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## 'Smart' design: greening the Total Product System

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How to cite:

Warren, James P. and Rhodes, Ed (2006). 'Smart' design: greening the Total Product System. In: Sarkis, Joseph ed. Greening the supply chain. Springer Verlag UK, pp. 271–291.

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Version: [not recorded]

Link(s) to article on publisher's website:

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## **‘Smart’ Design: Greening the Total Product System**

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### **15.1 Introduction**

When launched into the marketplace, the two-seat city car initially known as ‘the smart’ became iconic. In several respects, the smart car fits the criteria for an ideal city car (see Figure 15.1). Its two seat capacity matches the European average vehicle occupancy of 1.2 persons per vehicle. It is spacious inside yet still small enough to be very convenient for congested city driving. The marketing package combined within this single small vehicle; Mercedes’ standards of automotive engineering and quality, a high standard of safety, distinctive styling, striking use of colour internally and externally and a high standard of interior specification. The use of highly visible sales outlets and development of fashion accessories such as ‘smartware’ also contributed to product strength. Capitalizing on this, its makers moved ‘smart’ into the realm of a brand, and the initial smart car was later redesignated the smart ‘fortwo’ – the first in what was intended to be a family of products. To avoid confusion between ‘smart’ as a brand and the initial production model, we refer to the latter throughout this chapter as the fortwo.

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. More recent influences include increasing congestion in European cities and growing consumer concern for the environment which, in the European Union, has been reinforced by environmental regulation of the automotive sector. Thus, early concepts for the fortwo put environmental impact at the centre of the design brief, with initial emphasis on an electric vehicle. Although electric traction was eventually abandoned, a holistic approach to the design of the product and of production processes led to comparatively low environmental impact across all stages of the cradle-to-grave product lifecycle. The innovative approach embodied in the fortwo reflects the

influence of a partnership between Mercedes and Swatch during early development – see Table 15.1. Thus, the car draws strengths from Mercedes, such as in the standard of product engineering and from Swatch



in such respects as the strong fashion element in interior and exterior styling. These attributes brought environmentally conscious car use closer to higher income, city-based consumers.

**Figure 15.1.** A fleet of fortwo cars at a dealership, awaiting collection by customers

This case study reviews how the fortwo's evolution touches on several critical areas:

- holistic concern with environmental impacts;
- use of modularity in product design;
- an intensive use of modularity in the design of the dedicated production facility developed for the fortwo;
- emphasis on participation with supply chain partners from product creation to after-sales;
- use of a highly customized build-to-order product system to 'green' the entire supply chain;
- approaches to urban transport.

We look at several contrasting aspects of the fortwo's development. One concerns the emphasis in initial marketing of the fortwo on its size, maneuverability and virtuous level of fuel consumption. In part, this was viewed in the context of new approaches to urban transport, and the potential of the fortwo in relation to the transport needs of those who do not own a vehicle, such as through vehicle sharing schemes. A second issue

relates to our view of product supply as extending across the full product life cycle – in a ‘total product system’ (Rhodes, 2006). This concept has been given increasing meaning by the efforts of large lead companies to co-ordinate aspects of production and aftermarket support.

**Table 15.1.** Important events in the history of smart

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.
1992	The project is revived and the executive committee of Daimler Benz (Mercedes’ parent company) is shown the prototype city automobile, and gives the go-ahead.  Nicholas Hayek, Chairman of SMH (the Swiss Corporation for Microelectronics and Watchmaking Industries) 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.
June 1994	Large numbers of prototypes are built and tested.
Oct 1995	Foundation stone laid at Hambach, France, for a highly innovative manufacturing plant – smartville.
Sept 1997	The fortwo is premiered – as the smart – at the Frankfurt International Motor Show.
Oct 1997	The smartville factory officially opens.
1998	Mercedes and SMH decouple from the development, Mercedes taking full responsibility.
Oct 1998	The fortwo comes 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 (car & truck division of DC) takes full responsibility for MCC smart.
1999	Internet sales of fortwo 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 – a two seat sports car – scheduled for

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	release.
2004	A new model – the 4-seat smart ‘forfour’ – begins production and initial launch.
2005	forfour marketed more widely.
April 2005	Plans for a fourth model – the smart ‘formore’ abandoned.
October 2005	Production of the roadster ceases.

Source: authors

It also encompasses the relationship between end-of-life reprocessing and the supply of replacement parts and recycled materials at the high end of the recycling hierarchy. The concept of a total product system raises further issues, including the relationship between the prime movers in the development of the fortwo and the key suppliers (known as system partners) and the impact of these relationships on the environmental issues inherent in production organization. This prompts comparison between process organisation at the ‘smartville’ industrial park and more ‘traditional’ approaches to vehicle manufacture. In examining these issues, we review the actual or potential reduction of environmental impact in the three main phases of vehicle life – car manufacture, car use and end-of life vehicle processing.

