A total product system concept: a case-study of the smart™ automobile

J P Warren*, E Rhodes and R Carter****

*** The Faculty of Technology, Centre for Technology Strategy**
The Open University in the East of England,
Cintra House, 12 Hills Road,
Cambridge, CB2 1PF, UK.
Tel 44-1223 364721, Fax 44-1223 355207
j.p.warren@open.ac.uk (author for correspondence)
http:www.open.ac.uk

**** CASCAID,**
The Open University,
Walton Hall,
Milton Keynes, MK7 6AA, UK.

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Abstract

Increasing demand from consumers plus European Union (EU) legislation has raised awareness within the automotive production sector of the urgent need to reduce the environmental impacts from the three main stages in vehicle life – car manufacture, car use and end-of life vehicle processing. The paper reviews how the originator and manufacturer of the smart™ automobile has worked directly with its main system partners to address environmental issues in these three stages while optimizing performance across the parameters of commercial viability. This required the creation of strategic relationships within the supply chain. Overall, this innovative approach is viewed in the context of a total product system. The smart™ car highlights the following critical areas: use of modularity in product design and production facility layout; emphasis on partner participation from product creation to after sales; and use of a highly customized build-to-order product system to 'green' the entire supply chain.

In particular, the case study compares the process characteristics employed at the smart™ car factory, called 'smartville', to more 'traditional' approaches to vehicle manufacture. It examines these issues in a preliminary attempt to establish the actual or potential reduction of environmental impact in the three stages of vehicle life, including the role of main suppliers in this process.

Key words:
total product system, MCC smart™, sustainability, recyclability, automobile components,
ELV (end of life vehicle), supply chain, modularity, product lifecycle.

NOTE: smart™ is a DaimlerChrysler trademark and as such smart™ is implied in all cases. The word is not capitalized as part of this trademark process.

Introduction

For readers who are unfamiliar with it, the smart™ car is a two-seat city-car. Major events in the development of this project, including its extension to new smart™ models, are indicated in BOX 1, and the global unit sales figures are shown in Table 1 (Birch, 1997, Mildenberger, 2000). The production of very small automobiles has a long history in Europe, partly because of the constraints of ancient street layouts and as a means for bringing car ownership within the reach of lower income households. Recent developments reflect increasing concern for the environment, and increasing congestion in many European cities.

In general, the historical story of smart™ can be seen to have these major steps: product creation from 1992-1994, product realisation from 1995-1998 and market penetration, albeit in limited quantities, from 1999-2002. Table 1 shows the relatively low uptake of smart™ into the predominantly European market. The story continues with the smart™ product range expanding both in the form of new vehicles, but also in the form of accessing transport to the general public. In the broadest sense the end user (e.g .the customer) should be considered within the entire supply chain along with the major automobile sub-components suppliers that one may usually think of. This paper attempts to address how much does the smart™ automobile really represent a total product system concept, and more importantly in which areas of the supply chain system does it exceed other vehicle products. Conversely there are parts of the smart™ system which need further innovation for smart™ to become a more holistic product, for example the increased integration of smart™ use for transport for those who do not privately own a vehicle. Firstly a short overview of how smart™ fits into the European car market is presented. Beyond this the paper explores the way smart™ works with various systems suppliers to achieve best in class supply chain management, especially when considering the drive to incorporate practices which are considered to be less environmentally damaging.

BOX 1: Important events in the history of smart™, sources: authors' interviews and survey.

1972	A radical project proposal for a 2.5 metre length car for town centres was considered by Mercedes for the year 2000. Project was shelved.
July 1992	The executive committee of Daimler Benz is shown the prototype for a city automobile in the design studio. The committee gives the go ahead. Meanwhile, Nicholas Hayek, the SMH Chairman coins the term Swatch-mobile and claims a working prototype exists.
Dec 1992 – Jan 1993	Hayek meets with Mercedes officials to show them what types of panel design and interior/exterior he is working on.
March 1994	The Micro Compact Car (MCC AG) joint venture is formed between Mercedes Benz AG and SMH Group. (Swiss Corporation for Microelectronics and Watchmaking Industries).
June 1994	Large numbers of prototypes are built and tested to high mileage.
Oct 1995	Foundation stone laid at Hambach, France, for a highly innovative manufacturing plant, – smartville – following rejection of some 50 other sites.
Sept 1997	smart™ is premiered at Frankfurt International Motor Show.
Oct 1997	smart™ factory officially opens.
Oct 1998	smart™s begin to come to market after some initial chassis problems and quality issues.
Nov 1998	Daimler-Benz merges with Chrysler to form DaimlerChrysler (DC).
Dec 1998	Mercedes Benz (cars & truck division of DC) takes full responsibility for MCC smart™.
1999	Internet sales launched.
1999	smart™ centres (including sales and services network) re-launched under Mercedes stewardship.
2000	Further integration of smart™ network into DC.
2001-2002	Right hand drive models launched in Japan and UK.
2003	smart™ Roadster scheduled for release.
2004	4-seat smart™ scheduled for series production.

