process is defined in figure 4 http://www.leidenuniv.nl/interfac/cml/chainet/automret.rtf

The average percentages of material categories to recover in vehicle are indicated in Table 4.

Table 4: Categories of Material Use in 1984 vehicles

Material Category		lbs	% of total
Total vehicle		3142	
Ferrous metals	All steel	1747	
	Iron	454	
	Total	2201	70.1%
Non ferrous metals	Aluminium	137	
	Copper/Brass	44	
	Stainless steel	29	
	Zinc	17	
	Powder metals	19	
	Total	246	7.8%
Non-metals	Plastics	207	
	Fluids, Lubricants	180	
	Rubber	133	
	Glass	87	
	Other	88	
	Total	695	22.1%

Source: AAMA, 1994

Then with a 95% recovery rate for metallics, 74% of automotive materials would be recovered for recycling. The amount of energy in this stage (dismantling, shredding, separation, transportation) is relatively small compared with other life cycle stages (about 600 KJ/Kg).

4. ENVIRONMENTAL LIFE CYCLE DESIGN (LCD) PROCESS

This paragraph exposes the existing methods of planning a design process and how to integrate environmental issues in. Then a map of environmental practices, requirements and consideration is briefly explained.

4.1 Design process planning

Design process can be imagined as a co-ordinated process of breakdown, elaboration and assembling. The principal methods used in design process planning are:

- Phase analyse (basic activities);
- Block chart analyse (detailed and interrelationed tasks);
- GANTT (basic activities on a time scale);
- CPM/PERT (detailed, interrelationed and time scaled tasks).

Phase analyse is used to clarify the logic sequence of each design phase (i.e. activity) The following six major activities are identified in automobile product development:

1. Concept generation
   a) Specify target market
   b) Identify customer needs, wants, problems
   c) Vehicle description
2. Product planning
   a) Establish targets for vehicle: quality and environmental performance, styling, cost,
   b) Construct clay models
   c) Develop corporate business statement, potential sales and profit

3. Vehicle engineering
   a) Determine overall feasibility of vehicle: fit, function, component, compatibility
   b) Develop prototypes
   c) Verify design intent and adequacy
4. Product engineering
   a) Focus on single vehicle
   b) Design individual parts in detail
   c) Develop prototypes
   d) Conduct extensive testing of parts, components, systems in terms of durability, reliability, noise, ease of maintenance
5. Process engineering
   a) Design production facilities, processes, tooling
   b) Develop production scheduling and flow of materials
   c) Design material handling
6. Pilot run
   a) Train production personnel
   b) Verify processes and tooling
   c) Produce initial vehicles for testing

Each activity can be divided into a hierarchy of tasks, subtasks and sub-subtasks. At the base of the hierarchy is the set of activities, the unit tasks, beyond which further decomposition is not attempted. In product development there are two types of unit tasks: engineering and co-ordination. A project can be thought of as a network of interrelated engineering and co-ordination tasks. In concurrent engineering the goal is to optimize the network, that is to reduce the project duration (lead-time) and is usually adopted CPM/PERT method [Della Rolle, 1991].

4.2 Integrating environmental issues in LCD

As inputs to design are established, the project manager plans the design process dividing it in activities on a time scale. Then, supported by environmental experts, the project manager finds the positioning of environmental influence points and designs the environmental information flow as shown in figure 5 http://www.leidenuniv.nl/interfac/cml/chainet/GANTT.rtf. Setting environmental influence points in the design process achieve to design environmental issues in the design process and to influence all the sub-activities of the hierarchy, by the environmental information flow [Kaila, 1997]. It means that environmental issues are built in existing instructions, templates and software aided design. No separate document or software has to be created. In this way no environmental issue is by-passed for not enough time and environmental trained designers are more environmentally motivated.

4.3 Environmental practices in LCD

In order to make a reference to the mentioned company-specific integration, generic practices, requirements and considerations of the design process, for every life cycle stage, are expressed below.

a) <u>Materials production</u>
   Environmental considerations on material specification regard especially to avoid toxic substances, to use renewable/recycled/recyclable materials, to reduce material usage, to use low energy content materials, to reduce transport and packaging.

b) <u>Manufacturing and assembly</u>
In this context requirements regarding vendor qualification/inspection should be considered. Environmental requirements in vendor qualification/inspection regard the valuation of the suppliers' Environmental Management System (as per ISO 14001 and/or EMAS regulatory) and ecolabelled products (as per ISO 14020-1) even by auditing activities (as per ISO 14011). Environmentally conscious manufacturing design should consider alternative production techniques, fewer production steps, low/clean energy consumption, less production waste, few/clean production consumables.

c) <u>Vehicle use and service</u>
Environmental design for utilization should consider low energy consumption, clean energy source, few consumable needs, clean consumables, reliability and durability, environmental instructions for the consumer. In particular to limit the energy consumption and emission at this stage, innovation management is going towards different paths:

- alternative fuels for internal combustion energy: Liquid Petroleum Gas (LPG), Natural Gas (NG) and Alcohol, [Nichols, 1993], Hydrogen [Shelef, 1994]
- alternative vehicles: electric and hybrid vehicles [Riley, 1994], fuel cell vehicles [Haggin, 1995], hypercars [Lovins, 1994].

Environmental design for maintainability should consider easy maintenance and repair, strong product-user relation, modular product structure and selection, education and inspection of the maintenance services.

d) <u>End of life management</u>
Environmental design for end of life management should consider reuse of the product (component), disassembling, recycling, remanufacturing and safe incineration. In this particular stage, it is still difficult to:

- increase the amount of recycled plastics, above all because of the different plastic resins used, even if a 76% of plastic is made by recyclable thermoplastics. [Flynn, 1994]
- increase the amount of recycled tires (4%), compared with 63% landfilled and 33% used as energy source (more efficient than coal) [Reese, 1995]
- substitute mercury or mercury compounds (in electric switches, ABS, virtual image instruments panel) [Natchman, 1996]

5. ENVIRONMENTAL DESIGN REVIEWS

Design review is an essential technique in Design Management for evaluating a proposed design to assure that the design [Juran, 1988]:

- will perform successfully during use
- can be manufactured at low cost
- is suitable for prompt, low-cost field maintenance

Design reviews are planned and conducted at several phases of the progression of the design and at several levels of the product hierarchy.
In order to improve environmental life cycle design management, especially in comparing obtained results with established targets, design reviews should involve environmental experts in multifunctional design review's committees and integrate environmental issues in design review's checklists.

7. ENVIRONMENTAL LIFE CYCLE ASSESSMENT

At an advanced design process stage, i.e. at the end of the process engineering activity, the automobile life cycle is defined. Therefore in order to evaluate the environmental life cycle impacts of the innovative automobile and to find further improvements, an environmental life cycle assessment (as per ISO 14040) should be conducted.

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