## 15.2 Background

Overall, the development of the fortwo can be viewed as three major steps. Chronologically, these are:

- 1992-1994 – product creation;
- 1995-1998 – product realisation;
- 1999 onwards, market building and brand extension.

Some key events in the project’s development, including the extension to new smart models, are indicated in Table 15.1. The global unit sales figures are shown in Table 15.2. As can be seen this indicates the slow pace of market building, an outcome that reflects initial concentration on the European market. The pattern of market development also raises questions about the longer term viability of the smart venture. But that does not detract from the significance of the smart concept or from the highly practical knowledge and ideas that it has generated.

**Table 15.2** Annual unit sales of the fortwo.

Year	Units sold
1998	17,000
1999	79,900

2000	102,100
2001	101,937
2002	102,302
2003	98,890
2004	72,478

Source: authors

### 15.3 Modularity in the Car – and in the Transport System?

Important elements of innovation follow from a design emphasis on modularity in contrasting modes. The physical modularity of the fortwo is immediately apparent through the visually striking use of plastic body panels in strong colours. These are a direct reflection of the influence in early design stages of SMH – the pioneers of Swatch plastic fashion watches. The panels on the fortwo are replaceable, allowing end users to re-configure the exterior colour of the vehicle for a cost that amounts to approximately 10% of the original vehicle purchase price. An example of the high use of modularity can be seen in Figure 15.2, which shows the major body component on which the other modules and sub-components are attached. This 'Tridion cell', or cage also incorporates the crumple zones required to achieve high ratings in 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 fortwo assembly has been compared to the way aviation manufacturers make the most of aerospace frames when building aircraft.



**Figure 15.2.** The Tridion safety cell, after complete assembly at smartville by a main 'system partner', Magna Chassis. Here, it is being conveyed to the main fortwo assembly line.

The car was originally envisaged as a second car and as largely for city use. But it has also been associated with initiatives that seek alternative approaches to individual mobility in urban areas. These include reduced public transport fares for inter-modal journeys, reduced parking fees, preferential car rental agreements, incentives for car sharing and for using cars like the fortwo outside the prevailing owner-driver model (Mildenberger & Khare, 2000). In some parts of the EU, these initiatives have started to emerge – for example, in the case of the fortwo, in lower charges for parking and for car-wash (this reflects lower use of water, detergents etc.). The fortwo thus potentially contributes to reducing impact from personal vehicle use. So far, this potential has been limited by both the limited scope of incentives and the low sales figures shown in Table 15.2.

#### **15.4 The fortwo and the Total Product System**

Increasingly, large international companies emphasize co-ordination across all, or large parts of their supply chains. They attempt to co-ordinate product design as well as the highly complex flows of materials, components, support services, orders 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

(Christopher, 1992) – or, more accurately, between product supply networks<sup>1</sup>. Combinations of methods such as quality assurance, value stream analysis, concurrent engineering, kaizen and product life planning are applied throughout a supply chain in the pursuit of continuous enhancement of competitiveness which is derived from improvement in all areas of a chain. The emphasis on supply chain co-ordination has a number of roots, including attempts to match current highly demanding, diverse market conditions, and the exploitation of information and communications technologies in business-to-business and business-to-consumer electronic commerce. The competitive impact of methods developed by some leading Japanese companies – most notably by Toyota – has been particularly influential. This influence was initially seen in manufacturing sectors, but it is now increasingly evident in service sectors.

Co-ordination across a supply chain or network emphasizes the development of long term close relationships between lead companies and key suppliers. Lead companies generally occupy strategic positions close to the point of delivery to consumers and other end customers. Their market position and purchasing power enable them to establish chain-wide systems of governance (Kaplinsky, 2000). Examples of lead companies range from vehicle brand owners (such as Mercedes) to retailers. Typically, these prime movers seek to co-ordinate activities such as product design and development, production and logistics across all the diverse stages and types of activity – from raw materials processing through to the assembly and distribution of end products. Much of this co-ordination is undertaken indirectly through collaborative relationships with core suppliers who take responsibility for the design and supply of main product systems, sub-systems or support services. Core suppliers are generally expected to manage their own parts of the 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.

The ideal-type model can be viewed as a development from the popularized concept of 'lean production'. Co-ordination extends across all areas and stages of activity in the total supply chain. A critical factor in this objective is the high proportion of a company's costs that are now accounted for by purchases from suppliers – 70% or more is typical. Consequently, there is emphasis on optimal use of use of human resources, production capital, space and logistics, and on paring levels of waste (such as from producing faulty parts and high levels of stocks and work-in-process) down to minimal levels. Another aspect of the model is that production flows are 'pulled' at all stages by actual demand for different product variants. Ultra-high standards of quality at each production stage,

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<sup>1</sup> There is a long standing debate about which of 'chains' and 'networks' provides the most appropriate metaphor. While preferring the more flexible connotations of networks, we use supply chain generically here.

delivering products on time and the flexibility needed for low batch, high variety production are also part of the competitive equation. Consequently, the successful application across a supply chain of techniques such as 'just-in-time' (JIT) is a critical for the competitiveness of an end product. For many companies, this has involved a challenging 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.