In several respects, the smart™ car fits the criteria for an ideal city car. Its two seat capacity matches the European average vehicle occupancy of 1.2 persons per vehicle, while small size is combined with a high standard of safety. It is spacious inside yet still small enough to be very convenient for congested city driving. It also has comparatively low environmental impact, not just in use but over all stages of the lifecycle. Neither fuel efficient small cars nor two cars are unique in Europe, but smart™ is innovative in several respects. This reflects its emergence from a partnership between Mercedes and Swatch – see BOX 1. It draws strength from Mercedes' presence behind the smart™ brand, the standard of product engineering, lively performance, a high standard of interior specification, and an emphasis on safety. The influence of Swatch is reflected in a strong fashion element in interior and exterior styling. These attributes combine to bring environmentally conscious car use closer to higher income, city-based consumers. The striking design of smart™ is shown in Figure 1.

FIGURE 1: A fleet of smart™ cars at a dealership awaiting collection by customers.

Important elements of innovation follow from emphasis on modularity in contrasting modes, including mobility. The physical modularity of smart™ is immediately apparent through the visually striking use of plastic body panels. These are a direct reference to one of the original partners involved, SMH – who pioneered plastic watches in the form of Swatch watches. The panels on the smart™ are replaceable, allowing end users to re-configure the colour of the vehicle for a cost that amounts to approximately 10% of the original vehicle purchase price. An example of this high use of modularity can be seen in Figure 2, which is the major body component on which most of the larger sub-components are either attached or fitted. This 'cell', or cage, acts as not only the body but it also incorporates the crumble zones required to achieve the high ratings in the European crash tests. In design terms the cell gives the car a prominent line since the cell is visible on the exterior. The use of the cell within the smart™ assembly has been compared to the way aviation manufacturers make the most of aerospace frames when building aircraft.

FIGURE 2: The Tridion™ safety cell, after complete assembly, by Magna Chassis, being conveyed to the main smart™ car production line.

The car was originally targeted as a second car, largely for city use, but it was also associated with initiatives that envisaged alternative approaches to individuals' mobility. These offered incentives for using cars like smart™ outside the prevailing owner-driver model. They include reduced public transportation fares for inter-modal journeys, reduced parking fees, preferential car rental agreements, and incentives for car sharing. In some parts of the EU, these initiatives have started to evolve – for example, via lower charges for parking and for car-wash – the latter reflecting lower use of water, detergents etc. Smart™ thus appears to be contributing to reducing impact from personal vehicle use, but on a limited scale so far, as is indicated by the unit sales figures previously shown in Table 1.

Table 1: Annual unit sales of smart™
Source ANE 2001, 2002; Automotive News 2000 (provided courtesy of JATO Dynamics)

Year	Units sold
1998	17,000
1999	79,900
2000	102,100
2001	101,937

This paper provides a preliminary consideration of the impact of smart™ across the total process of production, product use, and end-of-life processing within the concept of a total product system. As will be seen, this involves both the vehicle manufacturer (MCC – Micro Compact Car), and its partners in the supply chain.

Supply chains, networks, and 'total product systems'

Increasingly, large companies in the EU and the US are emphasizing 'management of the supply chain'. They attempt to manage the highly complex flows of materials, components, order and other information that extend through the various stages in the manufacture and distribution of end products. The focus of competition is thus moving away from competition between individual companies towards competition between supply chains –more accurately, between supply *networks*. Through combinations of methods such as concurrent engineering, kaizen and product life planning which are applied throughout a supply chain, they aim for continuous extension of competitiveness. The emphasis on supply chain co-ordination has a number of roots, including attempts to match current highly demanding, diverse market conditions, and the application of information and communications technologies in business-to-business electronic commerce. Long established methods developed by leading Japanese companies – especially, Toyota – and their manifestation in competitive success have been particularly influential. While this influence was initially seen in manufacturing sectors, it is now evident in service sectors.

These methods emphasize long term close relationships between companies and their suppliers. The role of large companies that occupy strategic positions close to the point of delivery to consumers and other end customers are particularly significant; examples range from vehicle manufacturer to retailing. Typically, these are prime movers that seek to co-ordinate activities across all the diverse stages and types of activity – from raw materials processing through to the assembly of end products. This co-ordination is mainly undertaken indirectly through collaborative relationships with core suppliers who take responsibility for the design and supply of main product systems and/or sub-systems. The core suppliers also seek to manage their own supplier base – the network of companies involved in the system or sub-system for which they are responsible. Longer term, the process shifts emphasis away from performance within individual companies to performance across a network of companies.