The environmental impact of these fundamental shifts in the organization of production appears, in general, to be positive – although systematic comparisons present considerable difficulties. For instance, the impact of JIT 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, JIT supply can also be associated with relatively high environmental impact from the transport movements – needed for the collection and delivery of small part lots (Katayama & Bennett, 1996). Furthermore, JIT systems can lead to other adverse environmental impacts, such as when overall deliveries increase to a point where local congestion delays the supply of components. It is clear that various supply scenarios need to be examined carefully.

The performance of all stages of the supply chain in terms of resource use and impacts has become a focus of attention as a consequence of environmental regulation by regional, national and other bodies, and following initiatives such as ISO 9000 and ISO 14000. 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, extending from the point of sale through to a product's end-of-life. Companies now look beyond the supply of replacement parts in the aftermarket towards provision of a variety of services that support or enhance product use and functionality. The importance of aftermarket performance in total competitiveness is indicated by Gallagher et al's (2005) estimate that it may account for 40% of profits for a wide range of companies. 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 warranted 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. Ideally, this includes the extension of product lives, such as through the refurbishment or re-manufacture of products in the later stages of their use (Guide et al,

2000). But life extension sometimes increases environmental impacts so that different products require different approaches. For instance, engines require redesign as emissions standards rise whereas a car body may provide a stable platform for a longer time, reducing the impacts associated with investments in tooling, pressing, etc.

EU standards have also focused attention on the end-of-life stage of product life. 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 the collection of 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 also linked to a reshaping of 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, to 15 years or more after production of new models has ceased in the case of cars, and 25 to 40 years 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 (2000) who provide examples of re-manufacture linked to high levels of profitability.

However, as indicated above, the environmental viability of life extension is questionable. The efficiency of individual products tends to fall off as they are used. Also, in conditions such as rising real energy costs and increasing constraints on adverse environmental impacts, the associated influences on product design tend to lead to progressive improvements in performance that surpass earlier benchmarks – as the fortwo illustrates – see Figure 5. To determine the full extent of the environmental impact linked to a product, particularly one that, for its functioning, requires additional energy and other material inputs, requires analysis that extends well beyond concern the product's supply chain. To establish the full potential for reducing those impacts requires a focus on product and performance across the total product system to encompass the full cradle to grave product cycle, and to factor in the wide range of actors and interactions involved. This focus leads to emphasis on the sustainable product systems, reshaping production organization as well as product use and recycling.

## 15.5 Towards a Total Product System

Production organization has a particularly important role in establishing the relatively low environmental impacts associated with the fortwo. This is associated with the Mercedes-Benz automobile division of Daimler Chrysler (DC) which took full responsibility for MCC smart in 1998 when SMH (Swatch) ceased to be involved in the project. Mercedes took the project forward by developing a new brand, a new way of production and a new method of sales distribution (Renschler, 2000). They did this in a relatively short period of time but incurred substantial costs and encountered problems in product launch. These were mitigated by strong support and risk sharing on the part of core suppliers. Their facilities are purpose built, and co-located with the main assembly factory at smartville in Hambach, France. 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, as well as sharing investment costs and financial risk. They developed their own solutions to component design and sourcing, within parameters agreed with MCC as the lead company. Some elements of organization at smartville are contrasted with a somewhat stylized ‘traditional’ model in Table 15.3. The ‘traditional’ approach represented here is a synthesis between the patterns associated with vertically integrated mass production and the approaches to relationships with workforce members and procurement from suppliers that tend to be associated with, or are inherited from mass production (see Rhodes, 2006). There are, of course, many other approaches besides smartville that contrast with ‘traditional’ patterns.

We emphasize the procrustean nature of Table 15.3 and that it must be viewed in context. The smart venture is not an isolated example but provides a specific, if somewhat unusual example of more general trends. First, other vehicle assemblers have developed production organization along lines comparable with Hambach, such as by establishing suppliers parks around final assembly plants. Second, the development of the production system, which we consider further (below), needs to be viewed in conjunction with the product’s characteristics, and the way that these are now ‘part of the past’. The development of the smart fortwo has been overtaken by the work of other vehicle brand owners who have surpassed some of the environmental targets it set. Third, while Table 15.3 concentrates on issues of production organization, the contrast between early publicity about the fortwo’s urban role and the longer term outcomes needs to be kept in mind. For instance, the introduction of fortwo has not been accompanied by the extension of mobility concepts on any substantial scale. It has not been associated with moving private users away from personal vehicle habits anymore than other mobility projects. However, this does not follow from failings on the part of MCC smart. Rather, it reflects the way that public authorities, in the main, fail to think through the issues of urban transport holistically. Within such an approach, there is

scope for incentives for using smaller vehicles as well as public transport. Further thinking is needed.

**Table 15.3** Process Characteristics within the Supply Chain

Process	'Traditional'	'smartville'
1) Product design and development.	Little collaboration with suppliers. Bidding for job after product is proto-typed.	Systems partners have a large responsibility for collaborating and achieving lower costs. Work with supplier very early in design stage.
2) Ordering and purchasing.	Short term, focused on supplier price rather than suppliers' costs and capabilities.	Long term contracts emphasize cost and continuous improvement rather than price, with supply to advanced JIT standards.
3) Relationship between lead Manufacturer and suppliers.	Arm's length, low trust.	Close, classed as partners, higher levels of trust, information sharing.
4) Remuneration of production employees.	Elaborately tiered payment structures, hourly rate for most, bonus decided by upper-management.	Semi-autonomous teams, flatter organizational hierarchy, team bonus linked to team performance.
5) Main supply chain actors.	Geographically dispersed, historical layout, no room to grow.	Co-location, integrated facilities; potential for future growth.
6) Production facility.	Historically based with legacy problems.	Designed as greenfield site, best in class for environment and workers.
7) Warranty responsibility.	Largely held by final assembler.	Shared by all, traceability to individual component producers.
8) Supplier payment terms.	Delayed payment to suppliers commonplace.	When final product complete or sold to customer.
9) Supplier facilities.	Owned by supplier.	Total Hambach site managed by MCC and system partners, land owned by MCC.

Source: authors

Some examples amplify issues identified in Table 15.3. The extensive use of partnerships for collaborative solutions (points 1) and 2)) seems to be more effective than, say, solutions developed in traditional relationships where waste of effort, energy and materials, and the financial health and

innovative capabilities of a supplier are of no 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 in order 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 from suppliers further down the supply hierarchy (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 fortwo. One example included an axle assembly which was modified to reduce materials 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 cost savings.

The benefits indicated by points 2), 5) and 6) in Table 15.3 include:

- the system partners assemble main modules on sites abutting MCC's final assembly lines;
- the operations of the assembler and suppliers are very tightly coordinated with very small buffer stocks (generally equivalent to less than one hours production);
- suppliers assure the conformance of all delivered items and there is no inspection by the assembler when parts are received by MCC;
- system partners have their own direct entry ports into MCC's assembly area with direct delivery to auto-assembly line (via extensive conveyor systems);
- other suppliers deliver via trailers parked at entry ports that feed into adjacent line locations;
- direct ordering with shared responsibility for stock control.

The gains from these aspects of supply chain organization include contributions towards greening the supply chain as well as to higher levels of production efficiency. For instance, production and delivery of the door module illustrated in Figure 15.3 minimizes energy use and avoids waste. Door panels are produced by Dynamit Nobel and are colour coated by Cubic Europe, both of which are located in linked buildings at smartville. The finished panels are supplied to a further linked building, that of Magna

Doors where they are configured as part of a complete door module (which include trim, glass, mirrors, door-mounted controls, window and mirror motors). Operations in these three supplier facilities are tightly coordinated – with each other and with the main assembly line. Complete door modules are supplied via an enclosed link bridge, in pairs that match the build-to-order (BTO) specifications for interior and exterior colour choices and other variants. There is consistent emphasis on a very high standard of conformance with quality standards at all production stages, maximizing efficiency in the use of energy and materials. Large scale reductions in packaging waste and in transport-generated emissions become possible when components can be made locally. One estimate is 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 15.3.** Detail of the left-hand-side door interior, showing fittings

With direct ordering and correct sequencing of modular units (for example engine type, wheel/tyre configuration, interior/exterior colour, door panels, etc.) a BTO production system can be achieved. In an efficient 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 can be 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 in colours or features that turn out to have limited customer appeal should, ideally, be avoided. But this carries the risk of lost sales. Where a high level of co-ordination has been developed across the various stages and branches of a supply chain, reductions in order size are achievable 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. Additional 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.

Points 7), 8) and 9) in Table 15.3 indicate risk sharing. One of the main benefits for the assembler as lead partner is that it is possible to view the entire site holistically, and to undertake a comprehensive assessment of resource use on the site. In the case of smartville, MCC and its partners were able to shape resource use from the very start through site and building design. The factory buildings were constructed from sustainable materials, and all processes within smartville are both CFC and formaldehyde free (Treneman, 2001). Efficient use of energy was emphasized in the design of buildings, and the factory recycles the heat created and water used on the site. But in the case of off-site suppliers, additional environmental burdens such as transport to smartville need to be taken into account in the overall analysis.