In the ideal-type model, the total supply chain is co-ordinated across all areas and stages of activity. One of the critical elements of this model is the comparatively high proportion of total production costs accounted for by the supplier base – typically 70% or more. For large companies, such as most western car manufacturers, this represents a large scale shift from ‘traditional’, vertically integrated, mass-production – referred to later as ‘the traditional model’. In this model, the main company undertakes most types of activity internally, and may account for 70% or more of total production costs. Another central element is the use of ‘just-in-time’ approaches to production. In their mature forms, these provide high standards of product quality at each production stage, with emphasis on very low batch sizes within flexible, high variety, production flows.

At all stages, production flows are ‘pulled’ by actual demand for different product variants. There is emphasis on minimal, ideally zero, levels of waste, such as those arising from producing faulty parts, or from high levels of stocks and work-in-process. Wider emphasis on the efficient use of resources within companies and across supply chains – affecting use of human resources, production capital, space and logistics – has been captured in the concept of ‘lean production’ (Womack et al, 1990).

The environmental impact of these fundamental shifts in the organization of production <u>appears</u>, in general, to be positive – although systematic comparisons do not appear to have been undertaken and face considerable difficulties. For instance, the impact of just-in-time methods is necessarily associated with very low levels of defects in the supply of components etc. and, where suppliers are efficient, with commensurately low levels of waste of materials, energy, human effort and storage space. However, just-in-time (JIT) supply can also be associated with relatively high environmental impact from the transport movements – those needed for the collection and delivery of small part lots. Furthermore, JIT systems can lead to an overall increase in environmental impacts, especially when overall deliveries increase to such a point where local congestion delays the supply of components. It should be clear that various scenarios need to be examined carefully before implementation.

The performance of all stages of the supply chain in terms of resource use and impacts became a focus of attention as a consequence of environmental regulation by regional, national and other bodies, and following initiatives requiring traceability such as ISO 9000. However, assessment of environmental impact needs to extend beyond the point of sale to take in total product life. This is partly because businesses are increasingly aiming to generate, or to increase, revenue flows in the ‘aftermarket’. They now view performance in this area as important for total competitiveness. This stage extends from the point of sale through to a product’s end-of-life, and emphasis is moving beyond supply of replacement parts towards provision of a variety of services that support or enhance product use and functionality. Assisted by Internet based links, badge manufacturers seek to sustain long term relationships with customers, such as by providing on-line diagnosis of appliance faults and linked, rapid response from warranty support services.

Recent environmental regulation in the EU has also focused attention on the aftermarket stage of product life. Much of this relates to the performance of products in their use. In the case of non-durable products, this may aim to reduce the overall environmental impact through, say, return of packaging for reuse. For durable products from refrigerators to cars, such regulation is establishing mandatory performance targets, most obviously in terms of energy efficiency and emissions levels. This should encompass the extension of product life, such as through the refurbishment or re-manufacture of products in the later stages of their use (Guide et al, 2000). But again, similar to JIT, lifetime optimisation which leads to a longer lifetime can sometimes result in higher environmental impacts. In other words different products will require different optimisations, but for the major investments required for tooling, pressing, etc. in vehicle body manufacture, a core body which remains stable for more than 7-10 years can in theory lower environmental impacts.

The developing EU standards also focus attention on the final stage in product life – end-of-life processing. Pressure to improve environmental performance in this stage is partly indirect, for example, following from increasing restrictions on, and rising costs of, disposal in landfill sites. It also results directly from mandatory recycling targets and from requirements that manufacturers take responsibility for collecting their products at the end of their life and for optimising their reprocessing.

Growing emphasis on the environmental characteristics of product performance, and on end-of-life reprocessing, is reshaping approaches within production systems – such as in product design, in materials selection and in manufacturing processes. Revenue driven approaches to product support throughout the aftermarket stage add to a need for companies to focus on the total product life cycle. This can involve long time scales since supporting a product through to the end-of-life extends, for instance, beyond ten years for cars, and twenty five years or more in aviation. Within these long timescales, there is scope for 're-manufacture' – of components and/or of the total product – to support life extension, for either the product owners or new users. The potential economic viability of this approach is indicated by Guide et al (op cit) who provide examples of re-manufacture and of high levels of profitability. To establish the full extent of the environmental impact of products, particularly those which require energy and other material inputs for functioning, and of the full potential for reducing those impacts, requires approaches that extend well beyond concern with the supply chain. This entails a focus on the total product system, encompassing the full cradle to grave product cycle, and the wide range of actors and interactions involved. This focus leads to emphasis on the development of sustainable product systems.

We address some of these issues in relation to the smart™ car.

Creation of a total product system

The Mercedes-Benz automobile division (part of Daimler Chrysler [DC]) took full responsibility for the smart™ car and for MCC smart™ when SMH (Swatch) withdrew from the project in 1998. In a recent presentation a DC representative explained how they had developed an approach that incorporated a new brand, a new way of production and a new method of sales distribution (Renschler, 2000). This they did in a relatively short period of time but not without incurring substantial costs and product launch problems.

It is clear that launching the smart™ car could not have been achieved without the strong support of core suppliers whose plants are co-located with the main assembly factory in *smartville*, located in Hambach, France. The approach reflects Toyota's methods, but joint development on a greenfield site by MCC smart™ and lead suppliers has pushed the model substantially forward. Mercedes forged strong links with these suppliers through their involvement in product design from very early stages. These "system partners" shared in product development, taking much of the responsibility for major modules such as the cockpit and complete door assemblies, beside sharing in investment and financial risk. They developed their own solutions to component design and sourcing, within parameters agreed with the lead company – MCC. Some of the main elements of the contrast between the approach at smartville and 'traditional' models are summarized in Table 2.

Table 2: Process characteristics in the supply chain for a 'typical automotive factory' and for smartville

Process	Traditional	'*smartville*'
(a) product design and development	little collaboration with suppliers bidding for job after product is proto-typed	systems partners have a large responsibility to collaborate and achieve lower costs work with supplier very early in design stage
(b) ordering and purchasing	short term, focused on supplier price – not supplier cost and capabilities	long term contracts, emphasis on cost rather than price, with supply to advanced JIT standards
(c) supplier–lead manufacturer relationship	arm's length	very close classed as partners
(d) remuneration of production employees	salaried, bonus decided by upper-management highly tiered payment hierarchical	self-set teams with objectives (bonus to 12%) much flatter structures
(e) production layout:	far apart, historical layout, no room to grow	brown and greenfield site, integrated; basis for potential growth
(f) production facility:	historically based with legacy problems	designed from scratch, best in class for environment and workers
(g) warranty responsibility:	sole to final assembler	shared by all, traceability to individual component producers
(h) payment terms	when shipped to assembler	when final product complete or sold to customer
(i) supplier facilities	owned by supplier	land owned by assembler, total Hambach site managed by the vehicle assembler and on-site suppliers

We emphasize the summary nature of Table 2 and our concentration on the issue of incorporating environmentally sensitive practices within the supply chain. This must be viewed in the context of two reservations. First, the development of the smart™ car, has been followed by other vehicle assemblers who have surpassed some of the environmental targets set for smart™. Second, while Table 2 concentrates on issues of production organization, the wider limitations of the smart™ example need to be kept in mind. For instance, the introduction of smart™ car has not been accompanied by the extension of associated mobility concepts on any substantial scale. Smart™ has not yet succeeded in moving the private user away from personal vehicle habits anymore than any other mobility project. Clearly further thinking is needed with this issue probably with government intervention and some form of policy implementation.

Some examples illustrate the items in Table 2. Concerning 3 (a) and (c), the extensive use of partnerships for collaborative solutions seems to be more effective than, say, solutions developed in traditional 'arms length' relationships where waste of effort, energy and materials, and the investment health and innovative capabilities of a supplier are little concern to those purchasing components etc. An example of the collaborative approach at smartville is a large cost-reduction programme (Target smart™), which involved the partners in generating ideas for modifying specifications to reduce costs. Approximately 15% of the cost was cut from many of the components with about 60% of these savings achieved through renegotiation with suppliers (Chew, 2001a). In some cases, MCC accompanied its partners on visits to component makers to expose various 'tear-down' prices of sub-components. MCC were able to utilise Daimler-Chrysler information on various shared sub-components in order to compare costs in a benchmarking exercise with MCC's partners. The other 40% of savings came in the form of re-engineering suggestions from the partners and their suppliers (Chew, 2001a).

These savings followed from the revision of specifications to match a small car profile rather than the more expensive premium engineering solutions that characterize Mercedes. Because some MCC suppliers already manufactured components for other car manufacturers in the small car segment, it was relatively straightforward to transfer this product knowledge to the smart™. One example included an axle assembly which was modified to reduce material costs as well as to increase driving performance (Chew, 2001a). In another example, cost savings were made through transfer of assembly of a Bosch headlamp sub-component from smartville to the Czech Republic. The use of competitive logistic calculations also generated a cost savings.

These benefits identified within 3 (b), (e) and (f) are:

- direct delivery to auto-assembly line (via extensive conveyor systems);
- no inspection by assembler when parts received;
- direct ordering with shared responsibility for stock control;
- partners have their own entry ports into MCC's assembly area.

Each of these gains contributes towards greening of the supply chain and to higher levels of production efficiency. For instance, emphasis on consistent high standard conformance with quality standards at all production stages maximizes efficiency in the use of energy and materials. Where components can be made locally, large scale reductions in packaging waste and in transport-generated emissions become possible. It is estimated that more than 95% of the transport costs for the main modules have been reduced compared to a typical automotive assembly plant (Treneman, 2001).