### **15.6 Panels: An Example of Modularity within an Increased Product Range**

Offering customers a product built on modular lines 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 fortwo supplier who claimed that, in Italy, businesses have developed to rent replacement panels to fashion conscious consumers on a short term 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 needs to be available.

Regular 'edition' changes shuffle the colour range. But previous colours need to be available for repairs, reducing some of the environmental benefits. On the other hand, the need for more comprehensive model changes may be less necessary since body colours can be readily changed and because modular construction enables easier incorporation of the latest features.

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 behave as a rigid plastic and would limit environmental impact in manufacturing and in end-of-life reprocessing. The major panels are injection molded by Dynamit Nobel AG, including front fender, outer door, front and rear valences and wheel arch panels. Due to the high precision of the molding process, very little scrap waste is produced, and this is collected for recycling into the injection process feedstock. 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 and 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 spaces 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.

## 15.7 Extending Model Diversity

The smart brand is being extended to other products, most notably the 4-seat, 5 door smart forfour. This has required 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 smart variants built at Hambach share a much higher level of modular components than other cars utilising platform-sharing strategy, and there is some sharing with the forfour. 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 car brands –the VW Polo, the SEAT Ibiza and Skoda Fabia share a platform called 'PQ24' (Chew, 2001b).

Shared platforms reduce costs, but also enable cost reduction through increased levels of modularity (as in the examples of door modules and cockpit modules in the fortwo). Yet module components can be varied, supporting the production of final products that appear very different visually. 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 is a major factor in achieving both cost savings and reduced environmental impacts.

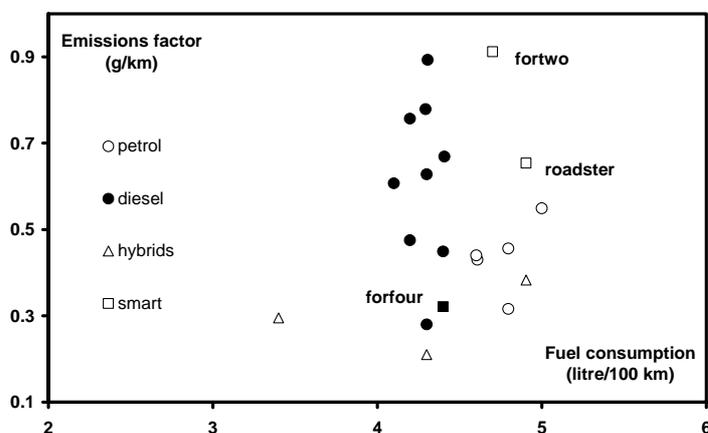
The use of shared platforms has also been important for the development of the forfour which competes in the most competitive market segment in the European automotive industry – one in which DC has limited experience beyond the Mercedes A-Class (Maynard, 2001). To succeed in this arena, the final product needed to be unique, cost-effective, have the highest levels of safety and to be environmentally-friendly (in terms of overall emissions) and lastly to be a high volume sales item (Maynard, 2001). This is a particularly acute point, since the fortwo was not forecast to be profitable for some time and, as was shown in Table 15.2, volumes have been disappointing. Like the fortwo, development of the forfour has involved partnership, albeit of a longer duration than that with Swatch. The forfour and the Mitsubishi Colt have been produced under a shared platform philosophy (Ostle, 2000), with DC jumping into the previously planned minicar platform that Mitsubishi was developing for the Colt. But there are important differences between the two vehicles – for instance in the forfour's use of a new version of the Tridion safety cell concept that was originally applied in the fortwo and in retention of the smart brand's distinctive plastic roof (fixed by very different methods to those used for the Colt which retains a steel roof). Nonetheless, substantial economies of scale were expected from part sharing across the fortwo, the forfour and the Colt. Production of the latter two vehicles, which share the same platform, commenced in 2004 at the NedCar factory in Born, Holland.

## 15.8 The 'In-Use' Product Phase

A major difference between MCC 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 & Khare, 2000). Much of this impact results from the high lifetime mileage of a vehicle.

When it was launched, the fortwo set new standards for in-use emissions compared with vehicles which it compete directly with. Most of the fortwo's competitors are larger in overall dimensions, are heavier and have higher fuel consumption. At the time of its launch, it was one of the lowest emissions cars available on the market in Europe. In the realm of fuel consumption, the diesel (which is not readily available in the UK) comes close to the 3 litre fuel target, achieving 100 km driving distance using only 3 litres of fuel. But comparisons are less favourable five years on, emphasizing how fuel consumption and emission standards tend to improve progressively, challenging earlier vehicle designs. smart's eventual response to the challenge of more recent vehicle designs may be to return to the original concept of an electric or a hybrid drive train system. MCC smart has been working with others to produce electric and diesel hybrid prototypes (Tremble, 2001). But product cost and consumer acceptance of hybrids remain a serious challenge – as they do for all car manufacturers!

Figure 15.4 summarises fuel consumption (FC) – as indicated by the fuel used to drive 100 km – and emissions. The emissions value is the sum of carbon monoxide (CO), unburnt hydrocarbons (HC), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM) that are emitted during the standard European test cycle, expressed in grams per kilometre (g/km). This represents a total emissions factor for the vehicle, where higher overall values are worse for the environment. In everyday use, the level of emissions depends on the driving style and cycle employed by the driver together with the condition of the vehicle and its sub-components (for instance, the condition of the catalyser system).



**Figure 15.4.** Fuel and emissions data for selected mini and small cars, UK, 2004

Note: the table shows emissions data as a function of fuel consumption for the ten cleanest diesel cars (filled circles) and the ten cleanest petrol cars (open circles) sold in the UK. Hybrids are displayed as open triangles and all are petrol-electric. smart petrol vehicles are shown as open squares, and the diesel forfour is a filled square.

Source: Vehicle Certification Agency, 2004, UK.

In summary, the fortwo is an efficient vehicle that, when launched, had a lower emissions impact on the environment and lower use of non-renewable resources than many cars in the mini to small car range. Two points stand out however. First, the fortwo has been overaken by subsequent developments that have improved fuel consumption and reduced emissions levels in newer cars. Second, overall sales of the car have been, so far, lower than most of its direct competitors, so that its impact is limited when looking at fleet wide effects. But the fortwo still represents a significant step towards the forward looking requirements set by various research bodies, such as the benchmarking criteria for environmentally optimised vehicles (Nieuwenhuis, 1997). Likewise, the fortwo stands up well against the stipulation of the UK's Foresight programme that mass market vehicles in 2020 need to embody the qualities shown in Table 15.5. Under the broad umbrella of requirements in Table 15.5, the fortwo scores well for its use of radical innovations that contribute environmental benefits. It compares favourably with the average vehicle parc standard.

**Table 15.5** Vehicle qualities required for 2020

Parameter	Requirement – to:
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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 optimize existing road structure use
intelligent	provide enhanced safety
lean	be manufactured competitively

Source: adapted from DTI 1999, UK

A further critical consideration is that the fortwo constitutes a move towards more environmentally sensitive car design without, as some might fear, compromising user safety, as is indicated by its Tridion safety cell, airbags and purpose designed crumple box zones. It has also been linked to telematic programmes that reduce environmental impact as is discussed in the next section.

## 15.9 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 owners through a package to be offered as 'smartmove'. In some cases, these services were to be offered with discounted rates and preferential treatment, as an incentive for customer purchase, particularly among those who are environmentally aware. Examples of these services include preferential rental rates for smart cars, and for similar vehicles, such as when renting during visits abroad. Preferential treatment can be, and has been extended to parking charges, recognizing the limited space required for a fortwo. Potentially, incentives can be extended to ferry and train tariffs, through lower prices compared to those for vehicles of more conventional lengths. The potential for links with 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 ensure getting from one place to another.

Like other car manufacturers, MCC also looked at the use of personal digital assistants and/or mobile telephones to access internet information, including vehicle routing/navigation, weather, electronic mail services and travel bookings. This is can be accomplished more easily than in a traditional car because the roof module is plastic and is transparent to the appropriate technology. The roof is thus compatable with the potential changes and growth expected in the telematics industry. A further example is provided by the control and diagnostic systems that are installed in smart cars. But the dual benefits from this development should also be noted.

Information flows to the parent company's data warehouse contribute to maintaining a vehicle's efficient use of fuel and low emissions. They also provide a flow of information on customer use of cars which can be used in planning new products, in customer retention and so on. This is also the case with telematic systems fitted in other recent cars. But 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 fortwos in advance of the launch of a righthand drive version, backed by a UK service network, their vehicles had to be taken to other European countries when they needed a 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, but it also raises concerns about constrained competitiveness in the aftermarket.

Major automobile manufacturers recognize the importance of consumer demand for new types of services and the potential for increased aftermarket revenues. Accordingly, they appear to be shifting their focus further down the product system, aiming to increase revenues by offering add-on services to customers. This extension into services may signify the increasing service orientation of manufacturers, indicating an operational shift towards the total product system. The logic of this for the automotive majors is perhaps indicated by the third smart product – the forfour. MCC does not manufacture this car (this is done under contract by Nedcar in Holland). MCC's roles in this case are overall product design, operational co-ordination, distribution to the smart dealer network, marketing and supply of aftermarket services.