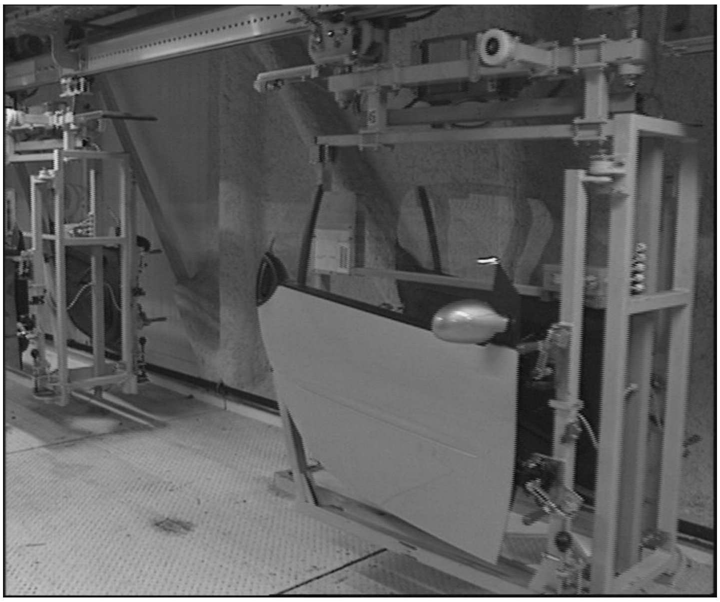

FIGURE 3: A complete pair of doors from the Magna doors production facility ready for fitting to the vehicle.

Furthermore, with direct ordering and correct sequencing of modular units (for example engine type, wheel/tyre configuration, interior/exterior colour, door panels, etc.) a built-to-order (BTO) production system can be achieved. In an efficient BTO system, no vehicle is assembled without a final (named) consumer or other end-user. BTO appears likely to contribute to reduced environmental impact – for example, stocks are minimized because manufacture is largely confined to units for which firm orders have already been placed. Using BTO incorporates consumers' actual demands as a controlling input to the production process. For instance, production of vehicles with unpopular colours or features should, ideally, be avoided. Where a high level of co-ordination has been developed across the various stages and branches of a supply chain, reductions linked to BTO extend throughout the production network.

Furthermore, experience in low inventory production systems shows clearly that the wasted energy, materials and so on that are associated with rework and mislaid or damaged components in poorly organized production systems, can be expected to reduce correspondingly. Further gains follow from reduced transport and storage. But direct measurement of the effects of BTO is difficult - see Hines, 2002 for a discussion of the issues. An example of a completed sub-unit is shown in Figure 3, the delivery of the doors to the production line. Door panels are produced by Dynamit Nobel and colour coated by Cubic Europe both located at smartville. The panels are then configured by Magna Doors and supplied as required to the line in pairs. Each pair of doors is BTO with specific interior and exterior colour choices and variants, and these are delivered in pairs to the appropriate vehicle under construction at the required time. The interior door fittings are shown in Figure 4.

In Table 2 (g), (h) and (i) the sharing of risks is shown, in both the warranty of components and the potential loss or increase of the overall business of the product. The main impact of co-location is that the vehicle manufacturer, as site owner can look holistically at the entire site in order to carry out a comprehensive assessment of resource use on the site. The factory buildings (see Table 2 (f)) are all built from sustainable materials, and all processes within smartville are both CFC and formaldehyde free (Treneman, 2001). The factory also recycles the heat and power created and water used on the site. With off-site suppliers, additional environmental burdens need to be added to the overall analysis.

FIGURE 4: Detail of the left hand side door interior, showing fittings.

Panels: an example of modularity within an increased product range

The offer of a modular product to customers includes the opportunity to update or change the colour of the car by replacing door and other panels. As yet, it is not clear how frequently this will occur per car-lifetime. (An indicator may be provided by a smart^{TM} supplier who claimed that businesses have developed – in Italy – to provide replacement panels to fashion conscious consumers on a short term rental basis.) This facility can be interpreted in several ways from an environmental perspective. For the consumer, extending a product's utility by updating its appearance is a bonus point from which, in theory all parties gain something. Less obvious to end users is that a more extensive colour range is needed. Smart™ regularly changes the colour range, but previous colours need to be available for repairs, offsetting other environmental benefits. A further factor is the potential for reduced impact from model updates. Traditional automobile facelifts occur regularly during the product lifecycle, supported by development expenditure to ensure the latest features are incorporated so that market competitiveness is sustained. Increasingly, these changes are preplanned in the initial stage of model development as part of product life planning.