### **15.10 End-of-life Provision**

Since the fortwo has only been in production since 1998, the reality of the end-of-life (e-o-l) stage of the total product system has yet to be proven. However, the design of smart as a direct response to consumers' environmental concerns and, incidentally, as an early response to the then emerging regulatory regime in the EU, is evident in three main respects. One is the choice of materials for their recycling potential – most obviously in the scale of use of plastics and the selection of plastic materials in relation to e-o-l recyclability. As a result, smart claimed at the time of launch that 80% by weight of the materials used in the construction of smart could be recycled – compared with the industry average at that time of 70%. However, this falls short of the target set subsequently by the EU Commission in its End-of-Life Vehicle Directive of 2000. This established that, by 2006, 85% of a vehicle's weight should be reused, recovered or recycled. This includes a 5% allowance for energy recovery through incineration (Seitz & Peattie, 2004), an allowance that might enable the fortwo to comply with the Directive. The fortwo's 80% figure also needs to

be viewed against the 90% recyclability claimed in Toyota's 2005 advertisements for its hybrid (petrol-electric) Prius model. The latter vehicle provides another illustration of continued innovation and progress in relation to environmental targets.

Second, achievement of the fortwo's 80% target is linked to conscious design for disassembly. Its modular assembly is accomplished 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 e-o-l removal of this module and separation of its components and materials. The removal of complete modules or separation of components from individual vehicles, that irredeemably reach the e-o-l stage, supports the extension of the life of the overall pool of fortwos.

Third, partnership with suppliers, dealers and vehicle reprocessors is important in planning for the e-o-l phase and in its subsequent management. Production partners (i.e., suppliers) are necessarily involved in the selection of recyclable materials and in design for dismantling. In relation to the other end of the life cycle, Integration of the dealer/aftermarket network through the use of information and communications technologies in the cars, at dealer/maintainer locations and at DC potentially enable an overview of the condition, use and age of the fleet. Among other things, this supports operational planning for both the e-o-l phase and its relationship to aftermarket supply through the remanufacture of components and subsystems, and their reuse in the aftermarket. Mercedes Benz (MCC's parent) was one of the early investigators of these issues when, like some other manufacturers, it explored the issues of reprocessing in partnership with specialists from outside the automotive industry (den Hond, 1998). However, the organization required to link e-o-l vehicle reprocessing with the aftermarket and to increase the use of such reprocessing is complex (Seitz & Peattie, 2004).

## 15.11 Conclusion

This chapter illustrates how the concept of a sustainable total product system can be advanced by utilizing the extensive interactions between a lead company – in this case MCC smart GmbH – together with its suppliers, sales/aftermarket network and e-o-l reprocessors. In order to qualify and quantify environmental impact across the total product system, it is necessary to look beyond the product life cycle and to deconstruct the entire product system. The potential benefits of deep integration within the total product system are indicated by the fortwo. This partly reflects the high level of modularity in the car's design in comparison with compared with the wider mini-car segment and the automotive industry as a whole. MCC smart has consistently emphasized the importance of building long term business relationships, in a similar way to that observed in successful

Japanese automakers operating in both Japan and the United States (Liker & Yu, 2000, Dyer & Chu, 2003).

There are clear benefits from the fortwo in the in-use phase, particularly when it is compared with other vehicles in similar segments of the automotive market. What remains unclear to date however, partly because the fortwo is a relatively new vehicle and in its first generation, is how much impact it will have on extending environmentally friendly lifestyles. This includes issues of mobility that extend beyond personal car ownership to the question of comprehensive access to mobility for those without cars. The 'public/private transport' division potentially includes a range of imaginative approaches, such as the integration of the Dutch rail network and local taxis<sup>2</sup>. But the limitations on the exploitation of such approaches reflect rather muddled and limited thinking on the part of many of those who are in positions where they can shape the issues of urban transportation. Instead of simplistic juxtaposition of car versus public transport, more discriminating approaches to 'the car' appear to be necessary to exploit the potential of developments such as the fortwo and the more recent availability of hybrid vehicles.

Where end-life re-processing is concerned, the ability of the fortwo to deliver remains to be tested in operational conditions. Nonetheless, it is a vehicle in which these issues have been comprehensively addressed. It is to be expected that Daimler Chrysler will have learned from, and will apply the lessons gained from this experience, as from other elements of the smart venture.

Acknowledgement: The authors wish to thank their research collaborator and colleague, Ruth Carter for her comments and support in the production of this chapter.