The body panels (door panels, front and rear outer-skin) play a central role in product refresh. They are comprised of Noryl GTX polyphenylene oxide resin produced by GE Plastics (Pryweller, 1998). The component manufacturers worked with MCC on the plastic body components. Part of the total product design process involved selecting materials that would limit environmental impact, and that would behave as a rigid plastic. The major panels are injection molded by Dynamit Nobel AG, including front fender, outer door, front, rear valence and wheel arch panels. The panels are then unitized to form a single wrap-around body product. Due the high precision of the molding process, very little scrap waste is produced, and that is collected for recycling into the feedstock of the injection process. Panels are produced in 4 basic plastic colours and then painted by electrostatic powder paint processes that eliminate all solvents, sludge and effluent (Treneman, 2001). The panels are 100% recyclable thermoplastic which are designed to be reversibly deformable, avoiding dents from parking bumps and impacts of up to speeds of 15 mph (Birch, 1997). This type of life-long design is important to ensure increased resistance to damage in the minimal parking space of many European cities.

The plastic panels have a single clear paint overcoat to enhance resistance to fading. The absence of primer and base coats saves some 50% of the costs of a typical painted body (Pryweller, 1998) reducing the resource impact of manufacture. In addition to high strength and bright colour, the use of plastics reduces overall vehicle weight. The car mass is about 725 kg – some 300 kg less than typical steel body compact vehicles (Pryweller, 1998; Wrigley, 2000). In the case of door panel manufacture, analysis of the total product system needs to consider the trade-offs between plastic and other materials. An important factor in comparison is the predicted vehicle unit volume, since the dies used for plastic panels have an expected life time of only some 200,000 vehicle platforms (Pryweller, 1998). In contrast, metal pressing dies can generally be used over a much larger volume – potentially over the entire product life time. Another consideration is consumer opinion. Steel and aluminium tend to be viewed as safer than plastic – regardless of what vehicle safety tests show. Such perceptions can be difficult to change.

Extending model diversity

The smart™ brand is being extended to other products, most notably a 4-seat, 5 door smart™. This will require additional production facilities. In a simplistic view, this growth is counter to green practices within the supply chain. At first glance, a doubling in component diversity could be seen as having a major adverse impact on both supply chain efficiency and the environmental burden. But the variants of smart™ that will be built at Hambach will share more than 50% of the same modular components (Chew, 2001a). This use of common components for multiple products is well known and documented within the automotive industry. One example of this is the way that Volkswagen has used common vehicle platform architecture across a wide range of various branded car products – like the VW Polo, the SEAT Ibiza and Skoda Fabia – these cars all share a platform called 'PQ24' (Chew, 2001b). A product platform is composed of necessary modules. Thus, although a platform can not be developed 'as a module', it is indeed based on modules, using a modular structure. The new Polo and the Fabia share over 150 major components including chassis, engines, and cooling sub-systems. This common sharing reduces labour intensive dual design pathways, achieving substantial savings in development costs (Chew, 2001b). The use of vehicle platforms will have a major factor in both economical savings but also gains in environmental impact.

The new four seat (five door) smart™ will use a new version of the Tridion™ safety cell developed for the original smart™. It will be built in the NedCar factory in Born, Nederlands in conjunction with a Daimler Chrysler partner – Mitsubishi Motors Corporation. This vehicle will compete in the most competitive market segment within the European automotive industry – one in which DC has limited experience beyond the Mercedes A-Class (Maynard, 2001). To succeed in this arena, the final product will need to be unique, cost-effective, have the highest levels of safety and environmentally-friendliness (in terms of overall emissions) and lastly be a high volume sales item (Maynard, 2001). This is a particularly acute point, since the original smart™ is not forecast to be profitable until 2004-2005. Both smart™ and Mitsubishi branded vehicles will be produced under the shared platform philosophy (Ostle, 2000). This new vehicle is due to start production in 2004, with DC jumping into a previously planned minicar platform that Mitsubishi had been designing. DC will be expecting to make large economies of scale from part sharing between the current smart™ car, the smart™ 4-seater and new small products from Mitsubishi. In the next section the smart™ is examined as a mobility concept from the perspective of personal ownership and finally how the product progresses into mobility services.

The 'in-use' product phase

In the EU, smart™ competes directly with various models – although these are mostly larger in overall dimensions, are heavier and have higher fuel consumption. Currently, smart™ represents one of the lowest emissions cars available on the market in Europe. It also comes close to the 3 litre fuel target (where a vehicle can achieve 100 km driving distance using only 3 litres of fuel). The original smart™ concept envisaged a purely electric or a hybrid drive train system. This was not pursued in the production car, but this may yet come to market. MCC smart™ has been working with Zytek to produce electric and diesel hybrid prototypes (Tremble, 2001).