## References

- ANE (Automotive News Europe) (2001) 'European Model Sales (Year to Date)', Automotive News Europe 6.24 (December 2001): 39
- \_\_\_\_ (2001) 'European Model Sales (Year to Date)' Automotive News Europe 7.5 (11 March 2002):39
- Anonymous, Automotive News Europe; 2003, Vol. 8 Issue 24, p. 26
- Anonymous, Automotive News Europe; 2004, Vol. 9 Issue 24, p 22 – 23, 20
- Automotive News Europe (ANE), Crain Communications, London
- Market Data Book, May 2000
  - European Model Sales (Year to Date), Automotive News Europe Vol. 6, Issue 24, December 2001
  - European Model Sales (Year to Date), Vol 7, Issue 5, 11 March 2002
  - Vol. 8, Issue 24, p 26; 2003

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<sup>2</sup> This supports pre-booking of local taxis, available at low cost in the hinterland around railway stations, with the taxis co-ordinated with train arrivals.

- Vol. 9, Issue 24, pp 22 – 23, 2004
- Birch, S., "Real smart, micro compact car", *Automotive Engineering* No. 11, Vol. 105, p. 21, Nov. 1997.
- Chew, E., "How D/C cut the smart car's cost base", *Automotive News Europe* Vol. 6, Issue 16, page 8, 30 July 2001 (2001a).
- Chew, E. "Modular approach brings cost savings for new Polo", *Automotive News Europe*, Vol. 6, No.24, p. 19, 3 Dec. 2001 (2001b).
- Christopher, M: *Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Services*, Financial Times, Pitman Publishing, London, 1992
- den Hond, F., The "Similarity" and "Heterogeneity" Theses in Studying Innovation: Evidence from the End-of-Life Vehicle Case, *Technology Analysis and Strategic Management*, Vol. 10, No.4, 1998
- DTI, UK Dept. of Trade and Industry, *Foresight Vehicle Strategic Plan*, January 1999, London. Publication no. 4402/1K/10/99/RP, UK
- Dyer, J. H. & Chu, W., The Role of Trustworthiness in Reducing Transaction Costs and Improving Performance: Empirical Evidence from the United States, Japan, and Korea, *Organization Science*, Vol. 14, No. 1, January–February, 2003
- Gallagher, T., Mitchke, M. D. & Rogers, M. C.: *Profiting from spare parts*, The McKinsey Quarterly, Feb 2005
- Guide, V D R, Jayaraman, V, Rajesh, S & Benton, W C: *Supply-Chain Management for Recoverable Manufacturing Systems*, *Interfaces* 30, May-June 2000, pp. 125 - 142
- Hines, P. and Holweg M., "Managing variability in the automotive supply chain – a foresight approach", *Society of Automotive Engineers*, technical paper 2002-01-0460, March 2002.
- Katayama, H. & Bennett, D., *Lean Production in a Changing Competitive World*, *International Journal of Operations & Production Management*, Vol. 16, No. 2, 1996
- Kaplinsky, R., *Globalisation and Unequalisation: What Can Be Learned From Value Chain Analysis?* *Journal of Development Studies*, Special Issue, 2000
- Liker, J.K. and Yu Y.-C., "Japanese automakers, U.S. suppliers and supply-chain superiority", *Sloan Management review*, Vol. 42, Issue 1, p.81-93, 2000.
- Maynard, M. "Get smart", *Fortune International*, p. 58, 30 April 2001.
- Mildenberger, U. and Khare, A., "Planning for an environmentally-friendly car", *Technovation* Vol. 20, p. 205-214, 2000.
- Nieuwenhuis, P. and Wells, P., "Environmentally optimised vehicle – a model for the future"., *Automotive Environment Analyst*’, 1 Feb. 1997.
- Ostle, D. and Treece, J., "DCX ready to build four-seat smart on Mitsubishi platform", *Automotive News Europe* Vol. 5, Issue 8, p. 4, 4 Oct. 2000.
- Pryweller, J., "smart's plastic body was a thorny problem", *Automotive News* Vol. 73, Issue 5782, p. 22, 31 Aug. 1998.
- Renscheler, A., remarks from "Opening presentation, smart", *Automotive News Europe e-Business Conference, smartville, Hambach, France*, 29 Nov. 2000.
- Rhodes, E., *From Supply Chains to Total Product Systems*, in Rhodes, E., Warren, J. P. & Carter, R., *Supply Chains and Total Product Systems*, Blackwell Publishing, Oxford, 2006
- Seitz, M. A. & Peattie, K: *Meeting the closed loop challenge: the case of remanufacturing*, *California Management Review*, Vol. 16, No. 2, 2004.
- Tremble, S., "Revving at full throttle into the fast lane", *The Engineer*, 21 Sept. 2001.
- Treneman, A., "smart new world", *The Times* (London), 29 Sept. 2001.

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Vehicle Certification Agency (VCA) – <http://www.vca.gov.uk/> accessed December 2005. (The data is also available on request from the Vehicle Certification Agency, 1 The Eastgate Office Centre, Eastgate Road, Bristol, BS5 6XX, UK).  
Wrigley, A., "Rising fuel prices create tempting mart for smart cars", American Metal Market Vol. 108, Issue 187, p. 1-3, 27 Sept. 2000.

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