The major difference between smart™ and its various competitors is that, while it combines fashionable design with high standards of safety and interior specification, it also contributes to reductions in environmental impacts, such as those arising from vehicle emissions. These factors are important in terms of the overall product 'package' that the end user purchases. About 80% of the environmental impact in the total product life cycle is attributable to the in-use phase (Mildenberger, 2000). Much of this impact results from the high lifetime mileage of a vehicle. Examples of the in-use emissions of the smart™ product and five other well know vehicles which compete directly with smart™ are shown in Table 3. The in-use emissions are derived from vehicle certification data based on all the various model types for sale in the UK, using the Euro 3 standard test for emissions. Note that certain smart™ competitors are not sold in the UK, such as the Renault Twingo. The vehicle manufacturers and models are not shown here for brevity.

Table 3 summarises carbon dioxide (CO_2) emissions and fuel consumption (FC) as indicated by the fuel used to drive 100 km. The total emissions value (in g/km) is the sum of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) all in grams per kilometre over the standard European test cycle. This represents a total emissions factor for the vehicle, where higher overall values are worse for the environment. Clearly, the level of emissions from consumer use depends on the actual driving cycle employed together with the condition of the vehicle and the associated sub-components (e.g. state of the catalyst system).

Table 3: Comparison of emissions and fuel consumption for selected minicars, derived from Vehicle Certification Agency (VCA), Bristol, UK.

Vehicle	CO_2 (g/km)	Fuel Consumption (litre/100 km)	Total Emissions (g/km)
smart™, diesel	118	3.4	0.634
smart™, petrol	122	5.0	0.524
Model A, petrol	149	6.3	1.652
Model B, petrol	160	6.4	0.559
Model C, diesel	119	4.4	1.031
Model D, petrol	149	6.3	0.431
Model E, petrol	161	6.1	0.830

In summary, the smart™ is an efficient vehicle that has a lower emissions impact on the environment and lower use of non-renewable resources than similar cars that it competes with. However, overall sales of the smart™ are, so far, lower than most of its direct competitors, so that only a limited impact has been achieved when looking at fleet wide averages. Smart™ also meets many of the forward looking requirements set by various research bodies, and compares favorably with the current vehicles on sale in the European market. For instance, the smart™ represents a big step in the direction identified by the UK's Foresight programme. This programme stipulates that mass market vehicles in 2020 need to embody the qualities shown in Table 4.

Table 4: Vehicle qualities required for 2020, adapted from DTI 1999.

Parameter	Requirement – to:
clean	have the lowest environmental impact
efficient	make best used of limited fuel resources
lightweight	use less energy to achieve mobility
telematic	communicate with other cars and network to optimise existing road structure use
intelligent	provide enhanced safety
lean	be manufactured competitively

When related to other benchmarking criteria, such as the environmentally optimised vehicle (Nieuwenhuis, 1997), smart™ appears to provide a major step towards the criteria identified for cars in the future. Under the broad umbrella of requirements in Table 4, the smart™ scores high values for use of radical innovations that contribute environmental benefits. This compares favourably with the average vehicle parc standard. The European Commission has considered a strategy to reduce carbon dioxide based on this type of benchmarking, although this has yet to be implemented fully. Examples of the efficiency, cleanliness and low weight were previously reviewed. Smart™'s Tridion™ steel safety cage, the airbags and purpose designed crumple box zones demonstrate smart™'s high standard of safety. The smart™ has also been linked with programmes to incorporate telematic practices to reduce environmental impact. This is discussed in the following section.

Extension of the total product system into mobility services

The original smart™ concept envisaged that a wide range of mobility services would be offered to smart™ owners through a package to be offered as 'smartmove'. In some cases, these services were to be offered at discounted rates to offer incentives, via preferential treatment, to encourage customer purchase in relation to cars with a greater environmental impact. Examples of these services include preferential rental rates for smart™ cars, and similar vehicles, such as when renting during visits abroad. Preferentially treatment can be, and has been extended to parking spaces. Potentially it can be extended to tariffs on ferries and trains, through lower prices compared to those for larger vehicles. The potential for links with various transport providers, including vehicle hire companies, opens up the possibility that owning a car may not be the only convenient way, or the 'best' way for a person to get from one place to another.

Like other car manufacturers, smart™ has also looked at the use of person digital assistants and/or mobile telephones to access internet information, including vehicle routing/navigation, weather, electronic mail services and travel bookings. This is much easier than in a traditional car because the plastic roof module is transparent to the appropriate technology. By using a design partly purpose built for the application, the roof is already viable for the potential growth and changes expected in the telematics industry over the next few years.

A further example is provided by the control and diagnostic system that is installed in smart™ cars. Like those installed in some other recent cars, this can be interrogated only by the authorized smart™ dealers, and information can be fed into the parent company's data warehouse. The smart™ dealer network differs from others in the EU in that dealers are linked directly to *smartville* as franchisees. The overall effect is to lock all smart™ users into the DC/smart™ network. Thus, when some 3,000 UK residents acquired smart™ cars in advance of the UK launch, their vehicles had to be taken to other European countries for service or repair. This apparent shift to a 'captive customer base' may have positive environmental benefits in so far as vehicle performance benefits from high standards of service and repair.

The major automobile manufacturers recognize the importance of consumer demand for new types of services and the potential for increased revenues in the aftermarket. Accordingly, they appear to be shifting down the supply chain to offer customers some of these add-on services. This extension into services also signifies the increasing service orientation of manufacturers, indicating an operational shift towards the total product system.

End-of-life provision

Since smart™ has only been in production since 1998, the reality of this stage of the total product system has yet to be proven – as is also the case for life extension. However, the design of smart™ was undertaken with this stage – and the developing EU regulatory regime – in mind. This is reflected in two main ways. One is the choice of materials for their recycling potential – most obviously in the selection of plastics. As a result, smart™ claim that about 80% of the materials used in the construction of smart™ can be recycled – compared with an average of 70% for the car industry. The achievement of this target will draw support from the second design element – (vehicle) design that supports dismantling. The modular assembly of smart™ is accomplished, in some cases at least, by simplicity in the design of fastenings and fixings. For example, the cockpit module is inserted into smart™ as a single unit that is secured with just two bolts. This will support easy removal and separation of materials when the vehicle needs to be dismantled.

Partnership with suppliers remains important in planning for the end-of-life phase and, eventually, in processing returned vehicles, Production partners are necessarily involved in the selection of recyclable materials and in design for dismantling. In relation to the other end of the life cycle, DC, like some other manufacturers, have explored partnership arrangements with specialist vehicle recyclers.

Conclusion

This paper illustrates how the concept of a sustainable total product system can be advanced by utilizing the extensive interactions between the lead product assembler – in this case MCC smart™ GmbH – and their suppliers. In order to qualify and quantify the environmentally aware practices within the total product system, it is necessary to look beyond the product life cycle and deconstruct the entire product system. The benefits of deep integration within the supply chain and assembler are quite clear in the case of smart™ which is essentially a more highly modularized vehicle than most in the mini-car segment. MCC smart™ has emphasized with great consistency the importance of building long term business relationships, in a similar way to that observed in successful Japanese automakers (Liker, 2000) operating in both Japan and the United States. The in-use phase also shows clear benefits for smart™ when compared to other similar segmented vehicles. What remains unclear to date, partly because smart™ is a relatively new vehicle, is how much impact the product has on extending environmentally friendly practices into the mobility, or the accessibility of being mobile beyond simple straightforward personal car ownership. Equally, the realities of end-life re-processing remain to be demonstrated. However, the smart™ is a vehicle in which these issues have been directly addressed. It is to be expected that Daimler Chrysler will have learned from, and will apply where appropriate, the lessons gained from this experience, as from other elements of the smart™ development.

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Table 1: Sales statistics are derived from the 2000 Market Data Book, Automotive News, 5/2000, courtesy of JATO Dynamics. Further values from Automotive News Europe, Vol. 6, No.24, p. 39, Dec. 2001, and from Auto. News Europe, Vol. 7, no.5, 11 March 2002.

Table 3: Emissions data was derived from the VCA (Vehicle Certification Agency) website at http://www.vca.gov.uk/ which contains all useful information on fuel and emissions, as well as noise for the majority of cars sold within the UK. The data is also available on request from the Vehicle Certification Agency, 1 The Eastgate Office Centre, Eastgate Road, Bristol, BS5 6XX, UK.

Table 4: These criteria were adapted from p. 7 of the Foresight Vehicle Strategic Plan, January 1999, Crown Copyright asserted. Dept. of Trade and Industry Publication no. 4402/1K/10/99/RP, UK.

Author biographies

Dr James Warren is a staff tutor/senior lecturer in the Faculty of Technology at the Open University, based in Cambridge. His main interests are in automotive supply chain systems, accessible mobility as well as vehicle emissions and their impacts. He currently chairs the University’s supply chain management course in the postgraduate program, with approximately 160 students per year taking the course. He is linked to the Department of Design & Innovation.

Ed Rhodes is Senior Lecturer in the Department of Design and Innovation in the Faculty of Technology at the Open University. He is Director of the Centre for the Analysis of Supply Chain Innovation and Dynamics (CASCAID) research group and Academic Director of the Knowledge and Learning in Advanced Supply Systems (KLASS) project. His teaching and research focus on the development of total product systems and the management of technological innovation. Ed is a visiting fellow at The Open University (2007).

Ruth Carter is Staff Tutor in Technology in the Yorkshire Region of the Open University. She is a member of the CASCAID research group and the KLASS project team. Her research centres on complex supply systems, currently in the automotive, health care and international retail sectors. Ruth formally retired from the University in July 2007.

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